Cretaceous lithostratigraphy of North-East Greenland

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[Abstract]
An updated and revised lithostratigraphic scheme is presented for the Cretaceous of North-East Greenland from Traill Ø in the south to Store Koldewey in the north. The Ryazanian to lower Maastrichtian succession is up to several kilometres thick and comprises four groups, 12 formations and 18 members. The groups record the tectonic evolution of the East Greenland depocentre on the western flank of the evolving proto-Atlantic seaway. The *Wollaston Forland Group* encompasses the uppermost Jurassic – lowermost Cretaceous rift-climax succession and contains the Lindemans Bugt and Palnatokes Bjerg Formations; two new members of the latter formation are erected from Store Koldewey. Post-rift Cretaceous strata are referred to the new Brorson Halvø Group and the Home Forland Group. The *Brorson Halvø Group* (uppermost Hauterivian – middle Albian) is dominated by slope and basinal mudstones of the new Stratumbjerg Formation but also includes fluvio-deltaic and shallow marine sandstones of the revised Steensby Bjerg Formation on northern Hold with Hope and submarine slope apron breccias and conglomerates of the revised Rold Bjerge Formation on Traill Ø. The *Home Forland Group* covers the middle Albian – Coniacian succession. The basal unconformity records an important mid-Albian tectonic event involving intrabasinal uplift, tilting and erosion, as exemplified by the middle Albian conglomerates of the new Kontaktravine Formation on Clavering Ø. The Home Forland Group is dominated regionally by mud-dominated slope to basinal deposits of the elevated and revised Fosdalen Formation; it also includes lowstand basin-floor fan sandstones of the new upper Albian Langsiden Member. The new *Jackson Ø Group* (upper Turonian – lower Maastrichtian), records a phase of basin reorganisation marked by a significant fall in sedimentation rate in North-East Greenland, probably linked to rift events in, and bypass to, the central proto-Atlantic rift system. The base of the group is an erosional unconformity on Traill Ø and Geographical Society Ø overlain by submarine slope-apron conglomerates of the Turonian Månedal Formation. The base is conformable on Hold with Hope but is defined by a condensed interval (the Coniacian Nanok Member) that is succeeded conformably by slope and basin-floor turbidite sandstones of the Coniacian–Santonian Østersletten Formation and slope to basinal mudstones of the Campanian – lower Maastrichtian Knudshoved Formation. The new Leitch Bjerg Formation of Campanian slope-apron conglomerates and sandstones in eastern Geographical Society Ø erosionally overlies the Knudshoved Formation.

Keywords: Cretaceous, lithostratigraphy, North-East Greenland

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Ryazanian–Maastrichtian sedimentary strata in North-East Greenland form a composite succession up to several kilometres in thickness. The Cretaceous basins in North-East Greenland covered by this study extend for more than 500 km from Traill Ø (72°N) in the south to Store Koldewey (76.5°N) in the north. The basins are aligned with roughly N–S trending basinal axes and are offset progressively eastwards from Traill Ø northwards to Store Koldewey (Fig. 1). They are exposed in 5–25 km wide fault blocks, measured perpendicular to the basin axes (Stemmerik *et al.* 1993; Whitham *et al.* 1999; Parsons *et al.* 2017). The Cretaceous succession commonly rests on older Mesozoic deposits, but locally onlaps upper Palaeozoic deposits or crystalline basement, thus presenting a range of different basin configurations and structural relationships (Fig. 1).

Although the Cretaceous crops out widely in the region (Figs 1–3), only few published studies have dealt with the lithostratigraphic subdivision of the succession. Pioneering observations on Cretaceous strata in the region were made under the Denmark Expedition to North-East Greenland in 1906–08 and Lauge Koch's East Greenland expedition in 1926–27 (Koch 1929). A few lithostratigraphic units were tentatively assigned at this time such as the 'Cape Hamburg Formation', though this name was later abandoned due to lack of stratigraphic information (Surlyk 1978a). Based on the work of Koch (1929), extensive mapping campaigns were conducted and combined with systematic aerial reconnaissance and photography during "The Three-year Expedition to East Greenland 1931–34" and "The Danish expeditions to East Greenland 1947–58" led by Lauge Koch. A few names, such as the 'Knudshoved Beds' and 'Home Forland Beds', were introduced for the upper part of the Cretaceous succession on Hold with Hope by Maync (1949) and later incorporated in formal lithostratigraphic definitions (Kelly *et al.* 1998). Other informal names were applied to Cretaceous strata in part based on their macrofossil content, e.g. 'Middle Cretaceous Shale Series', the '*Inoceramus lamarki Beds', the* '*Scaphites* Beds' and the '*Sphenoceramus* Beds' (Donovan 1957; Fig. 4).

Although the lowermost Cretaceous of the Wollaston Forland area was the subject of much study in the 1970s (Surlyk 1978a), the lithostratigraphy of post-Valanginian strata in North-East Greenland received little attention between 1960 and 1990. This resulted primarily from the challenges of relatively poor exposure over wide areas and the uniformity of the sparsely fossiliferous mudstone-dominated succession (Donovan 1955). The succession is characterised by a general scarcity of macrofossils, hampering biostratigraphy in the field, but a comprehensive palynostratigraphic study in the 1980s successfully dated the Hauterivian – Albian succession, informally assigned to the 'Mid Cretaceous sandy shale sequence' by Nøhr-Hansen (1993).

The previous formal lithostratigraphic subdivision that covers the Jurassic – Cretaceous boundary strata of the Wollaston Forland Group (Jameson Land Supergroup), comprehensively described by Surlyk (1978a, 2003) and recently reviewed by Surlyk *et al.* (in press), is retained here with only minor additions (Fig. 4). Local lithostratigraphic schemes exist from the northern part of Hold with Hope (Kelly *et al.* 1998) and from the northern and central parts of Traill Ø (Surlyk & Noe-Nygaard 2001); these schemes are incorporated, in modified form, in the regional framework described here. The main lithostratigraphic units of Kelly *et al.* (1998) were combined with bivalve zonations in order to subdivide the Cretaceous succession for the geological map of the Traill Ø – Geographical Society Ø presented by Parsons *et al.* (2017).

Lithostratigraphic data presented here were systematically collected by the Geological Survey of Denmark and Greenland (GEUS) during extensive fieldwork in 2008–2011 under the auspices of a multi-client industrial services package entitled "Petroleum Geological Studies, Services and Data". The aim was to erect a lithostratigraphic framework that is applicable to Cretaceous strata regionally in North-East Greenland (Bojesen-Koefoed *et al.* 2014).

The lithostratigraphic framework presented here includes four groups, subdivided into 12 formations and 18 members (Figs 4, 5). Chronostratigraphic ranges are based on the dinoflagellate cyst zonation, supplemented by ammonites, bivalves and other macrofossils, foraminifers and nannofossils (Nøhr-Hansen 1993; Alsen 2006; Nøhr-Hansen *et al.* 2019). The Wollaston Forland Group has been described in detail by Surlyk (1978a, 1984, 2003) and Surlyk *et al.* (in press), and only new complementary data and units of this group are included in this study; comprehensive descriptions of the remaining units of the Wollaston Forland Group are given by Surlyk *et al.* (in press).

Figure 6 shows a combined legend for all the lithological logs presented in this work.

Lithostratigraphy and basin evolution

The Cretaceous succession in North-East Greenland is subdivided into four main tectonostratigraphic units (comparable to the tectonostratigraphic sequences of Surlyk 2003) as represented by the Wollaston Forland, Brorson Halvø, Home Forland and Jackson Ø Groups (Fig. 5). The groups are bounded by unconformities and the development of the succession is considered similar to that of basins in the subsurface offshore East Greenland and on the conjugate Norwegian margin (Stoker *et al.* 2017; Fyhn *et al.* in press). The uplifted basins exposed in North-East Greenland, however, are situated in more marginal positions compared

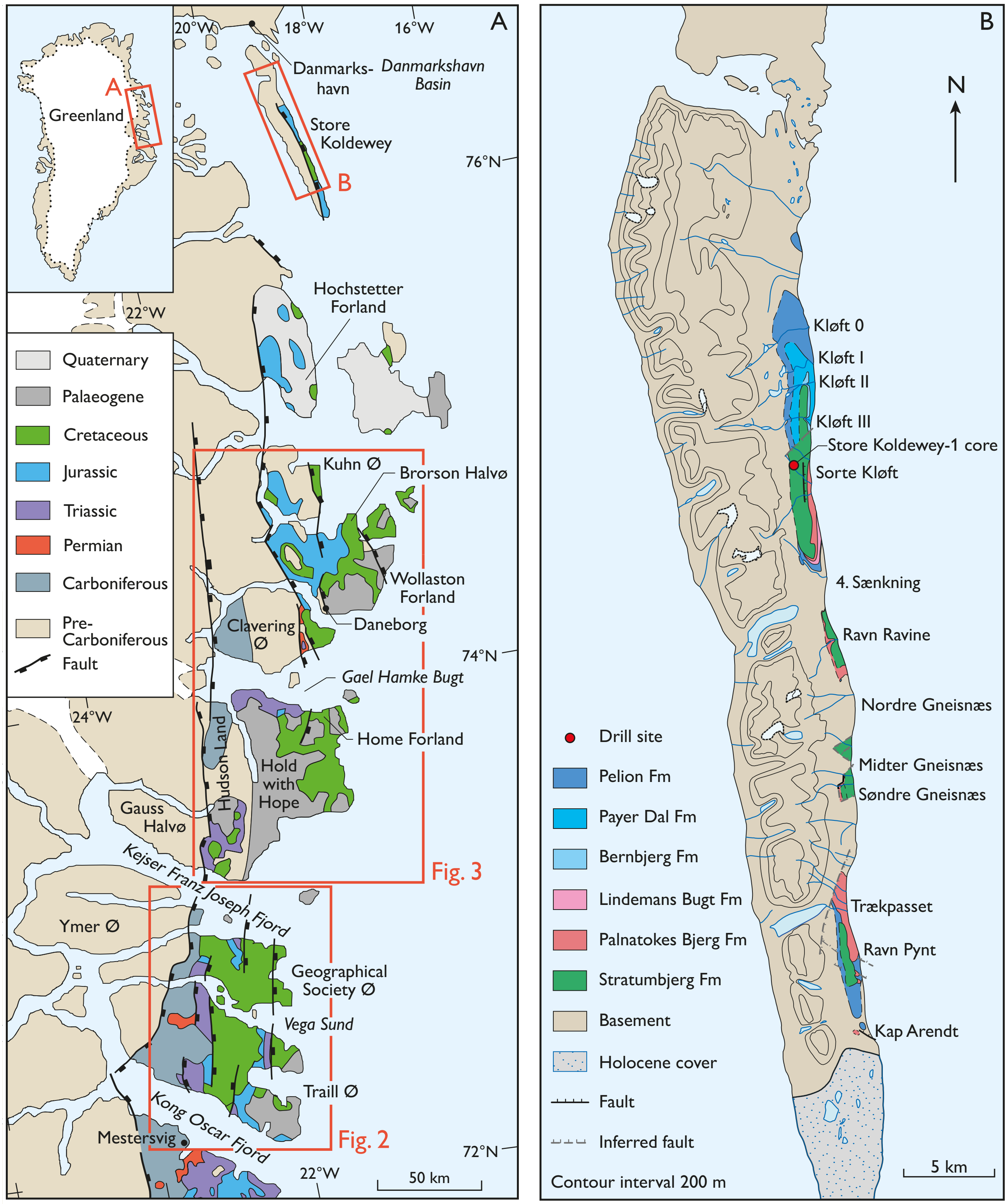


Fig. 1. A: Geological map of North-East Greenland with frames of detailed maps presented in Figs 2– 3. **B:** Simplified geological map of Store Koldewey.

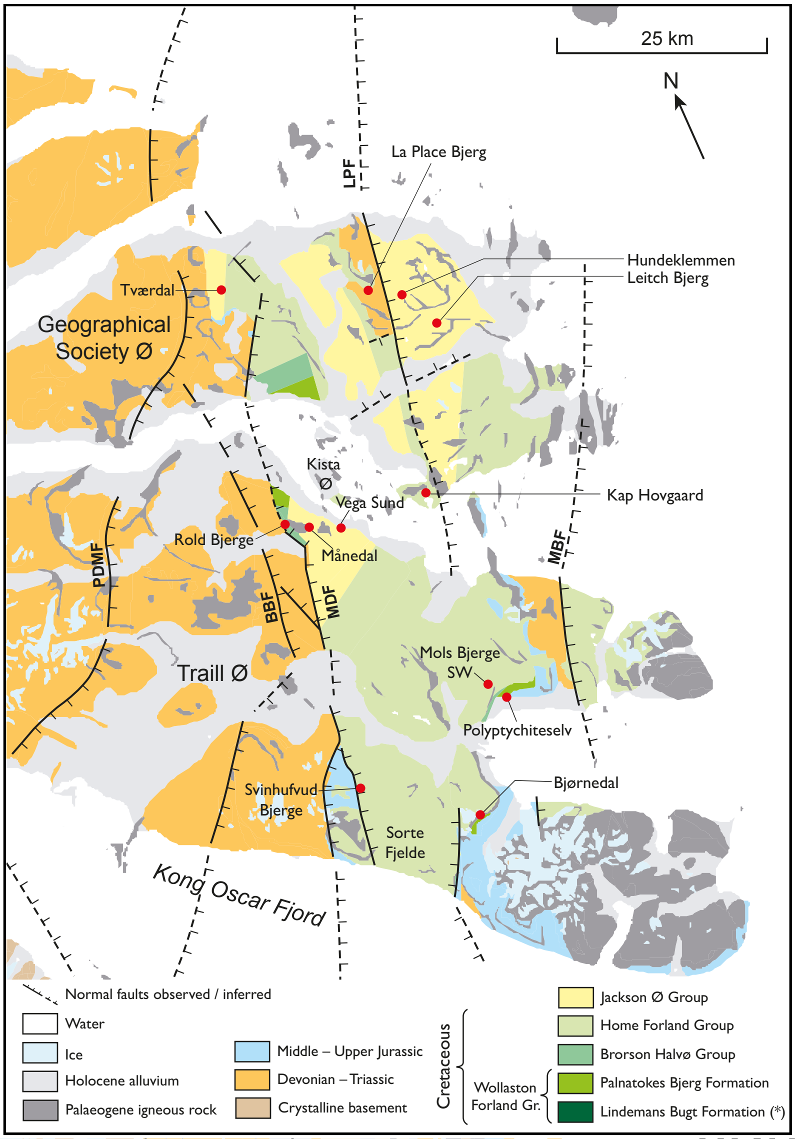


Fig. 2. Geological map of Traill Ø and Geographical Society Ø showing structural elements and distribution of main Cretaceous lithostratigraphic units and localities mentioned in the text. Modifed from GEUS 1:500.000 geological map with data added from Parsons *et al.* (2017). BBF = Bordbjerg Fault, LPF = Laplace Bjerg Fault, MDF = Månedal Fault, MBF = Mols Bjerge Fault, PDMF = Post Devonian Main fault, * in part Jurassic. Red dots show localities. The legend also covers Fig. 3.

with the subsurface deep-water basins, such as the Møre and Vøring Basins, which developed along the rift axis between Norway and Greenland (Fjellanger *et al.* 2005; Nøttvedt *et al.* 2008).

The Volgian – lower Barremian Wollaston Forland Group records the culmination of Middle Jurassic to earliest Cretaceous rifting (Surlyk 2003). The group is possibly up to about 2 km thick over the down-faulted western part of tilted fault blocks but wedges out to a few metres towards the hanging wall crest to the east. It is particularly well developed in the north-western part of Wollaston Forland (Fig. 7; Surlyk 1978a) but is also observed on Clavering Ø. Fault-associated submarine fan conglomerates and sandstones were deposited on the hanging wall along the main boundary fault and fine and thin towards the east. The main phases of coarse-grained deposition are represented by the Volgian Rigi and the Valanginian Young Sund Members; they are preceded, separated and succeeded by, respectively, fine-grained muddy deposits of the Laugeites Ravine, Niesen and Albrechts Bugt Members. Similar coarse- and fine-grained facies units are recognised on Store Koldewey and referred to the Midter Gneisnæs and Ravn Pynt Members. The condensed muddy and red Rødryggen Member, which concludes the syn-rift phase, is recognised on Traill Ø, Wollaston Forland and Hochstetter Forland (Surlyk 1978a, b; Alsen 2006); it is restricted to submarine highs such as the crests of tilted fault blocks. It is typically capped by an unconformity (Fig. 5).

The erosional unconformity that generally caps the syn-rift deposits marks the base of the new Brorson Halvø Group. The lowermost strata of the group are diachronous, as exemplified by the basal deposits of the Stratumbjerg Formation which are of early Barremian age in the Traill Ø – Wollaston Forland area but

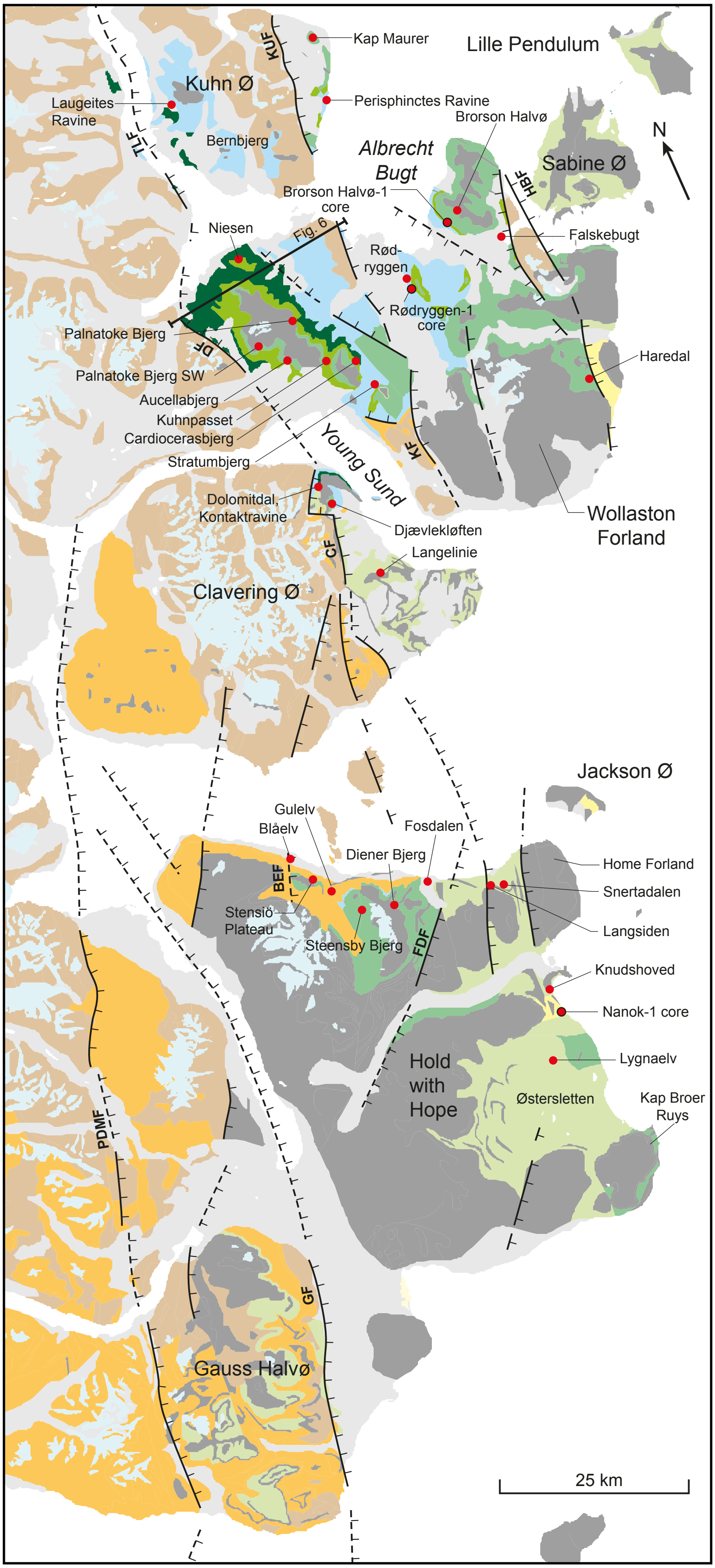


Fig. 3. Geological map of Hold with Hope, Clavering Ø and Wollaston Forland areas, showing structural elements and distribution of main Cretaceous lithostratigraphic units and localities mentioned in the text. Modified from GEUS 1:500.000 geological map. BEF = Blå Elv Fault, CF = Clavering Fault, DF = Dombjerg Fault, FDF = Fosdalen Fault, GF = Giesecke Fault, HBF = Hühnerbjerg Fault, KF = Kuppel Fault, KUF = Kuhn Fault, PDMF = Post Devonian Main Fault, TLF = Thomsen Land Fault. Red dots show localities. Legend in Fig. 2.

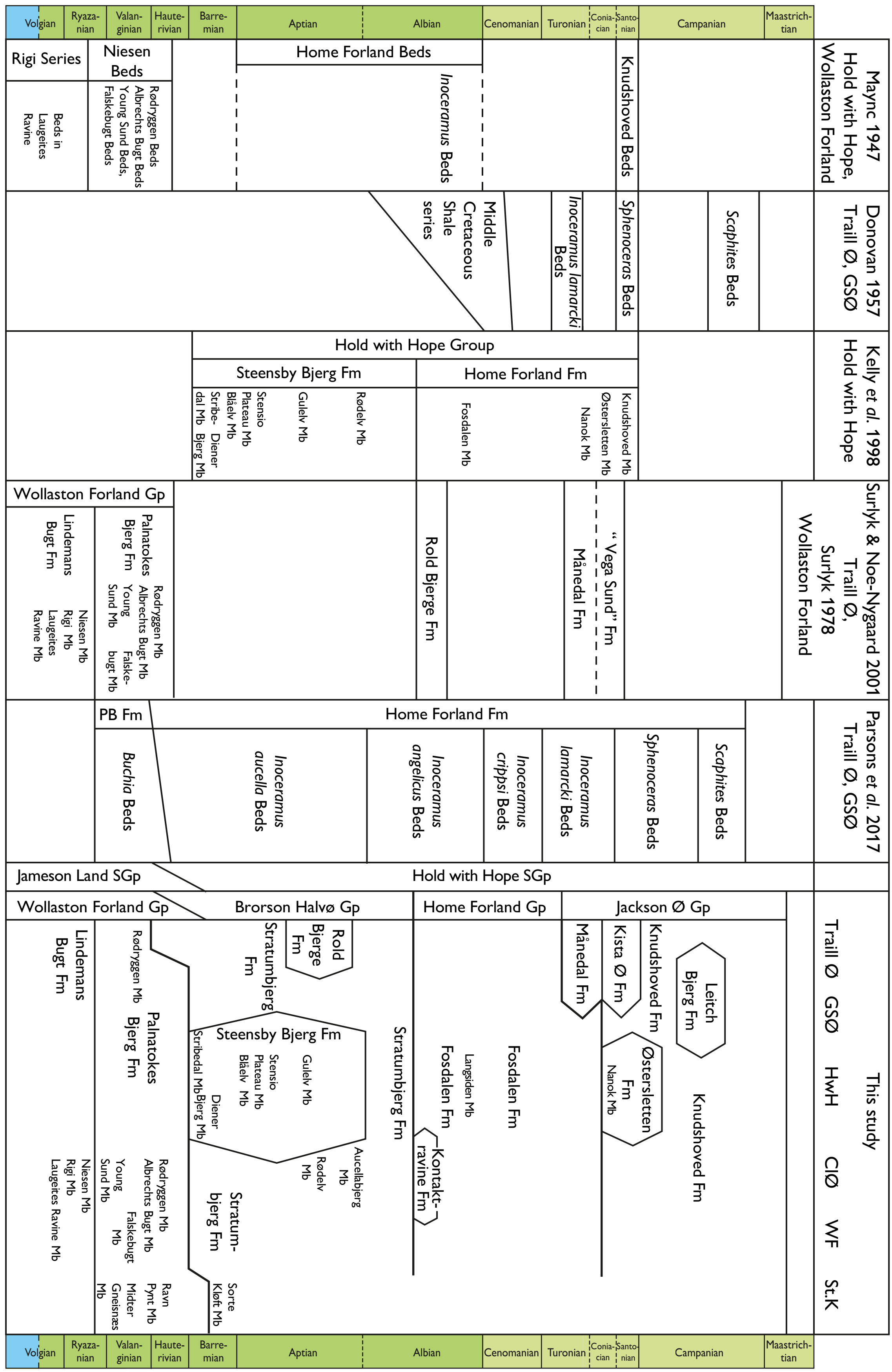


Fig. 4. Previous lithostratigraphic subdivisions of the Cretaceous succession in North-East Greenland and the subdivision of this study. GSØ = Geographical Society Ø, HwH = Hold with Hope, ClØ = Clavering Ø, St.K. = Store Koldewey.

of late Barremian age on Store Koldewey in the north (Fig. 5). The group extends into the Albian and is dominated by slope and basinal, mud-dominated deposits. Although largely filling and draping sea-floor relief inherited from the Late Jurassic – Early Cretaceous rift phase, deposition was also controlled locally by fault-related erosion and subsidence. The Steensby Bjerg Formation of northern Hold with Hope is atypical of the group as a whole as it represents a deltaic – shallow marine sand-dominated system that developed in an evolving relay ramp setting during the Barremian – early Albian (e.g. Kelly *et al.* 1998; Larsen *et al.* 2001). An additional shallow-marine sand unit, the Aucellabjerg Member, is recorded from the Aptian of south-west Wollaston Forland, and prominent fault-related submarine coarse clastics form the re-dated Aptian Rold Bjerge Formation on Traill Ø (Fig. 5). The spectrum of depositional systems recorded by the Brorson Halvø Group in North-East Greenland is closely comparable to that reported from the Aptian–Albian interval in the Møre Basin on the contiguous margin (Vergara *et al.* 2001; Fjellanger *et al.* 2005).

The base of the overlying Home Forland Group is also an unconformity linked to localised fault re-activation. It defines a marked drowning event that affected the crests of tilted fault blocks, and the group is dominated regionally by marine deep-water mud-rich deposits of the middle Albian – Coniacian Fosdalen Formation (Fig. 5). Basal middle Albian fault-associated conglomerates occur on Clavering Ø, represented by the new Kontaktravine Formation and minor thin conglomerate and sandstone units cropping out elsewhere on Traill Ø and Brorson Halvø. The new upper Albian Langsiden Member records widespread deposition of sandstone turbidites in basinal and slope settings on Hold with Hope and Traill Ø. The middle Albian unconformity at the base of the group represents an important basin reorganisation event in North-East Greenland, and a comparable event is well expressed on the Norwegian margin (e.g. the Trøndelag Platform). Upper Albian turbidite sandstones (Agat Formation) are also reported from the Møre Basin (Vergera *et al.* 2001).

