Nuussuaq Group

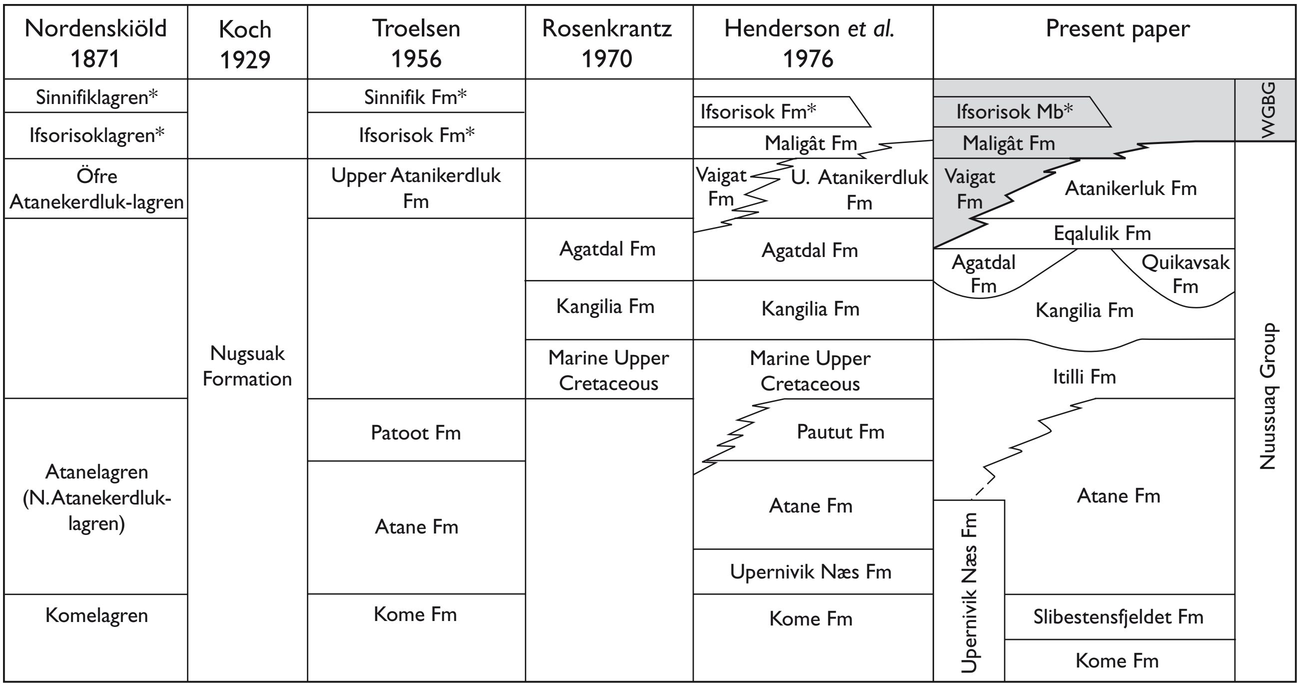
new group

History. The Nuussuaq Group comprises the pre- and synvolcanic Cretaceous–Paleocene sediments on a number of islands and peninsulas in West Greenland between 69° and 72°N (Fig. 10). Intrabasaltic sediments are not included in the Nuussuaq Group but in the overlying West Greenland Basalt Group, with the local exception of thin, intra-volcanic wedges of sediment that demonstrably interdigitate with prograding hyaloclastite breccias and lavas of the lowermost West Greenland Basalt Group. Initial investigations of the geology date back to K.L. Giesecke, who described the area in detail around 1810 (in: Steenstrup 1910), Rink (1853, 1857) and Nordenskiöld (1871); the latter erected three lithostratigraphic units for the pre-volcanic sediment, separate from the intra-basaltic Ifsorisok Beds (Fig. 13; see section on 'Previous work' above). However, these units were not recognised by L. Koch (1929) in his exhaustive account of the stratigraphy of Greenland. He referred all the sediments to one formation – the Nugsuak Formation – but also predicted that "future investigations will doubtlessly result in a division of the beds which I have included in one formation, into several formations" (L. Koch 1929 p. 258).

A more detailed lithostratigraphical scheme was developed as a result of the work during the Nûgssuaq Expeditions 1938–1968 (see section on 'Previous work' above; Rosenkrantz 1970). This was, however, rather incomplete and included units, especially at member level, that were not formally described (Fig. 13).

Name. After the Nuussuaq peninsula, where the most extensive outcrops occur (Fig. 10).

Type area. The south coast of Nuussuaq, where the most complete and best exposed sections of the Nuussuaq Group occur, e.g. at Atanikerluk, the coastal slopes at Paatuut, along the western slope of the Ataata Kuua river, and in river gorges in the southern part of the Itilli val-



* Intrabasaltic sediments

Fig. 13. Comparison of former lithostratigraphical subdivisions and the scheme used in this paper. All pre-volcanic and the earliest synvolcanic sedimentary rocks of the Nuussuaq Basin constitute the Nuussuaq Group (new), which comprises 10 formations (new or revised). **WGBG**, West Greenland Basalt Group.

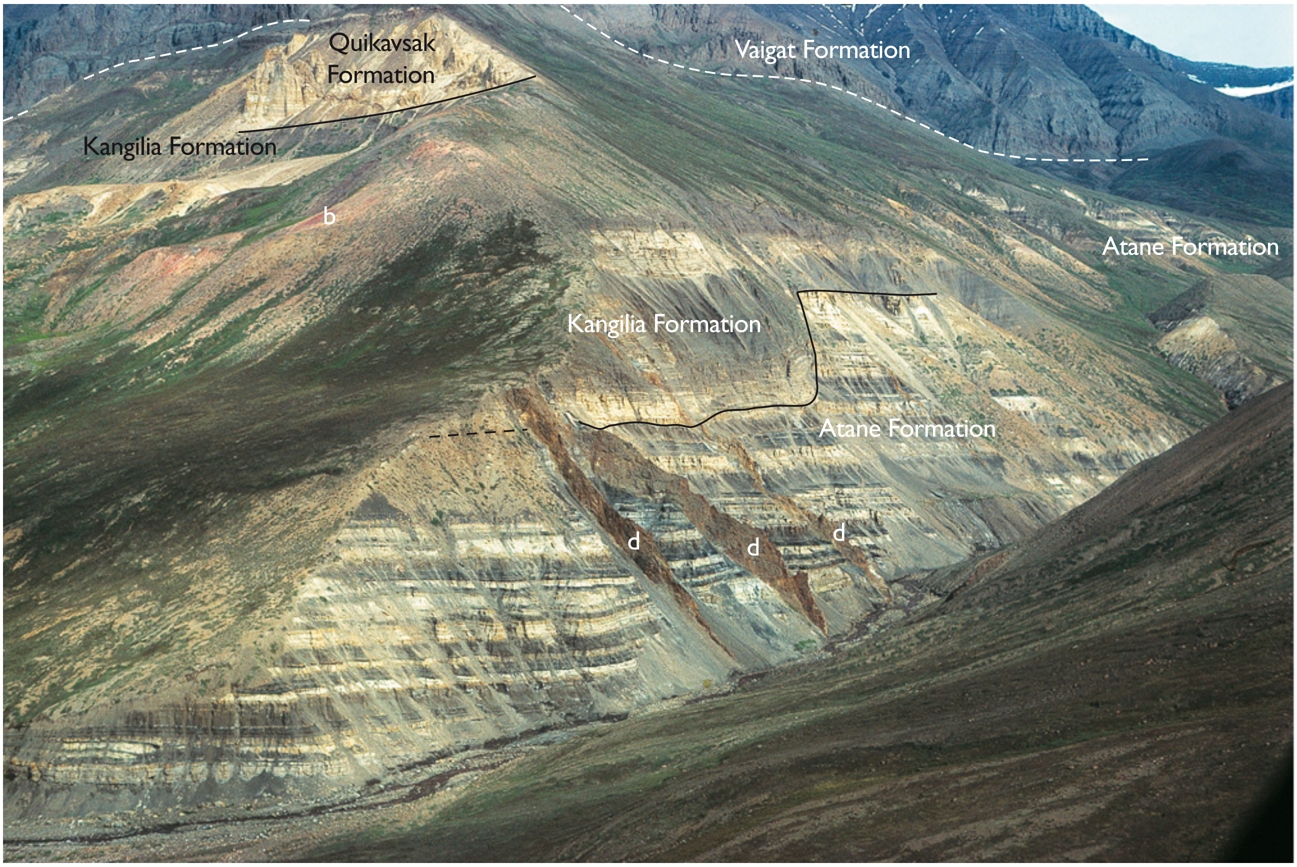


Fig. 14. The western side of the Ataata Kuua river gorge, in the type area of the Nuussuaq Group; **d**, dolerite dyke, **b**, burnt mudstones. For location, see Fig. 40; for scale, see Fig. 15.

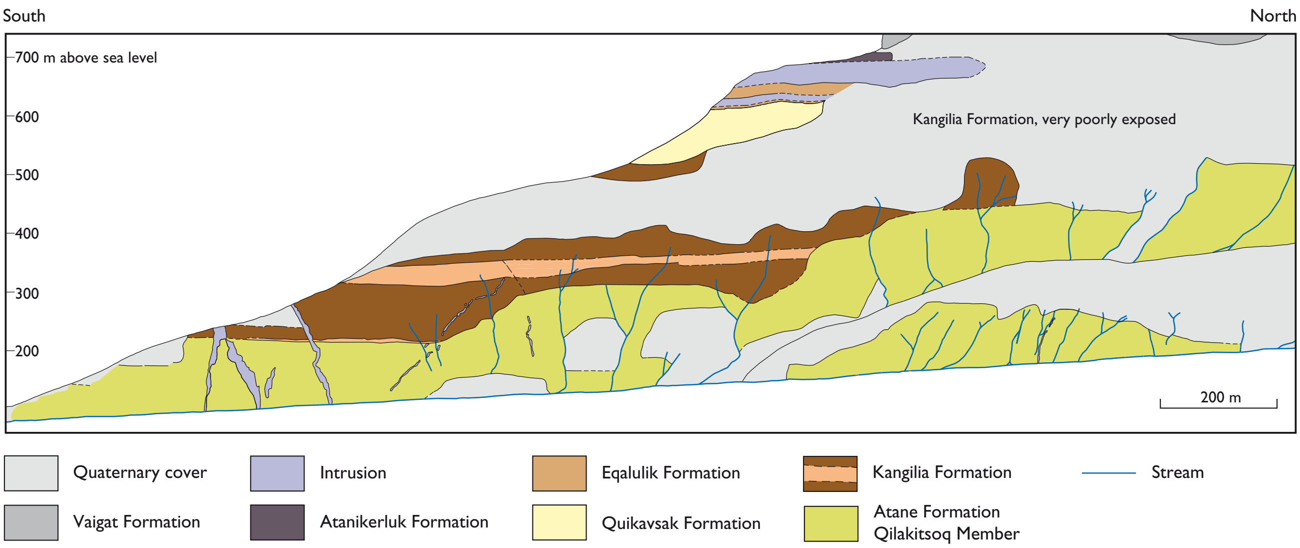


Fig. 15. The western side of Ataata Kuua, in the type area of the Nuussuaq Group, illustrates two phases of incision. The marine mudstone and turbidite sandstones of the Kangilia Formation represent a late Maastrichtian submarine canyon incised into the Santonian deltaic Atane Formation; mudstones of the Kangilia Formation are shown in brown, sandstones and conglomerates in beige. The Danian Quikavsak Formation represents a fluvial system incised into the Kangilia Formation. Photogrammetrically measured section, from A.K. Pedersen *et al.* (2007b). Borehole GGU 247801 is located *c.* 600 m north of the outcrop shown here (Figs 40, 43).

ley (Figs 2, 40, 65). The section along the west slope of Ataata Kuua has been measured photogrammetrically (Figs 14, 15; A.K. Pedersen *et al.* 2007b).

Distribution. The Nuussuaq Group outcrops in West Greenland between 69° and 72°N on Disko, Nuussuaq, Upernivik Ø, Qeqertarsuaq, Itsaku and Svartenhuk Halvø and has also been recorded in a number of shallow and deep wells in the region (Figs 2, 16, 17). Possible Palaeogene sediments have previously been reported on Angiissat, the south-easternmost island of a group of small islands in Disko Bugt named Grønne Ejland (Henderson *et al.* 1976 p. 345).

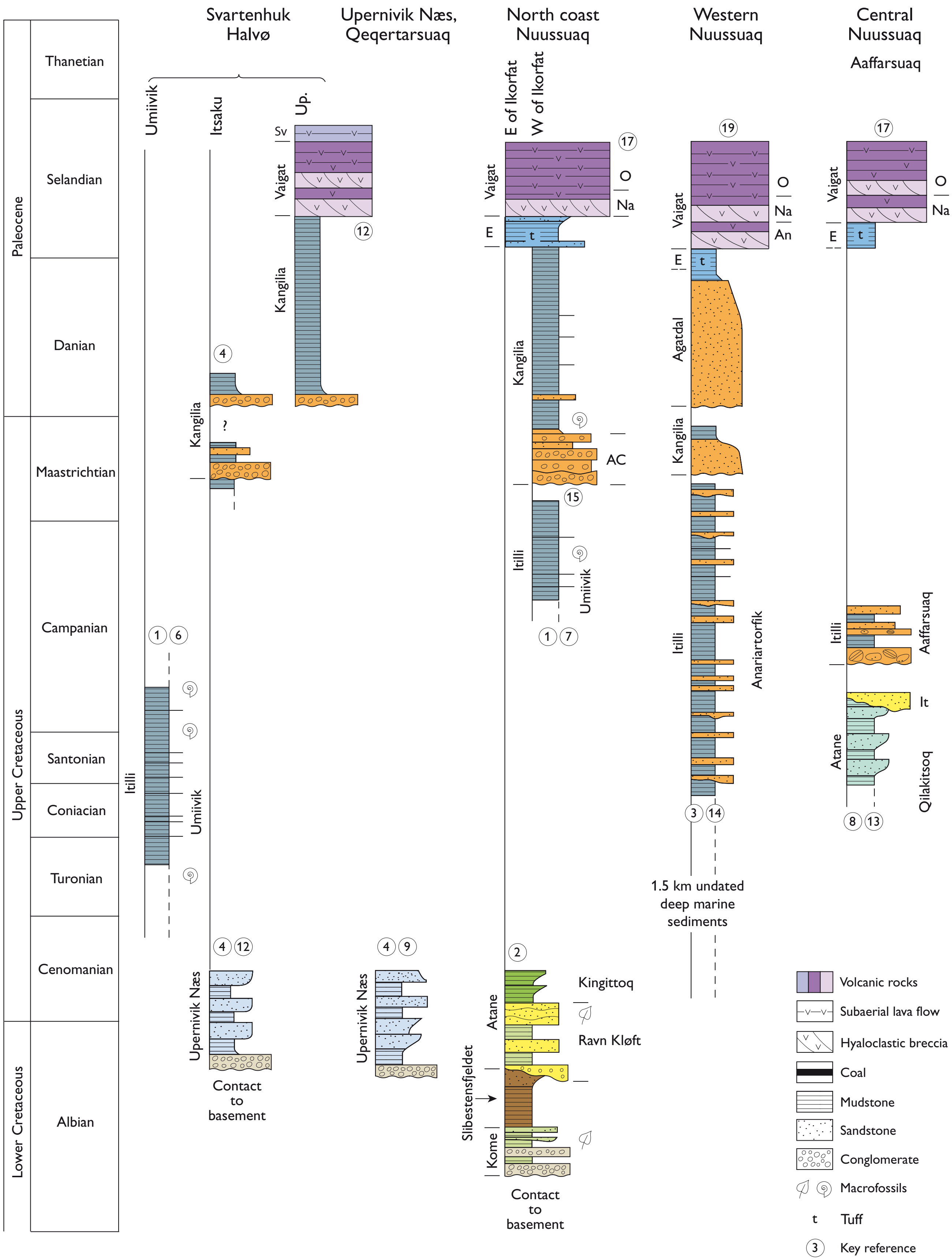
Differentiation of the Albian–Cenomanian Kome, Upernivik Næs and Atane Formations that form the lower part of the group can be difficult because these formations all include marginal marine deposits that are dominated by sandstones and have some sedimentary facies in common. For practical purposes, the Kome Formation is restricted to areas in northern Nuussuaq, east of Ikorfat, where alluvial sediments are in contact with basement. The Upernivik Næs Formation, which occurs north of Nuussuaq, comprises marginal marine sediments, while the fluviodeltaic Atane Formation is restricted to the Disko–Nuussuaq area.

