The occurrence of marine fossils in the Upper Cretaceous deltaic sediments at Pautût, central West Greenland

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Finds of Upper Cretaceous marine macrofossils from Pautût have been reported since 1874. Subsequent investigations have led to contrasting views concerning the stratigraphic position of the fossils, the general depositional environment, and the amount of marine influence.

During a brief visit to Pautût in the summer of 1989, a section of the exposed sediments was described. The sediments can be divided into 4 facies associations reflecting deposition on a prograding delta front, in distributary channels, on a subaerial to limnic delta plain and on an abandoned delta lobe during a marine transgression. The sedimentological model predicts that marine fossils, if present, should occur in the delta front association.

The sediments were thoroughly searched for marine macrofossils, which were found in the lower part of the prominent coarsening-upward delta front sequences. The number of fossils is generally low. Bivalves and echinoids constitute the dominant groups of fossils and seem to have been well adapted to a life in muddy marine bays, subject to fluctuations in salinity and rate of deposition and with much suspended sediment.

The fossils indicate that the beds at Pautût were deposited during latest Santonian to earliest Campanian times. Sediment accumulation rates were high. The stratigraphy within the Pautût area is discussed and all the Cretaceous sediments are referred to the Atane Formation.

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Introduction

The West Greenland basin comprises a thick sequence of marine and non-marine deposits of Early Cretaceous to Danian age (Rosenkrantz & Pulvertaft 1969). In Danian times vulcanism was initiated and the sediments in southern Nûgssuaq were gradually covered by a thick series of basalt flows and agglomerates (Clarke & Pedersen 1976).

The Cretaceous sediments are poorly consolidated and are exposed in the Nûgssuaq Embayment which extends from Grønne Ejland and Disko in the south to Svartenhuk Halvø in the north. The Nûgssuaq Embayment constitutes a minor part of the West Greenland basin (Henderson, Rosenkrantz & Schiener 1976; Henderson et al. 1981; Rolle 1985). The Atane Formation was first mentioned by Nordenskiöld (1871) and further specified by Heer (1883), who divided the sediments in the area on the basis of a collection of plant macrofossils. The formation has been interpreted as deposited within a major delta (Schiener 1975; Hansen 1976; Shekhar, Frandsen & Thomsen 1982; Pedersen 1989; Pedersen & Midtgaard 1990). Pulvertaft (1987) reviewed the age and correlations of the sediments on Disko and Nûgssuaq and although there are still correlation problems, the age of the Atane Formation is generally considered to be Late Cretaceous.

At Pautût (fig. 1) a number of deeply dissected gullies provide very good exposures of the Atane Formation, both the brick-red "burnt shales" and the ordinary greyish shale alternating with whiteish sand and coal seams. Marine fossils have been collected from this locality by a number of investigators but almost exclusively from "burnt shales". These rocks have been subject to post-Pleistocene spontaneous combustion at tempe-

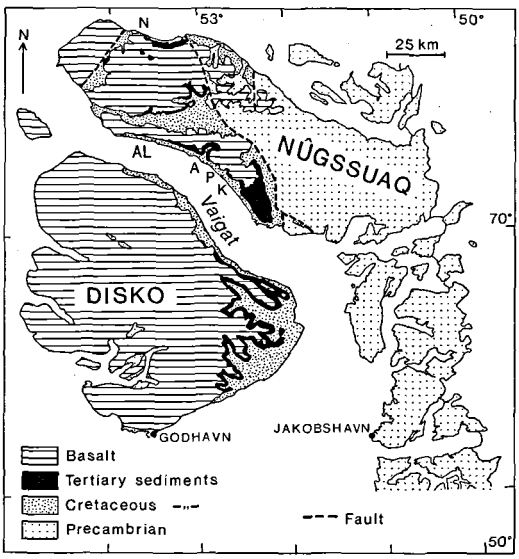


Fig. 1. Locality map showing Disko and Nûgssuaq. The Pautût locality is denoted by the P, K is Kingigtoq, A: Atâ, AL: Alianaitsúnguaq and N: Niaqornat. From Kingigtoq to Alianaitsúnguaq the depositional environment is becoming increasingly marine influenced.

ratures up to 1100° C (A.K. Pedersen, pers. comm.), a process well known today from the north coast of Nûgssuaq and from waste dumps at the now abandoned coal mine at Qutdligssat (Henderson 1969). In contrast to the ordinary shales, the burnt shales are hard and fissile. In consequence impressions of marine fossils are well preserved in these shales.

In the southeasterly part of the Pautût area the "burnt shales" are found as a discontinuous cover of scree on the slopes facing Vaigat. Field work by T.O. in the summer of 1988 had demonstrated that unburnt strata in one gully continue laterally without any break into "burnt" strata. Field work in 1989 was focused on this section in order to re-examine the occurrence of marine fossils.

The purpose of the present investigation is thus to demonstrate; (1) that the fossils are restricted to a single sedimentary facies, (2) that the delta front association formed by progradation into marine waters, (3) that the Atane Formation at Pautût comprises a stacking of almost identical delta cycles and that evidence of a central marine horizon is lacking, (4) that the sediments at Pautût may represent deposition within a fairly short period of time.

Previous work

Marine macrofossils were first found at Pautût by Steenstrup (1874, 1883a). He found the fossils in heights ranging from sea level and up to 650 m in burnt as well as unburnt strata. On this basis, he concluded that the majority of the strata were deposited in marine or brackish waters.

