Triassic lithostratigraphy of the Jameson Land Basin (central East Greenland), with emphasis on the new Fleming Fjord Group

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The lithostratigraphy of the Triassic deposits of the Jameson Land Basin in central East Greenland is revised. The new Scoresby Land Supergroup is now composed of the Wordie Creek, Pingo Dal, Gipsdalen and Fleming Fjord Groups. This paper only deals with the lithostratigraphy of the late Early-Late Triassic continental deposits of the latter three groups with emphasis on the vertebrate-bearing Fleming Fjord Group. The new Pingo Dal Group consists of three new formations, the Rødstaken, Paradigmabjerg and Klitdal Formations (all elevated from members), the new Gipsdalen Group consists of three new formations, the Kolledalen, Solfaldsdal (with the new Gråklint Member) and Kap Seaforth Formations (all elevated from members), and the new Fleming Fjord Group is subdivided into three new formations, the Edderfugledal, Malmros Klint and Ørsted Dal Formations (all elevated from members). The Edderfugledal Formation contains two cyclic bedded, lacustrine members, a lowermost Sporfjeld Member (elevated from beds), and an uppermost Pingel Dal Member (elevated from beds). The lacustrine red beds of the Malmros Klint Formation are not subdivided. The lacustrine and fluvial Ørsted Dal Formation contains three new members. In the eastern and central part of the basin, the formation is initiated by cyclic bedded, red lacustrine mudstones of the Carlsberg Fjord Member (elevated from beds), while in the northwestern part of the basin the lowermost part of the formation is composed of grey fluvial conglomerates and sandstones with subordinate red mudstones of the Bjergkronerne Member (elevated from beds). The uppermost part of the formations in most of the basin is composed of cyclic bedded, variegated lacustrine mudstones and grey to yellowish marlstones of the Tait Bjerg Member (elevated from beds). The sediments in the Fleming Fjord Group contain remains of a rich and diverse vertebrate fauna including dinosaurs, amphibians, turtles, aeotosaurs, pterosaurs, phytosaurs and mammaliaforms. Most vertebrate bones have been found in uppermost Malmros Klint Formation, and in the Carlsberg Fjord and Tait Bjerg Members. The Norian–early Rhaetian, lacustrine Fleming Fjord Group was deposited at about 41° N on the northern part of the supercontinent Pangaea. Lacustrine sedimentation was controlled by seasonal as well as longer-term (orbital) variation in precipitation. Precipitation was probably brought to the basin by southwesterly winds. The lacustrine sediments of the uppermost Fleming Fjord Group show deposition during increasingly humid conditions changing the lake environment from an ephemeral lake-steppe area to a perennial lake. This evolution of lake environment suggests a change from a winter-wet temperate climate to one with precipitation throughout the year.

Keywords: Triassic, East Greenland, lithostratigraphy, lacustrine sediments, palaeoclimate, vertebrate fossils

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The paper presents a lithostratigraphical revision of the late Early–Late Triassic continental deposits in the Jameson Land Basin, central East Greenland (Clemmensen 1980a, 1980b). The paper raises the former Pingo Dal, Gipsdalen and Fleming Fjord Formations to groups. Emphasis in the revision will be given to the new Fleming Fjord Group (Late Triassic), which has been the subject of extensive vertebrate palaeontological, sedimentological, and magnetochronological fieldwork since 1988 (e.g. Jenkins *et al*. 1994; Kent & Clemmensen 1996; Clemmensen *et al*. 1998; Clemmensen *et al*. 2016; Marzola *et al*. 2018). The new field data collected during these expeditions show the presence of vertebrate-bearing sedimentary units of wide distribution in the uppermost part of the Fleming Fjord Group; these units are here formally defined as formations (elevated from members) and members (elevated from beds). The Pingo Dal and Gipsdalen Groups are only described schematically with reference to previous work by Clemmensen (1980a,1980b). The elevation of former formations in the Scoresby Land Group (Supergroup in this paper) to groups is also a logical step after both the underlying Wordie Creek and overlying Kap Stewart Formations have been raised to groups (Surlyk, 2003; Surlyk *et al*. 2017).

Geological setting

This paper only deals with the stratigraphy of the Jameson Land Basin in central East Greenland (Fig. 1). Sediments belonging to the Wordie Creek, Pingo Dal,

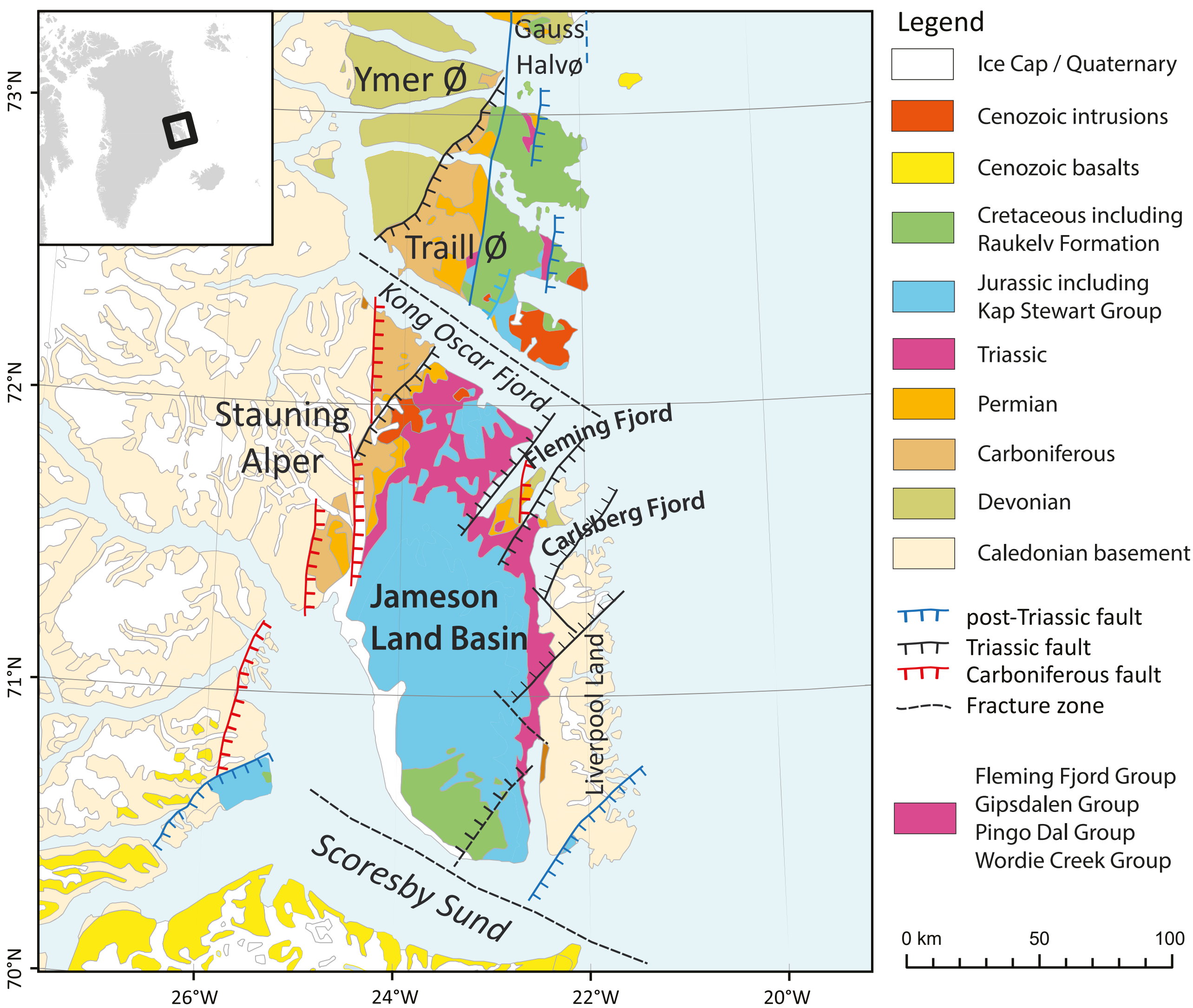

Fig. 1. Geological map of central east Greenland with the Jameson Land Basin. The basin is bounded by the N-S stretching Liverpool Land to the east and the Stauning Alper to the west. To the north and south, the basin is demarcated by fracture zones in the Kong Oscars Fjord and the Scoresby Sund respectively. Other Triassic faults are also indicated. Geological map modified from Guarnieri et al. 2017.

Fig. 2. Topographic map of Jameson Land and Scoresby Land. Type and selected reference sections for formations and members in the Fleming Fjord Group are indicated (Source of map: Kort- og Matrikelstyrelsen 1994). Coordinates (DD WGS 84) and approximate elevation of base of given section are indicated below. **1**: Lepidopteriselv (71.261762, -22.520303; base of Fleming Fjord Group in 100 m). Type section of Carlsberg Fjord Member. **2**: Mountain E of Buch Bjerg, "Track Mountain" (71.406746, -22.538515; base of Ørsted Dal Formation in 425 m). **3**: Tait Bjerg (71.488555, -22.647495; base of Tait Bjerg Member in 650 m). Type section of Tait Bjerg Member. **4**: E slope of Nordenskiöld Bjerg (71.575978, -22.513989; base of Fleming Fjord Group in 500 m).
5: Pingel Dal, mountain ridge at the northernmost side valley (71.586532, -22.937611; base of Fleming Fjord Group in 450 m). Type section of Pingel Dal Member. **6**: Malmros Klint (71.719395, -23.054341; base of Fleming Fjord Group in 200 m). Type section of Fleming Fjord Group, Malmros Klint Formation, and Ørsted Dal Formation.**7**: Sporfjeld W of Edderfugledal (71.882724, -22.696460; base of Fleming Fjord Group in 300 m). Type section of Edderfugledal Formation and Sporfjeld Member. **8**: West slope of Kap Biot (71.894274, -22.578467; base of Fleming Fjord Group in 300 m). **9**: SW slope of Bjergkronerne, Sydkronen (71.792488, -23.578467; base of Fleming Fjord Group in 450 m). Type section of Bjergkronerne Member. **10**: NW slope of Pictet Bjerge (72.109990, -23.483133; base of Pingo Dal Group in 100 m).

Gipsdalen and Fleming Fjord units are present north of the Jameson Land Basin, and their sedimentology and stratigraphy in these areas have been described by Surlyk *et al.* (2017) and by Andrews & Decou (2018). As this paper primarily deals with the sediments in the new Fleming Fjord Group emphasis is on the Late Triassic. During that time, central East Greenland was located at the northern rim of the Pangaea supercontinent (e.g. Clemmensen *et al.* 1998; Kent *et al.* 2014). The Jameson Land Basin was situated at the southern end of the East Greenland rift system, which formed part of a larger rift complex separating Greenland from Norway prior to the opening of the Atlantic (Nøttvedt *et al.* 2008; Guarnieri *et al.* 2017); in the Late Triassic (Norian), the Boreal Sea was situated far to the north of the basin (Andrews & Decou 2018). According to Haq (2018) Late Triassic sea level (long-term variation) reached a highstand at about 50 m above present-day mean sea level in the late Carnian and fell slowly thereafter and reached a minimum slightly below present-day mean sea level in the early Rhaetian.

Late Triassic sediments are well exposed in the Jameson Land Basin, which is located in central East Greenland at about 71° N at the present-day land areas of Jameson Land and Scoresby Land (Fig. 1; Clemmensen *et al.* 2016). The Jameson Land Basin was bounded by the N–S stretching Liverpool Land to the east and the Stauning Alper to the west. To the north and south, the basin was demarcated by a fracture zone in the Kong Oscar Fjord and the Scoresby Sund respectively (Fig. 1; Guarnieri *et al.* 2017). The basin has since the Late Triassic been rotated 45° anticlockwise and translated 30° northward relative to present-day meridians (Kent & Tauxe 2005).

A number of sedimentary logs are presented here to illustrate the characteristic lithologies of the Triassic sedimentary units with emphasis on type and reference sections on the new Fleming Fjord Group (Fig. 2). While early stratigraphical work included sites throughout the basin, studies since 2012 have been focused at localities along Carlsberg Fjord including Lepidopteriselv and mountain regions around MacKnight Bjerg and Buch Bjerg including "Track Mountain" as the new Fleming Fjord Group at these sites is particular rich in vertebrate remains.

Previous investigations of the new Fleming Fjord Group

Late Triassic sediments (corresponding to the new Fleming Fjord Group; Fig. 3A) of central East Greenland were first described by Nordenskjöld (1909). Later work on their stratigraphy and sedimentology include Noe-Nygaard (1934), Stauber (1942), and Grasmück &Trümpy (1969). The latter authors gave a first lithostratigraphical description of the Late Triassic sediments; formal designation of the deposits was given by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980a, 1980b), (Fig. 3B).

The palaeoenvironments of the sediments in the Late Triassic Fleming Fjord Group sediments have been dealt with in several papers. Stauber (1942) included the sediments in question in his Bunte Serie and interpreted the deposits as brackish-marine. Grasmück & Trümpy (1969) interpreted the deposits (their Fleming Fjord and Ørsted Dal Members) as delta or tidal flat deposits overlain by marine deposits including carbonate-rich sediments in the uppermost part of their Ørsted Dal Member; they did note the occurrence of sandstones in the middle part of this member, but offered no interpretation on their origin. Perch-Nielsen *et al.* (1974) saw the sediments in their Fleming Fjord Formation as representing shallow marine, tidally influenced environments (their Edderfugledal and Malmros Klint Members), while their Ørsted Dal Member was interpreted as primarily continental (river, floodplain and lake deposits) with possible marine influence in the topmost part. Clemmensen (1980a), Jenkins *et al.* (1994), Clemmensen *et al.* (1998), Clemmensen *et al.* (2016), and Decou *et al.* (2016) further refined the interpretations of these Late Triassic deposits and interpreted the sediments in the eastern and central part of the basin as lacustrine with fluvial input from western source areas.

In the late Late Triassic (late Norian – early Rhaetian), the Jameson Land Basin was situated at 41° N on the northern part of the supercontinent Pangaea (Kent & Tauxe, 2005). This position placed the basin in a transition zone between the relatively dry interior of the supercontinent Pangaea and the more humid peripheral part of this continent (Clemmensen *et al.* 1998; Sellwood & Valdes, 2006), or well inside the humid temperate belt (Kent *et al.* 2014). The local climatic conditions that controlled the Late Triassic lake and fluvial deposition in the basin have been interpreted in various detail in previous papers. Perch-Nielsen *et al.* (1974) write that the deposits in the uppermost part of the succession were formed during a general change in climatic conditions from arid to more humid, and Clemmensen (1980a) states that the fluvial deposits of the Ørsted Dal Member record a climatic shift towards greater humidity. More refined palaeoclimatic interpretations of the deposits were given by Jenkins *et al.* (1994), Clemmensen *et al.* (1998) and Clemmensen *et al.* (2016). In these papers it was suggested that lake sedimentation was strongly influence by orbital control on precipitation.

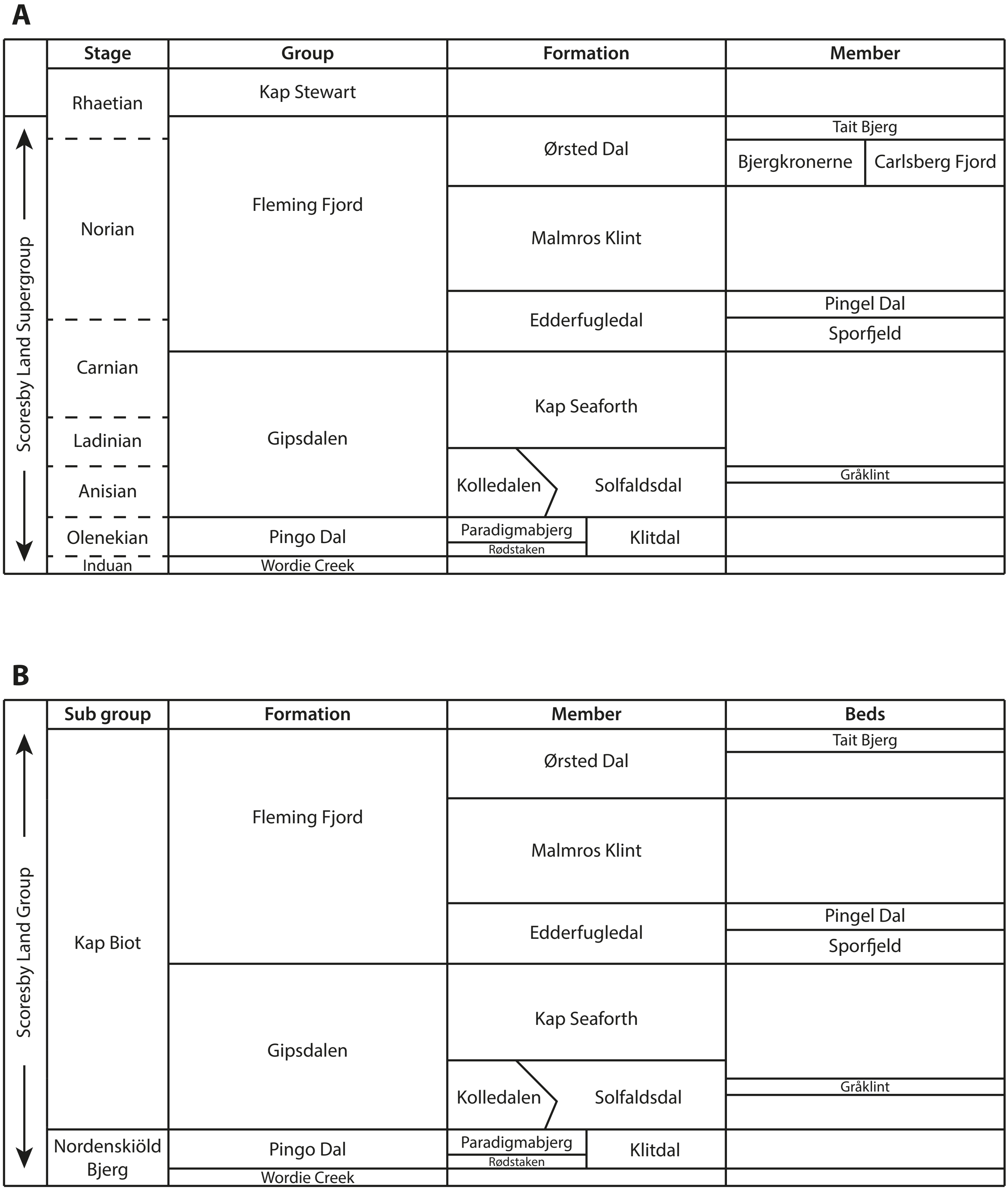

Fig. 3. A. New lithostratigraphical subdivision of the Triassic sedimentary rocks in the Jameson Land Basin, central East Greenland. Stages (tentative) modified after Clemmensen (1980a, 1980b) and Müller *et al.* (2005). See Andrews *et al.* (2014) for alternative age interpretations. **B.** Previous lithostratigrahical subdivision of the Triassic sedimentary rocks in the Jameson Land Basin, central East Greenland, Clemmensen (1980b). The Fleming Fjord Group is overlain by lacustrine and associated sediments of the Kap Stewart Group, the lowermost part of which is Late Triassic (Rhaetian).