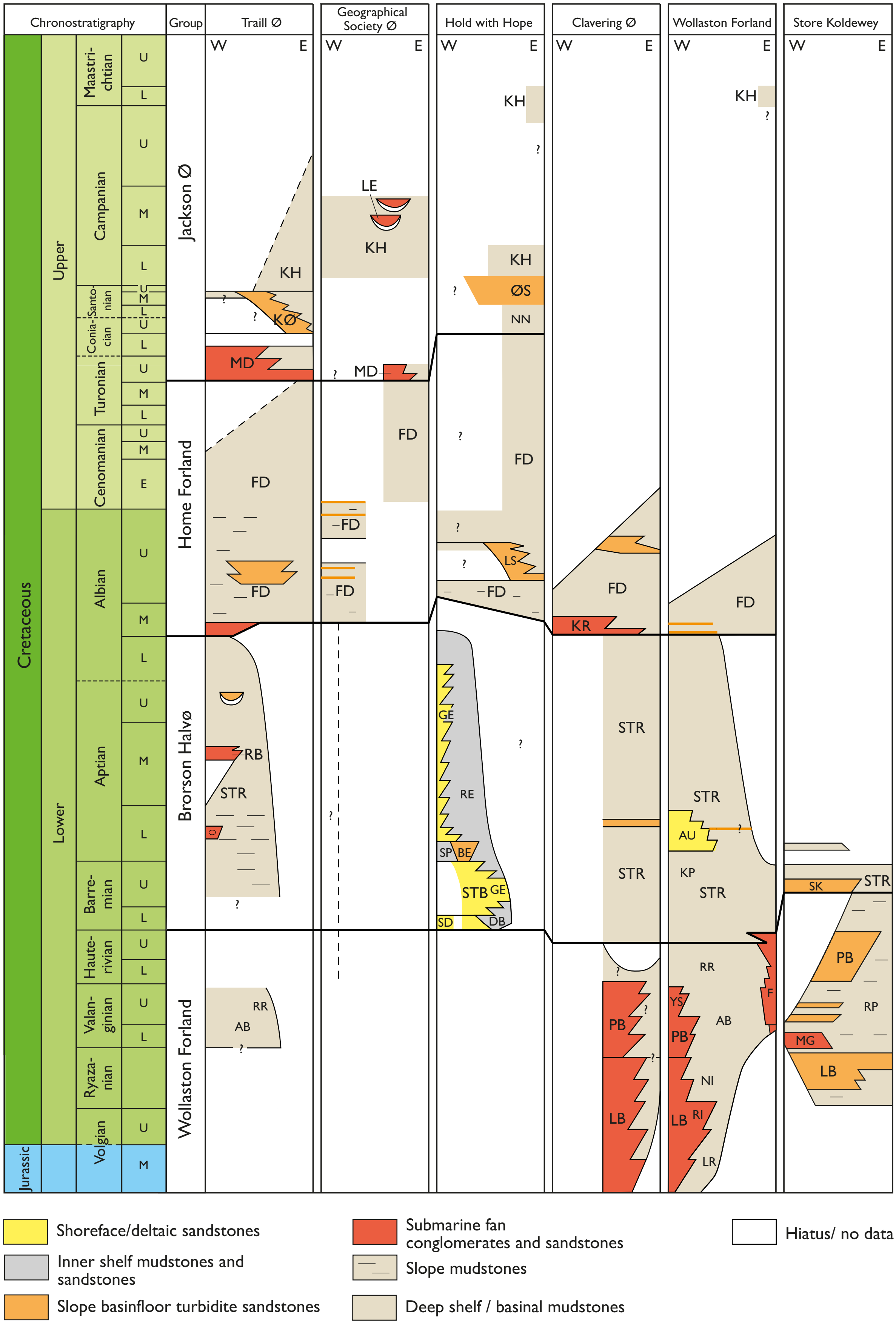
The new Jackson Ø Group rests on a prominent Turonian erosional unconformity in the south of the region. On Traill Ø, the lowermost strata are submarine slope breccias and conglomerates of the Månedal Formation (Fig. 5; Surlyk & Noe-Nygaard 2001). On eastern Hold with Hope, in a basinal setting, the basal part of the group is marked by the Coniacian condensed Nanok Member. Both these units are overlain by Coniacian – Santonian turbidite sandstone units – the Kista Ø Formation on Traill Ø and the Østersletten Formation on Hold with Hope and are followed by basinal mudstones of the Campanian – lower Maastrichtian Knudshoved Formation. The lower Campanian Leitch Bjerg Formation in eastern Geographical Society Ø comprises a distinctive succession of channelised slope-apron conglomerates. The Jackson Ø Group records a new phase of fault activity in the region, coeval with the onset of reduced sedimentation rates in basinal settings. Such features are compatible with eastward bypass and supply of coarse-grained material from Greenland to the Vøring Basin, as proposed for the turbidite sandstones of the Coniacian Lysing Member (Blålange Formation), the Santonian Tumler Member (Kvitnos Formation), and the Campanian Spekhugger Member (Nise Formation) in the Vøring Basin (Morton & Grant 1998; Vergera *et al.* 2001; Fjellanger *et al.* 2005; Morton *et al.* 2005; Gradstein & Waters 2016).

The regional lithostratigraphic framework of North-East Greenland presented here thus describes and defines the stratigraphic development of the western margin of the proto-Atlantic seaway and hence serves as an analogue for offshore basins on the East Greenland shelf margin and for basins on the conjugate Norwegian margin.

The spelling of a name of an established stratigraphic unit must not be changed even if the spelling of the place name has changed. Therefore, the old spelling of some units is maintained, e.g. of the Palnatokes Bjerg Formation, although the name of the place is now spelled Palnatoke Bjerg. This is the case for many place names with a genitive 's'.

Jameson Land Supergroup

The Jameson Land Group was erected by Surlyk *et al.* (1973) and elevated to the rank of supergroup by Surlyk *et al.* (in press). It spans the Jurassic succession of East and North-East Greenland, including the genetically associated uppermost Triassic and lowermost Cretaceous strata, and has a composite thickness of about 2.4 km. The supergroup is divided into five groups: the Kap Stewart (Rhaetian–Sinemurian), Neill Klinter (Pliensbachian – lower Bajocian), Vardekløft (upper Bajocian – Ryazanian), Hall Bredning (upper Callovian – Hauterivian), and the Wollaston Forland (middle Volgian – lower Hauterivian) Groups. The Wollaston Forland Group, which straddles the Jurassic–Cretaceous boundary, is described in part below with focus on the Palnatokes Bjerg Formation within which two new members are defined here from Store Koldewey.


Chronostratigraphy
Group
Traill Ø
Geographical Society Ø
Hold with Hope
Clavering Ø
Wollaston Forland
Store Koldewey
W
E
Cretaceous
Jurassic
Upper
Lower
Maastri-chtian
Campanian
Santo-nian
Conia-cian
Turonian
Cenomanian
Albian
Aptian
Barre-mian
Haute-rivian
Valan-ginian
Ryaza-nian
Volgian
U
M
L
E
Jackson Ø
Home Forland
Brorson Halvø
Wollaston Forland
KH
KØ
MD
FD
LE
ØS
NN
LS
KR
RB
STR
GE
RE
SP
BE
STB
SD
DB
AU
KP
SK
RR
AB
YS
PB
F
NI
LB
RI
LR
RP
MG
?
Shoreface/deltaic sandstones
Inner shelf mudstones and sandstones
Slope basinfloor turbidite sandstones
Submarine fan conglomerates and sandstones
Slope mudstones
Deep shelf / basinal mudstones
Hiatus/ no data

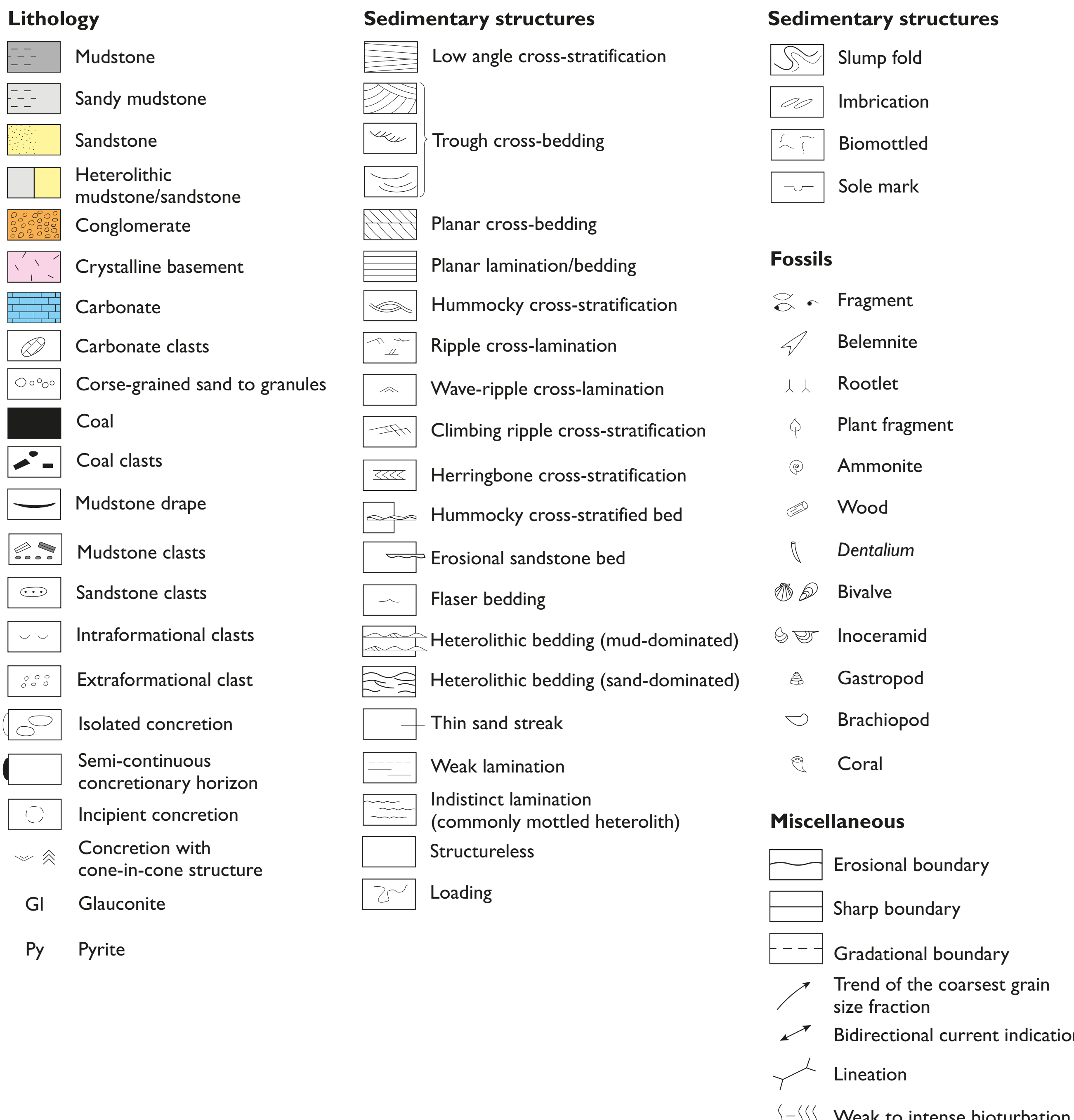


Fig. 6. Legend to all sedimentological logs.

◀ **Fig. 5.** Cretaceous stratigraphic schemes for Store Koldewey, Wollaston Forland, Clavering Ø, Hold with Hope, Geographical Society Ø and Traill Ø in North-East Greenland. Formations (Fm) and Members (Mb): AB = Albrechts Bugt Mb, AU = Aucellabjerg Mb, BE = Blåelv Mb, DB = Diener Bjerg Mb, F = Falskebugt Mb, FD = Fosdalen Fm, GE = Gulelv Mb, KH = Knudshoved Fm, KR = Kontaktravine Fm, KØ = Kista Ø Fm, LR = Laugeites Ravine Mb, LB = Lindemans Bugt Fm, LE = Leitch Bjerg Fm, LS = Langsiden Mb, MD = Månedal Fm, MG = Midter Gneisnæs Mb, NI = Niesen Mb, NN = Nanok Mb, PB = Palnatokes Bjerg Fm, RB = Rold Bjerge Fm, RE = Rødelv Mb, RI = Rigi Mb, RP = Ravn Pynt Mb, RR = Rødryggen Mb, SD = Stribedal Mb, SK = Sorte Kløft Mb, SP = Stensiö Plateau Mb, STB = Steensby Bjerg Fm, STR = Stratumbjerg Fm, YS = Young Sund Mb, ØS = Østersletten Fm.

Wollaston Forland Group

The group is distributed from Traill Ø in the south to Store Koldewey in the north. It comprises breccias, conglomerates, pebbly sandstones and dark grey sandy and silty mudstones of the Volgian – Ryazanian Lindemans Bugt Formation and conglomerates, sandstones, dark grey mudstones and calcareous light grey and red mudstones of the Ryazanian – Hauterivian Palnatokes Bjerg Formation (Fig. 5; Surlyk 1978a, 2003; Surlyk *et al.* in press). The pronounced west-tilted rift half-graben setting of the group is well illustrated in the type area in north-western Wollaston Forland (Fig. 7) where the thickness of the group is estimated at about 2 km along the Dombjerg Fault to the west, decreasing eastwards to a few metres on the crest of the fault block. Depositional environments include submarine fault scarp talus, slope apron, coalescent submarine fans, basin-floor fans and condensed mudstones over submerged block crest highs (Fig. 5, Surlyk 1978a, 1984; Henstra *et al.* 2016). The lower boundary is erosional in the observed parts of the basin, overlying yellow sandstones of the Pelion Formation, grey muddy sandstones of the Jakobsstigen Formation, dark mudstones of the Bernbjerg Formation or crystalline basement. The upper boundary is typically an unconformity, overlain by dark grey mudstones of the Lower Cretaceous Stratumbjerg Formation; probable conformable relationships, however, are locally suggested. The stratal architecture of the Palnatokes Bjerg Formation within this half-graben setting, overlain by the Stratumbjerg Formation, is illustrated in a panel with sections in Wollaston Forland (Fig. 8).

Palnatokes Bjerg Formation

History. The formation was erected by Surlyk (1978a) who subdivided it into the Young Sund, Falskebugt, Albrechts Bugt and Rødryggen Members. Two new members are defined here from Store Koldewey: the Midter Gneisnæs Member and the Ravn Pynt Member (Fig. 5). The previously established members are described in Surlyk *et al.* (in press) and to avoid repetition they are not treated further here. The 'Buchia Beds' mapping unit on Traill Ø recognised by Parsons *et al.* (2017) is included in the formation.

Type section. The formation was defined with a type area covering the mountains Palnatoke Bjerg and Niesen in north-west Wollaston Forland (Fig. 7; Surlyk 1978a; Surlyk *et al.* in press). Recently a type section was in addition selected on the mountain of Niesen, based on a section described in Hovikoski *et al.* (2018) (Fig. 8).

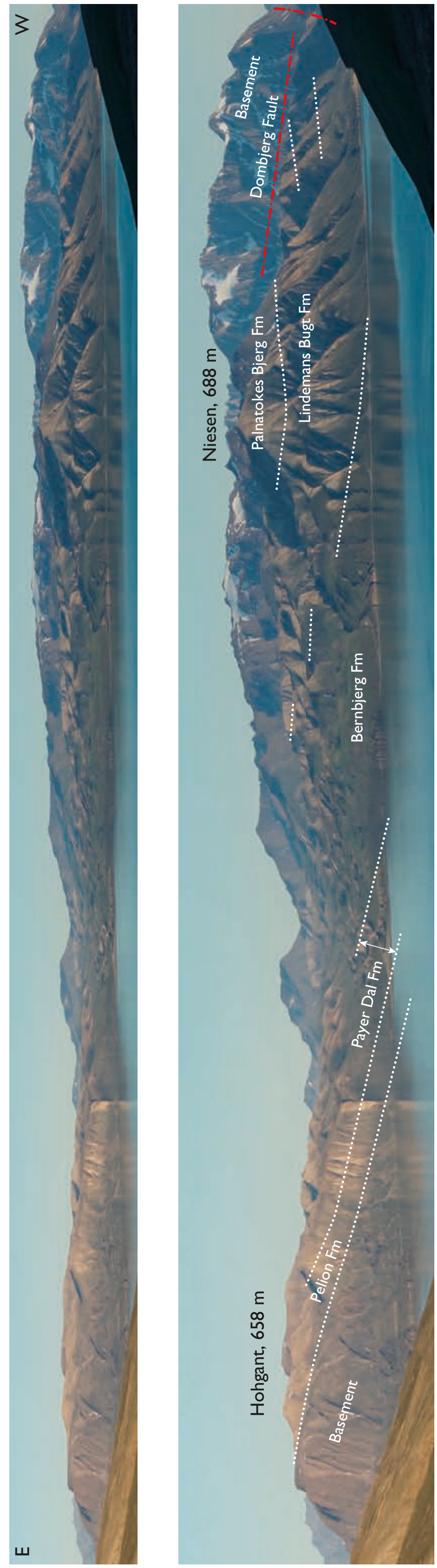


Fig. 7. Photographic panorama of north-western Wollaston Forland, looking south, showing the characteristic rift half-graben geometry of the Wollaston Forland Group. Lower section vertically exaggerated ×2. The Cretaceous Wollaston Forland Group with the Lindemans Bugt and Palnatokes Bjerg Formations rest on the Jurassic (Pelion, Payer Dal, and Bernbjerg Formations).

Reference sections. Rødryggen in Wollaston Forland, Perisphinctes Ravine on Kuhn Ø (Surlyk 1978a; Surlyk *et al.* in press), and Ravn Pynt, Midter Gneisnæs and Ravn Ravine on Store Koldewey (Figs 9–13).

Thickness. In the type area, the formation is up to about 600 m thick, wedging out to a few metres over a distance of about 20 km to the east. On Store Koldewey, the formation is up to 70 m thick.

Lithology. The formation is a heterogeneous succession of breccias, coarse conglomerates, pebbly sandstones, sandstones of the Young Sund and Falskebugt Members, dark grey and light grey mudstones commonly with abundant calcareous concretions and layers of the Albrechts Bugt Member, and yellow and dark-red mudstones of the Rødryggen Member (Fig. 8). The formation shows an overall fining-upward trend, though the lower, coarser levels also fine laterally eastwards, interdigitating with finer-grained sandy facies (for further details from the type area, see Surlyk 1978a, 1984; Hovikovski *et al.* 2018; Surlyk *et al.* in press).

Fossils. Bivalves, particularly of the genus *Buchia*, and cylindroteuthid and hibolitid belemnites are locally abundant, ammonites are common in some units but generally scarce (Surlyk *et al.* in press). Dinoflagellate cysts are rare in the Midter Gneisnæs Member but more common in the Ravn Pynt Member.

Depositional environment. In the type area, the formation represents slope apron, basin-floor fan and basin plain environments, and locally records condensed deposition on submarine intrabasinal highs (fault-block crests). On Store Koldewey, deposition occurred in submarine gullies, fault-scarp aprons and fans.

Boundaries. In the type area, the lower boundary is placed where fine-grained sandstones and thin light grey mudstones overlie conglomerates or dark mudstones of the Lindemans Bugt Formation (Surlyk 1978a). Over footwall crests, it is an erosional unconformity truncating Middle–Upper Jurassic sediments or crystalline basement (Fig. 11). The upper boundary is typically unconformable, overlain by dark grey upper Hauterivian or Barremian–Albian mudstones of the Stratumbjerg Formation (Figs 14, 15; Surlyk & Korstgård 2013). In distal areas or over isolated submarine highs, a conformable upper boundary may be recognised, such as locally on the mountain of Stratumbjerg.

Distribution. The main outcrops are in the Wollaston Forland – Kuhn Ø area, and minor occurrences are present on Traill Ø, Clavering Ø, Hochstetter Forland and Store Koldewey.

Chronostratigraphy. In the type area, the formation is referred to the upper Ryazanian (*Bojarkia mesezhnikovi* zone) – Hauterivian (*Simbirskites* beds), based on ammonites and bivalves (Maync 1949). On Store Koldewey, the formation is Valanginian – earliest late Barremian in age based on ammonites, belemnites, bivalves, nannofossils and dinoflagellate cysts.

Subdivisions. The formation comprises the Young Sund, Falskebugt, Albrechts Bugt and Rødryggen Members on Wollaston Forland (Surlyk *et al.* in press), and the new Midter Gneisnæs and Ravn Pynt Members on Store Koldewey defined here.

Key references. Maync (1947, 1949); Vischer (1943); Donovan (1953, 1964); Surlyk & Clemmensen (1975); Surlyk (1978a, 1984, 1991, 2003); Alsen (2006); Pauly *et al.* (2012); Parsons *et al.* (2017); Hovikoski *et al.* (2018); Piasecki *et al.* (in press); Surlyk *et al.* (in press).

Midter Gneisnæs Member

New member

History. This new member of the Palnatokes Bjerg Formation, which includes breccias, conglomerates and sandstones in the Store Koldewey area, was earlier assigned to the "Aucella-conglomerate" (Ravn 1911) and the Cape Hamburg Formation (Koch 1929); the latter name was suggested not to be employed by Donovan (1957), and subsequently abandoned (Surlyk 1978a).

Name. After Midter Gneisnæs, a small headland of Caledonian gneiss in the southern part of Store Koldewey (Fig. 1).

Type section. Trækpasset section on Store Koldewey constitutes the type section (76.1600°N, 18.5733°W, Fig. 9A, Surlyk *et al*. (in press).

Reference section. The section at Midter Gneisnæs on Store Koldewey constitutes the reference section (76.2273°N, 18.5924°W, Figs 9B, 10).

Thickness. The member is up to 48 m thick at Trækpasset, and here it thins out to less than a metre thick at gully margins. At Midter Gneisnæs it is at least 38 m thick. The member forms a thin veneer elsewhere on Store Koldewey, ranging in thickness from decimetres to a few metres.

Lithology. The thick successions referred to the mem-

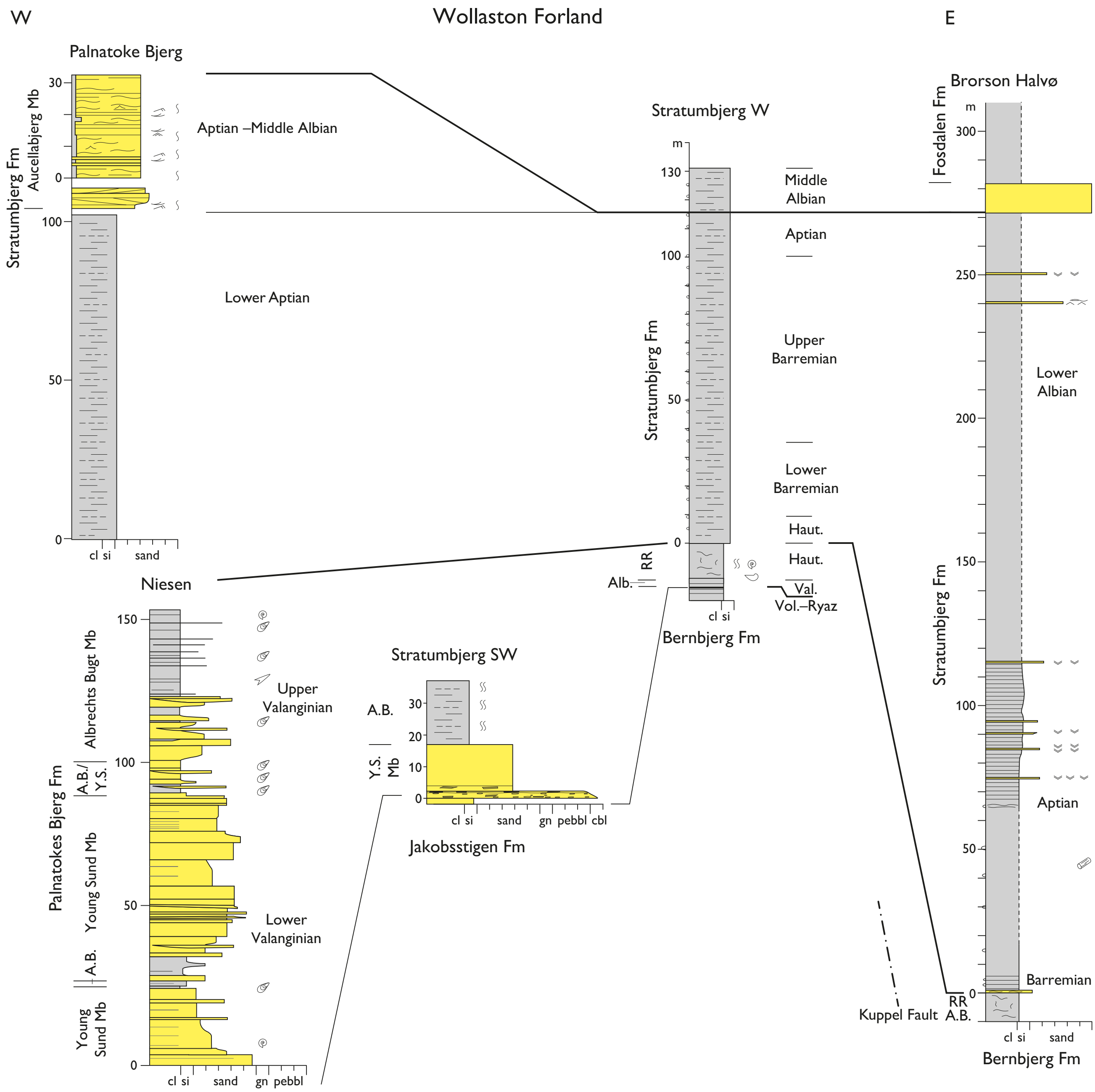


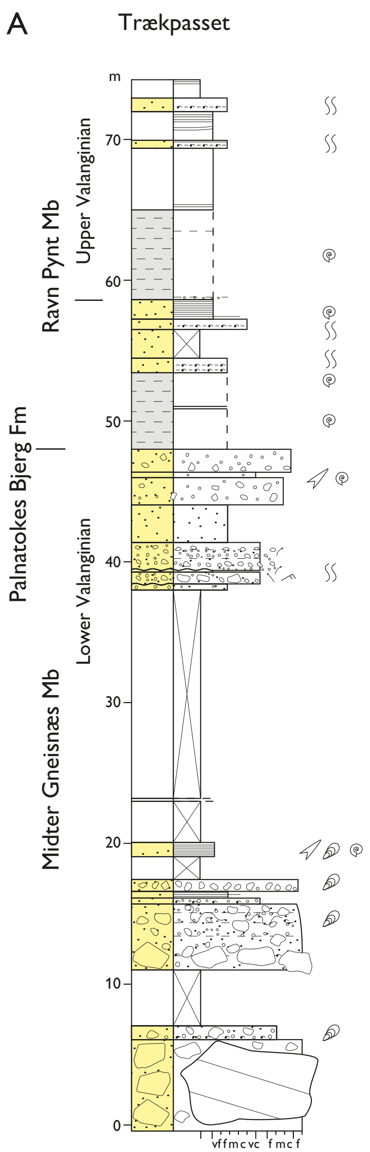
Fig. 8. Correlation panel of sections in Palnatokes Bjerg, Stratumbjerg and Fosdalen Formations in Wollaston Forland Group. Localities shown in Fig. 4 and legend in Fig. 6.

ber are dominated by breccias and coarse (boulder, cobble, pebble) conglomerates (Figs 9–10), with subordinate fossil-rich pebble conglomerates, coarse- and medium-grained sandstones with thin pebble layers and mudstone beds. The clasts consist mainly of gneissic basement; they are subangular to subrounded in the coarse conglomerates and rounded in the well-sorted pebble conglomerates. Few sedimentary clasts of muddy fine-grained sandstones occur. At Ravn Ravine and at gully margins, where the member is about one metre thick, it consists of muddy and sandy conglomerates with abundant fossils dominated by *Buchia* bivalves (Figs 11–12).

Fossils. Buchiid bivalves, cylindroteuthid belemnites and polyptychitid ammonites are common in certain intervals. Dinoflagellate cysts are very rare.

Depositional environment. The coarse-grained sediments were deposited in submarine gullies and along

Fig. 9. A: Type section of the Midter Gneisnæs Member (Palnatokes Bjerg Formation) at Trækpasset on Store Koldewey. **B:** Reference section of the Midter Gneisnæs Member (Palnatokes Bjerg Formation), unconformably overlain by sandstones of the Sortekløft Member (Stratumbjerg Formation). Legend in Fig. 6.