Thickness. Composite sections of outcrops and wells show thicknesses of up to *c.* 3 km for the Nuussuaq Group (Fig. 17). In the western part of the area, seismic and magnetic data suggest that the Mesozoic sediments are at least 6 km and possibly as much as 10 km thick (Christiansen *et al.* 1995; Chalmers *et al.* 1999). A seismic section across the Vaigat indicates that the non-marine Cretaceous section is at least 2500–3000 m thick (Fig. 44; Marcussen *et al.* 2002).

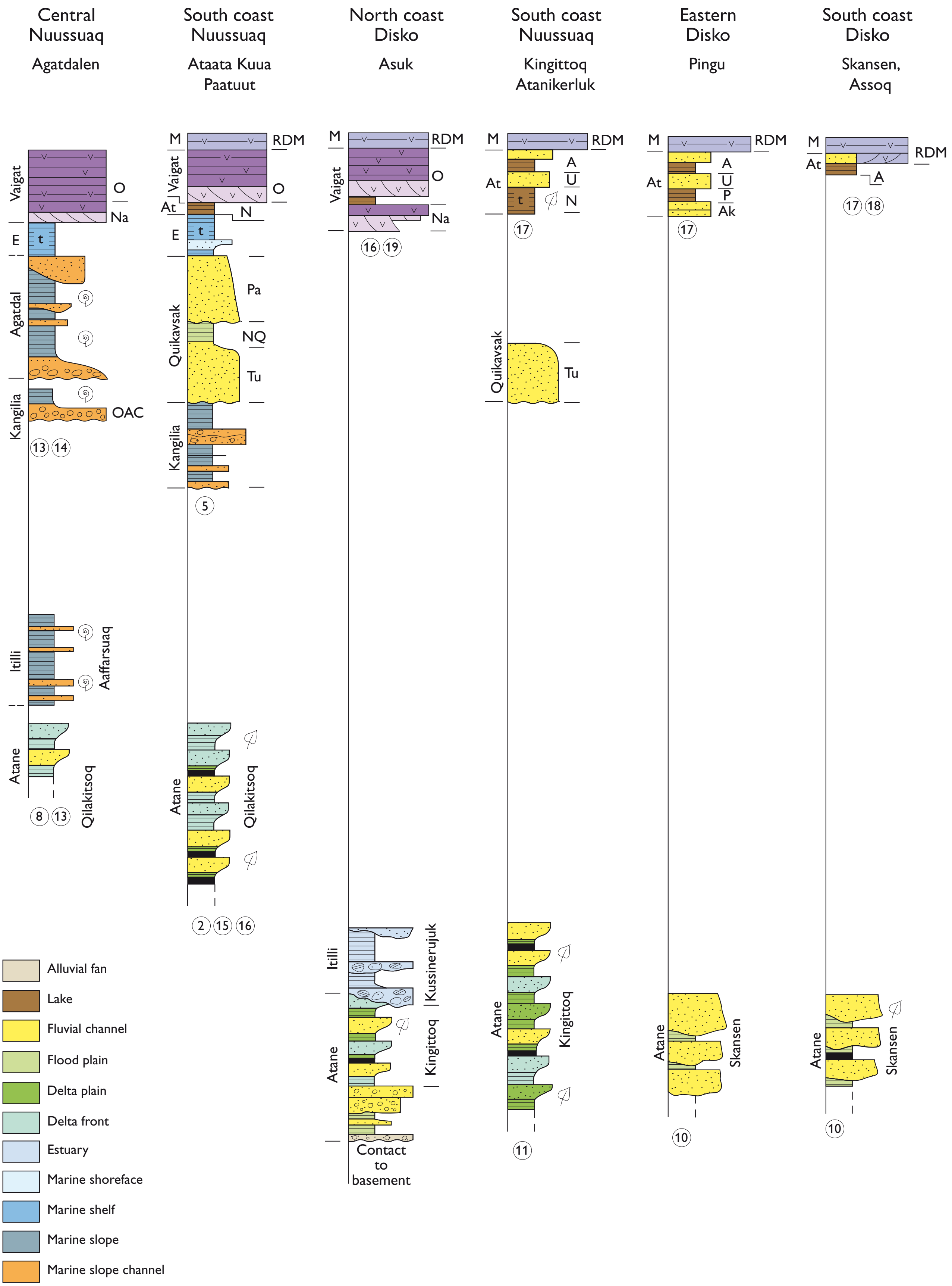
Lithology and depositional environment. The exposed part of the Nuussuaq Group consists entirely of siliciclastic sediments (Figs 16, 17). A reconnaissance study of the petrology of the Cretaceous and Paleocene sandstones revealed varying feldspar contents and three types of cement: carbonates, silica and Fe-hydroxides. Based on differences in texture, Schiener (1975) suggested two provenance areas: the Archaean crystalline basement rocks (angular feldspar grains) and older sedimentary rocks that have been recycled (well-rounded quartz grains). Detrital zircon dating of the sediments indicates that most of the Cretaceous sediments were transported from areas with Archaean basement, whereas the Late Cretaceous and Paleocene sediments at Itsaku on Svartenhuk Halvø contain Proterozoic zircons, probably derived from the Prøven Igneous Complex (Scherstén & Sønderholm 2007). The basal Lower Cretaceous part of the succession includes coarse-grained, syn-rift breccias and conglomerates that onlap basement highs and are overlain by sandstones, heteroliths and mudstones of non-marine, mostly alluvial origin (Fig. 16). Slightly younger braided river sandstones interbedded with sandstones, heteroliths and mudstones deposited in tidal estuarine and coastal plain environments crop out on Upernivik Ø and Qeqertarsuaq and are referred to the Upernivik Næs Formation.

On northern Nuussuaq, the Kome Formation is overlain by lacustrine mudstones and sandstones of the Slibestensfjeldet Formation. The Atane Formation unconformably overlies the Slibestensfjeldet Formation and possibly also the Kome Formation. The Atane Formation is dominated by coarsening-upward successions of mudstones and sandstones deposited in a deltaic and fluvial environment during the Albian to Santonian. Across the Kuugannguaq–Qunnilik Fault (Fig. 10), the deltaic sed-

Next pages 32-33:
Fig. 16. Stratigraphy and depositional settings of the formations and members of the Nuussuaq Group. The sections are located in Fig. 2 or in the detailed maps located in Fig. 2. **Up**., Uparuaqqusuitsut (Svartenhuk Halvø). Formations are shown on the left hand side of the logs and members on the right hand side. The vertical axis of the diagram indicates the approximate age of the lithostratigraphical units (data on ages are found in the selected numbered references below). Compare with Fig. 17.
Stratigraphic abbreviations: **A**, Assoq Member (Atanikerluk Formation); **Ak**, Akunneq Member (Atanikerluk Formation); **An**, Anaanaa Member (Vaigat Formation); **At**, Atanikerluk Formation; **AC**, Annertuneq Conglomerate Member (Kangilia Formation); **E**, Eqalulik Formation; **It**, Itivnera Bed (Atane Formation); **M**, Maligât Formation; **N**, Naujât Member (Atanikerluk Formation); **Na**, Naujánguit Member (Vaigat Formation); **NQ**, Nuuk Qiterleq Member (Quivaksak Formation); **O**, Ordlingassoq Member (Vaigat Formation); **OAC**, Oyster–Ammonite Conglomerate Bed (Kangilia Formation); **P**, Pingu Member (Atanikerluk Formation); **Pa**, Paatuutkløften Member (Quikavsak Formation); **RDM**, Rinks Dal Member (Maligât Formation); **Sv**, Svartenhuk Formation; **Tu**, Tupaasat Member (Quikavsak Formation); **U**, Umiussat Member (Atanikerluk Formation).
References: **1**, Birkelund (1965); **2**, Boyd (1998 a); **3**, Christiansen *et al.* (1999); 4, Christiansen *et al.* (2000); **5**, Dam & Nøhr-Hansen (2001); **6**, Dam *et al.* (1998b); 7, Dam *et al.* (1998c); 8, Dam *et al.* (2000); **9**, Koch (1964); **10**, Koppelhus & Pedersen (1993); **11**, Lanstorp (1999); **12**, J.G. Larsen & Pulvertaft (2000); **13**, Nøhr-Hansen (1996); **14**, Nøhr-Hansen *et al.* (2002); **15**, Olsen & Pedersen (1991); **16**, A.K. Pedersen (1985); **17**, A.K. Pedersen *et al.* (2006b); **18**, Piasecki *et al.* (1992); **19**, Storey *et al.* (1998).



Svartenhuk Halvø
Upernivik Næs, Qeqertarsuaq
North coast Nuussuaq
Western Nuussuaq
Central Nuussuaq
Aaffarsuaq
Paleocene
Upper Cretaceous
Lower Cretaceous
Thanetian
Selandian
Danian
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Umiivik
Itsaku
Up.
Sv
Vaigat
Kangilia
Itilli
Upernivik Næs
Contact to basement
E of Ikorfat
W of Ikorfat
E
O
Na
An
AC
Agatdal
Anariartorfik
Aaffarsuaq
It
Atane
Qilakitsoq
Kingittoq
Ravn Kløft
Slibestensfjeldet
Kome
1.5 km undated deep marine sediments
t
?
Volcanic rocks
Subaerial lava flow
Hyaloclastic breccia
Coal
Mudstone
Sandstone
Conglomerate
Macrofossils
Tuff
Key reference



Central Nuussuaq
Agatdalen
South coast Nuussuaq
Ataata Kuua Paatuut
North coast Disko
Asuk
South coast Nuussuaq
Kingittoq Atanikerluk
Eastern Disko
Pingu
South coast Disko
Skansen, Assoq
Vaigat
E
Agatdal
Kangilia
Itilli
Atane
O
Na
OAC
Aaffarsuaq
Qilakitsoq
M
At
Quikavsak
RDM
N
Pa
NQ
Tu
Kussinerujuk
Kingittoq
Contact to basement
A
U
P
Ak
Skansen
Alluvial fan
Lake
Fluvial channel
Flood plain
Delta plain
Delta front
Estuary
Marine shoreface
Marine shelf
Marine slope
Marine slope channel

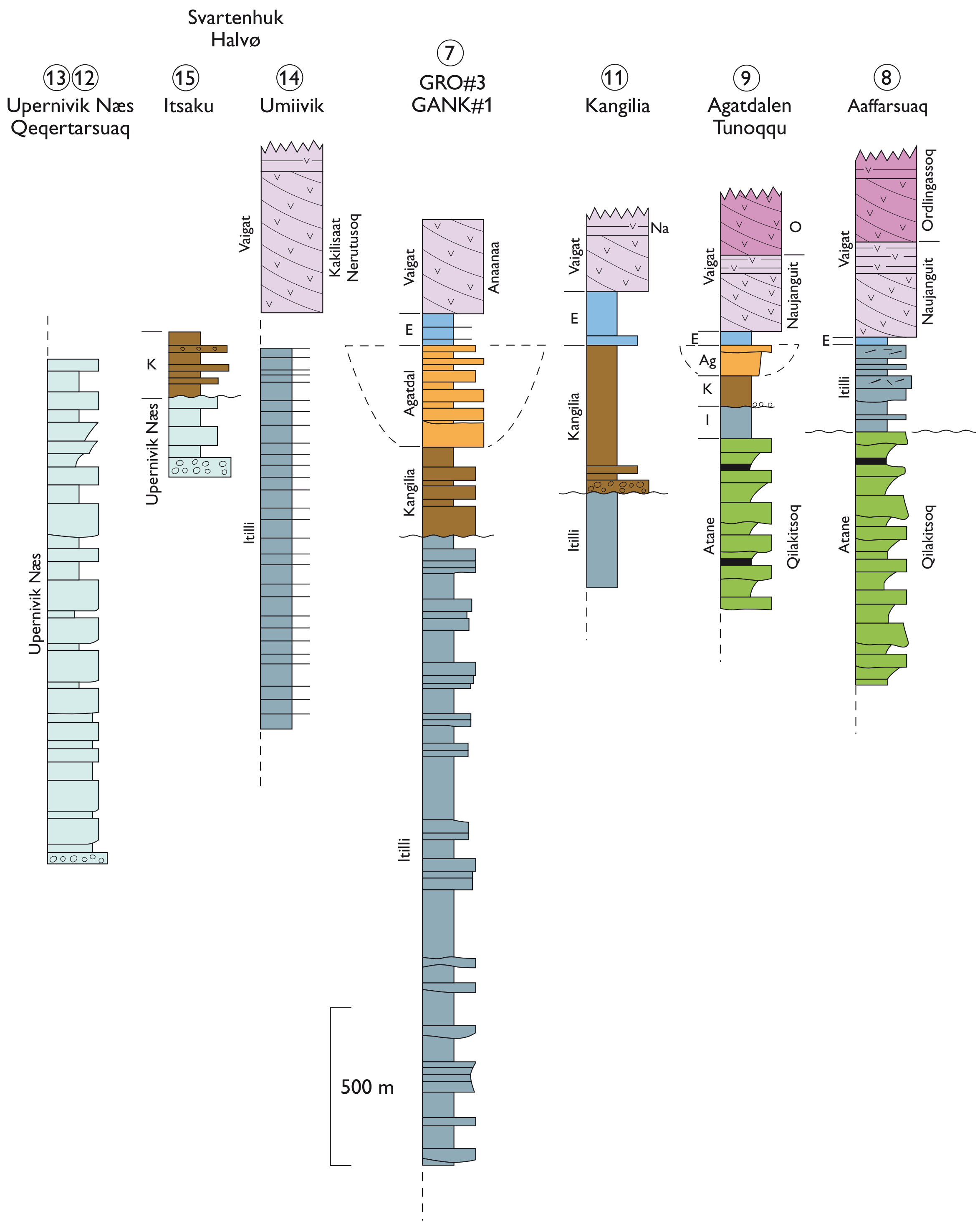
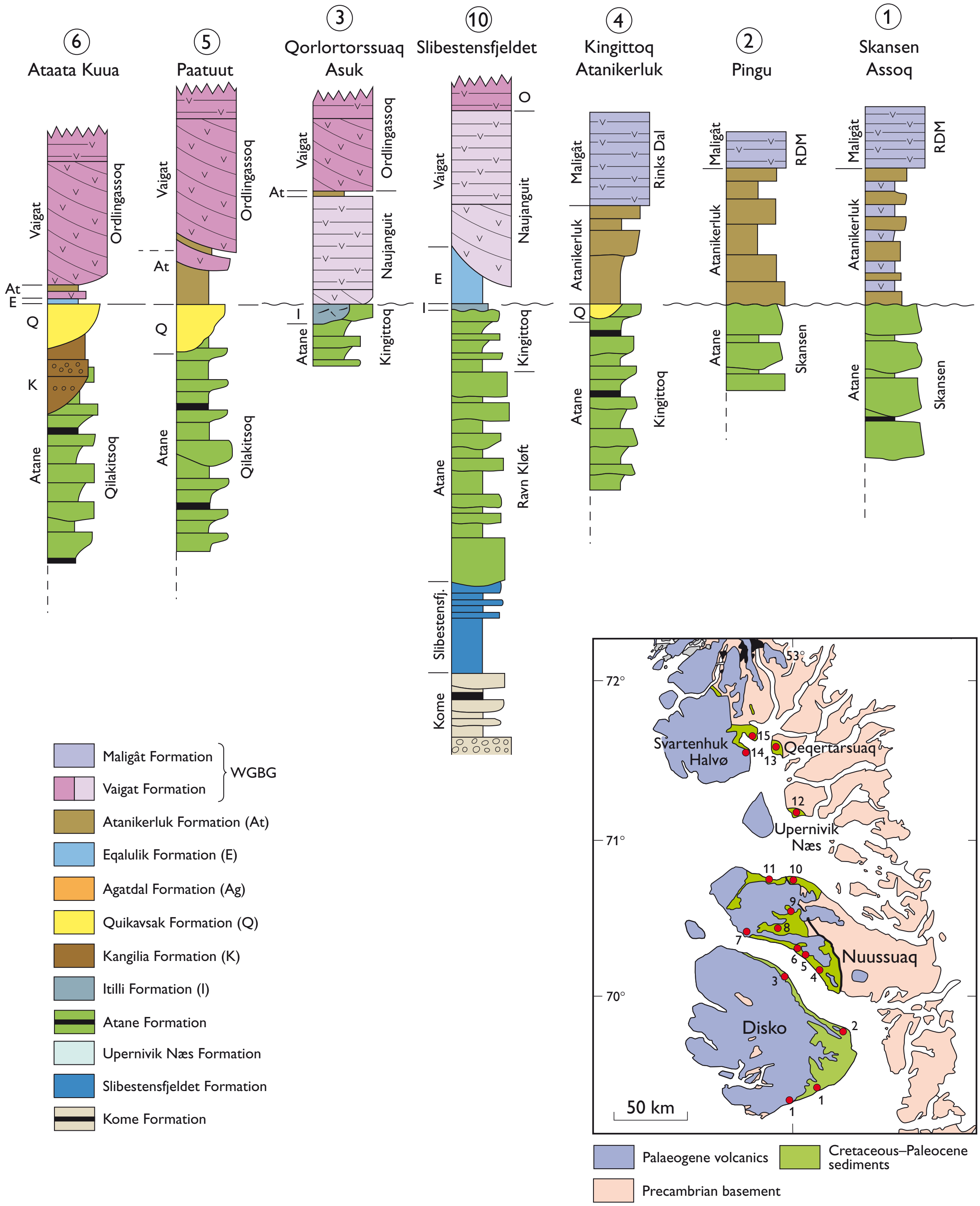