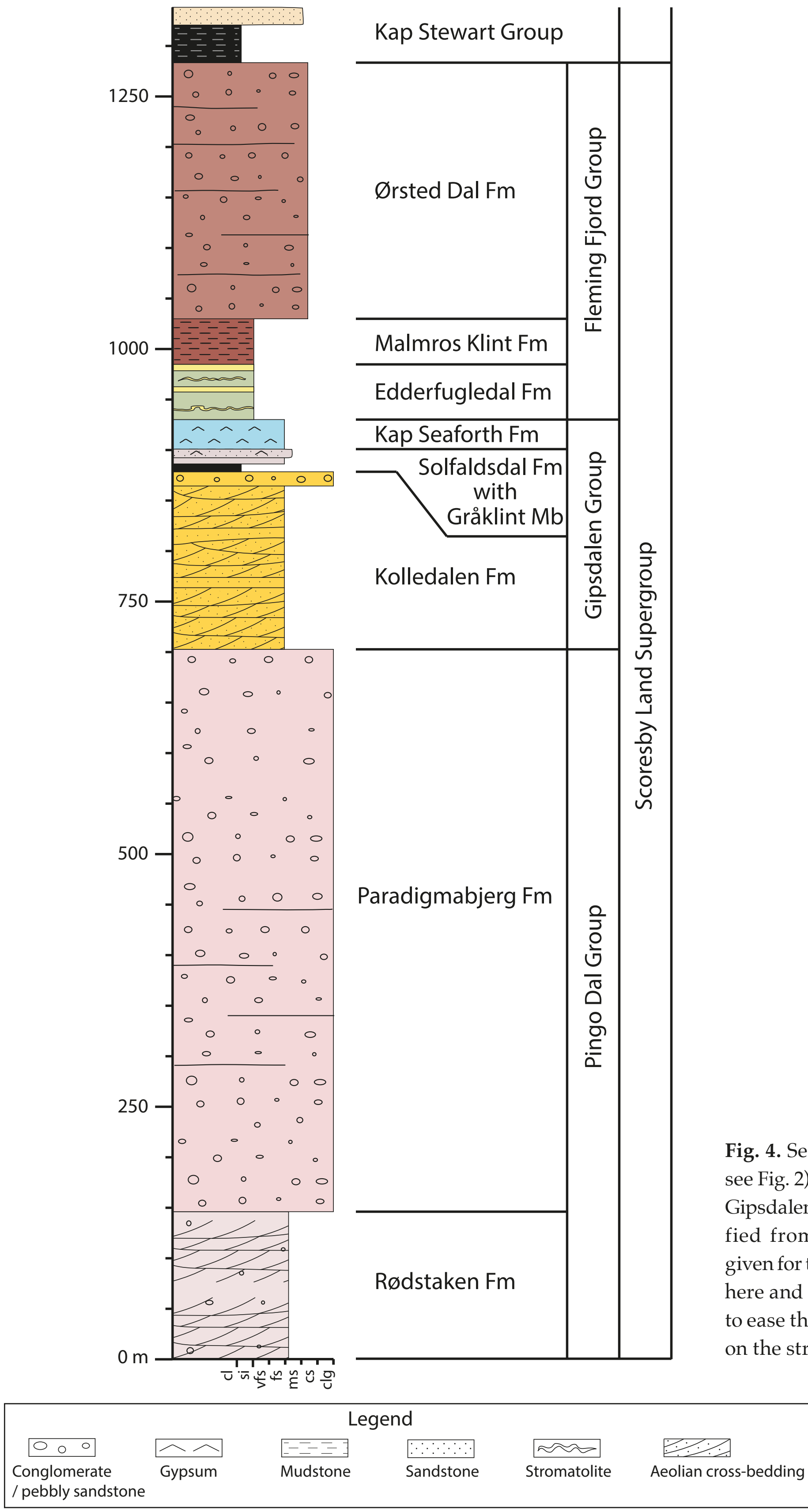

Fig. 4. Section at Pictet Bjerge (for location see Fig. 2) showing the complete Pingo Dal, Gipsdalen and Fleming Fjord Groups. Modified from Clemmensen (1980b). Colours given for the individual stratigraphical units here and on the following logs are selected to ease the visual identification of the units on the stratigraphical logs.

Brief reports on early finds of vertebrate remains in these Late Triassic deposits have been given by Stauber (1942), Grasmück & Trümpy (1969), Perch-Nielsen *et al.* (1974) and Clemmensen (1980b). Jenkins *et al.* (1994) summarized the vertebrate finds that were made during expeditions to the area in the late 1980ties and the early 1990ties, while Marzola *et al.* (2018) updated the fauna list by vertebrate finds discovered during expeditions in 2012 and 2016. Jenkins *et al.* (1997; 2001; 2008) Lou *et al.* (2015), and Marzola *et al.* (2017), gave more detailed anatomical descriptions of individual vertebrate finds including amphibians, pterosaurs, and mammaliaforms, and well-preserved vertebrate tracks including those made by dinosaurs were described by Gatesy *et al.* (1999), Gatesy (2001), Milán *et al.* (2004), Klein *et al.* (2016), and Lallensach *et al.* (2017).

The Fleming Fjord Group has been dated to the Late Triassic (most likely Norian – early Rhaetian) based on sparse invertebrate fossils, land-derived palynomorphs, vertebrate remains, and palaeomagnetic data (Clemmensen 1980b; Jenkins *et al.* 1994; Kent & Clemmensen 1996). More details are given below.

Lithostratigraphy

Scoresby Land Supergroup

New supergroup

This unit was originally described by Perch-Nielsen *et al.* (1974) as a group, and the readers are referred to this paper for details. The unit is here elevated to a supergroup (Fig. 3A). Perch-Nielsen *et al.* (1974) and Clemmensen (1980b) divided their Scoresby land Group into two subgroups, the Nordenskiöld Bjerg Subgroup, and the Kap Biot Subgroup (Fig. 3B); these subgroups are emended here and not treated further. The new Scoresby Land Supergroup consists of four new groups: the Wordie Creek, Pingo Dal, Gipsdalen and Fleming Fjord Groups (Fig. 3A). In the following the Wordie Creek, Pingo Dalen and Gipsdalen Groups are only described very schematically, while the vertebrate-bearing Fleming Fjord Group is described in some detail.

Wordie Creek Group

This unit was originally decribed by Grasmück & Trümpy (1969) and Perch-Nielsen *et al.* (1974) in the Jameson Land basin as a formation. It consists of grey, marine mudstones with ammonite and fish-bearing calcareous concretions; coarse to conglomeratic sandstones typically feldspatic occur in several intervals (Perch-Nielsen *et al.* 1974; Grasmück & Trümpy 1969). These coarse-grained sediments were viewed as turbidites by Seidler (2000). The unit was recently redefined by Surlyk *et al.* (2017) as a group (Fig. 3A), and readers are referred to this paper for details. In the Jameson Land Basin this group is not subdivided into formations. The Wordie Creek group was placed in the Early Triassic (Griesbachian substage of Induan stage) by Perch-Nielsen *et al.* (1974) and Surlyk *et al.* (2017), (Fig. 3A). The group has thicknesses between 70 and 500 m.

Pingo Dal Group

New group

The alluvial fan and fluvial conglomerates and sandstones of this unit were described by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b) as a formation. The unit is elevated here to a group (Fig. 3A); readers are referred to the above papers for name, type section, thickness, reference sections, lithology, boundaries and distribution. The Pingo Dal Group (Figs 4-8) consists of three formations, the Rødstaken, Paradigmabjerg and Klitdal Formations. The Pingo Dal Group was tentatively placed in the late Early Triassic by Clemmensen (1980b) and Müller *et al.* (2005), but new data (Andrews *et al.* 2014) seem to indicate that it spans a large time interval from late Early to early Late Triassic (Olenikian – early Carnian), (Fig 3A). The group has typical thicknesses between 450 and 700 m.

Rødstaken Formation

New formation

This unit was described by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b) as a member. The unit is elevated here to a formation (Fig. 3A); readers are referred to the above papers for name, type section, reference sections, thickness, lithology, boundaries and distribution. Clemmensen (1980b), and Müller *et al.* (2005) tentatively suggested that the coastal flood-plain deposits of this unit (Table 1; Fig. 4) were of late Early Triassic (Olenikian) age (Fig.3A).

Table 1. Pingo Dal Group. Lithology and main depositional environments. For further information see Clemmensen (1980a, 1980b).

		Lithology	Depositional environments
Pingo Dal Group	Paradigmabjerg Formation	Red, pink or greyish sandstones (typically rich in feldspar grains), pebbly sandstones and conglomerates. Many of the most fine-grained facies contain incipient caliche horizons and desiccation cracks are present in the rare mudstone facies. Burrows are common in the fine-grained sandstones. The sediments form closely associated matrix-supported conglomerates and sandstones with rare low-angle cross bedding or they form m-thick fining-upward units. In the former successions, conglomerates are typically matrix-supported and structureless, while the conglomerates in the fining-upward successions are better sorted and have an erosive, channeled base; the associated sandstones have large-scale cross bedding. The formation is most typically developed in the northwestern part of the basin but also occur in the central part of the basin and on Wegener Halvø. Palaeocurrents measured at localities in Scoresby land are consistently directed towards the southeast. The formations is 150 m at the type sections and up to 500 m thick in Scoresby Land.	The more coarse-grained successions probably record debris flow and fluvial sheet flood deposition on alluvial fans, while the sand-rich successions more likely record deposition by braided rivers on distal alluvial fans or associated floodplains. The sediments formed in the northwestern part of the basin in Scoresby land seem to represent a large distributive fluvial system initiated by rifting and the creation of uplifted source areas.
	Klitdal Formation	Pink, feldspar-rich pebbly sandstones with large-scale cross bedding and conglomerates. Fine-grained-grained facies typically contain caliche and/or jasper horizons. Burrows are scarce to absent. The sediments form closely associated conglomerates (matrix-supported and structureless) and sandstones or they form fining-upward successions initiated by an erosive base overlain by pebbly sandstone with cross bedding and capped by fine-grained sediment. The formation is restricted to a narrow belt along the southeaster margin of the basin, and large-scale cross bedding indicate sediment transport toward the west. The formation is 70-90 m thick in the type area, and 450 m thick at Nordenskiöld Bjerg.	The more coarse-grained successions probably record debris flow and fluvial sheet flood and stream flood deposition on the more proximal parts of alluvial fans, while the sand-rich successions more likely record deposition by braided rivers on the more distal parts of the alluvial fans. Alluvial fan formation was initiated by rifting; palaeocurrents and distribution of the formation indicate that deposition took place adjacent to uplifted source areas in Liverpool Land.
	Rødstaken Formation	Dark red, fine-medium-grained, often cross-bedded sandstones associated with variegated mudstones and sandstones in the lower part. Rare horizons with horizontal lamination, wave ripples and convolute bedding appear. Bioturbation is scarce to absent. Pebbly sandstones and conglomerates appear in the upper part of the formation. Layers with poorly preserved bivalves are locally present in the lower part of the formation. Palaeocurrents are directed towards the north or northeast. The formation is about 180 m thick at the type locality but reaches up to 330 m in thickness elsewhere in Scores by Land.	The formation probably records fluvial sedimentation on a low-gradient coastal plain.

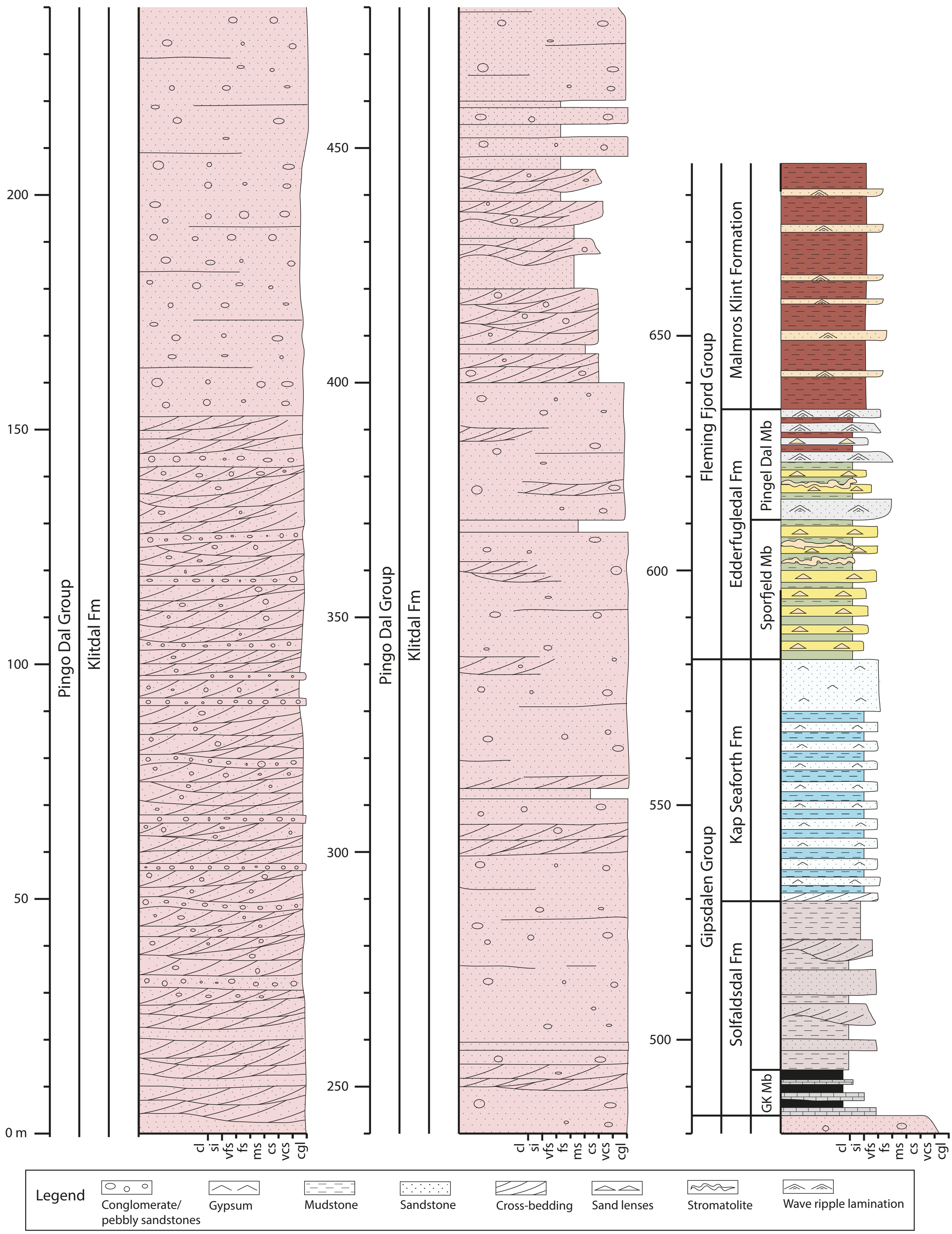

Fig. 5. Section at Nordenskiöld Bjerg (for location see Fig. 2) showing the main part of the Pingo Dal Group (Klitdal Formation), the complete Gipsdalen Group and the lowermost part of the Fleming Fjord Group. Modified from Clemmensen (1980b).

Table 2. Gipsdalen Group. Lithology and main depositional environments. For further information see Clemmensen (1980a, 1980b)

		Lithology	Depositional environments
Gipsdalen Group	Gråklint Member	Black or dark grey mudstones and limestones, more or less sandy calcarenites, and calcareous quartz sandstones. The mudstones are bituminous and form prospective source rocks. The member is relatively fossiliferous and contains bivalves, gastropods, conchostracans, and rare vertebrate remains. Burrows are moderately ommon.While the bivalves are indicative of a Middle Triassic age, palynological evidence suggests an early Late Triassic age. The formation is dominated by calcarenites at the type locality where it is 30 m thick. The formation thins to the south and has typical thicknesses around 10 m at northernmost Carlsberg Fjord.	The calcarenites and the calcareous sandstones probably formed in high-energy shoreline and shallow-marine environments, while the mudstones formed in lagoonal (or lacustrine) environments. This member therefore seems to record a short period of marine conditions in the otherwise continental basin.
	Kap Seaforth Formation	Greenish, greyish or variegated, gypsum-bearing sandstones and mudstones, and thin rather pure gypsum layers in a cyclically bedded succession. Sedimentary structures comprise large-scale cross bedding, wave-ripple structures, horizontal lamination, and irregular stratification. Desiccation cracks are common in the mudstones, and rare halite crystal casts are seen in some sandstones. Burrows are rare to absent. The thickness of the unit and the characteristics of the cycles vary across the basin indicating the presence of sub basins. The formation has a thickness of 160 m at the type section in the northeastern part of the basin and more than 100 m in the southeastern part of the basin. Elsewhere the member is thinner and locally less than 50 m thick.	The gypsum-bearing cycles probably originated in shallow lakes with fluctuating water levels and periods of complete desiccation. Typically, cycles involved aeolian sand sheet deposits, aeolian-influenced lake-shore sandstones, and open lacustrine mudstones. Cycle formation was most likely related to orbitally controlled variations in precipitation and lake depth. Overall climate was relatively dry.
	Solfaldsdal Formation	Red or variegated sandstones and mudstones with gypsum. One type of facies associations comprises regular alternations between current cross-stratified sandstones and current-ripple laminated or structureless siltstones. A second one comprises randomly interbedded wave-rippled fine-grained sandstones and siltstones. Both types are associated with horizontally laminated or large-scale cross-bedded medium-grained sandstone. Burrows are moderately common. Palaeocurrent data suggest fluvial transport towards the north. The formation has a thickness of 150 m at the type section.	The sediments record deposition in a floodplain environment gradually being replaced by a shallow lake system towards the north. Rivers were primarily of meandering nature. Overall climate was relatively dry.
	Kolledalen Formation	Yellowish, well-sorted, fine to medium-grained sandstones with large-scale cross bedding, horizontally laminated or ripple laminated sandstones, sandstones and silty sandstones with mud pebbles, structureless or horizontally laminated sandy siltstone, and conglomerates and pebbly sandstones. Gypsum nodules are rare to common in the most of the facies. Burrows are rare to absent. The formation is best developed along the northwestern margin of the basin where it reaches thicknesses between 90 and 180 m. Cross bedding indicate dominant sediment transport from the northeast but intervals with transport from the southeast are also present.	The sediments record deposition in an inland dune landscape that was influenced by intermittent reworking by river floods at its northwestern margin and graded into various sabkha and lacustrine/floodplain deposits toward southeast in the central part of the basin. Dominant palaeowinds from the northeast can be interpreted as ancient trade winds in a low-latitude desert basin.

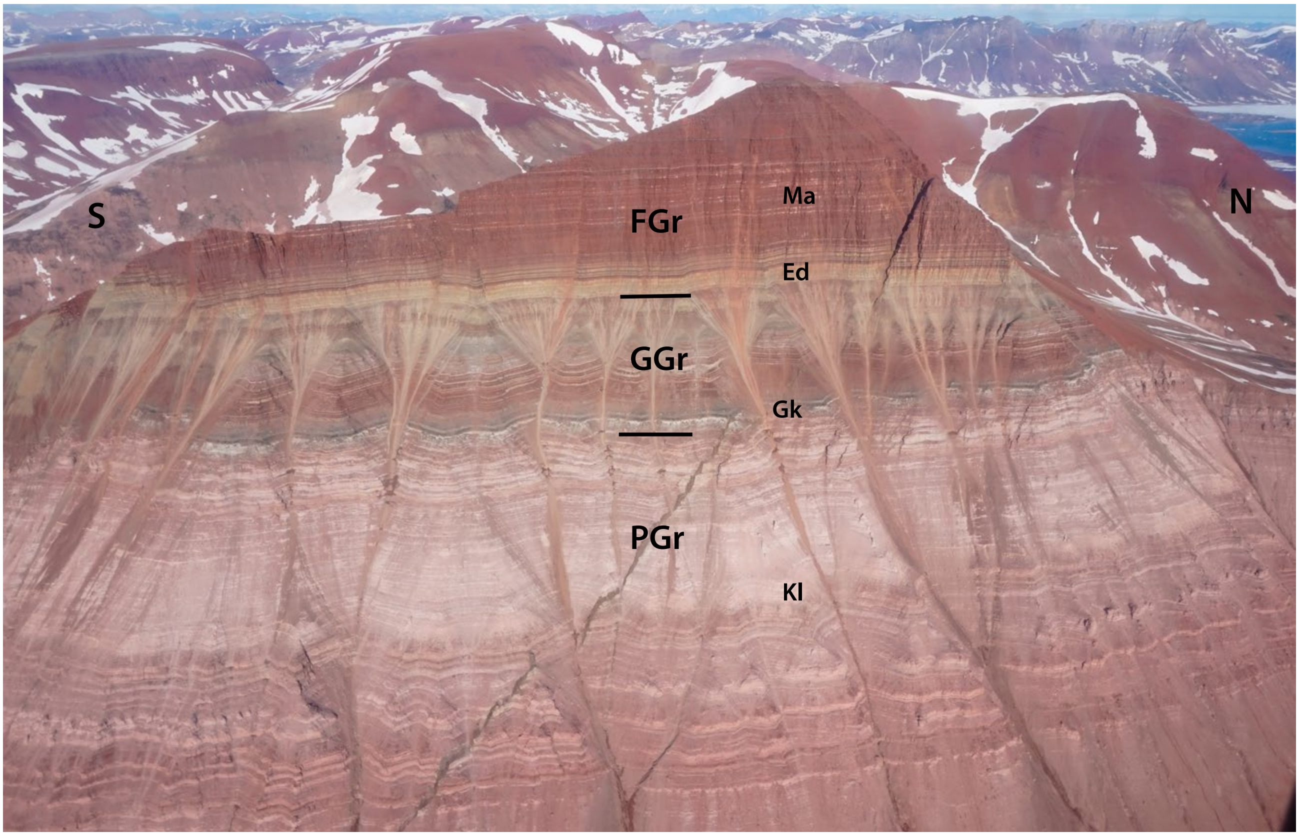

Fig. 6. East facing mountainside at Buch Bjerg showing the main part of the Pingo Dal Group (PGr) here composed of the Klitdal Formation (Kl), the complete Gipsdalen Group (GGr) with the Gråklint Member (Gk) and the lowermost part of the Fleming Fjord Group (FGr) here composed of the Edderfugledal Formation (Ed) and the lowermost part of the Malmros Klint Formation (Ma). Shown mountainside is about 500 m high (mountain top in 770 m). Buch Bjerg is facing the Carlsberg Fjord and situated about 5 km south of Nordenskiöld Bjerg.

