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New observations of marine trace fossils in delta plain sequences, southern Nûgssuaq, West Greenland

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During the 1988 field season new observations were made on the sediments of the Upper Cretaceous Atane Formation in southern Nûgssuaq. These observations indicate that the degree of bioturbation may be taken as an indicator of the degree of marine influence within the interdistributary delta plain environments. The field work was carried out during six days in July 1988 as part of a sedimentological research project supported by GGU and the Danish Natural Science Research Council.

Background

Impressive sections of Cretaceous deltaic deposits are exposed along the southern coast of Nûgssuaq and in the Auvfarssuaq valley (fig. 1). The Cretaceous deposits

Fig. 1. Location map, showing the distribution of the Cretaceous sediments in Nûgssuaq and Disko and the localities mentioned in the text. P: Pautût, N: Nûk kitdleq, A: Auvfarssuaq, Al: Alianaitsúnguaq.

of Disko and southern Nûgssuaq were all encompassed in the Atane Formation by Henderson *et al.* (1976, 1981) and have recently been reviewed by Pulvertaft (1987). The sedimentary sequences are characterized by interbedded shale, slightly consolidated sandstone and thin coal seams which in south-western Nûgssuaq make coarsening-upward sequences that have been interpreted as delta plain deposits (Schiener, 1975; Surlyk, 1982). Kleinspehn *et al.* (1984) demonstrated elegantly how a variety of sedimentary sequences showing a coarsening-upwards trend may result from delta front progradation reflecting the differences in the physical processes and depositional environments of the delta front. Fossil invertebrates are very rarely found and their scarcity has been interpreted as an indication of non-marine depositional environments (Rosenkrantz & Pulvertaft, 1969). Trace fossils are more common but few beds are totally bioturbated. Fürsich & Bromley (1985) described *Dactyloidites ottoi* from specimens collected near Qilakitsoq in the Auvfarssuaq valley by Rosenkrantz in 1952. Sedimentological data on the sequence containing *D. ottoi* sampled by Rosenkrantz are supplied below together with observations on other trace fossils present there and at Nûk kitdleq. The latter is a coastal cliff about 10 km east of Alianaitsúnguaq, where ammonites of Coniacian age have been found (Birkelund, 1965).

The association of sedimentary facies

Cretaceous sediments are excellently exposed in several gorges between Ilugigsoq and Qilakitsoq on the north slope of Auvfarssuaq. The sections are characterized by vertical stacking of coarsening-upward sequences that typically range from 5 to 20 m in thickness, and thus the gross depositional pattern is comparable to the sedimentary sequence at Pautût (Midtgaard & Olsen, 1989). The individual coarsening-upwards sequences comprise a basal shale facies, apparently devoid of trace fossils, interbedded with fine-grained sand occurring in laterally continuous beds characterized by cross-lamination. Evidence of wave-generated cross-lamination is found locally, but rippled surfaces are rarely exposed owing to the low degree of lithification. The wave-reworked beds of sand increase upwards in both thickness and frequency and contain rare burrows. *D. ottoi* occurs characteristically in low densities in this facies (figs 2 and 3). Some of the coarsening-upwards sequences are terminated by 20 to 200 cm of medium- to coarse-grained sand containing abundant trace fossils (*Planolites, Ophiomorpha* and others) (figs 2 and 3). However, several of the coarsening-upwards sequences are capped by sheets of large-scale, cross-bedded sand without burrows. The sheets of sand formed through migration of fluvial channels. Thin coal seams on top of some of the channels indicate the formation of subaerial, though wet, areas of dense vegetation protected from influx of clastic material.

The sequence at Nûk kitdleq deviates from the above description in the lack of coal seams, in the mottling of some fine-grained heteroliths and in the fainter development of the autocyclic pattern of coarsening-upwards sequences (fig. 2).

The stacking of coarsening-upwards sequences was noted by Hansen (1976) who interpreted them as interdistributary bay sequences in agreement with the model of Elliott (1974). According to this model the coarsening-upwards sequences at Auvfarssuaq may exemplify overbank flooding succeeded by mouth bar progradation. The mouth bar deposits were partly wave reworked and the sequences terminated by deposition of sand within fluvial channels.

