



Cretaceous–Tertiary sedimentary rocks of West Greenland

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Introduction

Sedimentary rocks of Cretaceous to Lower Tertiary age are present on land in West Greenland in an area extending from the inner part of the Ingnerit peninsula in the north to the Grønne Ejland group of islands in the south (fig. 301). This area constitutes only part of a much more extensive sedimentary basin – the West Greenland basin – that is known to extend along the entire western margin of Greenland, most of the deposits being concealed beneath the waters of Baffin Bay, Davis Strait and the Labrador Sea.

The deposits on land are present in an embayment for which the name Nûgssuaq embayment is proposed, after the Nûgssuaq peninsula in the central part of the onshore area. This account deals entirely with the rocks exposed on the various islands and peninsulas in this embayment.

The rocks exposed range in age from Lower Cretaceous (Barremian) to Lower Tertiary (mainly Danian). They comprise a sequence of predominantly clastic marine and non-marine sediments deposited in an environment transitional from fluviatile to deltaic. Apart from minor oscillations the relative positions of the subenvironments did not change significantly. The transport of material was mainly from the south, resulting in a northwards change from a deltaic-fluviatile to a prodelta marine environment. Various facets of this changing environment have been studied on the Nûgssuaq peninsula, where the exposures are reasonably good.

The surface on which these beds were deposited had considerable relief. For example, south-west of Kûk the pre-Cretaceous surface rises from sea level to 1800 m in the inner part of Nûgssuaq. This sur-

Fig. 300. The eastern slope of Qagdlúnguaq NW showing the Cretaceous Atane Formation in a section of about 300 m.

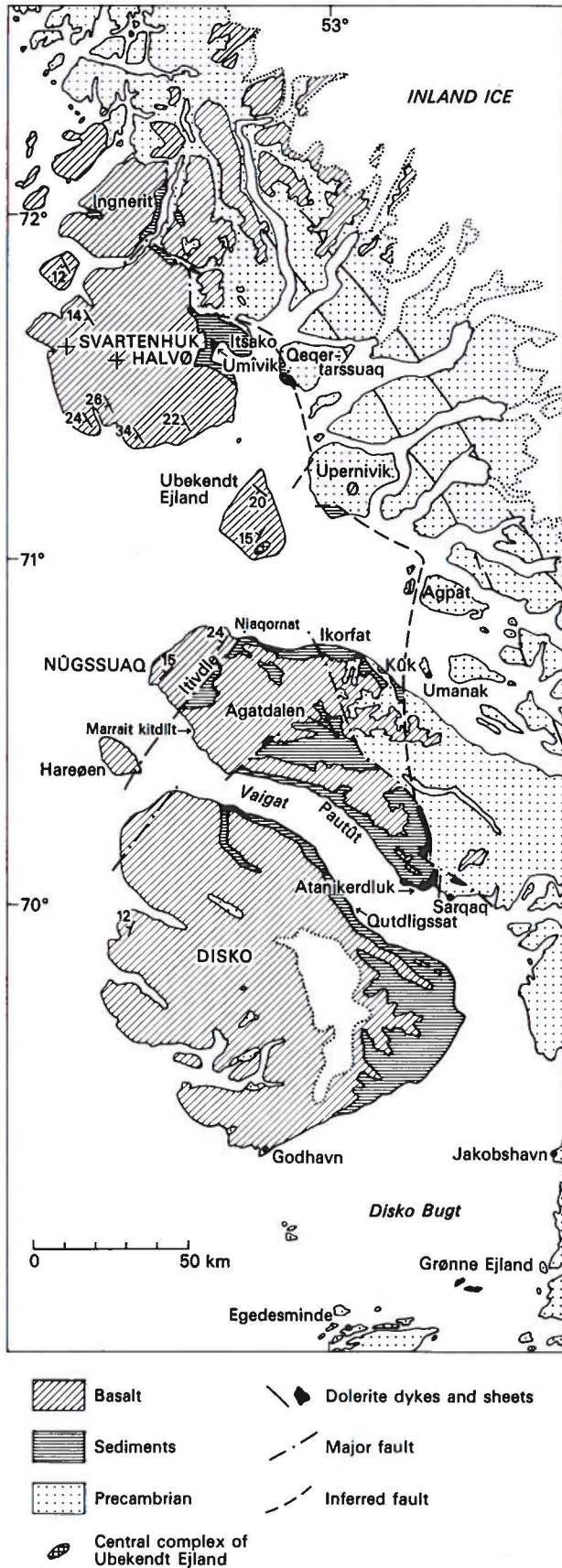


Fig. 301. Map showing the distribution of Cretaceous-Tertiary rocks in West Greenland. Modified from Rosenkrantz & Pulvertaft (1969).

face was deeply weathered, in places along the north coast to a depth of 35 m (Rosenkrantz & Pulvertaft, 1969).

Seismic surveys (Sharma, 1973; Elder, 1975) considered in conjunction with the known outcrop geology have shown that the thickest sequence of sediments is in the central part of the north coast of Nûgssuaq, where it amounts to about 4 km, of which 3 km of sediments are below sea level. In the central part of the Vaigat the total thickness of sediments is about 3 km of which 2 km are below sea level. Elsewhere in the embayment thicknesses of 1 km or more have been determined.

Composite sections determined by adding up thicknesses of known sections above sea level produce a maximum thickness of about 2 to 2.5 km. It thus seems very likely that the deepest sections below the Nûgssuaq peninsula consist of beds older than any exposed at the surface.

The sediments are overlain by a thick sequence of Tertiary basalts, which belong to the Brito-Arctic volcanic province (Clarke & Pedersen, this volume). The onset of volcanic activity is shown by the presence of tuff layers in the Danian sediments of southern, central and northern Nûgssuaq (Rosenkrantz, in Rosenkrantz *et al.* 1941; B. E. Koch, 1959; Rosenkrantz, 1970; Jürgensen & Mikkelsen, 1974). A thick sequence of subaquatic pillow breccias wedging towards the east-south-east marks the first major extrusive phase. The pillow breccias in turn are overlain by subaerial basalts, which are thought to be up to 8 km thick in the western part of the area.

A thin fossiliferous marine limestone conglomerate and another conglomerate intercalated in the lower part of the volcanic sequence of south-western Nûgssuaq have given an Upper Danian age. Interbasaltic non-marine sediments are known from several parts of the area. Plant remains from these show that the beds cannot be younger than Eocene.

The eastern limit of the pre-basaltic sediments is a system of faults with downthrow to the west. Some of the faults were active during the sedimentation but much, possibly most, of the movement along the faults took place after sedimentation. The vertical displacement in some areas must have been in the range of 1500 m.

On both Nûgssuaq and Svartenhuk Halvø basalts overlap the faults and rest directly on the Precambrian rocks to the east.

The western part of the onshore area consists exclusively of basalts, which here, in contrast to the basalts found capping the sediments in the central and eastern parts of the area, are tilted westwards and are extensively faulted.

AGE	FLORA	
Paleocene - Eocene	Interbasaltic Ifsorisok flora. Pillow breccias and plateau basalts	
Upper Danian	Upper Atanikerdluk flora	<i>Globoconusa daubjergensis</i> , <i>Tylocidaris</i> , <i>Latiarca</i> , <i>Stegoconcha</i> , <i>Venericor</i> , <i>Tylostoma</i> , <i>Creonella</i> , <i>Gilbertina</i> , <i>Ravniella</i>
Lower Danian		unconformity
		<i>Echinocorys</i> , <i>Tylocidaris</i> , <i>Dendrophyllia candelabrum</i> , <i>Thyasira conradi</i> , <i>Palaeocypraea</i> aff. <i>P. spirata</i> , <i>Ravniella</i> , <i>Cimomia</i> , <i>Hercoglossa</i>
		unconformity
Maastrichtian		<i>Saghalinites</i> , <i>Neophylloceras</i> , <i>Discoscaphites waagei</i> , <i>Inoceramus fibrosus</i>
		<i>Discoscaphites</i> , <i>Diplomoceras</i> sp.
Upper Campanian		<i>Hoploscaphites greenlandicus</i>
		<i>Hoploscaphites ikorfatensis</i> , <i>Pseudophylloceras</i>
Lower Campanian	Pautut flora	<i>Scaphites cobbani</i> , <i>Baculites obtusus</i> , <i>Pseudophyllites skoui</i>
		<i>Haresiceras</i> sp.
Upper Santonian		<i>Baculites codyensis</i> / <i>Inoceramus steenstrupi</i>
Lower Santonian		<i>Clioscapites</i> aff. <i>C. saxitonianus</i>
		<i>Clioscapites septentrionalis</i>
Coniacian	Atane flora	Angiosperm pollen in increasing amounts
Upper Turonian		
	<i>Scaphites preventricosus svarnehukensis</i> , <i>Inoceramus deformis</i>	
Turonian - Cenomanian-Albian	Upernivik Næs flora	
		no marine deposits
Barremian-Aptian	Kome flora	No angiosperm pollen
		no marine deposits
Precambrian		

Fig. 302. Biostratigraphy of the marine and non-marine Cretaceous-Tertiary sediments in West Greenland. Slightly modified after Rosenkrantz (1970).

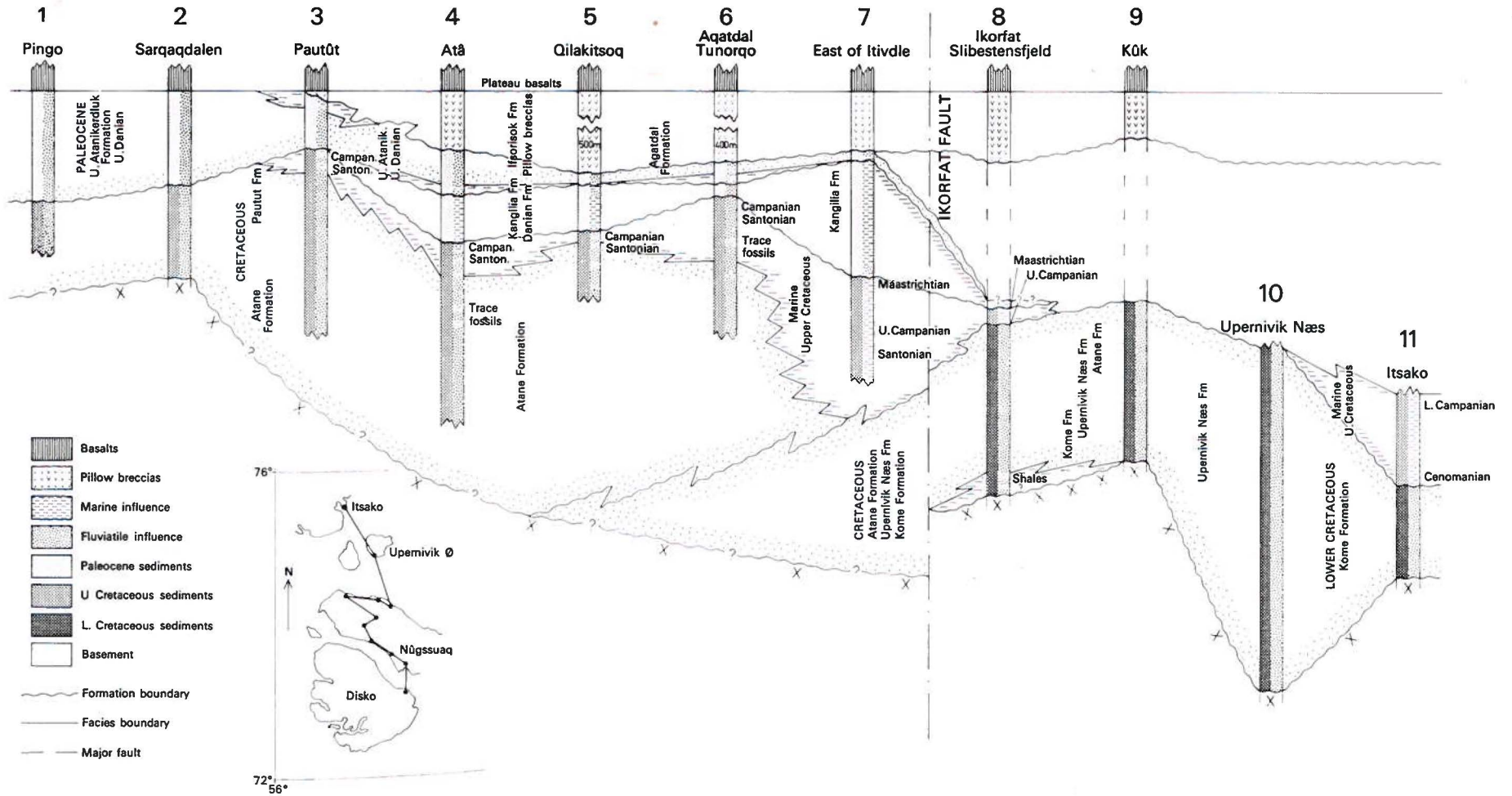
A N-S trending gneiss ridge on Disko was uplifted at the end of the sedimentation and positive movements continued during the deposition of the lowermost basalts. There is little direct evidence that this ridge contributed to the pre-basaltic sediments.