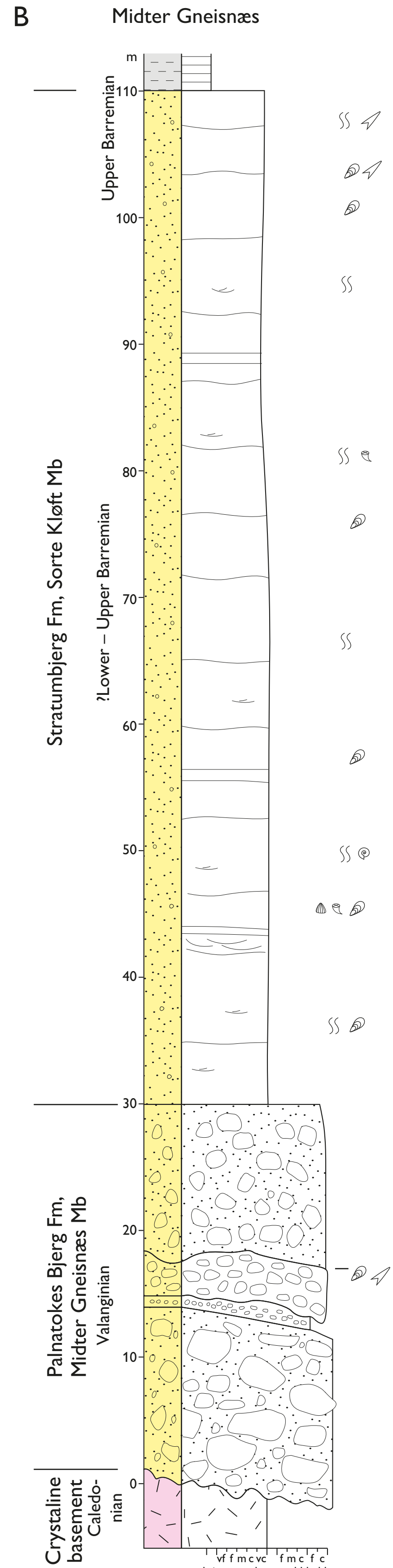


Fig. 10. A: Submarine fault-scarp breccias and conglomerates of the Midter Gneisnæs Member (Palnatokes Bjerg Formation), type section at Midter Gneisnæs, Store Koldewey. Location shown in Fig. 1. **B:** Clast-supported conglomerates of the Midter Gneisnæs Member in the type section. Note mix of rounded and subangular clasts of mainly Caledonian gneiss.

gully margins, as well as in submarine fault-scarp attached slope aprons and fans.

Boundaries. In the southern part of Store Koldewey (Trækpasset area), the base of the member is erosionally overlying sandstones of the Middle Jurassic Pelion Formation. At Midter Gneisnæs, the nature of the basal contact with crystalline basement is uncertain – it is either an erosional surface or a fault scarp. At Ravn Ravine the boundary is erosional in crystalline basement. The member is overlain conformably or erosionally by upper Valanginian, Hauterivian or lower Barremian mudstones and sandstones of the Ravn Pynt Member.

Distribution. The Midter Gneisnæs Member is known primarily from the southern part of Store Koldewey but may be present more widely on Store Koldewey as a thin conglomeratic veneer.

Chronostratigraphy. The lower, poorly fossiliferous part of the member is poorly constrained. The middle and upper levels of the member are assigned to the uppermost Ryazanian – upper Valanginian based on ammonites, belemnites, bivalves, dinoflagellate cysts and nannofossils.

Ravn Pynt Member

New member

History. This new member forms the upper part of the Palnatokes Bjerg Formation on Store Koldewey. It correlates in part biostratigraphically with the Diener Bjerg Member of the Steensby Bjerg Formation on the northern coast of Hold with Hope (Kelly *et al.* 1998), and with the lower part of the Stratumbjerg Formation in Wollaston Forland.

Name. After Ravn Pynt, a small coastal point in the southern part of Store Koldewey, named after the Danish palaeontologist J.P.J. Ravn, who described the first fossils recovered from Store Koldewey.

Type section. Ravn Pynt on Store Koldewey, showing the upper part of the unit (76.153990°N, 18.5521°W, Fig. 13).

Reference sections. Ravn Ravine on Store Koldewey (Figs 11, 12).

Thickness. The member ranges in thickness from 10 m to 100 m, the variation reflecting different settings on the slope, including slope channels.

Lithology. Bioturbated, grey, silty and sandy mudstones with thin, mainly fine-grained bioturbated sandstone beds that locally show parallel lamination and ripple cross laminations. Common trace fossils include *Zoophycos, Nereites, Diplocraterion, Palaeophycus* and rare *Paleodictyon*.

Fossils. Bivalves, including large inoceramids, and hibolitid and cylindroteuthid *Pachyteuthis* and *Acroteuthis* belemnites are common whilst ammonites are rare; wood fragments and dinoflagellate cysts are common. The dinoflagellate cyst flora is characterised by the presence of *Oligosphaeridium complex*, the FO (first occurrence) of *Boreocysta isfjordica* and *Nelchinopsis kostromiensis* indicating the upper Valanginian, the FO of *Batioladinium longicornutum* indicating the lower Hauterivian, the FO and LO (last occurrence) of *Pseudoceratium anaphrissum* indicating the upper Hauterivian and top lower Barremian respectively, and the FO of *Pseudoceratium toveae* at the base of the upper Barremian (Nøhr-Hansen *et al.* 2019).

Depositional environment. The member represents deep-water slope and slope gully environments.

Boundaries. The lower boundary is placed at an abrupt facies change where bioturbated sandy mudstones overlie conglomerates or sandstones of the Midter Gneisnæs Member. The upper boundary is more variable but is commonly an erosional surface. At the type section burrowed fine-grained sandstones of the Ravn Pynt Member are erosionally overlain by a pebbly mudstone and sandstones or sandy mudstones of the Stratumbjerg Formation (Fig. 13). At Ravn Ravine dark grey mudstones of the Stratumbjerg Formation sharply overlie bioturbated sandy mudstone and sandstone of the Ravn Pynt Member (Fig. 12).

Distribution. This member of the Palnatokes Bjerg Formation is recognised only on Store Koldewey.

Chronostratigraphy. The member is referred to the Valanginian – lower Barremian, based on ammonites, belemnites, and bivalves. Palynological data indicate the Valanginian – lower upper Barremian (NEG Cr2 I 1, I 2, and lower part of I 3 palynostratigraphic zones of Nøhr-Hansen *et al.* 2019).

Hold with Hope Supergroup

Elevated and revised supergroup

History. The Hold with Hope Group was erected by Kelly *et al.* (1998) for the lower Barremian – upper Santonian succession on Hold with Hope. It is here

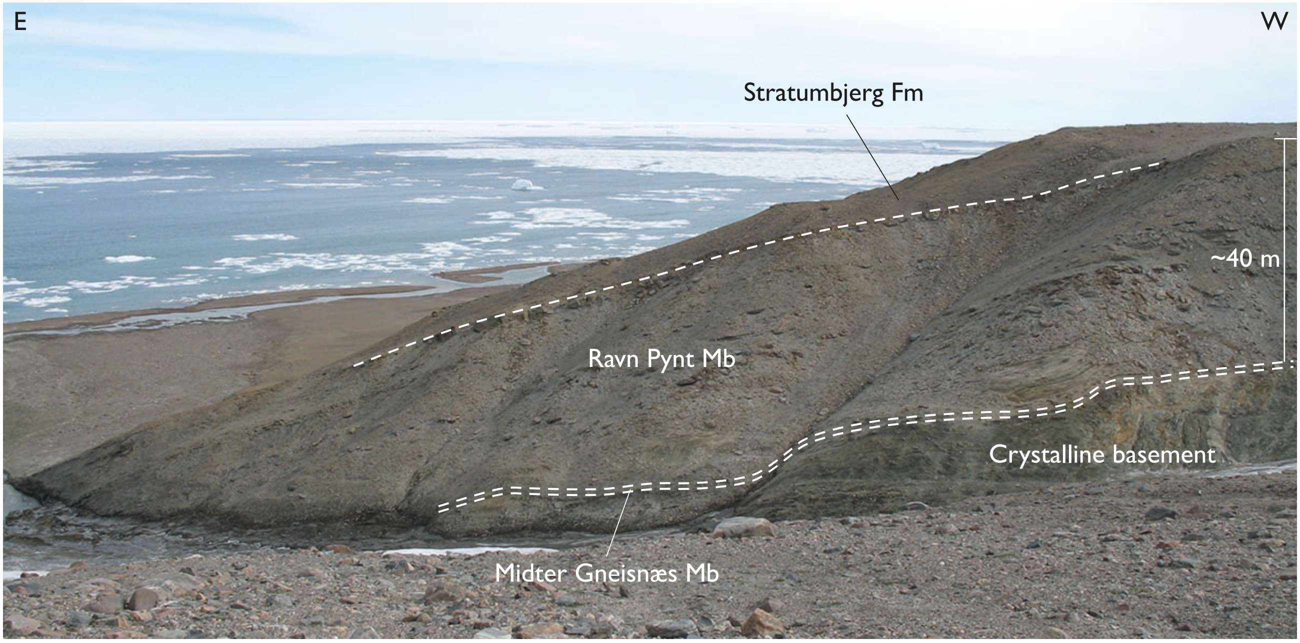


Fig. 11. Ravn Ravine on Store Koldewey. Caledonian crystalline basement overlain by a 1 m thick conglomerate of the Midter Gneisnæs Member and grey mudstone-dominated Ravn Pynt Member (Palnatokes Bjerg Formation), overlain again by dark grey mudstones of the Stratumbjerg Formation.

elevated to supergroup rank and represents the uppermost Hauterivian–Maastrichtian. It is distributed from Traill Ø in the south to Store Koldewey in the north.

Name. After the peninsula Hold with Hope (Fig. 3) where Cretaceous strata are particularly well developed (Kelly *et al.* 1998).

Type area. Northern and eastern part of Hold with Hope (Fig. 3).

Thickness. A combined thickness of more than 1300 m was estimated from several separate sections on Hold with Hope (Kelly *et al.* 1998). A maximum thickness in excess of 3 km is estimated for the Traill Ø area although this includes a contribution by Paleogene intrusions of up to 40 % (Parsons *et al.* 2017).

Lithology. The supergroup is dominated by marine mudstones with local prominent shallow marine to deltaic sandstones, fan delta to submarine fan sandstones and conglomerates and slope to basin-floor sandstones at various stratigraphic levels (Fig. 5).

Boundaries. The lower boundary of the supergroup is diachronous in the region, conformably or erosionally overlying mudstones of the Palnatokes Bjerg Formation or erosionally overlying older Jurassic or Triassic deposits (e.g. at Hold with Hope). The upper boundary is a major unconformity, where the Cretaceous succession is overlain by Paleocene silliciclastics and associated plateau lavas. In many places the top of the supergroup is defined by the Quaternary erosion surface.

Chronostratigraphy. The stratigraphic range is from the upper Hauterivian to the lower Maastrichtian. The age of the lowermost strata ranges from late Hauterivian in parts of Wollaston Forland, trough early Barremian in the Traill Ø – Hold with Hope region to late Barremian on Store Koldewey (Fig. 5).

Subdivision. The supergroup comprises the new Brorson Halvø Group, the revised and elevated Home Forland Group and the new Jackson Ø Group.

Key reference. Kelly *et al.* (1998).

Brorson Halvø Group

New group

History. The group comprises the lower part of the "Mid Cretaceous sandy shale sequence" of Nøhr-Hansen (1993). It includes the revised sand-dominated Steensby Bjerg Formation of Kelly *et al.* (1998) and the

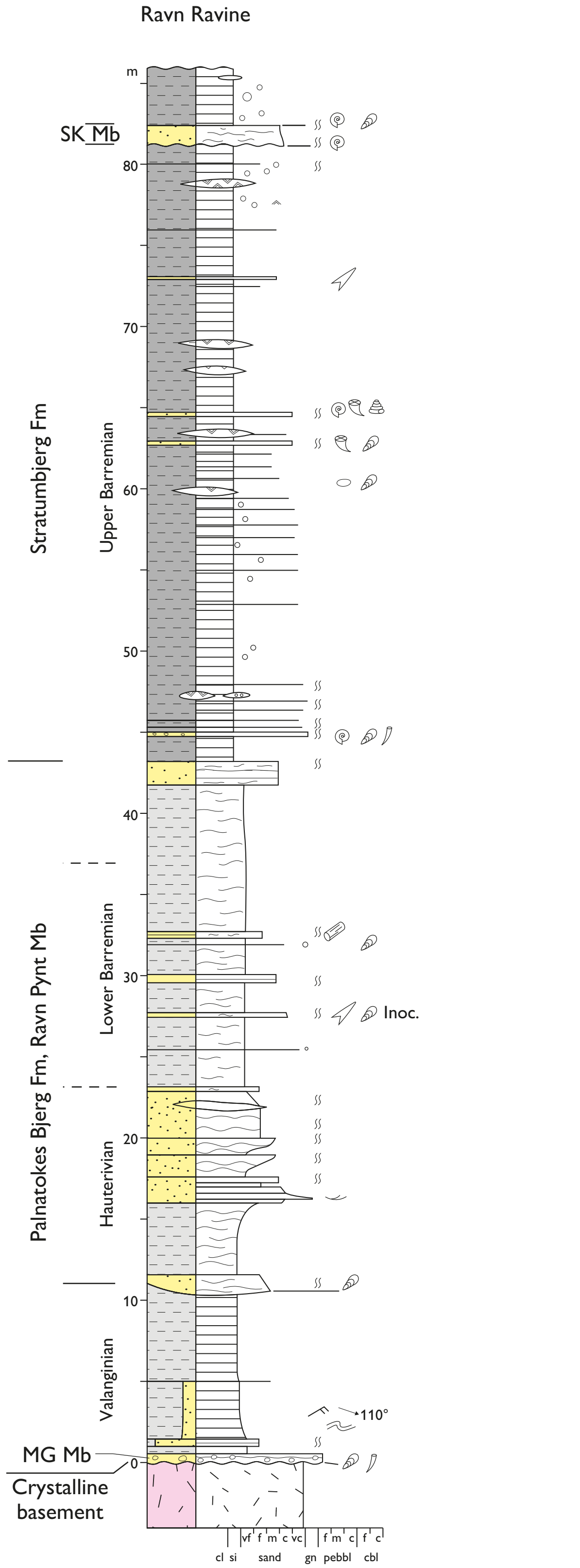


Fig. 12. Reference section of the Midter Gneisnæs Member (MG Mb), Ravn Pynt Member (Palnatokes Bjerg Formation), and Stratumbjerg Formation with Sorte Kløft Member (SK Mb) at Ravn Ravine (Fig. 11), Store Koldewey. Legend in Fig. 6.

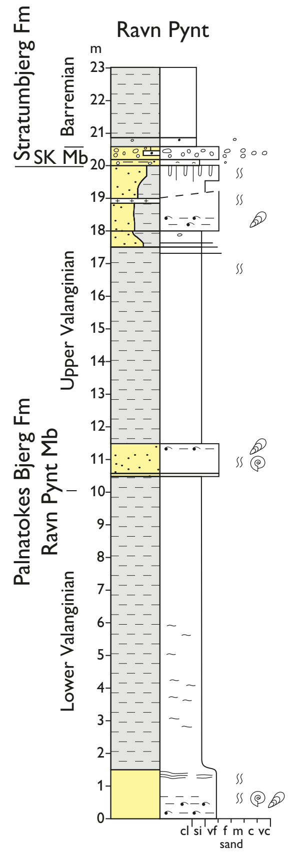


Fig. 13. Type section of the Ravn Pynt Member (Palnatokes Bjerg Formation) at Ravn Pynt, Store Koldewey. SK Mb, Sorte Kløft Member. Location shown in Fig. 1. Legend in Fig. 6.

coarse-grained Rold Bjerge Formation of Surlyk & Noe-Nygaard (2001).

Name. After the peninsula Brorson Halvø where the entire succession is present and comprises a thick, mudstone-dominated succession (Figs 3, 8).

Type area. Wollaston Forland.

Thickness. The group is about 270 m thick on Brorson Halvø. Kelly *et al.* (1998) indicated a maximum thickness of 300 m for this stratigraphic interval in central northern Hold with Hope.

Lithology. Dominated by marine mudstones and subordinate sandstones (the Stratumbjerg Formation) but includes a prominent sandstone-dominated succession (Steensby Bjerg Formation) in northern Hold with Hope. On Traill Ø, the group also locally includes coarse breccias and conglomerates (Rold Bjerge Formation). Further lithological details are given under the constituent formations.

Fossils. Ammonites, belemnites and bivalves are generally rare, but locally occur in rich assemblages.

Dinoflagellate cysts are present in the Steensby Bjerg Formation and are common in the Stratumbjerg Formation.

Depositional environment. The group represents a range of depositional settings from deep marine (basin, slope, degraded footwall slope) to shallow shelf and fluvio-deltaic environments.

Boundaries. In Wollaston Forland and on Store Koldewey, the group commonly overlies the varied facies of the upper Palnatokes Bjerg Formation; the boundary is commonly unconformable, but local conformable relationships are inferred (Fig. 5). The basal unconformity may also truncate older Mesozoic sediments (Fig. 14). The upper boundary is an erosional unconformity. In Wollaston Forland this is overlain at Brorson Halvø by a prominent sandstone bed or, elsewhere, by mudstones of the Fosdalen Formation (Fig. 8). In northern Hold with Hope, the upper boundary is an erosional unconformity separating sandy mudstones of the Rødelv Member (Stratumbjerg Formation) from the overlying mudstones of the Fosdalen Formation (Kelly *et al.* 1998; Larsen *et al.* 2001).

Distribution. The group crops out from Traill Ø in the south to Store Koldewey in the north (Figs 1-3).

Chronostratigraphy. The group is referred to the upper Hauterivian – lower Albian based mainly on dinoflagellate cysts, and more rarely on ammonites and bivalves.

Subdivisions. The group comprises the Stratumbjerg Formation (Figs 14–18), the Steensby Bjerg Formation (Figs 19–23), and the Rold Bjerge Formation (Figs 24–25).

Key references. Maync (1947, 1949); Vischer (1943); Donovan (1953, 1964); Nøhr-Hansen (1993); Kelly *et al.* (1998); Surlyk & Noe-Nygaard (2001).

Stratumbjerg Formation

New formation

History. This formation is equivalent to the lower part of the 'Middle Cretaceous shale series' of Donovan (1957) and the lower part of the 'Mid-Cretaceous sandy shale sequence' of Nøhr-Hansen (1993); it includes the Kuhnpasset Beds in Wollaston Forland (Kelly *et al.* 2000).

Name. After the mountain Stratumbjerg in Wollaston Forland (Figs 3, 14).

Type section. The type section is defined at Stratumbjerg, Wollaston Forland (74.45443°N, 20.169163°W) where the lower boundary is well exposed (Figs 8, 14–15).

Reference sections. Regionally, the formation is defined by a series of reference sections: Rold Bjerge, Månedal, Mols Bjerge and Polyptychiteselv on Traill Ø (Figs 24, 25), Djævlekløften on Clavering Ø (Fig. 26), Palnatoke Bjerg and Brorson Halvø in Wollaston Forland (Fig. 8) and Ravn Ravine on Store Koldewey (Fig. 12).

Thickness. The formation is 115 m thick at the type section but is variable in thickness regionally: 270 m in Brorson Halvø, 50 m in Djævlekløften, up to 140 m in Månedal and 120 m on Store Koldewey.

Lithology. The formation is dominated by bioturbated and laminated, dark grey to grey, silty and sandy mudstones with common siderite concretions; subordinate thin sandstone stringers and beds are present in some sections (Fig. 15). Sand-rich intervals are developed in the formation locally and are represented by the Aucellabjerg, Rødelv and Sorte Kløft Members. The Aucellabjerg Member has thin, fossil-rich, medium- to coarse-grained pebbly sandstone beds (Wollaston Forland, Figs 17–18). The Rødelv Member has bioturbated sandy mudstones coarsening locally into cross-bedded sandstones (northern Hold with Hope, Fig. 19). The Sorte Kløft Member has bioturbated sandy mudstones, muddy, fine- to medium-grained sandstones and pebbly sandstones (Store Koldewey, Fig. 16). Argillaceous carbonates are also recorded in the formation locally (the Kuhnpasset Beds of Kelly *et al.* (2000)). Trace fossils include *Ophiomorpha rudis* and *Paleodictyon* in sandier facies near the base of the formation, while *Gyrochorte, Chondrites, Nereites* and *Zoophycos* are typical forms in the mud-dominated sediments.

Fossils. Inoceramid bivalves and wood fragments are common. Ammonites, belemnites and nautilids are generally rare but locally abundant. The lowermost part of the formation contains a rich hibolitid-cylindroteuthid belemnite fauna in southern Brorson Halvø. Ammonites include large-sized Barremian–Aptian heteromorph crioceratids and gaudryceratids and lower Albian hoplitinid ammonites of the genus *Arcthoplites* (Donovan 1953). The mud-rich facies commonly yield dinoflagellate cysts. The dinoflagellate cyst flora is characterised by the following events: the FO and LO of *Batioladinium longicornutum* indicating the lower Hauterivian and top upper Barremian respectively; the FO and LO of *Pseudoceratium an-*

aphrissum indicating the upper Hauterivian and top lower Barremian respectively; the FO of *Pseudoceratium toveae* indicating the base of the upper Barremian; the FO of *Circulodinium brevispinosum* indicating the upper lower Aptian; the FO of *Pseudoceratium distinctum, Vesperopsis mayi*, *Leptodinium cancellatum* indicating the lower upper Aptian; the FO of *Canningia reticulata, Senoniasphaera microreticulata* indicating the upper upper Aptian; the FO of *Hapsocysta benteae* indicating the base of the lower Albian; and the FO of *Chichauouadinium vestitum* and *Rhombodella paucispina* indicating the base of the middle Albian (Nøhr-Hansen *et al.* 2019).

A rich invertebrate fauna has been recorded from seep-mound-forming carbonates of the Kuhnpasset Beds, including large-sized bivalves, a diverse ammonite fauna with *Lytoceras, Sanmartinoceras* and heteromorphs (Kelly *et al.* 2000).

Depositional environment. This mud-rich marine succession shows regional variation in facies but was predominantly deposited in slope and basin-floor settings. It locally records passive infill of submarine gullies and shallow marine deposition. In northern Hold with Hope, the formation represents lower shoreface – prodelta deposition.

Boundaries. At the type locality, the lower boundary is placed at a hiatal surface corresponding to a marked drowning surface overlying the Palnatokes Bjerg Formation or older Jurassic sediments. The boundary is thus defined at the shift from red mudstones of the Rødryggen Member to very dark grey mudstones (Fig. 8). Laterally at Stratumbjerg, the boundary is unconformably eroded into black mudstones of the Bernbjerg Formation (Fig. 14). On Store Koldewey, the basal sediments are younger than in the type area and the lower boundary is placed where grey biomottled sandy mudstones of the Palnatokes Bjerg Formation are erosionally overlain by a distinct sandstone unit commonly rich in fossils (*e.g.* at Ravn Pynt) succeeded by dark grey mudstones. Elsewhere on Store Koldewey (*e.g.* at Ravn Ravine), the boundary is marked by a prominent drowning surface where biomottled muddy sandstones are sharply overlain by very dark mudstones. In northern Hold with Hope, this surface may be strewn with outsized pebble or cobble clasts. Generally, in Wollaston Forland and farther south, the formation is unconformably overlain, in places with angular discordance, by Albian mudstones, sandstones or conglomerates of the Home Forland Group. On Store Koldewey, however, the formation forms the uppermost Cretaceous unit, being erosionally overlain by Pleistocene light grey mud and fine-grained sand.

Distribution. The formation crops out from Traill Ø in the south to Store Koldewey in the north (Figs 1–3).

Subdivision. The formation includes the Rødelv Member in northern Hold with Hope and two new members, the Sorte Kløft Member on Store Koldewey and the Aucellabjerg Member in Wollaston Forland. The seep mound limestones of the Kuhnpasset Beds described by Kelly *et al.* (2000) are also included in the Stratumbjerg Formation.

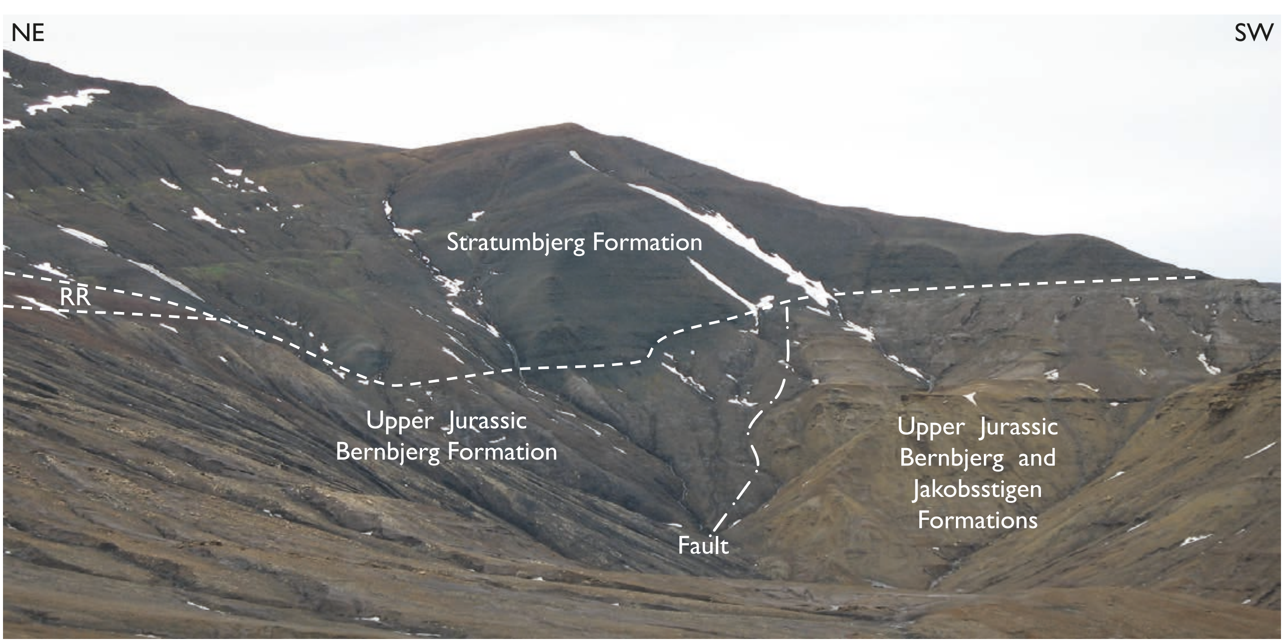


Fig. 14. Fault-associated erosional base of the Stratumbjerg Formation, type locality at Stratumbjerg, south-east Wollaston Forland. The thickness of the formation is up to about 100 m. RR: Rødryggen Member of the Palnatokes Bjerg Formation.