White & Schuchert (1898) found marine fossils in burnt shales east of Pautût. They noted that the most common species was an echinoid, but they also found specimens of *Avicula* and *Pinna?*. The fossils were found at several levels.

During a regional investigation of invertebrate fossils from West Greenland, Ravn briefly visited the Pautût area in 1908 (Ravn 1918). He tentatively suggested that the marine fossils were confined to the central part of the exposed sequence. Both of his described localities appear, however, to be different from Steenstrup's (1883a). Ravn (1918) interpreted the depositional environment as fresh to brackish lagoons, where fully marine conditions only occasionally were established. The fossils studied by Ravn (1918) included older collections and his paper contains the latest description of the fauna from Pautût and adjacent localities. Ravn's data are summarized in fig. 2.

Name	Superfamily	Locality				
		K	P	A	Al	N+
Spenoceramus pinniformis	*Pteriacea*	-	4	-	-	-
Spenoceramus patootensis	-	-	many	-	-	-
Oxytoma (Hypoxytoma) tenuicostata	*Pectinacea*	-	many	-	-	-
Chlamys striatissima Ravn non Hagenow	-	-	-	2	-	-
Chlamys ? ataensis	-	-	-	3	-	-
Camptonectes pfaffi	-	-	-	1	1	1
Syncyclonema cf. *halli*	-	-	1	-	-	-
Variamussium ignoratum	-	-	-	14	1	3
Arcoperna glabra	*Mytilacea*	-	-	2	-	-
Nucula cancellata	*Nuculacea*	1	-	-	-	-
? Nucula planomarginata	-	-	-	1	-	-
Nucula sp	-	1	-	7	-	-
Yoldia sp.	-	-	-	1	-	-
? Nuculana bisulcata)	*Nuculanacea*	-	-	7	-	-
Arca sp.	*Arcacea*	-	-	-	1	-
Opis sp.	*Crassatellacea*	-	-	1	-	-
Thyasira s.l. *delorioli*	*Lucinacea*	-	-	2	-	-
? Thyasira s.l. *occidentalis*	-	1	1	17	-	1
"Lucina" pfaffi	-	-	-	1	-	-
Lucina sp.	-	-	1	-	-	-
Lucina sp.	-	-	-	1	-	-
Tellina ? steenstrupi	*Tellinacea*	-	-	22	-	-
Solemya ? cf. subplicata	*Solemyacea*	-	2	3	-	-
Neaera moreauensis	*Poromyacea*	-	-	1	-	-

Fig. 2. The bivalve fauna from various localities in Nûgssuaq (Ravn 1918). The names of the fossils are revised according to suggestions provided by A.V. Dhondt (pers. comm. 1987, 1990). Note that most species occur in very low numbers. K, P, A & Al refers to localities shown in fig. 1, N+ is Niaqornat and other localities in northern Nugssûaq.

Sequence no. GGU sample no.	1 358540	2 -	3 358541	4 358542	5 358543
Sphenoceramus sp.	3	-	6	5	5
Oxytoma	-	-	15	1	-
Echinoids	-	-	14	2	1
Thalassinoides	1	-	-	-	-
Chondrites	-	-	-	-	1

Fig. 3. The numbers and distribution of the fossils found during the present study. The fossils are referred to the CU-sequences of the measured section (fig. 8). Within each CU-sequence the fossils were collected as one sample.

As can be seen, many of the species are only represented by very few specimens and often were only found at a single locality.

B.E. Koch visited the south coast of Nûgssuaq several times during the fifties. He was mainly interested in plant macrofossils but one of his co-workers, K. Raunsgaard Pedersen, found marine fossils *in situ* in a bed in the central part of the sequence (Koch 1964).

Rosenkrantz & Pulvertaft (1969) and Henderson et al. (1976) have discussed the occurrence of marine fossils from Pautût. They stated, primarily based on Koch (1964), that the predominantly limnic sediments grade up into and then away from a marine horizon in the central part of the sequence.

The clastic sedimentology and coal petrography of the Atane Formation was studied by Shekhar et al. (1982). They concluded that the sediments at Pautût were deposited in a fluvial dominated deltaic environment.

Midtgaard & Olsen (1989) indicated that the prominent coarsening-upward sequences were very persistent laterally and could be used at least locally as marker units. Primarily on sedimentological evidence they interpreted these sequences as deposited in marine interdistributary bays.

The total of more than 5 km of sedimentary logs measured by Shekhar et al. (1982) and Midt-