Rosenkrantz (1970) has published a table that shows in summary form the biostratigraphy of the marine and non-marine Cretaceous-Tertiary sediments (fig. 302).

Although some lithostratigraphic subdivision of the sediments of parts of the embayment has been undertaken there is by no means a comprehensive system that can be applied to the entire embayment. The non-marine Cretaceous-Tertiary succession of the areas from southern Nûgssuaq northwards has been divided into formations. However, exact dating of the many disconnected areas of the Cretaceous

non-marine strata has not been achieved yet. As pointed out by B. E. Koch (1964), the biostratigraphic status of the Kome, Atane and Pautut (= Patoot) floras of the classic studies (Heer, 1883; Seward, 1926) is questionable. Intercalations containing marine body fossils are known only from a few localities, both on the south coast and in the central valley of Nûgssuaq. Elsewhere on Nûgssuaq and on Itsako marine shales overlie the Cretaceous non-marine beds and thus permit at least the upper age of the latter to be established at these localities.

No formal correlative framework has been applied to the Cretaceous marine strata apart from local sections, but the Danian marine beds of central and northern Nûgssuaq have been correlated and further sub-divided. Because of this lack of correlation over larger parts of the embayment the rocks will



be discussed area by area. Reference will be made to lithostratigraphic and biostratigraphic divisions when such have been made.

Some of the lithostratigraphic units that have appeared in the literature on this area over the years have not been defined according to modern standards, but the existing nomenclature has been retained in this article, whose first part is mainly a compilation of already published material (see fig. 303).

Non-marine strata

Grønne Ejland

The islands constituting this group (fig. 301) consist almost entirely of dolerite which has been intruded as a sill close to the boundary between the sediments and the Precambrian rocks. On the south-easternmost of the islands, Angíssat, a 4–6 m section of sediments is exposed at sea level below the dolerite sill at one place on the south coast. The base of the sill is discordant in places and is chilled against the sediments. The sediments comprise striped cherty shales, chert, siltstones with plant remains and friable strongly convoluted sandstone. Tuffaceous material has been found in the sandstone, which indicates that the beds are Tertiary.

Disko

The sedimentary succession of Disko comprises entirely non-marine clastic sediments (fig. 304) ranging in age from Cretaceous to Danian. Cretaceous beds belonging to the Atane Formation (Nordenkiöld, 1871), which is now considered to be of Upper Turonian – Coniacian age (Rosenkrantz, 1970) occur along the east and south coasts of Disko. The formation consists of alternating shales and sandstones, and contains coal seams, which were worked in the Qutdligssat area until 1972. Only the lowest 150–200 m of the exposed section are directly comparable on lithological grounds to the Cretaceous rocks occurring on Nûgssuaq.

The Tertiary part of the succession on north-east Disko has only been studied on a reconnaissance basis. According to B. E. Koch (1964) three members of the Upper Atanikerdluk Formation (Nordenkiöld, 1871 – see under Nûgssuaq) can be recognised. Fluvial deposits resembling the basal Quikav-

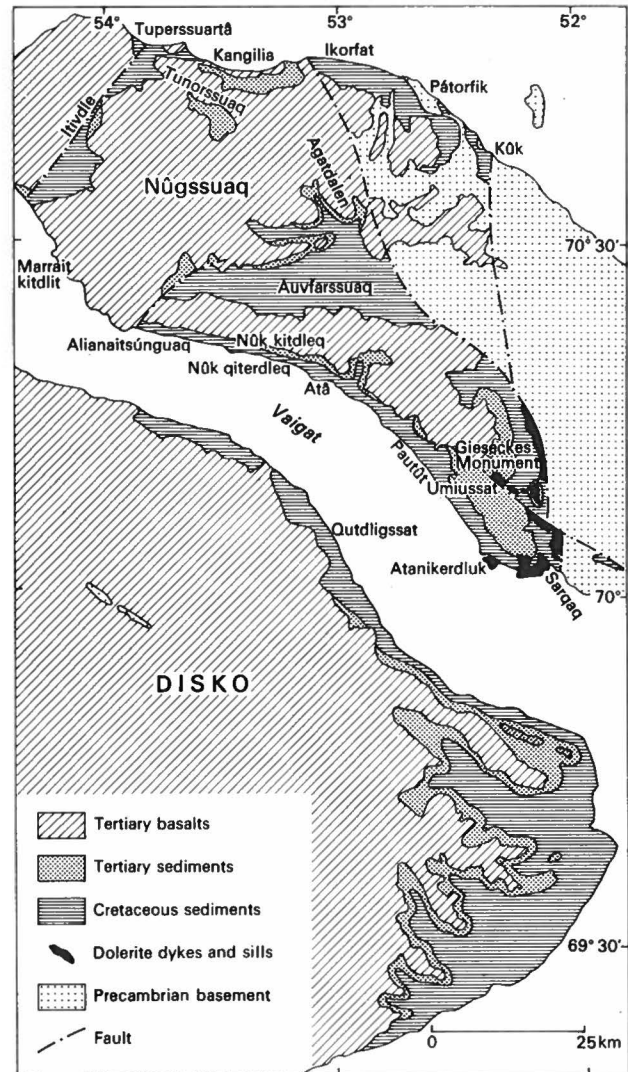


Fig. 304. Cretaceous–Tertiary sediments in the southern part of the Nûgssuaq embayment.

sak Member of Nûgssuaq have been observed over large parts of south-east and south Disko. Their thickness (> 400 m) and wide distribution, however, is here not consistent with the interpretation as a channel deposit. Dark shales considered to represent the succeeding Naujât Member are present over most of south-east Disko. The Aussvik Member which is the fourth of the five members described by Koch may be represented at Qutdligssat by shales occurring above a thick sequence of pillow breccias.

The thickness of the Cretaceous sediments and the stratigraphic position of the Tertiary sediments relative to the volcanic rocks in north-eastern Disko are shown as profiles in Pedersen (1973). One unit in the profiles from Qutdligssat and Qordlortorsuaq contains black shales up to 15 m thick with tuffs and plant fossils, including *Macclintockia*. It is tentatively correlated with the lower part of the Naujât Member. The profile from Qutdligssat also shows the shales

Fig. 303. Schematic section through the Cretaceous–Tertiary formations of the Nûgssuaq embayment.

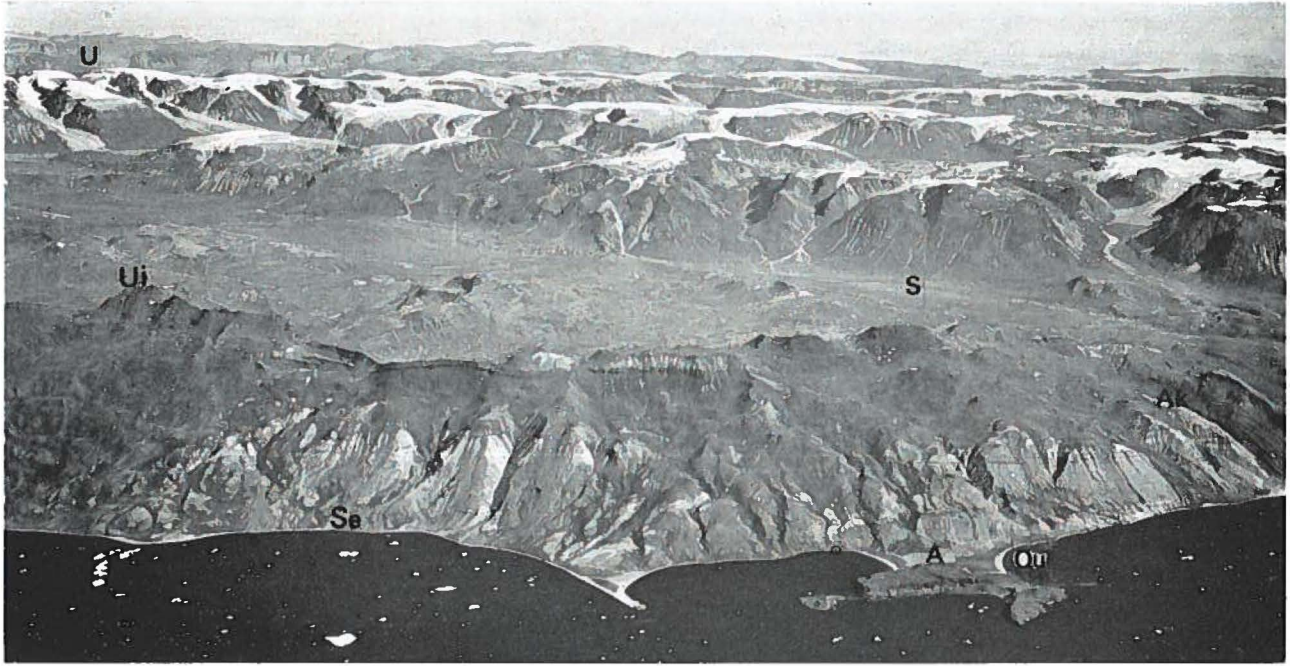


Fig. 305. Aerial view of Atanikerdluk with localities referred to in the text. A: Atanikerdluk, Ak: Aussiviup kûa, Qu: Quikavsauk kûa, S: Sarqaqдалen, Se: the ravine of Qagdl-únguaq SE, U: Umanak Fjord, Ui: Umiussat. After B. E. Koch & K. R. Pedersen (1960). Copyright Geodetic Institute.

above the thick pillow breccias, which Koch thought could be equivalent to the Aussvik Member shales of Nûgssuaq.

Nûgssuaq

North coast

The oldest non-marine strata are also the oldest sediments present above sea level in the embayment. These are the beds of the Kome Formation which are found on the north coast of Nûgssuaq (and at Itsako on Svartenhuk Halvø – see later).

The Kome Formation (Nordenskiöld, 1871) has as its type locality Kûk (syn: Kook, Kome) on the north coast of Nûgssuaq. The formation consists of a sequence of clastic sediments, comprising alternating thinly bedded shales and sandstones with occasional coal seams. It rests on deeply weathered Precambrian gneiss, the weathered zone being up to 35 m thick. The lowest deposits normally consist of a poorly sorted arkose representing a local redistribution of the top layer of weathered gneiss.

The Kome Formation with an exposed thickness of about 200 m occurs almost continuously along the north coast of Nûgssuaq from Kûk in the east to Ikorfat (syn: Ekorfat) in the west, interrupted only by a younger down-faulted deposit of Upper Cretaceous age between Angiarssuit and Ujaragtôrssuaq. Im-

mediately east of Ikorfat the formation is developed in a siltstone-shale dominated facies attaining up to 100 m in thickness.

Fossil plants occur in black shales in the formation and constitute the Kome flora of Heer (1883). K. R. Pedersen (1968) has found a few leaves of angiospermous affinity in Kome beds at Pátorfik, a short distance west of Kûk. On the basis of these he considers that the formation is of Barremian–Aptian age. No fossils indicative of a marine environment have been found in the Kome Formation.

West of Kûk and east of Ikorfat the Kome Formation is overlain unconformably by a sequence consisting largely of sandstones. In the lower part of the sequence immediately east of Ikorfat angiosperm pollen appears and increases in quantity upwards. These lower beds are overlain by beds containing a flora of the type contained in the Atane Formation of southern Nûgssuaq, which is of Upper Turonian to Coniacian age. Rosenkrantz (1970) considered the lower beds to be equivalent to the Upernivik Næs Formation (see under Upernivik Ø), which is of Albian to Turonian age.

Along the coast west of the fault at Angiarssuit the down-faulted younger beds contain an Atane flora and freshwater molluscs. Yen (1958) considered that the molluscs were indicative of the upper part of the Upper Cretaceous.

A thin sequence (maximum 120 m) of marine Campanian and Lower Danian shales overlies the non-marine Cretaceous sediments and is followed upwards by Tertiary basalts in the area immediately east of Ikorfat.

South coast

The Cretaceous–Tertiary succession in the Atanikerdluk area of south Nûgssuaq (fig. 305) is predominantly non-marine. The sediments are separated by the fault through Sarqaq dalen from the Precambrian rocks to the east and the base of the succession west of the fault is not exposed. An isolated outcrop of gneiss on the west side of the valley could be part of the pre-sedimentary floor, in which case much of the dolerite mass immediately west of the valley may have been intruded close to the boundary between the Precambrian rocks and the overlying sediments.

The lowest parts of the succession exposed in this area are clastics belonging to the non-marine Atane Formation (Nordenskiöld, 1871). The Atane Formation has its type locality in the gorge of the Kugssinerssuaq river at Atâ, 40 km north-west of Atanikerdluk. It consists of alternating shales and sandstones containing coal seams. The thickness of the total (Atane) sequence along the south coast of Nûgssuaq is 1000–1500 m (B. E. Koch, 1964).