Trace fossils

Seven ichnogenera were recognized in the trace fossil assemblages at Qilakitsoq and Nûk kitdleq. They may be referred to the *Cruziana* and *Skolithos* ichnofacies of Ekdale *et al.* (1984).

Chondrites, Planolites and *Teichichnus* represent the activities of an assemblage of deposit feeders showing a

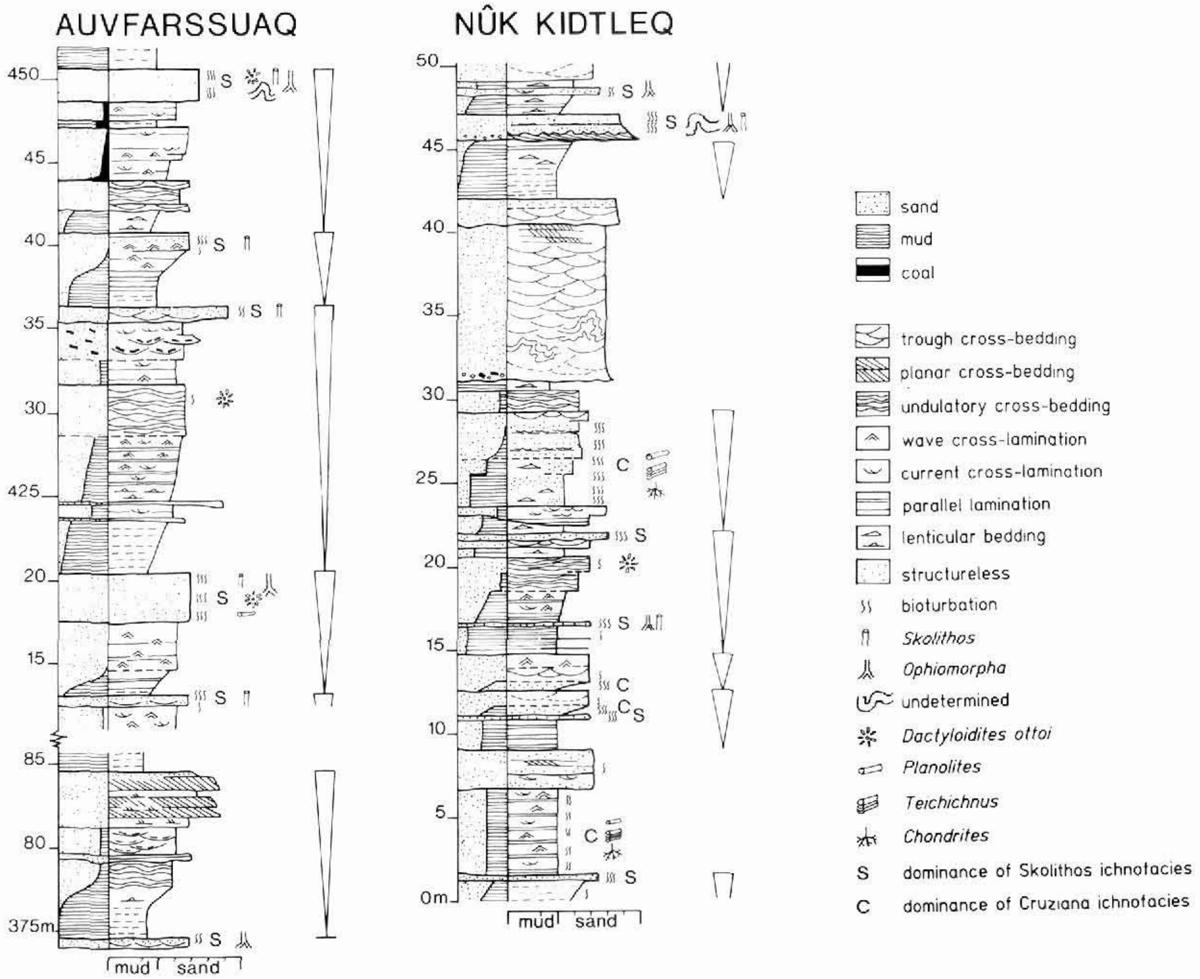

Fig. 2. Sedimentary log showing the characteristic coarsening-upwards sequences and the distribution of trace fossils at Auvfarssuaq and Nûk kitdleq. Note that the trace fossils at Auvfarssuaq are restricted to few horizons and that the degree of burrowing generally is higher at Nûk kitdleq. The *Cruziana* ichnofacies is only recognized at Nûk kitdleq.