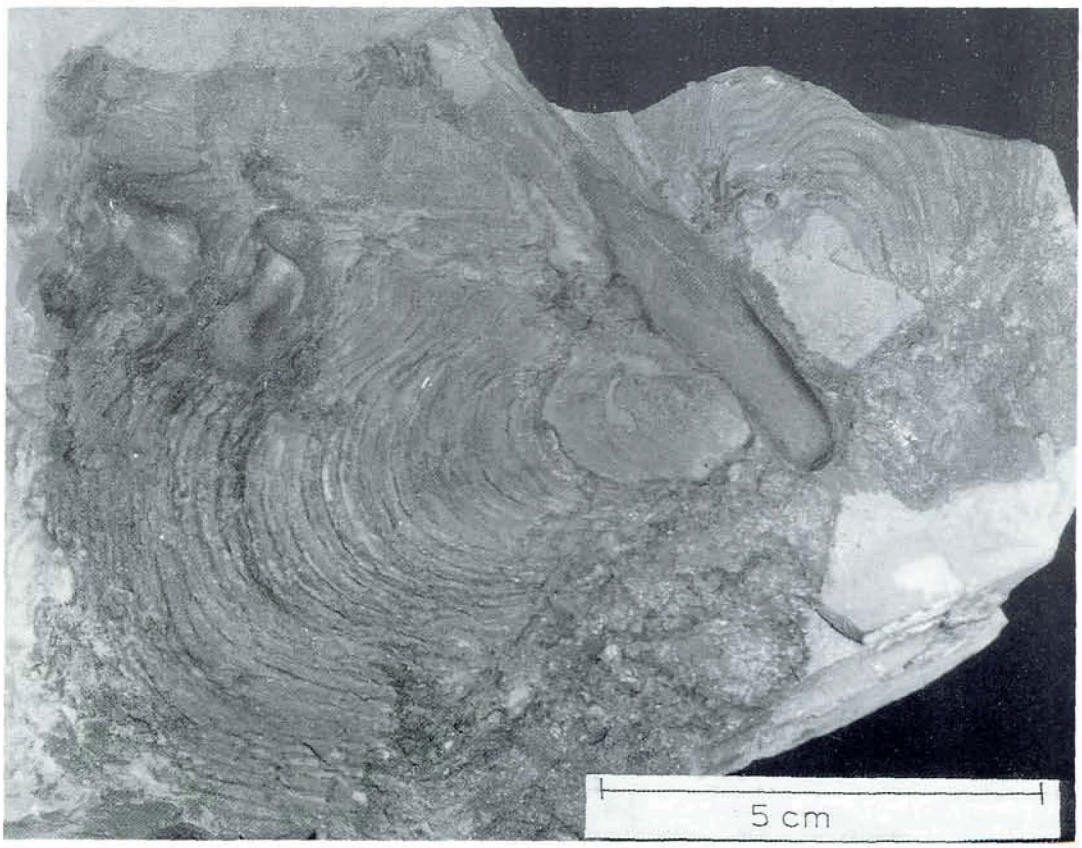


Fig. 4. *Sphenoceramus patootensis* (de Loriol). Note the articulated valves and the incipient melting in the hinge and on the valve seen to the left. Sample number GGU 358542 (MGUH 20516).

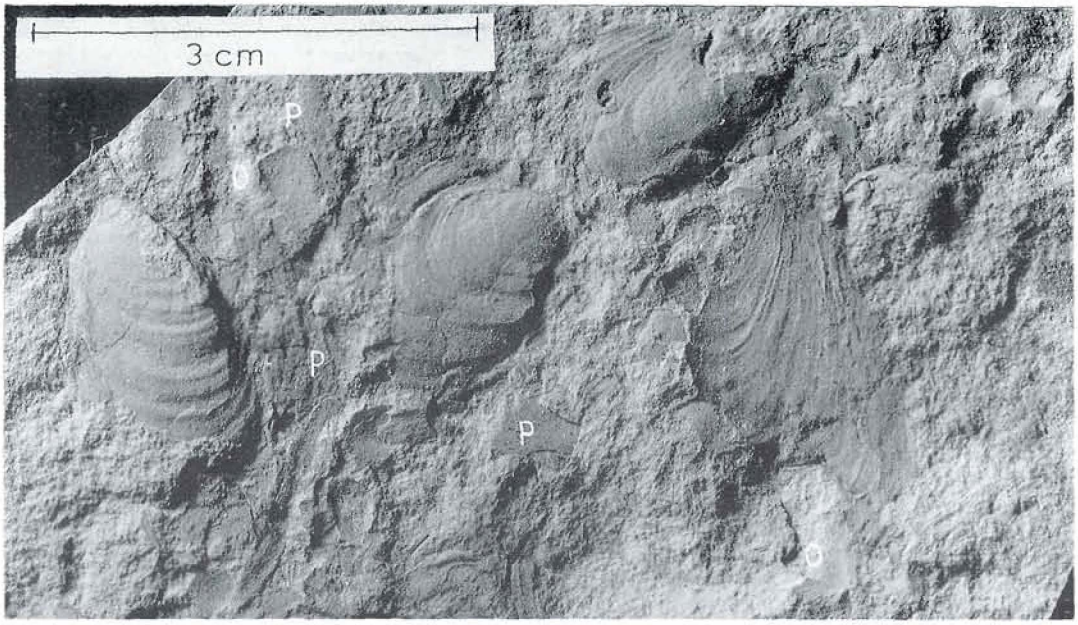


Fig. 5. *Sphenoceramus* sp. (juvenile). Note also faint impressions of *Oxytoma* (O) and plant debris (P). Sample number GGU 358541 (MGUH 20517).

gaard & Olsen (1989) documents a cyclicity in the sedimentary sequence at Pautût. None of these geologists have, however, recorded any distinct marine zone or layer, nor have they described any occurrence of marine fossils. It is thus evident that the fossils are scarce, that they are poorly preserved in the grey shales, and that the fossils are just as likely to occur in several horizons, as in only the middle part of the section.