Paradigmabjerg Formation

New formation

This unit was described by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b); readers are referred to the above papers for name, type section, reference sections, thickness, lithology, boundaries and distribution. The unit is elevated here to a formation (Fig. 3A). Clemmensen (1980b) and Müller *et al.* (2005) tentatively suggested that the alluvial fan and fluvial deposits of this unit (Table 1; Fig. 4) were of late Early Triassic age, while Andrews *et al.* (2014) found that it spans a large time interval from late Early to early Late Triassic (Olenikian – early Carnian), (Fig. 3A).

Klitdal Formation

New formation

This unit was described by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b) as a member. The unit is elevated here to a formation; readers are referred to the above papers for name, type section, reference sections, thickness, lithology, boundaries and distribution. Clemmensen (1980b) and Müller *et al.* (2005) tentatively suggested that alluvial fan deposits of the unit (Table 1; Figs 5, 6, 7) were of late Early Triassic age, while Andrews *et al.* (2014) found that it spans a large time interval from late Early to early Late Triassic (Olenikian – early Carnian), (Fig 3A).

Gipsdalen Group

New group

The gypsum-bearing deposits of this unit were described by Perch-Nielsen *et al.* (1974) and by Clemmensen 1980b as a formation. The unit is elevated here to a group (Figs 4–8); readers are referred to the above papers for name, type section, reference sections, thickness, lithology, boundaries and distribution. In the Jameson Land Basin, the Gipsdalen Group consists of three new formations, the Kolledalen, Solfaldsdal and

Kap Seaforth Formations. The Solfaldsdal Formation contains the new Gråklint Member. The Gipsdalen Group was given a Middle Triassic (Anisian – Ladinian) age by Clemmensen (1980b), a Middle to early Late Triassic (Anisian – early Carnian) age by Müller *et al.* (2005), and a Late Triassic (mid Carnian – early Norian) age by Andrews *et al.* (2014), (Fig. 3A). The group has typically thicknesses between 100 and 375 m.

Kolledalen Formation

New formation

This unit was described by Clemmensen (1980b) as a member. The unit is elevated here to a formation (Fig. 4); readers are referred to the above paper for name, type section, reference sections, thickness, lithology, boundaries and distribution. The aeolian and associated deposits of the Kolledalen Formation (Table 2; Fig. 4) were given a Middle Triassic (Anisian – early Ladinan) age by Clemmensen (1980b) and Müller *et al.* (2005). Andrews *et al.* (2014) suggested that the deposits were of Late Triassic (Carnian) age (Fig. 3A).

Solfaldsdal Formation

New formation

This unit was described by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b) as member. The unit is elevated here to a formation (Fig. 3A); readers are referred to the above papers for name, type section, reference sections, thickness, lithology, boundaries and distribution. The gypsum-bearing lacustrine and floodplain deposits of the Solfaldsdal Formation (Table 2; Figs 4, 5) were given a Middle to early Late Trias-

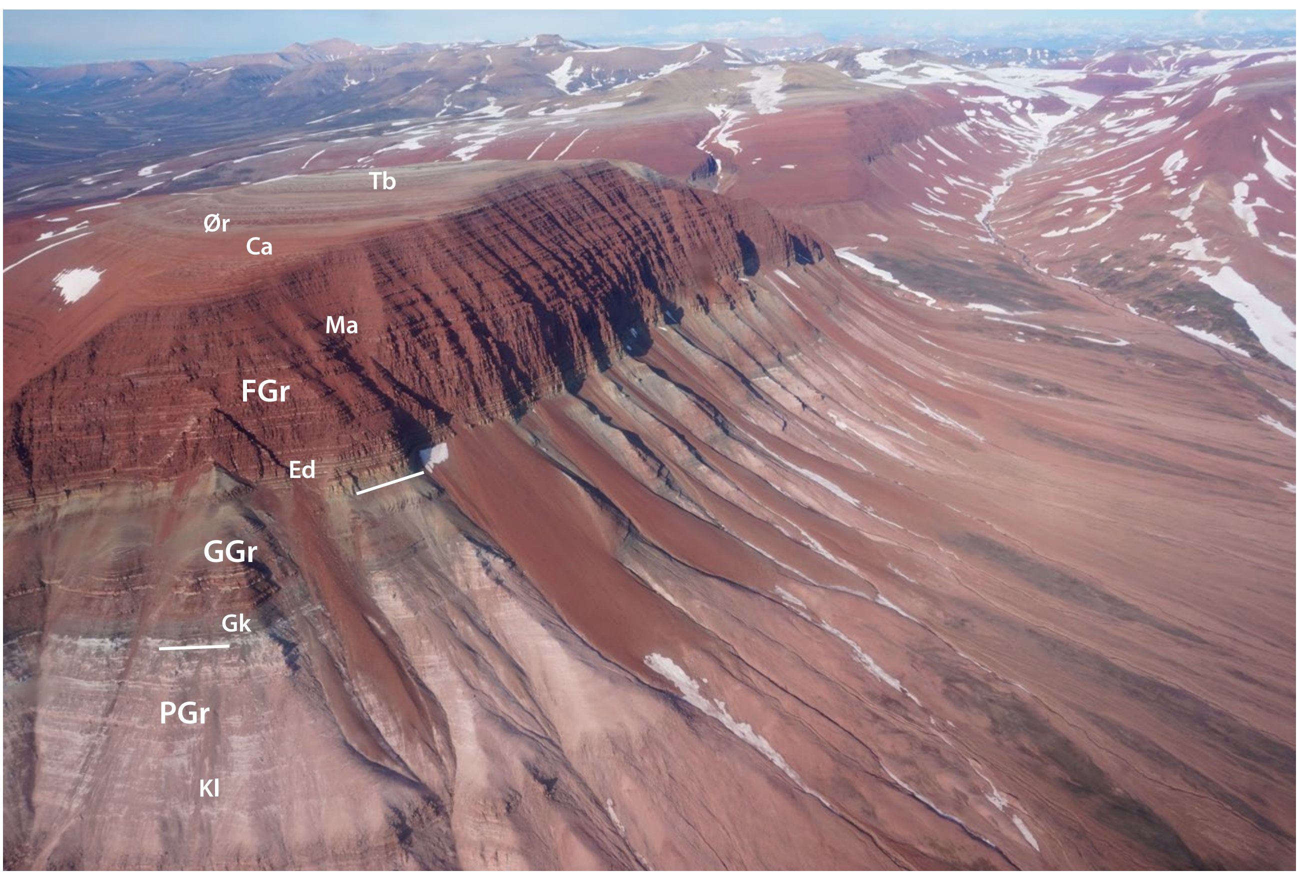

Fig. 7. East and north facing montainsides of Tait Bjerg showing the main part of the Pingo Dal Group (PGr) here composed of the Klitdal Formation (Kl), the complete Gipsdalen group (GGr) with the Gråklit Member (Gk), and the near complete Fleming Fjord Group (FGr) with the Edderfugledal Formation (Ed), the Malmros Klint Formation (Ma) and the Carlsberg Fjord Member (Ca) and the Tait Bjerg Member (Tb) of the Ørsted Dal Formation (Ør). The Carlsberg Fjord Member at the top of the mountain displays numerous bedding planes with *Grallator* tracks as well as one site with the ichnogenus *Brachychirotherium*. Remains of at least three prosauropod dinosaurs were found in the Malmros Klint Formation (Marzola *et al.* 2018). Type section of the Tait Bjerg Member. Mountain top in 710 m.

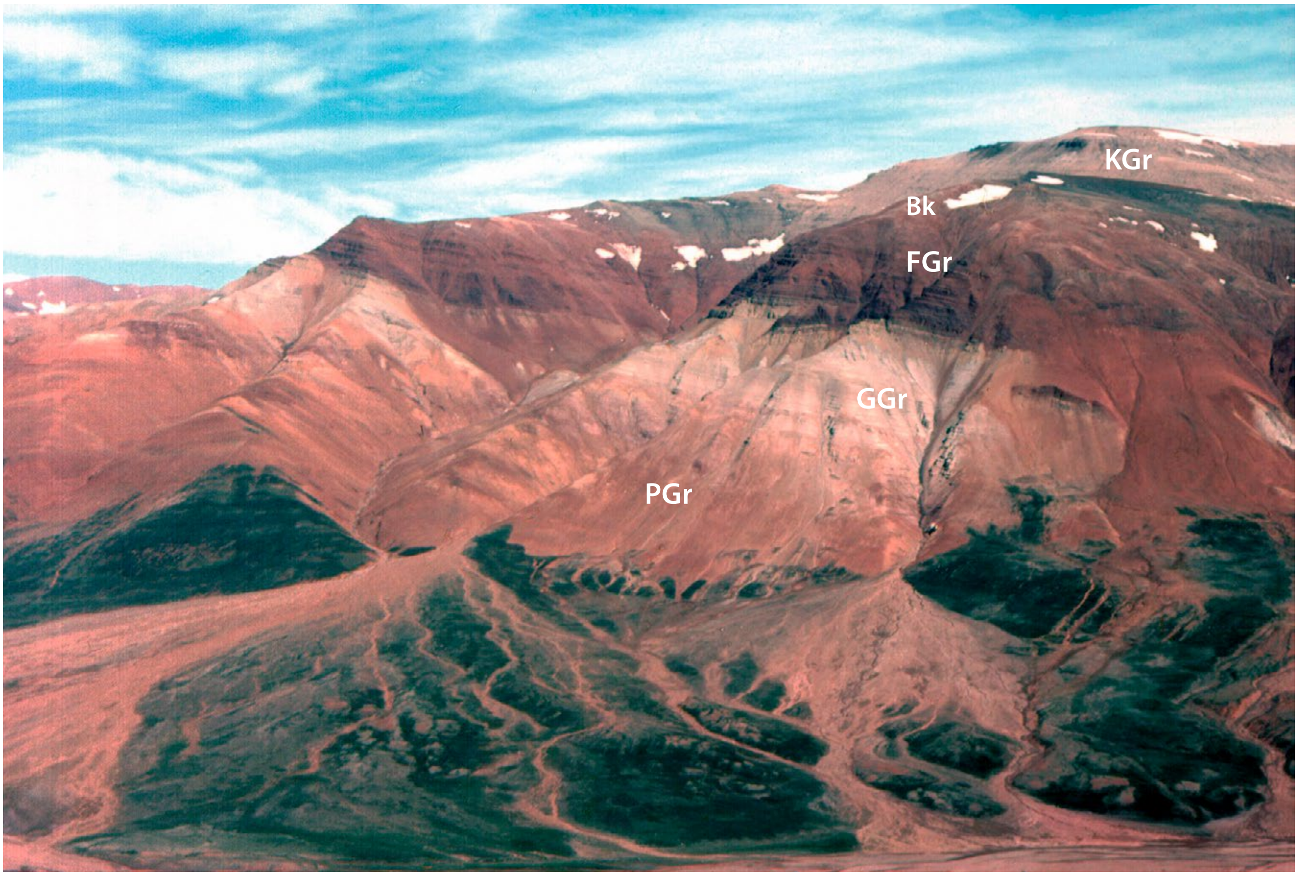

Fig. 8. Southeast facing mountain sides at Sydkronen in Bjergkronerne showing the main part of the Pingo Dal Group (PGr), the complete Gipsdalen Group (GGr), the complete Fleming Fjord Group (FGr) and the lowermost part of the Kap Stewart Group (KGr). Type section of the Bjergkronerne Member (Bk). Mountain top in 1140 m.

sic (Anisian – early Ladinian) age by Clemmensen (1980b) and Müller *et al.* (2005). Andrews *et al.* (2014) suggested that the deposits were of early Late Triassic (Carnian) age primarily based on fossil evidence from the Gråklint Member (see below). The Solfalsdal Formation contains the new Gråklint Member (elevated from the Gråklint Beds).

Kap Seaforth Formation

New formation

This unit was described by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b) as a member. The unit is elevated here to a formation (Fig 3A); readers are referred to the above papers for name, type section, reference sections, thickness, lithology, boundaries and distribution. The gypsum-bearing lacustrine deposits of the Kap Seaforth Formation (Table 2; Figs 4, 5) were given a Middle to early Late Triassic (Ladinian – early Carnian) age by Clemmensen (1980b) and Müller *et al.* (2005); Andrews *et al.* (2014) suggested that the deposits were of early Late Triassic (Carnian – early Norian) age (Fig. 3A).

Gråklint Member

New member

The limestones and dark grey and black mudstones of this unit (Fig. 6; Table 2) were described by Grasmück & Trümpy (1969) and Perch-Nielsen *et al.* (1974) and formally designated as the Gråklint Beds by Clemmensen (1980b). The unit is elevated here to a member (Fig 3A); readers are referred to Clemmensen (1980b) for name, type section, reference sections, thickness, lithology, boundaries and distribution. The marine and lagoonal deposits of the Gråklint Member (Table 2; Figs 4, 5, 6, 7) were given a Middle Triassic (late Anisian – early Ladinian) age by Clemmensen (1980b) and Müller *et al.* (2005). Andrews *et al.* (2014) suggested that the deposits were of early Late Triassic (Carnian)

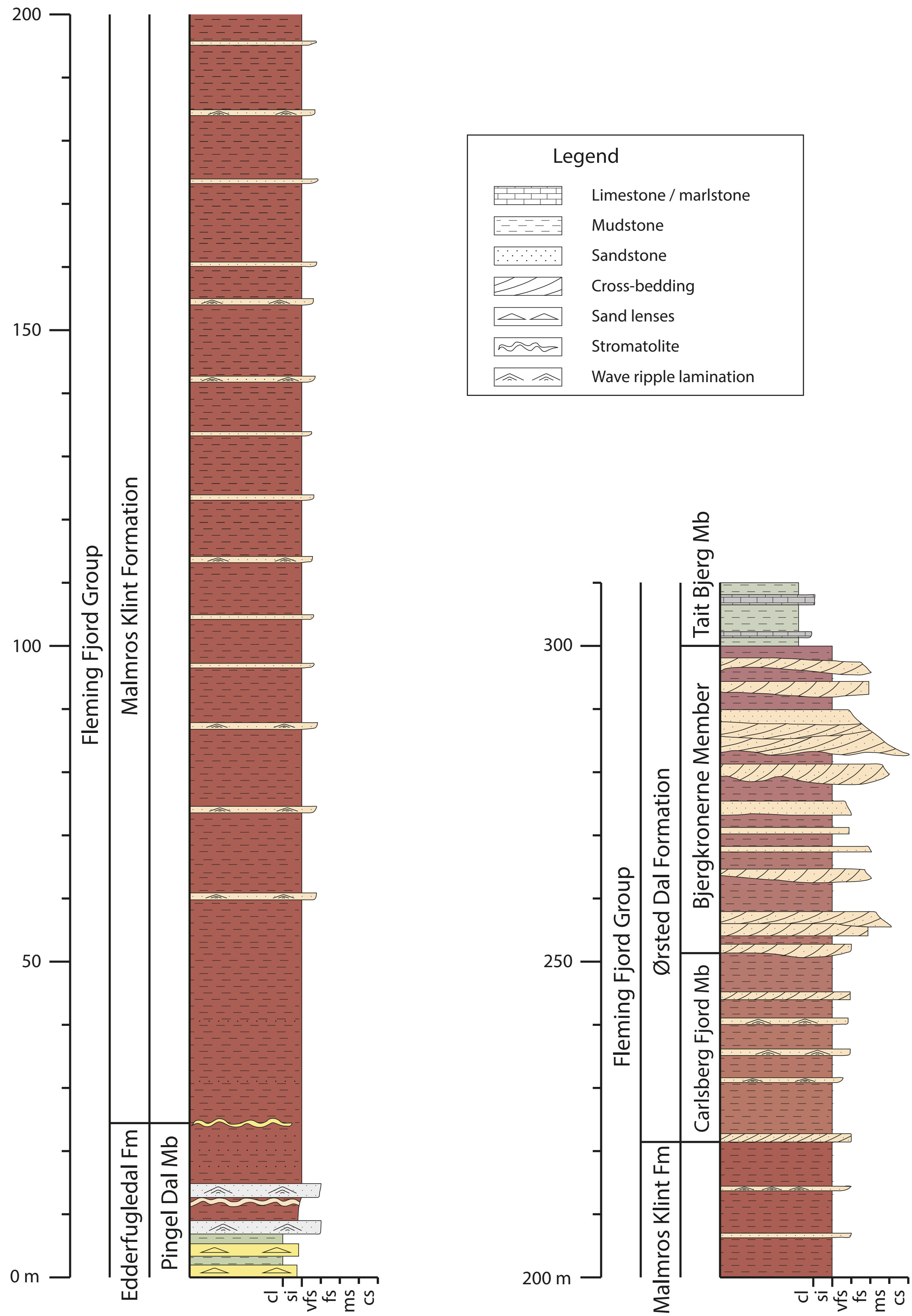

Fig. 9. Section at Malmros Klint (for location see Fig. 2) showing the main part of the Fleming Fjord Group. No vertebrate bone remains have been found at this site. Modified from Clemmensen 1980b.

age primarily based on palynological evidence (Fig. 3A). The unit contains relatively abundant bivalves, but they have proved less useful in constraining the age of the member (Andrew *et al.* 2014).

Fleming Fjord Group

New group

History. This unit was described as the Fleming Fjord Formation by Perch-Nielsen *et al.* (1974) and by Clemmensen (1980b). Supplementary descriptions of the deposits in this unit were given by Jenkins *et al.* (1994), Clemmensen *et al.* (1998), Clemmensen *et al.* (2016), and Decou *et al.* (2016). The unit is here elevated to a group (Fig. 3A) in order to allow that vertebrate-bearing beds of considerable thickness and wide distribution in the uppermost part of the group to be raised to members (details are given below).

Name. From Fleming Fjord, a large fjord that marks the northeastern boundary of Jameson Land (Fig. 2).

Type section. Malmros Klint at Fleming Fjord (Figs 9, 10).