diverse behavioural spectrum resulting in structures referrable to dwelling, feeding, escape etc.; they belong to the *Cruziana* ichnofacies (Ekdale *et al.*, 1984). The *Cruziana* ichnofacies is typical of shallow marine environments usually above wave-base. A high diversity of trace fossils is a result of abundant food supplies in both suspended and deposited form and of environmental conditions ranging from medium to low energy levels (Ekdale *et al.*, 1984). The *Cruziana* ichnofacies is represented by mottled heterolithic fine-grained sediments (fig. 3b). Fig. 2 shows that the *Cruziana* ichnofacies is restricted to Nûk kitdleq whereas comparable heteroliths farther to the east and south at Pautût and Auvfarssuaq lack the *Cruziana* ichnofacies.

Dactyloidites ottoi is a rosette-shaped endogenic trace fossil comprising a central tube and branching incomplete radial protrusive spreiten (Fürsich & Bromley, 1985). These authors interpreted the trace fossil as produced by a worm-like organism that systematically reworked the sediment in seach of food. The similar length of each radial burrow within a rosette suggests that part of the organism occupied a fixed position within the central shaft from which it probed the sediment repeatedly (Fürsich & Bromley, 1985). *D. ottoi* was also observed by Ehman *et al.* (1976).

D. ottoi occurs characteristically in fine- to medium-grained sand showing undulatory and intricately interwoven low-angle cross-bedding. The sedimentary structures are enhanced by thin drapes of comminuted plant debris on most foreset laminae. The cross-bedding is interpreted as wave generated, owing to similarity to the lithofacies M2 and S1 in figs 10 and 13 of Raaf *et al.* (1977). This sedimentary facies occurs characteristically towards the top of the coarsening-upwards sequences