In the Atanikerdluk area the top of the formation is at a height of 350–500 m above sea level (fig. 300). In one 200 m section recorded by Koch & Pedersen (1960) there are seven coal seams 20–40 cm thick.

The fossil flora obtained from the Atane Formation (Heer, 1883) is now considered to be of Upper Turonian to Coniacian age (Rosenkrantz, 1970).

At Alianaitsûnguaq 50 km north-west of Atanikerdluk an Atane flora has been found in beds closely following marine Coniacian shales. At the type locality Atâ there is only a short vertical interval between the beds containing the Atane flora and overlying marine beds of Santonian to Campanian age.

The status of the Upper Cretaceous Pautut Formation (Heer, 1883) is problematical. The type locality is Pautût (syn: Patoot) on the south coast of Nûgssuaq between Atâ and Atanikerdluk, where 800 m of alternating sandstones, dark shales and numerous coal seams extend from sea level to the overlying basalts (fig. 306). The area is greatly affected by landslides accompanied by ignition of the shales, so that hard, red and yellow burnt shales are a prominent feature. B. E. Koch (1964) has thrown doubt upon the status of this as a separate formation. He believes that it passes laterally and vertically into the Atane Formation exposed to the north-west and

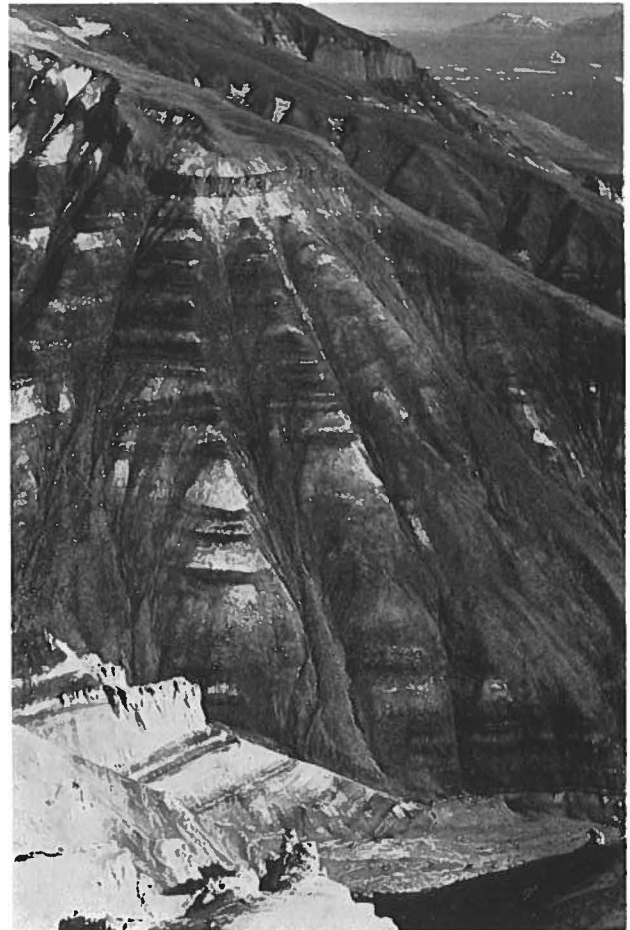


Fig. 306. Sandstones and shales of the Pautut Formation at the type locality. Photo: K. Skou.

south-east, and thus represents in accordance with its content of marine fossils a facies variation.

In central parts of the undisturbed sequence marine fossils were found *in situ* (K. R. Pedersen in B. E. Koch, 1964). Their presence in loose blocks has long been known in the Pautût area (for summary of earlier investigations see Rosenkrantz, 1970). On the basis of these fossils, which include *Sphenocerasmus steenstrupi* and *Sphenocerasmus patootensis*, the Pautût section with its fossil flora has been assigned to the level Upper Santonian to Lower Campanian. A Pautut flora has been retained by Rosenkrantz in his stratigraphic table (fig. 302).

In the Atanikerdluk area the contact between the underlying Cretaceous Atane Formation and a sequence of Tertiary beds, the Upper Atanikerdluk Formation (Nordenskiöld, 1871) which has its type locality at Quikavsauþ kûa, consists of an erosional surface (fig. 307). The Upper Atanikerdluk Formation has been divided by B. E. Koch (1959) into five members, two argillaceous and three mainly arenaceous units (fig. 308).

The lowest member, the Quikavsak Member (type

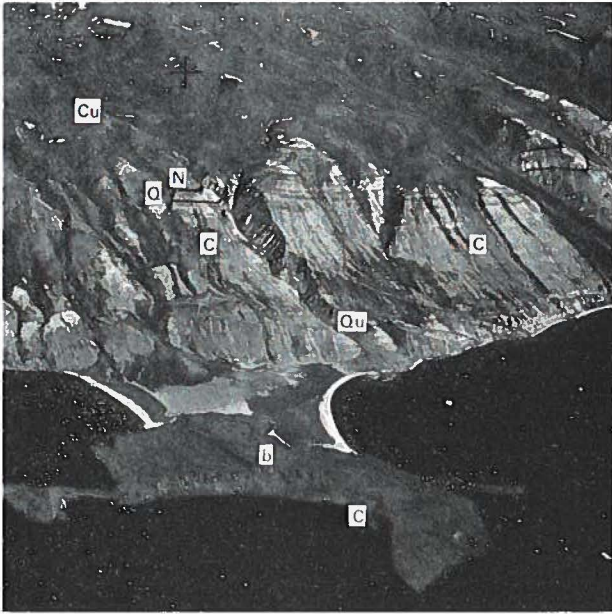


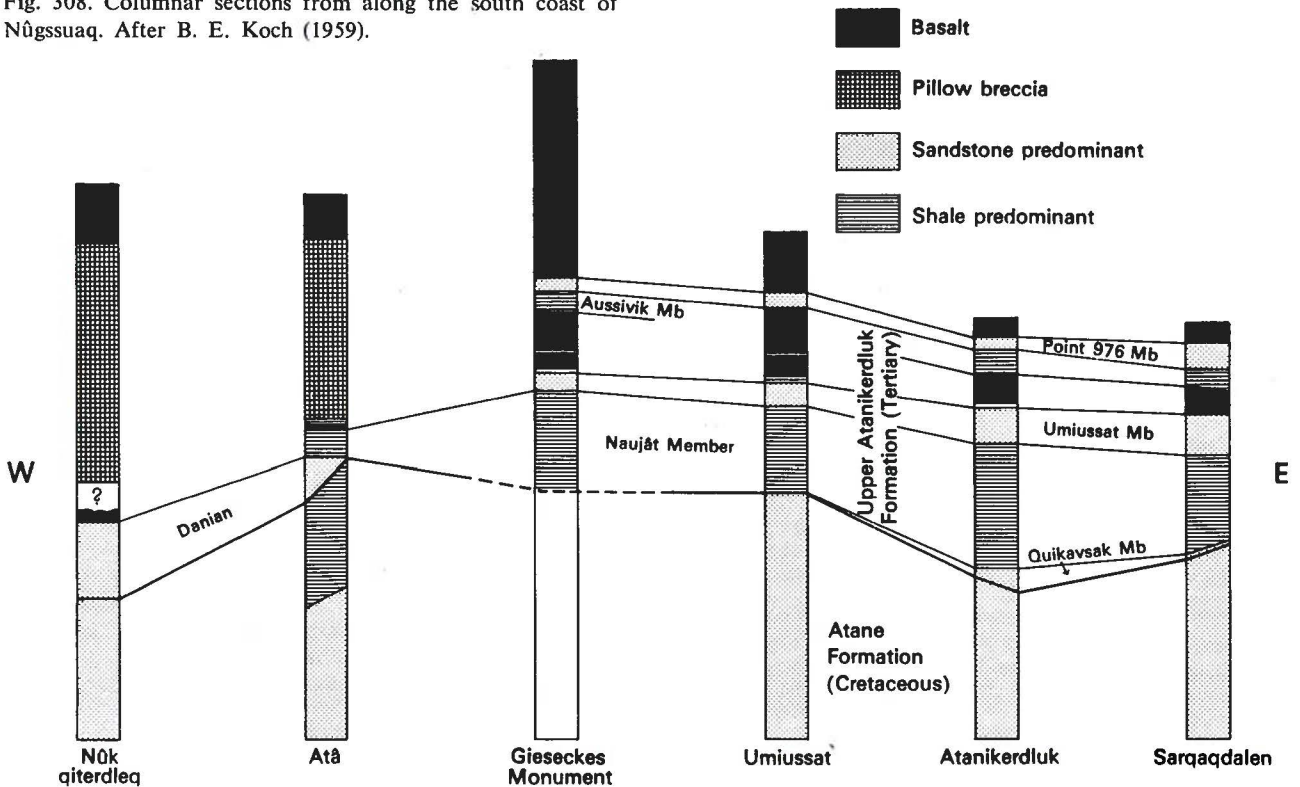
Fig. 307. Aerial view of Atanikerdluk and the coastal slope immediately to the north of the peninsula. b: basalt, C: Cretaceous Atane Formation, Q: Tertiary Quikavsak Member, N: Tertiary Naujât Member, Cu: landslipped mass, Qu: Quikavsauk kûa. The black lines show the limits between the Cretaceous beds, the Quikavsak Member and the Naujât Member. Copyright Geodetic Institute.

locality: Quikavsauk kûa) is described as a fluvatile-estuarine deposit, consisting of cross-bedded sandstone with fragments of coal and fossil wood, thin shale bands, and clay-ironstone nodules; the nodules are found in both the sandstone and the shale. Locally a conglomerate up to 2 m thick marks the base of the member. The boulder components up to 30 cm in diameter are of gneiss, though the nearest gneiss outcrops are 20 km distant.

Along the south coast of Nûgssuaq, these beds occur in channels cut in the underlying either non-marine Cretaceous or Lower Danian marine sediments. North-westwards the typical fluvatile channel facies loses its character. At Pautût isolated outcrops of an apparently continuous marine layer with *Ostrea* sp. of a type similar to those found in the Agatdal Formation of central Nûgssuaq show through scree just above the uppermost Cretaceous outcrops. A few molluscs have also been found 5 m below basalt that rests directly on the Quikavsak Member. At the locality Nûk kittleq, 30 km north-west of Pautût, boulders of sandstone with numerous specimens of *Ostrea* sp. were found in scree above strata considered to be Cretaceous.

The Quikavsak Member contains a fossil flora, the Upper Atanikerdluk A flora (Heer, 1883). An equivalent flora was obtained from deltaic deposits of Upper Danian age in the Agatdalen area of central

Fig. 308. Columnar sections from along the south coast of Nûgssuaq. After B. E. Koch (1959).



Nûgssuaq (the Sonja and Andreas Members of the Agatdal Formation; B. E. Koch, 1963, 1964).

The Naujât Member (type locality: Naujât in the valley Sarqaq dalen) consists of up to 200 m of black shales with tuff bands which, within the lowest 10 m of the section, contain Heer's Upper Atanikerdluk B flora. Fossil plants have also been recorded from a higher stratigraphic level in the shales (Upper Atanikerdluk C flora). According to B. E. Koch (1963) the basal part of the Naujât Member can be compared with the Abraham Member of the Upper Danian Agatdal Formation. B. E. Koch (1959) considers that the beds of the Naujât Member were deposited in a shallow marine, possibly lagoonal, environment, but no marine fossils have been found in the beds.

The Umiussat Member (type locality at the mountain Umiussat, north of Atanikerdluk) consists of clastic sediments, predominantly sandstones, with intercalated beds of black, sandy shale. The member has a maximum thickness of 100 m.

The Aussivik Member (type locality: Aussiviup kûa at Tartunaq) is 130–150 m thick and consists of black and grey shales with about 80 m of basalt in the lower part. The basalt was believed by B. E. Koch (1959) to be extrusive. Recent work by A. K. Pedersen has shown that it is intrusive and represents part of the extensive sill complex which is characteristic for this level close to the base of the lava flows. Individual tuff bands occur in the shales.

The uppermost member of the Upper Atanikerdluk Formation, the Point 976 Member (type locality: the mountain with summit 976 m above Atanikerdluk) consists of a sequence of clastic sediments, mainly sandstones, up to 60 m thick.