Reference sections. At Malmros Klint both the upper and lower boundary of the group is covered by scree at many sites. Impressive exposures of the group occur along the western shore of Carlsberg Fjord where mountain sides display not only the Fleming Fjord Group but also most of underlying Pingo Dal and Gipsdalen Groups (Figs 6, 7). The steepness of most of these cliff sides, however, does not allow field measurements of sedimentary logs. Only at Nordenskiöld Bjerg a log was measured through part of this group (Fig. 5).

Other reference sites include: Kap Biot (Figs 11, 12), Sydkronen (Figs 8, 13); Pictet Bjerge (Fig. 4), and Lepidopteriselv (Figs 14, 15).

Fig. 10. Mountain slopes at Malmros Klint. The succession exposed in Malmros Klint is the complete Fleming Fjord Group (FGr) with the Edderfugledal Formation (Ed), the Malmros Klint Formation (Ma), and the Bjergkronerne Menber (Bj) and Tait Bjerg Member (Tb) of the Ørsted Dal Formation (Ør). At top of the mountain the lowermost part of the Kap Stewart Group (KGr) is seen. Type section of the Fleming Fjord Group, the Malmros Klint and Ørsted Dal Formations. The Malmros Klint mountains, which face the Fleming Fjord, are almost 700 m high.

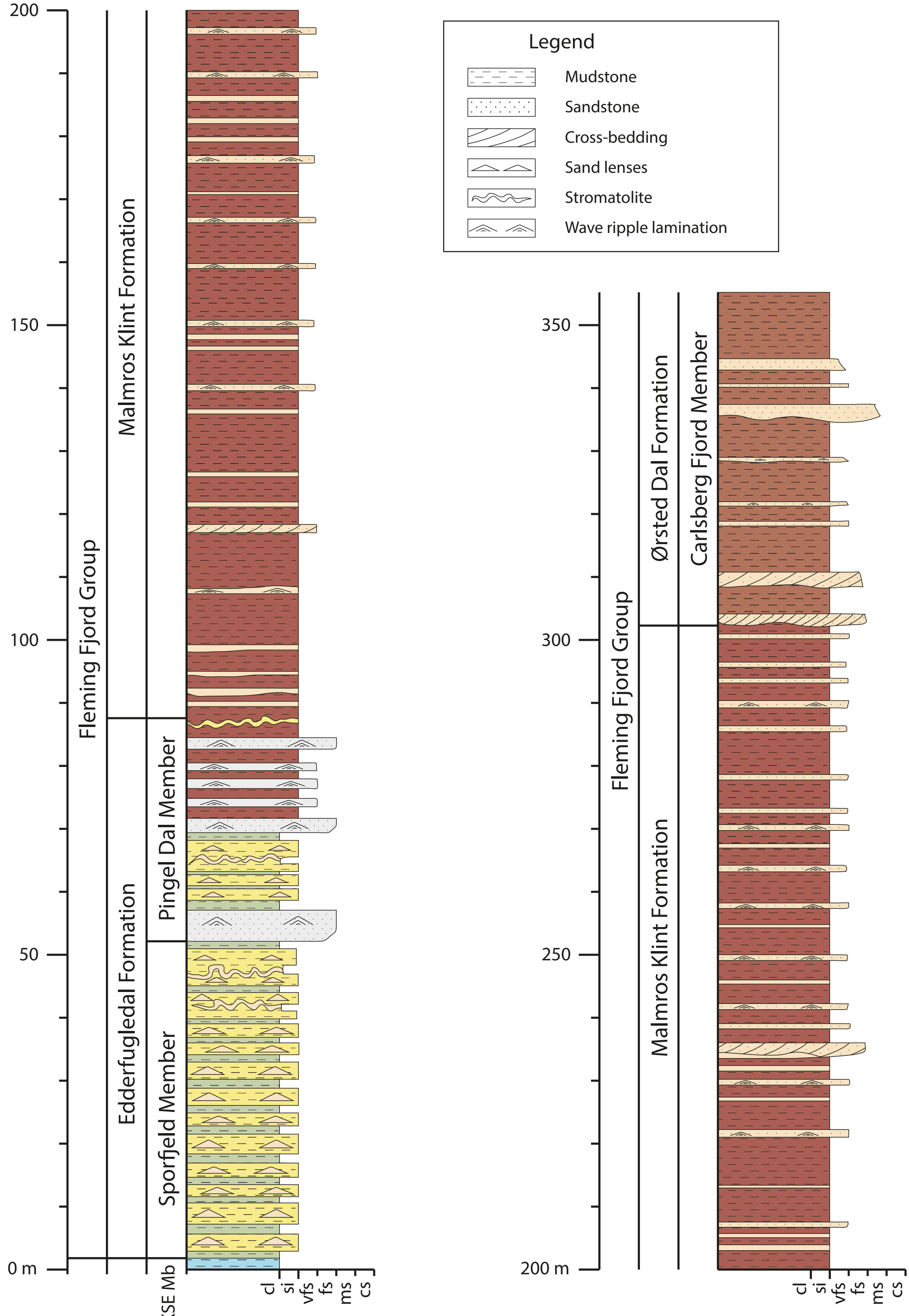

Fig. 11. Section at Kap Biot (for location see Fig. 2) showing the main part of the Fleming Fjord Group including the boundary to the underlying Kap Seaforth Formation of the Gipsdalen Group. Small bone fragments and rare dinosaur track are present in the uppermost part of the Ørsted Dal Formation. Modified from Clemmensen (1980b).

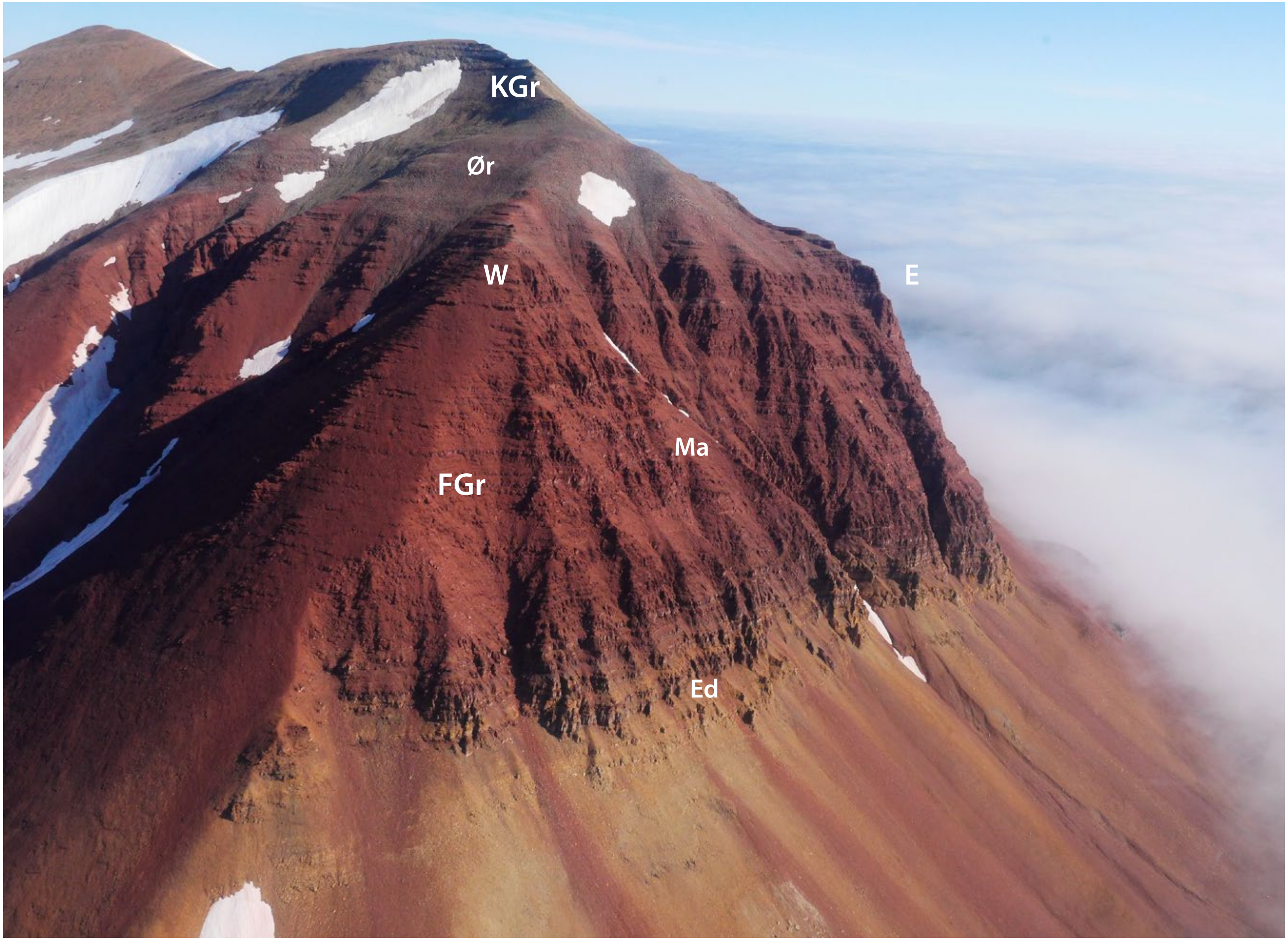

Fig. 12. South facing mountain slopes at Kap Biot (for location see Fig. 2) showing the complete Fleming Fjord Group (FGr) and the lowermost part of the Kap Stewart Group (KGr). In the Fleming Fjord Group the basal Edderfugledal Formation (Ed), the middle Malmros Klint Formation (Ma), and the uppermost Ørsted Dal Formation (Ør) are well exposed. Mountain top is in 680 m; thickness of Fleming Fjord Group is about 400 m.

Thickness. About 400 m at the type section and around Kap Biot, around 350 m along the western side of Carlsberg Fjord, 285-300 m in Gipsdalen, around 225 m in Kolledalen, and around 350 m at Pictet Bjerge.

Lithology. Stromatolite-bearing dolostones, mudstones and sandstones at the bottom, and red, fine-grained sandstones and mudstones in the middle are followed by red mudstones or grey sandstones and conglomerate with subordinate red mudstones and light grey marlstones and dolomitic limestones at the top. See individual units for details.

Fossils. Trace fossils are abundant in this group and includes a rich and diverse series of freshwater ichnocoenoses (Bromley & Asgaard 1979; Clemmensen 1980a). Vertebrate fossils are relatively abundant in the Malmros Klint and Ørsted Dal formations (Jenkins *et al*. 1994; Clemmensen *et al*. 2016; Marzola *et al*. 2018), while invertebrate fossils are scarce. See individual units for details.

Boundaries. The lower boundary is defined, at most sites, by the sharp change from gypsiferous sediments to yellow weathering dolostones and associated sediments. At the upper boundary greyish, coarse sandstones and black claystones of the Kap Stewart Group overlie grey carbonates and associated mudstones of the Tait Bjerg Member or lie directly upon variegated sandstones and mudstones.

The nature of the upper boundary to the Kap Stewart Group has been discussed by a number of authors. Grasmück & Trümpy (1969) wrote that the sediments of the Kap Stewart Group lie without visible discontinuity upon a bone bed in uppermost Tait Bjerg Member. Perch-Nielsen *et al*. (1974) found that there is a hiatus between the Fleming Fjord Group and the

Kap Stewart Group, while Dam & Surlyk (1993) writes that an unconformity in marginal areas of the basin is replaced by a correlative conformity in the central part of the basin. In a more recent review, Decou *et al.* (2016) suggest that the boundary between the two groups is transitional. Our observations from Lepidopteriselv at the eastern margin of the basin, however, clearly demonstrates there here is an erosional unconformity as the lowermost sandstone in the Kap Stewart Group contains lithified slabs of Tait Bjerg Member marlstone.

Distribution. The group occurs over the whole Jameson Land Basin. Sediments belonging to this group are also found north of the basin on Traill Ø and Geographical society Ø (Andrews & Decou 2018).

Age. The Fleming Group was given a Late Triassic (late Carnian – early Rhaetian) age by Clemmensen (1980b) and Müller *et al*. (2005). Kent and Clemmensen (1996) placed the main part of the group in the late Norian – early Rhaetian, while Andrews *et al.* (2014) suggested that the deposits were of Norian – early Rhaetian age (Fig. 3A). More details below.

Subdivisions. The Group consists of three new formations, the Edderfugledal, Malmros Klint, and Ørsted Dal Formations (Fig. 3A). Emphasis in the following will be given to the Malmros Klint and Ørsted Dal Formations as these units are relatively rich in vertebrate fossils (Jenkins *et al.* 1994, Clemmensen *et al.* 2016, Marzola *et al.* 2018). The Ørsted Dal Formation contains two vertebrate-bearing units that so far only have been described as informal bed units (Jenkins *et al.* 1994). These units are here defined as the Carlsberg Fjord and Bjergkronerne Members.

Depositional environments. The Fleming Fjord Group is composed of lacustrine sediments with fluvial sediments forming a main part of the unit in the northwestern part of the basin. See formations and members for details.

Edderfugledal Formation

New formation

History. This unit forms the lowermost unit in the Fleming Fjord Group; it was defined as a member by Perch-Nielsen *et al.* 1974 and Clemmensen 1980b. It is here raised to a formation (Fig. 3A). Sedimentological descriptions of the formation were given by Clemmensen (1978), Clemmensen (1980a), and by Decou *et al.* (2016).

Name. From Edderfugledal near Kap Biot, eastern Scoresby land.

Type section. Sporfjeld W of Edderfugledal (Fig. 2; Figs 17, 18 in Clemmensen 1980b).

Reference sections. Kap Biot (Fig. 11), Nordenskiöld Bjerg (Fig. 5), Sydkronen (Fig. 13), Pictet Bjerge (Fig. 4).
Thickness. The formation has a thickness of 70 m at the type section and at Kap Biot, it is 55 m thick at Nordenskiöld Bjerg, 40 m at Sydkronen, and about 50 m thick at Pictet Bjerge.

Lithology. Cyclically bedded yellow dolostones, green mudstones, flat pebble conglomerates and stromatolitic limestones occur in the lower part of the member. In the upper part grey sandstones with wave ripples and reddish sandstone and mudstones also occur.

Fossils. The uppermost part of the formation contains rare and poorly preserved bivalves including *?Trigonodus* sp., *?Myophoria* sp., or *?Eotrapezium* sp., common conchostracans (e.g. *Eustheria forbesii* Jones) as well as numerous fresh-water trace fossils (Bromley& Asgaard 1979, Clemmensen 1980a). The formation only contains very sparse vertebrate remains primarily from amphibians. No detailed study of these fossils, however, has been carried out.

Boundaries. The lower boundary is identical to the lower boundary of the Fleming Fjord Group and at most localities characterized by the appearance of yellow dolostones. The upper boundary is placed immediately above the uppermost grey sandstone or yellow, stromatolitic limestone.

Distribution. The formation occurs in the eastern and central part of the basin.

Age. The Edderfugledal Formation was tentatively given a Late Triassic (Carnian) age by Clemmensen (1980b), a late Carnian – early Norian age by Müller *et al.* (2005), and an early Norian age by Andrews *et al.* (2014), (Fig. 3A).

Subdivisions. This formation is subdivided into two new members, the Sporfjeld Member and the Pingel Dal Member.

Depositional environments. The Edderfugledal Formation formed in a shallow lake. Periods of subaerial exposure were common in particular during deposition of the uppermost part of the formation. The existence of sparse bivalves with marine affin-

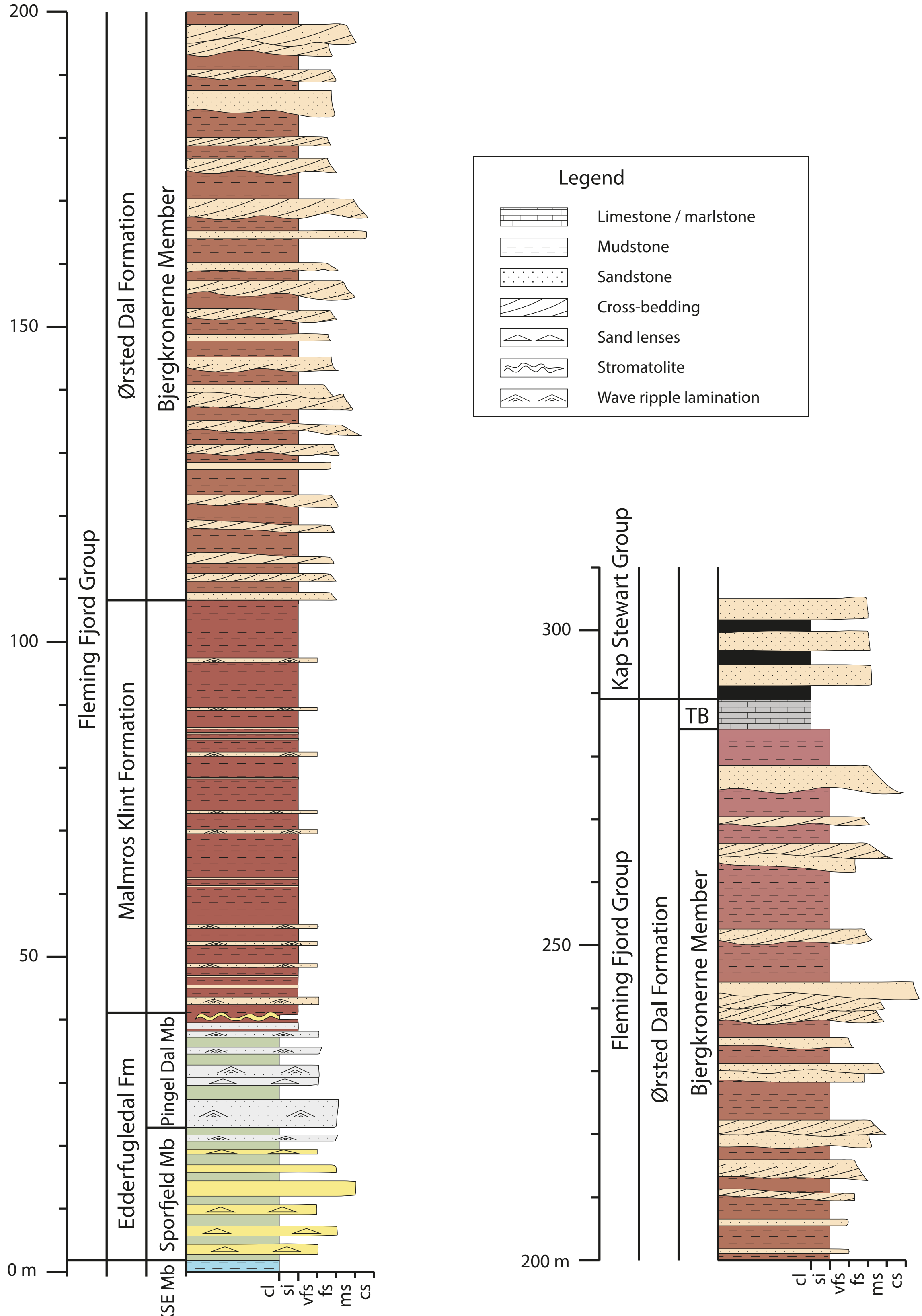

Fig. 13. Section at Sydkronen in Bjergkronerne (for location see Fig. 2) showing the complete Fleming Fjord Group including its lower boundary to the Kap Seafort Formation of the Gipsdalen Group and its uppermost boundary to the Kap Stewart Group. There is no visible discontinuity at the base of the Kap Stewart Group. Bone remains of aetosaurs and theropod dinosaurs are present in the Bjergkronerne Member. Modified from Clemmensen (1980b).

ity suggest occasional marine flooding of the basin (Clemmensen 1978; 1980a). The formation is characterized by a well-developed cyclicity including a number of basic cyclothems (Clemmensen 1978, 1980a). These cycles record fluctuating water depth in the lake probably influenced by seasonal as well as orbital control on precipitation in the basin. There is a long-term trend towards more shallow lake water (Clemmensen 1980a).