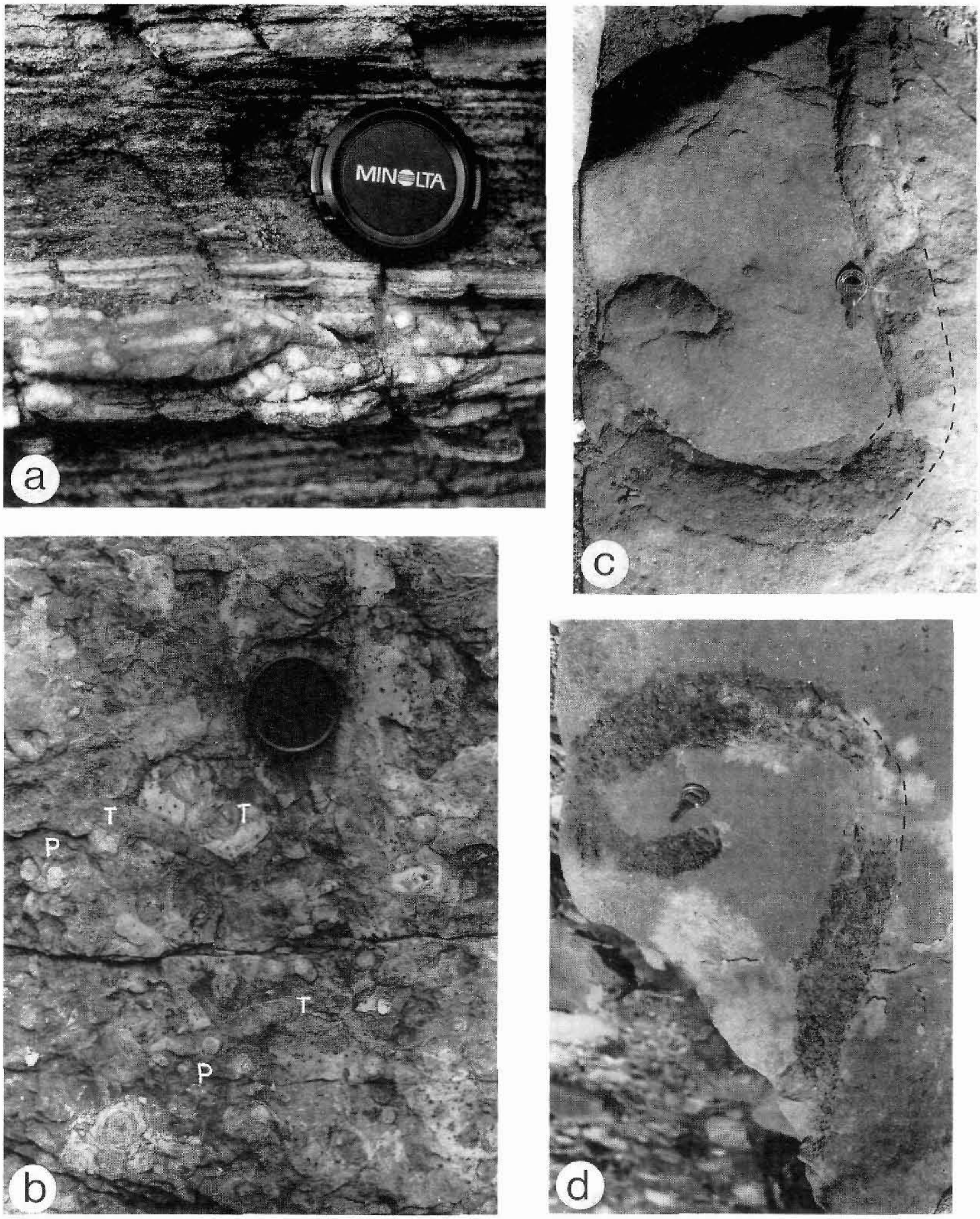

Fig. 3. a. Vertical section of *D. ottoi* in the coarsening-upwards sequence in Auvfarssuaq. b. Bioturbation of the fine-grained heteroliths at Nûk kitdleq showing the *Cruziana* ichnofacies with *Planolites* (P) and *Teichichnus* (T). Key (3 cm) and lens cap (5 cm) for scale. c & d. Sinuous trace fossil with a large single shaft and a knobbly wall structure. The burrow is included in the *Skolithos* ichnofacies but not referred to any known ichnogenus. Loose block from Auvfarssuaq.

and may represent the wave-reworked front of a mouth bar. Owing to its inferred ecology as the work of a deposit feeder, *D. ottoi* is referred to the *Cruziana* ichnofacies. Fig. 2 shows, however, that *D. ottoi* is more characteristic of higher energy environments than the other ichnogenera of the *Cruziana* ichnofacies.

Skolithos and *Ophiomorpha* exemplify infaunal suspension feeders. Their burrows tend to be long, vertical dwelling structures and they are characteristic members of the *Skolithos* ichnofacies (Ekdale *et al.*, 1984). The *Skolithos* ichnofacies occurs in coastal environments characterized by shallow water depth and relatively high energy settings with shifting sandy substrates. These conditions favour abundant domichnia as well as preservation of primary sedimentary structures. Fig. 2 shows that the *Skolithos* ichnofacies mostly occurs at the top of the coarsening-upward sequence where relatively high energy settings are indicated by medium- to coarse-grained sand.

The *Skolithos* ichnofacies contains a trace fossil that cannot at present be referred to an ichnogenus owing to the lack of complete burrows. The trace fossil is seen as single sinuous shafts or tunnels with a knobbly wall structure, a diameter of 2–6 cm and lengths of 10–40 cm. Recent burrows of comparable size are known to be generated in the Bahamas by ghost crabs (Curran & White, 1987). The occurrence of this burrow is indicated on the logs (fig. 2).

Discussion

It is noteworthy that the number of trace fossils tends to increase upwards through each coarsening-upwards sequence and that the traces generally are domichnial burrows indicating suspension feeding behaviour. The *Skolithos* ichnofacies, which is frequently observed in shallow marine environments, recurs at the top of many coarsening-upwards sequences.