Fig. 17. Simplified logs showing the distribution and thickness of the formations of the Nuussuaq Group. Members are only indicated for the Atane Formation and for the volcanic formations. In most areas, the lower boundary of the Nuussuaq Group is not seen, and the thicknesses indicated for the formations are therefore minimum values. Note that the marginal marine deposits (Kome, Slibestensfjeldet, Upernivik Næs and Atane Formations) are thick on Disko, eastern Nuussuaq and northwards to Qeqertarsuaq. Deep marine deposits (Itilli, Kangilia and Agatdal Formations) are thickest on western and northern Nuussuaq and on Svartenhuk Halvø. At localities 1, 3, 5 and 6, the mudstones of the Atanikerluk Formation are interbedded with volcaniclastic breccias or subaqueous lava flows that have chemical compositions characteristic of the Vaigat and Maligât Formations. **Na**, Naujánguit Member; **O**, Ordlingassoq Member; **RDM**, Rinks Dal Member; **WGBG**, West Greenland Basalt Group. Compare with Fig. 16.


6 Ataata Kuua
5 Paatuut
3 Qorlortorssuaq Asuk
10 Slibestensfjeldet
4 Kingittoq Atanikerluk
2 Pingu
1 Skansen Assoq
Vaigat
Ordlingassoq
Naujanguit
Maligât
Rinks Dal
RDM
Atanikerluk
At
E
Q
K
I
O
Atane
Qilakitsoq
Kingittoq
Ravn Kløft
Skansen
Slibestensfj.
Kome
Maligât Formation
Vaigat Formation
WGBG
Atanikerluk Formation (At)
Eqalulik Formation (E)
Agatdal Formation (Ag)
Quikavsak Formation (Q)
Kangilia Formation (K)
Itilli Formation (I)
Atane Formation
Upernivik Næs Formation
Slibestensfjeldet Formation
Kome Formation
72°
71°
70°
53°
Svartenhuk Halvø
Qeqertarsuaq
Upernivik Næs
Nuussuaq
Disko
50 km
Palaeogene volcanics
Cretaceous–Paleocene sediments
Precambrian basement

iments of the Atane Formation pass westwards into marine, fault-controlled slope deposits. These sediments are referred to the Itilli Formation, of Cenomanian to Maastrichtian age, and comprise mainly homogeneous mudstones, thinly interbedded mudstones and sandstones, and turbidite channel sandstones. In the Aaffarsuaq valley, an angular unconformity separates the deltaic Atane Formation from Campanian turbidite deposits of the Itilli Formation (Dam *et al.* 2000).

Major uplift during the Maastrichtian resulted in incision of underlying units; submarine canyon incision is seen at several localities on Nuussuaq, viz. at Ataata Kuua, at Kangilia, in Agatdalen and west of the Kuugannguaq–Qunnilik Fault (Fig. 15, see Plate 3). At these localities, the valley and canyon fill consists of successions of homogeneous sandstones and conglomerates, in many instances resulting from catastrophic gravity flow deposition. Intercalated mudstones represent deposition from turbidity currents. These deposits are referred to the Kangilia Formation. Renewed uplift during the Danian generated new incision and fluvial to tidal valley deposits separated by lacustrine sediments filled the fluvial valleys. The lacustrine deposits comprise thin coarsening-upward successions composed of mudstones and sandstones with *in situ* and drifted tree trunks. These sediments are referred to the Quikavsak Formation (Dam 2002). The pre-volcanic phase culminated with major subsidence of the basin and deposition of sandstones from sediment gravity flows (the Agatdal Formation). During this period, the Disko area was characterised by sedimentary bypass.

The next phase of Nuussuaq Group sedimentation coincided with submarine volcanism west of Nuussuaq. The oldest rocks of the West Greenland Basalt Group are hyaloclastic breccias of the Vaigat Formation (Hald & Pedersen 1975; A.K. Pedersen 1985; A.K. Pedersen *et al.* 1993, 1996, 2002, 2006b; G.K. Pedersen *et al.* 1998). The contemporaneous siliciclastic marine sediments comprise mudstones, thinly interbedded sandstones and mudstones and chaotic beds. Volcaniclastic sandstones and conglomerates deposited from turbidity currents are common in this part of the succession. The marine syn-

Fig.18. The sediments onlapping and overlying the basement high at Ikorfat on the north coast of Nuussuaq (view towards the south) represent the base of the Nuussuaq Group. The basal sediments are represented by the Kome Formation overlain by the Slibestensfjeldet and Atane Formations. The highest peak is *c.* 2000 m a.s.l.; for location, see Fig. 22. **E**, Eqalulik Formation.

volcanic sediments are referred to the Eqalulik Formation from the latest Danian (Nøhr-Hansen *et al.* 2002). As the Early Paleocene volcanic breccias of the Vaigat Formation (West Greenland Basalt Group) prograded eastwards from sources west of the present coastline, the formerly marine basin was dammed and large lakes formed on eastern Nuussuaq and Disko. The lakes were filled from the west by hyaloclastite breccias while siliciclastic sedimentation continued from the south-east. These sediments are referred to the Atanikerluk Formation and consist of shales with thin tuff beds and fine-grained sandstones deposited in two coarsening-upward successions.

Fossils. A rich flora and fauna from the group has been described. The fauna numbers several hundred species including bivalves, gastropods, nautiloids, ammonites, belemnites, echinoderms, cirripeds, brachiopods, corals, decapod crustaceans, serpulids, fish, ostracods, foraminifera, bryozoans and insects. Fossil invertebrates are best known from the Itilli, Kangilia and Agatdal Formations. The rich flora comprises more than 600 species of plant leaves, wood, fruits, spores, pollen and dinoflagellate cysts (hereafter named dinocysts). Well-preserved plant fossils are mainly found in the Kome, Atane, Quikavsak, Agatdalen and Atanikerluk Formations (for summary of studies, see section on 'Previous work' above). Dinocysts form the basis of biostratigraphy and correlation in recent studies.

Boundaries. The lower boundary of the group is only exposed on the north coast of Nuussuaq at Kuuk, Vesterfjeld, Talerua and Ikorfat (Fig. 18), on the east coast of Itsaku and on Svartenhuk Halvø where the group overlies metamorphic basement that locally is strongly weathered. The boundary was also penetrated in the FP93-3-1 borehole on northern Disko where the Atane Formation overlies a basement high (Fig. 19).

The upper boundary with the West Greenland Basalt Group is diachronous (Hald & Pedersen 1975; A.K. Pedersen *et al.* 1993). During the Paleocene, volcanic breccias of the Vaigat Formation prograded eastwards from offshore sources and isolated the formerly marine basin in eastern Nuussuaq and Disko, eventually onlapping the Precambrian basement east of the Ikorfat fault zone (L.M. Larsen & Pedersen 1992; A.K. Pedersen *et al.* 1996, 2002; G.K. Pedersen *et al.* 1998).

Geological age. Dating of the exposed and drilled parts of the basin is mainly based on ammonites, corals, foraminifera, coccoliths, spores, pollen, dinocysts and macroflora fossils. The fossils indicate that outcrops of the Nuussuaq Group span the Albian to the Upper Danian – Selandian. Brackish-water dinocysts from sediments onlapping the basement indicate a pre-Late Albian age, and this is supported by the scarcity of angiosperms

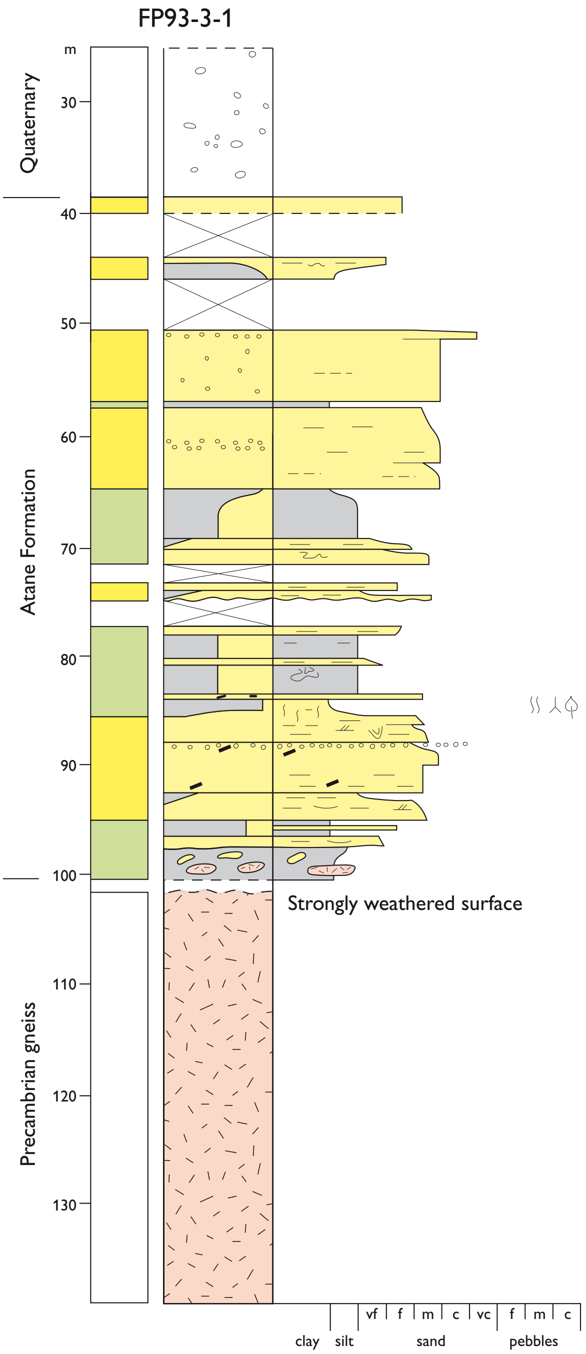


Fig. 19. Detailed sedimentological log of the Atane Formation overlying weathered gneiss basement in the the FP93-3-1 core in the Kuugannguaq valley on north-west Disko. The well dips 60° and driller's depths are shown. The stratigraphic thickness of the Atane Formation is *c.* 50 m; the sediments are not referred to a member. For location, see Fig. 2. Depositional environments are indicated by colours in the left column of the log (see Plate 1).

in the Ikorfat flora (Boyd 1998a, b, c, 2000). In the Umiivik-1 well, the oldest dateable marine dinocysts are of Turonian age; these were recorded 800 m above the base of the well (Dam *et al.* 1998b). In the GRO#3 well, the oldest dateable dinocysts are of Coniacian age and were recorded 1500 m above the base (Christiansen *et al.* 1999). Consequently, the deeper parts of these wells may have penetrated successions older than Albian.

Age-specific biomarker data from oil seeps at several outcrops of the Nuussuaq Group suggest that source rocks of Aptian–Albian and Cenomanian–Turonian age are present in the Nuussuaq Basin (Bojesen-Koefoed *et al.* 2004, 2007).

^{40}Ar/^{39}Ar dating of the volcanic rocks coeval with the upper levels of the Nuussuaq Group (the Vaigat Formation and the Rinks Dal Member of the Maligât Formation) indicates an age of 60.4 ± 0.5 Ma for these rocks (Storey *et al.* 1998). This age has been recalculated to 60.8 ± 0.5 Ma based on recalibration of the Fish Canyon Tuff standard (Skaarup & Pulvertaft 2007).

Correlation. The Nuussuaq Group is coeval with the Cretaceous Hassel and Kanguk Formations and the uppermost Cretaceous–Oligocene Eureka Sound Group of the Canadian Arctic Islands (e.g. Miall *et al.* 1980; Miall 1986; Burden & Langille 1990; Harrison *et al.* 1999). It constitutes an onshore analogue to the Cretaceous–Paleocene basins offshore West Greenland (Rolle 1985; Chalmers & Pulvertaft 2001; Dalhoff *et al.* 2003; Sørensen 2006; Gregersen *et al.* 2007) and to the Cretaceous Bjarni, Markland and Cartwright Formations offshore eastern Canada in the Davis Strait and Labrador Sea (Balkwill *et al.* 1990; Government of Newfoundland and Labrador 2000; Sønderholm *et al.* 2003).

Subdivision. The Nuussuaq Group is subdivided into the Kome, Slibestensfjeldet, Upernivik Næs, Atane, Itilli, Kangilia, Quikavsak, Agatdal, Eqalulik and Atanikerluk Formations (Figs 13, 17).