Sporfjeld Member

New member

History. This unit, which forms a lowermost lacustrine succession in the formation, was defined as the Sporfjeld Beds by Clemmensen (1980b). It is here raised to a member (Fig. 3A).

Name. From Sporfjeld, west of Edderfugledal (Fig. 2; Clemmensen 1980b).

Type section. Sporfjeld (Fig. 17 in Clemmensen 1980b)

Reference sections. Kap Biot (Fig. 11), Nordenskiöld Bjerg (Fig. 5); Sydkronen (Fig. 13).

Thickness. 35–40 m at the type locality, Kap Biot, and Nordenskiöld Bjerg, and 20 m at Sydkronen.

Lithology. Cyclically bedded, green mudstones and yellow dolostones with rare flat-pebble conglomerates and stromatolitic limestones in the uppermost part. Halite crystal casts as well as vugs and cavities, probably formed by dissolution of gypsum, are present in the lowermost part of the formation.

Fossils. Only conchostracans and non-marine trace fossils.

Boundaries. The lower boundary of the member corresponds to that of the Edderfugledal Formation. The upper boundary is set at the bottom of an up to 4–5 m thick cliff-forming grey quartz sandstone with wave ripples. This boundary is also characterized by a change from yellowish-greenish to variegated sediments.

Distribution. The member has the same distribution as the Edderfugledal Formation.

Age. The Sporfjeld Member was tentatively given the same age as the Edderfugledal Formation (Carnian) by Clemmensen (1980b).

Depositional environments. The Sporfjeld Member was probably deposited in a moderately deep to shallow lake (Clemmensen 1978, Clemmensen 1980a). Lake salinities decreased with time from fairly high to near-freshwater conditions. Cyclicity records seasonal as well as orbital control on precipitation and lake depth. The stromatolitic limestones possibly formed in shallow nearshore lacustrine water during periods of reduced clastic input.

Pingel Dal Member

New member

History. This unit, which forms an uppermost lacustrine succession in the formation, was defined as the Pingel Dal Beds by Clemmensen (1980b). It is here raised to a member (Fig. 3A).

Name. From Pingel Dal in northeastern Jameson Land (Fig. 2; Clemmensen 1980b)

Type section. Pingel Dal (Fig.19 in Clemmensen 1980b)

Reference sections. Kap Biot (Fig. 11), Nordenskiöld Bjerg (Fig. 5); Sydkronen (Fig. 13).

Thickness. 28 m at the type section, 34 m around Kap Biot, 24 m at Nordenskiöld Bjerg and 20 m at Sydkronen.

Lithology. Cyclically bedded, grey or reddish grey quartz sandstones with wave ripples, red sandstones and siltstones, green mudstones, and yellow dolostones. Flat-pebble conglomerates and stromatolitic limestones are also present. The wave-rippled sandstones (four to six in numbers) can be traced throughout large parts of the basin. Wave ripples on their bedding planes are mostly trending between ESE–WNW (100°–280°) and SE–NW (125°–305°) (Clemmensen 1980a, and new unpublished data), and knowing that the basin was rotated 45° anticlockwise since the Late Triassic, it indicates that they originally were trending between SE–NW (145°–325°) and SSE–NNW (170°–350°).

Fossils. This member contains rare and poorly preserved bivalves including *?Trigonodus* sp., *?Myophoria* sp., or *?Eotrapezium* sp., common conchostracans (e.g. *Eustheria forbesii* Jones) as well as numerous freshwater trace fossils (Bromley& Asgaard 1979; Clemmensen 1980a).

Boundaries. The lower boundary is set at the bottom of an up to 4–5 m thick cliff-forming grey quartz sandstone with wave ripples and the upper boundary is defined by the last appearance of reddish grey sandstone with wave ripples or yellow stromatolitic limestone.

Distribution. The member has the same distribution as the Edderfugledal Formation.

Age. The Pingel Dal Member was tentatively given the same age the Edderfugledal Formation (Carnian) by Clemmensen (1980b).

Depositional environments. The Pingel Dal Member was probably deposited in a fairly shallow lake that was subject to frequent subaerial exposure (Clemmensen 1978, Clemmensen 1980a). Lake margin environments including wave-rippled shoreline sand deposits were well developed probably due to an increased input of clastic detritus from the uplands. Lake salinities were of near-freshwater conditions as indicated by the numerous fresh-water trace fossils. The pronounced cyclicity most likely records seasonal as well as orbital control on precipitation and lake depth.

Malmros Klint Formation

New formation

History. This unit forms the middle unit in the Fleming Fjord Group. Its sedimentary characteristics were initially described in some detail by Grasmück & Trümpy (1969) and the unit was defined as the Malmros Klint Member by Perch-Nielsen *et al*. (1974) and by Clemmensen (1980b). The unit is here elevated to a formation. Supplementary sedimentological descriptions of the formation were given by Clemmensen (1980a, 1980b), Clemmensen *et al.* (1998, 2016), and Decou *et al.* (2016).

Name. From Malmros Klint at the north side of Fleming Fjord (Fig. 2).

Type section. Malmros Klint (Figs. 9, 10).

Reference sections. Kap Biot (Figs 11, 12), Lepidopteriselv (Fig. 14); Sydkronen (Figs 8, 13), Pictet Bjerge (Fig. 4).

Thickness. The formation is almost 200 m thick at the type locality, 220 m around Kap Biot, 120–40 m along Carlsberg Fjord, 75 m at Sydkronen, and 45 m at Pictet Bjerge.

Lithology. This formation forms conspicuous, cliff-forming mountain slopes of brownish red to greyish red mudstones and fine-grained sandstones. Most common facies are: brownish red massive siltstone, greyish red laminated siltstone, reddish grey muddy sandstone with wave-generated structures, yellowish disrupted dolomitic sediments, and intraformational conglomerate (Clemmensen *et al.* 1998). Bedding planes with desiccation polygons are abundant and the uppermost part of the sediments frequently contain vertical desiccation cracks up to 10–20 cm or occasionally nearly 100 cm deep. Wave ripples on bedding planes are mostly trending between ESE–WNW (100°–280°) and SE–NW (125°–305°) (Clemmensen 1980a, and new unpublished data), and knowing that the basin as part of Greenland was rotated 45° anticlockwise since the Late Triassic, it indicates that they originally were trending between SE–NW (145°–325°) and SSE-–NNW (170°–350°). The sediments form composite sedimentary cycles with typical thicknesses of 1.6 m and 5.9 m probably indicating orbital control on sedimentation (Clemmensen *et al.* 1998).

Fossils. Invertebrate fossils are restricted to conchostracans (*Euestheria minuta* (van Zieten)), Clemmensen (1980b).

Vertebrate fossils, in contrast, are relatively abundant and include skeletal remains of a diverse vertebrate fauna comprising sauropodomorph dinosaurs, phytosaurs, as well as unpublished finds of amphibians and fishes (Marzola *et al.* 2018). The Malmros Klint Formation contains a number of bedding planes with *Grallator* tracks. Track-bearing surfaces, however, are much less abundant than in the overlying Ørsted Dal Formation. Numerous fresh-water trace fossils occur in this unit (Bromley & Asgaard 1979; Clemmensen 1980b).

Boundaries. The Malmros Klint Formation overlies the variegated sediments of the Pingel Dal Member of the Edderfugledal Formation, and the boundary is placed on top of the last grey sandstone unit in this member. Stromatolitic limestones typically also disappear at about this level. The upper boundary is placed at the base of a single well-defined channel sandstone (eastern part of the basin) or where such channel sandstones become a prominent part of the succession (central and western part of the basin). The uppermost part of the unit is relatively clay-rich at several sites in the central and northwestern part of the basin making it difficult to distinguish this unit from the Carlsberg Fjord Member.

Distribution. The formation occurs throughout the basin. It is thickest developed in the eastern and central parts of the basin and thin towards the west and northwest (Fig.15). Sedimentary deposits of this formation

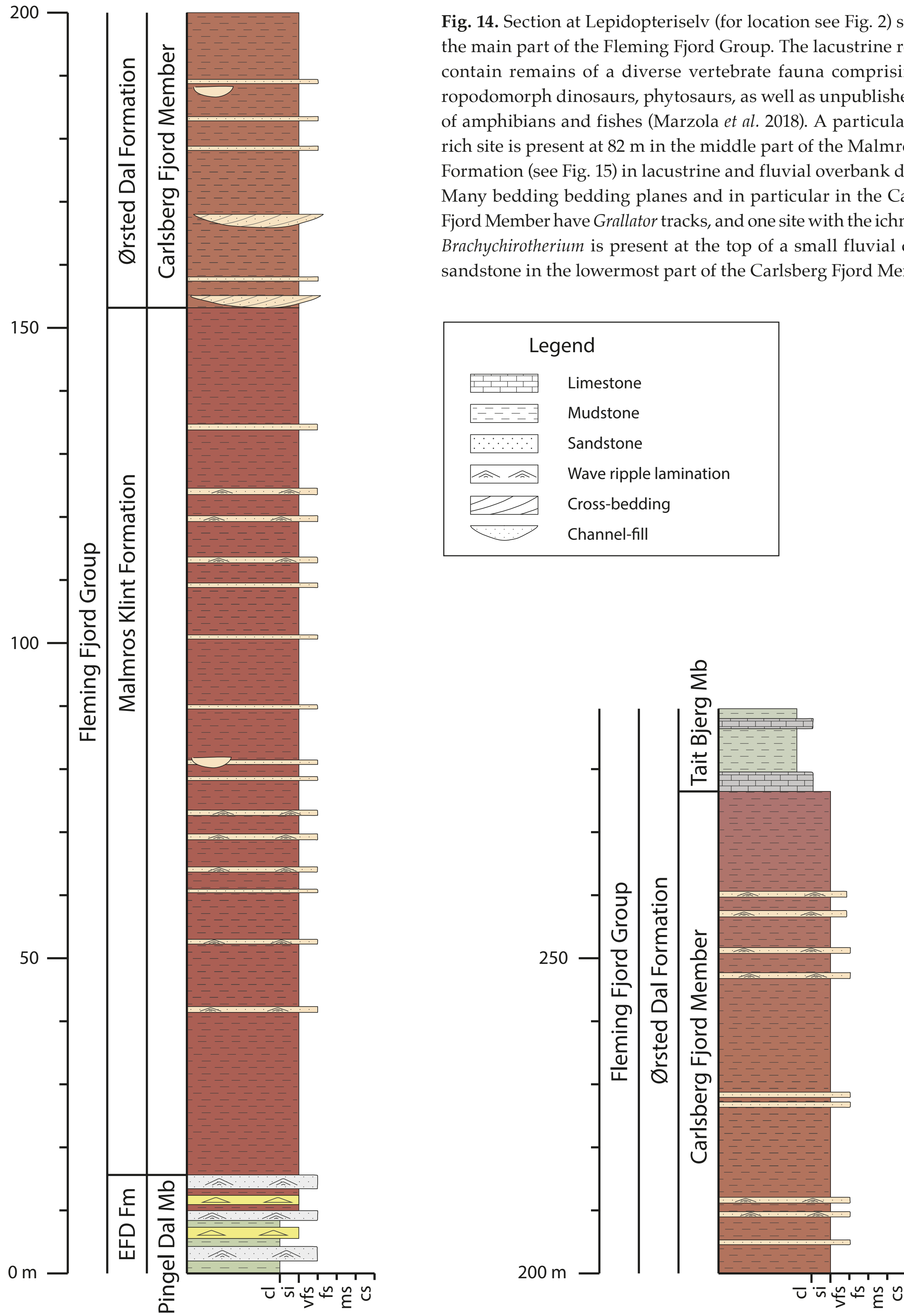

Fig. 14. Section at Lepidopteriselv (for location see Fig. 2) showing the main part of the Fleming Fjord Group. The lacustrine red beds contain remains of a diverse vertebrate fauna comprising sauropodomorph dinosaurs, phytosaurs, as well as unpublished finds of amphibians and fishes (Marzola *et al*. 2018). A particular fossil-rich site is present at 82 m in the middle part of the Malmros Klint Formation (see Fig. 15) in lacustrine and fluvial overbank deposits. Many bedding bedding planes and in particular in the Carlsberg Fjord Member have *Grallator* tracks, and one site with the ichnogenus *Brachychirotherium* is present at the top of a small fluvial channel sandstone in the lowermost part of the Carlsberg Fjord Member.

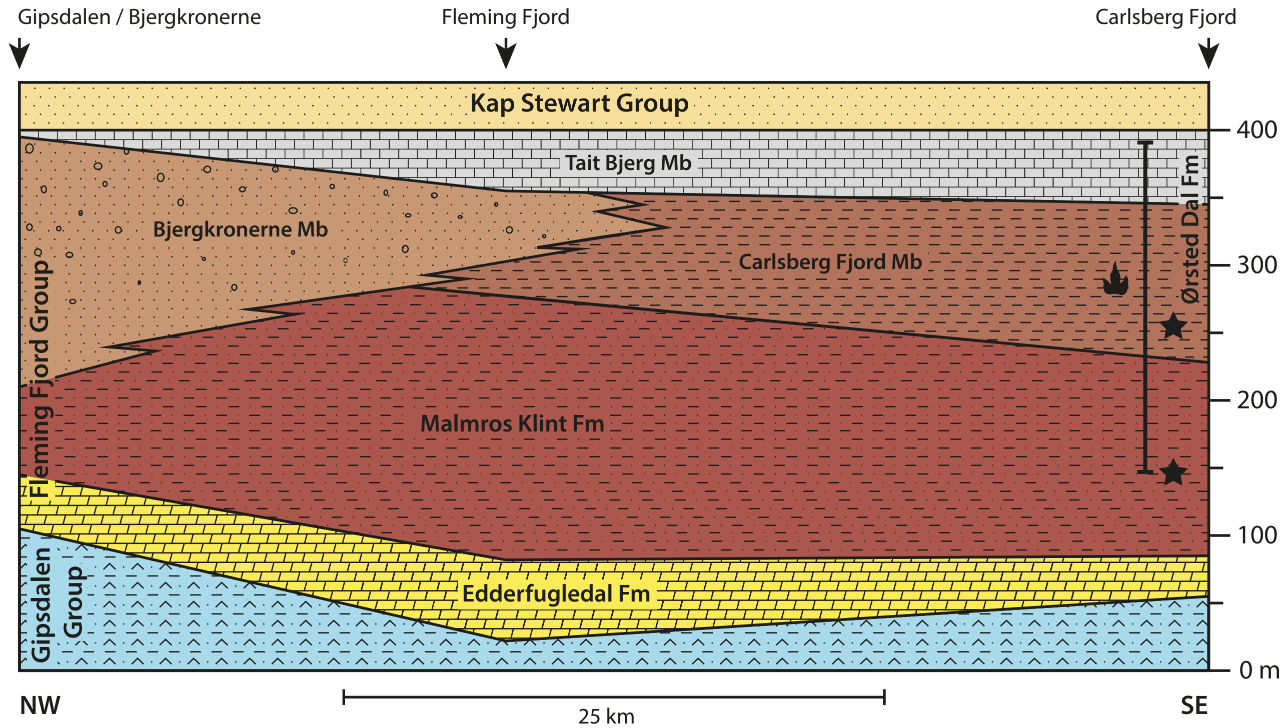

Fig. 15. Cross-section of the lithostratigraphical units in the Fleming Fjord Group between Gipsdalen, Fleming Fjord and Carlsberg Fjord (see Fig. 2 for location of section). The lacustrine Malmros Klint Formation and in particular the lacustrine Carlsberg Fjord Member are replaced by the fluvial Bjergkronerne Member towards the NW. Vertebrate remains have been documented from the Malmros Klint Formation, and the Carlsberg Fjord, Bjergkronerne and Tait Bjerg Members. *Grallator* tracks are common on bedding planes and have been observed in uppermost Malmros Klint Formation, the Carlsberg Fjord Member and the lowermost and middle part of the Tait Bjerg Member (vertical bar). Two of the most fossil-rich sites are indicated. The quarry in the middle part of the Malmros Klint Formation at Lepidopteriselv has yielded phytosaur material of at least four individuals and three size classes (Clemmensen *et al.* 2016). The quarry in the lowermost part of the Carlsberg Fjord Member at MacKnight Bjerg contained numerous remains of amphibians including plagiosaurs (*Gerrothorax*) and a new cyclotosaurid (*Cyclotosaurus naraserluki*), as well as a small pterosaur (Jenkins *et al.* 1994; Marzola *et al.* 2017; Marzola *et al.* 2018). Figure modified from Jenkins *et al.* (1994).

also occur to the north at Traill Ø and Geographical Society Ø (Andrews & Decou 2018). However, these areas (north of Kong Oscar Fjord), belongs to a separate Triassic basin (Guarnieri *et al.* 2017).

Age. The Malmros Klint Formation has been dated to the late Norian, based on sparse invertebrate fossils, vertebrate remains, and combined cycle stratigraphy and magnetochronology (Clemmensen 1980b; Kent & Clemmensen 1996; Clemmensen *et al.* 1998). By comparison with the magnetochronology of the Newark Basin in eastern USA, Kent & Clemmensen (1996) and Clemmensen *et al.* (1998) suggested that the formation records a relatively short time interval from about 211 to about 209.5 Ma, which according to the most recent views places the unit in the latest Norian (Kent *et al.* 2017). Müller *et al.* (2005) in contrast consider the formation to cover most of the Norian, while Andrews *et al.* (2014) consider that the formation was deposited over a time interval in the early Norian from about 223 and to about 218 Ma (Fig. 3 A). Ongoing work on refined magnetostratigraphy and cyclostratigrahy will hopefully determine more precisely the exact age of the Malmros Klint Formation.

Subdivision. This formation is not subdivided into members.

Depositional environment. The formation represents lake and playa lake/mud flat deposits most likely formed in a steppe-like climate (Clemmensen *et al.*1998; Decou *et al.* 2016). The lake-mud flat system dried out frequently during dry seasons. Precipitation was linked either to summer monsoons or to westerlies bringing winter rain (see later). Longer-term variation in climate and rainfall in the area was probably linked to orbital control that also caused a cyclic appearance of the succession (Clemmensen *et al.* 1998). From the cycle stratigraphy, it is implied that the average accumulation rate was around 55 mm/ka (Clemmensen *et al.* 1998).

Ørsted Dal Formation

New formation

History. This is the uppermost unit in the Late Triassic Fleming Fjord Group. The unit was first described in some detail by Grasmück and Trümpy (1969) and formally defined by Perch-Nielsen *et al.* (1974) and Clemmensen (1980b) as the Ørsted Dal Member. It is here elevated to a formation (Fig. 3A). Clemmensen (1980a, 1980b) described the sedimentology of this member and defined the uppermost marlstone/limestone-bearing succession in the new formation as the Tait Bjerg Beds; this unit is here elevated to a member (Fig. 3A). Jenkins *et al.* (1994) described two additional informal units in the Ørsted Dal Member, the Carlsberg Fjord beds and the Bjergkronerne beds. These two units are here formally designated as members (Fig. 3A).

Name. From Ørsted Dal, a prominent river valley at the boundary between Jameson land and Scoresby land (Clemmensen 1980b).

Type section. Malmros Klint (Figs 9, 10)

Reference sections. Sydkronen (Figs 2, 8, 13); Pictet Bjerge (Fig. 4); Kap Biot (Figs 11, 12). Lepidopteriselv (Figs 14, 16), and mountain east of Buch Bjerg, "Track Mountain" (Figs 17, 18).

Thickness. The formation is 130 m thick at the type locality, 185 m at Sydkronen, about 250 m at Pictet Bjerge, 130 m at Kap Biot, 125 m at Tait Bjerg, 135 m at "Track Mountain", and more than 130 m thick at Lepidopteriselv (the uppermost part is partly covered by scree at this locality).