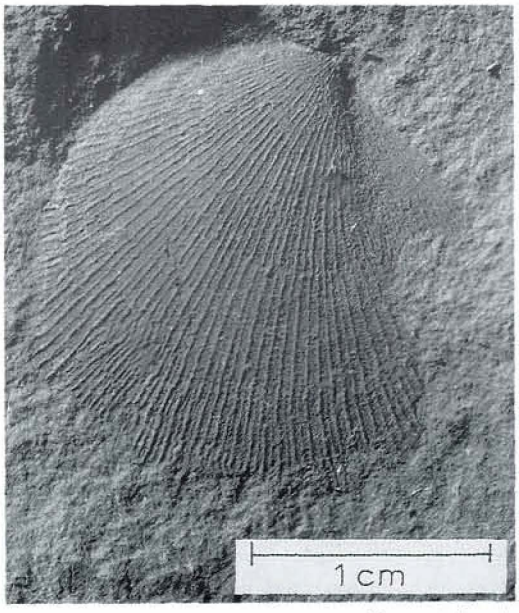


Fig. 6. *Oxytoma (Hypoxytoma) tenuicostata* (Roemer). Sample number GGU 358541 (MGUH 20518).

Palaeontology

A sparse fauna of bivalves and echinoids was found at Pautût in shales representing the delta front association. All fossils were collected in the shown section (figs 3, 8). Many fossils were found in life position and there are no coquinas indicating transport of shell material. We assume that the fossils are representatives of a life assemblage (fig. 3). In the burnt shales the fossils are mostly preserved as inner molds or as impressions. Some of the original shell material occasionally appears to have been preserved, but closer inspection reveals that this material has been more or less molten during combustion. Thus, except for the shape, most of the diagnostic features of the fossils are not distinguishable.

Ravn (1918) listed the fauna from Pautût, and stated that only the echinoids and three of the bivalves occur in fairly large numbers (fig. 2). The fossils found have been identified by comparison with Ravn's plates V – VII. The fossils

Fig. 7. *Hemiaster* sp. Sample number GGU 358541 (MGUH 20519).

are stored at the Geological Museum in Copenhagen (MGUH numbers 20516–19).

In 1987 the Geological Survey of Greenland through Dr. F. Surlyk, approached Dr A.V. Dhondt in Brussels concerning the bivalve fauna from West Greenland. In her reply, she suggested modern names for some of the fossils listed by Ravn (1918) and also provided palaeoecologic comments on the fauna. Ravn's faunal list has been revised according to her suggestions (see also fig. 2).

The following species were found and determined during this investigation.

Bivalvia

Inoceramus (Sphenoceramus) patootensis (de Loriol) (figs 4, 5)
Oxytoma (Hypoxytoma) tenuicostata (Roemer) (fig. 6)

According to Seitz (1965) *Sphenoceramus patootensis* (de Loriol) is probably synonymous with *Inoceramus lingua* Goldfuss. As our specimens originate from the type locality of *Sphenoceramus patootensis* and as no original shell material is present for precise identification, we have retained the name *Sphenoceramus patootensis*. Ravn (1918) reported fragments of *Inoceramus steenstrupi* from Pautût. According to Seitz (1965) this species is identical to *Sphenoceramus pinniformis* Willet. We have not identified *Inoceramus steenstrupi* in our samples.

Specimens of *Oxytoma* was also reported by Ravn (1918), who referred them to the North American species *Oxytoma nebrascana*. Dr A. V. Dhondt (pers. comm. 1990), however, considers the *Oxytoma* from the present material as much closer and probably identical to the European species *Oxytoma (Hypoxytoma) tenuicostata* Roemer.

Echinodermata

Schizaster sp.
Hemiaster sp. (fig. 7)

According to U. Asgaard (pers. comm. 1989) the flattened thecas in the present material does not permit determination to species level. Likewise, distinction between the two species of echinoderms is only possible in complete and well preserved specimens.

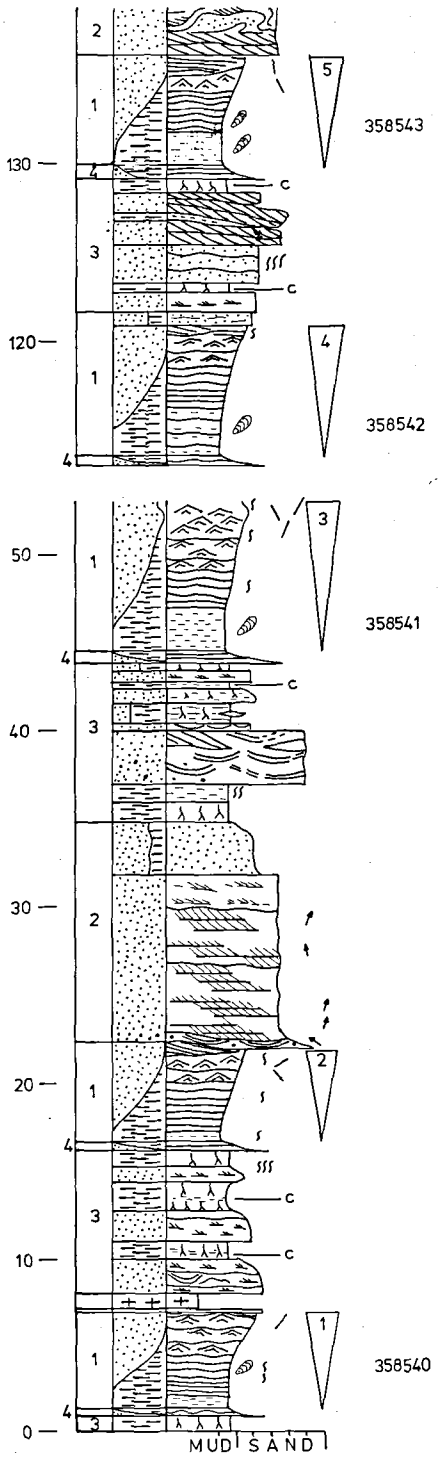
Trace fossils

Two ichnospecies were identified:. *Thalassinoides* and *Chondrites*. The trace fossils occur in the delta front association above the layers with invertebrates. The degree of bioturbation varies in the coarsening-upward sequences, but is generally low. Both ichnospecies are common in fine grained marine sediments.