North-western area

Interbasaltic sediments are present in the lava sequence west of the Itivdle valley in north-western Nûgssuaq (fig. 309), where they are considered to mark a level within the upper lava formation. They are described by Hald (1973) as layered coarse-grained sediments of greyish brown or yellow brown colour consisting of angular fragments of a generally aphyric basalt in a fine-grained matrix. The fragments are typically 1–5 cm across, but blocks up to ½ m across also occur. Some size sorting is recognisable in the sediments, which locally appear very tuffaceous. Non-basalt fragments (coal, clay-ironstone, siliceous sinter) are rare. At a few places there are thin sandstone layers in which plant remains can be found. The coarse-grained sediments at the base are generally overlain by layers of feldspar-porphyrific tuffs, sandstone, clay-ironstone and coal. The total

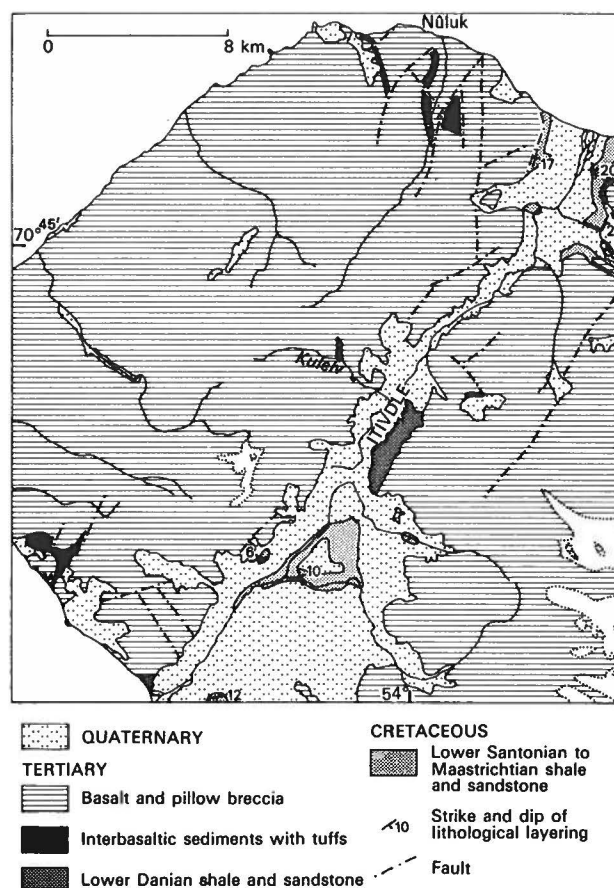


Fig. 309. Simplified geological map of western Nûgssuaq.

thickness of this sequence is in excess of 100 m.

The deposits in the gully of Kulelv are known as the Ifsorisok Formation (Nordenskiöld, 1871), with type locality Ivssorigsoq (syn: Ifsorisok = Qissugssarigsûp qôrua = Kulelv). Similar deposits occur on the east coast of Hareøen.

The sedimentary deposits on both Nûgssuaq and Hareøen contain fossil plants. The presence of *Cercidiphyllum arcticum* (Heer) Brown var. *richardsoni* (Heer) Seward & Edwards from Hareøen and Ivssorigsoq places the upper limit of the formation towards the end of the Eocene (Brown, 1939; Seward & Edwards, 1941).

Upernivik Ø

South-west coast

The south-west corner of Upernivik Ø (fig. 310) consists of a sequence of sandstone and subordinate dark carbonaceous shales about 800 m thick. The beds are separated by a fault from the Precambrian rocks.

They have been termed the Upernivik Næs Formation (Steenstrup, 1883) with type locality Upernivik Næs, the headland on the south-west corner

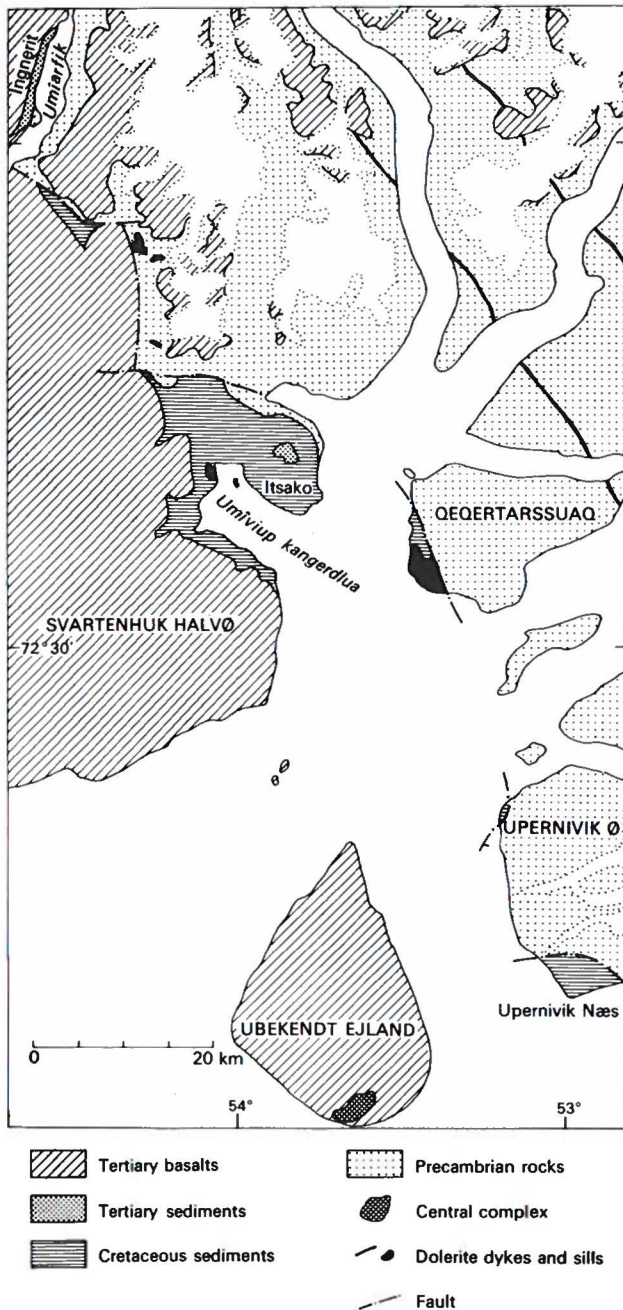


Fig. 310. Cretaceous–Tertiary sediments in the northern part of the Nûgssuaq embayment.

of the island. The formation contains a fossil flora consisting mainly of remnants of ferns, and cycadales and other gymnosperms, together with a single sycamore (*Platanus latiloba* Newberry). Gleicheniaceae is the dominant fern family. Koch (1964) considers it likely that the formation occupies an intermediate position between the Kome and Atane Formations, this being followed by Rosenkrantz (1970), whose stratigraphic table shows it as being of Albian to Turonian age.

North-west coast

A small area of clastic sediments occurs on the north-west coast of Upernivik Ø. The sediments are not well exposed, but the boundary with the Precambrian rocks is clearly a fault. Conglomerates with boulders of Precambrian gneiss up to 2 m in length in these sediments must have been deposited at the base of a gneiss cliff, which was presumably a scarp formed by the fault.

No fossils have been found in these rocks. On the basis of their lithology and regional setting they are considered to be Cretaceous.

Qeqertarsuaq

On the west side of the island of Qeqertarsuaq there are 300 m of sandstones and sandy shales with pebbly and conglomeratic layers. Boulders in the conglomerates are up to 50 cm in diameter.

The sediments have been down-faulted to the west in relation to the Precambrian basement. The Precambrian floor of the sedimentary rocks can be seen west of the fault in the northern part of the area, but disappears southwards.

The beds contain fossil plants including *Platanus latiloba* Newberry and are thought to be equivalent to the Upernivik Næs Formation.

Svartenhuk Halvø

About 1000 m of clastic sediments are exposed on the Itsako peninsula on the east side of Svartenhuk Halvø. In their lower part they are deposits of fluvial facies consisting of thin conglomerates with loose sand and sandstone with intercalated sandy shales and a little coal (Gry, in Rosenkrantz *et al.*, 1942). These beds have yielded a Kome (Barremian–Aptian) flora; on these and on lithological grounds they have been assigned to the Kome Formation. The upper part of the succession consists of shales with subordinate sandstone bands.

On the southern side of Itsako marine shales are present and have yielded Lower Campanian ammonites (Birkelund, 1965, 11–14). The highest shales have yielded a fossil flora of early Tertiary age (K. R. Pedersen, personal communication).

The non-marine sediments of Itsako continue north-west along the border of the Precambrian basement and are presumed to be in part equivalent to the Atane Formation (A. Rosenkrantz, personal communication).

In north-west Svartenhuk Halvø interbasaltic sedimentary beds comprising sandstone with thin seams of carbonaceous shale or coal separate the lower,

olivine-rich basalts from the upper plagioclase-porphyrific basalts (Pulvertaft & Clarke, 1966). Their precise age is unknown. There is an isolated occurrence of arkose with coal in a gully east of the inner part of Umîarfik.

Ingnerit

On the west side of the fjord Umîarfik, where the lower basalts and pillow breccia become thinner, the interbasaltic sedimentary unit continues northwards and directly overlies the Precambrian. The sedimentary occurrence shown on the west side of Ingnerit (fig. 310) comprises impure sandstones and shales with coal seams. The base is not exposed, but the sequence is probably equivalent in level to the interbasaltic beds to the east.

Marine strata

Nûgssuaq

South coast

Marine Cretaceous beds are found at only a few localities on the south coast of Nûgssuaq. At Alianait-sûnguaq a marine horizon beneath beds with an Atane flora was found by Birkelund (1965, p. 14 & 16) to contain *Scaphites ventricosus* Meek & Hayden, and was assigned to the Coniacian. These are thus the oldest marine beds on Nûgssuaq.

Farther east, at Atâ, the beds with the Atane flora are overlain by marine beds representing the passage Santonian–Campanian (Rosenkrantz, 1970, p. 448).

Marine fossils from the Pautût area south-east of Atâ include *Sphenoceras steenstrupi* (de Loriol) and *Sphenoceras patootensis* (de Loriol), and indicate an Upper Santonian to Lower Campanian age for the zone from which they are derived (Frebold, 1934).

The Cretaceous beds at Atâ are overlain unconformably by marine Lower Danian beds (Kangilia Formation), consisting mainly of black shales with subordinate sandstone horizons, the sequence being about 300 m thick.

According to Rosenkrantz (1970, p. 419) the *Thyasira* Member of the Kangilia Formation can be recognised at Alianait-sûnguaq, Tupaussat (just west of Atâ) and at Atâ. The overlying *Propeamussium* Member is represented by concretions at Alianait-sûnguaq and by burnt shales at Tupaussat and Atâ.

Black shales with intercalated sandstone bands immediately west of the south-west end of the Itivdle valley are separated by a fault from the Tertiary ba-

salts. These have yielded a *Natica* sp. which is only known from Danian strata on Nûgssuaq. The sandstones and shales outcropping in the south-western part of the valley itself are believed to be of Senonian age.

The Quikavsak Member of the Upper Atanikerdluk Formation, which overlies the Kangilia Formation on the south coast of Nûgssuaq and has been assigned to the Upper Danian, is essentially non-marine, but marine molluscs (including *Ostrea* sp.) found at Pautût and Nûk kidtleq indicate some marine influence (B. E. Koch, 1959).

Central area

Cretaceous–Tertiary marine sediments are present for a considerable distance on both sides of the long valley Auvfarssuaq, which runs E-W through the centre of Nûgssuaq, and in the valley Agatdalen, which runs into the north side of Auvfarssuaq. The oldest beds found to date are of Lower Santonian age (Birkelund, 1965, p. 16–17); the sediments range up to Upper Danian in age.

In central Nûgssuaq the Maastrichtian and parts of the Campanian are absent with the Lower Danian resting unconformably on Lower Campanian or older beds. The sequence Lower Santonian – Lower Campanian in this area is up to 600 m thick. The sediments consist of sandstones alternating with black shales, the proportion of shale increasing upwards. The lower 400 m are largely devoid of marine body fossils and coal seams are common, but some thin horizons have yielded a marine fauna.

At localities on the north side of Auvfarssuaq *Clioscapites saxitonianus septentrionalis* Birkelund and *Clioscapites* sp. aff. *saxitonianus* (McLearn) were found, both of which indicate a Lower Santonian age. At Qilakitsoq, also on the north side of Auvfarssuaq, the Upper Santonian – Lower Campanian beds contain specimens of *Sphenoceras steenstrupi* (de Loriol) almost two metres long. Large specimens of *S. steenstrupi* have also been found in Agatdalen (fig. 311). In the northern part of Agatdalen the Lower Campanian beds contain *Pseudophyllites skoui* Birkelund, *Baculites obtusus* Meek, *Scaphites cobbani* Birkelund and *Scaphites rosenkrantzi* Birkelund. This ammonite assemblage is accompanied by some other faunal elements, viz. echinoids, indeterminable gastropods and pelecypods, and crustaceans such as *Callianassa* and raninids (Rosenkrantz, 1970).

The Danian of Agatdalen has been divided into two formations, the Kangilia Formation (lower) and the Agatdal Formation (upper).