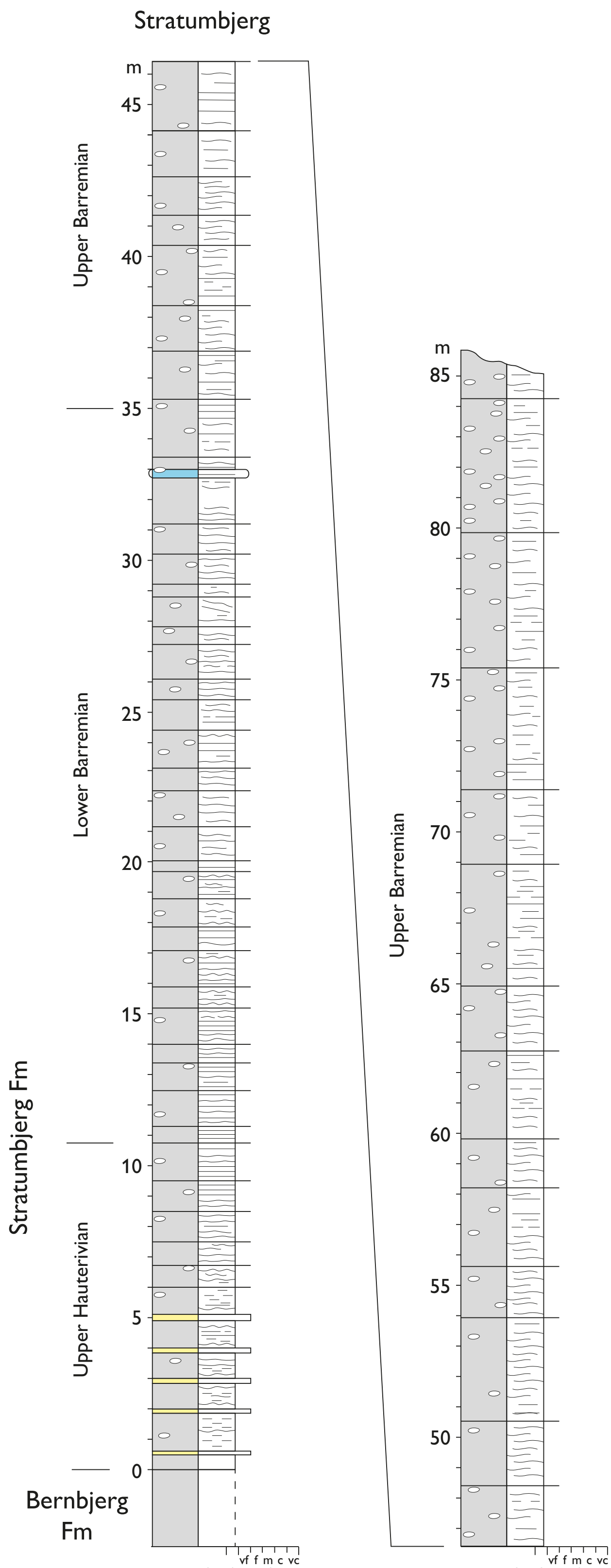


Fig. 15. Type section of the Stratumbjerg Formation, Stratumbjerg, Wollaston Forland. Legend in Fig. 6.

Chronostratigraphy. The succession is referred to the upper Hauterivian – lower middle Albian based mainly on dinoflagellate cysts, belemnites and ammonites. A Hauterivian to early Albian age is indicated based on dinoflagellate cysts (palynostratigraphic zones I 1, I 2, I 3, II, III and lower part of IV 1 of Nøhr-Hansen *et al*. 2019).

Key references. Surlyk 1978b; Nøhr-Hansen (1993); Kelly *et al.* (2000); Surlyk & Korstgaard (2013); Nøhr-Hansen *et al.* (2019).

Sorte Kløft Member

New member

Name. After the prominent gully Sorte Kløft in northern Store Koldewey (Fig. 1).

Type section. The cored section in the Store Koldewey-1 borehole drilled at Sorte Kløft on Store Koldewey is defined as the type section of the member (76.3847°N, 18.7214°W, Fig. 16). The core is available for inspection at the Geological Survey of Denmark and Greenland, Copenhagen, Denmark.

Reference section. The section at Midter Gneisnæs represents an outcropping reference section (Fig. 9B).

Thickness. The Sorte Kløft Member forms part of a series of lenticular, sand-dominated, channelised bodies oriented W–E. In the type area, in the axis of one such body, the member is up to 90 m thick at Sorte Kløft and in the Store Koldewey-1 core. It wedges out to a few metres in thickness laterally over a distance of less than 1 km towards both north and south. At Midter Gneisnæs, within a separate channel body, the member decreases in thickness from 80 m to zero within 600 m laterally to the south.

Lithology. The member is dominated by bioturbated, muddy fine- to medium-grained sandstones interbedded at some levels with subordinate pebbly sandstones and sandy mudstones (Fig. 16). The succession is light grey, grey and dark grey in core but weathers yellowish in outcrop. It is typically well developed in confined channels oriented W–E. Isolated sandstone bodies, up to a few metres thick, which occur at different levels within the Stratumbjerg Formation on Store Koldewey, are also included in the Sorte Kløft Member (Fig. 12). Characteristic trace fossils include *Rhizocorallium*, *Palaeophycus*, and *Nereites*. The cored section (type) reveals sedimentary and ichnological details that are poorly preserved in outcrop (compare Figs 9B and 16).

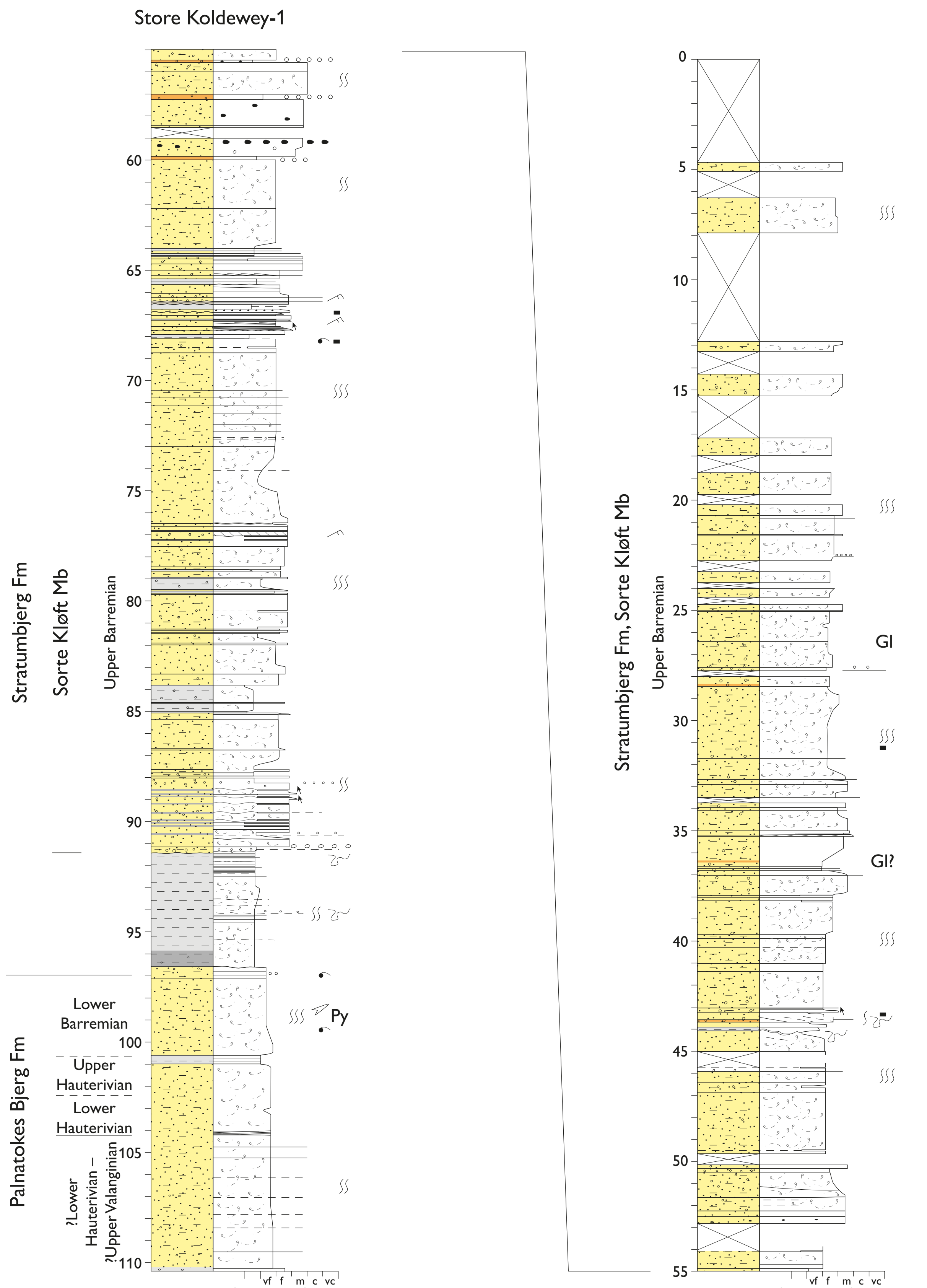


Fig. 16. Type section of the upper Barremian slope channel sandstones of the Sorte Kløft Member (Stratumbjerg Formation), type section in the Store Koldewey-1 Borehole. Legend in Fig. 6.

Fossils. The member yields a macrofauna of common bivalves, oxyteuthid belemnites and wood fragments, together with a few lytoceratid ammonites. The dinoflagellate cysts are characterised by the presence of *Batioladinium longicornutum* (with the LO indicating the top of the upper Barremian), *Pseudoceratium toveae* (with the FO indicating the base of the upper Barremian) and *Pseudoceratium* aff. *iveri* (with the FO and LO indicating the lower part of the upper Barremian; Nøhr-Hansen *et al.* 2019).

Depositional environment. The Sorte Kløft Member was mainly deposited within a series of slope channels eroded into sediments of the Palnatokes Bjerg Formation or within Stratumbjerg Formation slope mudstones.

Boundaries. In the type section (Store Koldewey-1 core), the lower boundary is placed at the erosional base of a pebbly sandstone bed that caps a 5 m thick mudstone-dominated unit forming the basal beds of the Stratumbjerg Formation (Fig. 16). Elsewhere, the member lies at the base of the Stratumbjerg Formation, overlying mudstones (north of 4. Sænkning; Fig. 1 map) or conglomerates (Midter Gneisnæs) of the Palnatokes Bjerg Formation. Isolated sandstone bodies, up to a few tens of metres thick, occur at different levels within the Stratumbjerg Formation mudstone succession. The upper boundary is placed where the bioturbated sandstone succession is abruptly overlain by upper Barremian mudstones also belonging to the Stratumbjerg Formation (Fig. 9).

Distribution. The unit is restricted to Store Koldewey where it is typically well developed in confined channels in the basal part of the Stratumbjerg Formation or as isolated sandstone bodies, up to a few tens of metres thick, that occur at different levels within the Stratumbjerg Formation (Fig. 12).

Chronostratigraphy. A late Barremian age is indicated for the Sorte Kløft Member based both on the palynology (lower part of I 3 palynostratigraphic zone of Nøhr-Hansen (1993) and Nøhr-Hansen *et al.* (2019), and the belemnites.

Key reference. Nøhr-Hansen *et al.* (2019).

Aucellabjerg Member

New member

Name. After the mountain Aucellabjerg in western Wollaston Forland (Fig. 3). The name of the mountain itself derives from the discovery of *Aucella* bivalves by Hans Frebold in the area during the "1931–34 Treårsekspeditionen" (Higgins 2010). Note that this member and the locality should not be confused with the informally named 'Aucella-conglomerate' (Ravn 1911), nor the similarly named mountain Aucellabjerget, both located on Store Koldewey.

Type section. The type section of the Aucellabjerg Member is located on the south-west slope of Palnatoke Bjerg in western Wollaston Forland (74.5510°N, 20.6219°W, Fig. 18A).

Reference section. An exposed succession, 6.5 m thick, occurs on the western slope of Aucellabjerg in western Wollaston Forland (Figs 17, 18B).

Thickness. More than 30 m is recorded in the type section; note that the true thickness at this locality cannot be estimated due to poor exposure of the lower and upper boundaries.

Lithology. The member is dominated by fine-grained sandstones and heterolithic sandstones–mudstones showing parallel stratification, current and wave ripple cross-lamination, flaser and wavy bedding and common bioturbation. Locally, fine- to medium-grained sandstones display large-scale low-angle cross-bedding and trough cross-bedding (Fig. 18B). Typical trace fossils include *Diplocraterion*, *Ophiomorpha* and *Thalassinoides.*

Fossils. The member yields common dinoflagellate cysts. The flora is characterised by the LO of *Odontochitinan nuda, Exiguisphaera plectilis* and the FO of *Vesperopsis longiconis* indicating the upper lower Aptian, the FO of *Leptodinium cancellatum* indicating the lower upper Aptian, and the FO of *Hapsocysta benteae* indicating the base of the lower Albian (Nøhr-Hansen *et al.* 2019). Ammonites are rare and *Deshayesites* was recorded by Kelly *et al.* (2000).

Depositional environment. Tidal influenced, shallow marine environment.

Boundaries. At the type section, the boundaries of the member are poorly exposed. The lower boundary is inferred to be erosive into marine dark grey mudstones internally in the Stratumbjerg Formation, but no hiatus is recorded. The lowest exposed sediments of the member consist of a bioturbated, yellowish light grey heterolithic unit dominated by fine-grained sand. The upper boundary is inferred to be conformable and is placed where faintly parallel-bedded sand-dominated heterolith is overlain by dark grey marine mudstones of the Stratumbjerg Formation.

Distribution. The unit is restricted to the western part of Wollaston Forland.

Chronostratigraphy. The member straddles the lower to upper Aptian boundary and extends into the lower Albian, palynostratigraphic zones II and III of Nøhr-Hansen (1993) and Nøhr-Hansen *et al.* (2019).

Rødelv Member

Revised member

History. The Rødelv Member was defined by Kelly *et al.* (1998) as the uppermost member of the Steensby Bjerg Formation. The unit, which is dominated by mudstones, contrasts markedly with the sandstone-dominated Steensby Bjerg Formation and is thus re-assigned here to the Stratumbjerg Formation.

Type section. Kelly *et al.* (1998) defined the type section of the Rødelv Member about 4 km east of Steensby Bjerg, northern Hold with Hope.

Thickness. The member is 58 m thick at the type section (Kelly *et al.* 1998), increasing eastwards to about 140 m thick at Steensby Bjerg. It is only 16 m thick in south-west Gulelv (Fig. 19).

Lithology. The member is characterised by bioturbated micaceous silty or sandy mudstones with common oval and spherical siderite concretions. Between eastern Steensby Bjerg and Diener Bjerg, the lower levels of the member in places include a coarsening upward unit 5–10 m thick that grades upwards from bioturbated sandy mudstone to muddy fine-grained sandstone with discrete medium-grained sandstone beds, 5–20 cm thick, that locally show small-scale pla-

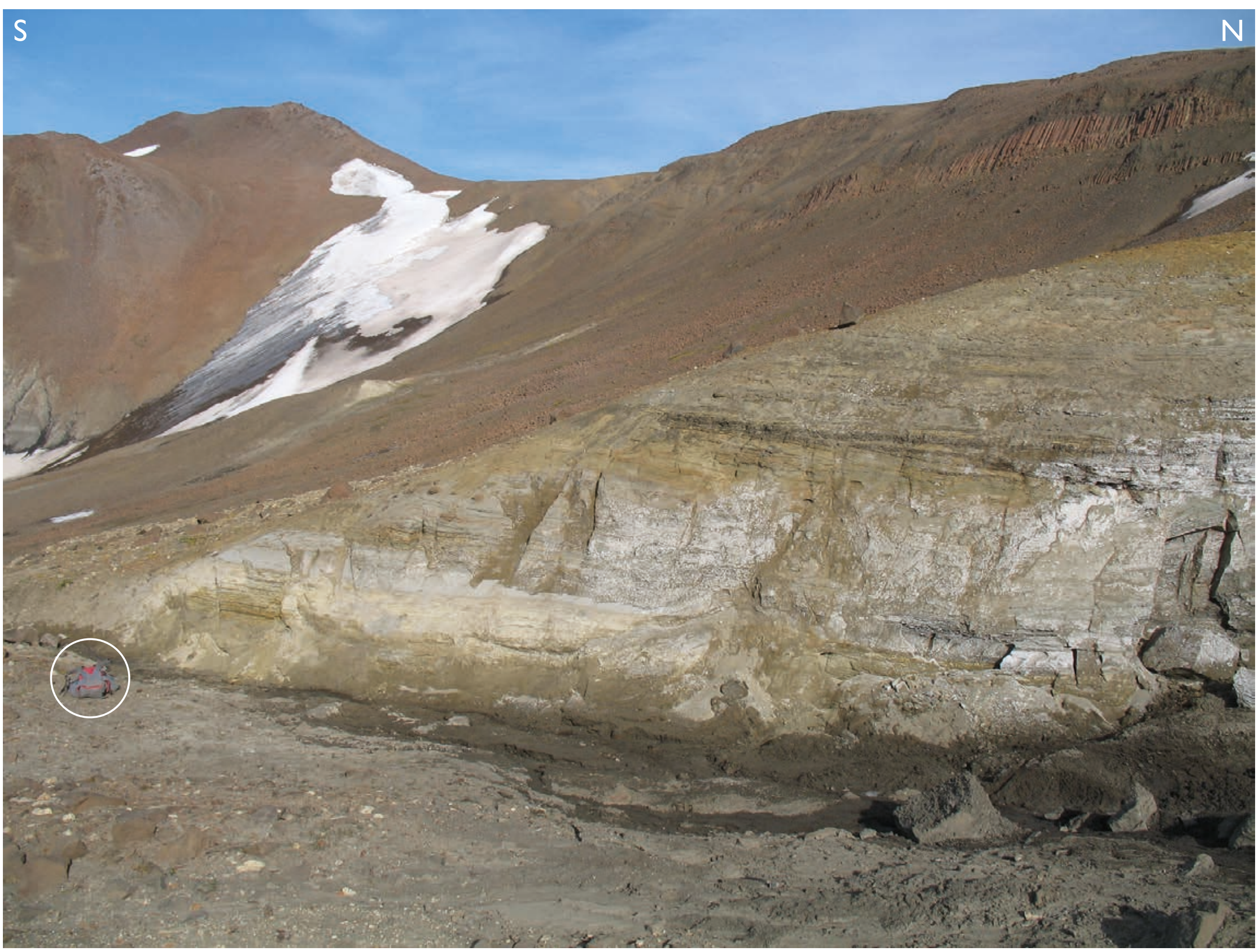


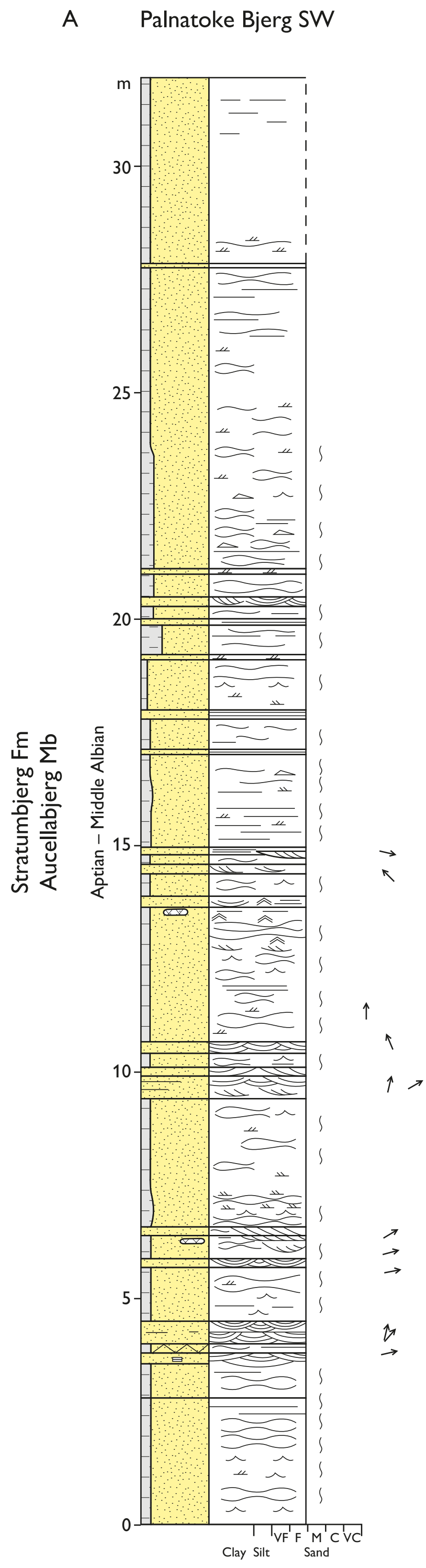
Fig. 17. Shallow marine sandstones of the Aucellabjerg Member (Stratumbjerg Formation) in the reference section at Palnatoke Bjerg/Aucellabjerg, north-west Wollaston Forland. The exposure is 5-6 m thick. (encircled bag for scale beside creek in front of exposure).

nar cross-bedding. Characteristic trace fossils include *Helminthopsis*, *Chondrites* and *Nereites*.

Fossils. Recorded macrofossils include *Deshayesites* ammonites and inoceramid bivalves (Kelly *et al*. 1998; Kelly & Whitham 1999). The member yields common dinoflagellate cysts. The flora is characterised by the following events: the FO of *Circulodinium brevispinosum* indicating the upper lower Aptian; the FO of *Pseudoceratium distinctum, Vesperopsis mayi, Leptodinium cancellatum* indicating the lower upper Aptian; the FO of *Senoniasphaera microreticulata* indicating the upper upper Aptian; the FO of *Hapsocysta benteae* at the base of lower Albian; and the FO of *Rhombodella paucispina* indicative of the base of the middle Albian (Nøhr-Hansen *et al*. 2019).

Depositional environment. The succession records the transition from the sandy deltaic facies of the Steensby Bjerg Formation to the marine shelf, and probably represents distal mouth bar – prodelta and lower shoreface – proximal shelf settings. The Rødelv Member thus represents a more proximal marine, mud-dominated facies belt than much of the deeper-water Stratumbjerg Formation mudstones.

Boundaries. The Rødelv Member conformably overlies the Gulelv Member of the Steensby Bjerg Formation (Fig. 19). The boundary is placed where dark, bioturbated mudstones abruptly overlie bioturbated, medium- to coarse-grained sandstones; a pebble or cobble lag may be present immediately above the boundary. The upper boundary of the Rødelv Member is an unconformity at the base of the Fosdalen Formation (Home Forland Group). This unconformity cuts down towards the east so that the Rødelv Member is less than 10 m thick in the easternmost sections at Diener Bjerg (Kelly *et al*. 1998). Thin developments of the Rødelv Member beneath the unconformity are also observed in its south-western outcrop (Fig. 19).



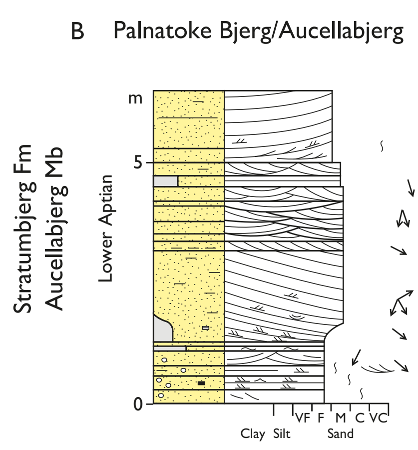


Fig. 18. A: Type section of the shallow marine sandstones of the Aucellabjerg Member (Stratumbjerg Formation) at Palnatoke Bjerg, north-west Wollaston Forland. **B:** Reference section shown in Fig. 17. Legend in Fig. 6.

Distribution. The member is restricted to the area from Diener Bjerg and westwards as far as Stensiö Plateau in the northern part of Hold with Hope.

Chronostratigraphy. The Rødelv Member is referred to the lower Aptian – lowermost middle Albian based on ammonites, belemnites and dinoflagellate cysts (palynostratigraphic zones III 1–4 and IV 1 of Nøhr-Hansen (1993) and Nøhr-Hansen *et al.* (2019)). The lower boundary of the member towards the Gulelv Member of the Steensby Bjerg Formation is diachronous, younging westwards so that the boundary lies within the lower Aptian east of Steensby Bjerg but in the lowermost Albian in the west at Stensïo Plateau.

Key references. Kelly *et al.* (1998); Larsen *et al.* (2001); Nøhr-Hansen *et al.* (2019).

Steensby Bjerg Formation

Revised formation

History. The formation was erected from central northern Hold with Hope by Kelly *et al.* (1998), and historical references to this succession are given by these authors. It is here revised to restrict the Steensby Bjerg Formation to the sandstone-dominated Lower Cretaceous deposits in this area (Fig. 20). Hence, the mudstone-dominated Rødelv Member of Kelly *et al.* (1998) that caps the sand-rich succession is here re-assigned to the new Stratumbjerg Formation (Figs 4, 19).

Type area and section. Kelly *et al.* (1998) defined a type area and composite type section from subsections at four localities in the Steensby Bjerg area (northern

Fig. 19. Shallow marine sandstones of the Gulelv Member (Steensby Bjerg Formation) conformably overlain by offshore sandy mudstones of the Rødelv Member (Stratumbjerg Formation). An unconformity with a slight angular discordance occurs between the Rødelv Member and the overlying slope mudstones of the Fosdalen Formation. Section south-west of Gulelv in northern Hold with Hope. Encircled person for scale.

Hold with Hope) which include the type sections of the individual members.

Reference sections. A number of sections through the Steensby Bjerg Formation are presented in Kelly *et al.* (1998) and Larsen *et al.* (2001); additional sections are presented here under the individual members.

Thickness. The formation is about 170 m thick at Steensby Bjerg, thinning eastward to 82 m at Diener Bjerg. In the western outcrop area (Stensiö Plateau), the formation is *c.* 150 m thick.

Lithology. The formation is dominated by medium- to very coarse-grained sandstones with subordinate pebbly sandstones and conglomerates. Discrete units of fine- to very fine-grained muddy sandstone and sandy mudstone occur scattered. Further lithological descriptions are included under the component members.

Fossils. Much of the Steensby Bjerg Formation is unfossiliferous but macrofossils (ammonites, belemnites, bivalves and plant fragments) and dinoflagellate cysts are present locally, particularly in the muddier facies (Diener Bjerg Member, upper Gulelv Member, Stensiö Plateau Member).

Depositional environment. Shoreface, delta top (fluvial and tidally influenced estuarine), delta front and prodelta facies associations are recognised in the formation (Fig. 20, Larsen *et al.* 2001).

Boundaries. The Steensby Bjerg Formation unconformably overlies Middle–Upper Jurassic or Triassic strata that define SW-dipping fault blocks beneath the flat unconformity surface (Fig. 20). A thin (<1 m) conglomerate or pebbly sandstone bed typically marks the base of the formation. The upper boundary is conformable and overlain by the Stratumbjerg Formation (Rødelv Member). In vertical section, the boundary is characteristically abrupt and placed at the base of dark bioturbated sandy mudstones overlying a pebble lag atop bioturbated or cross-bedded medium- to coarse-grained sandstones. Laterally, the boundary is diachronous, the sand-rich upper Steensby Bjerg Formation interdigitating eastwards with mud-rich Stratumbjerg Formation strata; the boundary thus rises stratigraphically westwards (Kelly *et al.* 1998).

Distribution. The Steensby Bjerg Formation is known only from northern Hold with Hope. It is recognised from Diener Bjerg in the east to Stensiö Plateau in the west, a distance of about 15 km, and southwards for about 12 km in Gulelv (Fig. 3).

Subdivision. With the re-assignment of the Rødelv Member to the Stratumbjerg Formation, the Steensby Bjerg Formation as recognised here is composed of five members: the Diener Bjerg, Gulelv, Stribedal, Blåelv and Stensiö Plateau Members (Figs 4, 5).

Chronostratigraphy. The formation is assigned to the lower Barremian – lowermost Albian based mainly on dinoflagellate cysts and few macrofossils of bivalves, ammonites and belemnites. The diachronous nature of the Steensby Bjerg – Stratumbjerg formation boundary results in a more restricted age range in the east (early Barremian – earliest Aptian at Diener Bjerg) than in the west (early Barremian – latest Aptian/earliest Albian at Stensiö Plateau).