Palaeoecology

The fossils from Pautût are all found in shales interpreted as delta front mud. *Sphenoceramus patootensis* and *Oxytoma tenuicostata* occur frequently with articulated valves and are found in weakly laminated shale, often associated with plant remains. The echinoids are found usually as complete, flattened thecas normally within rather massive mudstone. All of the bivalves are considered fully marine (A.V. Dhondt pers. comm.). The echinoids are likewise marine.

The bivalves and echinoids found in the stud-



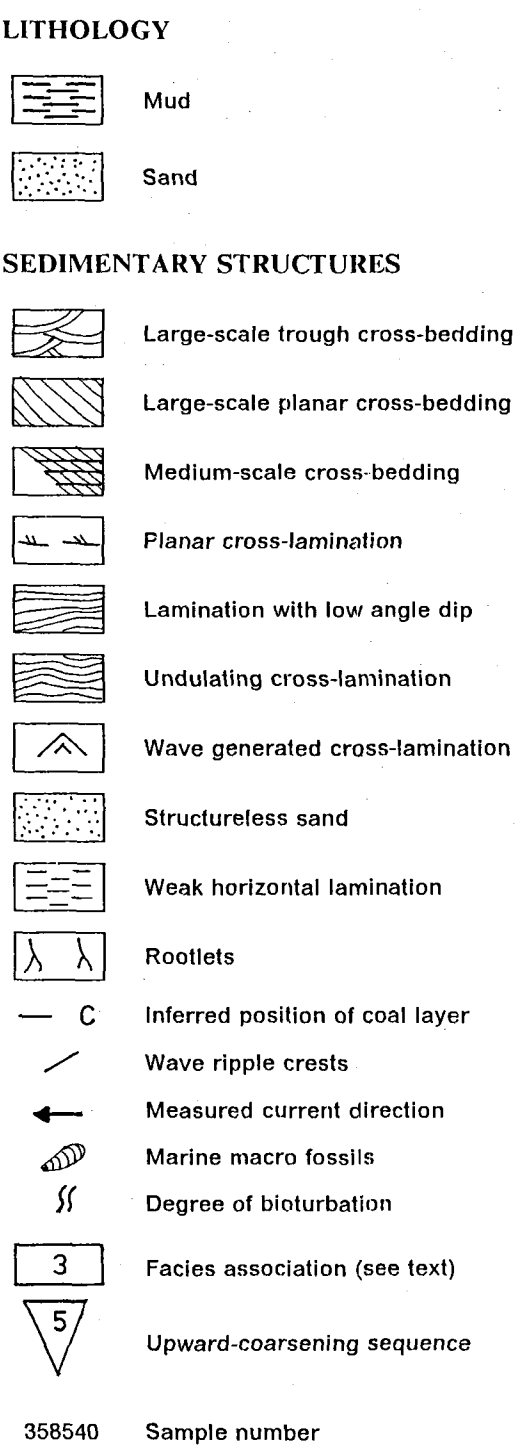


Fig. 8. Section through burnt shales at Pautût. The coal seams that generally characterize the delta plain association have been destroyed, but their inferred position is indicated (– c). Note the distinct coarsening-upward trend of the delta front association (1). Within the section a stratigraphic gap of approximately 60 m exists. Vertical scale in meters.

ied section are calcitic. Fossils with aragonitic shell material (e.g. nuculoids) appears to be lacking. This is not ascribed to a diagenetic effect as nuculoids are reported from identical sedimentary facies at the nearby localities Atâ and Kingigtoq.

During the Cretaceous, the inoceramids were among the most common bivalves in many environments, often living in clusters (Kennedy 1978). At Pautût, both juvenile and mature specimens of *Sphenoceramus* are found, the largest reaching sizes of 20 – 40 cm. When juvenile, *Sphenoceramus* probably lived partly in the sediment and was byssally attached. It was thus a semi-infaunal suspension feeder. During growth this position apparently changed to a reclining mode of life where this species lay on one side. It was probably still attached with a byssus which may have facilitated minor adjustments of its position in response to sedimentation.

Oxytoma tenuicostata has been reported to occur at Pautût in comparatively high numbers (Ravn 1918). *Oxytoma tenuicostata* is strongly inequivalve and the byssal notch is not well developed. The left valve is the largest and shows radial ribbs. In contrast, the right valve is much smaller and more flat and shows very weak concentric and radial lines.

These bivalves were epifaunal and lived byssally attached, probably with their small right valve closest to the substrate and the left valve covering the animal. Species of *Oxytoma* occur in very high numbers on particular bedding planes in Jurassic shales deposited in low-oxygen environments (Duff 1975; Hallam 1976; Fürsich 1976). Duff (1975) and Fürsich (1976) both referred *Oxytoma* to the pendent epifauna, i.e. bivalves that lived attached to water plants. The association of the bivalves with plant debris at Pautût may support this interpretation (fig. 5). We thus propose that these bivalves lived attached to plants and in this respect were similar to modern equivalve *Pteria colymbus* described by Stanley (1970).

