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EOLIAN "SANDY LIGNITE" AND ASSOCIATED SEDIMENTS FROM THE MIOCENE OF THE LOWER RHINE BASIN' WESTERN GERMANY

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ABSTRACT

Eolian flats are often encountered along modern shorelines in association with wash-over fans, storm inlets and swamps. A possible ancient analogy to this environmental situation has been confronted in the Miocene sediments in the Garsdorf Quarry, Western Germany. These sediments consist of several facies associations, the uppermost of which is notable due to the occurrence of sandy lignite. The sandy lignite displays several sedimentary structures of presumably colian origin and is interpreted as an eolian sediment formed during humid conditions on eolian flats. Deposits associated with the sandy lignite include stratified channel-sand, most probably representing storm inlets filled by eolian and ephemeral stream deposits, sheets of faintly laminated sand of wash-over fan origin, and lignite formed in coastal swamps.

INTRODUCTION

The deposits described in this paper are exposed in the Garsdorf Quarry of the Rheinische Braunkohlenwerke A.G., which is situated in the southern part of the Lower Rhine Basin near Cologne, Western Germany (fig. 1). The author's investigations were made during a series of visits to the quarry in 1972 and 1973.

The sediments in question, which are mainly dark-coloured sands, are thought to be of Lower Miocene age; they belong to the upper portion of the "Kölner Schichten" described by G l i e s e (1972/1973). The depositional environment of the "Kölner Schichten" has been discussed in several papers (see e.g. G l i e s e, 1972/1973), and the sediments are now generally agreed to represent a transition from marine to continental environments. On top of the "Kölner Schichten" lies the "Hauptflöz", a several tens of metres thick lignite seam, which is commercially exploited. Between the dark-coloured sands and the lignite seam there is a transitional facies – the sandy lignite. This remarkable facies, which is a mixture of sand and lignite detritus, has been investigated in detail and will be interpreted here on the basis of a study of the characteristic sedimentary structures of the sediment. The sandy lignite facies will be discussed in its broader environmental context.

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SEDIMENTARY FACIES AND ENVIRONMENTAL SETTING

G l i e s e (1972/1973) divided the upper portion of the "Kölner Schichten" in the Garsdorf Quarry into four main facies and interpreted the sediments as shallow marine and lagoonal deposits.

As a result of the present author's fieldwork twelve sedimentary facies are distinguished ranging from subtidal shallow marine to supratidal eolian and wash-over fan deposits (C l e m m e n s e n, 1974); the sedimentary facies can be grouped together into three facies associations (in the sense of C o l l i n s o n, 1969). The total thickness of the studied sediments is approximately 30 m (fig. 2).

The first facies encountered in Facies Association I (fig. 2) is light-coloured fine-grained sand with *Ophiomorpha*. The sediment generally lacks physical sedimentary structures, but occasionally displays low-angle cross-bedding or horizontal lamination. This sediment is abruptly overlain by dark-coloured medium-grained planar and trough cross-bedded sand, which gradually gives way to a sequence of dark-coloured fine to medium-grained sand dominated by horizontal lamination. Close inspection made it possible to divide the latter interval into three sub-facies, each characterized by one or more sedimentary structures (fig. 2). The facies lying immediately above the cross-bedded sand displays horizontal parallel lamination; then follows a facies with horizontal discontinuous lamination and a few cross-bedded sets, which again is overlain by a facies with faintly horizontally laminated sand.

Facies Association II is dominated by dark-coloured fine to medium-grained cross-bedded and horizontally laminated sand with numerous *Ophiomorpha*. In some horizons the burrow density is so high that the bedding can no longer be discerned. This facies association is just like the former one topped by an approximately 2 m thick lignite seam.

The uppermost Facies Association III varies considerably in thickness (figs. 2 & 3) and is characterized by the occurrence of sandy lignite often in association with cross-bedded channel-sand and structureless to faintly laminated sheet sand (fig. 3). The sandy lignite may reach a thickness of approximately 4.5 m.

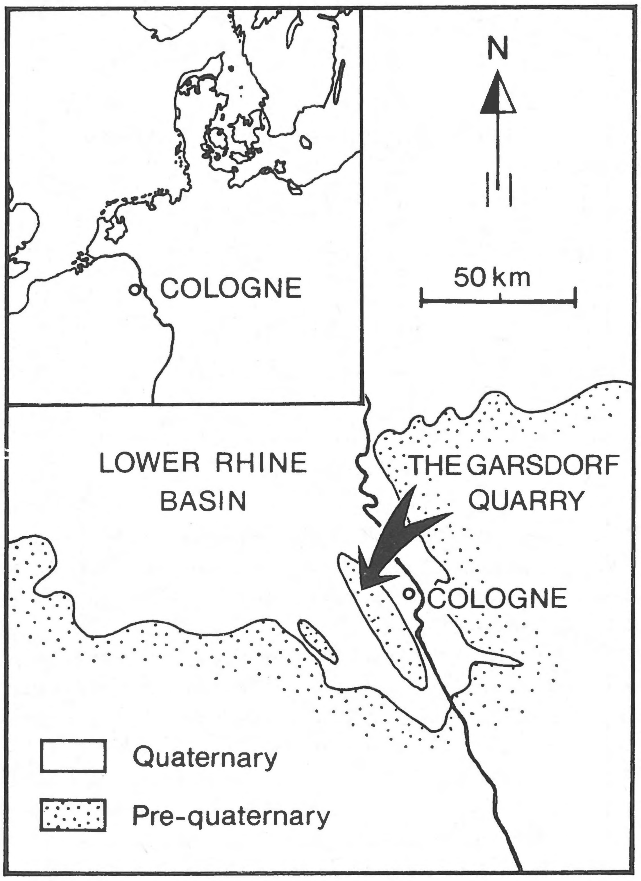


Fig. 1
Location map of the investigated area. The Garsdorf Quarry is situated on a NW-SE running horst in the southern part of the Lower Rhine Basin.

