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New sedimentological data on Lower Tertiary shales from Disko and Nûgssuaq, West Greenland

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The sedimentological data described and discussed below were collected during a period of 47 days in the summer of 1986. The field work was carried out over 23 days from four camps: Tartunaq, Akúneq, Skansen and Tuapait (fig. 1). The main objective was investigation of the Naujât Member, through which a number of sections were measured, but in addition the under- and overlying, predominantly sandy facies associations were also studied.

Introduction

Cretaceous to Tertiary sediments are exposed in up to 1000 m thick sequences on Disko and Nûgssuaq in West Greenland. The sediments were deposited in a major delta with sediment transport from south to north (Henderson *et al.*, 1976). The area studied is located within the fluvial-dominated parts of the delta where the main lithology is whitish, slightly consolidated sand.

The sand is interbedded with heteroliths as well as with dark grey to black shales among which an early Tertiary sequence is prominent due to its thickness (up to 100 m), its lateral continuity, and its lack of marine fossils. On Nûgssuaq this shale was erected as the Naujât Member of the Upper Atanikerdluk Formation by Koch (1959).

Geochemical data from the Naujât Member show that the total organic content is unusually high, partly liptinitic, and the shale is thus transitional to an oil shale (Schiener & Leythaeuser, 1978). These authors interpreted the Naujât Member as lacustrine, deposited in a body of fresh water dammed up behind a barrier of contemporaneous volcanic rocks.

This study of the sedimentology of the Naujât Member was undertaken to record vertical and lateral facies relationships; to interpret depositional processes of clastic as well as organic material; and finally to relate the sedimentary environment of the shale to the geological development of the delta. The interpretation presented below is necessarily of a preliminary character, and emphasis is therefore placed on descriptions of the sedimentary facies with comments on their spatial distribution.

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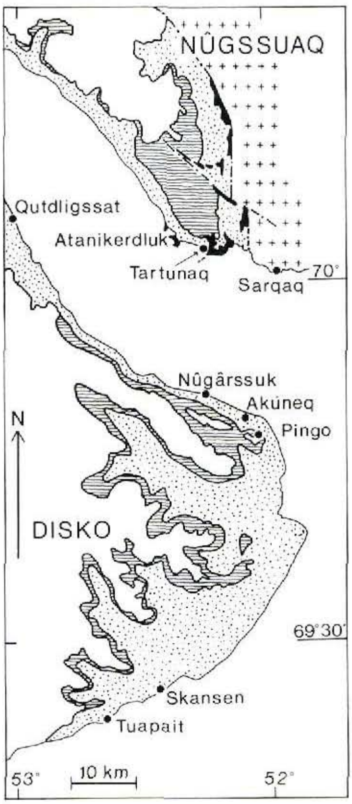


Fig. 1. Geological map of eastern Disko and adjacent Nûgssuaq. Drawn from Henderson *et al.* (1976, fig. 304). Cretaceous sediments are dotted, Tertiary ones are ruled while volcanic rocks are white. Sills on southern Nûgssuaq are black and crosses denote Precambrian basement.

Geological setting

The Cretaceous and Tertiary sediments exposed on Disko and Nûgssuaq were deposited in the Nûgssuaq embayment which is part of the West Greenland Basin (Henderson *et al.*, 1976, 1981; Rolle, 1985). The Nûgssuaq embayment is a fault-controlled graben complex bounded to the east by Precambrian basement and to the west by the Disko Gneiss Ridge (Henderson *et al.*, 1981, fig. 2). The thickness of the sedimentary sequence increases northwards along the axis of the embayment from eastern Disko to northern Nûgssuaq (Rosenkrantz & Pulvertaft 1969; Henderson *et al.*, 1981, fig. 4).