Kome Formation

redefined formation

History. The geology of the Kuuk area was described by Giesecke in 1811 (diary entry for 18 June; in: Steenstrup 1910). He mentioned that the coal seams provided fuel for 'Kolonien Omenak', now the town of Uummannaq (Fig. 20). A 0.7–1.3 m thick coal seam was exposed and exploited until 1832 (Rink 1857). The Mineralogical Museum in Copenhagen received 21 samples of "shale with remains and imprints of different fossil plants, especially ferns" collected near Kome (Rink 1855 p. 214). Heer (1883b) described an Early Cretaceous fossil flora from the north coast of Nuussuaq that he termed the Kome flora. According to Nordenskiöld (1871), several of these fossils had been collected by Rink and were sent to Heer from the Mineralogical Museum in Copenhagen.

The Kome Formation was defined in the area between Kuuk and Ikorfat by Nordenskiöld (1871 p. 1040) and described as follows (translated by the authors): "The Komelagren [Kome Formation] constitutes the older part of the Cretaceous, according to Heer (1868). The name designates a sedimentary, coal-bearing formation exposed at various localities between Kuuk and Ikorfat along the coast of Nuussuaq, south-west of Uummannaq. The name originates from the outcrop which has the most important coal bed and where Giesecke and Rink most likely collected plant fossils. These beds [Komelagren, the Kome Formation] are not restricted to Kuuk, but are found, except where interrupted by gneiss highs, along the entire coastal section between Kuuk and Ikorfat" (Figs 2, 21, 22). Nordenskiöld (1871) proposed a stratigraphy with a geographically restricted Lower Cretaceous Kome Formation overlain by the Upper Cretaceous Atane Formation which also covered southern Nuussuaq and northern Disko. Gry (1940) interpreted the boundary between the Kome and the Atane Formations as an unconformity.

Koch (1964) described the Kome Formation as occurring almost continuously between Kuuk and Ikorfat, interrupted only between Angiarsuit and Ujarattoorsuaq where younger Upper Cretaceous deposits are downfaulted (Figs 21, 22). He suggested that the beds that unconformably overlie the Kome Formation on the north coast of Nuussuaq could be equivalent to the Atane Formation or, alternatively, to the Upernivik Næs Formation.

Schiener (1977) did not find convincing evidence for an unconformity within the section at Ikorfat and concluded that the majority of the sediments were deposited during the Early Cretaceous. He implied that the Atane Formation is absent on northern Nuussuaq east of the Ikorfat fault zone (Fig. 10).

In the Kuuk area, the Kome Formation was interpreted to comprise fluviodeltaic deposits (Pulvertaft 1979) that were suggested to form part of the Atane Formation by G.K. Pedersen & Pulvertaft (1992). In contrast, Midtgaard (1996b) distinguished five sedimentary units in the area between Ikorfat and Qaarsut and the lowest of these is here assigned to the Kome Formation.

Fig. 20. View from Uummannaq towards the coal-bearing deposits of the Kome Formation at Kuuk on the north coast of Nuussuaq. The coal was being mined as early as the 18th century for use in Uummannaq. View foreshortened due to the use of a telescopic lens. For location, see Figs 2, 21.

Name. In his descriptions of the coal seams on northern Nuussuaq that provided fuel for 'Kolonien Omenak' (the town of Uummannaq), Giesecke in 1811(in: Steenstrup 1910) spelled the name either 'Koome' or 'Kook'. Thalbitzer (1910) explained 'Koome' as *casus locativus* of 'Kook', e.g. 'in or at Kook'. The spelling 'Kome' was used by Rink (1857) and Heer (1882, 1883b). Rink (1853 p. 175) wrote: "The settlement of Kome lies at the mouth of the large valley Tuëparsoït [now Tuapassuit, Fig. 21]. Between this and Sarfarfik a broad open valley is found. This contains a small river (Kook) thus the name of the site, where it reaches the shore" (translation from Danish by the authors). The site is shown as Kook, Kûk or Kuuk on newer maps (Fig. 21).

Distribution. The Kome Formation is presently known from the coastal area on the north coast of Nuussuaq between Kuuk and Ikorfat (Figs 21, 22). Gry (1940, 1942) briefly described sediments onlapping the basement on Itsaku (Fig. 73) and referred these to the Kome Formation on the basis of plant fossils from the lower part of the sedimentary succession. These sediments were tentatively referred to the Atane Formation by Christiansen *et al.* (2000) and J.G. Larsen & Pulvertaft (2000) on the basis of sedimentological similarities. In the present paper they are referred to the Upernivik Næs Formation. East of Saqqaqdalen on southern Nuussuaq (Fig. 2), outcrops of fluvial pebbly sandstones overlying the basement are preserved in a small down-faulted area (Pulvertaft 1989a, b) and are tentatively assigned to the Kome Formation.

Type section. The type section is at Majorallattarfik, immediately west of the Kuuk delta (Figs 21, 23). The base of the type section is located at 70°38.60´N, 52°21.83´W.

Reference sections. Reference sections have been measured at Slibestensfjeldet and Ikorfat (Midtgaard 1996b) (Fig. 22). These sections illustrate the marked lateral and stratigraphic, lithological changes in the formation from stacked conglomerates to coarsening-upward, fine-grained sandstones and mudstones (Figs 24, 25).

Thickness. The thickness of the Kome Formation varies from *c*. 25 m at Vesterfjeld to more than 150 m between Talerua and Ikorfat, and 140 m at Majorallattarfik near Kuuk (Figs 21, 22).

Lithology. The basal part of the Kome Formation overlies and onlaps Precambrian basement at Kuuk, Talerua and Ikorfat. The basement rocks are in places weathered to a depth of 35 m (Heim 1910; Gry 1942; Pulvertaft 1979; Midtgaard 1996b). The uppermost part of the basement consists almost exclusively of quartz grains within a powdery matrix of kaolinite. The gneiss has a greenish colour probably due to alteration of biotite to chlorite (Heim 1910; Pulvertaft 1979). The basal sediments are typically one of three main facies: (1) poorly sorted sandstones, rich in kaolinite and devoid of sedimentary structures, (2) diamictites, with blocks of vein quartz in a sandy clay matrix, or (3) unsorted conglomerates with poorly rounded quartz boulders and slabs of silty mudstones (Fig. 26; Gry 1942; Schiener 1977; Pulvertaft 1979). At Talerua (between Vesterfjeld and

Ikorfat), the basal sediments are breccias with large clasts comprising both gneiss with weathered feldspars and carbonaceous mudstones (Fig. 25A). At Ikorfat, breccias with angular gneiss clasts are overlain by a conglomerate bed, a few metres thick, comprising subangular clasts of quartz and intensely kaolinised feldspars. The diamictites and poorly sorted conglomerates are not seen above the basement highs. The poorly sorted, coarse-grained deposits are overlain by thin conglomerates, cross-bedded, locally channellised, coarse-grained sandstones, mudstones and thin discontinuous coal beds (Fig. 25). Root horizons are frequent and the mudstones commonly contain abundant comminuted plant debris (Fig. 25; Schiener 1977; Pulvertaft 1979; Midtgaard 1996b). Fine-grained sandstones with wave-ripples forming coarsening-upward successions occur in the upper part of the formation and are common in the Ikorfat area. The topmost bed of the Kome Formation is a bleached, crumbly mudstone with abundant root-casts overlain by a coal bed (Fig. 25C; Midtgaard 1996b).

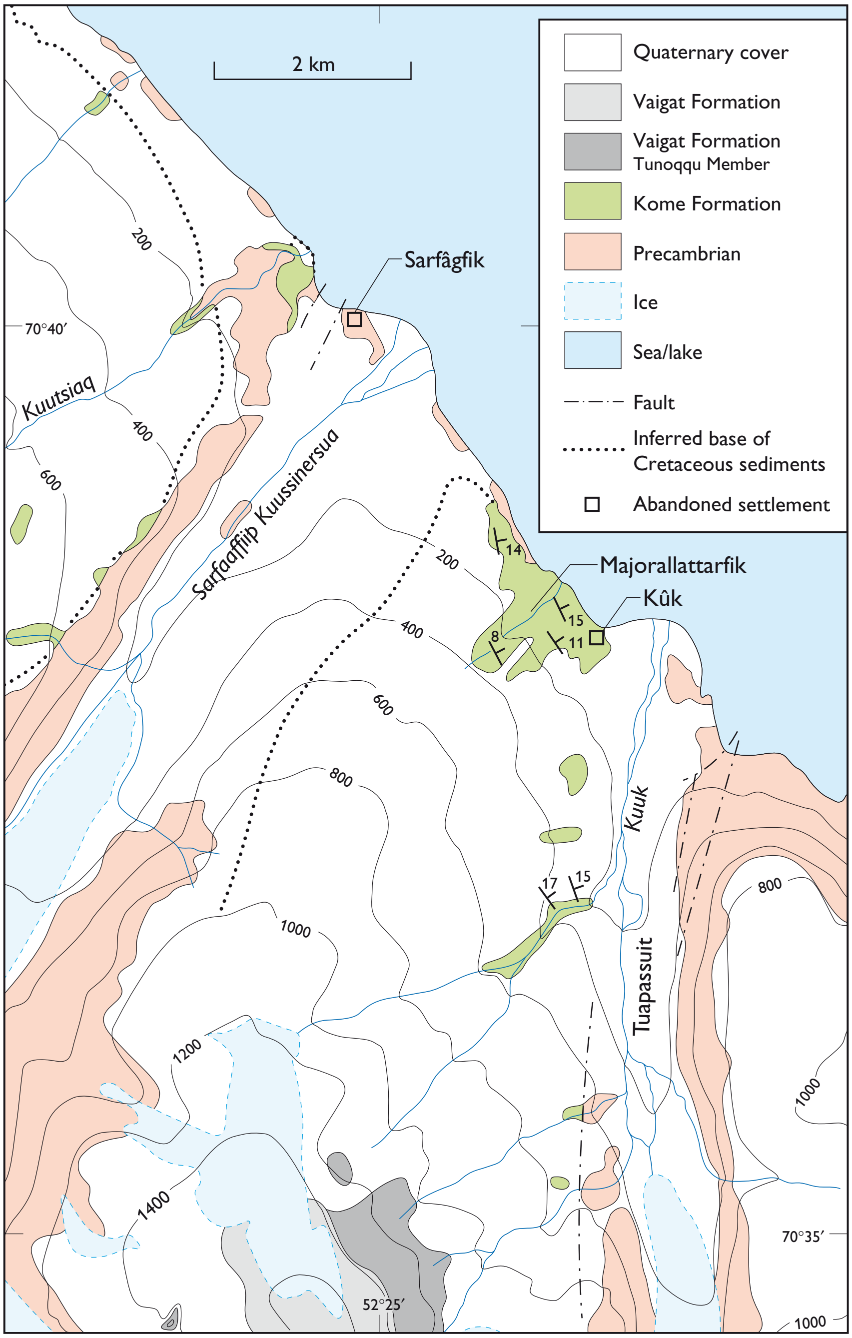


Fig. 21. Geological map of the area around Kuuk (from Pulvertaft 1979). Majorallattarfik is the type locality of the Kome Formation. The sediments overlie weathered basement and are well exposed. For location, see Fig. 2.

In the Kuuk area, the sediments overlying the coarse-grained, basal deposits consist of three facies associations: A, B and C (Figs 24, 27, 28). Association A is dominant and consists mainly of trough cross-bedded, erosionally based sandstones in shoe-string or irregular tabular bodies up to 5 m thick (Figs 24, 28). The sandstones are coarse-grained, often gravelly, with angular clasts, and is poorly sorted. It contains slightly to moderately kaolinised feldspars and kaolinite cement. Fragments of coalified wood and fine-grained plant debris are common. The orientation of shoe-string bodies and dip direction of foresets indicates transport from the south-east. The sandstones alternate with dark laminated silty mudstones containing much coalified plant debris, thin lenses of lustrous, coalified, woody tissue and thin coal seams (Fig. 24; Pulvertaft 1979). Association B consists of distinctive coarsening-upward successions of mudstones, cross-laminated siltstones, sandstones and locally thin layers of gravelly sandstones (Figs 24, 27). Association C is dominated by tabular cross-bedded, medium-grained, moderately well-sorted subarkosic sandstones with pebble lags of quartz or chert. Comminuted coalified plant debris and mica are common in the sandstones. Foresets dips are to the north-west. Cross-laminated, fine-grained

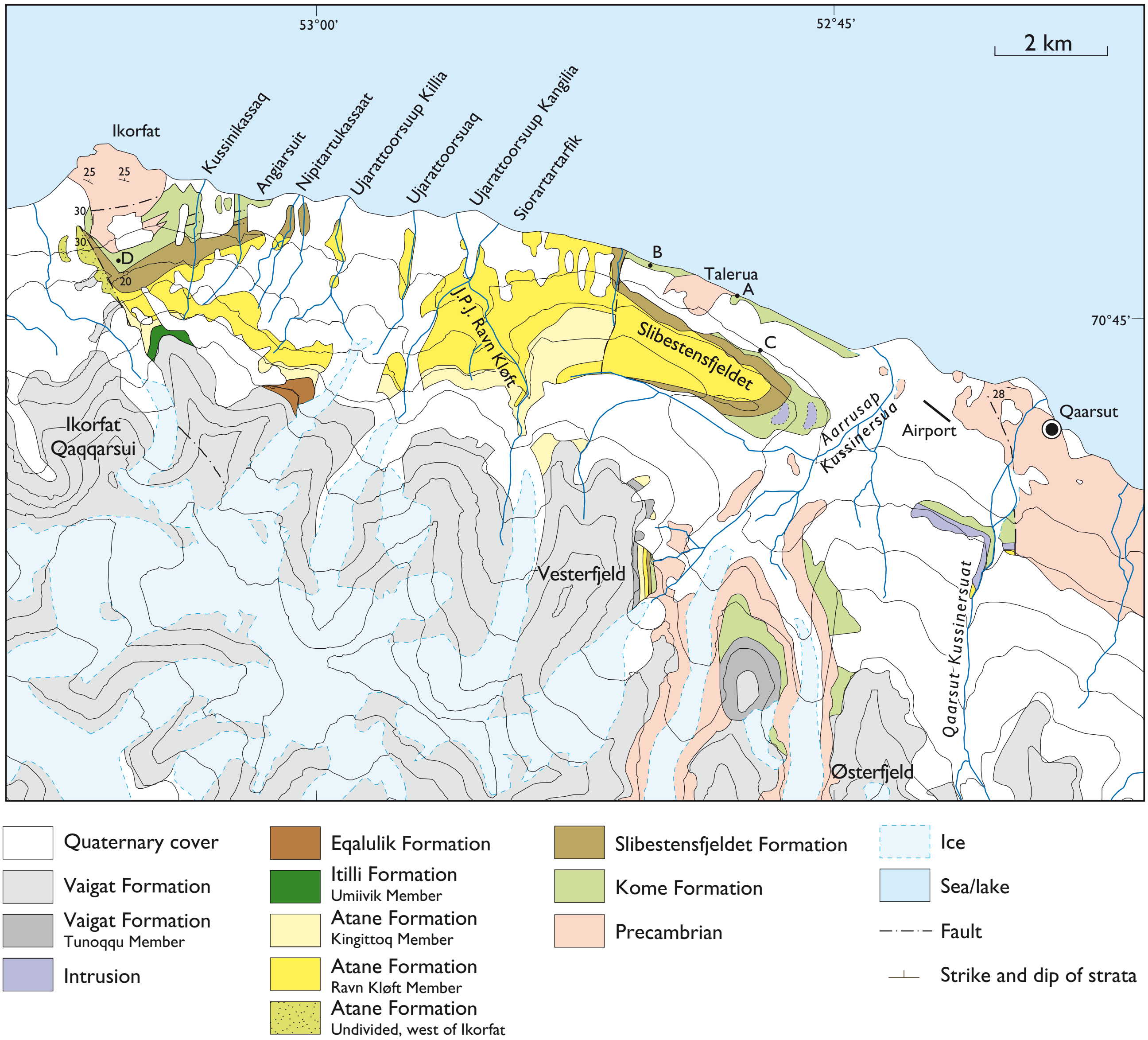


Fig. 22. Detailed geological map of the north coast of Nuussuaq, from Qaarsut to Ikorfat. The locations of the four sedimentological logs (**A–D**) in Fig. 25 are indicated. Contour interval 200 m. Modified from Rosenkrantz *et al.* (1974) and Midtgaard (1996b). For location, see Fig. 2.