Lithology. In the region between Carlsberg Fjord and Fleming Fjord, the basal part of the Ørsted Dal Formation is composed of a siliciclastic mudstone unit (the new Carlsberg Fjord Member). This unit has a thickness around 120 m and is composed of cyclically bedded mudstones of various redbrown and purple colors interrupted by thin greenish grey siltstone or sandstone horizons with wave ripples. More detailed description of this unit is given below. In this region these sediments are overlain by 50–60 m of light grey to yellowish marlstones cyclically interbedded with siliciclastic mudstone of different colours (the Tait Bjerg Member). More detailed description of this unit is given below. In the northwestern part of the basin the basal unit (the Carlsberg Fjord Member) is replaced by conglomerates, pebbly sandstones, sandstones and minor mudstones of the new Bjergkronerne Member having a thickness around 200 m; this unit will be described in detail below. In this part of the basin, the coarse-grained clastic deposits of the Bjergkronerne Member are overlain by a relatively thin unit with marlstones and variegated mudstones of the Tait Bjerg Member.

Fossils. This member contains terrestrial palynomorphs, invertebrate fossils, and vertebrate fossils. These fossils are described below in their respective member.

Boundaries. At most sites, the lower boundary is characterized by a shift from cliff-forming red beds of the Malmros Klint Formation to more gently dipping slopes with red beds (the Carslberg Fjord Member). Clemmensen (1980b) defined the lower boundary by the first appearance of a relatively thick fluvial sandstone horizon above the red cliff-forming lake mudstones and fine-grained sandstones of the Malmros Klint Formation. This lowermost sandstone is typically about 0.5 m thick and of fluvial origin. In the southeastern part of the basin the Carlsberg Fjord Member comprises a second sandstone facies, which is typically developed approximately 15 m higher in the section. At some places, however, the lowermost sandstone is not developed making it more difficult to place the boundary between the Malmros Klint and Ørsted Dal Formations. The upper boundary is placed at the top of the last dolomitic marlstone of the Tait Bjerg Member, or at the change from red sediments to light grey sandstones and dark mudstones of the Kap Stewart Group (Clemmensen 1980b). This upper boundary is developed as an unconformity along the basin margins, but as a correlative conformity in the central parts of the basin (Dam & Surlyk 1993). A clear erosional contact between the Ørsted Dal Formation and the Kap Stewart Group is present at Lepidopteriselv near the southeastern margin of the basin.

Distribution. The member is widely distributed in the Jameson Land Basin including the isolated outcrops at Kap Hope (Clemmensen 1980b). Sedimentary deposits of this member also occur to the north at Traill Ø and Geographical Society Ø (Andrews & Decou 2018). These areas (north of Kong Oscar Fjord), however, belongs to a separate Triassic basin (Guarnieri *et al.* 2017).

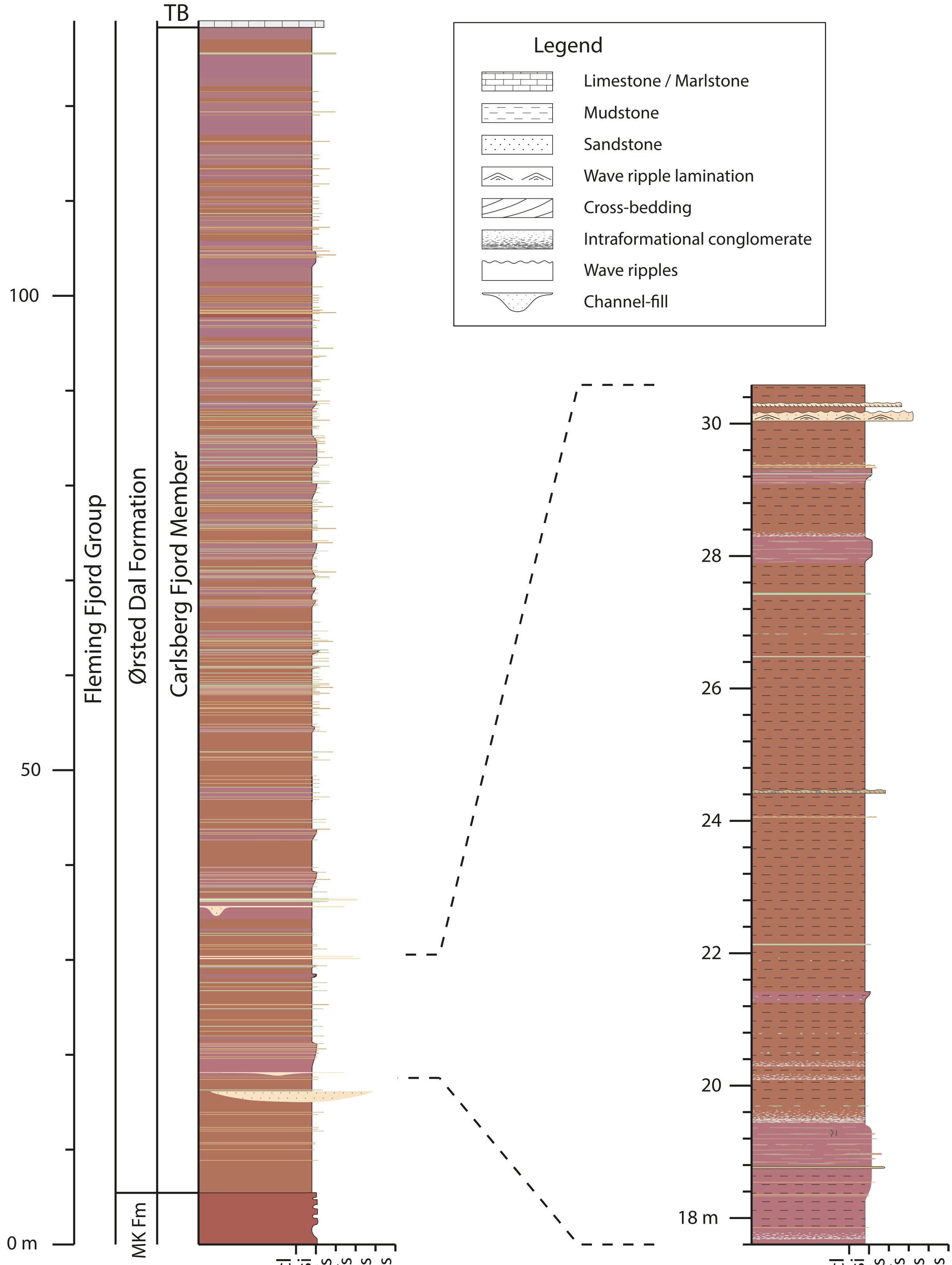

Fig. 16. Section at Lepidopteriselv showing the detailed lithology of the Carlsberg Fjord Member. The mudstones, which vary from purple to redbrown in color are interbedded with many thin silt- and sandstones of redbrown to greenish grey colors. These latter beds carry wave ripples and dinosaur tracks on their upper bedding planes. The log displays the observed color variation.

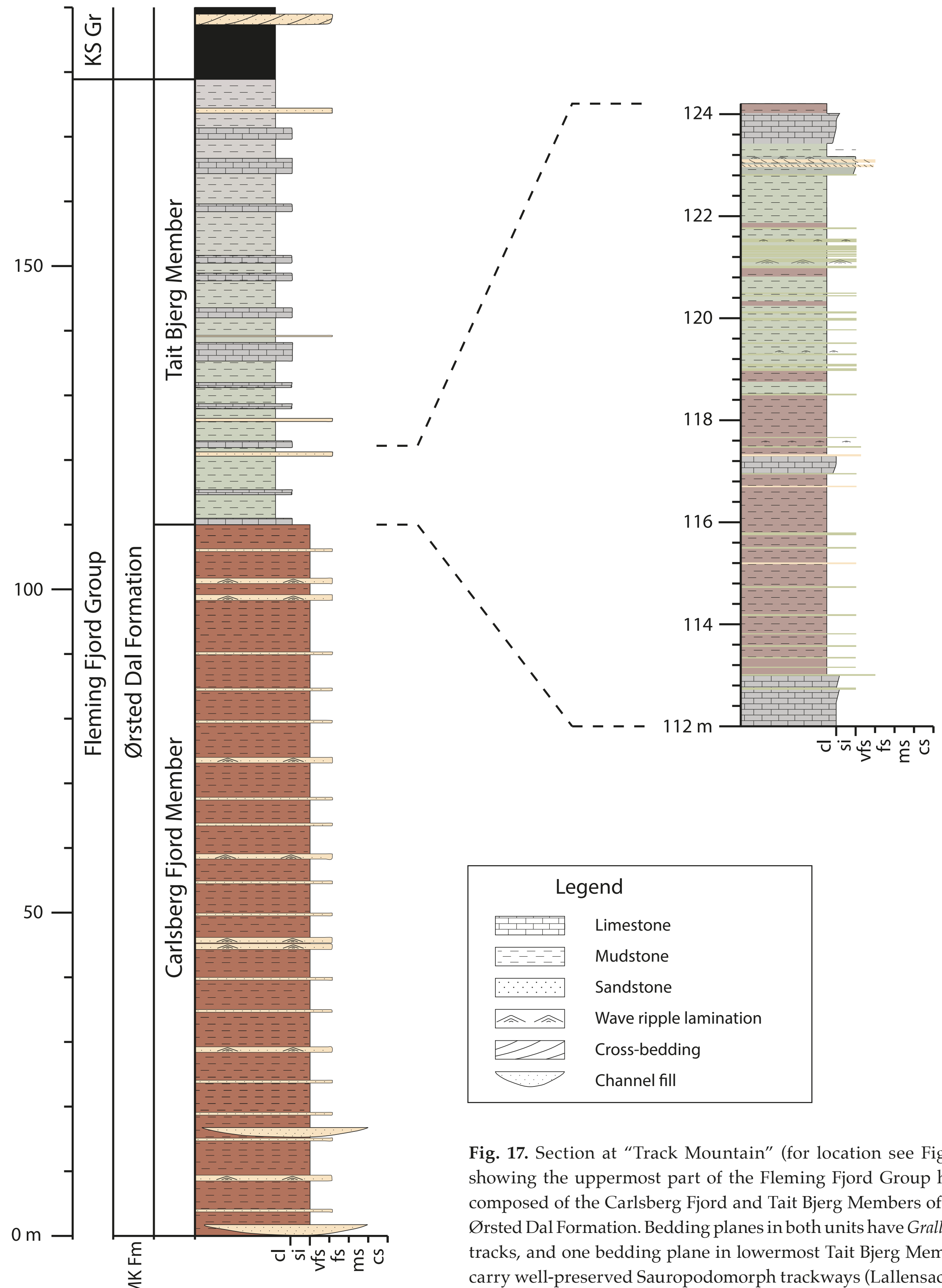

Fig. 17. Section at "Track Mountain" (for location see Fig. 2) showing the uppermost part of the Fleming Fjord Group here composed of the Carlsberg Fjord and Tait Bjerg Members of the Ørsted Dal Formation. Bedding planes in both units have *Grallator* tracks, and one bedding plane in lowermost Tait Bjerg Member carry well-preserved Sauropodomorph trackways (Lallensach *et al.* 2017). The Kap Stewart Group ovelies the Tait Bjerg Member without any visible discontinuity.

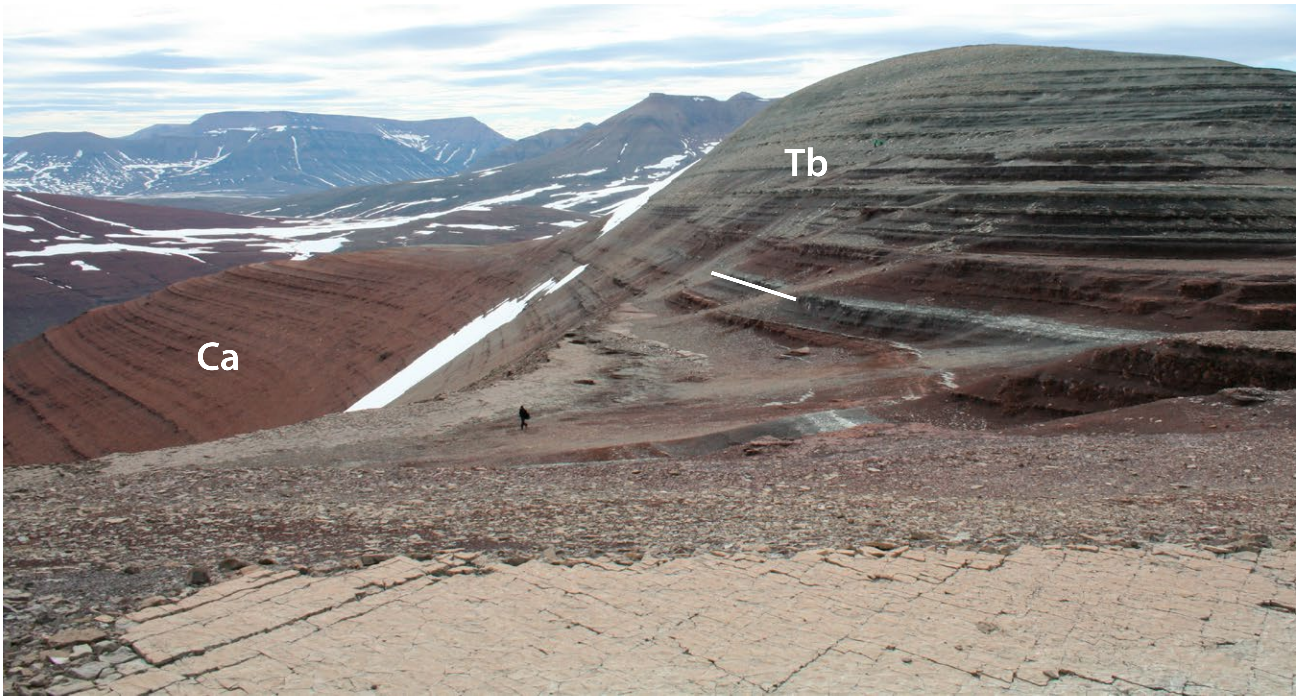

Fig. 18. "Track Mountain" showing the uppermost part of the Carlsberg Fjord Member (Ca) and the main part of the Tait Bjerg Member (Tb). Both units show cyclic bedding probably related to orbital climatic variation in precipitation. Person for scale. Exposed thickness of the Tait Bjerg Member is about 55 m.

Age. The Ørsted Dal Formation has been dated to the late Norian – early Rhaetian, based on sparse invertebrate fossils, terrestrial palynomorphs, vertebrate remains, and palaeomagnetic data (Clemmensen 1980b; Kent & Clemmensen 1996; Clemmensen *et al.* 1998). Müller *et al.* (2005) consider the formation to be primarily of early Rhaetian age (Fig. 3A). By comparison with the magnetochronology of the Newark Basin in eastern USA, Kent & Clemmensen (1996) and Clemmensen *et al.* (1998) suggested that the Ørsted Dal Formation records a relatively short time interval from about 209.5 to about 207 Ma, which according to the most recent views places the unit in the latest Norian (Kent *et al.* 2017). In contrast, Andrews *et al.* (2014) consider that the Ørsted Dal Formation was deposited during a longer time interval in the Norian from about 218 to about 208 Ma. Ongoing work on a refined magnetostratigraphy and cyclostratigrahy will hopefully determine more precisely the exact age of the Ørsted Dal Formation.

Subdivisions. The Ørsted Dal Formation is subdivided into three units, the new Carlsberg Fjord Member, the new Bjergkronerne Member, and the Tait Bjerg Member; these members are described in the following.

Depositional environment. This formation comprises fluvial depositional environments in the northwestern part of the basin and lacustrine environments in the central and southeastern part of the basin.

Carlsberg Fjord Member

New member

History. This unit was first described by Jenkins *et al.* (1994) and informally designated as the Carlsberg Fjord beds. It is here formally described as a member (Fig. 3A). The sedimentology and vertebrate palaeontology of this unit have been described by e.g. Clemmensen *et al.* (1998), Clemmensen *et al.* (2016), Decou *et al.* (2016), Klein *et al.* (2016), Marzola *et al.* (2017, 2018), and Lallensach *et al.* (2017).

Name. From Carlsberg Fjord, a large fjord that separates the Jameson Land Basin from Liverpool Land (Fig. 2).

Type section. Lepidopteriselv (Figs 14, 16, 19, 20).

Reference sections. "Track Mountain" (Figs 17, 18), Kap Biot (Figs 11, 12), Malmros Klint (Figs 9, 10).

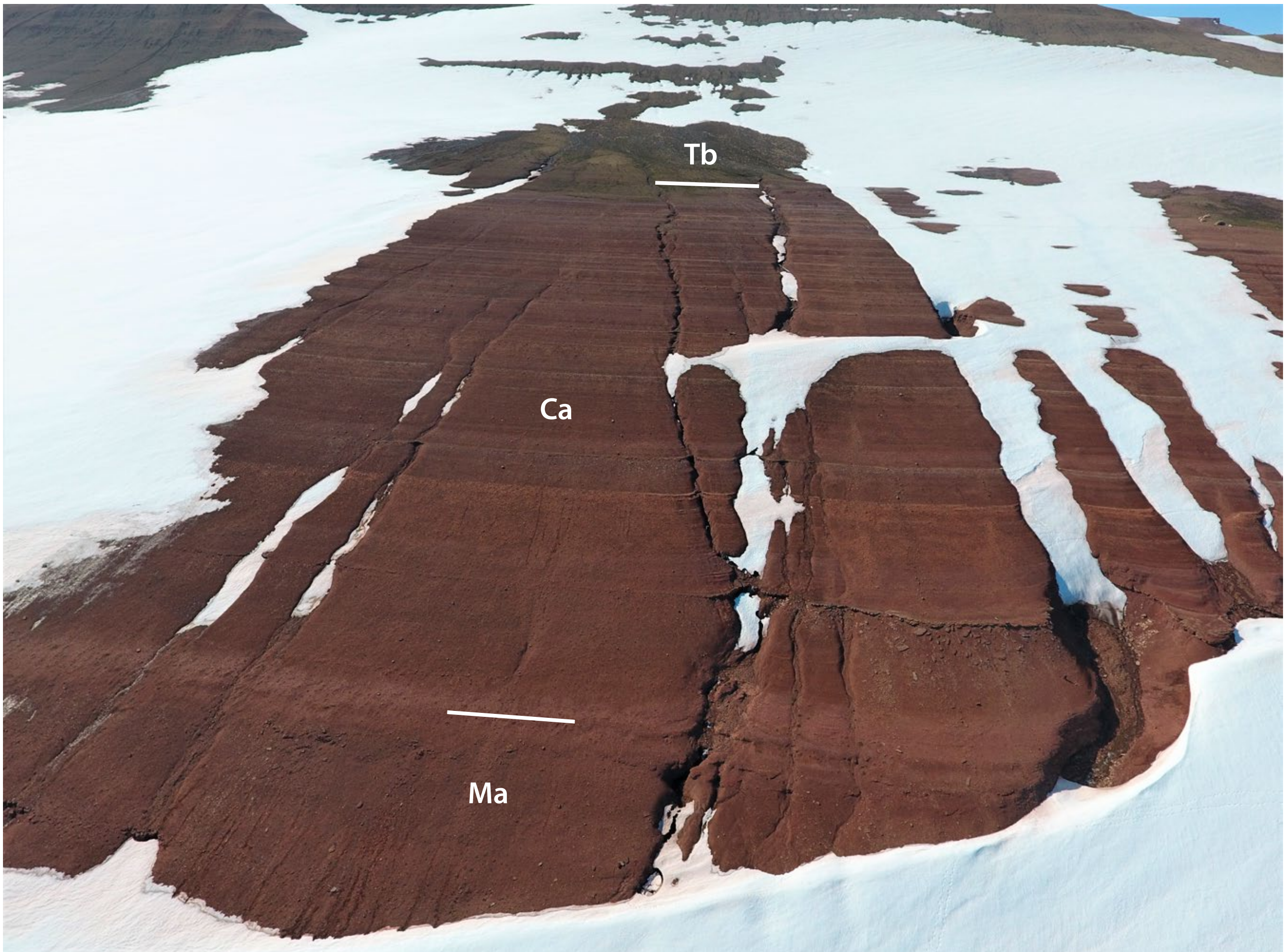

Fig. 19. Outcrops of the Carlsberg Fjord Member (Ca) at Lepidopteriselv (drone photography; viewed from the east). Note the cyclic bedding of the lacustrine red beds. Underlying Malmros Klint Formation (Ma) and overlying Tait Bjerg Member (Tb) are indicated (Most of this latter unit, however, is covered by scree). Type section of the Carlsberg Fjord Member. Thickness of exposed section of Carlsberg Fjord Member is 135 m.