The Kangilia Formation (Rosenkrantz, 1970) has

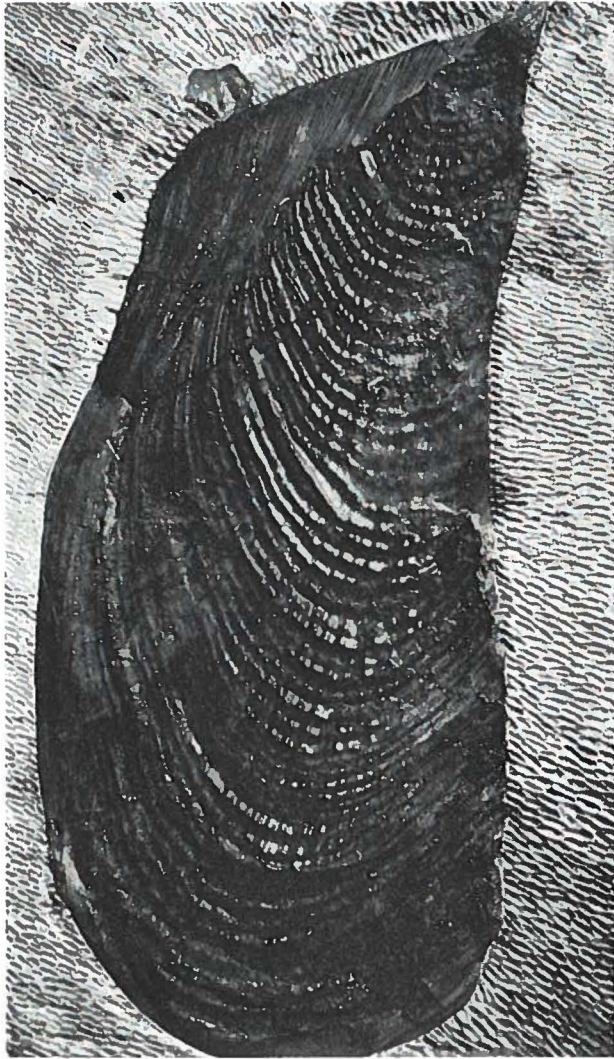
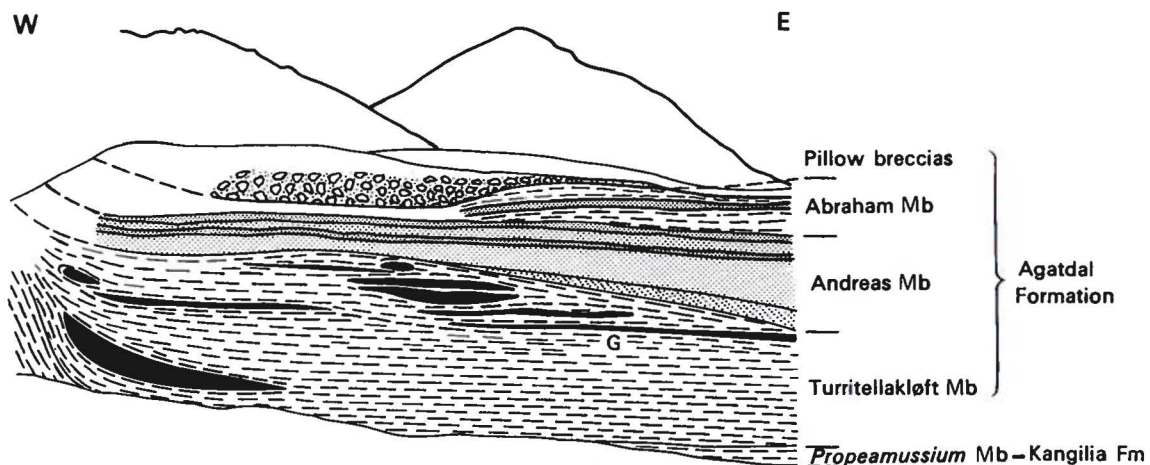


Fig. 311. Specimen of *Sphenoceras steenstrupi* (de Loriol) from Agatdalen, central Nûgssuaq. Length c. 75 cm.

Fig. 312. Section at 'Store Profil' in Turritelakløft in Agatdalen. G: *Gilbertina* lens, conglomeratic in the eastern part. Height of section c. 80 m.



its type locality at Kangilia on the north coast of Nûgssuaq. In Agatdalen it rests unconformably on the Cretaceous beds and has at the base a conglomerate known as the 'oyster-ammonite conglomerate' containing abundant derived concretions, mainly of Maastrichtian age, in a shaly matrix containing Danian oysters and other pelecypods belonging to the *Thyasira* Member. The Maastrichtian concretions contain a rich ammonite fauna, which includes *Neophylloceras groenlandicum* Birkelund, *Saghalinites wrighti* Birkelund, *Baculites* cf. *meeki* Elias, *Disco-scaphites waagei* Birkelund and *D. angmartussutensis* Birkelund (Birkelund, 1965, p. 18). In addition they have a rich variety of other faunal elements, including nautiloids, pelecypods, gastropods and crustaceans (Rosenkrantz, 1970, p. 426). The conglomerate, which is up to 5 m thick, is overlain by about 75 m of black shale with concretions belonging to the *Propeamussium* Member. In Agatdalen the sequence is of Lower Danian age.

Both the *Thyasira* and *Propeamussium* Members have been recognised in the upper part of the sequence at localities along the north side of the Auv-farsuaq valley.

The Upper Danian beds constitute the Agatdal Formation (Rosenkrantz, *in* Koch, 1959, p. 75–78) and rest unconformably on the Lower Danian or older rocks. The type locality is in Turritelakløft, which is a tributary valley at the north-west end of Agatdalen (syn: Agatdal). The formation comprises three members at the type locality (figs 312, 313). The Turritelakløft Member, which is up to 50 m thick, consists of black shales with sandstone lenses; the overlying Andreas Member, which is up to 25 m thick, consists of coarse sandstone and is probably of deltaic origin; the Abraham Member (uppermost), which is up to 12 m thick, consists of alternating black shales and rather coarse fossiliferous tuffs. This is overlain by pillow breccia.

To the east of the type locality an additional member, the Sonja Member (fig. 314), which is approximately equivalent to the Turritlekløft and Andreas Members (Rosenkrantz, in B. E. Koch, 1959, p. 75-77) has been distinguished. This is about 50 m thick. At the base is a coarse gneiss conglomerate up to 10 m thick. Above the conglomerate is a sequence of alternating arkosic sandstones, shales and conglomerates with marine fossils and plant remains. A sandstone lens ('Sonja lens') 20 m above the basal conglomerate, has yielded large numbers of macrofossils, mainly gastropods and pelecypods. This member has also yielded 51 species of foraminifera including the planktonic foraminifera *Globoconusa daubjergensis* (Brönnemann), *Globigerina compressa* (Plummer), *Subbotina triloculinoides* (Plummer), and *S. pseudobulloides* (Plummer), which is a typical Upper Danian faunal assemblage (Hansen, 1970; Troelsen, 1957).

The Sonja Member also contains a rich coccolith assemblage, though relatively poor in species (Perch-Nielsen, 1973). A few of the species are Maastrichtian and Upper Campanian in age and are clearly reworked. The Danian coccolith assemblage belongs to NP3, the *Chiasmolinthus danicus* Zone of the 'Standard Tertiary Calcareous Nannoplankton Zonation' of Martini (1971). The presence of *Neochiastozygus modestus* suggests a high part of this zone while the absence of *N. chaepes* and *Chiasmolinthus bidens* as well as the very small size of the coccoliths of *Prinsius* suggests that the deposits belong to the lower part of the Upper Danian.

The Agatdal Formation is the most fossiliferous of all the marine units in West Greenland, containing at least 500-600 species, many of which are identical, or closely related, to fossils from the type Danian in Denmark.

Both the Turritlekløft and Sonja Members have yielded an ostracod assemblage amongst which Szczechura (1971) has identified 39 species of 24 genera. None of the specimens could be assigned with certainty to any hitherto described species and for this reason the assemblage is considered to be endemic.

Scleractinian corals have been described from all the members of the Agatdal Formation by Floris (1972), who also collected and studied corals from the Danian beds of the Tunorssuaq valley between Agatdalen and the north coast, and from the north coast (Kangilia). Eleven species from the Danian as a whole were considered to have palaeogeographical significance. They show affinities with both North American and European forms.

An echinoid *Tylocidaris*, similar to older forms of

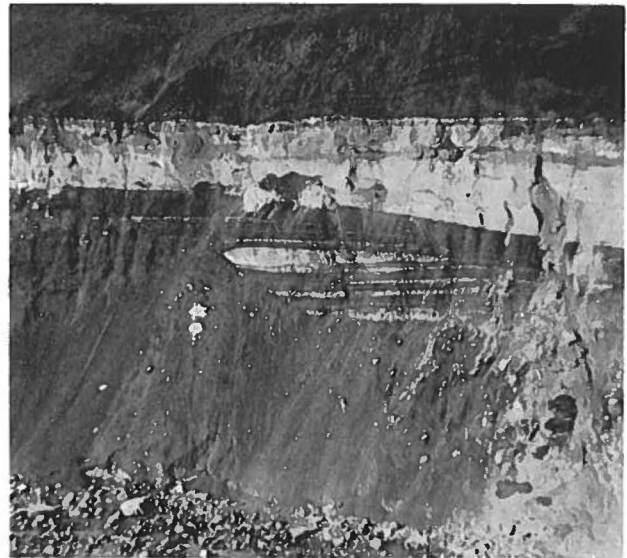


Fig. 313. The Turritlekløft, Andreas and Abraham Members of the Agatdal Formation exposed at the type locality, 'Store Profil' in the Turritlekløft gorge, Agatdalen. Height of section about 80 m. Photo: A. Rosenkrantz.

Fig. 314. Measured section, the Sonja Member of the Agatdal Formation in the south wall of Agatkløft. Heights shown are above the river bed. After Hansen (1970).

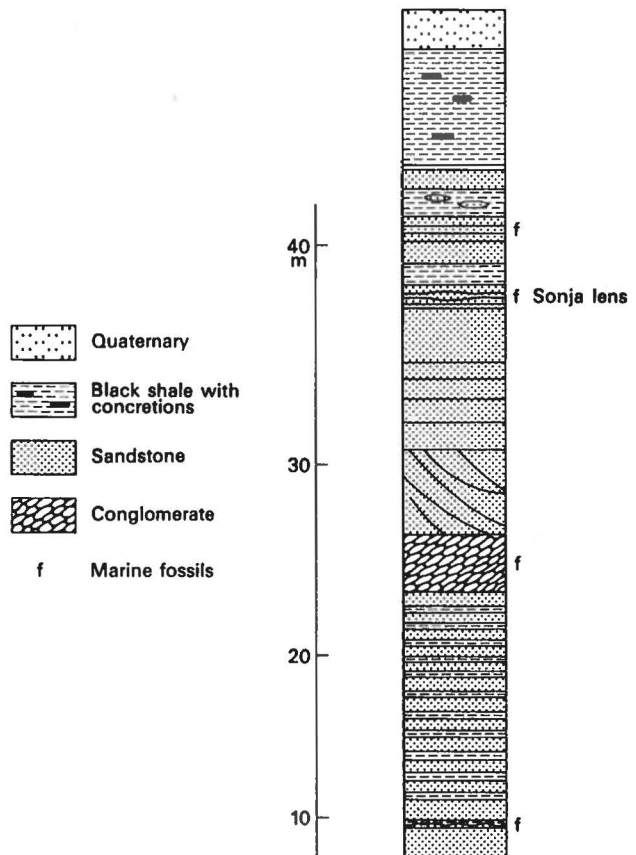




Fig. 315. The mud volcano Qapiortoq kitdleq in the Auvfarssuaq valley. Photo: H. Gry.

T. vexilifera Schlüter of the uppermost Danian in Denmark and southern Sweden (Scania), is found in the Abraham Member (Rosenkrantz, 1970).

The Agatdal Formation has also yielded crinoids, asteroids and ophiuroids (Rasmussen, 1972), fish faunas (Bendix-Almgreen, 1969) and crustaceans (Rasmussen in Rosenkrantz, 1970). The pelecypods, gastropods and nautiloids are closely related to Danian forms and species from Denmark. The fauna contains some genera representing the last survivors of Mesozoic genera (Rosenkrantz, 1970). No ammonites or inoceramids have been found in the marine Danian of Nûgssuaq.

The fossil flora of the Agatdal Formation allows a comparison to be made with the Quikavsak Member and the basal part of the Naujât Member of the Upper Atanikerdluk Formation (B. E. Koch, 1963, 1964).

The Agatdal Formation varies greatly in thickness in the central area, from 2 m near the southern en-

trance to Agatdalen to more than 75 m in the northern part of Agatdalen. Outside Agatdalen it rests unconformably on the Lower Danian and the Upper (?) Campanian (Nuilarssarssuaq, south-west of Agatdalen), Lower Campanian–Upper Santonian (northern tributary of the Navssât river, east of Agatdalen) and even on Precambrian gneiss (east of Navssât) (Rosenkrantz, 1970).

Mud volcanoes and genetically related lakes are common features in the Nûgssuaq embayment, occurring in Svartenhuk Halvø, Nûgssuaq and Disko (for review see Henderson, 1969). They only occur in valleys believed to be underlain by Cretaceous–Tertiary sediments or by volcanic rocks presumed to be overlying these sediments and are never found in valleys that are known to be underlain by Precambrian rocks. Two prominent mud volcanoes are present in the Auvfarssuaq valley (fig. 315).