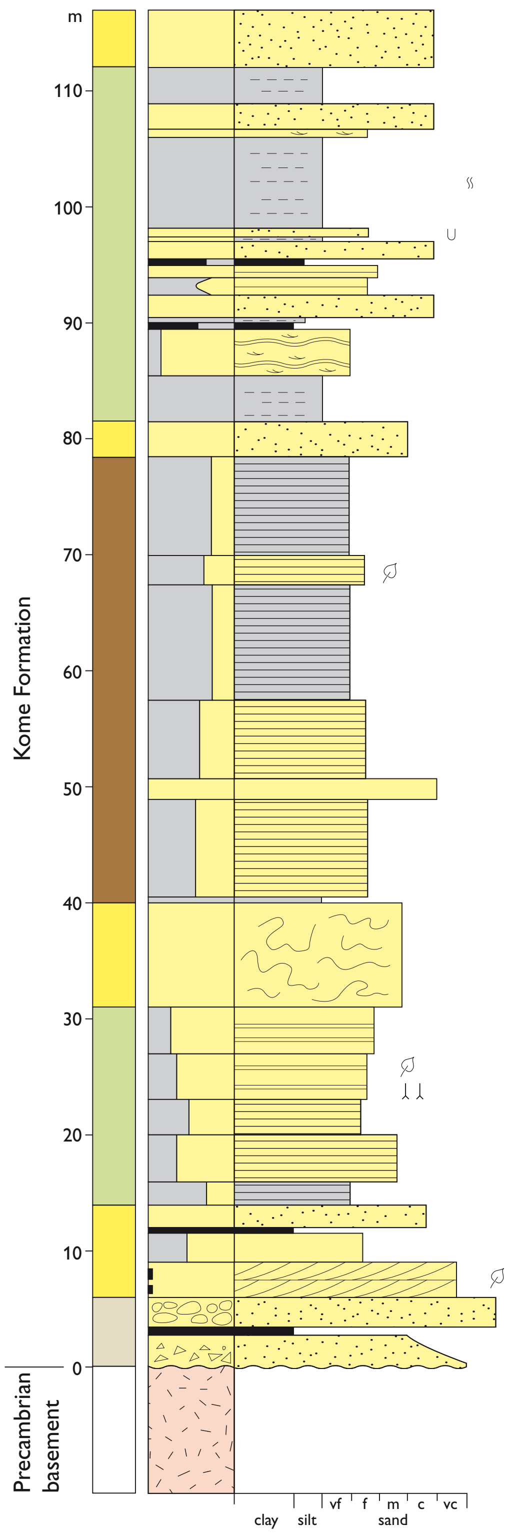


Fig. 23. Type section of the Kome Formation at Majorallattarfik, immediately west of Kuuk, redrawn from Croxton (1978a, b). The uppermost *c.* 20 m of the formation are poorly exposed and are not shown on the log. Note that the facies illustrated in detail in Fig. 24 recur here in a thicker succession. For location, see Fig. 21; for a possible correlation between Kuuk and Slibestensfjeldet, see Fig. 29; for legend, see Plate 1.

sandstones overlying the medium-grained sandstones form a minor part of the association. Wave-generated sedimentary structures or mud-draped foresets indicating tidal influence have not been seen (Pulvertaft 1979). Facies association C occurs at the top of the sections at Kuuk and Majorallattarfik (Fig. 28; T.C.R. Pulvertaft, personal communication 2008).

Fossils. The Kome Formation contains macrofossil plants referred to the Kome flora (Heer 1883a). The genera in the Kome flora were revised by K.R. Pedersen (1976). A separate Ikorfat flora has been distinguished by Boyd (1998a, b, c, 2000) in the Ikorfat area and is suggested to be slightly older than or contemporaneous with the Kome flora (Boyd 1998a, b, c, 2000).

Samples of mudstones collected by Croxton (1978a, b, section C20) at Majorallattarfik near the top of the section at Kuuk contain a poor assemblage of brackish-water dinocysts, spores and pollen. Few specimens of the dinocyst *Vesperopsis nebulosa* occur in the lower part, whereas few specimens of *Nyktericysta davisii* and *Pseudoceratium interiorense* occur in the upper part. The presence of the spore *Cicatricososporites auritus* may indicate a Middle to Late Albian age, whereas the absence of the pollen *Rugubivesiculites rugosus* indicates a pre-Late Albian age. The presence of *Nyktericysta davisii* may indicate a younger age, as at other localities this species first occurs in the overlying Ravn Kløft Member (Atane Formation).

Samples of mudstones collected by Midtgaard (1996b) from the upper part of the Kome Formation reference section at Slibestensfjeldet (Fig. 25C) also contain *Vesperopsis nebulosa* and common *Pseudoceratium interiorense* and, in common with the Kuuk section, the pollen *Rugubivesiculites rugosus* is absent.

Assemblages dominated by *Pseudoceratium interiorense* are known from the Slibestensfjeldet Formation, whereas assemblages dominated by *Nyktericysta davisii* first occur in the Ravn Kløft Member of the Atane Formation between Vesterfjeld and Ikorfat (Fig. 29). Croxton (1978a, b) noted the absence of angiosperm pollen and the presence of spores such as *Cicatricosisporites, Gleicheniidites, Pilosisporites* and *Vitreisporites*, indicating an early to mid-Cretaceous age.

Depositional environment. The diamictites and poorly sorted conglomerates in close association with the basement highs are interpreted as mass-flow deposits (Figs 25, 29); talus cones and alluvial fans filled the topographic lows on the basement surface with immature sediments (Midtgaard 1996b). The lack of mass-flow deposits above the basement highs suggests that the ini-

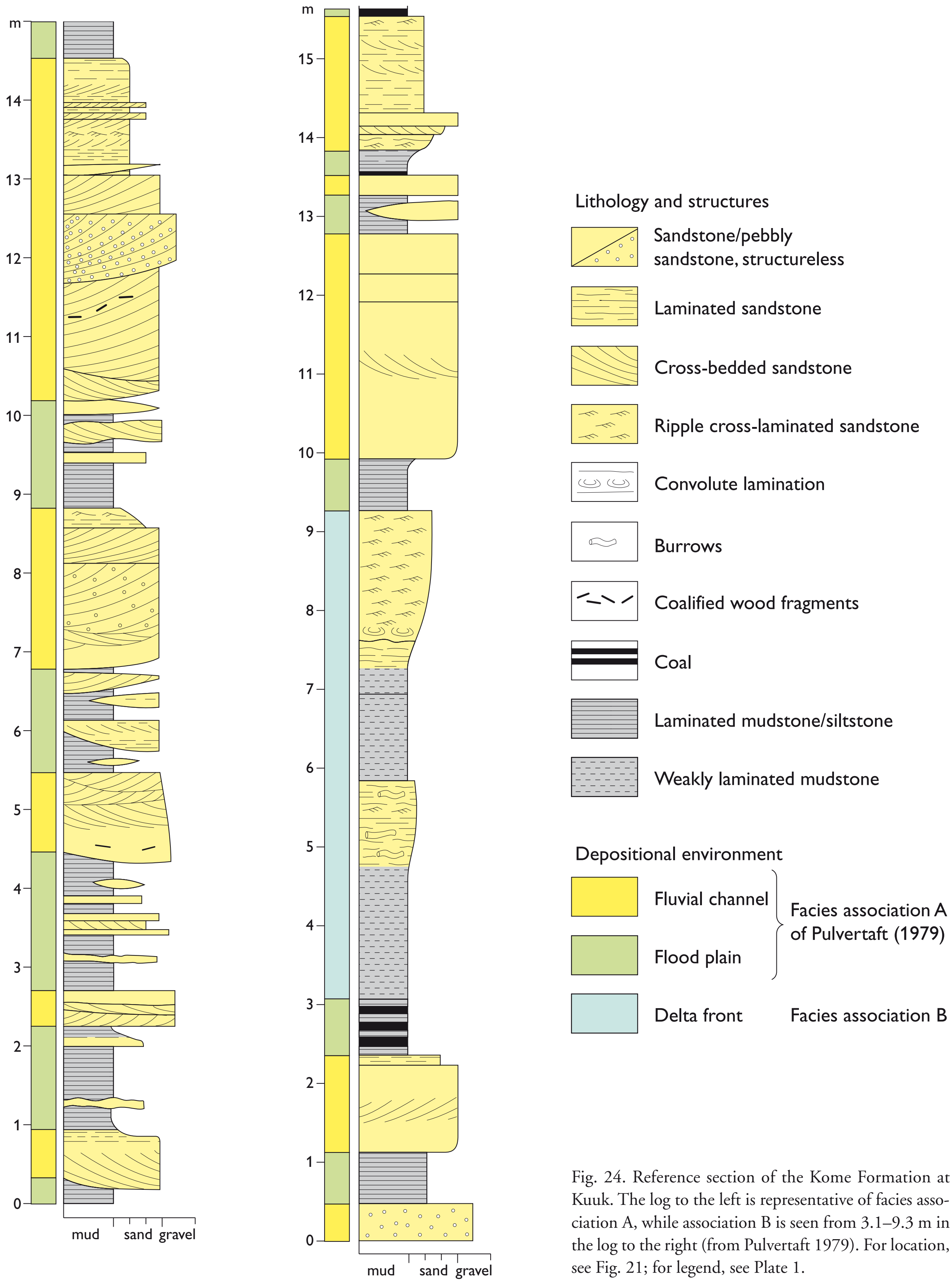


Fig. 24. Reference section of the Kome Formation at Kuuk. The log to the left is representative of facies association A, while association B is seen from 3.1–9.3 m in the log to the right (from Pulvertaft 1979). For location, see Fig. 21; for legend, see Plate 1.

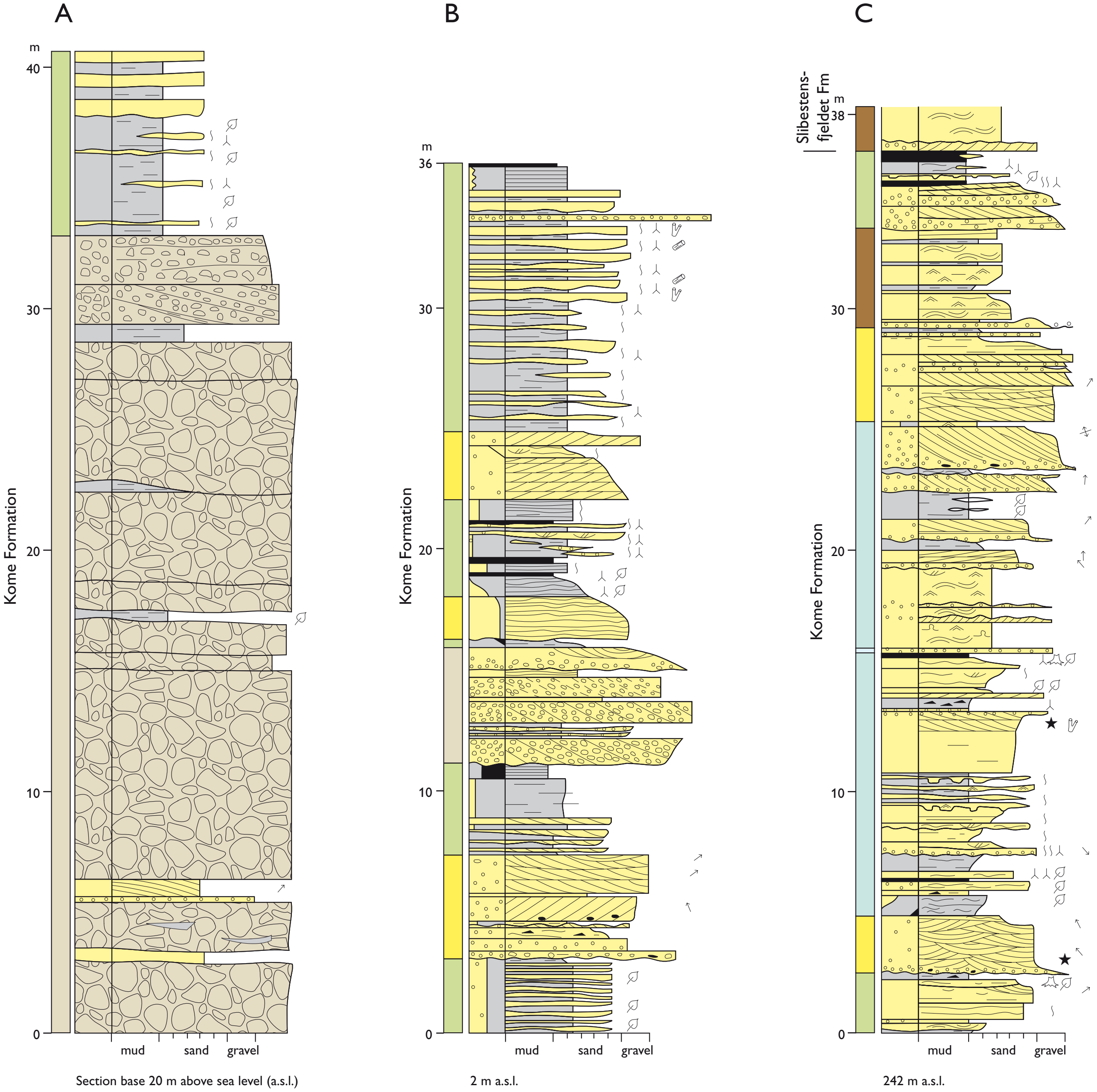
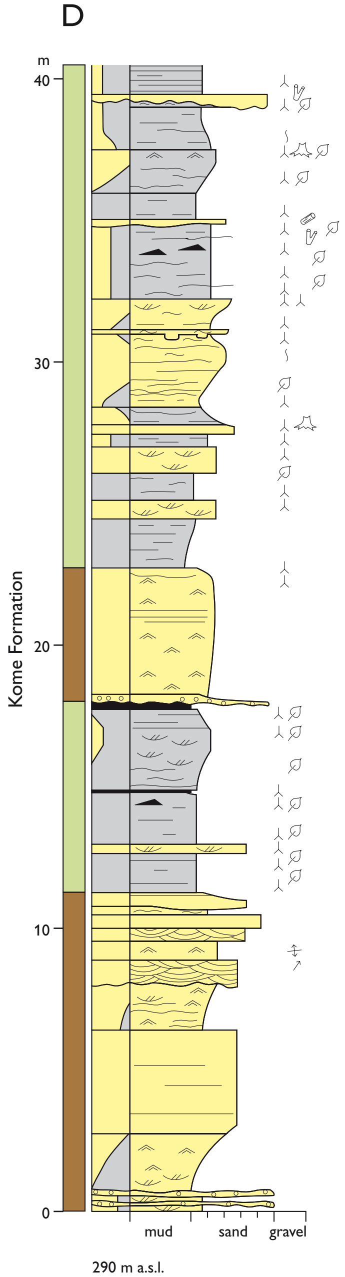


Fig.25. Reference sections of the Kome Formations illustrating abrupt facies change and numerous horizons with rootlets. **A** and **B** are from the lower part of the formation and **C** and **D** are from the uppermost part of the formation. Sections **C** and **D** also show the overall decrease in grain-size towards the west. The boundary between the Kome Formation and the overlying Slibestensfjeldet Formation is shown in section **C**. From Midtgaard (1996b). For legend, see Plate 1; for location, see Fig. 22.



tial relief was levelled out as sediments accumulated and buried the highs. The alluvial fans were succeeded by fan deltas representing both subaerial and subaqueous deposition; the latter increases towards Ikorfat (Fig. 25D). The sparse dinocyst assemblage indicates that the water was intermittently brackish.