Key references. Kelly *et al.* (1998); Whitham *et al.* (1999); Larsen *et al.* (2001).

Stribedal Member

History. The member was erected in a small valley of Stribedal in the Stensiö Plateau area of northern Hold with Hope by Kelly *et al.* (1998).

Type section. Kelly *et al.* (1998) defined the type section on the north-western side of Stensiö Plateau, Hold with Hope.

Reference section. The reference section illustrated here is located a few hundred metres north-west of the type section (Fig. 21A).

Thickness. The member is 19 m thick in the reference section (Fig. 21A); elsewhere in Hold with Hope it varies between 10 and 40 m with a general thinning towards the west.

Lithology. Pale-coloured buff to yellow-brown sandstones and pebbly sandstones are interbedded locally with lenticular pebble conglomerate beds. Fine- to medium-grained sandstones show hummocky and swaley cross-stratification, whereas coarse-grained pebbly sandstones and conglomerates commonly display trough cross-bedding. Thin micaceous mudstones locally drape scours. Bioturbation is common in the sandstone intervals. Trace fossils are common, *Curvolithus multiplex* being particularly characteristic.

Fossils. No macrofossils have been recorded, but dinoflagellate cysts are present.

Depositional environment. The Stribedal Member was deposited in the middle–upper shoreface on a high-energy, wave and storm-dominated coastline.

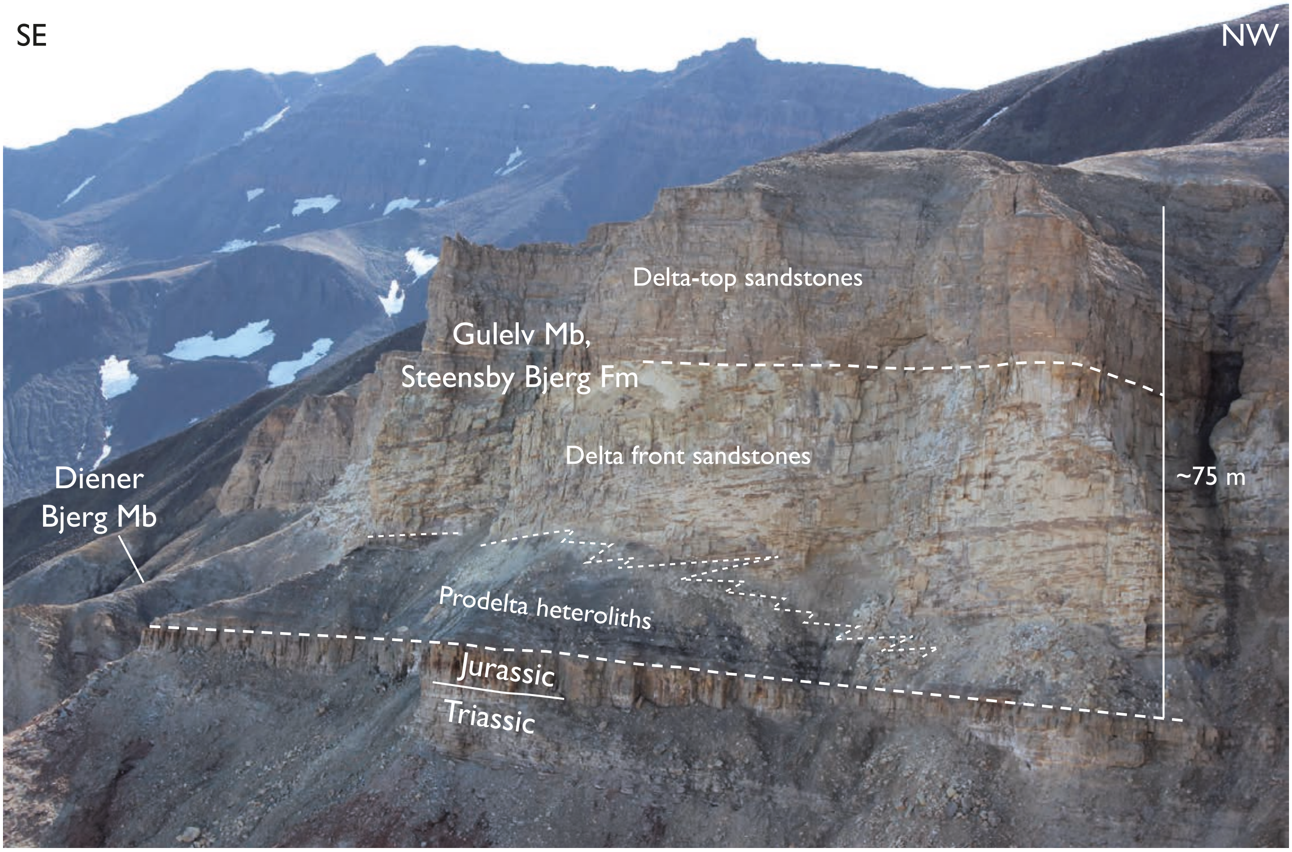


Fig. 20. Overview of the deltaic sandstones of the Steensby Bjerg Formation at Steensby Bjerg, north coast of Hold with Hope.

Boundaries. The member forms the base of the Steensby Bjerg Formation at Stensiö Plateau, unconformably overlying Jurassic strata. A conglomerate bed up to 30 cm thick typically defines the base of the member. The upper boundary is a strongly erosional surface with local relief of several metres and maximum relief of about 20 m along the cliff section; this surface is overlain by pebbly sandstones of the Blåelv Member (Fig. 22).

Distribution. The member is limited to a section 2 km long on the northern flank of Stensiö Plateau, Hold with Hope.

Chronostratigraphy. The member is referred to the Barremian based on dinoflagellate cysts (Kelly *et al.* 1998; Nøhr-Hansen *et al.* 2019).

Key references. Kelly *et al.* (1998); Larsen *et al.* (2001).

Diener Bjerg Member

History. The Diener Bjerg member was erected in the eastern outcrops of the Steensby Bjerg Formation in northern Hold with Hope by Kelly *et al.* (1998).
Type section. Kelly *et al.* (1998) defined the type section on north-eastern Diener Bjerg, Hold with Hope.

Reference sections. The type section is relatively poorly exposed and a reference section is illustrated here from eastern Steensby Bjerg, about 2.5 km west of the type section (Fig. 21B).

Thickness. Kelly *et al.* (1998) measured 23.5 m at the type section. The member thins westwards and is about 15 m thick between Diener Bjerg and eastern Steensby Bjerg (Fig. 21B), where it wedges out westward within the lower Gulelv Member of the Steensby Bjerg Formation (Fig. 20).

Lithology. A pebbly sandstone bed (< 1 m thick; Kelly *et al*. 1998) at the base is overlain by grey to dark grey, heavily bioturbated sandy mudstones and muddy fine- or very fine-grained sandstones. The succession coarsens upward and grades upwards and laterally westwards into clinoform-bedded delta front sandstones of the Gulelv Member (Fig. 20).

Fossils. Few ammonites and gastropods occur. A reworked macrofauna of Hauterivian hibolitid and cylindroteuthid Hauterivian belemnites and bivalves is recorded (Kelly *et al.* 1998). Dinoflagellate cysts are common and are characterised by the FO of *Muderongia simplex microperforata* indicating the

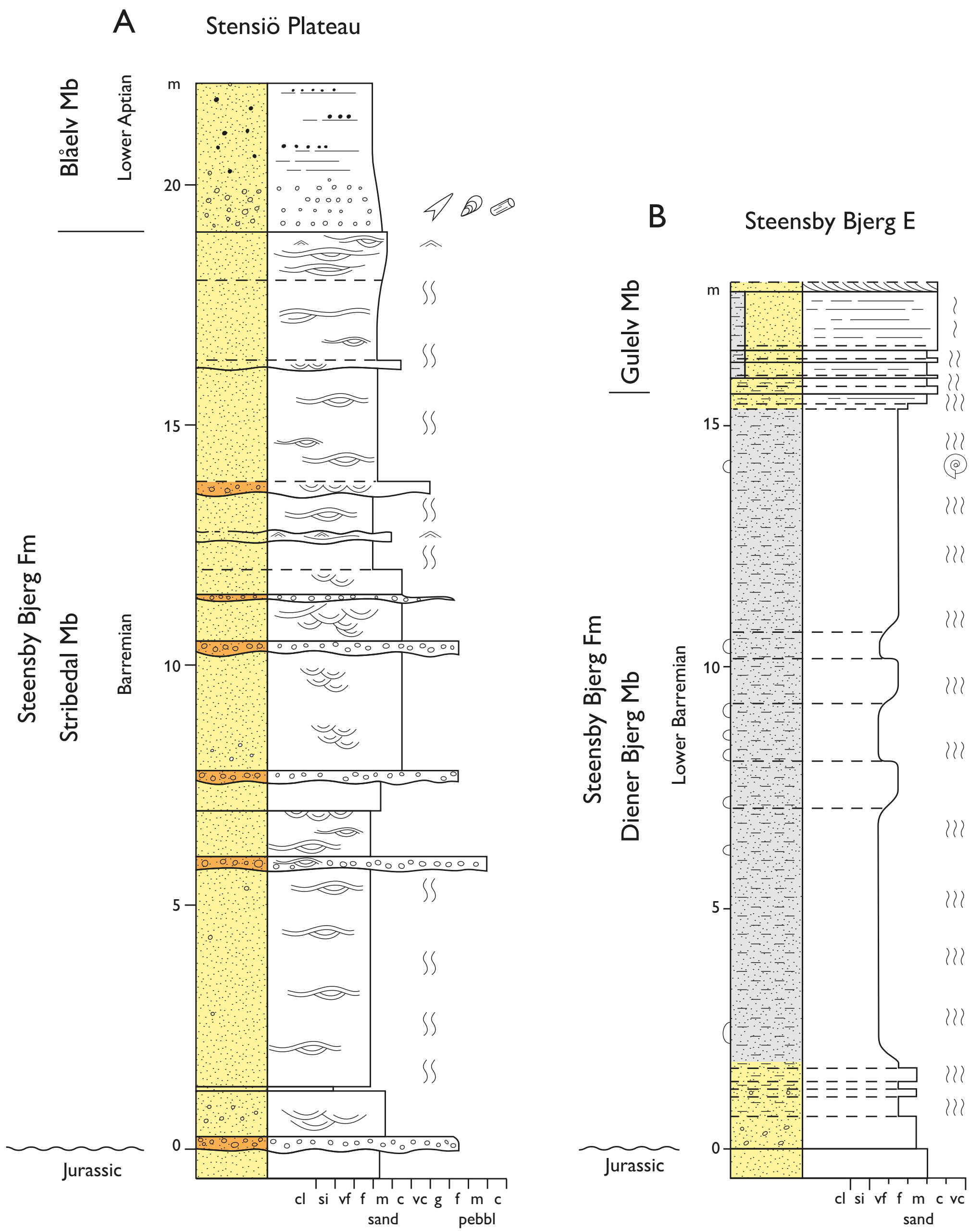


Fig. 21. A: Reference section of the Stribedal Member (Steensby Bjerg Formation) showing shoreface sandstones at Stensiö Plateau, Hold with Hope. **B:** Reference section of the Diener Bjerg Member (Steensby Bjerg Formation) showing prodeltaic mudstones and sandstones, at Steensby Bjerg, Hold with Hope.

lower Barremian and by the LO of *Pseudoceratium anaphrissum* indicating the top of the lower Barremian (Nøhr-Hansen *et al.* 2019).

Depositional environment. Marine prodelta environment, forming the toesets of a south and south-eastward prograding Gilbert-type delta represented by the Gulelv Member.

Boundaries. In the area of the type section, the member forms the basal unit of the Steensby Bjerg Formation, unconformably overlying Middle Jurassic sandstones of the Pelion Formation; westwards, close to the pinch-out of the member, it conformably overlies the lowermost tongue of Gulvelv Member sandstones (Fig. 5). The upper boundary to the Gulvelv Member is also gradational and the member interfingers laterally with the clinoform-bedded Gulelv Member towards the west (Fig. 21B).

Distribution. The Diener Member has a limited outcrop area. It is best developed in the Diener Bjerg area, extending westwards about 3 km as far as to the steep cliffs of eastern Steensby Bjerg where it pinches out in the lowermost Gulelv Member.

Chronostratigraphy. The member is assigned to the lower Barremian based on dinoflagellate cysts (I 2 Subzone; Nøhr-Hansen 1993; Nøhr-Hansen *et al*. 2019) and macrofossils (Kelly *et al.* 1998; Larsen *et al.* 2001).

Key references. Kelly *et al.* (1998); Larsen *et al.* (2001).

Blåelv Member

History. The Blåelv Member was erected from the Stensiö Plateau area of northern Hold with Hope by Kelly *et al.* (1998).

Type section. Kelly *et al*. (1998) defined the type section on the north-western flank of Stensiö Plateau, Hold with Hope.

Reference section. A reference section located a few hundred metres north-west of the type section is presented here (Fig. 22).

Thickness. Kelly *et al.* (1998) indicated a thickness range of 9.8–26.5 m (19.5 m in the type section). The top of the formation is essentially flat, based on photogrammetric observations, whereas the base is a highly irregular, locally deeply scoured erosion surface. The member is broadly wedge-shaped, however, thinning from 15-25 m thick in the west to *c.* 5 m in the east along the 2 km long section.

Lithology. The lower levels of the member comprise medium- to coarse-grained pebbly sandstones, grading laterally into pebble and boulder conglomerates with rafts of mudstone in deep basal scours (Fig. 22). These pass up into stratified medium- to fine-grained sandstones which are commonly bioturbated in the uppermost 5–10 cm.

Fossils. The member contains a fragmented macrofauna of bivalves and belemnites, probably of reworked origin (Kelly *et al.* 1998). Reworked Jurassic (upper Oxfordian) dinoflagellate cysts are also recorded, together with scarce Cretaceous forms.

Depositional environment. A fluvial origin within an incised valley was suggested by Larsen *et al.* (2001), the environment is here interpreted as the result of a single, surging sediment gravity-flow event that filled the relief on an irregular hiatal surface (see also Whitham *et al.* 1999), probably in a relatively deep marine, prodeltaic setting.

Boundaries. The base of the member is strongly erosional, cutting progressively deeper westwards into the underlying Stribedal Member and representing an intra-Barremian hiatus. The upper boundary is flat and placed where the laminated or bioturbated sandstones pass abruptly into the thoroughly bioturbated sandy mudstones or muddy sandstones of the overlying Stensiö Plateau Member.

Distribution. The member is known only from the cliffs on the north side of Stensiö Plateau, Hold with Hope, where it can be traced for about 1.2 km from the west to the east.

Chronostratigraphy. Much of the fauna in this member is reworked (Kelly *et al.* 1998), but the available data indicate a latest Barremian – early Aptian age based on dinoflagellate cysts from the Blåelv Member itself and from the conformably overlying Stensiö Plateau Member.

Key references. Kelly *et al.* (1998); Whitham *et al.* (1999); Larsen *et al.* (2001).

Stensiö Plateau Member

Revised member

History. The member was erected in the Stensiö Plateau, northern Hold with Hope, by Kelly *et al.* (1998) and is revised here.

Type section. Kelly *et al.* (1998) defined the type section in the north-western Stensiö Plateau, Hold with Hope.

Reference section. The reference section illustrated here is located a few hundred metres north-west of the type section (Fig. 22).

Thickness. As redefined here, the member is typically about 30 m thick (range 27.5–34 m in measured sections).

Lithology. The lower levels of the member comprise a weakly coarsening-upward succession of bioturbated, grey to dark grey sandy mudstones and muddy, very fine- to fine-grained sandstones. In the upper half of the member, this facies is interleaved with pale-coloured, lenticular medium-grained or coarse- to very coarse-grained sandstone beds up to 10 m thick and lenticular on a scale of tens to hundreds of metres.

Heterolithic bedding becomes common upwards in the muddy facies with local preservation of current ripple cross-lamination; characteristic trace fossils in this facies are *Zoophycos*, *Planolites*, *Muensteria*, *Curvolithus* and *Helminthopsis*.

Fossils. The Stensiö Plateau Member yields a relatively diverse marine macrofauna with deshayesitid ammonites, oxyteuthid(?) belemnites, bivalves, a crustacean and a moderately well-preserved dinoflagellate assemblage (Kelly *et al.* 1998; Nøhr-Hansen *et al.* 2019).

Fig. 22. Reference section of the Steensby Bjerg Formation showing gravity flow conglomerates and sandstones of the Blåelv Member and prodelta and gravity flow sandstones of the Stensiö Plateau Member at Stensiö Plateau, Hold with Hope.

The dinoflagellate cyst flora is characterised by the LO of *Pseudoceratium iveri* indicating the lower Aptian (Nøhr-Hansen *et al.* 2019).

Depositional environment. Marine prodelta, the accumulation of bioturbated fines being interrupted by sandy sediment gravity-flows probably derived from collapse of deltaic mouthbars, either due to seismic activity or to oversteepening during flood events.

Boundaries. The base of the member is placed where burrowed sandy mudstones or muddy sandstones overlie laminated or bioturbated sandstones of the upper Blåelv Member. The upper boundary, as redefined here, is placed *c*. 20 m higher than defined by Kelly *et al.* (1998) at a marked, laterally persistent erosion surface that shows local relief of up to several metres and up to 10 m relief over several hundreds of metres laterally. Coarse- to very coarse-grained sandstones that overlie this surface and typically show large-scale planar cross-bedding are referred to the Gulelv Member (Fig. 22).

Distribution. The member crops out for a distance of about 1.2 km in a WNW–ESE transect on the northern slopes of Stensiö Plateau, northern Hold with Hope.

Chronostratigraphy. The member is referred to the lower Aptian based on ammonites, belemnites and dinoflagellate cysts (palynostratigraphic zone II; Nøhr-Hansen 1993; Nøhr-Hansen *et al.* 2019).

Key references. Kelly *et al.* (1998); Larsen *et al.* (2001).

Gulelv Member

Amended member

History. The member was erected in northern Hold with Hope by Kelly *et al.* (1998); their definition is followed here except for a local redefinition of the lower boundary in the Stensiö Plateau area.

Type section. The type section of the Gulelv Member was defined as section W.3122 of Kelly *et al.* (1998). Although stated to be east of Steensby Bjerg, this section is situated *c*. 3 km west of the mountaintop as indicated correctly on fig. 2 of Kelly *et al.* (1998).

Reference section. A section immediately north of Steensby Bjerg is defined to illustrate the salient facies of the lower levels of the member in the area of the type section (Fig. 23).

Thickness. The member is 170–180 m thick in the area of the type section at Steensby Bjerg, where it forms the entire thickness of the Steensby Bjerg Formation. It thins out towards the east to 70 m at Diener Bjerg. To the west, at Stensiö Plateau, a summary log figured by Kelly *et al.* (1998) indicates a thickness of about 110 m for the Gulelv Member (as defined by these workers), while Larsen *et al.* (2001) reported a thickness of at least 125 m. Given the revised lower boundary of the member introduced here (see below), the Gulelv Member is *c*. 93 m thick in this area.

Lithology. In the Steensby Bjerg area, the lower two-thirds of the member consists of medium- to very coarse-grained sandstones, commonly poorly sorted, with scattered granules and fine pebbles, and locally interbedded with fine pebble conglomerates (Fig. 23). Cross-bedding is common, ranging from decimetre- and metre-scale planar, trough and compound cross-strata to giant-scale clinoforms in sets up to 45 m thick. Bioturbation is rare in these facies, being largely restricted to the lower levels of the clinothems and associated toesets. The upper third of the Gulelv Member is dominated by planar cross-bedded, medium- to coarse-grained sandstones that form coarsening-upward units 10–30 m thick (Fig. 23); bioturbation (particularly *Ophiomorpha*) and foreset drapes of mud and finely comminuted plant material are characteristic. This upper portion of the member interdigitates eastward with mud-rich strata of the Rødelv Member (Stratumbjerg Formation). At Stensiö Plateau, the succession referred to the Gulelv Member resembles that of the upper Gulelv Member in the east, being characterised by medium- to coarse-grained sandstones showing planar cross-bedding, commonly with mud-draped, bioturbated foresets. Burrowed heterolithic, very fine- to fine-grained sandstone intervals are also represented.

Fossils. Much of the sand-dominated Gulelv Formation is unfossiliferous although rare ammonites and other macrofossils have been recorded (Kelly *et al.* 1998), and fragmentary plant remains occur in the upper levels. Dinoflagellate cysts have been recovered from thin mudstones in the lower levels (age correlative with the Diener Bjerg Member) and from the upper third of the member. The dinoflagellate cyst flora is characterised by the following events: the FO of *Pseudoceratium toveae* indicating the base of the upper Barremian; the LO of *Batioladinium longicornutum* indicating the top upper Barremian; the LO of *Pseudoceratium iveri* indicating the lower Aptian; the FO of *Circulodinium brevispinosum* indicating the upper lower Aptian; the FO of *Leptodinium cancellatum* indicating the lower upper Aptian; and the FO of *Senoniasphaera microreticulata* indicating the upper upper Aptian (Nøhr-Hansen *et al.* 2019).

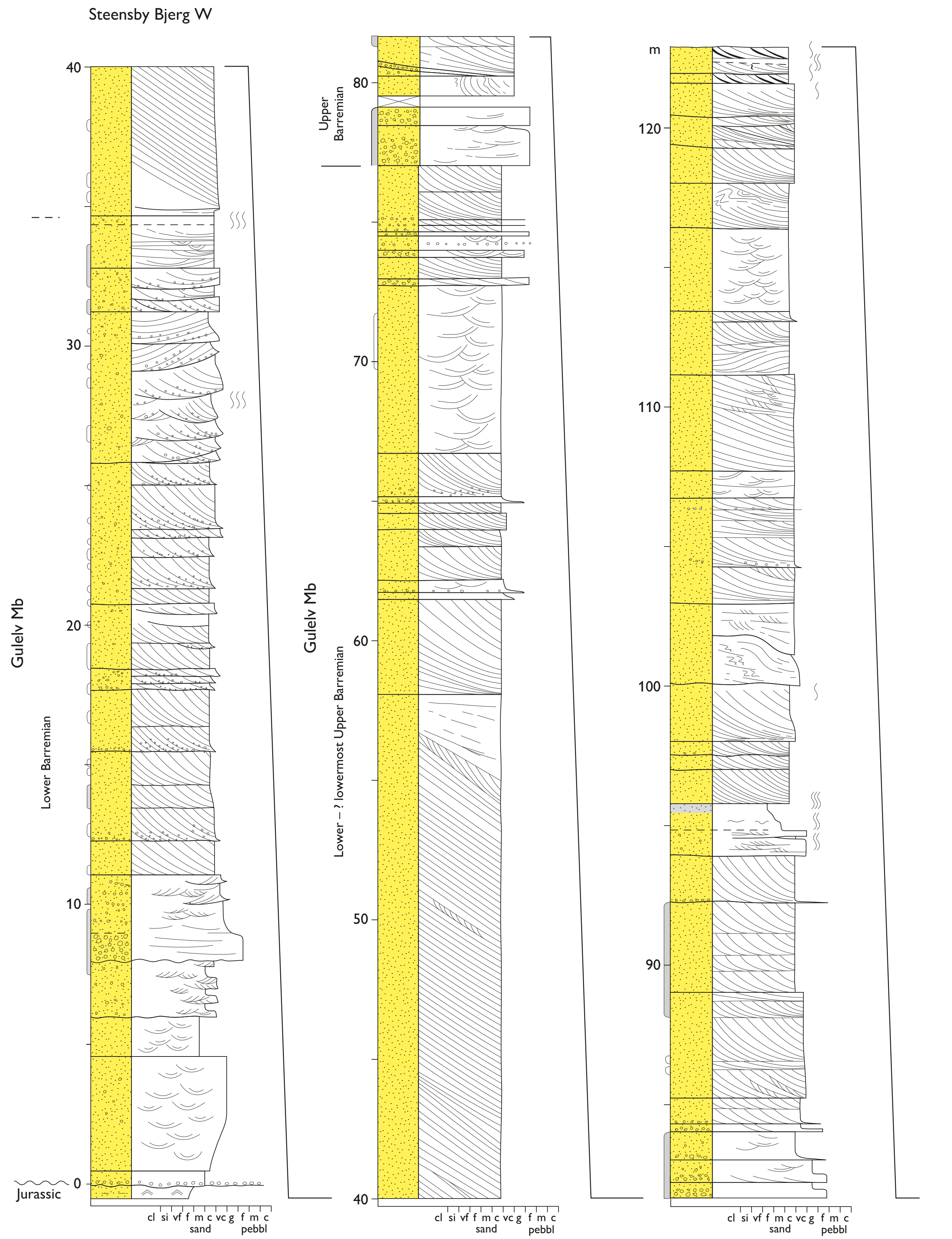


Fig. 23. Reference section of the Gulelv Member (Steensby Bjerg Formation) showing delta front and delta top sandstones at Steensby Bjerg, Hold with Hope.

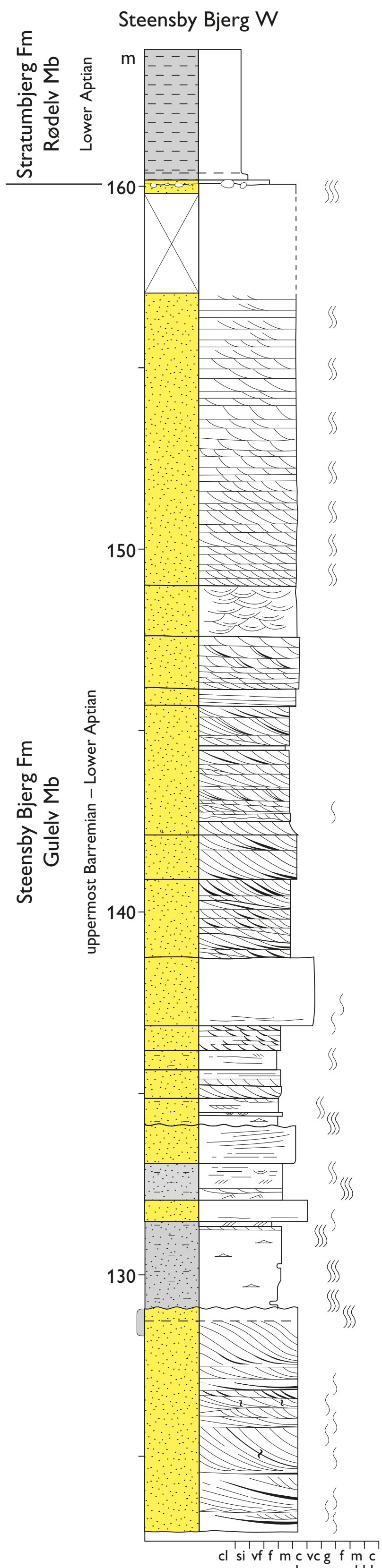


Fig. 23 continued

Depositional environment. At Steensby Bjerg, where the member is fully developed, it records a complex array of environments from fluvio-deltaic through tidally-influenced delta or estuarine to shoreface (see Whitham *et al.* 1999; Larsen *et al.* 2001). At Stensiö Plateau, it represents an estuarine/tidally-influenced delta within an incised valley.

Boundaries. In the Steensby Bjerg area, the Gulelv Member rests unconformably on Jurassic or Triassic strata. A thin pebbly sandstone or conglomerate (typically < 1 m thick) may be present above this boundary. East of Steensby Bjerg, the Gulelv Member conformably and gradationally overlies the Diener Bjerg Member, the boundary reflecting the progressive eastward migration of delta front sands. The Gulelv Member is conformably overlain by the Rødelv Member (Stratumbjerg Formation; Fig. 19). The boundary is commonly sharp and in the type section area it is marked by a pebble- or cobble-strewn surface. Eastwards, the upper levels of the Gulelv Member interdigitate with sandy mudstones and muddy sandstones of the lower Rødelv Member.