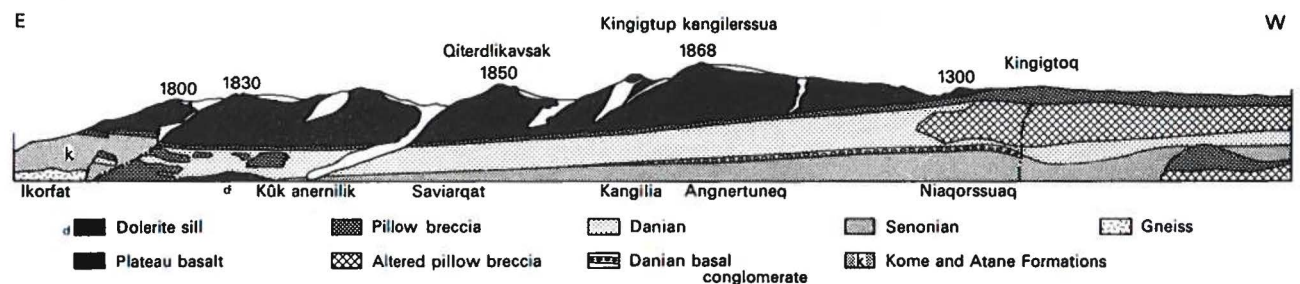
North coast and Tunorssuaq valley

Along the north coast of Nûgssuaq between Tuperssuartâ and Ikorfat, a succession of strata covering the interval from Lower Santonian to Upper Danian is almost continuously (but often poorly) exposed, interrupted only by the Itivdle valley (fig. 316).

The sequence west of the Itivdle valley comprises about 300 m of black shales with minor sandstone bands dipping westwards towards, and in fault contact with, Tertiary basalts. The lowest beds have yielded *Clioscaphtes* sp. aff. *saxitonianus* (McLearn) and *Baculites nugssuaqensis* Birkelund together with radially ribbed inoceramids of the *steenstrupi* group and belemnites identified as *Actinocamax groenlandicus* Birkelund (Birkelund, 1956, 1965). The beds belong to the Lower Santonian.

To the east of the Itivdle valley (fig. 316) the lowest beds are black shales with sandstone bands. These show some spectacular slump structures. These beds have not yielded marine fossils but pass up into a sequence about 300 m thick consisting largely of black shales of Upper Campanian to

Fig. 316. The north coast of Nûgssuaq from Ikorfat to east of Niaqornat showing Cretaceous–Tertiary sediments overlain by Tertiary basalts. Modified from sketch by A. Rosenkrantz.



Maastrichtian age. The Upper Campanian is characterised by two species of *Hoploscaphites* (*H. greenlandicus* Donovan and *H. ravni* Birkelund) while Upper Campanian beds in the fault zone at Ikorfat contain *H. ikorfatensis* Birkelund and *Pseudophyllites skoui* Birkelund. The Maastrichtian contains *Disco-scapites* aff. *angmartussutensis* Birkelund, *Diplomoceras* sp. and *Pseudophyllites* sp.

The Senonian black shales of the north coast of Nûgssuaq have a substantial content of organic material. They are prone to landslip and the slipped masses become ignited, probably owing to spontaneous combustion (fig. 317). This phenomenon has been discussed by Henderson (1969).

Overlying the marine Cretaceous rocks of the north coast is a thick sequence of Danian sediments belonging to the Kangilia Formation and the Agatdal Formation. The Kangilia Formation (Rosenkrantz, 1970) has as its type locality the gully Kangilia east of Niaqornat, where it is over 600 m thick. Rosenkrantz (1970, p. 419) has recognised four members of this formation, all of which have type localities in the section above Kangilia (fig. 318).

The Conglomerate Member comprises up to 50 m of coarse conglomerate and rests with a slight angular unconformity on the Maastrichtian beds. The member thins out completely to the east and west along the north coast.

The Fossil Wood Member is about 425 m thick and consists of black shales with a sandstone layer in the lower part. Some of the fossil wood is excellently preserved and has been bored by *Teredo* (Mathiesen, 1961).

The *Thyasira* Member is about 35 m thick and consists of a fossiliferous tuff layer, up to 7 m thick, overlain by 20 m of black shale with a thin sandstone at the top which is overlain by another fossiliferous tuff layer up to 7 m thick. These tuff layers are the first manifestations of volcanism along the north coast. The concretions in the shale have a rich fauna and the tuffs are especially fossiliferous. The rich fauna in the concretions consists of gastropods, pelecypods, corals, echinoderms and nautiloids. The pelecypod *Thyasira* (*Conchocele*) aff. *T. conradi* Rosenkrantz is particularly common in the concretions together with a large thick-shelled *Echinocorys*, *Hercoglossa groenlandica* Rosenkrantz and stems of *Isselocrinus groenlandicus* Wienberg Rasmussen. A *Tylocidaris* closely related to the Lower Danian *T. oedumi* from Denmark is also present (Rosenkrantz, 1970). A fish fauna described by Bendix-Almgreen (1969) is in good agreement with the Lower Danian fauna from Denmark. Scleractinian corals have been collected from the tuff beds (Floris, 1972) includ-

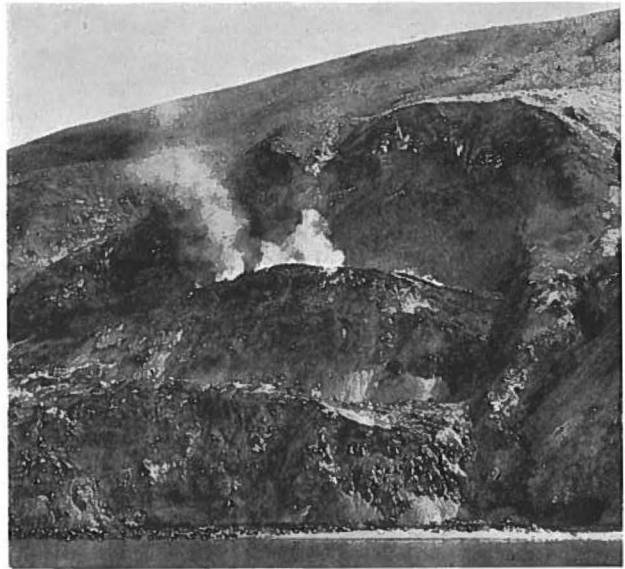


Fig. 317. Landslipped shales on fire at Pujôrtoq, north coast of Nûgssuaq. The lowest terrace comprises shales that slipped in 1932. Photo: A. Rosenkrantz, 8 July 1958.

ing *Dendrophylla candelabrum* Henning, which is known from the Danian of Denmark and Sweden.

The *Propeamussium* Member consists of about 100 m of black shales with some sandstone intercalations. The fauna consists largely of pelecypods and gastropods. The pectinid *Propeamussium igno-ratum* Ravn is particularly abundant.

Overlying these beds at the type locality is a 20 m section of unfossiliferous sandstone, tentatively assigned to the Agatdal Formation.

The Kangilia Formation at the type locality was hitherto considered to be entirely Lower Danian in age. However, recent studies of coccoliths from the upper of the two tuffs of the *Thyasira* Member (Jürgensen & Mikkelsen, 1974) have shown that these belong to the upper part of NP3, the *Chiasmolinthus danicus* Zone of the 'Standard Tertiary Calcareous

Fig. 318. Columnar section through the Senonian-Danian sequence at Kangilia. After Rosenkrantz (1970).

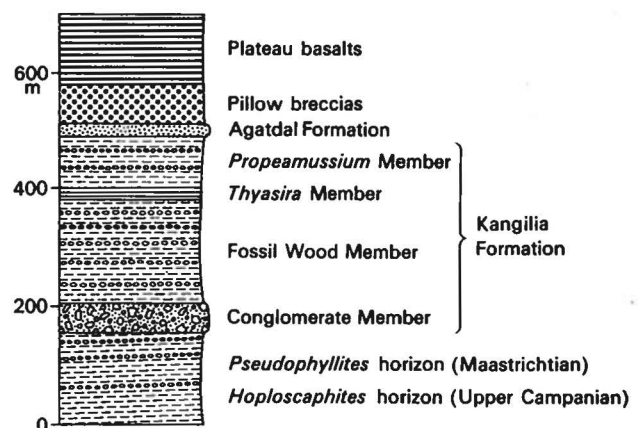




Fig. 319. Fossiliferous conglomerates at Marrait kitdlit. Total thickness 4 m.

Nannoplankton Zonation' of Martini (1971). Thus the nannofossil evidence suggests that this tuff and hence the uppermost 107 m (or more) of the Kangilia Formation are of Upper Danian age.

Marine Cretaceous–Tertiary beds are also present in the Tunorssuaq valley and include a continuation of the *Propeamussium* Member of the Kangilia Formation. The Danian beds in this area also contain scleractinian corals (Floris, 1972).

The *Propeamussium* Member is also represented in the central part of the Itivdle valley, on the east side of the valley.

Marrait kitdlit

Thin intercalations of marine sediments have been found at several localities at Marrait kitdlit, in the lower part of the Tertiary volcanic sequence. Since the base of the volcanic sequence is not exposed in this area and the whole sequence is very much broken up by faulting it is impossible to state how far above the base these occurrences are.

The sediments are exposed on a low N–S ridge between two branches of a stream. On the west face of the ridge (fig. 319) the sequence from the stream bed up consists largely of thin, very vesicular flows. These are overlain in part by a lenticular pillow breccia up to 3 m thick, which is in turn overlain by about

4 m of fossiliferous sediment. The sediment overlaps the breccia and comes to rest on the flows. It also fills vertical fissures in the flows.

The sediment, which is coarsely layered, consists of a spectacular conglomerate with boulders, cobbles and pebbles of basalt set in a limestone matrix. The limestone comprises much bioclastic debris in a lutite (lime mud) matrix.

The fauna comprises foraminifera, bryozoa, gastropods and pelecypods, especially oysters. Several spines of a *Tylocidaris* of the *T. vexilifera* type like the *Tylocidaris* spines from the Abraham Member of the Agatdal Formation in Agatdalen have been found. The age is Upper Danian (Rosenkrantz, 1970).

Another fossiliferous conglomerate from this area has recently been described by Jürgensen & Mikkelsen (1974) who identified coccoliths of Upper Danian age in it.

Svartenhuk Halvø

In the area round the inlet Umíviup kangerdlua (fig. 310), south-west of Itsako, marine Cretaceous rocks consisting of black shales with subordinate sandstone bands and lenses form a sequence up to 400 m thick underlying the Tertiary basalts. They range from Upper Turonian to Campanian in age.

The Upper Turonian is characterised by *Scaphites corvensis* Cobban, which occurs *in situ*. Derived concretions containing *Scaphites mariasensis umivikensis* Birkelund and *Scaphites preventricosus svartenhukensis* Birkelund indicate a Lower Coniacian age. The lowermost part of the Santonian is characterised by *Clioscapites saxitonianus septentrionalis* Birkelund. The Santonian beds above contain shells of a *Sphenoceras* of the *steenstrupi* group. Black shales on south-western Itsako contain a *Haresiceras* (Lower Campanian).

To the north-west, in the area known as Simiútáp kúa, there is a continuation of this marine sediment belt. The beds contain *Actinocamax* cf. *primus* Arkhangelsky, a species known from the Middle and Upper Cenomanian (Birkelund, 1956). It is thus possible that these beds are Cenomanian and if so they constitute the oldest marine beds in West Greenland. It seems as if the marine transgression came from the north-west, reaching north Svartenhuk Halvø in the Cenomanian, south Svartenhuk Halvø in the Turonian and Nûgssuaq in the Coniacian.

Structure

The eastern limit of the Cretaceous sediments, and of the Tertiary sediments excluding the interbasaltic sediments, is a system of faults that extends from the valley at Sarqaq in the south to Svartenhuk Halvø in the north (fig. 301). Rosenkrantz & Pulvertaft (1969) described the system in detail, concluding that the faulting along the eastern margin of the sedimentary beds most likely occurred intermittently during the Cretaceous and early Tertiary, defining the new sedimentary basin.

In particular, they stated that there was clear evidence of 400 m of movement on the Ikorfat fault between the Maastrichtian and the deposition of the Danian sediments, and a further 500 m of movement after the basalts were laid down. They also drew attention to the boulder conglomerates of north-west Upernivik Ø, which were deposited close to a steep slope (probably a fault scarp). On the other hand, they noted that the lithology of the sediments west of the valley at Sarqaq (lack of coarse conglomerate) indicated that these rocks were not deposited at the foot of a cliff of great height.

The sediments on each side of the Ikorfat fault provide clear evidence of synsedimentary movements. On the upthrown side a sequence of dark shales and sandstones of Senonian age shows at least two well expressed intraformational unconformities with pronounced wedging of sedimentary units. The wedging can be explained by channelling and infill. The strong channelling is considered to be related to movements along the nearby Ikorfat fault. On the downthrown side, at a height of 475 m, there is a bedded sandstone and shale sequence of Senonian age with numerous exotic sandstone blocks, which are regarded as having come from a fault scarp. One of these blocks on an outcrop face was found to be 2 m long and 1 m wide.