The coarse sandstones of facies association A at Kuuk are interpreted as fluvial deposits. Their low textural and mineralogical maturity together with palaeocurrent indicators point to derivation directly from a weathered basement to the south-east, without reworking *en route*, and to rapid sedimentation. The dark mudstones are interpreted as overbank deposits of a floodplain environment or deposition in shallow lakes. The mudstones of facies association B are interpreted as having been deposited from suspension in bodies of standing water, presumably interdistributary bays or lakes (Fig. 23, 24). Sedimentary structures in the sandstones of facies association C suggest deposition from a sandy braided river flowing from the south, and the higher textural and mineralogical maturity of the sandstones indicates more protracted fluvial transport (Pulvertaft 1979). The palaeosol that caps the Kome Formation represents a widespread regressive event (Figs 25C, 30; Midtgaard 1996b).

Boundaries. The Kome Formation overlies an undulating Precambrian gneiss topography, filling valleys or depressions (Henderson *et al.* 1976; Schiener 1977; Pulvertaft 1979; Midtgaard 1996b). The lower boundary of the formation is exposed at Kuuk, Ikorfat and Talerua (Figs 2, 21, 22). In the coastal cliffs of northern Nuussuaq, the relief on the gneiss surface can be seen to exceed 225 m (Fig. 22). At Vesterfjeld, the basement is weathered to a depth of 30 m with a gradual downward transition into unaltered gneiss. In western Disko (Stordal), the Precambrian basement is exposed, locally with a 5–10 m thick weathered cap (A.K. Pedersen & Ulff-Møller 1980). In other exposures, the gneiss is relatively unweathered (Schiener 1977; Midtgaard 1996b). The lower boundary of the Kome Formation thus displays a variety of basement–sediment transitions.

The upper boundary of the Kome Formation is a sharp lithological boundary that varies very little laterally (Figs 25C, 30). It is placed on top of a palaeosol horizon and was interpreted as a sequence boundary by Midtgaard (1996b). Previous workers, e.g. Nordenskiöld (1871), Gry (1942) and Midtgaard (1996b), have considered the Kome Formation to be overlain by the Atane Formation on Nuussuaq. We propose that the new Slibestensfjeldet Formation separates the Kome and Atane

Fig. 26. Contact between Precambrian basement and the Kome Formation at Talerua. The sediments onlap the relief on the basement surface. The height of the coastal cliff is *c*. 30 m. For location, see Fig. 22.

Formations in the area between Ikorfat and Slibestensfjeldet.

Geological age. Various fossils contribute to the determination of the geological age of the Kome Formation. Plant macroflora suggests a Barremian to Aptian age (Heer 1882; K.R. Pedersen 1968). The Ikorfat flora suggests an Early to Middle Albian age (Boyd 1998a, b, c, 2000). Based on spores and pollen as well as scarce dinocysts, Ehman *et al*. (1976) suggested a Late Albian to Early Cenomanian age, whereas Croxton (1978a, b) interpreted the sediments to be older than Middle Albian. In this study, the spores, pollen and brackish-water dinocysts are considered suggestive of a pre-Late Albian age. Consequently, the Kome Formation is suggested to be of albian age.

Correlation. It has previously been stated by Troelsen (1956) and Rosenkrantz (1970) that the sediments exposed on the north coast of Nuussuaq, east of the Ikorfat fault zone, are older than the fluviodeltaic Cretaceous sediments known from the rest of the Nuus-

Fig. 27. The type locality of the Kome Formation at Majorallattarfik showing outcrop of facies association B (see text for explanation). Person for scale (circled) is standing on delta front deposits (see also Fig. 24, right-hand column). For location, see Fig. 21. Photo: T.C.R. Pulvertaft.

Fig. 28. Reference locality of the Kome Formation at Kuuk showing outcrop of facies associations **A** and **C** (see text for explanation, see also Fig. 29). For location, see Fig. 21. Photo: T.C.R. Pulvertaft.

suaq Basin. However, Lanstorp (1999) suggested a Middle to Late Albian age for the Atane Formation at Tartunaq (south-east Nuussuaq), thereby shortening (or removing) the time gap between the Kome and Atane Formations. Nevertheless, the Kome Formation is retained as a discrete lithostratigraphic unit characterised by the onlap relationship to the basement, the coarse-grained conglomeratic character and the significant lateral facies changes (Fig. 25). These features indicate a depositional environment that was markedly different from that which produced the cyclic, aggradational Atane Formation.

In the Kuuk area, the mudstones of association B and the sandstones of association C (Pulvertaft 1979), referred here to the Kome Formation, may correlate laterally with the Slibestensfjeldet and Atane Formations, respectively, farther to the north-west (Fig. 29). Thus, the mudstones of association B (Fig. 24) and the mudstone-dominated unit of the type section (40–80 m in Fig. 23) are thought to represent proximal correlatives of the Slibestensfjeldet Formation. The sandstones of association C display an erosional base and occur towards the top of the exposed sections (Fig. 29). This unit contains chert pebbles, a characteristic feature of the Atane Formation and particularly the fluvial sandstones of the Ravn Kløft Member of the Atane Formation (see below). It is tentatively suggested, therefore, that the erosional base of the sandstones in facies association C may correlate with the erosional boundary between the Slibestensfjeldet and Atane Formations, i.e. that the uppermost Kome Formation in the Kuuk area correlates with the lowermost Atane Formation to the north-west (Fig. 29).

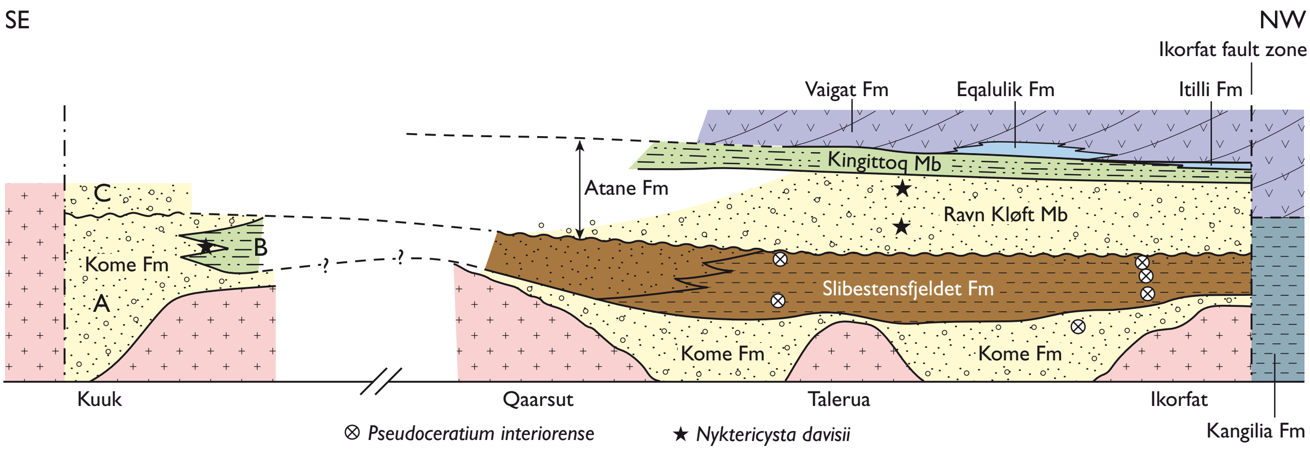


Fig. 29. Schematic profile (scale arbitrary) along the north coast of Nuussuaq between Kuuk and Ikorfat showing correlation of the lithostratigraphic units. The sediment outcrops are bounded to the east by the basin boundary fault and to the west by the Ikorfat fault zone. The occurrence of two species of dinoflagellate cysts is shown. These species are known from other localities in the Nuussuaq Basin. For location of outcrops, see Figs 21, 22; **A**, **B**, **C**, facies associations discussed in the text. Pale red indicates Precambrian basement.

Slibestensfjeldet Formation

new formation

History. The Slibestensfjeldet Formation has previously been described as Unit 2, an informal lithological unit in the Slibestensfjeldet–Ikorfat area (Midtgaard 1996b).

Name. After the prominent mountain of Slibestensfjeldet on the north coast of Nuussuaq (Fig. 22).

Distribution. The Slibestensfjeldet Formation is known only from the north coast of Nuussuaq between Vesterfjeld and Ikorfat (Fig. 22; Midtgaard 1996b). The formation is not known to be preserved north of Nuussuaq, but it is expected to continue southwards, for some distance, in the subsurface. The extent of the formation west of the Ikorfat fault is not known.

Type section. The type section is at Kussinikassaq where the formation is thickest (Figs 22, 30), immediately east of the basement high at Ikorfat beginning at an altitude of *c*. 60 m a.s.l. The base of the type section is located at 70°46.20′N, 53°03.37′W.

Reference sections. Reference sections are found at Vesterfjeld, *c*. 860 m a.s.l., and in two gullies on Slibestensfjeldet *c*. 1 km east of Talerua, beginning at an altitude of *c*. 320 m a.s.l. (Fig. 30).

Thickness. The Slibestensfjeldet Formation increases in thickness from 90 m at Vesterfjeld to *c*. 200 m at Kussinikassaq (Figs 22, 30).

Lithology. A considerable lateral change in lithology characterises the Slibestensfjeldet Formation from Vesterfjeld to Ikorfat, a distance of approximately 10 km (Fig. 30; Midtgaard 1996b). At the type section, the formation is dominated by mudstones, interbedded with 0.2–2 m thick sandstone beds, which are structureless, parallel laminated, cross-laminated or hummocky cross-stratified (Figs 30, 31, 32). The mudstones contain *c*. 5% carbon, almost entirely of organic origin, traces of pyrite are restricted to a thin coal bed, and the calculated carbon/sulphur (C/S) ratios are *c*. 100. The sandstone interbeds in the *c*. 200 m thick mudstone unit become increasingly common upwards. At the top of this coarsening-upward succession is a medium-grained sandstone unit 5 m thick, showing steeply dipping foresets; this facies is restricted to the areas west of the Talerua fault. In the east, the formation is dominated by sandstones interbedded with thin mudstones and conglomerate beds. Laminated black mudstones with sand streaks are abruptly overlain by very fine- to fine-grained, well-sorted sandstones dominated by horizontal lamination and hummocky cross-stratification, whereas low-angle cross-bedding and wave ripple cross-lamination are subordinate (Midtgaard 1996a). The sandstones are often slightly bioturbated. Thin conglomerate beds composed of well-rounded clasts and showing erosional bases and wave-rippled tops, recur throughout the formation (Midtgaard 1996a).

Fossils. The mudstones contain an assemblage of brackish-water dinocysts dominated by *Pseudoceratium interiorense* whereas the pollen *Rugubivesiculites rugosus* is absent (Figs 29, 30). Plant macrofossils from the lowermost part of the formation are referred to the Ikorfat flora, which has been assigned to the Early–Middle Albian (Boyd 1998a, b, c, 2000).

Depositional environment. The widely distributed and thick coal bed at the base of the Slibestensfjeldet Formation indicates accumulation of peat under a slowly rising ground-water table. The overlying fine-grained, wave-rippled sandstones are interpreted as lake shoreline deposits and indicate an increasing rate of water level rise, which continued to the deposition of mudstones at depths below wave-base. In the mudstones, the C/S ratios of *c*. 100 and the stratigraphical position between the fluvial Kome and the fluvial Ravn Kløft Member indicate that the Slibestensfjeldet Formation was deposited in a large and deep lake. The overall, coarsening-upward, vertical facies succession is interpreted to record the infill of the lake and progradation of the shoreline. The presence of dinocysts, which are interpreted as brackish-water forms, suggests that the lake was connected to a coastal lagoon. The lake increased in depth from east to west, and wave-influenced, relatively shallow-water facies are only known from Vesterfjeld and Slibestensfjeldet. The conglomerate beds represent transgressive lags created by wave erosion and winnowing. The nearshore sandstones accu- mulated in large complex bedforms overprinted by wave-ripples (Midtgaard 1996a). The upper part of the Slibestensfjeldet Formation locally developed as a

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Fig. 30. Type section of the Slibestensfjeldet Formation at Kussinikassaq; reference sections of the formation at Vesterfjeld and Slibestensfjeldet. Note the marked increase in thickness towards the west (Kussinikassaq). All logs are from the north coast of Nuussuaq (Fig. 22). For legend, see Plate 1; **GD**, Gilbert Delta; **Ps**, palaeosol.