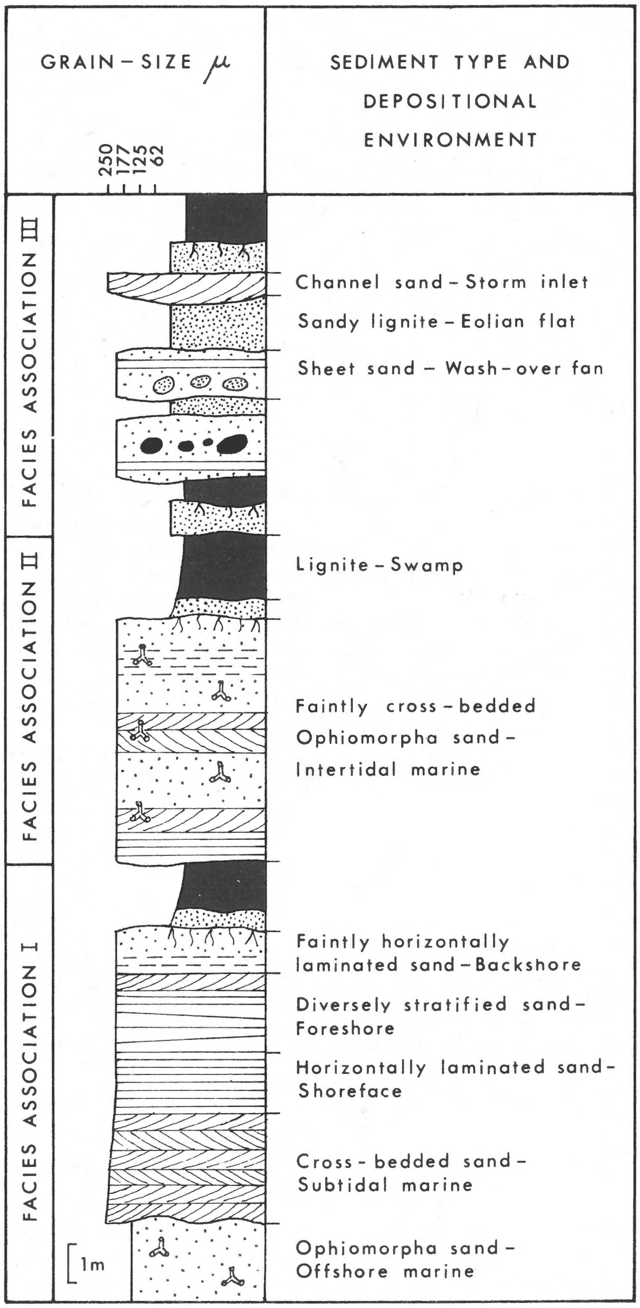


Fig. 2
Typical graphic log of the exposed sequence in the Garsdorf Quarry. The small "grain-size" of the sandy lignite is due to the considerable content of organic matter.

Sandy lignite also appears in small quantities in the two lowermost facies associations, where it forms thin transitional horizons between the dark-coloured sands and the pure lignite seams.

As an outcome of the investigation of the Miocene sediments in the Garsdorf Quarry a tentative sedimentological model has been established depicting the environments of deposition (fig. 4). The model is a compilation of the data from the measured sections (figs. 2 & 3). Each facies association is interpreted as a regressive linear clastic shoreline (S e l l e y, 1970). This interpretation is based on the study of the sedimentary structures characterizing each facies enclosed In the facies associations (figs. 2 & 3) and the comparison of the established facies associations with data from modern coastal environments (H o w a r d & R e i n e c k, 1972; R e i n e c k & S i n g h, 1973). Accordingly the model portrays a prograding Miocene shoreline where coastal swamps occurred immediately behind dunes and eolian flats. Directional measurements undertaken in the dark-coloured cross-bedded sand (G l i e s e, 1972/1973; C l e m m e n s e n, 1974) gave a bimodal NE-SW current pattern. The sheet-like geometry of this facies seems to preclude a tidal inlet genesis and accepting a longshore current genesis for the cross-bedded snad it is suggested that the shoreline in the Garsdorf area ran NE-SW with the open sea towards the north-west.