The basal shale apparently offered unfavourable conditions for organisms, probably either due to low salinities or to anoxic conditions stemming from the surplus of comminuted plant debris. The existence of a salinity gradient is indicated by the occurrence of the *Cruziana* ichnofacies only at Nûk kitdleq, which is the westernmost of the localities studied and the one closest to the areas of marine Cretaceous deposits (Rosenkrantz & Pulvertaft, 1969; Surlyk, 1982). Most of the shales are therefore interpreted as accumulations of mud carried in suspension and deposited in the non-marine parts of interdistributary bays, and the *Cruziana* ichnofacies at Nûk kitdleq indicates a marine influence in the outer parts of the interdistributary bays.

The overlying heterolithic sequence of mud alternating with thin beds of cross-laminated fine-grained sand is interpreted as a result of mouth bar progradation. The upwards increasing importance of wave-generated sedimentary structures indicates an increasing degree of reworking of the mouth bar by basinal processes. The accompanying increase in bioturbation indicates a gradual improvement in living conditions. The occurrence of *D. ottoi* in this relatively stable energy environment agrees with its inferred behavioural pattern of systematic exploitation of sediment from a fixed position (Fürsich & Bromley, 1985).

The coarsening-upwards sequences are frequently completed by large-scale, cross-bedded, medium- to coarse-grained sand interpreted as having been deposited within fluvial channels. The top of this facies is often developed as relatively thin beds of bioturbated coarse-grained sand. The increase in grain-size reflects reworking and winnowing of the fluvial sand within the upper shoreface and the resultant shifting sandy substrate supported a marine infauna which produced the *Skolithos* ichnofacies.

In conclusion, the organic-rich shales generally constituted unfavourable habitats while the mouth bar fronts were colonized by a probably marine fauna characteristic of the *Skolithos* ichnofacies. In the present study the degree of bioturbation may thus be taken as an indicator of the degree of marine influence within the interdistributary delta plain environments.

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Discovery of andesite tuffs with graphite from the Vaigat Formation of south central Nûgssuaq: stratigraphical implications

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During helicopter reconnaissance in 1987, one of us (F. U.-M.) found patches of poorly exposed tuffaceous rocks within the Vaigat Formation on the west side of Ilugigsoq valley north of Auvfarssuaq (fig. 1). Subsequent investigation under the microscope revealed that the tuff consists of graphite-rich andesite very similar to the most abundant tuff type described from the Abraham Member of the Agatdal Formation by Pedersen (1978). The discovery of the new locality with this rare rock type led to a helicopter-based reconnaissance in the Ilugigsoq and Qilakitsoq valleys in the summer of 1988 by two of us (A. K. P. & L. M. L.) in order to trace this possible marker horizon and put it into a stratigraphical context. Similar tuffs were found at two localities described below. Graphite andesites are known from other localities on Nûgssuaq and Disko, and notes on these are also given below.

North-west side of Ilugigsoq

On the mountain side about 1 km south-east of a 1613 m high peak (fig. 2) a layer of conspicuous grey tuffaceous sediment occurs within a sequence of subaerial picrite lava flows from the Vaigat Formation. The layer crops out intermittently over a distance of several kilometres along the northern west side of the Ilugigsoq valley. Fig. 3 shows a preliminary section through the Vaigat Formation in this area. Here the Vaigat Formation below the sediments consists of, in ascending order, a more than 140 m thick lower hyaloclastite horizon, *c.* 45 m of subaerial picrite lavas, a *c.* 25 m thick upper hyaloclastite horizon, and *c.* 30 m of subaerial picrite lavas on which the sediment horizon is situated. The sediment horizon is about 35 m thick, and its grey colour is due to disseminated graphite. The sediment consists of a large number of horizontal beds of redeposited tuffs with varying clast sizes and very variable degrees of sorting. The maximun clast size is about 2 cm. A particularly erosion-resistant set of beds (fig. 4) occur in the interval 15–20 m above the base of the sediment, and these crop out to form a graphite grey bench on the mountain slope. This bench is quite characteristic when seen from a distance. In the poorly exposed upper few metres of the sediments there are