At Stensiö Plateau, the base of the Gulelv Member as redefined here (see Stensiö Plateau Member) is an undulating erosion surface that can be recognised laterally as far as exposure permits (*c.* 800 m). It marks an abrupt facies shift from thin-bedded heterolithic muddy sandstones with lenticular gravity-flow sandstone interbeds of the Stensiö Plateau Member into large-scale cross-bedded, coarse- to very coarse-grained sandstones referred to the Gulelv Member (Fig. 22). The upper boundary is placed where bioturbated coarse- to very coarse-grained pebbly sandstones are overlain by sandy mudstones referred to the Rødelv Member (Stratumbjerg Formation).

Distribution. The member is recognised in northern Hold with Hope in a 20-km coastal stretch from Stensiö Plateau in the west to Diener Bjerg in the east, and southwards in the Gulelv valley.

Chronostratigraphy. The member has a gross stratigraphic range of lower Barremian – lower Albian based on the stratigraphic and architectural relationship with the other members of the Steensby Bjerg Formation. It is referred to the lower Barremian to lower Aptian in the Steensby Bjerg area but probably ranges from the lower Aptian to the lowermost Albian at Stensiö Plateau. A late Barremian to Early Albian age is documented for the middle and upper part of the member based on dinoflagellate cysts (palynostratigraphic zones I 3, II and III of Nøhr-Hansen *et al.* 2019).

Key references. Kelly *et al.* (1998); Whitham *et al.* (1999); Larsen *et al.* (2001); Nøhr-Hansen *et al.* (2019).

Rold Bjerge Formation

History. The Rold Bjerge Formation was erected by Surlyk & Noe-Nygaard (2001) from northern Traill Ø.

Type section. Surlyk & Noe-Nygaard (2001) defined the type section at a pass in the mountain of Rold Bjerge, central northern Traill Ø (Fig. 24). The type section was illustrated photographically by these workers; a sedimentological log through the formation is presented here from the reference section in Månedal.

Reference section. The formation is also represented by a succession of conglomerates, sandstones and isolated blocks intercalated with mudstones in Månedal, about 1 km south-east of the type section (Fig. 25).

Thickness. The formation is up to 25 m thick in the type section, decreasing to 12 m in the reference section (Fig. 25), and to <1 m a few kilometres farther towards the south-east.

Lithology. In the type area, the formation comprises a chaotic breccia sheet with clast sizes ranging from pebbles and cobbles to large blocks up to 60 × 10 m across (Surlyk & Noe-Nygaard 2001). Clasts consist of Permian and Triassic carbonates and Triassic–Jurassic sandstones. Elsewhere along depositional strike, the formation is represented by lenticular beds of conglomerate and pebbly sandstone, and isolated sandstone boulders intercalated with, and enveloped by, dark grey mudstones comparable to the underlying and overlying Stratumbjerget Formation (Figs 24, 25).

Fossils. The breccia–conglomerate beds yield rare reworked Middle Jurassic ammonites. The under- and overlying Stratumbjerg Formation mudstones yield common dinoflagellate cysts. The dinoflagellate cyst flora is characterised by the FO of *Pseudoceratium distinctum* indicating the lower upper Aptian and the FO of *Canningia reticulata* indicating the upper upper Aptian (Nøhr-Hansen *et al.* 2019).

Depositional environment. The formation is interpreted to represent submarine debris avalanches sourced from the footwall of the Post-Devonian Main Fault about 25 km to the west (Surlyk & Noe-Nygaard 2001).

Boundaries. At the type section, the lower boundary is poorly exposed but appears mainly flat; local erosion is suggested at the reference section. The irregular top of the Rold Bjerge Formation is draped and overlain by upper Aptian – lower Albian dark grey mudstones of the Stratumbjerg Formation.

Distribution. The formation is locally exposed for a few kilometres on the eastern, hanging-wall side of the Månedal Fault in the Rold Bjerge area, northern Traill Ø. Triassic sediments comprise the footwall block to the west, and Upper Aptian mudstones dominate the succession below and above the Rold Bjerge Formation in the hanging-wall block to the east (Figs 24, 25).

Chronostratigraphy. The formation was assigned to the middle Albian based on inoceramid bivalves in the overlying mudstone succession (Surlyk & Noe-Nygaard 2001). New biostratigraphic data from dinoflagellate cysts in the under- and overlying mudstone succession indicate the upper Aptian (Palynozones III 1 – III 2 of Nøhr-Hansen (1993) and Nøhr-Hansen *et al.* (2019)).

Key references. Surlyk & Noe-Nygaard (2001); Nøhr-Hansen *et al.* (2019).

Home Forland Group

Elevated and revised group

History. The Home Forland Formation, here elevated to group rank, was defined by Kelly *et al.* (1998) based on the the informal Home Forland Beds of Maync (1949). Parsons *et al*. (2017) informally extended the distribution of the unit to Traill Ø and extended the stratigraphic range to Ryazanian – Campanian. The Home Forland Group corresponds in part to the Cretaceous shale series of Donovan (1957), to the upper part of the 'mid Cretaceous sandy shale sequence' of Nøhr-Hansen (1993) and to the *Inoceramus angelicus – I. crippsi* Beds of Parsons *et al.* (2017).

Type area. The group is best developed and exposed in north-east Hold with Hope (Fig. 3).

Thickness. The group is probably up to 1 km thick although complete successions are not exposed at any one locality and the group is known from a number of partial sections. Parsons *et al.* (2017) estimated a minimum thickness of 1–2 km for the combined *Inoceramus angelicus* and *I. crippsi* Beds on Traill Ø and Geographical Society Ø based on constructed cross sections, though up to 40% of this estimate consists of volcanic sills.

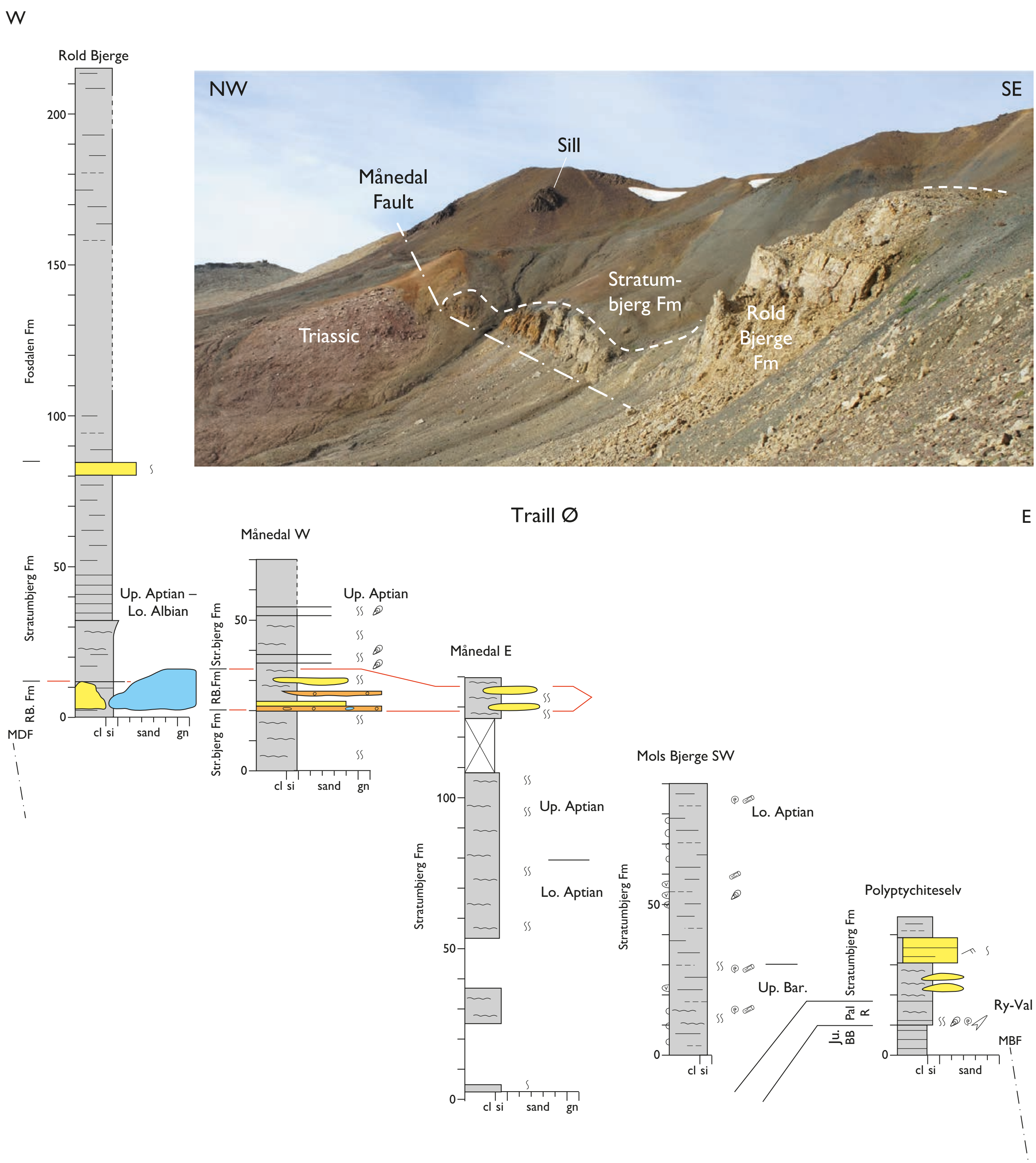


Fig. 24. Sections of the Brorson Halvø Group from Rold Bjerge to Polyptychiteselv on Traill Ø. Note western proximal to eastern distal development of the Aptian Rold Bjerge Formation in relation to the Månedal Fault (MDF), and the condensed Palnatokes Bjerg Formation on the footwall crest at the Mols Bjerge Fault (MBF). Inserted photograph of the Rold Bjerge Formation at the type section showing carbonate breccia clasts up to about 25 m thick, Rold Bjerge, Traill Ø. Ju. BB = Jurassic Bernbjerg Fm, Pal R = Palnatokes Bjerg Formation Rødryggen Member, RB Fm = Rold Bjerge Fm, Ry-Val = Ryazanian–Valanginian.

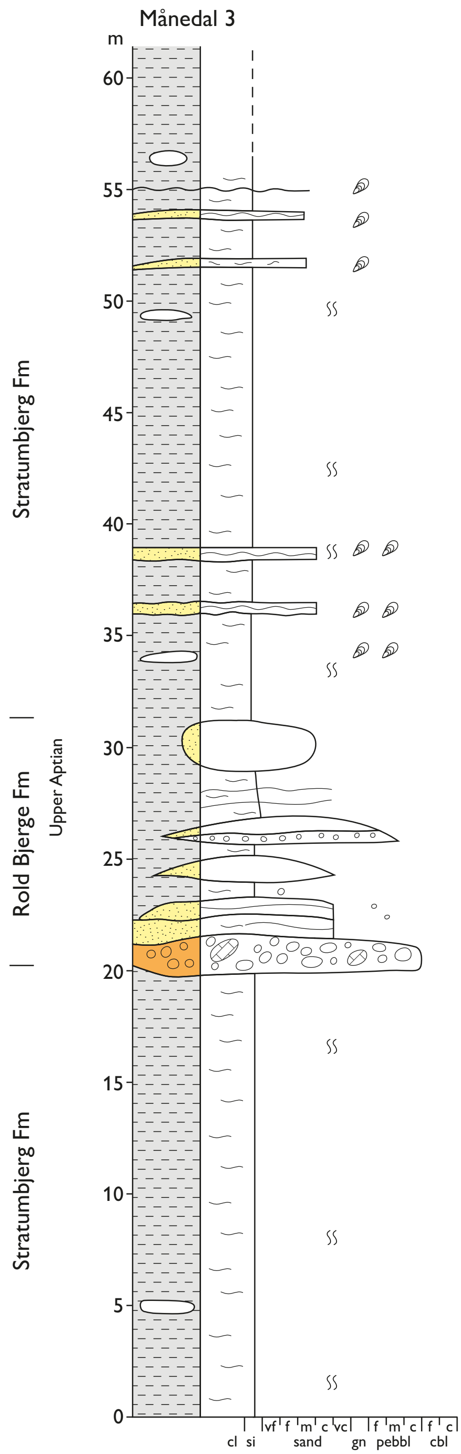


Fig. 25. Reference section of the Rold Bjerge Formation in the western part of Månedal, Traill Ø.

Lithology. The group is characterised regionally by dark grey to black mudstones with subordinate thin sandstone beds that are referred to the Fosdalen Formation (Figs 26, 27). Discrete sand-dominated packets occur locally within the latter formation and are given member status, e.g. Langsiden Member. The basal beds of the group are locally developed as a coarse-grained wedge that on Clavering Ø comprises sandstones and conglomerates referred to the Kontaktravine Formation (see below). At Brorson Halvø and Traill Ø, the basal beds respectively comprise a thin sandstone unit (Fig. 8) and a conglomeratic unit.

Fossils. Inoceramid bivalves are common at some levels, ammonites are recorded but are scarce overall, and belemnites are very rare. The dominant mudstone facies yields dinoflagellate cysts which represent the most consistently applicable biostratigraphic tool.

Depositional environment. Deeper-water marine settings including outer slope and basin, slope apron and basin-floor fan.

Boundaries. The group erosionally overlies the Stratumbjerg Formation (Brorson Halvø Group) on Hold with Hope and Wollaston Forland (Kelly *et al.* 1998; Figs. 5, 8), or rests with angular unconformity on older Mesozoic – Upper Palaeozoic strata or on crystalline basement (Figs 27, 29). The upper boundary is an erosional surface in some sections, particularly where the Home Forland Group mudstones are overlain directly by coarse-grained deposits of the Upper Cretaceous Jackson Ø Group.

Distribution. The Home Forland Group is recognised in North-East Greenland from Traill Ø in the south to Wollaston Forland in the north.

Chronostratigraphy. Middle Albian – middle Coniacian based on ammonites, bivalves and dinoflagellate cysts; for details see component formations (below).

Subdivision. The group is subdivided (from below) into the Kontaktravine Formation and the Fosdalen Formation.

Key references. Maync (1949); Vischer (1943); Donovan (1953, 1964); Nøhr-Hansen (1993); Kelly *et al.* (1998); Nøhr-Hansen *et al.* (2019).

Kontaktravine Formation

New formation

Name. After the gorge Kontaktravine, in which it is well exposed. The gorge itself was named to recognise

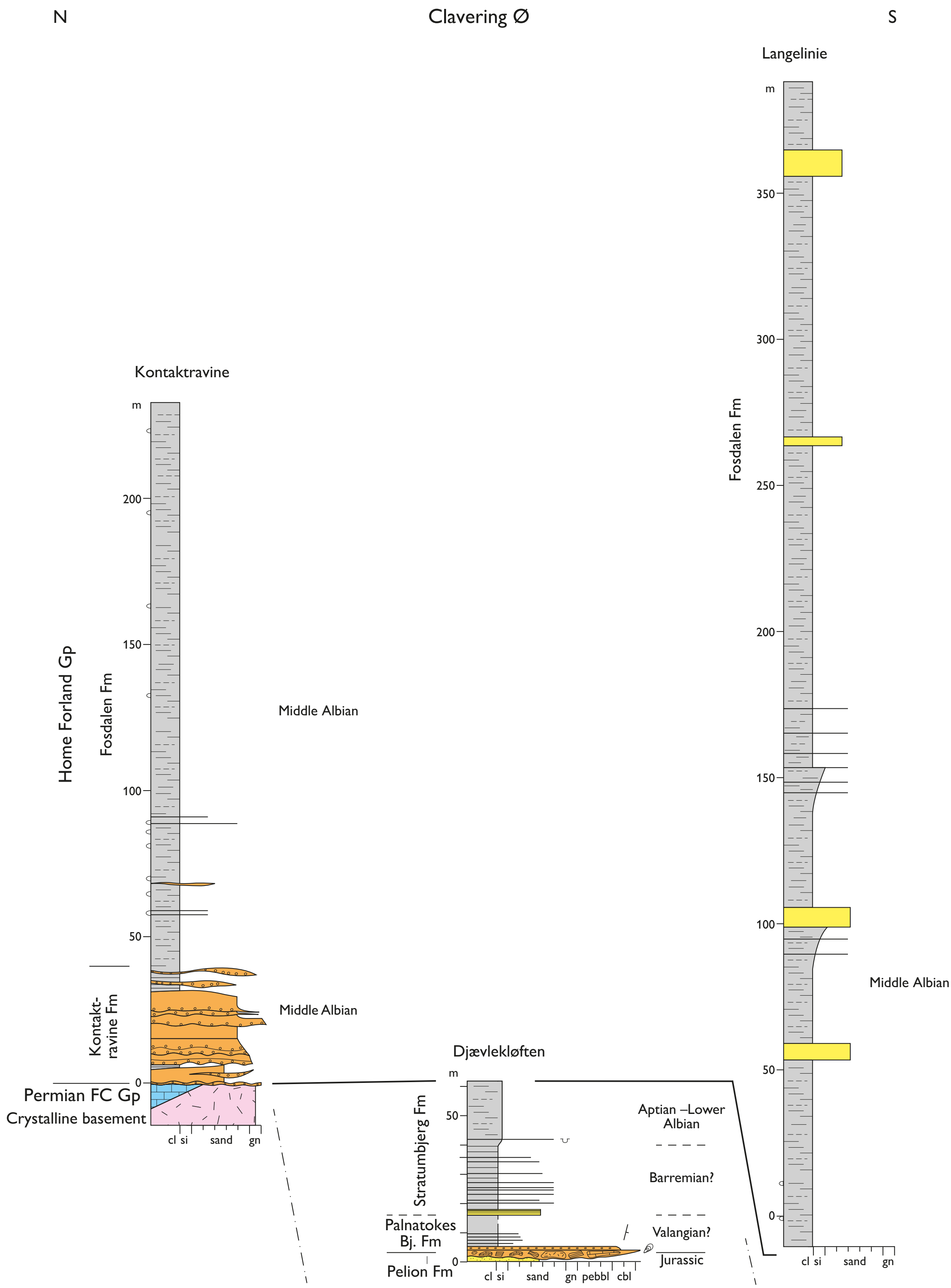


Fig. 26. Cretaceous sections from Kontaktravine, Djævlekløften and Langeline at Clavering Ø showing basal boundary transitions in relation to location on different fault blocks. FC Gp = Foldvik Creek Group.

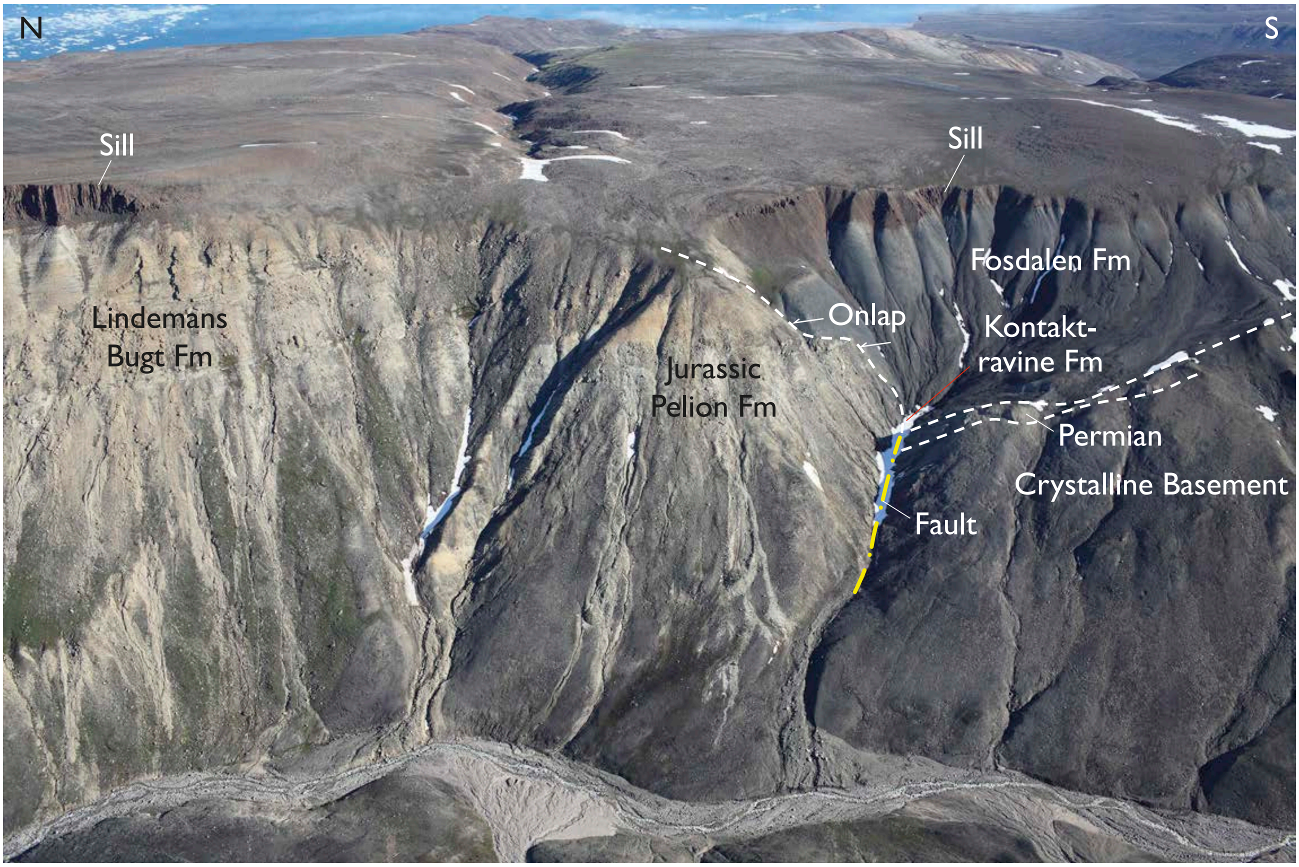


Fig. 27. Type section of Kontaktravine Formation, overlain by an about 200 m thick succession of dark grey Albian mudstones of the Fosdalen Formation in fault-associated erosional contact with sandstones of the Middle Jurassic Pelion Formation to the left (north) and Permian carbonates/crystalline basement to the right (south). The type section of the Kontaktravine Formation is situated in the narrow gully in the fault zone. Note the onlapping character of the overlying Fosdalen Formation. Kontaktravine, Dolomitdal, north-eastern Clavering Ø.

a prominent geological boundary involving a complex fault zone, crystalline basement, Permian carbonate, Jurassic sandstones and onlapping Cretaceous sediments (Noe-Nygaard & Söderberg 1932; Maync 1938).

Type section. The type section of the formation is in the gorge Kontaktravine, Dolomitdal, north-east Clavering Ø (74.37805°N, 20.592502°W; Figs. 3, 27, 28).

Thickness. The formation is about 40 m thick in the type section. Scattered exposures occur in the Dolomitdal area but lateral variation in the thickness of the formation is not known.

Lithology. The Kontaktravine Formation is sandstone-dominated but includes prominent conglomerate intervals, particularly in the lower half of the formation, and interbedded grey to dark grey mudstones, mainly in the upper levels (Fig. 28). The formation shows an overall fining-upward trend. The conglomerates are crudely sheet-like or lensoid, with common erosional bases and internal clay drapes. Clasts are mainly well-rounded and of pebble grade, but up to metre-sized boulders of gneiss and Permian carbonates occur locally. Mudstone intraclasts are common in some beds. The conglomerates are interbedded with coarse-tail graded pebbly and homogeneous sandstone beds with mudstone intraclasts and internal thin mudstone drapes. Slump structures and other evidence of soft-sediment deformation are common. The upper part of the formation comprises lensoidal bodies of crudely bedded sandstones and pebbly sandstones intercalated with laminated very dark grey mudstones.

Fossils. Dinoflagellate cysts are recorded in the muddy beds. The flora is characterised by the FO of *Chichaouadinium vestitum* and *Ovoidinium* sp. 3 (Nøhr-Hansen 1993) indicating the lower middle Albian (Nøhr-Hansen *et al.* 2019). Very rare belemnites occur in the upper part of the formation.

Depositional environment. The Kontaktravine Formation represents the deposits of gravity flows in a fault-scarp attached slope apron.

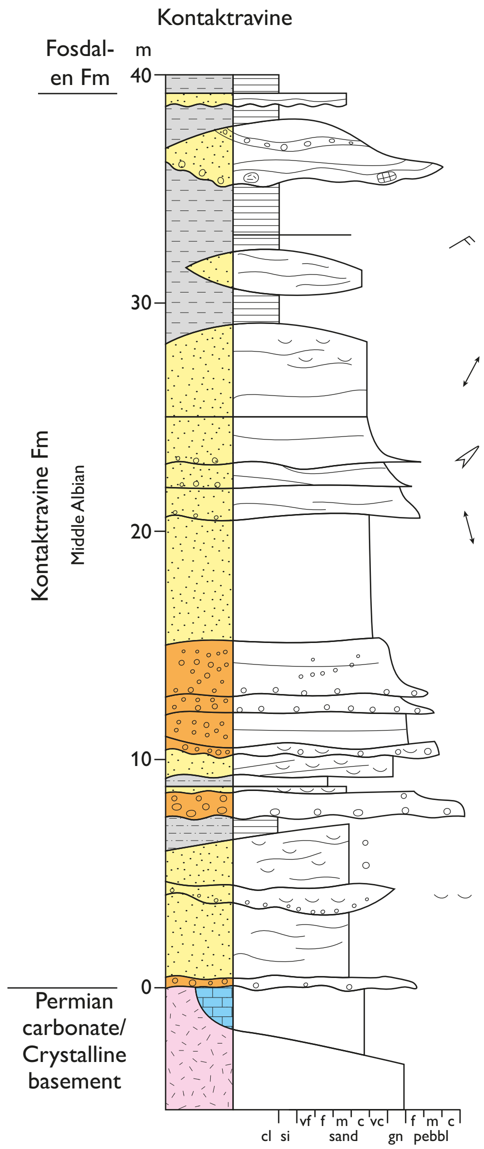


Fig. 28. Type Section of the Middle Albian gravity flow conglomerates and sandstones of the Kontaktravine Formation, with basal contact against crystalline basement in Dolomitdal, Clavering Ø.

Boundaries. In the type section, the basal pebbly sandstone bed rests directly on crystalline basement. Elsewhere in the fault zone, the formation unconformably overlies Permian carbonates of the Wegener Halvø Formation or Jurassic sandstones of the Pelion Formation. The upper boundary is conformable and placed at the top of crudely bedded sandstone overlain by laminated dark grey mudstones of the Fosdalen Formation (Fig. 28).

Distribution. The formation is only recognised in north-eastern Clavering Ø. The base of the formation correlates to the mid-Albian unconformity represented by hiatal surfaces at Stratumbjerg in Wollaston Forland, at Hold with Hope, at Geographical Society Ø, and at Mols Bjerge on Traill Ø (Fig. 5).

Chronostratigraphy. The formation is referred to the middle Albian palynostratigraphic zone IV 1 based on dinoflagellate cysts in the mudstone bed in the basal part of the formation (Nøhr-Hansen 1993; Nøhr-Hansen *et al.* 2019; Fig. 28, at *c.* 7 m).

Key references. Maync (1938, 1949).