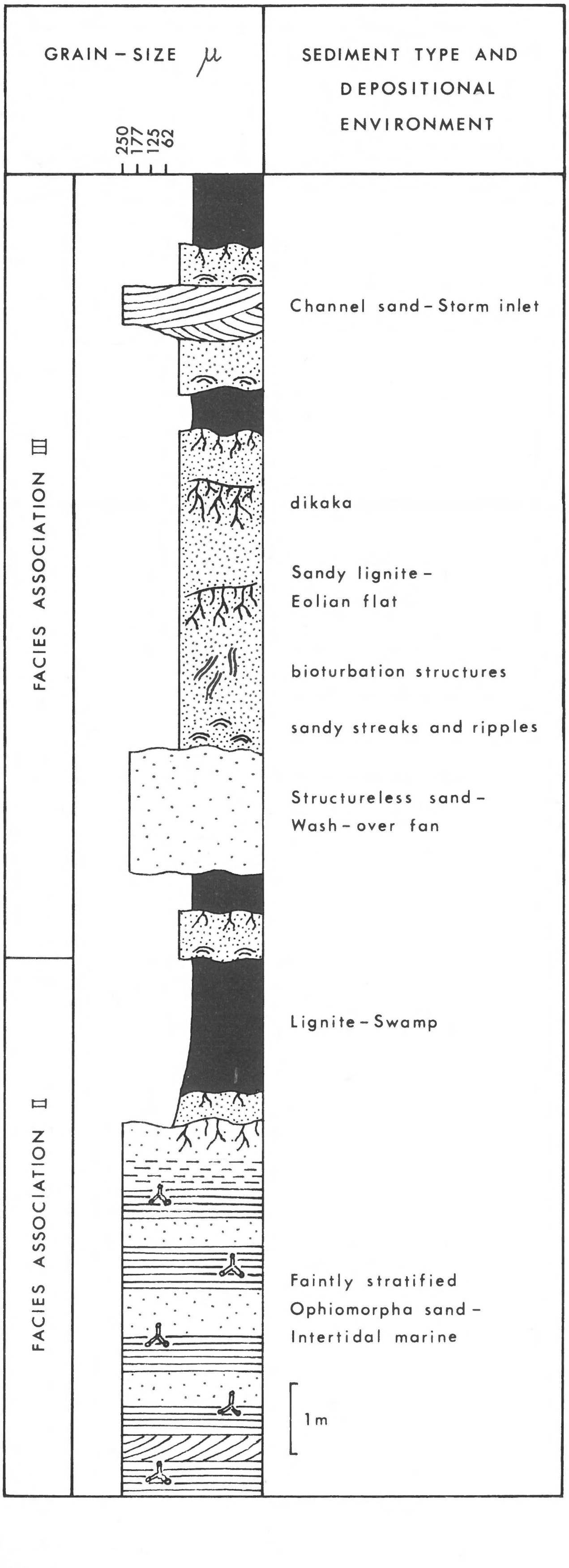


Fig. 3
Graphic log of the sandy lignite and associated sediments, Garsdorf Quarry.

The generally strongly bioturbated sand with *Ophiomorpha* was most likely deposited below mean wave base in the offshore region. Longshore currents presumably of tidal or combined tidal and wave-induced origin built up shoals along the coast. The "shoal" sand displays vectorial bidmodality of the cross-bedding, which according to d e R a a f & B o e r s m a (1971) is diagnostic for sediments deposited under tidal influence. Inside the shoals waves were mainly responsible for the formation of a gently seawards sloping backshore, foreshore, and shoreface. The backshore is represented by faintly horizontally laminated sand, the foreshore by horizontally discontinuous laminated sand, and the shoreface by horizontally parallel laminated sand. On top of the backshore cross-bedded sand probably representing eolian dunes is sometimes to be found, which gives the impression that a low dune ridge originally flanked the beach deposits on their landward side. Behind the dunes there was a zone with eolian flats and storm inlets. These environments finally merged into the coastal swamps.

Here we are mainly concerned with the sandy lignite and associated sediments (Facies Association III of figs. 2 & 3). The sandy lignite possesses an assemblage of sedimentary structures which hitherto has not been described from this or similar ancient sedimentary rocks.

Among the associated sediments channel-sand of complex origin is the most noteworthy.

THE SANDY LIGNITE

Description

The facies constitutes a mixture of quartz sand and lignite detritus and possesses a typical light brownish colour easily recognized in the field. The sand: lignite-detritus ratio of the sediment varies considerably though generally quartz sand dominates. Grain-size analyses of the quartz sand have shown that the sand is fine-grained and very well sorted (fig. 5). The lignite detritus, which constitutes up to 40 weight percent of the sediment (G l i e s e, 1972/1973), is generally very fine-grained and crumbly. Recognizable plant remains, mostly small rootlets but occasionally also big tree trunks in the original position of growth, are often enclosed in the sandy lignite.

The sandy lignite is "structureless", mottled or cross-laminated. The "structureless" sandy lignite consists of an apparently homogeneous mixture of sand and lignite detritus. Close inspection of the sediment, however, discloses that the sand grains are often concentrated in very small pockets (a few mm in diameter) giving the sediment a knobbly irregular appearance on weathered surfaces.