During the Cretaceous the Nûgssuaq embayment constituted a large delta with fluvial, upper delta plain environments in the south followed north-westwards by delta plain and interdistributary bays, and subsequently by sandy delta front and prodelta mud environments (Henderson *et al.*, 1976). The predominantly fluvial environments are characterized by slightly consolidated sand, heterolithic sand and thin coal seams and constitute the Atane Formation (Nordenskiöld, 1871). Hansen (1980) draws attention to the fact that the sand : clay : coal ratio remains remarkably constant in all vertical sections through the Atane Formation indicating that the delta, which occupied the Nûgssuaq embayment, neither prograded nor was drowned. This vertical accretion must reflect near equilibrium between subsidence and supply of sediment.

During the Tertiary, a complex palaeogeography resulted from the interplay between fluvial sediments supplied mainly from the south and marine environments prevailing in central and northern Nûgssuaq on a topography determined by volcanic eruptions and synvolcanic block-faulting (Rosenkrantz & Pulvertaft, 1969; Schiener & Leythaeuser, 1978; Hansen, 1980). The Paleocene faulting created a cuesta-like topography of eastwards tilted blocks which strongly controlled facies distribution of the Paleocene sediments as well as thickness variations in the overlying volcanics (Hansen, 1980).

The eruptions of Tertiary volcanics began on north-western Disko, and the volcanics comprise hyaloclastites and plateau basalts divided into the Vaigat, Maligât and Hareøen Formations (Clarke & Pedersen, 1976). Subaqueous volcanic breccias overlain by subaerial plateau basalts prograded eastwards during the early Tertiary and eventually covered the sediments in the Nûgssuaq embayment.

The non-marine Tertiary on south-east Nûgssuaq and north-east Disko

The stratigraphy, palaeontology and to some extent the sedimentology of the Cretaceous–Tertiary on south-east Nûgssuaq has been studied previously (Koch, 1959; Koch & Pedersen, 1960; Hansen, 1980; Shekhar *et al.*, 1982). In comparison, little is published about the sequence exposed on north-east Disko, though the outcrops from Pingo to Nûgârssuk are excellent (fig. 2). The major lithostratigraphic units defined on Nûgssuaq and their possible correlation across the Vaigat are briefly discussed below.

Along the southern coast of Nûgssuaq an angular unconformity is seen between the coal-bearing, fluvial, sand-dominated Atane Formation and the overlying non-marine, Tertiary

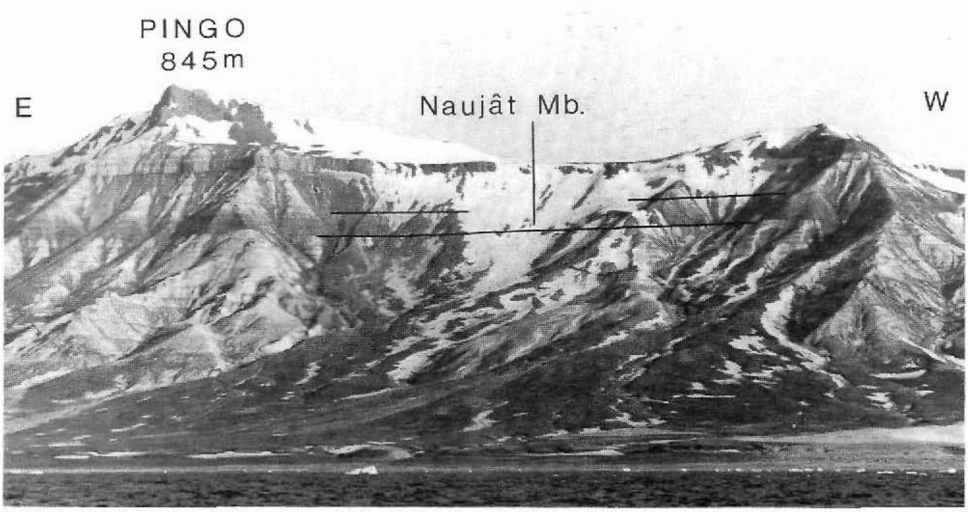


Fig. 2. The mountain Pingo on north-east Disko reaches a height of 845 m a.s.l. A prominent sill has its base *c.* 570 m a.s.l. The Tertiary mudrocks studied are seen as the thick, dark grey band around 400–450 m a.s.l.