Nuculoids have been reported from Atâ and Kingigtoq (Ravn 1918, fig. 2), where sedimentological data indicate that similar depositional environments prevailed. The nuculoids represent the infaunal deposit feeders and were abundant in both Jurassic and Cretaceous marine organic-rich shales (Duff 1975; Hallam 1976; Fürsich 1976). The nuculoids are tolerant of low contents of dissolved oxygen and fluctuating salinity and are consequently characteristic of prodelta muds (Rhoads, Speden & Waage 1972) and interdistributary bay mudstones (Fürsich 1981).

Four more species of bivalves were reported from Pautût by Ravn (1918); one pectinid, two lucinids and a *Solemya*. The four species were apparently rare (none found during this investigation).

Echinoids are found fairly frequently at Pautût (Ravn 1918; fig. 3). The two species are almost identical in size and outer shape and witness the establishment of marine conditions. Both species were infaunal deposit feeders adapted to a life 10–20 cm below the bottom in muddy sediments (U. Asgaard pers. comm.).

Sedimentology

The sediments at Pautût (fig. 8) are divided into 4 facies associations interpreted as representing deposition from prograding delta lobes, in distributary channels, on the delta plain and from transgressive marine reworking of delta front and channel deposits (see also Midtgaard & Olsen, 1989 and Pedersen 1989). The measured section comprises five well developed coarsening-upward sequences.

Delta front association (1).

This association constitutes 5–20 m thick coarsening-upward sequences. Photogrammetric mapping has demonstrated that these CU-sequences can be traced laterally for up to 8 km without much change in thickness.

The association consists of three facies which always appear in the same order, each facies grading into that above (fig. 8). The lowermost facies is formed by mudstone with a very weak lamination. It is in this facies that marine fossils can usually be found, whereas plant fragments are more rare. The mudstone is gradually succeeded by sand-streaked mudstone leading up into a heterolithic fine-grained sandstone. The sedimentary structures change from mainly horizontal bedding to wavy and lenticular bedding. On bedding surfaces symmetrical wave generated ripples can be seen.

A predominantly sandy facies forms the top of the coarsening-upward sequence. In the very fine to fine grained sand wavy bedding and undulating cross-lamination can be found. The latter is similar to the wave generated undulating cross-lamination discussed by Raaf, Boersma & van Gelder (1977). Wave ripples are sometimes recognized and most of the intricate cross lamination is attributed to waves. In the top of the sequence the sedimentary structures change to parallel lamination with low angle dips interpreted as beach lamination. Above this, the association is capped with deposits referred to the delta plain association or erosively cut by the distributary channel association (fig. 8).

The association is interpreted as deposition at the front of a prograding delta lobe. The progradation followed a period of maximal transgression and non-deposition during which the salinity approached that of a normal marine environment. Consequently a marine fauna was established. The invertebrate fauna persisted during the initial phase of delta front progradation.

The lateral continuity of the facies and the presence of wave generated structures indicate reworking of the delta front. Though the delta front sand was supplied by distributary channels, it has not been possible to trace distinct mouth bar complexes.

Distributary channel association (2)

This association comprises isolated sand bodies that are 3–30 m thick and have width/depth ratios around 15. Some good examples of epsilon cross bedding have been found (e.g. Midtgaard & Olsen 1989). Current directions measured on foresets are rather uniform from bed to bed and indicate a general transport direction towards the NW. Medium and coarse grained sand dominates the channel fill.

The sandstone units have an erosive base and local channel lag deposits contain extra-basinal pebbles, intraformational clay clasts and rare calcified tree-trunks. Above, layers of poorly sorted sand with different types of large-scale cross bedding and sediment deformation structures comprise the main part of the association (fig. 8). At the top, the sand normally grades rapidly into the overlying finer grained deposits. Despite this, an overall fining-upward trend is rarely seen.

The association is interpreted as having been deposited within channels of moderate sinuosities. The variation in thickness and width of the sandbodies reflects the variable time of existence of individual distributary channels.

Delta plain association (3)

The association is characterized by a variety of horizontal to gently dipping beds of clay, silt and very fine grained sandstone. These layers are penetrated by numerous roots up to 10 cm thick, but well defined root horizons are rare. In the sandy beds unidirectional small scale cross lamination is found together with rare isolated large scale trough cross beds. Sand is also found as discontinuous structureless layers and lenses. Coal seams, many of which exceed 80 cm in thickness, form a significant part of the association. Due to the combustion of the coal seams this association is somewhat condensed in the shown section of burnt shale. The inferred position of coal layers is, however, shown on fig. 8 with -c.

The sediments in the association were deposited on a generally subaerial delta plain. Here unchannelized crevasse splays periodically deposited fine grained cross-laminated sandstone. Silt and clay settled out from suspension at the distal end of the splays and in very shallow lakes and swamps. In sediment-starved back swamps large amounts of organic material accumulated and eventually became coalified.

Transgressive sand sheet association (4)

This association overlies the delta plain sediments and constitute the top of the depositional cycles. It consists of 5 – 50 cm rapidly upward-fining sand (fig. 8). The sand is fine-grained and has a horizontal to weakly undulating lamination, often with much plant debris intercalated between individual laminae.

This sandstone facies formed by marine reworking of former delta front and distributary channel deposits during the trangression of an abandoned delta lobe. Corresponding facies from the Mississippi delta have been discussed by Penland, Boyd & Suter (1988). The FU-trend reflects reworking and deposition in gradually deeper water. After the initial transgression, marine condi-

tions were established in the area followed by a period of subsidence and non-deposition.