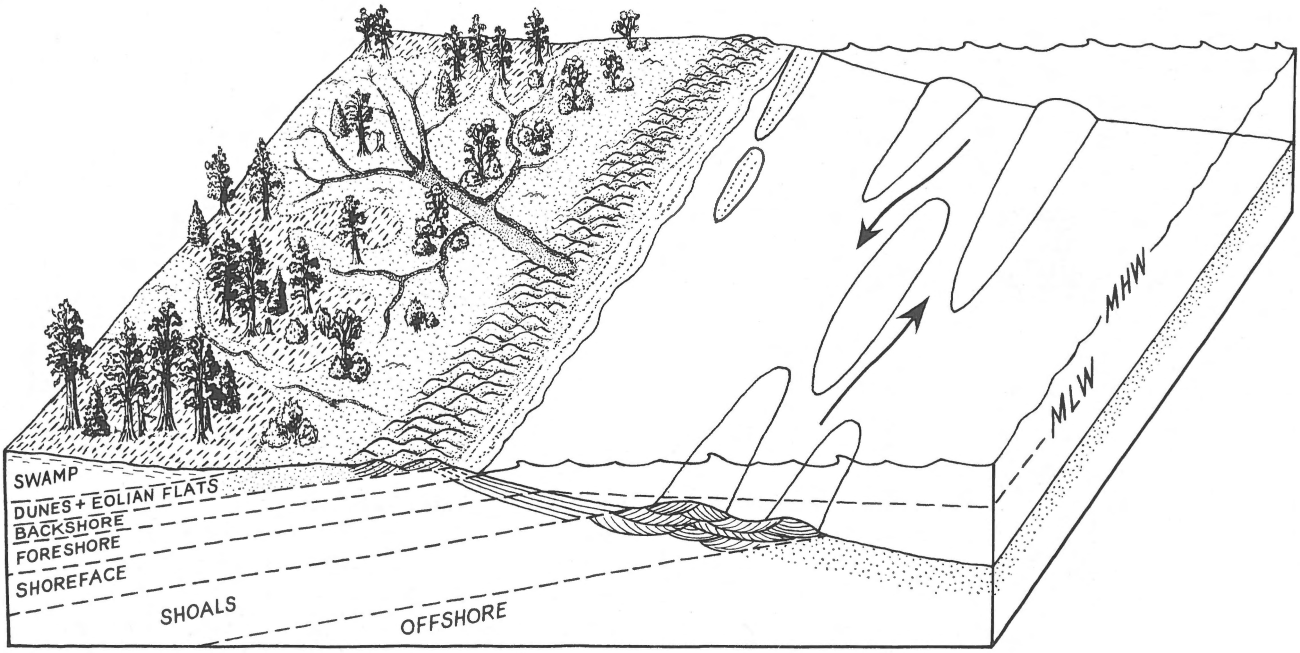


Fig. 4
Palaeogeographical reconstruction of environments of deposition of the upper portion of the "Kölner Schichten" in the Garsdorf area, Lower Rhine Basin. The wash-over fans deposited around the distal parts of the storm inlets have been given the same sign as the eolian flats. The bedding is not drawn to scale.

The mottling of the sediment is of two different types. One is due to faint burrow features (fig. 6). The burrows are unbranched shafts with a vertical orientation. The walls are lined with a thin coating of lignitic material. The other type of mottling is due to branched interlaced pattern of small ridges that are etched out by weathering on exposed surfaces (fig. 7).

The most remarkable feature of the sandy lignite is the presence of sandy patches or streaks and small-scale cross-lamination, the latter often with the original ripple-form preserved (fig. 8). In a few cases foreset laminae with dips up to 40 degrees are encountered (fig. 9), otherwise the laminae have only moderate dip. The sandy patches are a few centimetres long and several milimetres thick and have a weakly undulatory appearance.

The various subfacies of sandy lignite, each characterized by a definite structure type, displays often a characteristic sequential pattern. Just above the contact to the underlying sand, which often contains thin rootlets, sandy lignite with well-defined sand ripples appear. The sandy lignite with ripples gradually gives way to sandy lignite characterized by sandy patches (fig. 8), which again is overlain by knobbly "structureless' sandy lignite. In the last-mentioned sediment type several horizons of the above described mottled sandy lignite occur.

The sandy lignite occurs in sheets of variable thickness, and as fill in many of the channels encountered in the upper facies association. The thickness of the individual sandy lignite sheets increases considerably in a southeastern direction. The section represented in fig. 3 illustrates a situation met in the southeastern part of the Garsdorf Quarry, whereas the section in fig. 2 was measured approximately 300 m towards the north.

Interpretation

Recent peat deposits often contain minor quantities of eolian sand. It is suggested that the sandy lignite in the Garsdorf Quarry has been formed in a similar way, by mixing of peat or peat detritus and eolian sand. This interpretation of the genesis of the sandy lignite is supported by the presence of various sedimentary structures of presumably eolian origin.

The knobbly "structureless" sandy lignite with a concentration of the sand in small pockets has a striking resemblance to the adhesion warts of Reineck (1955) and of Reineck & Singh (1973). The wart-like accumulations are generated when sand is blown over a moist surface, where much of the sand adheres to the thin water films on the surface. Many of the sandy patches could easily be antiripplets (van Straaten, 1953), also named adhesion ripples (Glennie, 1970) or eolian microridges (Hunter, 1969), and likewise indicate eolian activity on a smooth surface. Whereas the adhesion ripples are formed during rather constant wind conditions and are built up at right angles to the prevailing wind direction, the adhesion warts are the