On north-west Upernivik Ø the present boundary between the Cretaceous sediments and the Precambrian rocks is a fault, and it is logical to believe that this fault is a rejuvenation of a fault that created a fault scarp at the foot of which the boulder conglomerates accumulated.

Recent work by one of the authors (Schiener, 1975) has demonstrated that most of the sediment in the embayment came from the south and not, as might have been expected, from the east. Further work in the Sarqaq area has shown that here, too, transport from the south is predominant with some sediment originating from the south-east. The present boundary is a fault with a throw of 1200 m

or more to the west, but no fault scarp of this height was present during the sedimentation. The coastline at that time must have been somewhat further east.

The role played by the Disko gneiss ridge is still uncertain, not least because there are no outcrops of Cretaceous–Tertiary beds close to the ridge. There is little evidence that the ridge contributed material to the sediments of eastern Disko. On the other hand the presence of channel deposits in eastern Disko does suggest some confining influence to the west. There was certainly substantial movement at the end of the (Cretaceous?) sedimentation, since on the south coast of Nûgssuaq, and on the north coast of Disko east of the Kugánguaq valley, the sediments strike N–S and dip east at angles of up to 22°. This is interpreted as being due to uplift along the gneiss ridge. The Tertiary basalts along part of the south coast of Nûgssuaq rest unconformably on these dipping sediments, but evidence from Disko suggests that there were still movements along the ridge during the earlier part of the volcanism (A. K. Pedersen, 1973).

Whereas there was renewed movement along the Ikorfat fault after the deposition of the basalts there was apparently little or no movement along the Sarqaq–Kûk segment after the volcanism, but confirmation of this must await detailed mapping and correlation of the basalt outliers east of the fault with those to the west. At the northern end of the fault system the final, post-basaltic, movements on the fault across Svartenhuk Halvø were a partial reversal of earlier movements (Rosenkrantz & Pulvertaft, 1969, fig. 3d).

Further west there was substantial block-faulting and down-warping of the basalts which has concealed whatever sediments may be below these rocks.

Seismic work undertaken on land (Sharma, 1973; Elder, 1975) and offshore (Denham, 1974) has now provided a general picture of the floor of this embayment. It is deepest along a zone between the north coast of Nûgssuaq, west of Ikorfat and the Vaigat, where it is 2–3 km below sea level. Elsewhere depths of about 1 km to the underlying basement are common. In detail, the structure of the floor of the embayment is complicated, partly owing to original, irregular topography (some of this can be seen along the north coast of Nûgssuaq) and because of later faulting.

The gross structure of the sedimentary sequences themselves varies considerably. In eastern Disko the bedding is nearly horizontal. On both sides of the Vaigat and below the Vaigat there is large-scale warping of the Cretaceous beds. On south-western

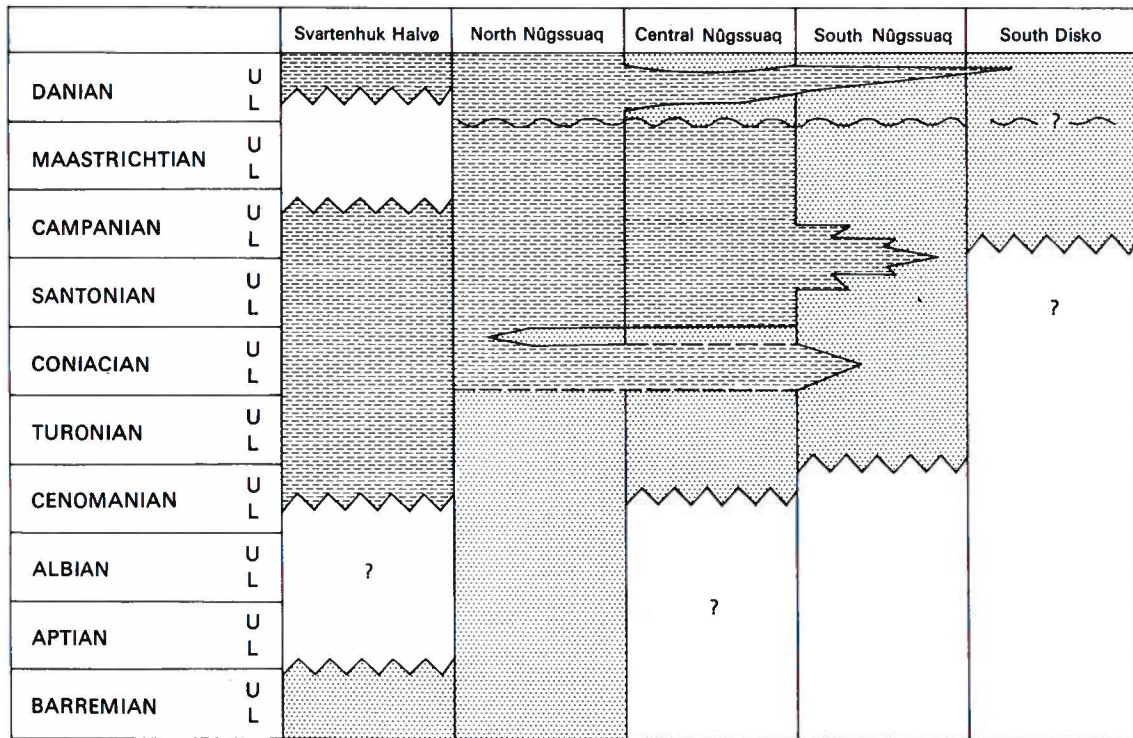


Fig. 320. Diagram showing the predominant regional facies development (*stippled* fluvatile-deltaic, *dashed* pro-delta-marine) for the sedimentary sequence in central West Greenland.

and north-western Upernivik Ø the Cretaceous beds have been tilted during movements along the boundary faults. However, there is no evidence of compressional folds. Such warps as there are can be explained by vertical movements related to tensional conditions.

Depositional model for the Cretaceous – Tertiary sediments

Detailed lithostratigraphic correlation of the sediments of the Nûgssuaq embayment is seriously impeded by the opposed facies development. In the north there is a predominantly marine shale facies development where the established biostratigraphy is based on macropalaeontology; in the south the sandstone–shale facies is of fluvatile–deltaic origin, and only a few stages and the boundary between the Cretaceous and Paleogene have been established with reasonable certainty on palaeobotanical evidence.

Correlation of the Paleogene strata is facilitated by the occurrence of sufficiently well preserved plant fossils together with marine fossils in certain horizons. The increased tectonic activity, recognisable in minor lacunas within the post-Maastrichtian sediments, led

to increased facies differentiation. Older strata became reworked and their fossil content incorporated in the still unconsolidated Paleogene deposits.

Cretaceous

The change from non-marine facies in the south to marine facies in the north (fig. 320) is traceable through four major facies developments with approximately ENE–WSW palaeostrike and an established palaeoslope to the north. The rate of subsidence during the Cretaceous must have been uniform for most of the region since facies boundaries migrate very little. However, short lived and weak transgressions in the Lower Coniacian, and subsequently in the Santonian and Campanian, left their traces in thin marine intercalations in the otherwise barren sequence. The progressive transition from up-dip continental to down-dip marine in going from south to north suggests the combination of an alluvial and a deltaic system with a number of sub-environments.

Alluvial system

In the southernmost parts of the embayment coarse, poorly sorted sandstones predominate as both tabular and lensoid units in which cross-bedding constitutes the main internal structures. Directional values from

foreset orientation all have a southerly component (fig. 321). Carbonised plant debris is frequent either dispersed or concentrated on the foreset beds. Coal occurs in lenses where fragments of branches and tree trunks were washed together.

The facies criteria suggest an alluvial plain environment with meandering channels in which stagnant pools are represented by much finer grained siltstone-shale-coal facies. The floral elements are predominantly allochthonous with larger fragments in the channel facies, and the delicate leaves in the overbank deposits.

Deltaic system: distributary flood basin

In the Nūgssuaq embayment the transition from alluvial plain to deltaic flood plain is taken where the sand-dominated facies is replaced by a sandstone to carbonaceous siltstone-shale-coal facies.

A marked increase in the carbonaceous siltstone-shale is immediately recognisable down dip, the sand/shale ratio decreasing to less than 1:2. Several levels are intensively bioturbated; one assemblage is dominated by the horizontal burrows of *Haentzschelina ottoi* (Geinitz), another one by subhorizontal burrows of *Planolites* affinity.

Towards the top of the Cretaceous section a rejuvenation of erosional activity is recognisable through the development of thick channel sandstones which lose their pronounced channel characteristics northwards. In the southern parts of the deltaic environment this development continues, apparently without break, into the Quikavsak Member of the Lower Paleogene.

Intercalated carbonaceous sediments range from sandy shales and siltstones to shales and coal seams.

The lensoid and cross-bedded sandstones represent the distributary channel facies in continuation of the updip alluvial plain facies with the carbonaceous sediments culminating in coal seams representing the interdistributary deposits of marshes, lakes and flood basins with mostly continuous water cover. The rich organic content of interfingering fine-grained, thinly bedded sands and muds led to the development of trace fossils in specific thin subfacies. The marine transgressions reached this environment documented by the thin carbonate-bearing shaly horizons containing a marine shelly fauna.

Deltaic system: delta front

The transition from the distributary flood basin to the delta front deposits is indicated by the gradual disappearance of coal seams and a concurrent increase in sand/shale ratios to around 4:1 in a northerly direction.

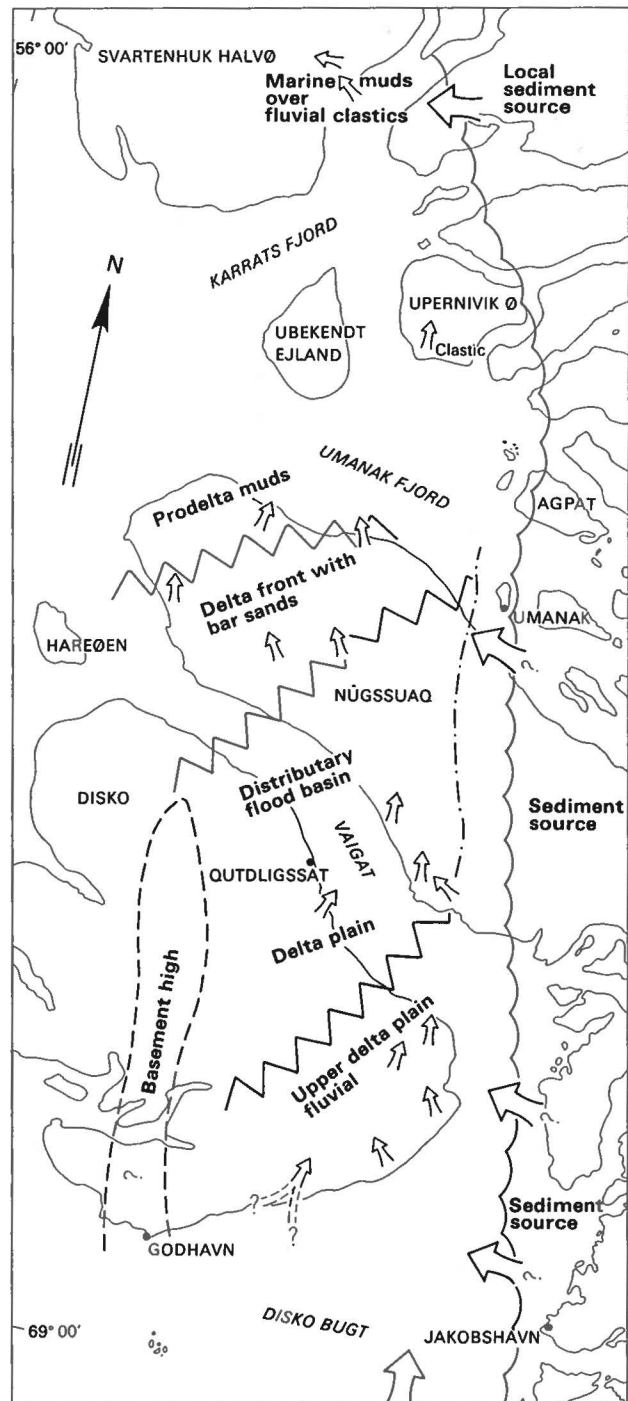


Fig. 321. Generalised facies distribution with sediment transport directions for the Cretaceous rocks of central West Greenland.

The dominating sandy facies is characterised by well-bedded, tabular sandstone units in which parallel lamination, low angle and small scale ripple cross-laminations are most common. Recognisable bioturbation is restricted to a few levels and to the laminated sandstones. Since well defined cross-bedding is practically absent in the facies development directional readings are greatly reduced.

The main criteria for the identification of the delta front deposits are the tabular nature of the sand units and, though indistinct, the change in palaeocurrent directions; sandstones with distinct large to medium scale cross-bedding have almost disappeared. Although no marine fauna has been found in this facies, the presence of trace fossils (predominantly subvertical burrows) would indicate marine influence. Currents, either tidal or wave produced, must have been sufficiently strong to prevent deposition of mud, both interstitial and in laminae.