Fosdalen Formation

Amended formation

History. Kelly *et al.* (1998) erected the Fosdalen Member, named after a valley in north-eastern Hold with Hope, to encompass a thick mudstone-dominated succession of middle Albian to late Turonian and possibly Coniacian age, which crops out extensively in eastern Hold with Hope. In this study, the unit is elevated to the rank of formation and includes all marine mudstones of middle Albian to middle Coniacian age between Traill Ø in the south and Wollaston Forland in the north. On Traill Ø, the formation is equivalent to the *Inoceramus anglicus* Beds (in part), *I. crippsi* Beds and *I. lamarcki Beds* (in part) of Parsons *et al.* (2017).

Type section. Situated on the north coast of Home Forland, Hold with Hope, about 5 km east of the Fosdalen Fault and the Fosdalen valley (Kelly *et al.* 1998).

Reference sections. Reference sections are present in Snertadal on Hold with Hope, in Tværdal on Geographical Society Ø, at Mols Bjerge on Traill Ø, and at Dolomitdal and Langelinie on Clavering Ø (Figs 26, 29, 30, 32, 33).

Thickness. The formation is about 1100 m thick in the type section (Kelly *et al.* 1998), and similar thicknesses are estimated on Traill Ø (Parsons *et al.* 2017). These figures are minimum estimates, as both lower and upper boundaries are nowhere exposed in the same section. Immediately west of the Fosdalen Fault in northern Hold with Hope, the formation thins and wedges out westwards from a maximum of *c.* 100 m, onlapping the degraded footwall slope of Triassic, Jurassic and Lower Cretaceous sediments (Kelly *et al.* 1998). The formation reappears westwards in Gulelv but is only locally exposed (Fig. 19).

Lithology. The formation is dominated by dark marine mudstones with varying proportions of interbedded fine- to very fine-grained sandstone, typically in beds showing ripple cross-lamination and parallel lamination. In expanded sections, as in eastern Traill Ø (Mols Bjerge, Fig. 29) and eastern Hold with Hope, sand-rich intervals up to 300 m thick occur, particularly in the upper Albian part of the succession. In the Snertadal reference section it is characterised by stacked 30–50 m thick fining-upward units (Fig. 30). These are typically sand-dominated in their lower levels and may include slumped intervals up to 8 m thick, comprising rotated intraformational blocks and contorted strata. Low-angle erosional surfaces are common, draped by sheet-like fine-grained sandstones showing parallel- and ripple cross-lamination. Upwards, the increasingly mud-rich succession may show minor (< 2 m thick) cycles, including both gradationally based coarsening/thickening upward cycles and sharp-based fining/thinning upward cycles. The upper levels of the large-scale fining-upward units are mud-dominated, comprising laminated mudstones and heterolithic facies, commonly poorly exposed. Slumped complexes are common in the Fosdalen Formation, especially in the Albian part of the formation as recorded on Hold with Hope (Fig. 30) and on Traill Ø (Surlyk & Noe-Nygaard 2001). A discrete medium- to coarse-grained sand unit is referred to the new Langsiden Member.

Fossils. Inoceramid bivalves are relatively common, whereas ammonites, belemnites, echinoderms and serpulids occur only rarely (Kelly *et al*. 1998; Parsons *et al.* 2017). Ammonites include Albian hoplitinids and Cenomanian *Schloenbachia* (Donovan 1953, 1954, 1957).

The dinoflagellate cyst flora is characterised by the following events. **Albian**: the FO of *Chichaouadinium vestitum, Rhombodella paucispina* indicating the base of the middle Albian; the FO of *Subtilisphaera kalaallitii, Wigginsiella grandstandica* indicating the base of the upper Albian; the FO of *Odontochitina ancala* indicating the lower upper Albian; and the FO of *Sindridinium borealis* indicating the upper Albian. **Cenomanian**: the FO of *Senoniasphaera* aff. *Microreticulata*, common *S. borealis, Epelidosphaeridia manifesta* and *Ovoidinium epelidosphaeroides* indicating the lower lower Cenomanian; the FO of *Sindridinium anaanae, Xenascus* aff. *plotei* indicating the upper lower Cenomanian; the FO of *Endoceratium ludbrookiae*, *Ginginodinium* aff. *evittii* indicating the middle Cenomanian; the FO of *Isabelidinium magnum, Trithyrodinium suspectum* indicating the upper middle/lower upper Cenomanian; the FO of the *Cyclonephelium compactum – Cauveridinium membraniphorum* complex and *Surculosphaeridium longifurcatum* indicating the middle upper Cenomanian. **Turonian–Coniacian**: the FO of *Heterosphaeridium difficile, Chatangiella* spp. indicating the Lower Turonian; the FO of *Senoniasphaera rotundata* indicating the middle Turonian; the FO and LO of *Odontochitina rhakodes* indicating the upper Turonian and the uppermost lower Coniacian, respectively; the FO of *Xenascus gochtii* indicating the lower–middle Coniacian (Nøhr-Hansen *et al.* 2019).

Depositional environment. Deep-water marine settings, including slope, submarine fan and basin floor.

Boundaries. The formation rests unconformably on mudstones of the Stratumbjerg Formation at Stratumbjerg on Wollaston Forland (Fig. 8). The lower boundary is also an unconformity in Tværdal on Geographical Society Ø, where the formation overlies Jurassic strata (Fig. 29). On north-east Clavering Ø, it conformably overlies the Kontaktravine Formation (Fig. 26). In the type area of eastern Hold with Hope the base of the formation is not observed, but west of the Fosdalen Fault it rests unconformably on mudstones of the Rødelv Member (Stratumbjerg Formation, Figs 5, 19) or on coarse-grained deltaic deposits of the Steensby Bjerg Formation. In this area, the unconformity surface rises westwards and has a topographic relief of up to 600 m, interpreted as the degraded footwall of the Fosdalen Fault (Kelly *et al.* 1998; Whitham *et al.* 1999). The Fosdalen Formation onlaps this surface from the east to the west (Larsen *et al.* 2001). It thus overlies block-faulted Triassic and Jurassic strata between Diener Bjerg and the Fosdalen Fault and onlaps progressively younger Cretaceous strata westwards.

On Traill Ø and Geographical Society Ø, the upper boundary is an erosional surface overlain by conglomerates and breccias of the Månedal Formation (Fig. 5). In eastern Hold with Hope, the upper boundary is an abrupt, weakly erosional surface overlain by muddy and pebbly sandstones of the Nanok Member of the Østersletten Formation (Fig. 5; Stemmerik *et al.* 1993). West of the Fosdalen Fault the upper boundary is not present, the formation being truncated by Cenozoic sediments or lava flows.

Distribution. The Fosdalen Formation is recognised from Traill Ø in the south to Wollaston Forland in the north (Figs 2–3).

Chronostratigraphy. Middle Albian – middle Coniacian represented by the palynostratigraphic zones IV, V, VI, VII, VIII and IX of Nøhr-Hansen (1993) and Nøhr-Hansen *et al.* (2019).

Subdivision. The Fosdalen Formation includes the new Langsiden Member.

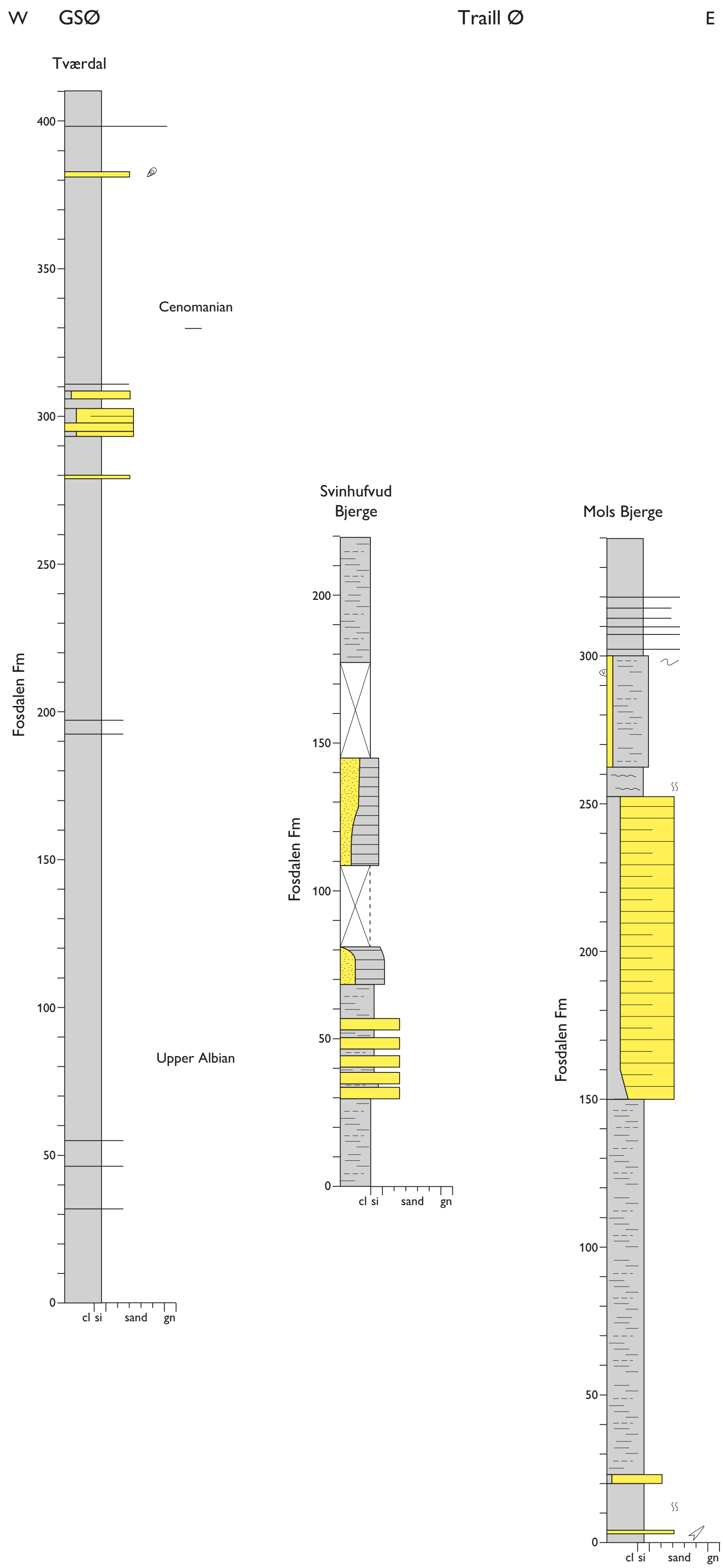


Fig. 29. Sections of the Fosdalen Formation of the Home Forland Group on Geographical Society Ø (GSØ) and Traill Ø.

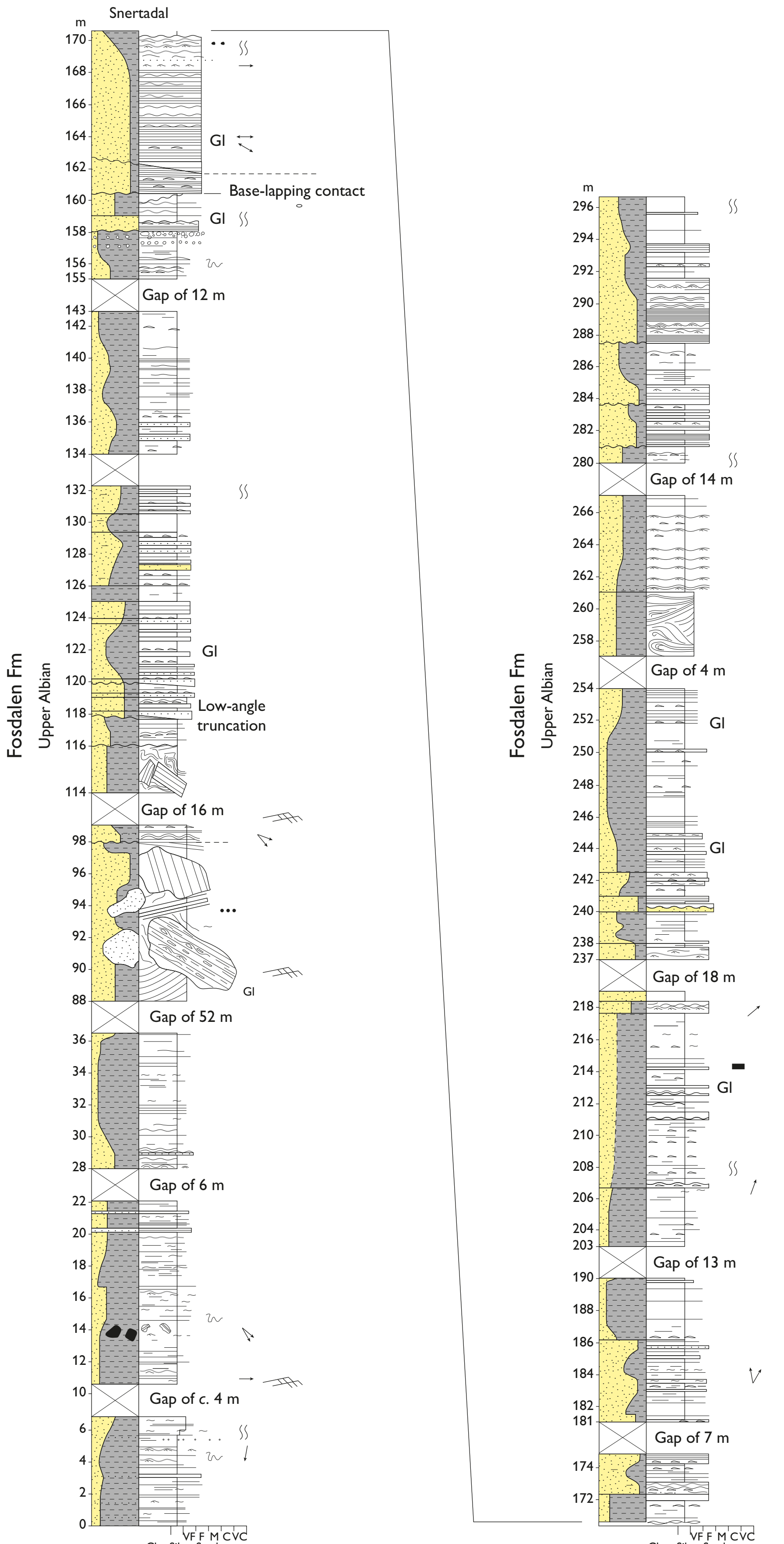


Fig. 30. Reference section of the Fosdalen Formation in Snertadal, Hold with Hope. The log represents an upper Albian interval (above the likewise upper Albian Langsiden Member shown in Fig. 32).

Key references. Maync (1949); Kelly *et al.* (1998); Surlyk & Noe-Nygaard (2001); Nøhr-Hansen *et al.* (2018); Nøhr-Hansen *et al.* (2019).

Langsiden Member

New member

History. Hartz *et al.* (2002) informally referred a sand-dominated interval to the Langsiden submember within the Fosdalen Member (*sensu* Kelly *et al.* 1998). The interval crops out locally in north-eastern Hold with Hope and is here defined formally as a member within the Fosdalen Formation; (Fig. 5).

Name. After a N–S trending ridge in Home Forland, north-eastern Hold with Hope (Higgins 2010).

Type section. The type section is situated in the Snertadal valley, north-eastern Hold with Hope (73.86618°N, 20.59138°W) (Figs. 31–32).

Thickness. The member is 13 m thick at the type section (Figs 31, 32).

Lithology. Pebbly medium- to coarse-grained sandstones dominate in the type section, showing lenticular beds, scoured boundaries, parallel- and cross-stratification with fining-upward and coarsening-upward packets up to several metres thick (Fig. 32).

Fossils. The mudstones yield dinoflagellate cysts. The flora is characterised by the FO of *Odontochitina ancala* indicating the lower upper Albian (Nøhr-Hansen *et al.* 2019). Macrofossils have not been found.

Depositional environment. Lower slope and basin-floor fan.

Boundaries. The base is inferred to be erosional in the type area, whereas the upper boundary is gradational and conformable, being marked by a discernible decrease in the proportion of interbedded discrete sandstones and heteroliths.

Distribution. The Langsiden Member is recognised in north-eastern Hold with Hope.

Chronostratigraphy. Upper Albian based on dinoflagellate cysts that indicate the palynostratigraphic zone V 2 of Nøhr-Hansen (1993) and Nøhr-Hansen *et al.* (2019).

Key references. Hartz *et al.* (2002); Kelly *et al.* (1998).

Fig. 31. Basin-floor fan sandstones of the Langsiden Member (Fosdalen Formation), Snertadal, Hold with Hope. Person encircled for scale.

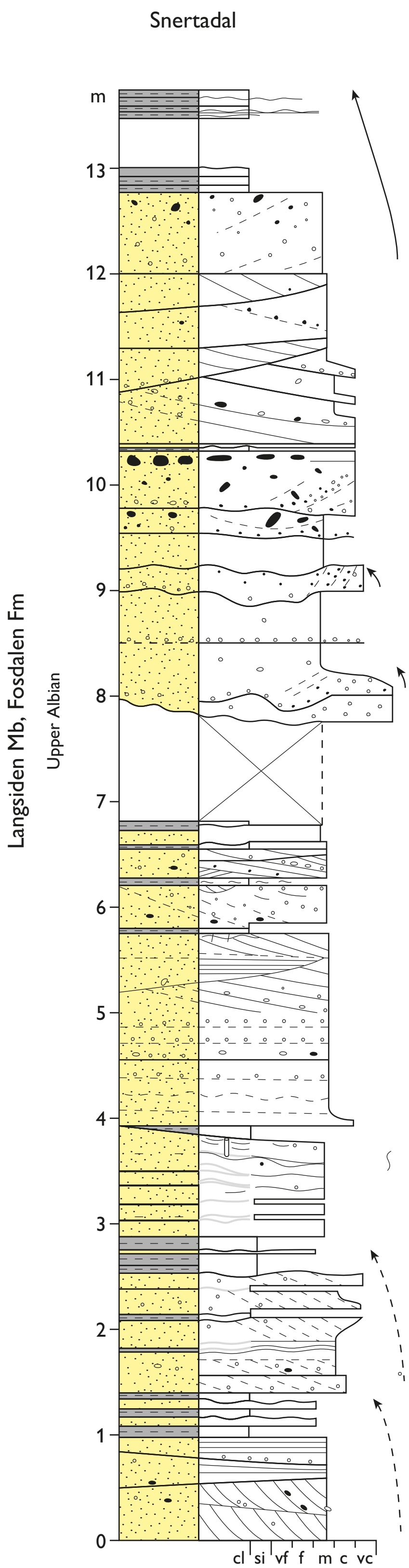


Fig. 32. Type section of the upper Albian sandstones of the Langsiden Member, Fosdalen Formation at Snertadal, Hold with Hope.

Jackson Ø Group

New group

History. The Jackson Ø Group encompasses the Turonian – lower Maastrichtian mudstone-dominated succession of North-East Greenland. The group includes a number of lithostratigraphic units defined by Kelly *et al.* (1998) from Hold with Hope: the Nanok Member, the Østersletten Member (herein elevated to formation status) and the Knudshoved Member (herein elevated to formation status) of the Home Forland Formation (herein revised and elevated to group status). The Vega Sund Formation (here renamed the Kista Ø Formation) and the Månedal Formation of Surlyk & Noe-Nygaard (2001) are also included in the new group. In addition, the group incorporates the *Inoceramus lamarcki* (in part), *Sphenoceramus* and *Scaphites* Beds of Donovan (1957) and Parsons *et al.* (2017).

Name. After Jackson Ø, an island about 5 km off the north-eastern corner of Hold with Hope where Upper Cretaceous mudstones crop out (Fig. 3). The island was named by William Scoresby Jr. in 1822 (Higgins 2010).

Type area. The group is best developed and exposed in north-eastern Hold with Hope and on Jackson Ø (Fig. 3).

Thickness. In north-eastern Hold with Hope, the group is probably up to several hundred metres thick, but complete successions are unknown. Based on constructed cross-sections, Parsons *et al.* (2017) estimated that the combined *Inoceramus lamarcki, Sphenoceramus* and *Scaphites* Beds (broadly equivalent to the Jackson Ø Group), have a minimum thickness of 1.2–1.4 km on Traill Ø and Geographical Society Ø, with the reservation that up to 40% of this thickness may be represented by igneous intrusions (sills).

Lithology. The exposures of the group are scattered and the regional lithological composition is poorly known; the exposed sections indicate a heterogeneous sedimentary package where coarse-grained units are separated by marine mudstones (Figs 4, 5). In Hold with Hope, the group comprises basal reddish sandy and pebbly mudstones of the Nanok Member overlain by sandstones of the Østersletten Formation and mudstones of the Knudshoved Formation (Figs 33–34, see also Fig. 38). On Traill Ø and Geographical Society Ø, disorganised conglomerates typify the Månedal Formation at the base of the group (Figs 35–36). On Traill Ø, a thick interbedded marine sandstone-dominated succession (Kista Ø Formation, the renamed Vega Sund Formation of Surlyk & Noe-Nygaard (2001)) occurs higher in the group (Fig. 37). The uppermost exposed strata of the group on Geographical Society Ø comprise a succession of marine conglomerates, sandstones and intercalated mudstones here referred to the new Leitch Bjerg Formation (Figs 39–40).

Fossils. Inoceramid bivalves are recorded at certain intervals, whereas ammonites and belemnites are generally rare. Serpulids and wood fragments are common in the upper part at Leitch Bjerg.

Depositional environment. The marine succession records deposition in an outer slope – basin setting; the coarser-grained units represent slope apron and basin-floor fan environments (Surlyk & Noe-Nygaard 2001).

Boundaries. The lower boundary is probably an erosional surface on Traill Ø and Geographical Society Ø, where conglomerates of the Månedal Formation abruptly overlie dark mudstones of the Fosdalen Formation. In Hold with Hope, however, the lower boundary is abrupt but probably conformable, where red sandy and calcareous mudstones of the Nanok Member (Østersletten Formation) overlie Fosdalen Formation mudstones. The lower boundary is not exposed in Wollaston Forland. The upper boundary is an unconformity, the group being variably overlain by Paleocene sediments, Paleogene basalts and Quaternary deposits.

Distribution. The Jackson Ø Group is recognised on eastern central Traill Ø and eastern Geographical Society Ø, in Hold with Hope, on Jackson Ø and in Wollaston Forland.

Chronostratigraphy. The group is referred to the upper Turonian – lower Maastrichtian based on ammonites and bivalves (*Inoceramus lamarcki*, *Sphenoceramus* and *Scaphites* Beds) and dinoflagellate cysts (Donovan, 1957; Kelly *et al.* 1998; Nøhr-Hansen *et al.* 2019).

Subdivision. The group is divided into the Månedal, Kista Ø, Østersletten, Knudshoved and Leitch Bjerg Formations (Fig. 4).

Key references. Vischer (1943); Maync (1949); Donovan (1953, 1957, 1964); Nøhr-Hansen (1993); Kelly *et al.* (1998); Surlyk & Noe-Nygaard (2001); Nøhr-Hansen *et al.* (2011); Nøhr-Hansen *et al.* (2019).

Månedal Formation

History. The Månedal Formation was erected by Surlyk & Noe-Nygaard (2001).

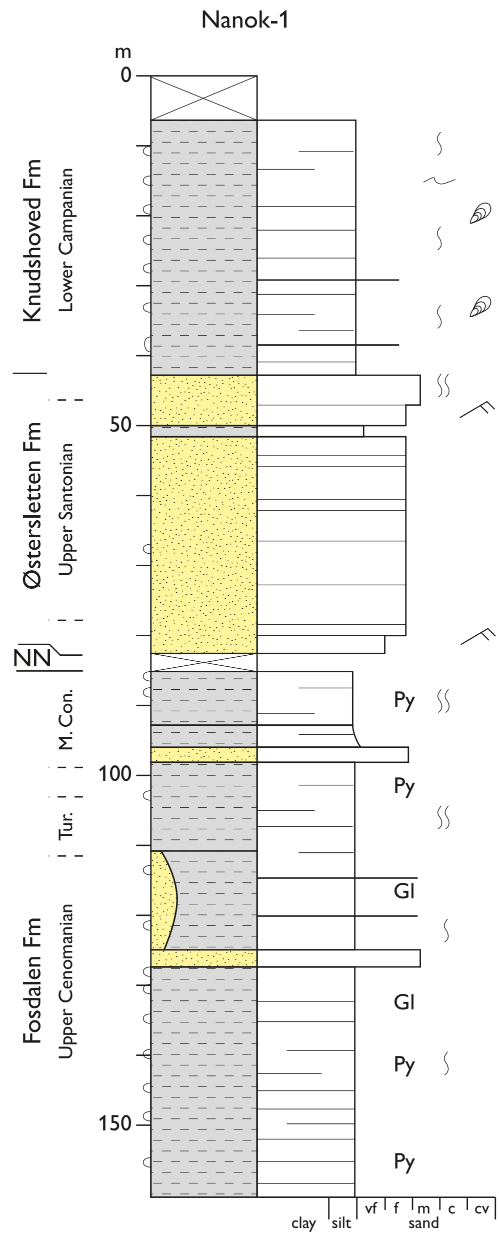


Fig. 33. The upper Cenomanian – lower Campanian succession in the Nanok-1 borehole, with the Fosdalen, Østersletten and Knudhoved Formations. NN: Nanok Member. No core was recovered from the Nanok Member, but its presence at this level is known from exposures near the drill site.

Type section. Northern bank of the Månedal valley in northern central Traill Ø (Figs 35, 36; Surlyk & Noe-Nygaard 2001).

Thickness. According to Surlyk & Noe-Nygaard (2001), the formation is about 45 m thick at the type section, although a thickness of 80–100 m was estimated by Donovan (1953). In this study, a section 55 m thick was measured in the type section (Fig. 36).

Fig. 34. Pebbly and sandy, red, calcareous mudstones of the Nanok Member overlain by sandstones of the Østersletten Formation at Knudshoved, Hold with Hope. Hammer 32 cm long for scale.

Lithology. The Månedal Formation mainly comprises coarse conglomerates and sandstones with minor mudstone units (Fig. 36). The conglomerates are typically clast-supported and both chaotic, disorganised and graded, imbricated variants are represented. The coarse-grained intervals typically show little systematic grain-size or facies trends, alternating abruptly with mudstone units (Fig. 36). Clasts in the conglomerates comprise crystalline basement rocks, Permian carbonates and undifferentiated Mesozoic sandstones and mudstones, apparently showing a weak tendency to occur in inverse stratigraphic order up through the succession; the largest clast recorded is 2.5 × 6 m in cross-section.

Fossils. Poorly preserved inoceramid bivalves occur in the upper levels of the formation. Rare and poorly preserved ammonites and belemnites were also reported by Donovan (1953) and Surlyk & Noe-Nygaard (2001). No dinoflagellate cysts have been recorded from the formation.

Depositional environment. The conglomerates and sandstones were deposited in a submarine slope apron with intermittent fine-grained sedimentation from suspension (Surlyk & Noe-Nygaard 2001). Although occurring close to the Månedal Fault (Fig. 2), Surlyk & Noe-Nygaard (2001) argued that this slope apron was probably sourced from the active Post-Devonian Main Fault, some 25 km farther to the west.

Boundaries. At the type section, the lower boundary is poorly exposed but is inferred to be an erosional surface, overlying mudstones of the Fosdalen Formation, which are mapped in the vicinity. The upper boundary is also poorly exposed but stratigraphic considerations in the area indicate that it is overlain by mudstones of the Knudshoved Formation.

Distribution. Although defined locally on northern Traill Ø, similar deposits at this stratigraphic level at Kap Hovgaard, southern Geographical Society Ø described by Donovan (1954) are also referred to the Månedal Formation.