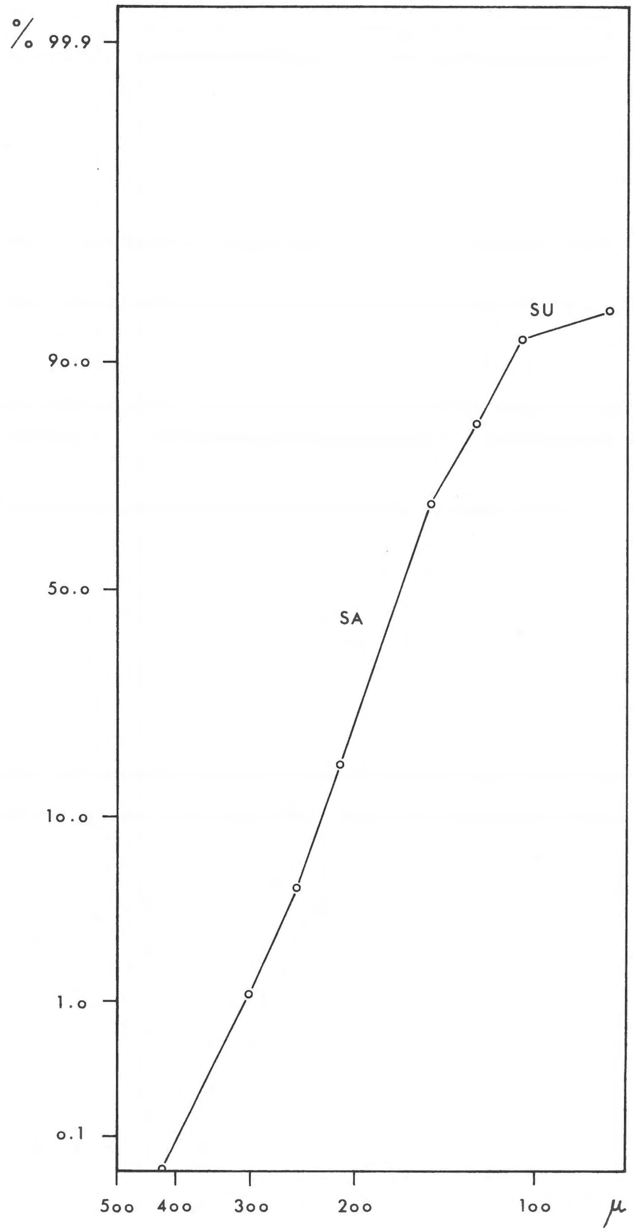


Fig. 5
A grain-size analysis of the sandy lignite (sand fraction only) plotted on log-probability paper. Note the large and excellently sorted saltation population (SA) and the small and less well sorted suspension population (SU).

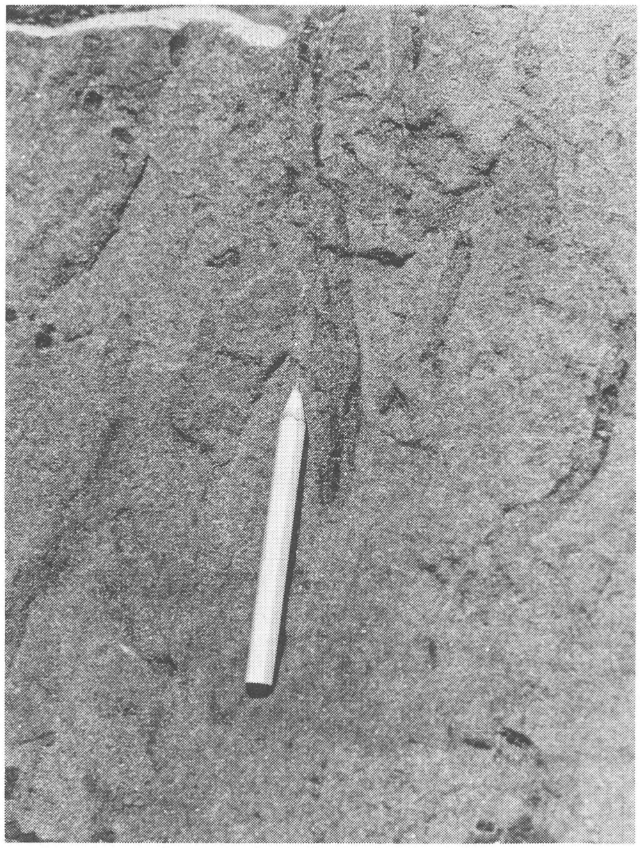


Fig. 6
Sandy lignite displaying bioturbation structures. The burrows possess a thin lining of lignitic material along the walls, which makes them visible in the field.

result of rapidly changing wind directions (R e i n e c k & S i n g h, 1973).

The small-scale ripples and associated cross-lamination are interpreted as eolian. However, a concentration of larger sand grains is to be expected along the crests of eolian sand ripples (S h a r p, 1963). In the present case this could not be observed, and this is perhaps due to the extreme uniformity of the grainsize. The very steep foresets recorded from a few cross-laminated beds suggest eolian activity, and especially in humid environments as pointed out by, for example, B i g a - r e l l a (1972), who explained the unusual high angles of repose as due to a high moisture content during deposition of the sand.

The small burrows found in some horizons could perhaps be ascribed to the activity of small crabs. Rather similar burrows are made by the Recent fiddler crab, *Uca pugilator*, on Sapelo Island, U.S.A., where they are common in the sandier parts of the saltmarsh (F r e y & M a y o u, 1971).

The other type of the mottling in the sandy lignite (fig. 7) is thought to represent moulds after rootlets and is thus a fossil example of dikaka, regarded by G l e n n i e (1970) and G l e n n i e & E v a m y (1968) as indicative of very humid eolian environments with a stablishing plant cover.

The sequential pattern observed in the sandy lignite is interpreted to denote a gradual increase in humidity during deposition of the sediment.