The coarse, massive sandstones were most likely deposited during flood phases of the alluvial system. Their occurrence together with the laminated facies would indicate an environment of deposition protected from direct influence of wave activity and thus from rapid reworking while thicker shale and siltstone units accumulated in ponds or lagoons cut off from the main supply of sand.

Delta system: prodelta muds

The transition from delta front sheet sands to prodelta muds is mostly covered by younger rocks. Slumped sandstone units in an otherwise shale dominated facies are the most characteristic feature. North of this poorly exposed belt shales containing a marine fauna ranging in age from Lower Santonian to Lower Danian constitute the main facies.

The intercalated sandstones are lensoid with the thickness of individual beds rarely exceeding 50 cm. In contrast to the delta top sands they contain up to 15% interstitial clayey and carbonaceous matter in addition to shale fragments. Bioturbation is recognisable in some of the sandy units.

The occurrence of a predominantly shaly facies containing a pelagic ammonite fauna with some benthonic elements (gastropods and lamellibranchs) (Birkelund, 1965) at the northern downdip termination of a combined alluvial–deltaic system lends credibility to the identification of the whole depositional system.

Paleogene (Danian)

The relative tectonic stability persisting through the Cretaceous changed into a more mobile period in post-Maastrichtian times. This is documented by local lacunas of varying magnitude, most commonly affecting Maastrichtian and Campanian strata, whose reworked fossil content is found in Danian conglomerates.

There is a striking similarity in the basin development and facies distribution between the Cretaceous and the Danian. On the north coast of Nûgssuaq the

shaly facies predominates with marine fossils occurring towards the top. Deposits with a marine element reach southwards through Agatdalen south of which marine fossils become scarce, but are found together with plant material. Further south on southern Nûgssuaq and Disko the sandy and shaly deposits are barren of macrofossils except plant debris. Correlation within the Danian sediments should therefore be less troublesome than in the Cretaceous strata but is complicated by facies differences and thickness variations. The main complication lies in the subdivision of the post-Cretaceous sediments into a Lower Danian Kangilia Formation and an Upper Danian Agatdal Formation. The former is 550 m thick, mostly unfossiliferous, developed predominantly as shales and exposed on the north coast of Nûgssuaq. The latter is at the most 90 m thick, is highly fossiliferous, predominantly sandy and exposed in central Nûgssuaq. Both formations are described as having tuff members in their upper parts. Contacts between the two formations are rare and respective faunal elements are not significantly different (Rosenkrantz, 1970). Nowhere are the two horizons with tuff layers found in a continuous section.

The first evidence for a possible correlation of the tuff-bearing horizons was provided by Jürgensen & Mikkelsen (1974) who, by using nannofossils, correlated the tuffs in the upper part of the Kangilia Formation with Upper Danian calcareous deposits occurring within the basalt breccias.

The onset of the volcanic activity in the Maastrichtian–Danian must have been accompanied by significant vertical movements, especially in central Nûgssuaq. There, spectacular penecontemporaneous slides of sediments and volcanic breccias are fairly widespread phenomena at the base of the volcanic pile. Southern parts of the area must have remained relatively stable since there the succession is complete and continuous through the Cretaceous to the base of the volcanics.

Correlation

B. E. Koch (1959) has already provided a palaeogeographic interpretation of the sediments exposed on the south coast of Nûgssuaq and in Agatdalen. With some modifications this interpretation is still applicable.

The transition from alluvial to marine, in going from south to north, is recognisable mostly in the fossil content, both body fossils and trace fossils. A clear cut subdivision into environmental elements is, however, no longer possible largely due to the more differentiated tectonic activity in central Nûgssuaq

where movements during sedimentation produced quickly changing sedimentation patterns.

The basal conglomeratic development ('Basal Danian conglomerate') is best developed in the tectonically active areas, whereas on southernmost Nûgssuaq and on Disko it is absent. Sedimentation on Disko was apparently uninterrupted until the onset of the basalt volcanism. The disconformity with the underlying Cretaceous deposits is seen as the culmination of the development of channel deposits. Also here the change in sedimentation pattern occurs first with the onset of quiet conditions leading to shale deposition.

In central parts of Nûgssuaq (Auvfarssuaq) the conglomerates are weakly developed, attaining only gravel size. Approaching the eastern margin of the embayment (Navssât in Agatdalen) the conglomerates increase in thickness and size of components, to reach the maximum in the spectacular development on the north coast of Nûgssuaq west of Ikorfat.

Subsequent to the strong tectonic movements in certain regions of the embayment sedimentation continued relatively undisturbed. Shale deposition prevailed, reaching its maximum on the north coast of Nûgssuaq; southward a gradual thinning of the sequence is recognisable. Concurrently with the thinning, the proportion of sand increases. Generally the depositional environment was of shallow water character as indicated by individual dominating faunal elements like gastropods and lamellibranchs. Additional evidence is provided by small patch reefs, observed both in shale (as at Auvfarssuaq) and in clean sand facies (Tunorssuaq). These bodies attained a maximum horizontal extent of 20 m across and a thickness of 2–3 m.

The first basalt eruptions appear to have occurred in western parts of Nûgssuaq (B. E. Koch, 1959). This resulted presumably in major changes of the updip drainage pattern, which up to this time was still predominantly from south to north (southern Nûgssuaq to Auvfarssuaq). A damming effect of the volcanics could then be responsible for the development of a predominantly freshwater shaly sequence including the various Tertiary members of B. E. Koch (1959), which are ascribed to partial interfingering with the basal breccias of the volcanic sequence on Nûgssuaq and Disko (A. K. Pedersen, personal communication).

References

- Bendix-Almgreen, S. E. 1969: Notes on the Upper Cretaceous and Lower Tertiary fish faunas of northern West Greenland. *Bull. geol. Soc. Denmark* **19**, 204–217.
- Birkelund, T. 1956: Upper Cretaceous belemnites from West Greenland. *Bull. Grønlands geol. Unders.* **13** (also *Meddr Grønland* **137**, 9) 28 pp.
- Birkelund, T. 1965: Ammonites from the Upper Cretaceous of West Greenland. *Bull. Grønlands geol. Unders.* **56** (also *Meddr Grønland* **179**, 7) 192 pp.
- Brown, R. W. 1939: Fossil leaves, fruits and seeds of *Cercidiphyllum*. *J. Paleontology* **13**, 485–499.
- Denham, L. R. 1974: Offshore geology of northern West Greenland. *Rapp. Grønlands geol. Unders.* **63**, 24 pp.
- Elder, J. E. 1975: A seismic and gravity study of the western part of the Cretaceous-Tertiary sedimentary basin of central West Greenland. *Rapp. Grønlands geol. Unders.* **69**, 5–9.
- Floris, S. 1972: Scleractinian corals from the Upper Cretaceous and Lower Tertiary of Nûgssuaq, West Greenland. *Bull. Grønlands geol. Unders.* **100** (also *Meddr Grønland* **196**, 1) 132 pp.
- Frebald, H. 1934: Obere Kreide in Ostgrønland. *Meddr Grønland* **84**, 8, 33 pp.
- Hald, N. 1973: Preliminary results of the mapping of the Tertiary basalts in western Nûgssuaq. *Rapp. Grønlands geol. Unders.* **53**, 11–19.
- Hansen, H. J. 1970: Danian foraminifera from Nûgssuaq, West Greenland. *Bull. Grønlands geol. Unders.* **93** (also *Meddr Grønland* **193**, 2,) 132 pp.
- Heer, O. 1883: Oversigt over Grønlands fossile flora. *Meddr Grønland* **5**, 79–202.
- Henderson, G. 1969: Oil and gas prospects in the Cretaceous-Tertiary basin of West Greenland. *Rapp. Grønlands geol. Unders.* **22**, 63 pp.
- Jürgensen, T. & Mikkelsen, N. 1974: Coccoliths from volcanic sediments (Danian) in Nûgssuaq, West Greenland. *Bull. geol. Soc. Denmark* **23**, 225–230.
- Koch, B. E. 1959: Contribution to the stratigraphy of the non-marine Tertiary deposits on the south coast of the Nûgssuaq peninsula, northwest Greenland with remarks on the fossil flora. *Bull. Grønlands geol. Unders.* **22** (also *Meddr Grønland* **162**, 1) 100 pp.
- Koch, B. E. 1963: Fossil plants from the Lower Paleocene of the Agatdalen (Angmârtussut) area, central Nûgssuaq peninsula, northwest Greenland. *Bull. Grønlands geol. Unders.* **38** (also *Meddr Grønland* **172**, 5) 120 pp.
- Koch, B. E. 1964: Review of fossil floras and non-marine deposits of West Greenland. *Bull. geol. Soc. Amer.* **75**, 535–548.
- Koch, B. E. & Pedersen, K. R. 1960: Geological map of Atanikerdluk and environs 1:10 000. *Bull. Grønlands geol. Unders.* **23** (also *Meddr Grønland* **162**, 4) 38 pp.
- Martini, E. 1971: Standard Tertiary and Quaternary calcareous nannoplankton zonation. *Proc. 2nd Planktonic Conf. Rome 1970*, 739–785.
- Mathiesen, F. J. 1961: On two specimens of fossil wood with adhering bark from the Nûgssuaq peninsula. *Bull. Grønlands geol. Unders.* **30** (also *Meddr Grønland* **167**, 2) 54 pp.
- Nordenskiöld, A. E. 1871: Redogörelse för en expedition till Grönland år 1870. *Öfvers. Vetensk. Akad. Förh., Stockh.* **27**, 10, 923–1082.

- Pedersen, A. K. 1973: Report of field work along the north coast of Disko, 1971. *Rapp. Grønlands geol. Unders.* **53**, 21–27.
- Pedersen, K. R. 1968: Angiospermous leaves from the Lower Cretaceous Kome Formation of northern West Greenland. *Rapp. Grønlands geol. Unders.* **15**, 17–18.
- Perch-Nielsen, K. 1973: Danian and Campanian/Maastrichtian coccoliths from Nûgssuaq, West Greenland. *Bull. geol. Soc. Denmark* **22**, 79–82.
- Pulvertaft, T. C. R. & Clarke, D. B. 1966: New mapping on Svartenhuk peninsula. *Rapp. Grønlands geol. Unders.* **11**, 15–17.
- Rasmussen, H. W. 1972: Lower Tertiary Crinoidea, Asteroidea and Ophiuroidea from northern Europe and Greenland. *Biol. Skr.* **19**, 7, 83 pp.
- Rosenkrantz, A. 1970: Marine Upper Cretaceous and lowermost Tertiary deposits in West Greenland. *Meddr dansk geol. Foren.* **19**, 406–453.
- Rosenkrantz, A. & Pulvertaft, T. C. R. 1969: Cretaceous–Tertiary stratigraphy and tectonics in northern West Greenland. *Mem. Amer. Ass. Petrol. Geol.* **12**, 883–898.
- Rosenkrantz, A., Noe-Nygaard, A., Gry, H., Munck, S. & Laursen, D. 1941: [Nûgssuaq ekspeditionens geologiske resultater.] *Meddr dansk geol. Foren.* **9**, 654–663.
- Rosenkrantz, A., Noe-Nygaard, A., Gry, H., Munck, S. & Laursen, D. 1942: A geological reconnaissance of the southern part of the Svartenhuk peninsula, West Greenland. *Meddr Grønland* **135**, 3, 72 pp.
- Schiener, E. J. 1975: Sedimentological notes on sandstones from Nûgssuaq, central West Greenland. *Rapp. Grønlands geol. Unders.* **69**, 35–44.
- Seward, A. C. 1926: The Cretaceous plant-bearing rocks of western Greenland. *Phil. Trans. roy. Soc. Lond.* **B**, **215**, 57–175.
- Seward, A. C. & Edwards, W. N. 1941: Fossil plants from East Greenland. *Ann. Mag. nat. Hist.* (11) **8**, 169–176.
- Sharma, P. V. 1973: Seismic velocity and sediment thickness investigations by refraction soundings in Nûgssuaq, West Greenland. *Rapp. Grønlands geol. Unders.* **54**, 22 pp.
- Steenstrup, K. J. V. 1883: Beretning om Undersøgelsesrejserne i Nord-Grønland i Aarene 1878–80. *Meddr Grønland* **5**, 1–41.
- Szczuchura, J. 1971: Paleocene ostracoda from Nûgssuaq, West Greenland. *Bull. Grønlands geol. Unders.* **94** (also *Meddr Grønland* **193**, 1) 42 pp.
- Troelsen, J. C. 1957: Some planktonic foraminifera of the type Danian and their stratigraphic importance. *Bull. U. S. natn. Mus.* **215**, 125–132.
- Yen, J. T. C. 1958: A Cretaceous non-marine molluscan fauna of West Greenland. *Bull. Grønlands geol. Unders.* **21** (also *Meddr Grønland* **162**, 6) 13 pp.