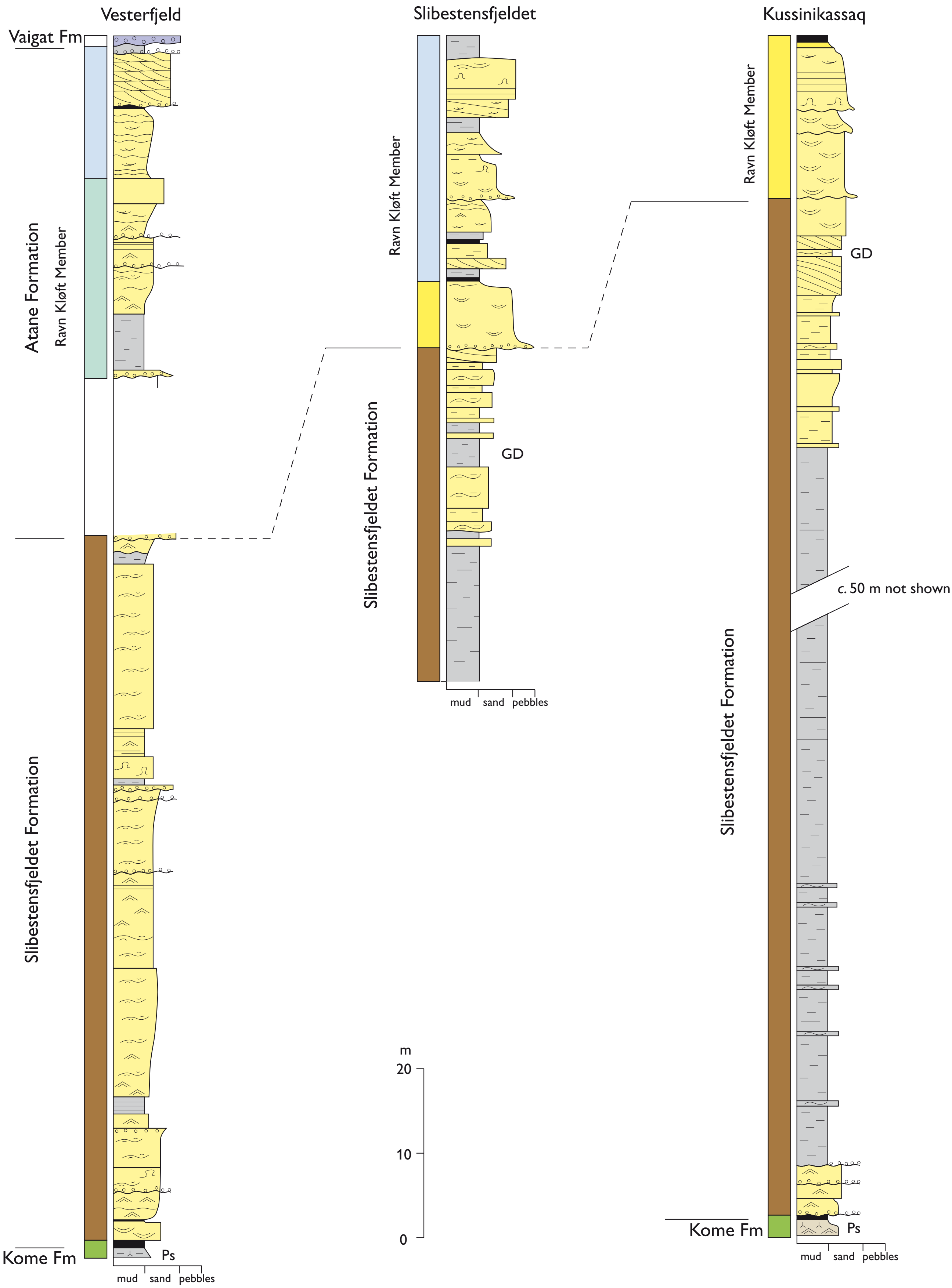
Vesterfjeld
Slibestensfjeldet
Kussinikassaq
Vaigat Fm
Atane Formation
Ravn Kløft Member
Slibestensfjeldet Formation
Kome Fm
Ps
mud
sand
pebbles
GD
c. 50 m not shown
m
20
10
0

Fig. 31. Mudstones with thin sandstone beds in the lower part of the Slibestensfjeldet Formation at Kussinikassaq, near Ikorfat. For location, see Fig. 22.

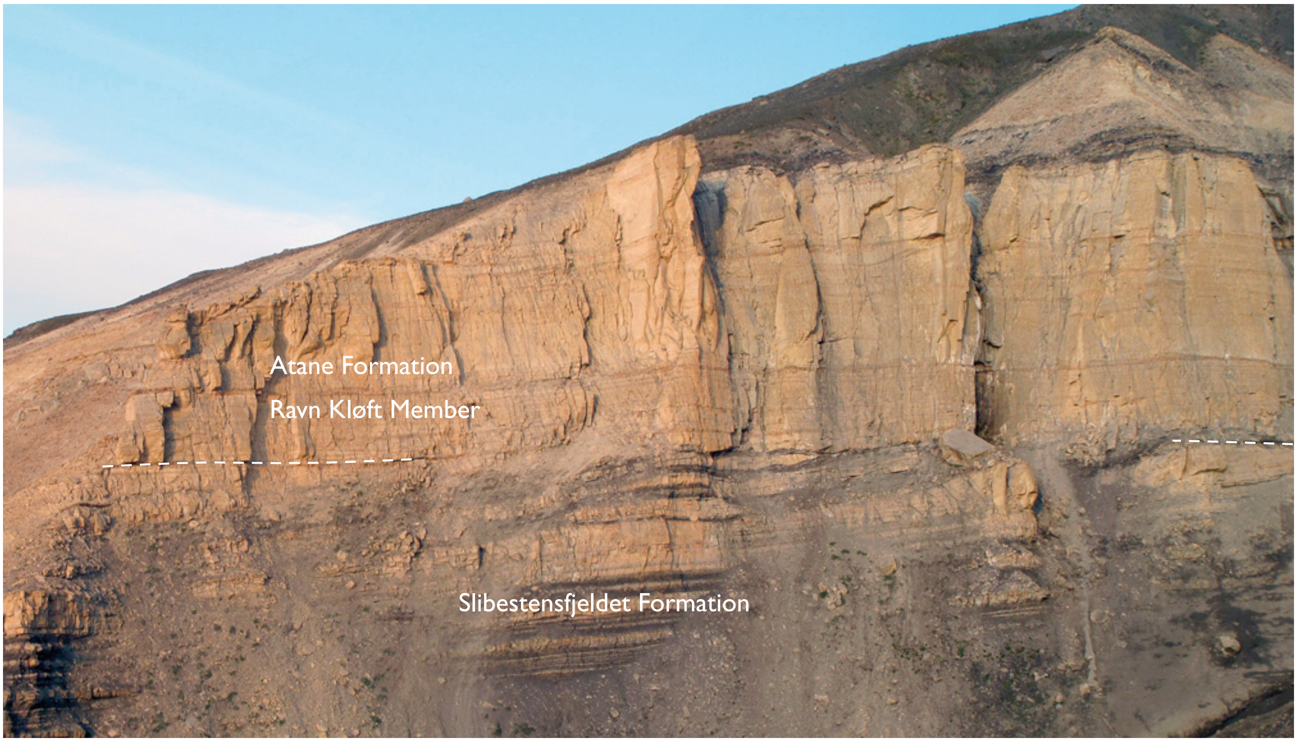

Fig. 32. The upper part of the Slibestensfjeldet Formation in its type locality at Kussinikassaq, where heterolithic sandstone bodies with wave-generated sedimentary structures (see also Midtgaard 1996 a, b) are overlain by lower shoreface sandstones (see Fig. 30) and locally by Gilbert delta foreset beds. The Slibestensfjeldet Formation is erosionally overlain (dashed line) by the fluvial Ravn Kløft Member of the Atane Formation. The height of the section is *c*. 100 m. For location, see Fig. 22.

Gilbert delta in the Ikorfat area (Figs 30, 32; Midtgaard 1996b). The extent of the lake or lagoon west of Ikorfat is not known. It may be speculated that subsidence along the Ikorfat Fault affected the development of the lake.

Boundaries. The lower boundary of the Slibestensfjeldet Formation is sharp and varies very little laterally; it is placed at the base of a 20–110 cm thick, continuous coal bed that overlies a palaeosol (Fig. 30).

The upper boundary of the Slibestensfjeldet Formation with the Atane Formation is defined by an abrupt contact between shoreface sandstones or Gilbert delta sandstones and coarse-grained, pebbly fluvial sandstones of the Ravn Kløft Member (Figs 30, 32). The boundary has been interpreted either as a minor angular unconformity (Gry 1940; Koch 1964) or as the conformable, yet erosional base of a channel (Ehman *et al.* 1976; Schiener 1977; Croxton 1978a, b; Midtgaard 1996b). Midtgaard (1996b) interpreted the boundary as a sequence boundary.

Geological age. Based on plant macrofossils referred to the Ikorfat flora, the Slibestensfjeldet Formation has been assigned an Early to Middle Albian age (Boyd 1998a). The dinocysts suggest a Late Albian age (Ehman *et al.* 1976; Croxton 1978a, b) or more likely a pre-Late Albian age (this study).

Correlation. The Slibestensfjeldet Formation in the Slibestensfjeldet outcrops may correlate with coarsening-upward successions in the Kome Formation at Kuuk (Fig. 29). Outcrops connecting these two areas are, however, not present.

Upernivik Næs Formation

revised formation

History. The sedimentary outcrops at Upernivik Næs were described by Steenstrup (1883b) who noted that the coal-bearing sediments have a thickness of at least 860 m. The lithology was not considered different from the coal-bearing successions known from Nuussuaq and Disko. The macrofossil plants collected at Upernivik Næs by Steenstrup were referred to the Atane flora by Heer (1883b). In contrast, Seward (1926) compared them to the Kome flora. Koch (1964) considered the fossil flora from Upernivik Ø as difficult to interpret due to similarities to both the Kome and the Atane floras and suggested that the Upernivik Ø flora could occupy an intermediate position. Troelsen (1956) did not recognise the Upernivik Næs Formation, which was later described by Koch (1964).

Name. The formation is named after Upernivik Næs on the south-western corner of the island of Upernivik Ø (Figs 2, 33).

Distribution. The formation is known from Upernivik Ø. The marginal marine sediments on the island of Qeqertarsuaq and on Itsaku are here referred to the Upernivik Næs Formation (Figs 2, 73; Ødum & Koch 1955, Christiansen *et al.* 2000; J.G. Larsen & Pulvertaft 2000).

Type section. The type section is located on the south-western corner of Upernivik Ø, along a large stream that flows out on the south coast of the island *c.* 2.5 km east of Upernivik Næs (Figs 33–35). The base of the type section is located at 71°09.88´N, 52°54.52´W.

Reference section. A reference section is exposed in a coastal cliff on western Qeqertarsuaq (Figs 2, 36, 73).

Thickness. The formation is *c.* 1600 m thick at Upernivik Næs, where the strata generally dip *c.* 15° towards the north-east (Henderson & Pulvertaft 1987). Croxton (1978b) measured a 1310 m long section (termed the C9 section) along the southern coast of Upernivik Næs; this section coincides with the type section in its upper part. In the type section, the formation is exposed up to *c.* 500 m a.s.l. (Fig. 33).

Lithology. The section at Upernivik Næs is dominated by sandstones; mudstones constitute only a minor part (Figs 34, 35). On Qeqertarsuaq, sandstone-dominated successions are locally overlain by clast-supported conglomerates, in which the clasts are dominantly from the metamorphic rocks of the widely exposed Karrat Group (Fig. 37; Henderson & Pulvertaft 1987). The formation has been studied at a reconnaissance level by Midtgaard (1996b), who divided the sediments of the formation into four facies associations.

Facies association A. Coarse-grained, poorly sorted sandstones constitute up to 34 m thick composite depositional units (Fig. 38). Some of these are distinctly fining upwards. Basal channel lags contain pebbles of crystalline rocks and locally also mudstone clasts, logs and carbonaceous debris. The sandstones are cross-bedded with most palaeocurrent directions towards the western quadrant. Soft-sediment deformation structures are common.

Facies association B. Well-sorted, fine- to medium-grained sandstones with abundant mudstone clasts characterise the association. Siltstone and mudstone beds and laminae form an important component and in places are heterolithic and ripple-cross laminated. The sandstones are dominated by planar or trough cross-bedding that indicates palaeocurrents to the north. Some sandstones have mud-draped foresets and show bundled lamination (Fig. 39). The mud-dominated heteroliths and mudstones contain much comminuted plant debris; bioturbation varies from moderate to intense (Fig. 39).

Facies association C. Sandstones interbedded with mudstones constitute 3–8 m thick successions. The sandstones range from very fine- to very coarse-grained, the beds are erosionally based and pinch out laterally. They are cross-laminated, cross-bedded or locally horizontally stratified. The tops of the sandstone beds are moderately bioturbated. The mudstones are black, fissile and sand-streaked, and sometimes contain abundant plant debris and vitrinite lenses. Sandstone dykes are common, and gentle folding indicates that they were intruded before or during compaction.

Facies association D. Coarsening-upward successions comprising black fissile mudstones, mudstones with sandstone lenses, mud-draped ripple cross-laminated, fine-grained sandstones, and trough cross-bedded sandstones with comminuted plant debris (Midtgaard 1996b). These deposits constitute only a minor part of the section shown in Fig. 34.

Fossils. The Upernivik Næs Formation contains angiosperm plants referred to the Upernivik Næs flora (or Upernivik flora), which is interpreted as intermediate in age between the Kome flora and the Atane flora (Koch 1964; Boyd 1998a). Macrofossil plants from Qeqertarsuaq correspond to species known from outcrops at Upernivik Næs and Atanikerluk (Ødum & Koch 1955). Few palynomorphs have been recorded from Croxton's (1978b) C9 section through coastal exposures and the type section at Upernivik Næs. The presence of a few specimens of the pollen *Rugubivesiculites rugosus* throughout the section indicate a Middle Albian to Turonian age, and the co-occurrence with a few specimens of the dinocysts *Nyktericysta davisii* and *Quantouendinium dictyophorum* in the lower part of the section suggests correlation to the lower part of the Atane Formation (?Ravn Kløft Member). A large specimen of the dinocyst *Nyktericysta davisii* has been recorded from the middle part of the C9 section. Similar forms are common in sediments on Qeqertarsuaq (Christiansen *et al*. 2000) and from a single fully marine sample from the Atane Formation at Ikorfat dated as Early Turonian. The sediments in facies

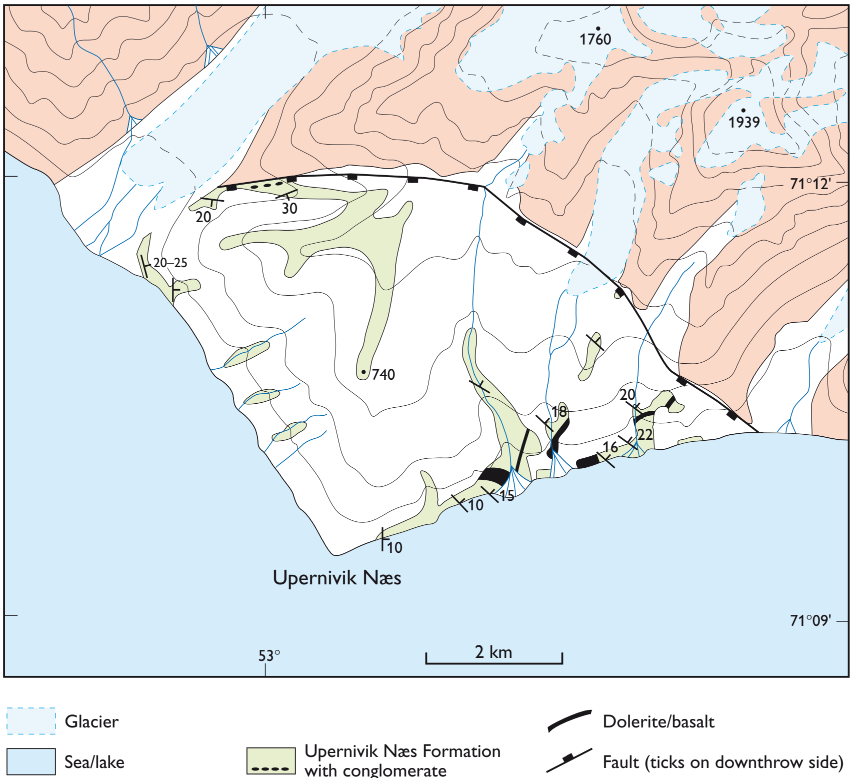

Fig. 33. Geological map of Upernivik Næs on the south-western tip of Upernivik Ø. The type section of the Upernivik Næs Formation is located in the ravine 2.5 km east of Upernivik Næs. Slightly modified from Henderson & Pulvertaft (1987). For location, see Fig. 2. The contour interval is 200 m.

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Fig. 34. Type section of the Upernivik Næs Formation; from Midtgaard (1996b). Notice the presence of tidal deposits. For legend, see Plate 1; for location, see Fig. 33.