On the basis of the above considerations it seems justified to interpret the sandy lignite as formed in a humid supratidal

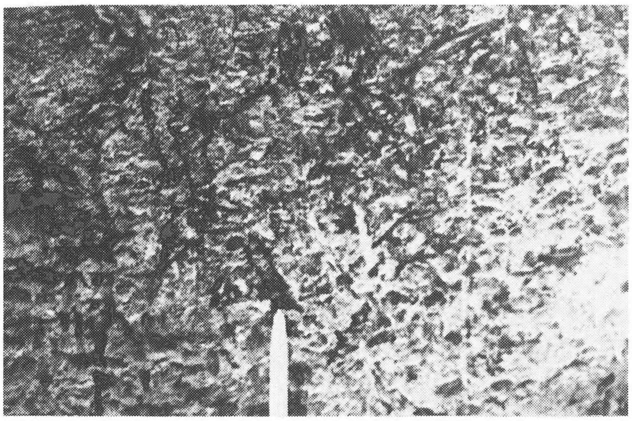


Fig. 7
Sandy lignite with moulds after rootlets (dikaka).

environment characterized by eolian activity and plant growth.

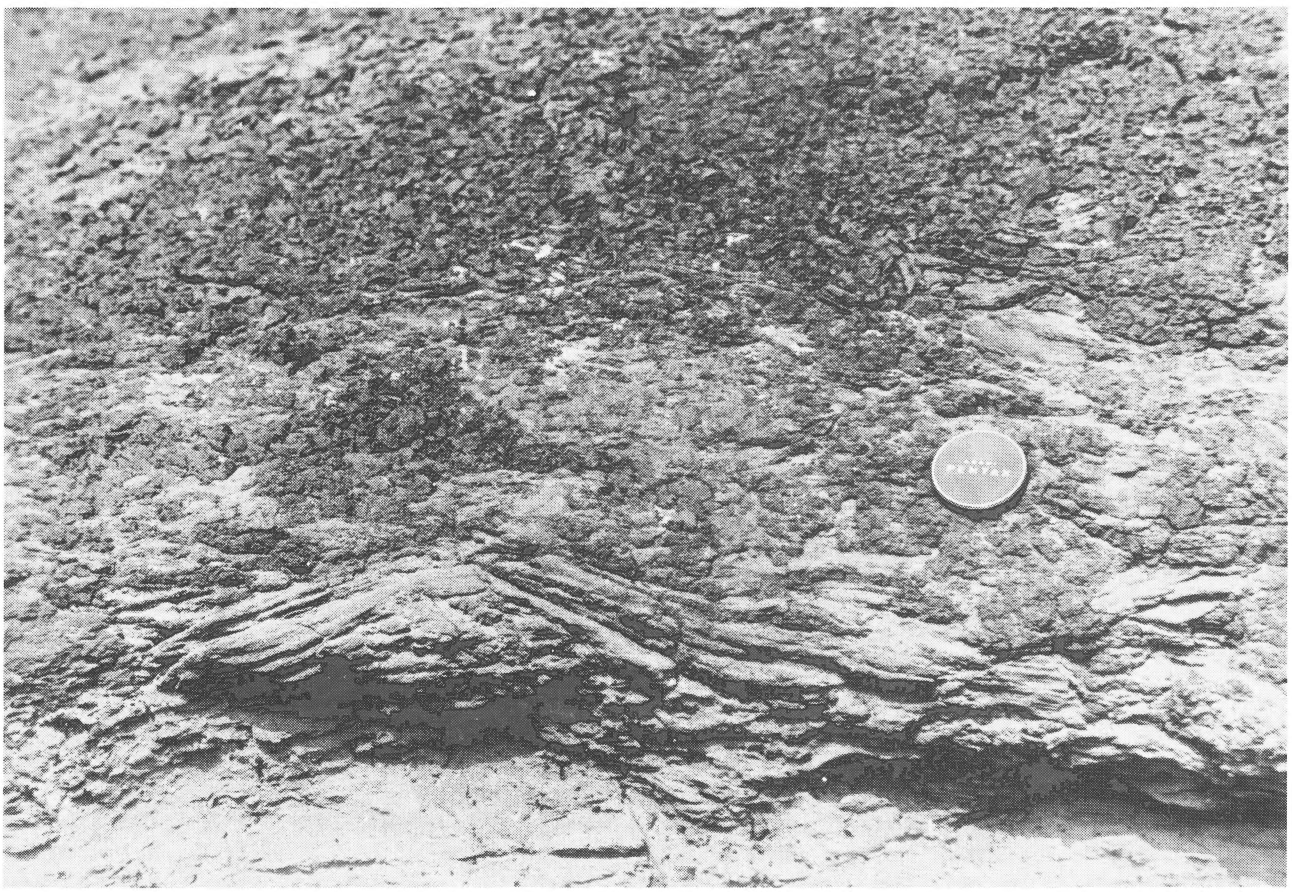
The eolian origin of the sand fraction of the sediment is also supported by the grain-size analysis, which gave a log-probability curve (fig. 5) very similar to the curves for dune sand published by V i s c h e r (1969).

ASSOCIATED SEDIMENTS

Description

The sandy lignite is overlain by and intercalated with darker brown lignite and displays a gradual and irregular contact with this sediment (figs. 2 & 3). The content of sand in the sandy lignite typically decreases near the contact to a lignite seam.

Fig. 8
Ripple formset and sandy patches in the lower portion of a sandy lignite horizon which overlies structureless greyish sand. Note the arrangement of ripple laminae in foresets and topsets.