Discussion

The sedimentological investigation has shown that the Atane Formation at Pautût comprises a vertical stacking of c. 32 almost identical depositional cycles. This is interpreted as a result of autocyclic switching of delta lobes. The similarity between the cycles suggests that the successive delta lobes had identical depositional histories. Marine conditions were established intermittently prior to and during deposition of the delta front association.

The sedimentary facies indicate a rapid progradation of the delta front and associated high sediment accumulation rates. On the top of the delta lobe sedimentation took place in fluvial channels and on the adjacent lower delta plain. When the clastic input to the delta lobe dwindled, the progradation stopped. During the subsequent transgression, a thin veneer of sand was deposited. The dominance of small scale sedimentary structures and the low proportion of sand in the delta front association indicates only small amounts of wave and tide influence. The exposed sediments at Pautût therefore were deposited in a fluvially dominated delta. The size of the distributary channels and the rate of progradation points to a high influx of riverine waters resulting in fluctuating salinities, especially in the shallower part of the delta front. The thickness of the coarsening-upward sequences indicates deposition in waters not more than 20 m deep. The sedimentology thus suggests that the main environmental hazard of the fossil-bearing shales were high sedimentation rates.

Fürsich (1981) distinguished five salinity-controlled benthic associations (bivalves and trace fossils) in fluvial channel to prodelta deposits in the Upper Jurassic of Portugal. These prodelta mudstones have a fauna dominated by shallow burrowing bivalves where the commonest faunal element is a deposit-feeding nuculoid. Apart from substrate consistency, the fauna was influenced by salinity, as indicated by the lack of ammonites and the generally low diversity. Fürsich (1981) interpreted this faunal association as characteristic in prodelta environments where salinities approach those of the open sea but he noted that it also could be found in the brachyhaline regime.

Fürsich & Kauffman (1984) discussed the palaeoecology of brackish to freshwater sedimentary cycles in the Albian of SW Wyoming. Their brackish water bivalve assemblage contain neither the lucinids, the nuculoids, the pectinids nor the sphenoceramids characteristic of the delta front shales from the Atane Formation. The fossil-bearing shales from Pautût are consequently interpreted as marine rather than brackish.

Kranz (1974) reported a set of experiments on the ability of bivalves to escape burying in rapidly deposited sediments. He found that mucus tube suspension feeders (lucinids), labial palp deposit feeders (nuculoids) and infaunal siphonate deposit feeders are generally able to escape burying beneath up to 50 cm of their native sediment. In the delta front mud of the Atane Formation nuculoids and lucinids are the only common infaunal bivalves. This suggests that the fauna was to some extent adapted to an environment characterized by intermittent high rates of deposition.

Birkelund (1965) studied the ammonite faunas of the West Greenland basin in central and northern Nûgssuaq. She suggested (pp. 145–150) that the Coniacian and Santonian ammonites found here represent the remains of breeding swarms that migrated *en masse* and possibly were sensitive to changes in salinity, temperature etc. The ammonites are found in fully marine prodelta shales occuring in northern Nûgssuaq and Svartenhuk. Very recently, two incomplete ammonites were found in burnt shales from Pautût by A. Boyd (in press). These are the only ammonites ever found at Pautût but they might possibly have drifted in from somewhere else in the basin. The almost total lack of ammonites in delta front association thus suggests that the delta front did not constitute a suitable environment for ammonites. This is further confirmed by the sporadic occurrence of ammonites in the more distal parts of the delta and even here only as migrating swarms (Birkelund 1965).

On the basis of the discussion above, we conclude that the fossiliferous delta front shales corresponds to periods of marine conditions. However, the scarcity of fossils and the low diversity also points to serious ecological limitations. The presence of many juvenile sphenoceramids and

the occurrence of several complete echinoids closely together on the same bedding plane is attributed to major floods, during which river water significantly lowered the salinity. In effect, most animal life was killed. Reestablishment of the fauna would then take place until the next flood. Lowered levels of dissolved oxygen is envisaged due to the decay of large amounts of comminuted plant debris and were tolerated by *Oxytoma,* the nuculoids and probably also the large sphenoceramids. Finally, the very high sedimentation rates would seriously have limited normal marine animal life as well as producing a "dilution" of the fossils (Galloway & Hobday 1983).

Stratigraphy and age

The bivalves *Sphenoceramus patootensis, Sphenoceramus pinniformis* and *Oxytoma (Hypoxytoma) tenuicostata* clearly indicate the age of the beds as: transition Santonian – Campanian (A. V. Dhondt, pers. comm. 1990). According to Seitz (1965) *Sphenoceramus patootensis* is younger than *Sphenoceramus pinniformis*. In the present investigation only *Spenoceramus patootensis* has been identified, but the older species (*Sphenoceramus pinniformis*) is known to occur in higher stratigraphic levels (Steenstrup 1883a; Ravn 1918). Thus some of our unidentified material may represent the latter species. Consequently, the Pautût section corresponds to the relatively brief period when *Sphenoceramus pinniformis* and *Sphenoceramus patootensis* coexisted. In addition, the sedimentary facies indicate that the 300 – 400 m of fossiliferous sediments at Pautût very likely were deposited within a limited time span.

ARCO (Ehman, Sodero & Wise 1976) dated a section at Pautût on the basis of palynomorphs. They indicated a Coniacian – Santonian age for the sediments above 380 m (their section N6), while the samples below represent the Middle Cenomanian. Subsequent fieldwork have failed to find sedimentological evidence for this hiatus.