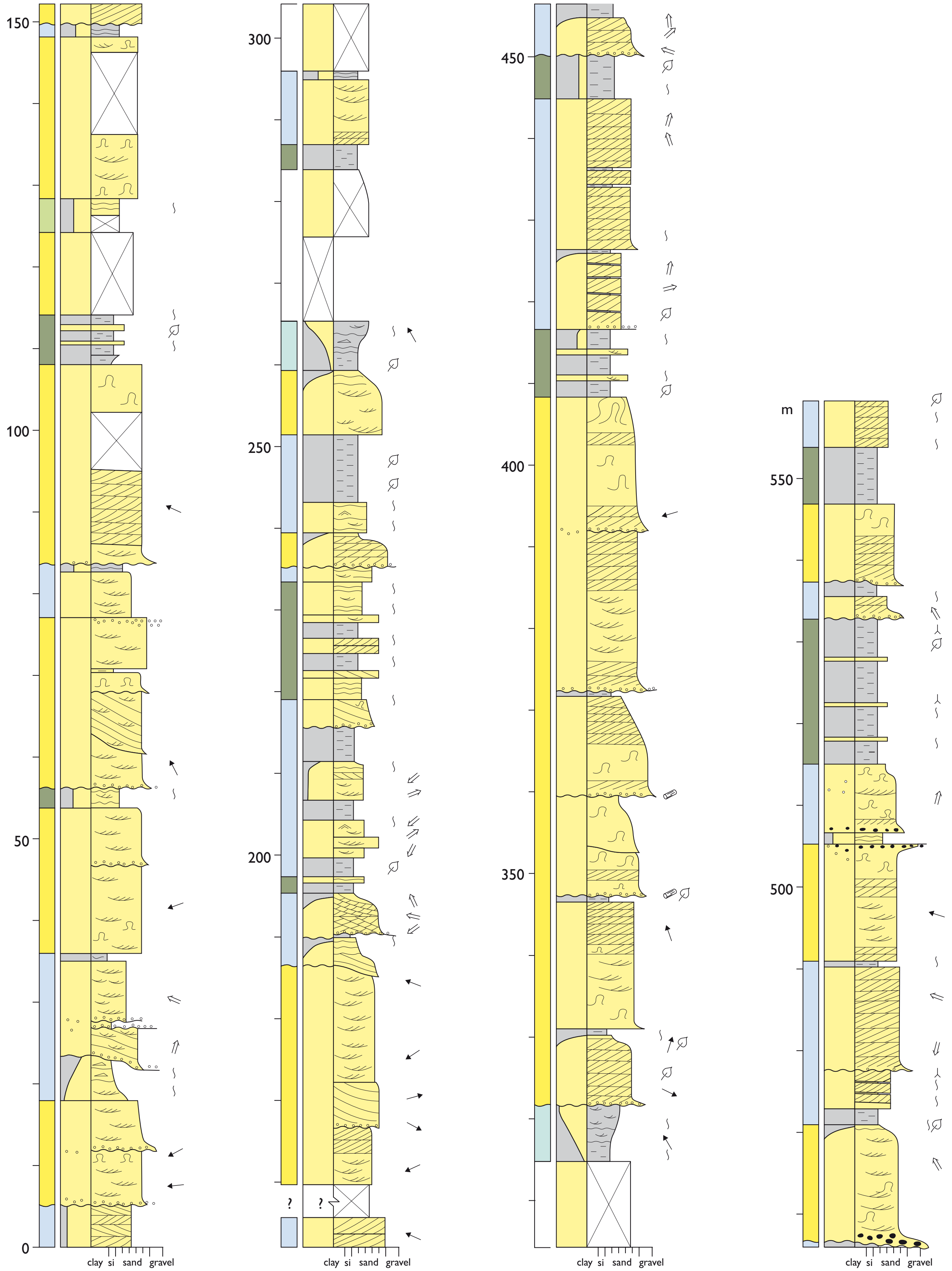
150
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Fig. 35. Type locality of the Upernivik Næs Formation. The central peak is *c.* 1700 m high. For location, see Fig. 33.

association B contain trace fossils such as *Skolithos, Arenicolites, Conichnus, Planolites, Rhizocorallium* and *Pelecypodichnus* (Midtgaard 1996b).

Depositional environment. The sandstones of facies association A are interpreted to have been deposited in braided fluvial channels. The scarcity of interbedded floodplain or levee facies suggests that the channels were migrating laterally. The abundant soft-sediment deformation structures suggest synsedimentary tectonic activity.

The heterolithic, burrowed sandstones (facies association B) are interpreted to have been deposited in an estuarine environment – in tidal channels, tidal point bars, tidal deltas, tidal flats, bay mudstones, and on the shoreface as transgressive lags. The palaeocurrents are interpreted to reflect longshore tidal transport.

The interbedded sandstones and mudstones (facies association C) are thought to represent a coastal plain environment and include lagoonal, mudflat and marsh deposits, crevasse splay deposits and deposits in small channels. The scarcity of rootlets and the presence of trace fossils suggest brackish-water conditions. Intrusion of the sandstone dykes may have been triggered by earthquakes.

The coarsening-upward successions (facies association D) are interpreted as deltaic deposits. The lack of wave-generated sedimentary structures in facies association D in the Upernivik Ø section indicates deposition in a low-energy environment, probably an interdistributary bay or the inner part of an estuary, i.e. a bayhead delta (Midtgaard 1996b). Higher-energy facies on Qeqertarsuaq and Itsaku suggest the influence of waves and storms on the delta deposits (J.G. Larsen & Pulvertaft 2000).

Boundaries. The lower boundary of the Upernivik Næs Formation is not exposed in the type section nor in the reference section. Conglomerates with large clasts of both weathered and fresh basement rocks have been reported close to the boundary fault at Upernivik Næs (Fig. 33), from a small outcrop on the north-western part of Upernivik Ø (Henderson & Pulvertaft 1987 fig. 46), from Qeqertarsuaq and from Itsaku (Rosenkrantz &

Fig. 36. Outcrop of the Upernivik Næs Formation on Qeqertarsuaq; for location, see Fig. 73. Reddish-brown intrusions cross-cut (right) and cap the sediments.

Pulvertaft 1969). The boundary between the Kome and the Upernivik Næs Formations is at present not known.

The upper boundary of the formation is an erosional contact with the Kangilia Formation on Itsaku and with Quaternary deposits on Upernivik Næs and Qeqertarsuaq.

Geological age. The Upernivik Næs flora contains angiosperm plants, which suggests a greater similarity to the Atane flora than to the Kome flora (Koch 1964). Koch recommended, however, that until the Cretaceous floras are thoroughly revised, the Upernivik Næs flora should

Fig. 37. Clast-supported conglomerate of the Upernivik Næs Formation on Qeqertarsuaq. Hammer for scale; for location, see Fig. 73.

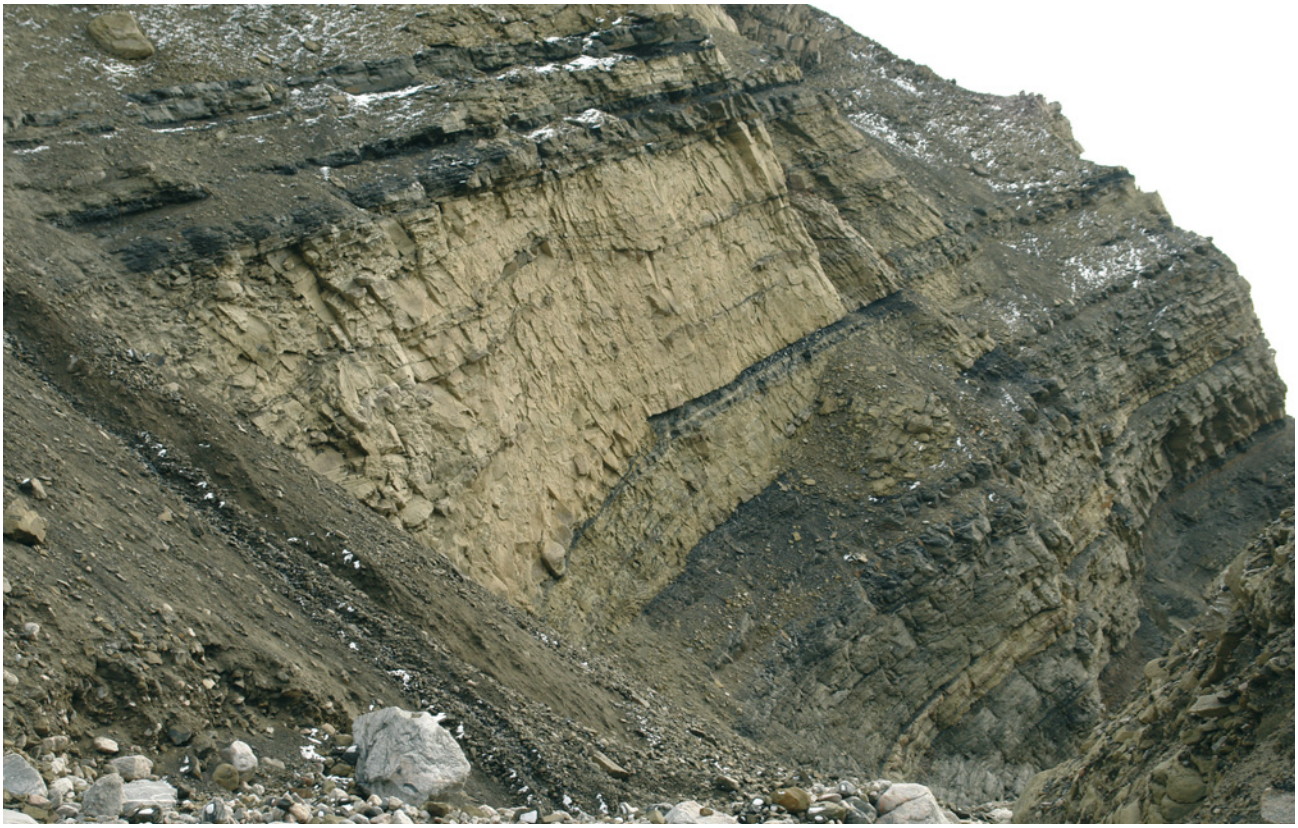

Fig. 38. Channellised sandstones of the Upernivik Næs Formation in the lower part of the type section. Thickness of sandstone unit is approximately 10 m. For location, see Fig. 33.

be eliminated from the discussion of the age of the Kome and Atane Formations and treated as an independent problem (Koch 1964 p. 540).

Rosenkrantz (1970) suggested that the Upernivik Næs flora is of Albian–Turonian age. Boyd (1998a) suggested that the Upernivik Næs flora is contemporaneous with his Ravn Kløft flora which he referred to the Middle–Late Albian and earliest Cenomanian. The poor palynological assemblage indicates a Late Albian to Early Turonian age (Croxton 1978a, b; this study).

Fig. 39. Detail of tidally influenced deposits of the Upernivik Næs Formation in the lower part of the type section. Person for scale; for location, see Fig. 33.

Correlation. The Upernivik Næs flora was suggested to be coeval with the Ravn Kløft flora by Boyd (1998a). This suggests a correlation between the Upernivik Næs Formation and the Ravn Kløft Member of the Atane Formation (Figs 13, 16).

Atane Formation

redefined formation

History. Nordenskiöld (1871) erected the Atane Formation (Atanelagren), naming it after the now-abandoned settlement of Atane (now Ataa, Figs 3, 40). He described the unit to be more shaly than both the underlying Kome Formation and the overlying Upper Atanikerdluk Formation, and interpreted the Atane Formation as freshwater deposits. He referred the formation to the Upper Cretaceous, following Heer (1868), with a distribution on southern Nuussuaq (between Atanikerluk and Ataa), northern Disko (at Qullissat) and at Kuuk on northern Nuussuaq (at altitudes above 250–300 m). Outcrops with coal seams were visited by Steenstrup (1874), who noted the occurrence of marine invertebrates in mudstones between the coal seams at Paatuut and Nuuk Qiterleq.

The Atane Formation normally appears as a striped white, grey and black sandy and shaly unit rich in coalified plant fossils (Fig. 41) that formed the basis of the classic studies by Heer (1868, 1870, 1874a, b, 1880, 1883a, b). However, self-combustion of the mudstones has locally produced brick-red, hard and fissile burnt slabs (Fig. 42) in which fossils are excellently preserved as impressions. Burnt mudstones are fairly common in the Paatuut (formerly spelled Patoot, Pâtût or Pautût) and Kingittoq areas, and they were included in the regional collection that Steenstrup sent to O. Heer (Steenstrup 1883a, b). Based on their colour, Heer treated the samples of burnt mudstones from Paatuut as lithostratigraphically different from those containing the Atane flora. Thereby a Patoot Formation (i.e. the sediments comprising the Patoot flora) was introduced and subsequently treated as a formal unit (Troelsen 1956). Steenstrup (1883c) objected to Heer's interpretation of a stratigraphic boundary between the unburnt and the burnt mudstones from Paatuut since he had observed that the burnt mudstones are laterally equivalent to the normal, unburnt sediments.

Steenstrup (1883a) suggested that all the Cretaceous sediments from Svartenhuk Halvø to Disko should be enclosed in one lithostratigraphic unit. He envisaged the depositional environment of the horizontally bedded mudstones and sandstones as shallow marine on account of his collections of invertebrates (bivalves and echinoids), although the well-preserved plant remains indicated deposition close to vegetated areas (Steenstrup 1883a p. 48).

The Early Cretaceous to Miocene age proposed by Heer for the coal-bearing deposits in West Greenland was discussed by A. Heim and J.P.J. Ravn, who both suggested that Heer's interpretation spans too long a period. Instead they interpreted all the sediments as Upper Cretaceous to Eocene (Heim 1910), more specifically the Kome flora as Albian, the Atane flora as Cenomanian, the Patoot flora as Senonian and the Atanikerdluk flora as Eocene (Ravn 1918 p. 320). Ravn (1918) envisaged the plant bearing sediments as having been deposited in a fresh- to brackish-water environment, in which the rate of deposition equalled the rate of subsidence. The inoceramids provided evidence of marine conditions and Ravn therefore concluded that at times subsidence exceeded deposition and marine environments were established. Furthermore, he observed no changes in the style of sedimentation during the Cretaceous and inferred that deposition had occurred continuously, presumably within a restricted period and consequently at relatively high rates of sediment accumulation.

Troelsen (1956) maintained the distinction between the Kome, Atane and Patoot Formations, quoting descriptions by Nordenskiöld (1871) and Heer (1883b). These authors suggested that the Kome and Atane Formations are separated by a slight angular unconformity (Troelsen 1956).

Koch (1964) regarded the Pautût Formation (*sensu* Heer 1883b) as an artificial unit. Henderson *et al.* (1976 fig. 303) quoted the lithostratigraphy of Troelsen (1956), but stressed that the Kome, Atane and Pautût formations lacked formal stratigraphic definition and referred all the fluvial and deltaic Cretaceous sediments on Disko and southern to central Nuussuaq to the Atane Formation. Ehman *et al.* (1976) used the term Atane Formation informally for the Cretaceous non-marine deposits and found that the sediments range in age from Albian through Santonian.

G.K. Pedersen & Pulvertaft (1992) referred all non-marine Cretaceous sediments on Disko and Nuussuaq to the Atane Formation. They claimed (p. 263) that the term Atane Formation "had outlived the other formation names that have been used in the past for the different isolated outcrops of Cretaceous non-marine strata in West Greenland". Based on the data available at that time, G.K. Pedersen & Pulvertaft (1992 p. 263) interpreted these strata as "belonging to the same deposi-