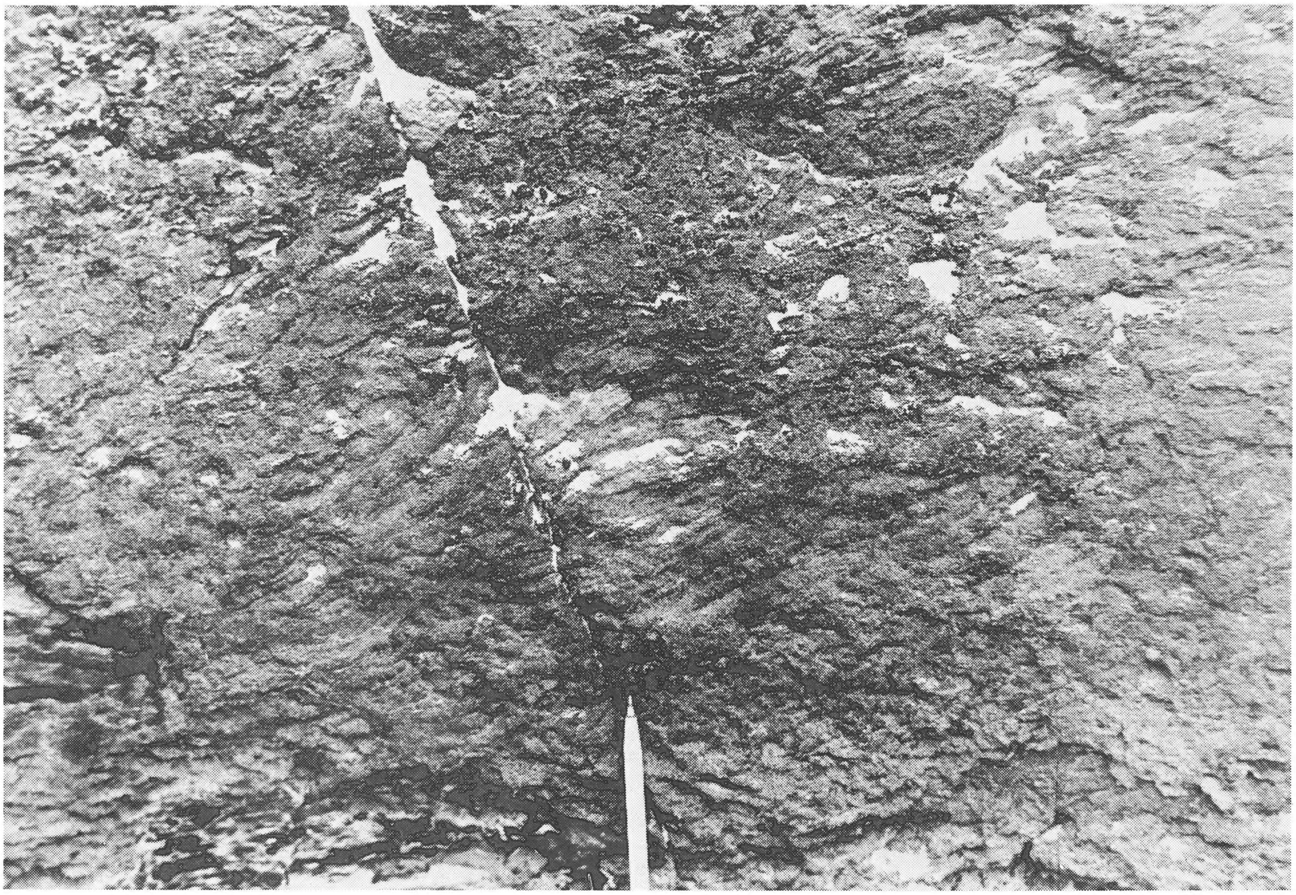


Fig. 9
Sandy lignite displaying faint cross-lamination with remarkably steep lee-side laminae. Note the relatively large and delicate sets due to eolian transport during humid conditions.

Within the sandy lignite one often finds cross-bedded channelsand (fig. 10), sheets of structureless to faintly horizontally laminated sand, and small dune-like elevations, the last being especially common along the lower contact of a sandy lignite horizon (fig. 11).

The channel-shaped depressions are of very variable size. The smallest channels have a width of approximately 1 m and have a depth of 30 cm, whereas the biggest channel have a width of roughly 100 m and a depth of 8-10 m.

The small channels show a clearly erosive lower surface and are filled by sand, sandy lignite or both. A typical channel-fill sequence consists of a lag-deposit of rolled sand-fragments or lignite lumps just above the lower contact, followed by sand displaying cross-bedding of different types and topped by sandy lignite. The directions of dips of the cross-bedded sand are variable.

The biggest channel cuts deeply into the underlying sediments and displays rootlet horizons along its lower contact. The channel is filled up by structureless or cross-bedded withish sand containing numerous plant remains, sandy lignite with rootlet horizons, and locally pure lignite. The sand encountered in the channel occurs mostly as small lenses or channel-like depressions enclosed in the sandy lignite. No sequential regularity could be discerned.

The sheets of structureless or faintly horizontally laminated sand intercalated with sandy lignite never exceed 2 m in thickness and are laterally very persistent. They are sometimes overlain by small dune-like elevations of structureless pure white sand (fig. 11).