Thickness. The member is 125 m thick at the type section, 135 m at "Track Mountain", at least 50 m at Kap Biot, and almost 30 m at Malmros Klint.

Lithology. The Carlsberg Fjord Member is dominated by red-brown to purple massive mudstone punctuated by thin light red or greenish grey mud-peloid siltstones. The mudstones are less frequently interrupted by intraformational conglomerates, quartz-rich sandstones, and sandy channel-fill deposits. The lake sediments possess a well-developed composite cyclicity (Fig. 19) interpreted to represent orbital cycles (Jenkins *et al.* 1994; Clemmensen *et al.* 1998; Clemmensen *et al.* 2016).

The red-brown to purple mudstone is clayey and structureless. The purple mudstone is generally more coarse-grained than the red-brown mudstone and is commonly associated with millimeter- to centimeter-scale siltstone lenses. Desiccation cracks are very common in the mudstone. Faint horizontal lamination or very small-scale wavy bedding are rarely observed. The red-brown mudstone weather to small equidimensional pieces with a conchoidal fracture pattern, while the purple mudstone tends to weather to tabular pieces with a poorly developed flaky cleavage. Even though the mudstone is dominantly massive, intense bioturbation is sometimes visible and some beds show very small root structures. Aquatic trace fossils are very frequently preserved as impressions on the sole of small siltstone layers in the mudstone. In thin section, the mudstone is composed of very fine-grained hematite-stained mud displaying a well-developed clotted texture where siliciclastic grains are very rare or totally absent (Clemmensen *et al.* 1998).

Light red or greenish grey mud-peloid siltstone beds are frequently punctuating the structureless mudstone. The siltstone beds are 0.5-5 cm thick, well-defined, and laterally continous. Thin sections show that the beds are composed of silt-sized or more rarely sand-sized mud peloids, a little quartz, and some organic material (Clemmensen *et al.* 1998). Individual siltstones typically possess a composite build-up with a sharp and weakly erosional base, often associated with intraformational conglomerate with millimeter-size mudstone clasts, followed by lamination and finally small-scale wave-formed cross-lamination in the uppermost part of the bed (Clemmensen *et al.* 1998). Symmetrical wave ripples are commonly preserved on the upper bedding plane and are mostly orientated ES–WSW (105°–285°) (Clemmensen 1980a; Clemmensen *et al.* 1998, and new data). Knowing that the basin was rotated 45° anticlockwise since the Late Triassic, it indicates that they originally were trending SE–NW (150°–330°).

Rare fluvial sandstone beds are present in the lower part of the Carlsberg Fjord Member (Fig. 20). The beds are up to one meter thick and contain large-scale cross-stratification (including point bar structures) as well as small-scale cross-stratification. These fluvial sandstones extend tens of meters laterally and are protruding more from the mudstone than other beds. Smaller isolated channels with a lateral extension of one meter or less are also present. Beds of intraformational conglomerate are common in the unit, especially in the lowermost part. The conglomerates have thicknesses of a few centimeters to 20 cm and are laterally continuous.

Fossils. Invertebrate fossils are sparse including *Unio*-like freshwater bivalves as well as undetermined bivalves and gastropods.

Vertebrate fossils in contrast are relatively abundant and include a near complete skeleton of a Plateosaurus (Sauropodomorpha), two temnospondyls (*Cyclotosaurus naraserluki* and *Gerrothorax* cf. *pulcherrimus)*, one testudinatan (cf. *Proganochelys*), the eudimorphodontid *Arcticodactylus cromptonellus,* and mammaliamorph teeth (cf. ?*Brachyzostrodon* and *Kueneotherium)*, (see Marzola *et al*. 2018 for details on the vertebrate finds) as well as the lungfish *Ceratodus tunuensis* (Agnolin *et al.* 2018).

The Carlsberg Fjord Member contains numerous bedding planes with tracks. Most abundant are *Grallator* tracks which are particularly abundant on exposed bedding planes of the wave-rippled siltstones/sand-

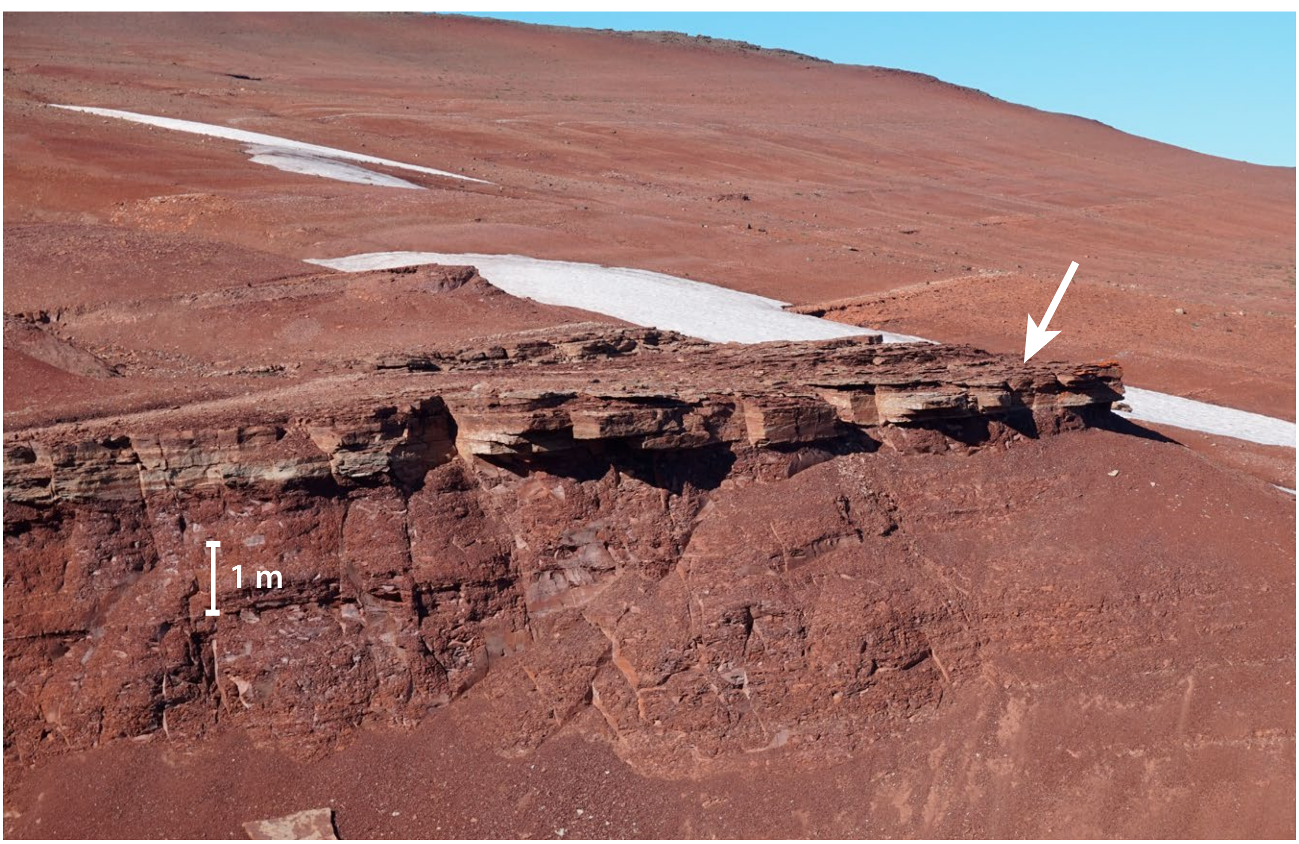

Fig. 20. Outcrop of the lowermost part Carlsberg Fjord Member at Lepidopteriselv (viewed from the southeast). The sloping red lacustrine mudstones are here cut by a meandering river channel sandstone with lateral accretion deposits (arrow). The fluvial sandstone is about 0.8 m thick. Type section of the Carlsberg Fjord Member.

stones (Jenkins *et al.* 1994; Gatesy *et al.* 1999; Milan *et al.* 2004; Clemmensen *et al.* 2016); at two sites footprints of the ichnogenus *Brachychirotherium* were observed (Klein *et al.* 2016).

Numerous fresh-water trace fossils occur in this unit (Bromley & Asgaard 1979; Clemmensen 1980b). Circular impressions after tree trunks are also seen, while rootlet horizons are rare to absent.

Boundaries. The lower boundary is defined by the first appearance of a relatively thick fluvial sandstone horizon above the red cliff-forming lake mudstones and fine-grained sandstones of the Malmros Klint Formation. The sandstones typically contain copper mineralizations. At this level, the cliff-forming red beds of the underlying member are replaced by red mudstones forming less steep slopes. The upper boundary is defined by the first appearance of a light grey and relatively thick marlstone.

Distribution. The Carlsberg Fjord Member occurs in the eastern and central part of the basin. Towards the west and northwest it is replaced by coarser clastics of the Bjergkronerne Member (Fig. 15). In the central and northeastern part of the basin the Carlsberg Fjord Member is overlain by the Bjergkronerne Member. The contact between the members suggests that they interfinger although this is difficulty to prove from existing data.

Age. The vertebrate fossils are indicative of a Norian age (Jenkins *et al.* 1994). Palaeomagnetic data indicates a late Norian age from about 209.5 Ma to about 208 Ma (Kent & Clemmensen 1996; Clemmensen *et al.* 1998).

Subdivision. This member is not subdived into formal units, although it is obvious that a relatively monotonous succession of red mudstones at the base is gradually replaced by more cyclic and more variegated mudstones in the uppermost part of the member.

Depositional environment. The Carlsberg Fjord Member represents playa-lake and mudflat deposition that most likely took place in a dry steppe-like climate (Clemmensen *et al.* 1998). The common desiccation features witness frequent subaerial exposure of the floor of the lake, and rare root structures and stem imprints indicate periods during which plants could colonize exposed land surfaces. The thin siltstone beds and intraformational conglomerate represent episodes of lacustrine flooding of the mudflats. During many of these flooding episodes, the water level was sufficiently high to allow the formation of wave ripples.

The frequent exposure and flooding episodes indicate deposition in an ephemeral lake system. However, a gradual shift in colour and lithology throughout the uppermost Carlsberg Fjord Member most likely represents the periodic establishment of a semi-perennial lake system (Clemmensen *et al.* 2016). Meandering rivers occasionally crossed the lake/mudplain and transported sediment towards the north (tributary rivers).

The cyclic stratigraphy of the lake deposits has been related to orbital control of precipitation in the source areas, sediment loads to the basin, and lake environment (Clemmensen *et al.* 1998; Clemmensen *et al.* 2016). From the cycle stratigraphy, it is implied that the average accumulation rate was about 45 mm/ka (Clemmensen *et al.* 1998).

Bjergkronerne Member

New member

History. This unit was first described by Jenkins *et al.* (1994) and informally designated as the Bjergkronerne beds. The unit is here formally described as a member (Fig. 3A). The sedimentology of this unit has been described briefly by Clemmensen *et al.* (1998) and Decou *et al.* (2016), while the vertebrate palaeontology has been described by Jenkins *et al.* (1994) and Marzola *et al.* (2018).

Name. After the mountains Bjergkronerne in the northwestern part of the basin.

Type section. Sydkronen in Bjergkronerne (Figs 8, 13).

Reference section. Malmros Klint (Figs 2, 9, 10), Kap Biot (Figs 11, 12), Pictet Bjerge (Fig. 4).

Thickness. The member is 185 m thick at the type locality, around 60 m at Malmros Klint, around 250 m at Pictet Bjerge, and at least 60 m at Kap Biot.

Lithology. In the northwestern part of the basin around the type locality, the member is composed of interbedded fine-to coarse-grained sandstones and red or occasionally green mudstones (Fig. 21). Towards the top of the unit, pebbly sandstones and conglomerates become more common. The sandstones have low-angle lateral accretion bedding, large and small-scale cross-stratification, and wave-ripple lamination (on upper bedding planes). Desiccation cracks as well as fresh-water trace fossils are abundant in the mudstones. Laterally, the sandstones display pinch out and/or swell in lateral respect and individual sandstones (channel bodies) may form amalgamated units. The base of the channel

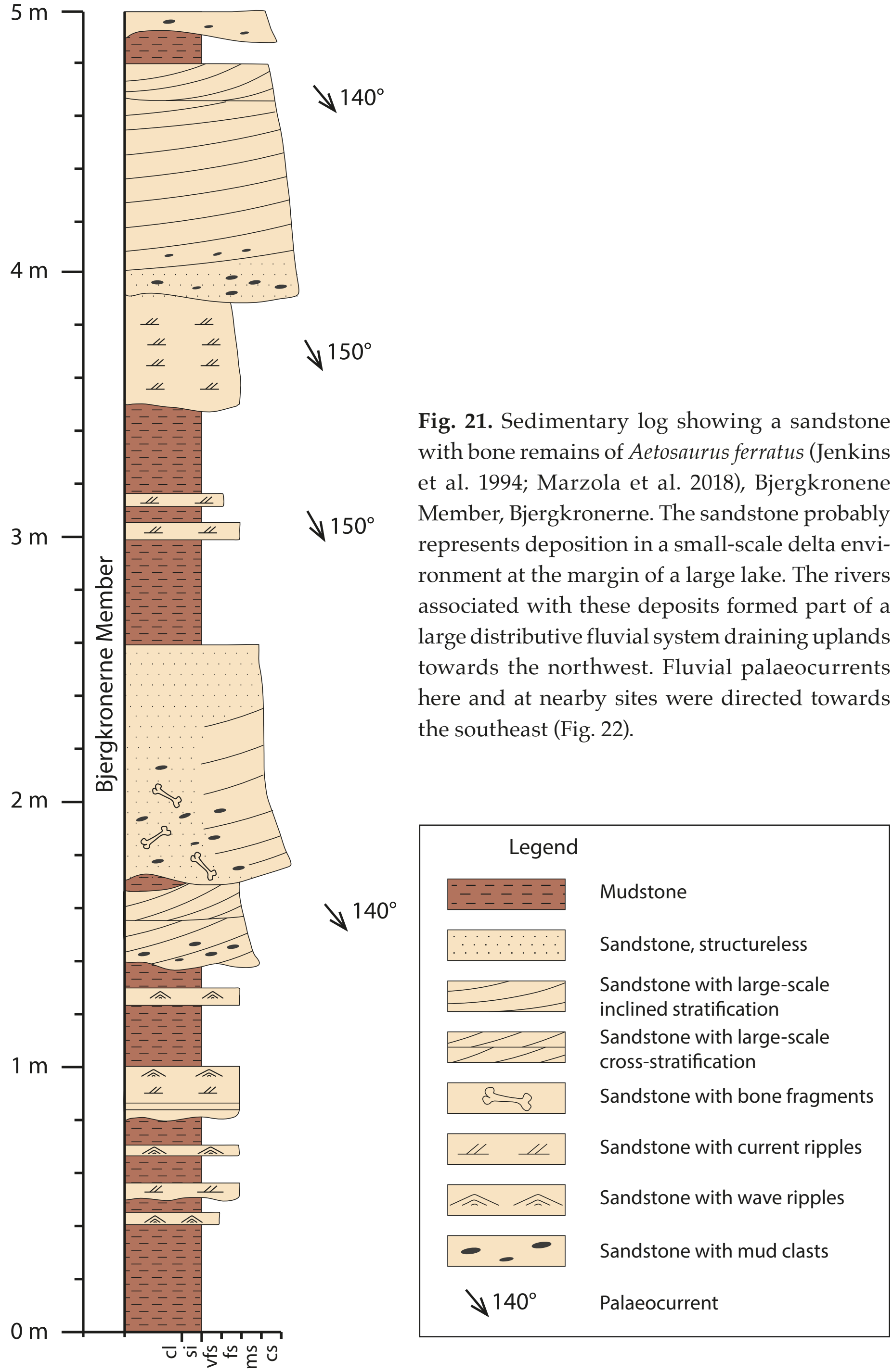

Fig. 21. Sedimentary log showing a sandstone with bone remains of *Aetosaurus ferratus* (Jenkins et al. 1994; Marzola et al. 2018), Bjergkronene Member, Bjergkronerne. The sandstone probably represents deposition in a small-scale delta environment at the margin of a large lake. The rivers associated with these deposits formed part of a large distributive fluvial system draining uplands towards the northwest. Fluvial palaeocurrents here and at nearby sites were directed towards the southeast (Fig. 22).

deposits typically includes mud- clast conglomerates (finer-grained examples), or extraformational conglomerates (coarser-grained examples). The fluvial deposits commonly form fining-upward cycles (from less than 1 m to several metres thick) that formed by deposition in meandering river channels (finer-grained examples with lateral accretion deposits) or in braided river channels (coarser-grained examples with trough cross-stratification).

In the northeastern part of the basin exemplified by exposures around Kap Biot, the uppermost part of the member is composed of red-brown to purple massive mudstones interbedded with light red or greenish grey mud-peloid siltstones and thin wave-rippled sandstones. The lithological characteristics of this unit are almost indistinguishable from those of the Carlsberg Fjord Member.

Fossils. Sparse *Unio*-like bivalves are found in association with abundant fresh-water trace fossils (Clemmensen 1980b), *Grallator* tracks and some vertebrate bones. Vertebrate finds include aetosaurs (*Aetosaurus ferratus*, Jenkins *et al.* 1994; Marzola *et al.* 2018), and theropod dinosaurs (Jenkins *et al.* 1994).

Boundaries. The lower boundary is defined by the base of a fluvial sandstone horizon above the red cliff-forming lake mudstones and fine-grained sandstones of the Malmros Klint Formation or the red mudstones of the Carlsberg Fjord Member. The upper boundary is defined by the first appearance of a relatively thick, light grey marlstone.

Distribution. This member is thickest developed in the northwestern part of the basin; it thins towards the east and southeast where it overlies or is replaced by the fine-grained deposits of the Carlsberg Fjord Member (Fig. 15).

Age. Aeotosaurus ferratus is indicative of a Norian age (Jenkins *et al.* 1994; Marzola *et al.* 2018). There are no palaeomagnetic data from this unit, but by comparison with the laterally equivalent Carlsberg Fjord Member, the unit seems to be primarily of late Norian age (Kent & Clemmensen 1996; Clemmensen *et al.* 1998).

Depositional environment. The Bjergkronerne Member represents various river channel and overbank deposits. The lowermost part of the succession in the northwestern part of the basin as well as most of the succession in the central part of the basin were deposited by meandering rivers, while the uppermost part of the succession in the northwestern part of the basin was deposited by braided rivers. The fluvial sediments in the northwestern part of the basin formed part of a distributive fluvial system (cf. Weismann *et al.* 2015; Fig. 22). The central and eastern part of the basin was occupied by a large lake, the Carlsberg Fjord Member (Fig. 22); the lake frequently dried out and the area was episodically crossed by meandering rivers running toward the north (axial tributary fluvial system). There was apparently no distributive fluvial system developed along the eastern margin of the basin.

The m-scale cyclic nature of the member can primarily be related to autocyclic fluvial processes although climatic control cannot be excluded. It is speculated that such climatically controlled sedimentation would be most obvious to detect in the transition zones between fluvial and lacustrine deposition in the central part of the basin.

Tait Bjerg Member

New member

History. Grasmück & Trümpy (1969) were the first to describe the carbonate rocks in this unit. Perch-Nielsen *et al.* 1974 and Clemmensen (1980a) gave additional descriptions of this unit, and Clemmensen (1980b) formalized this unit as the Tait Bjerg Beds. The unit is here elevated to a member (Fig. 3A).