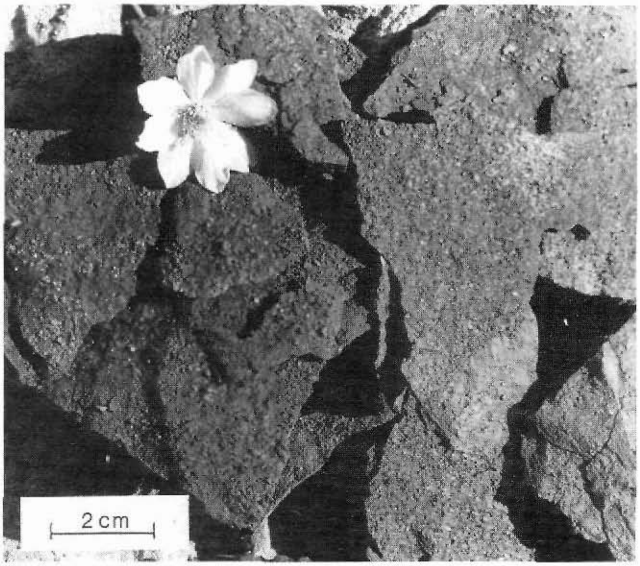


Fig. 3. Sand-streaked shale from the Naujât Member. The bedding planes illustrate a one-grain-thick layer of coarse-grained sand.

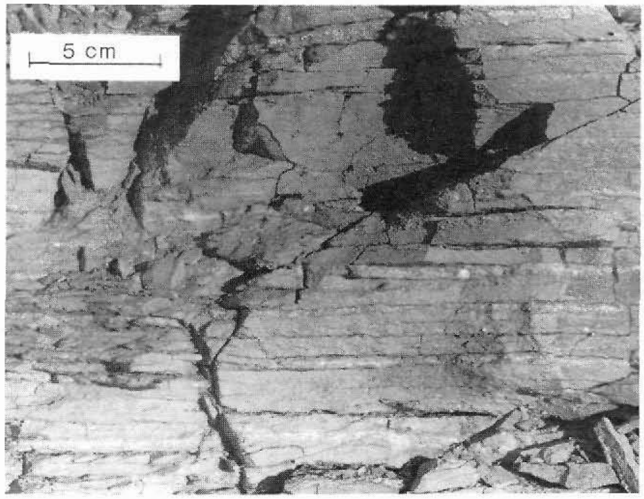
Upper Atanikerdluk Formation (Koch, 1959; Hansen, 1980). The latter is described in great detail by Koch (1959, 1964; Koch & Pedersen, 1960) who erected five members within the Upper Atanikerdluk Formation. The basal Quikavsak Member is fluvial, often conglomeratic and overlies directly the fault-tilted Cretaceous, and is itself overlain by the Naujât Member.

Koch (1959) describes the Naujât Member as a shale sequence, relatively uniform lithologically, with sparse plant fossils at certain levels and intercalated with thin tuff layers. The Naujât Member varies in thickness and interfingers eventually with some of the marine deposits of central and northern Nûgssuaq. It is suggested that the Naujât Member was deposited in swamps or coastal lagoons (Koch, 1959).

Above the Naujât Member lies the sandy Umiussat Member, the dark grey shales of the Aussivik Member, and above these heterolithic sand of the Point 976 Member (Koch, 1959). Koch suggested that this non-marine vertical sequence of conglomerate, shale, sand, shale, and sand is coeval with a Paleocene marine transgression and that the shales (Naujât and Aussivik Members) were deposited during phases of drowning of the delta while the sandy (Umiussat and Point 976) members reflect intermittent phases of progradation of the delta (Koch, 1959, plate 4; redrawn in Henderson *et al.*, 1976, fig. 308). The comparable, generalized N–S section is illustrated by Henderson *et al.* (1976, figs 303, 320) and by Schiener & Leythaeuser (1978, fig. 4).