Previously, the sediments found at Pautût have been divided into two formations based on the plant macrofossils collected by Steenstrup. These were sent to O. Heer, who assigned the sediments either to the greyish and white Atane Formation or to reddish (burnt shales) Patoot Formation (Heer 1883). This division is, however, based on two major misinterpretations: 1. The Patoot Formation do not form a separate unit overlying the Atane Formation but is laterally equivalent as recognized by Steenstrup (1883b) and Koch (1964). 2. The "burnt shales" of Pautût are not stratigraphically connected with those at Atâ or Kingigtoq.

Koch (1964) discussed the stratigraphy of the Pautût locality. He revised the fossils determined by Heer and also presented new material which minimized the difference between the Patoot Formation and the Atane Formation. He concluded, that all the fossils found at Pautût originated from one formation.

The investigations within the Pautût area have revealed identical fossil faunas at many stratigraphic levels (Steenstrup 1883a; Ravn 1918; Koch 1964; this paper). This indicates that out of the total 700 m exposed deltaic deposits at Pautût at least 300 to 400 m have the same marine fauna. It is therefore considered likely, that no major breaks in the sedimentation occurred within this interval.

The Upper Santonian marine fossils have been found in sediments dated on the basis of palynomorphs as equivalent to the rest of the Atane Formation. Thus, very little evidence remains in favour of a distinct Patoot Formation. We agree with Koch (1964) in regarding the Patoot Formation as an artificial unit. The Cretaceous sediments at Pautût should therefore be referred to the Atane Formation.

Conclusions

Based on the sedimentology, the described sediments from Pautût appears to have been deposited within a major fluvial dominated delta. The well developed coarsening-upward trend and the content of marine macrofossils show that the delta front association formed during progradation of a delta lobe. In the sub-aerial part of the delta extensive wetlands with distributary channels, very shallow lakes and large vegetated areas existed. The vertical repetition of the marine coarsening-upward sequences as well as their limited thickness (5–20 m) points to progradation

out into relatively shallow water probably resulting in a lobate delta morphology.

Based on the sedimentology and the distribution of the fossils, previously mentioned hiati within the Pautût area can be discarded. It is thus impossible to retain the Patoot Formation as a separate stratigraphical unit. All Cretaceous sediments at Pautût should henceforth be referred to the Atane Formation with the bivalves indicating the age of the beds as latest Santonian – earliest Campanian.

The evidence from the scarce fauna confirms the interpretations of the depositional environment based on the sedimentary structures. We conclude that the fossil fauna appears to be adapted to a low-energy muddy environment that were subject to fluctuations in salinity and rate of deposition.

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Dansk sammendrag

Det vestgrønlandske bassin rummer en tyk lagserie af sedimenter fra Kridt og Tertiær, overlejret af vulkanske breccier og plateaubasalter. Atane Formationen omfatter fluviale og deltaiske sedimenter fra Kridt (fortrinsvis Cenomanien til ældste Campanien) og kan undersøges i 100–400 m høje blotninger på Disko og på den sydlige halvdel af Nûgssuaq. Pautût er en 8 km lang kyststrækning (fig. 1) hvor Atane Formationen er detaljeret opmålt. De sedimentologiske undersøgelser viser, at Atane Formationen her er cyklisk aflejret. Fire faciesassociationer er tolket som aflejret på en prograderende delta front, i deltafordelingskanaler, i lavvandede søer eller på vegetationsdækkende dele af deltasletten samt på en forladt deltalobe under marin transgression. Faciesassociationerne opbygger 32 næsten identiske deltasekvenser hvoraf 5 er repræsenteret i fig. 8. Den sedimentologiske model forudsiger, at såfremt marine fossiler forekommer, burde de findes i deltafront associationen.

I Pautûtområdet findes brændte skifre. Selvantændelse og forbrænding af Atane Formationens kulholdige sedimenter har resulteret i temperaturer over 1100°C hvorved de smuldrende grå skifre omdannes til hårde røde skifre med relativt god spaltelighed og fin bevaring af aftryk af marine invertebrater. Alt skalmateriale er dog ødelagt. Det undersøgte profil (fig. 8) dækker faststående brændte skifre. Der blev fundet aftryk af fossiler i de skifre, som udgør den nederste del af deltafront associationen. Dette viser, at hver deltacyklus repræsenterer en udbygning i et marint bassin. Antallet af fossiler er lavt (fig. 3) og kun få arter af muslinger og søpindsvin blev fundet (fig. 4–7). Fossilerne repræsenterer dyr, som synes tilpasset til en eksistens i et miljø med mudderbund, med varierende sedimentationshastigheder og muligvis med fluktuationer i saltholdigheden. Såvel Steenstrup (1883) som Ravn (1918) rapporterede om fund af marine fossiler ved Pautût. Den foreliggende undersøgelse viser, at fossilerne ikke er knyttet til en bestemt *horisont men* at de er karakteristisk forekommende i en bestemt faciesassociation i hele det tidsrum, som lagserien repræsenterer. Selv om faunaen er sparsom, supplerer den de sedimentologiske data og styrker tolkningen af aflejringsmiljøet.

Muslingerne daterer sedimenterne til et snævret tidsinterval på overgangen Santonien-Campanien. De sedimentologiske undersøgelser indicerer, at lagserien ved Pautût ikke indeholder længerevarende hiati.

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