Name. After the mountain Tait Bjerg at Carlsberg Fjord (Fig. 2).

Type section. Tait Bjerg (Fig.7; Fig. 20 in Clemmensen 1980b)

Reference sections. "Track Mountain" (Figs 17, 18), Sydkronen (Fig. 13).

Thickness. The member is 65 m thick at the type locality, around 55 m at "Track Mountain", around 53 m at Lepidopterislev, 45 m at Malmros Klint, up to 12 m in Gipsdalen, and 2–3 m at Pictet Bjerge.

Lithology. The carbonate deposits in this unit were described as light grey, fine-grained, somewhat silty limestones by Grasmück & Trümpy (1969); towards the top these limestones become more and more dolomitic and show a yellow patina. Clemmensen (1980a) described these carbonate rocks as impure limestones and dolomitic limestones, while Clemmensen *et al.* (1998) termed all these deposits marlstones. A recent detailed study of the geochemistry of these lithologies (unpublished) show that the carbonate content varies between 47 and 81% with an average of 63%. The carbonate sediments thus range from marlstones (between 35 and 65% $CaCO_3$), and calcareous marlstones (between 65 and 75% $CaCO_3$), to argillaceous limestones (between 75 and 95 % $CaCO_3$). However, to simplify the following description all these carbonate rocks are termed marlstones. The carbonate minerals comprise calcite and ankerite; three XRD analyses show 22–34 % ankerite, equal to or slightly less than the content of calcite.

The marlstones are associated with various siliciclastic mudstones. Clemmensen *et al.* (1998) described the following facies: massive to faintly laminated red mudstone, partly laminated greenish mudstone, and laminated greyish mudstone. Thin wave-rippled sandstones and intraformational conglomerates also occur. At "Track Mountain", a unit a few meters below the base of the Kap Stewart Group carries up to 13 biochemical accretionary structures (thrombolites or stromatolites).

This member displays a distinct difference in lithology between variegated mudstones and light grey marlstones (approximately 20 m thick at "Track Mountain") and overlying grey mudstones and greyish to yellowish dolomitic marlstones (approximately 35 m thick at "Track Mountain"). This change in lithology is associated with an upward decrease in bedding planes with *Grallator* tracks.

The sediments possess a well-developed composite cyclicity (Clemmensen *et al.* 2016; Fig. 18). Typical cycles in the lower and middle part of the member comprise red and purple siliciclastic mudstones alternation with light greyish marlstones and grey or greenish grey mudstones alternating with light greyish marlstones. Thin wave-ripple siltstones typically occur on top of the marlstones in the first mentioned cycles.

Fossils. Invertebrate fossils include ostracods (*Darwinula* sp.) and pelecypods *(Cardiniia* sp), (Grasmück & Trümpy 1969; Clemmensen 1980b). Terrestrial palynomorphs comprise *Brachysaccus* sp., *Circulina/Paracirculina* group, *Deltoidaspora* sp., *Eucommiidites* sp., and *Microchacrydirtes* sp. (D.K. Goodman, pers. Communication 1979; Clemmensen 1980b).

Vertebrate fossils comprise a cynodont (*Mitredon cromptoni*), mammaliamorph teeth (cf.*?Brachyzostrodon* and *Kuehneotherium*), and skeleton remains of a mammal (*Haramiyavia clemmenseni)*, (Jenkins *et al.* 1994; Marzola *et al*. 2018).

Numerous *Grallator* tracks are seen in the lowermost part of the unit in association with three sauropodomorph dinosaur trackways (Jenkins *et al.* 1994; Clemmensen *et al.* 2016; Lallensack *et al*. 2017).

Boundaries. The lower boundary is defined by the first appearance of a light grey impure marlstone. At Tait Bjerg this marlstone is very thin, while at "Track Mountain" and Lepidopteriselv it is around 0.5 m thick.

The uppermost boundary of the Tait Bjerg Member is frequently covered by scree or solifluction material from the overlying Kap Stewart Group. At other sites, sills are present near the boundary masking the lithological characteristics of the sediments near the contact. At the type section, Clemmensen (1980b) placed the boundary at the contact between a dark grey mudstone and an overlying yellowish grey sandstone block of Kap Stewart sediments. The isolated nature of the large sandstone block makes it a little uncertain whether it is *in situ*. However, as judged from the relative large thickness of the Tait Bjerg Member at this locality, only insignificant amounts of the unit might be missing. At Lepidopteriselv the lowermost siliciclastic sandstones in the Kap Stewart Group contain lithified limestones slabs formed by erosion of the topmost part of the Tait Bjerg Member, but at other sites the Kap Stewart Group overlies the deposits of the Tait Bjerg Member without visible discontinuity.

Distribution. This unit occurs in the southeastern and central part of the basin; the unit seems to reach farther to the northwest than the underlying Carlsberg Fjord Member.

Age. Probably early Rhaetian as indicated by age-diagnostic ostracods and terrestrial palynomorphs (Grasmück & Trümpy 1969; Clemmensen 1980b). Müller *et al.* (2005) and Andrews *et al.* (2014) also consider the Tait Bjerg Member to be of early Rhaetian age (Fig. 3A). Palaeomagnetic data supplemented by cyclostratigraphic analysis (Kent & Clemmensen 1996; Clemmensen *et al.* 1998) seem also to indicate an early Rhaetian age. The vertebrates fuana supports a late Triassic (probably middle to late Norian) age, (Jenkins *et al.* 1994; Marzola *et al.* 2018). Grasmück & Trümpy (1969) reported a Rhaetian bone bed with abundant bone fragments, fish scales and reptilian teeth in the uppermost part of the Tait Bjerg Member. Unfortunately, we were not able to locate this bone bed during our expeditions to the basin in 2012, 2016 and 2018.

Depositional environment. The lowermost part of the unit with marlstones and variegated mudstones was probably deposited in a lake that varied from ephemeral to semi-perennial. The upper part of the unit composed of marlstones and grey mudstones was deposited in a perennial lake (Clemmensen *et al.* 1998; Clemmensen *et al.* 2016).

The cyclic stratigraphy of the lake deposits has been related to orbital control of precipitation in the source areas, sediment loads to the lake basin, and lake environment (Clemmensen *et al.* 1998; Clemmensen *et al*. 2016). From the cycle stratigraphy, it is implied that the average accumulation rate was about 50 mm/ka (Clemmensen *et al*. 1998).

Basin configuration and sedimentary systems

Clemmensen (1980a) interpreted the Triassic Jameson Land Basin as a rift valley with extensive rifting in the Early (to Middle) Triassic and the formation of alluvial fans and braided river plains on both sides of the basin (the Klitdal and Paradigmabjerg Formations of the Pingo Dal Group). According to Clemmensen (1980a, 1980b) minor rifting also took place during the Late Triassic and caused the formation of a river plain with coarse clastics along the western boundary

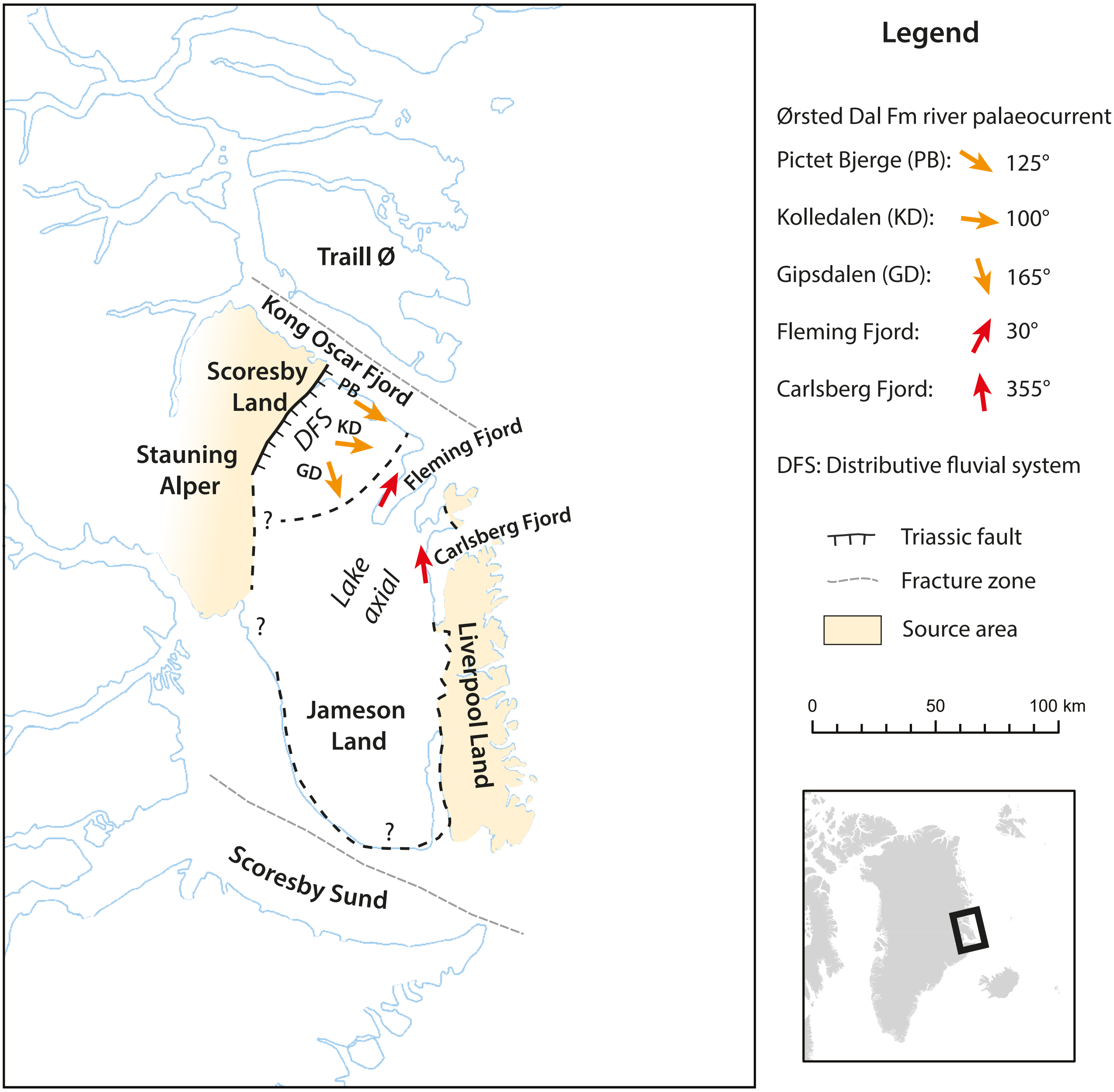

Fig. 22. Palaeogeographic reconstruction of the depositional environments of the Late Triassic Ørsted Dal Formation depicting the distributive fluvial system of the Bjergkronerne Member and the lake system with sporadic development of tributary (axial) fluvial drainage of the Carlsberg Fjord Member. The northwesterly boundary fault in Scoresby Land apparently formed a major topographic element while the remaining Triassic faults shown on Fig. 1 seemed to have had little influence on the evolution of the depositional system. The Late Triassic basin was situated at about 41° N and most precipitation was probably brought to the basin by southwesterly winter winds.

faults (Bjergkronerne Member of the Ørsted Dal Formation). The central and eastern part of the basin was occupied by a large lake.

Olsen & Kent (2000) suggested that the Triassic basin in East Greenland was a half graben; during deposition of the Late Triassic Fleming Fjord Group a lacustrine complex formed where low-relief delta and fluvial sediments were transported into the basin from both eastern (Liverpool Land High) and western source areas (foot wall scarp). Also Decou *et al.* (2016) saw the Triassic basin as a half graben. According to Decou *et al.* (2016), the increased input of clastic material from western source areas in the Ørsted Dal Formation (Bjergkronerne Member) was related to the initiation of more humid conditions in the catchment areas.

Guarnieri *et al.* (2017) made a detailed study of the Triassic rift basin with focus on the Early (to Middle) Triassic extensional event and the formation of NE–SW trending basin and highs segmented by NW–SE trending transfer zones. The Early (to Middle) Triassic syn-rift sediments of the Pingo Dal Group were followed by Middle to Late Triassic post-rift sediments including deposits of the Gipsdalen and Fleming Fjord Groups. The stratigraphic architecture of the Fleming Fjord Group supports the model of Guarnieri *et al.* (2017) as the sediments of this group do not increase in thickness towards the western border fault and thereby represent post-rift deposits (Fig.15).

Data compiled by Clemmensen (1980a), Jenkins *et al.* (1994), and Decou *et al.* (2016) reveal that almost all clastic sediment supplied to the basin during deposition of the Late Triassic Fleming Fjord Group and in particular the Ørsted Dal Formation was derived from westerly or northwesterly uplands in the form of a distributive fluvial system. Fluvial palaeocurrents in the Bjergkronerne Member were directed towards the southeast (Figs 21, 22) or almost perpendicular to the NE-SW trending boundary fault that according to Guarnieri *et al.* (2017) delineated the northern part of the basin from uplands in Stauning Alper and adjacent areas with Carboniferous rocks.

The studied outcrops of the Fleming Fjord Group and in particular those corresponding to the Carlsberg Fjord and Tait Bjerg Members of the Ørsted Dal Formation show little evidence of sediment input from the Liverpool Land High. This probably indicates that the lake margin with possible coarse-grained lake shoreline and fluvial deposits was situated farther east than the present outcrops along Carlsberg Fjord. Such coarse-grained marginal deposits have not yet been documented but may be present in Klitdal.

Regional context

In a broader regional context Triassic deposition in the present day North-West European region of northern Pangaea occurred during the punctuated rifting episodes that initiated the break-up of Pangaea (McKie 2014; Guarnieri *et al.* 2017). Lacustrine deposits similar to those found in the Late Triassic Eddderfugledal, Malmros Klint and Ørsted Dal Formations in the Jameson Land Basin are seen to the north on Traill Ø (Andrews & Decou 2018). Late Triassic lacustrine red beds sharing many characteristics with those in the Malmros Klint Formation and Carlsberg Fjord Member are also seen in several areas in present day North-West Europe including in the Germanic Basin (South Permian Basin), the eastern Danish Basin, the Norwegian-Danish Basin, in basins in the central and northern North Sea region, and in a basin in southwest England (Reinhardt & Ricken 2000; Kemp & Coe 2007; McKie 2014; Nystuen *et al.* 2014; Lindström *et al.* 2017). Late Triassic (Norian-Rhaetian), lacustrine red beds (Unit Tr 5) are also present in sedimentary basins on the Mid-Norwegian shelf (Müller *et al.* 2005).

The lacustrine red beds in the Jameson Land Basin (*i.e.* the Carlsberg Fjord Member of the Ørsted Dal Formation and the underlying Malmros Klint Formation) form a unique, up to 250 m thick succession of Late Triassic lake deposits. These red beds were termed the Fleming Fjord-type lacustrine complex by Olsen & Kent (2000) and compared to the Late Triassic Trossing (Knollenmergel) and Arnstadt (Steinmergelkeuper) formations of the German Basin, and it was suggested that similar deposits probably characterize most of the Late Triassic basins of northern Europe.

In the Jameson Land Basin, the Late Triassic lake (the Carlsberg Fjord Member) was flanked by a distributive fluvial system draining northwestern uplands (the Bjergkronerne Member). An almost identical Late Triassic lake-fluvial system developed on Traill Ø in a basin immediately north of the Jameson Land Basin (Andrews & Decou 2018). In sedimentary basins on the Mid-Norwegian shelf, the lacustrine succession in Unit Tr 5 shows an upward-increase of fluvial sandstones (Müller *et al.* 2005). These fluvial sediments were compared to the Bjergkronerne Member of the Jameson Land Basin although it was not stated whether the fluvial deposits on the Mid-Norwegian shelf formed distributive draining systems or tributary rivers.

In the central North Sea and adjacent areas, similar Late Triassic distributive fluvial systems were developed as intermittent (arid intervals) to perennial (humid intervals) streams (McKie 2014). The intermittent streams were characterized by terminal splays and the perennial streams by deltas at the transition zones to the playa/lake system. Similar depositional facies have only been identified locally in the investigated basin (Fig. 22), but their presence are considered to be more widespread in the context of the overall environmental setting. In a similar way, the Late Triassic (Keuper) lake of the Germanic Basin was flanked by a distributive fluvial system (the Norian Stubensandstein), (Hornung & Aigner 1999; Reinhardt & Ricken 2000). In contrast no fluvial deposits have been recognized in association with the late Norian lake deposits of the Branscombe Mudstone Formation; St Audrie's Bay, in south England (Kemp & Coe 2007).

The lacustrine red beds of the Jameson Land Basin contain remains of a rich and diverse vertebrate fauna, and even though Greenland was situated relatively close to North America, its Late Triassic fauna has most affinities to coeval European faunas (e.g. Jenkins *et al.* 1994; Marzola *et al.* 2018). The preponderance of vertebrate faunal evidence favours a Norian age for a least the upper part of the Fleming Fjord Group (Jenkins *et al.* 1994). However, from faunal evidence it is not possible to determine whether the uppermost part of the Ørsted Dal Formation is of Rhaetian age and whether the lowermost part of the group, including the Edderfugledal Formation, extends into the Carnian (Jenkins *et al.* 1994). Magnetochronological work supports that the vertebrate bearing red beds of the Fleming Fjord Group are of late Norian age (Kent & Clemmensen 1996).

Palaeoclimate

In the Late Triassic, the Jameson Land basin was situated on northernmost Pangaea. Kent & Clemmensen (1996) found a palaeolatitude of approximately 35°N, but Kent & Tauxe (2005) corrected that estimate to approximately 41° N. Based on the work of Kutzbach (1994) and using a palaeolatitude of 35° N, Clemmensen *et al.* (1998) suggested that the basin in late Norian – early Rhaetian time was situated in an area where dry desert-like, dry steppe-like, and warm moist temperate climate belts met (Koeppen climate classification). Using a corrected value of 41° N for the basin, the Kutzbach model indicates that the basin was situated at the boundary between a dry steppe-like and a warm moist temperate climate zone, or even close to the southern margin of a boreal climate belt. Sellwood & Valdes (2006) made an alternative climate model for the Late Triassic, and in their model the basin at 41° N is situated in a winterwet (warm temperate, dry summer) climate belt just outside a desert (subtropical arid) climate belt (Walter biozone classification). McKie (2014) also places the basin in a semi-arid climate zone north of the arid interior of the basin, while Kent & Tauxe (2005) and Kent *et al.* (2014) places the Jameson Land Basin in the temperate humid climate belt well outside the dry interior of the continent.

The orientation of wave ripples in lacustrine deposits of the Malmros Klint Formation and the Carlsberg Fjord Member was used by Clemmensen (1980a) to interpret the ancient wind climate of the basin to be dominated by trade winds from the NNE or NE (controlling the ESE–WNW and SE–NW orientation of the wave ripples) alternating with subordinate monsoons winds from southerly directions. This interpretation was based on the assumption that the basin was situated at 35° N and only had experienced insignificant rotation since the Late Triassic. New data, however, show that the basin as part of Greenland within Pangaea was rotated 45° anticlockwise with respect to meridians since then (Kent & Tauxe 2005). Thus dominant winds as judged from corrected wave ripple orientation (SE–NW and SSE–NNW) should have been from the NE and ENE and/or the SW and WSW. Using a corrected value of 41° N for the basin, the Kutzbach model indicates that the most likely interpretation of the deduced palaeowinds would be winter winds from southwesterly directions. Thus it is likely that precipitation during deposition of the main part of the Fleming Fjord Group was related to Westerlies. The increased precipitation with time as shown by the evolution from an ephemeral to a perennial lake system could therefore indicate a shift (induced or influenced by continental drift) from a temperate winter-wet climate to one with precipitation throughout the year. A modern analogue could be Spain, where the southern and central parts have a Mediterranean-type steppe climate with hot dry summer and cool wet winters, while the northernmost part has an oceanic climate with year-round precipitation. Ongoing research will deal in more detail with this issue.

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