The Tertiary sediments on north-east Disko are not readily distinguishable from the Cretaceous ones, in contrast to the situation on Nûgssuaq. The 800 m of Cretaceous–Tertiary sediments exposed between Pingo and Nûgârssuk include *c.* 300 m of medium- to coarse-grained sand deposited in sandy braided rivers and referred to the Atane Formation (Johannesen & Nielsen, 1982). The overlying facies association is characterized by medium- to fine-grained sand with horizontal stratification or low-angle cross bedding and with frequent clay drapes. The facies association includes several thin sequences of shale, which form the base

Fig. 4. Section through sand-streaked shale from the Naujât Member. Coarse-grained sand-streaks of varying thickness are seen.



of CU sequences and suggest a flood plain depositional environment. In addition a major shale sequence occurs (figs 2, 5). It is up to 50–60 m thick, and contains numerous layers of tuff which, together with some plant fossils, indicate a Tertiary age of the shale. This might therefore correspond to the Naujât Member on south-east Nûgssuaq. Data on the sedimentary facies support this correlation, and in the following the shale occurring at 400–450 m between Pingo and Nûgârssuk is treated provisionally as Naujât Member. It is noteworthy, however, that the Naujât Member is intercalated in an association of presumed flood plain facies which contains minor shale sequences which are not visibly different from the Naujât Member shale. The latter seems thus to represent an extreme prevalence of a sedimentary environment which otherwise recurred intermittently.

Sedimentary facies in the Naujât Member

Black mudshale. Dark grey to black mudshale with a well developed fissility and grain-sizes within the clay and silt fractions constitute a characteristic facies, especially on Nûgssuaq. The shale is generally weakly laminated on a scale of millimetres. It is subordinate in the section shown in fig. 5. Neither trace fossils nor invertebrate remains have been observed, but well preserved plant fossils are locally fairly common. The leaves belong mainly to the genera *Macclintockia, Cercidiphyllum* and *Metasequoia* (Koch, 1959, 1964). A high content of siderite is found in yellowish-brown continuous layers, 1–5 cm thick, or in rows of small concretions. The former are locally cross-laminated and apparently coarser grained than the surrounding uncemented shale. Neither pyrite nor the pale yellowish green colours characteristic of jarosite have been observed, which is consistent with a non-marine depositional environment.

Grey mudstone. There is a gradational transition between the black, fine-grained mudshale and the grey mudstone facies. The latter has a higher content of silt and is generally less fissile. The lack of lamination may be the result of bioturbation, but distinct trace fossils have not been observed. Plant remains and siderite concretions occur in approximately the