Chronostratigraphy. The formation is referred to the Turonian–Coniacian based on ammonites and bivalves, and bracketing ages from the Fosdalen Formation beneath and the Knudshoved Formation above it.

Key references. Donovan (1953, 1954); Surlyk & Noe-Nygaard (2001).

Kista Ø Formation

Renamed formation

History. This lithostratigraphic unit was defined as the Vega Sund Formation by Surlyk & Noe-Nygaard (2001). It was subsequently appreciated that this name is invalid due to previous usage in North-East Green-

Fig. 35. A: East-dipping Turonian fan conglomerates and sandstones of the Månedal Formation, type section in Månedal, Traill Ø (encircled person for scale). **B:** Detail of conglomerate with muddy matrix and mudstone clasts sharply overlain (boundary indicated with a dashed line) by an inversely graded conglomerate showing imbricated clasts. Scale bar 1.2 m.

land for a member of the Middle Triassic Gipsdalen Formation (Clemmensen 1980). It is thus renamed here as the Kista Ø Formation.

Name. After the island Kista Ø, which lies in Vega Sund just north of the type locality (Fig. 2).

Type section. Surlyk & Noe-Nygaard (2001) defined the type section in a gorge immediately inland of the mouth of the Månedal valley, northern Traill Ø (Fig. 37).

Thickness. The formation is at least 90 m thick in the area of the type section, but the base of the formation is not seen.

Lithology. In the type section, the formation comprises a uniform succession of parallel-bedded, decimetre-thick sheet sandstones interbedded with thin mudstones. The sandstones are typically normally graded and show parallel and current ripple cross-lamination (Tb, Tbc turbidites). The lower c. 55 m is sand-dominated but the formation shows an overall fining upward trend (Fig. 37; Surlyk & Noe-Nygaard 2001)

Fossils. Rare inoceramid bivalves have been recorded (see discussion in Surlyk & Noe-Nygaard 2001). The dinoflagellate cyst flora is characterised by the FO of *Alterbidinium ioannidesii* indicating the upper Santonian (Nøhr-Hansen *et al.* 2019).

Depositional environment. Surlyk & Noe-Nygaard (2001) referred the formation to a basin-floor fan environment.

Boundaries. The base of the formation is not observed. The upper boundary is poorly exposed but the overall fining-upward trend in the upper 30 m of the formation suggests that it grades transitionally up into mudstone-dominated facies of the Knudshoved Formation.

Distribution. The formation is only recognised at the mouth of the Månedal valley on northern Traill Ø.

Chronostratigraphy. The formation is referred to the Coniacian–Santonian, where inoceramid bivalves suggest a Coniacian age (Surlyk & Noe-Nygaard 2001). The upper 23 m of the 90 m thick type section is referred to the upper Santonian based on dinoflagellate cysts (palynostratigraphic zone XI of Nøhr-Hansen *et al.* (2019)).

Key references. Donovan (1953, 1955); Surlyk & Noe-Nygaard (2001); Nøhr-Hansen *et al.* (2019).

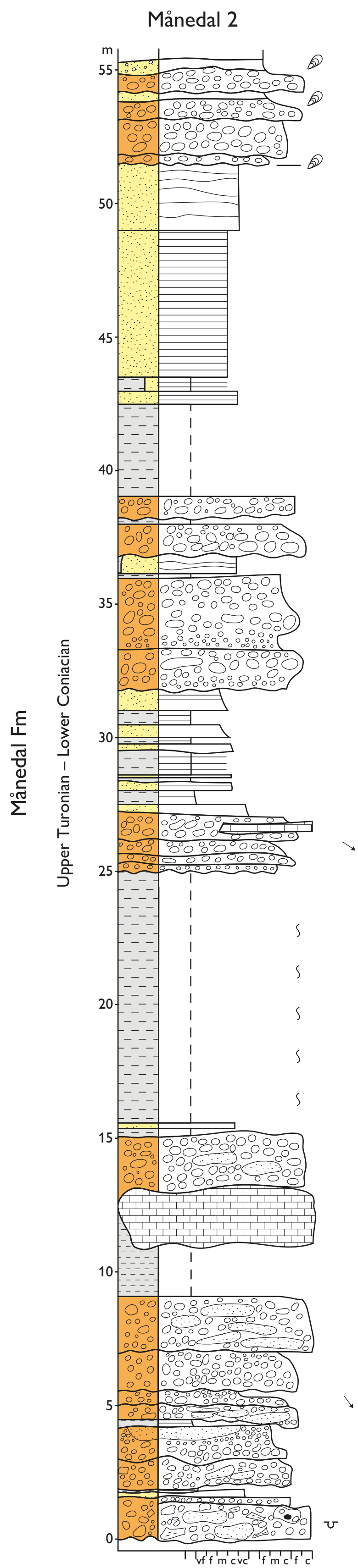


Fig. 36. Type section of the Turonian–Coniacian Månedal Formation showing coarse-grained gravity flow deposits and poorly exposed interbedded mudstones. Measured at the type locality of Surlyk & Noe-Nygaard (2001), Månedal, Traill Ø.

Østersletten Formation

Elevated formation

History. This sand-dominated formation was erected as a member by Kelly *et al.* (1998) in Hold with Hope. It is here elevated to formation rank and includes the Nanok Member as the basal unit of the formation.

Type section. The type section is situated 4 km south-west of Knudshoved, north-eastern Hold with Hope (Figs 3, 38; Kelly *et al.* 1998).

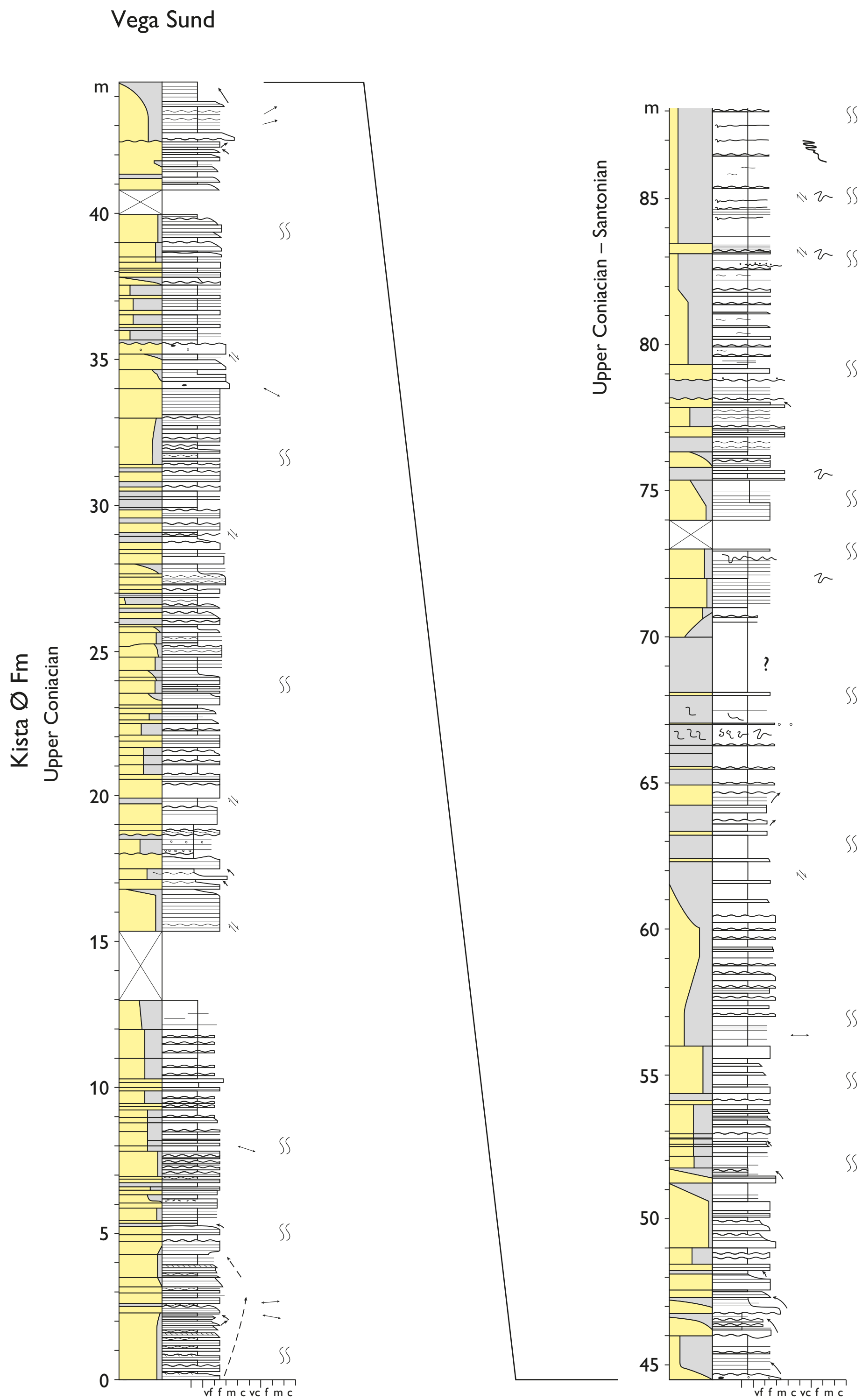


Fig. 37. Type section of the Turonian–Santonian basin floor fan sandstones of the Kista Ø Formation (the Vega Sund Formation of Surlyk & Noe-Nygaard 2001), mouth of Månedal at Traill Ø.

Reference section. The Nanok-1 cored section in north-eastern Hold with Hope provides a reference section (Fig. 33; the core is stored at GEUS, Copenhagen, Denmark).

Thickness. The formation is 46 m thick in the type section (Kelly *et al.* 1998), and a thickness of about 42 m was recorded in the Nanok-1 borehole.

Lithology. With the exception of the basal *c*. 6 m of sandy and pebbly mudstones (Nanok Member, see below), the formation is sandstone-dominated and mainly consists of stacked light brown, fine- to medium-grained, homogeneous sandstone beds (up to 6 m thick) with erosional bases and in places showing diffuse parallel stratification. Floating mudstone clasts occur locally. Interbeds include dark grey sandstones with a high content of mica and organic material, locally showing parallel- and cross-lamination, and thin heterolithic fine-grained sandstone – mudstone intervals showing bioturbation at some levels.

Fossils. Macrofossils are rare but some bivalves, gastropods and cephalopods have been reported (see discussion in Kelly *et al.* 1998). The dinoflagellate cyst flora is characterised by the FO of *"Chatangiella spinosa"* (undescribed species, informally so named in industrial reports) indicating the middle Coniacian, the FO of *Alterbidinium ioannidesii* indicating the upper Santonian and the FO of the pollen *Aquilapollenites* spp. indicating the lower Campanian (Nøhr-Hansen *et al.* 2019).

Depositional environment. The sandstone-dominated portion of the formation represents gravity-flow deposits that accumulated in a basin-floor fan setting (Whitham *et al.* 1999).

Boundaries. The reddish-brown muddy Nanok Member abruptly overlies dark mudstones of the Fosdalen Formation in the type area. The top of the formation is marked by a prominent surface where sandstones of the Østersletten Formation are abruptly overlain by mudstones of the Knudshoved Formation.

Distribution. The Østersletten Formation is restricted to the type area of eastern Hold with Hope. The Kista Ø Formation of Traill Ø is broadly age-equivalent though probably represents a separate turbidite system.

Chronostratigraphy. Dinoflagellate cyst biostratigraphy indicates that the formation is largely Santonian in age though potentially ranging from the middle Coniacian to the earliest Campanian (palynostratigraphic zones X, XI, lower XII 1 of Nøhr-Hansen *et al.* (2019)).

Subdivision. The Østersletten Formation includes the Nanok Member as the basal unit.

Key references. Kelly *et al.* (1998); Whitham *et al.* (1999); Nøhr-Hansen *et al.* (2019).

Nanok Member

Reassigned member

History. The Nanok Member was erected as a member of the Home Forland Formation of Hold with Hope by Kelly *et al.* (1998). This characteristic unit is herein transferred to the Østersletten Formation (previously also a member of the Home Forland Formation). It is recognised as a discrete unit of the Østersletten Formation due to its distinctive facies and colour, forming a key stratigraphic marker in the area (Fig. 34).

Type section. Kelly *et al.* (1998) defined the type section a few kilometres south-west of Knudshoved, in north-eastern Hold with Hope.

Thickness. The member is about 6 m thick in the type section.

Lithology. The Nanok Member comprises a lower unit of reddish brown muddy and pebbly sandstones with common reworked phosphatised concretions overlain by grey glauconitic, medium-grained sandstones and muddy sandstones (Fig. 34; Kelly *et al.* (1998)).

Fossils. Macrofossils include bivalves, a few gastropods and vertebrate teeth (Kelly *et al.* 1998). Biostratigraphically significant dinoflagellates have been recovered from the upper beds and from adjacent underlying and overlying lithostratigraphic units. The dinoflagellate cyst flora is characterised by the FO of *"Chatangiella spinosa"* (undescribed species, informally so named in industrial reports) indicating the middle Coniacian (Nøhr-Hansen *et al.* 2019).

Depositional environment. The member records a period of slow sedimentation (a condensed section) on a deep marine shelf.

Boundaries. The lower boundary is sharp and probably erosional and placed at the base of a muddy sandstone with phosphatic concretions overlying dark grey mudstones of the Fosdalen Formation (Kelly *et al.* 1998). The member is overlain abruptly by thick-bedded sandstones of the Østersletten Formation (Fig. 34).

Fig. 38. The Østersletten Formation type section showing metre-thick massive sandstone beds, Knudshoved, Hold with Hope. Person for scale points at boundary between the Østersletten and Knudshoved Formations.

Distribution. The Nanok Member is restricted to the area of the type section on eastern Hold with Hope.

Chronostratigraphy. Middle Coniacian to middle Santonian based on dinoflagellate cysts, palynostratigraphic zone X of Nøhr-Hansen *et al.* (2019).

Key references. Maync (1949); Stemmerik *et al.* (1993); Kelly *et al.* (1998); Nøhr-Hansen *et al.* (2019).

Knudshoved Formation

Amended and elevated in rank

History. The formation was erected as a member of the Home Forland Formation locally in Hold with Hope by Kelly *et al.* (1998), based on the upper mudstone-dominated part of the Knudshoved Beds as described by Maync (1949). In the Geographical Society Ø – Traill Ø region it includes the *Sphenoceramus* and *Scaphites* Beds of Donovan (1955, 1957) and Parsons *et al.* (2017).

Type section. Kelly *et al.* (1998) defined the type section 4 km south-west of Knudshoved, north-eastern Hold with Hope.

Thickness. The formation is up to 80 m thick in the type area (Kelly *et al.* 1998) but probably exceeds 100 m at Leitch Bjerg on Geographical Society Ø.

Lithology. The formation is dominated by micaceous, dark grey mudstones with siderite concretions, and subordinate thin, normally graded sandstone beds. The mudstones are represented by laminated or bioturbated units and are locally fossiliferous. Thinly interlaminated sandstone–mudstone heteroliths are developed locally.

Fossils. Macrofossils are common, particularly in concretions where both complete and fragmentary shells are preserved; Kelly *et al.* (1998) recorded an abundant bivalve fauna. Ammonites are rare and include scaphitids (Donovan 1953, 1954, 1957). The mudstones yield rich dinoflagellate cyst assemblages in the Geograpical Society Ø – Wollaston Forland region (Kelly *et al.* 1998; Nøhr-Hansen *et al.* 2019). The pollen and dinoflagellate cyst flora is characterised by the FO of *Aquilapollenites* spp., *Chatangiella bondarenkoi* indicating the base of the lower Campanian, the FO of *Isabelidinium microarmum* indicating the upper lower Campanian, the FO of *Cerodinium diebelli* indicating the upper Campanian, the FO of *Alterbidinium biaperturum* and *Wodehouseia gracile* indicating the uppermost Campanian – lowermost Maastrichtian, and the FO of *Hystrichosphaeridium* sp. 3 McIntyre 1974 indicating the lower Maastrichian (Nøhr-Hansen *et al.* 2019).

Depositional environment. Marine slope and basin.

Boundaries. The mudstones of the Knudshoved Formation conformably but abruptly overlie the uppermost sandstones of the Østersletten Formation; a thin hiatal lag and bioturbated horizon may mark this boundary. In central Geographical Society Ø, the upper boundary is an erosional surface overlain by conglomerates of the Leitch Bjerg Formation. Elsewhere, the formation is unconformably overlain by Paleocene sediments or Palaeogene basalts.

Distribution. The formation occurs at Knudshoved in eastern Hold with Hope, on Jackson Ø, in the valley of Haredal in Wollaston Forland, in the Hundeklemmen, Leitch Bjerg and west of Laplace Bjerg areas on Geographical Society Ø and in the Rold Bjerge – Månedal area on Traill Ø.

Chronostratigraphy. The formation is known from a number of partial sections over a wide area, and the upper levels of the formation in particular are only rarely exposed and thus poorly known. Overall, the formation is considered as Campanian – Lower Maastrichtian based on dinoflagellate cysts, pollen, bivalves and ammonites (palynostratigraphic zones XII–XIII of Nøhr-Hansen *et al.* (2019)).

Key references. Donovan (1955, 1957); Kelly *et al.* (1998); Parsons *et al.* (2017).

Leitch Bjerg Formation

New formation

History. The Campanian conglomeratic succession at Leitch Bjerg, central eastern Geographical Society Ø (Fig. 2) was briefly described but not formally defined as a lithostratigraphic unit by Parsons *et al.* (2017).

Type section. The type section is located on the south side of Leitch Bjerg, central eastern Geographical Society Ø (72.84907°N, 22.46157°W; Figs 39, 40).

Thickness. The formation is 109 m thick at the type section, thinning westwards to 40 m over a distance of 3 km (Parsons *et al.* 2017).

Lithology. The formation comprises a series of stacked fining-upwards cycles (Figs 39, 40). Channelised, mainly clast-supported conglomerates that may be ungraded and disorganised or show coarse-tail normal grading and imbrication pass up into structureless or parallel-stratified sandstones with common mudstone clasts. Bioturbation occurs locally. Interbedded mudstones and thin sheet sandstones typically form the upper part of the fining-upwards cycles and dominate the upper *c.* 15 m of the formation (Fig. 40).

Fossils. Serpulids and wood fragments are common in certain beds, a few ammonoids were collected and dinoflagellate cysts were recorded from samples from the Hundeklemmen area. The dinoflagellate cyst flora is characterised by the presence of *Isabelidinium microarmum* indicating the upper lower Campanian and the presence of *Alterbidinium ioannidesii* (Nøhr-Hansen *et al.* 2019).

Depositional environment. The facies record deposition from sediment gravity flows within a high-energy channelised environment in a deep marine setting – probably part of an inner fan or slope apron system.

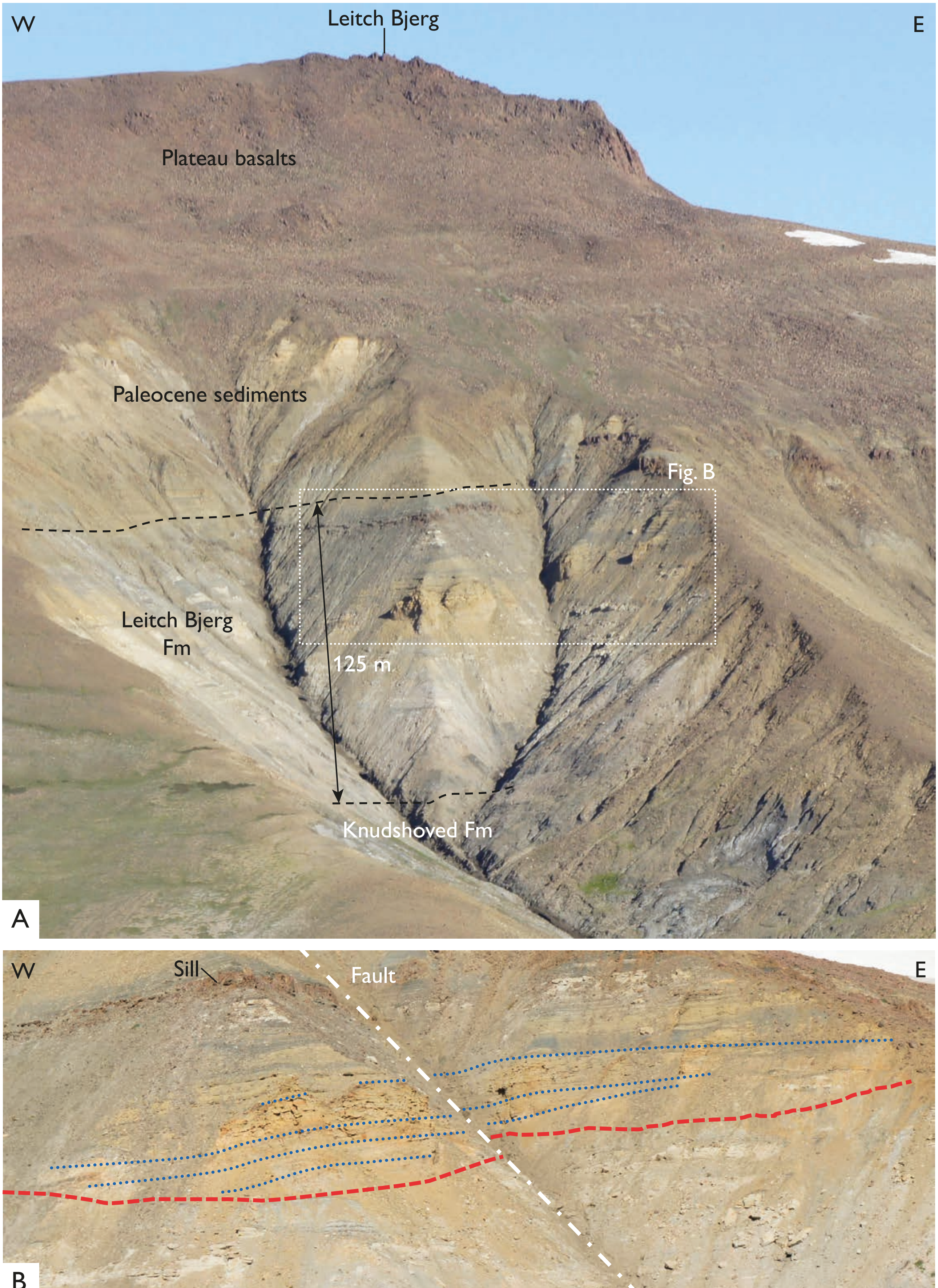
Boundaries. The basal conglomerate bed erosionally overlies dark grey mudstones of the Knudshoved Formation. The upper boundary is an erosional unconformity overlain by Paleocene sand-rich deposits (Fig. 39).

Distribution. The formation is only known from the Leitch Bjerg – Hundeklemmen area of eastern Geographical Society Ø.

Chronostratigraphy. Ammonoids and dinoflagellate cyst assemblages in the Hundeklemmen and Leitch Bjerg sections are assigned to the lower–middle Campanian (palynostratigraphic zone XII 2 of Nøhr-Hansen *et al.* (2019)).

Key references. Parsons *et al.* (2017); Nøhr-Hansen *et al.* (2019).

▶ **Fig. 39. A:** Jackson Ø Group with dark grey mudstones of the lower Campanian Knudshoved Formation erosionally overlain by the Campanian Leitch Bjerg Formation, which is unconformably overlain by sandy Paleocene deposits. Geographical Society Ø, type locality of the Leitch Bjerg Formation. **B:** Erosional and channelised slope apron conglomerates and sandstones and inter-channel mudstones. Dashed red line indicates base of channel; dotted blue lines indicate bedding surfaces.


W
Leitch Bjerg
E
Plateau basalts
Paleocene sediments
Fig. B
Leitch Bjerg
Fm
125 m
Knudshoved Fm
A
W
Sill
Fault
E
B

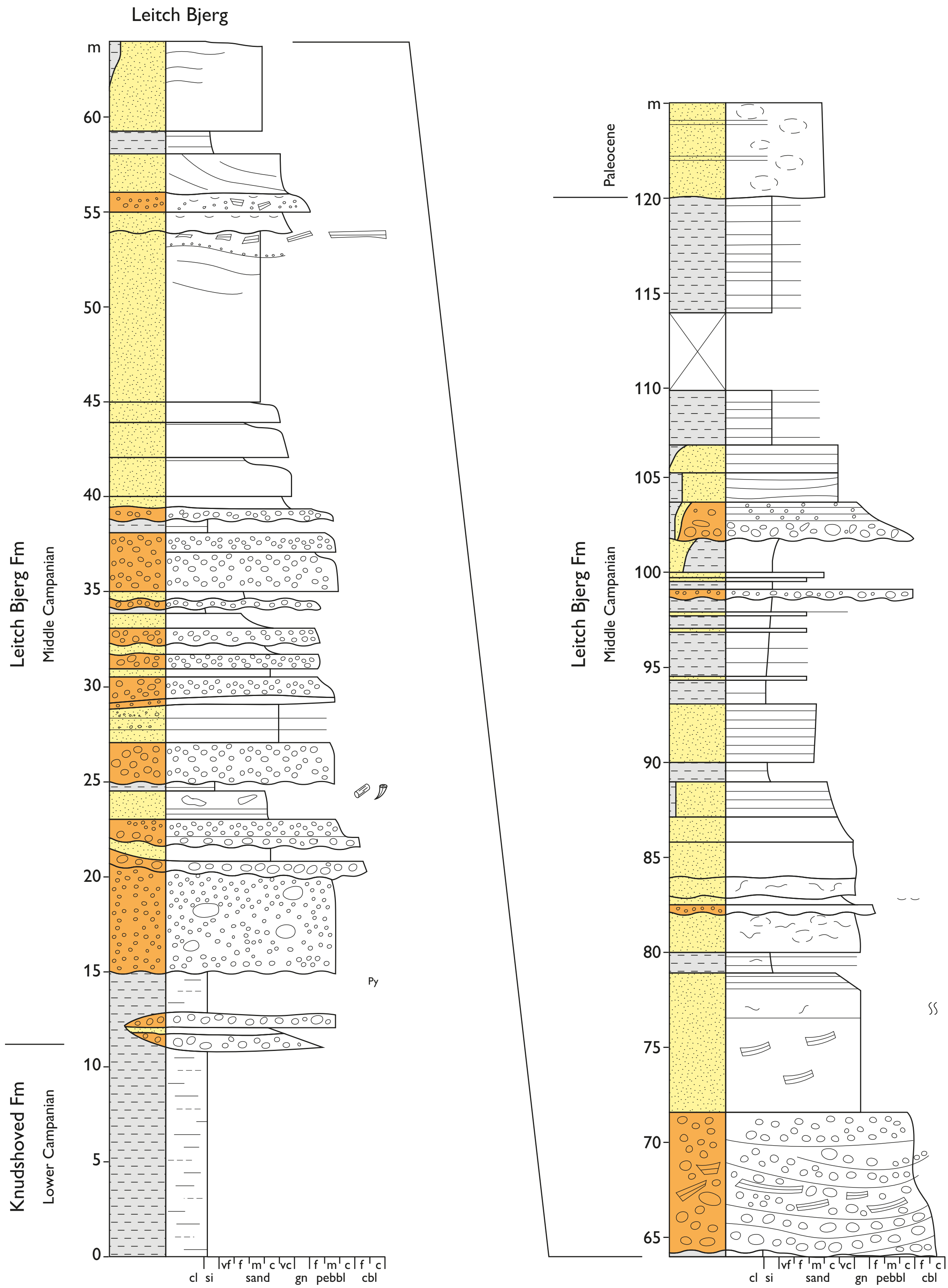


Fig. 40. Type section of the Leitch Bjerg Formation with channelised slope apron conglomerates and sandstones and inter-channel mudstones. Leitch Bjerg, Geographical Society Ø.

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