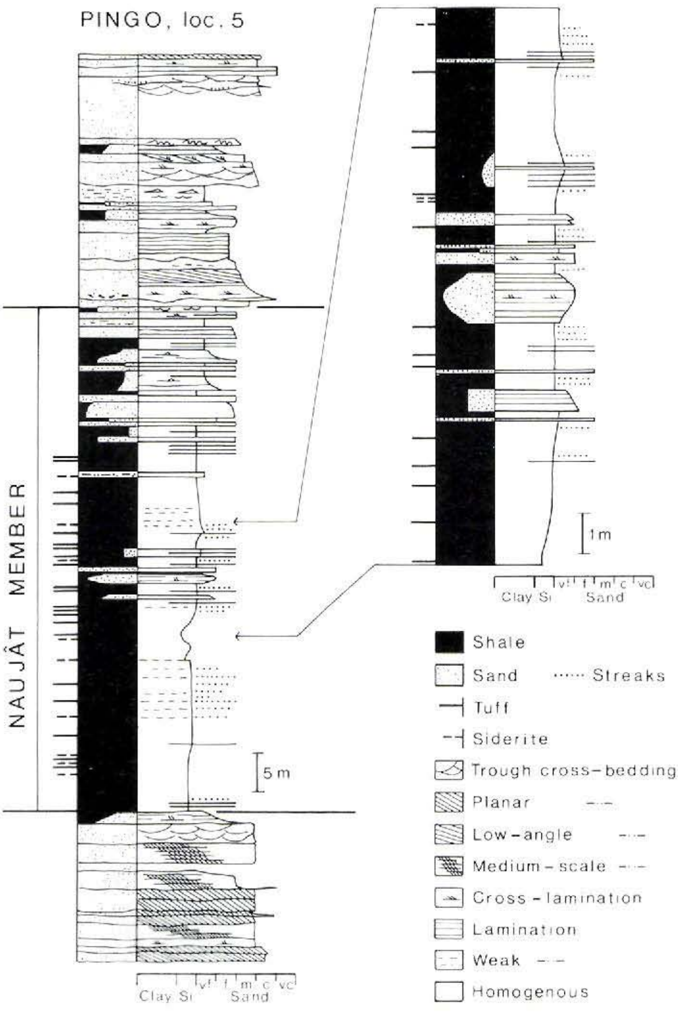


Fig. 5. Sedimentological log through parts of the Naujât Member at Pingo. The section was measured close to the one shown in fig. 6.

same proportions as in the black mudshale, but the paler colour may reflect a lower content of organic matter. The grey mudstone is dominant in the section of the Naujât Member shown in fig. 5.

Sand-streaked shale. This facies is characterized by laminae of coarse- or very coarse-grained sand which are often only one grain thick (figs 3, 4). The individual sand laminae are separated by 3–10 mm of shale. The distribution of sand is patchy, and with gradual transitions, both vertically and laterally, from the one-grain-thick laminae to 0.5 cm thick layers. Two to three centimetre thick layers of sand with erosive bases and internal cross-stratification are rarely seen.

The distribution pattern of the coarse-grained sand awaits detailed investigation, but the field observations suggest that the sand was supplied by episodic currents generated from several sources.

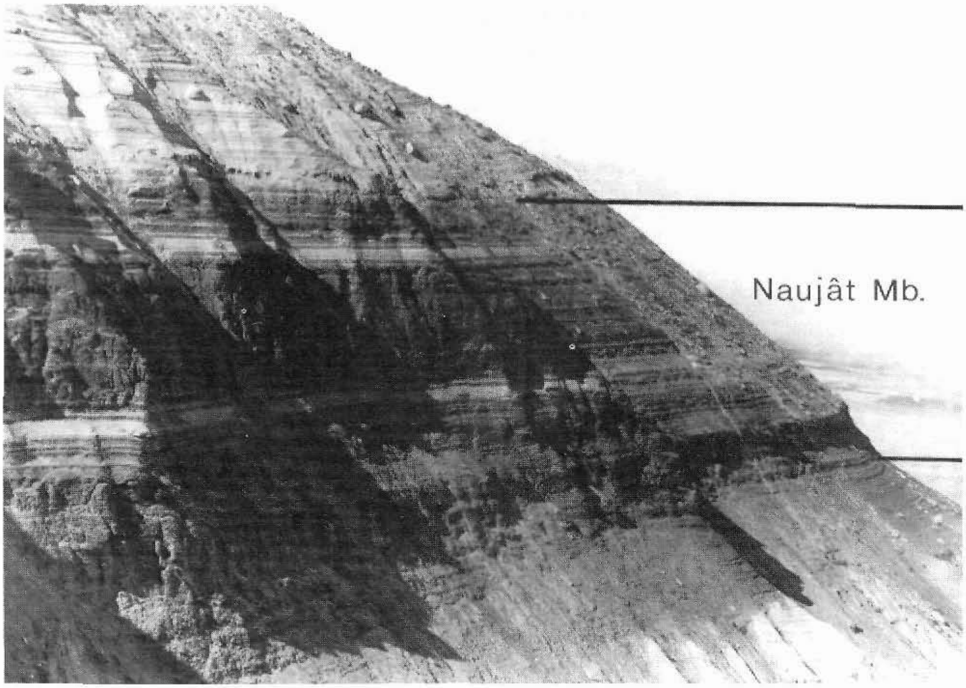


Fig. 6. The blackish Naujât Member at Pingo. Note the uniform thickness and the lateral continuity of the pale sand layers, and the coarsening-upwards trend towards the top of the Naujât Member.

Shale with sand layers. Thin layers of fine-grained sand are intercalated in silty, grey mudstone at two levels in the Naujât Member (figs 5, 6). The sand is loose, relatively rich in comminuted plant debris and mica and occurs as layers which are 1–10 cm thick and laterally continuous. Their bases are not erosive. The thinnest layers are massive, though locally with a slight normal grading, while the thicker layers are parallel laminated and the thickest are cross-laminated. Sand layers thicker than 10 cm are always found to be composite, constituted of several superimposed sand layers.

In the middle of the Naujât Member, at Pingo, the sand layers form symmetrical CU-FU sequences, while a distinct CU trend is seen in the top of the member at all localities (fig. 6). The upwards increasing frequency and increasing thickness of the sand layers reflect a progradation of the source of the sand-sized sediment. The distinct sheet-geometry of the sand layers, their non-erosive bases and their lack of Bouma-sequences could suggest a crevasse splay origin.

Discussion

All three mudrock facies are characterized by mud deposited from suspension. Primary sedimentary structures, such as lamination, are rarely seen and estimates of current-transport, of water depth, or of rate of deposition await further detailed investigation. However, some control is exerted by the geological setting, especially on Disko, where the presumed Naujât Member is sandwiched between associations of lower flood plain facies, suggestive of shallow water depths. The supposed crevasse splay sand layers also indicate a shallow lake – interdistributary bay environment, and the sand-streaked shale facies might well fit into this.

Summary

The sedimentary logs measured during the summer of 1986 support the earlier interpretations of the Naujât Member as a non-marine mudrock deposited in a standing body of fresh water, either a lake or an interdistributary bay (Koch, 1959; Henderson *et al.*, 1976; Schiener & Leythaeuser, 1978). The E–W section on Disko (Pingo to Nûgârssuk) suggests that the shale is thickest, most completely developed and has the highest number of volcanic tuff layers towards the east. The S–N section from Pingo to Atanikerdluk suggests that the mudrocks increase in thickness and decrease in average grain-size as well as in the number of distinct sand layers towards the north. Future field work may be carried out to delineate the fresh water body more clearly, including its shoreline against the fluvial parts of the delta, and its separation from the contemporaneous marine environments.

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Geophysical investigations of the Qaqarssuk Carbonatite Complex, southern West Greenland

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During the summers of 1984 and 1985, geophysical investigations were made in the Qaqarssuk area, situated 65° 23′N, 51° 40′W, in connection with exploration for phosphorus, niobium and lanthanide deposits of potential economic interest. The geophysical field work carried out in the summer of 1984 has previously been briefly discussed (Kjærgaard & Olsen, 1985a). Most of the interpretations have now been completed, some of which are presented below, together with the new results from 1985.

The investigations focussed on three subjects:

(1) Shallow seismic and geoelectric measurements to map the thickness of residual soil (possibly enriched in P and Nb) overlying the carbonatite.

(2) Radiometric measurements to localise pyrochlore-rich (U bearing) and lanthanide-rich carbonatites (Th bearing).

(3) Magnetic investigations, primarily to map the structures in the carbonatite.

A general description of the geology of the complex is given in Knudsen (1985) and Knudsen (1986). A geological sketch map is shown in fig. 1.

Shallow seismic and geoelectric investigations of the overburden

The interpretation of the seismic lines (Kjærgaard & Olsen, 1985a, b) was made by computer, and the plus–minus method of interpreting seismic sections was used where possible. The DC geoelectric sounding curves were interpreted by an iterative computer programme at the Laboratory of Geophysics, Aarhus.

In most places the interpretation of the seismic and geoelectric measurements gives consist-