Interpretation

The origin of the channels enclosed in the sandy lignite is still rather obscure. The question arises whether the erosion of the channels and the formation of the lag-deposit were a result of a marine influx in the supratidal area (storm floods)

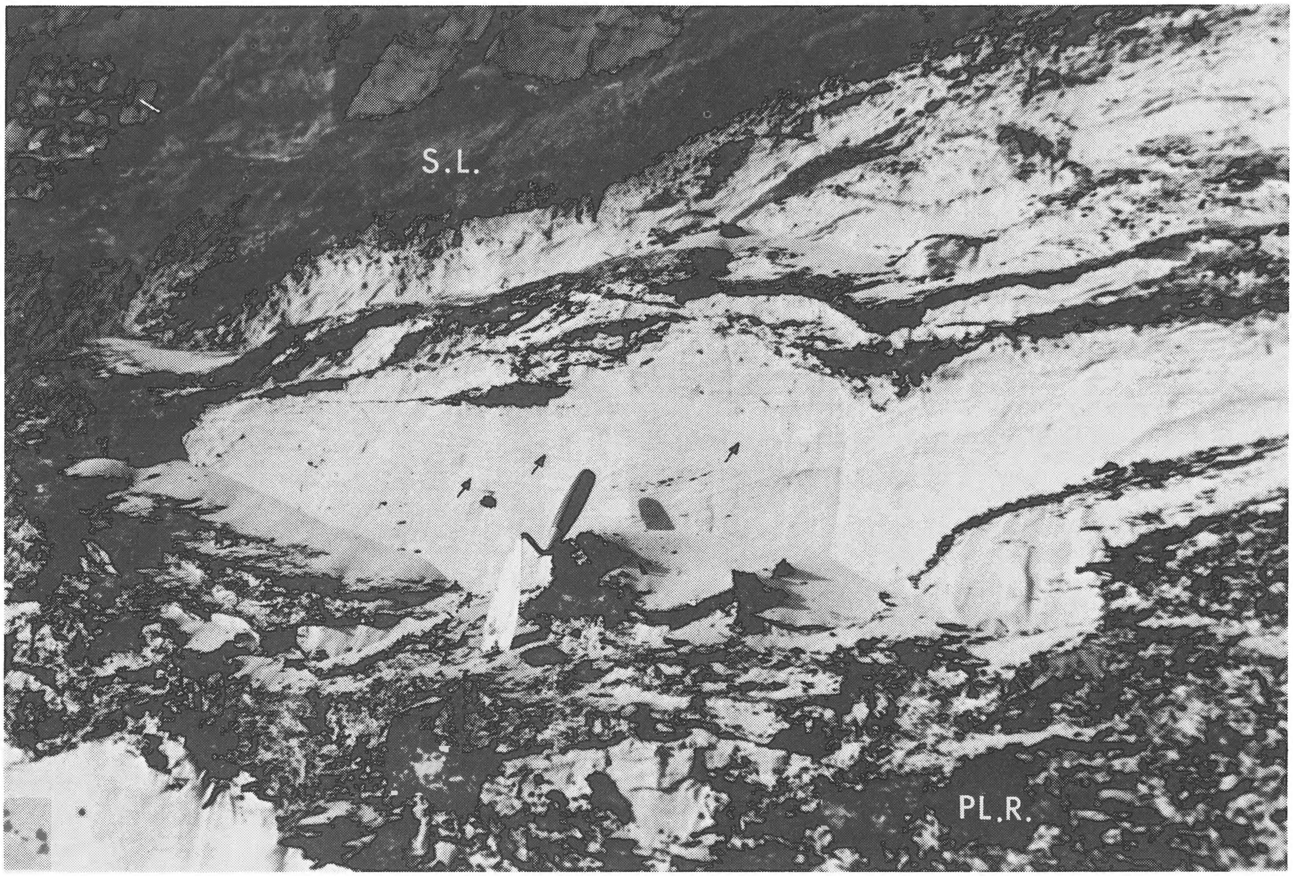


Fig. 10
Transverse section of a channel-fill sequence. The sediment displays large-scale festoon-like cross-bedding consisting of several sets of laminae separated by trough-shaped bounding surfaces (arrowed). The sand contains an abundance of transported plant remains (PL.R.) and is enclosed in sandy lignite (S.L.).

or a consequence of flood-generated incursions from nearby river distributaries. At the present stage of investigation the writer tends to favour the first mentioned possibility, mainly because no well-defined distributary channels are encountered in the Garsdorf area. After the channels were formed, presumably from the sea-side, a period of non-deposition often followed, as indicated by the occurrence of rootlet horizons along the lower contacts of some channels. Renewed activity in the channels is indicated by the presence of cross-bedded sand. The assemblage and type of sedimentary structures (fig. 10) suggest that in most of the channels this sand was deposited by ephemeral streams (Picard & High, 1973). Rather similar channel-fill sequences have recently been described from Upper Cretaceous eolian sediments in Mongolia by Gradziński & Jerzykiewicz (1974). They also interpret the channel-fill as intermittent stream deposits. In some channels, however, wind activity may have blown in the sand, as the cross-bedded channel-fill here displays the marked differences in grain-size between successive foreset laminae often reported from eolian cross-bedding (e.g. Glennie, 1970). This agent was also active during the formation of the sandy lignite, which often makes up a part of the channel-fill sequence. The clay-free nature of the sediment makes it likely that the source of the sand encountered in the channels was nearby dunes (Glennie, 1970).

Dickinson et al. (1972) described the effects of hurricanes along the coast of the Gulf of Mexico. The storms impinging on the coastline often erode a channel through the beach and dune-ridge. The channel is often closed very quickly by longshore transport and the remaining depression filled up mainly by eolian sediments.

It is suggested that the channels described in the present account make up part of one or several storm inlets cut through the Miocene shoreline and that the sediments filling the channels are of combined intermittent stream and eolian origin.

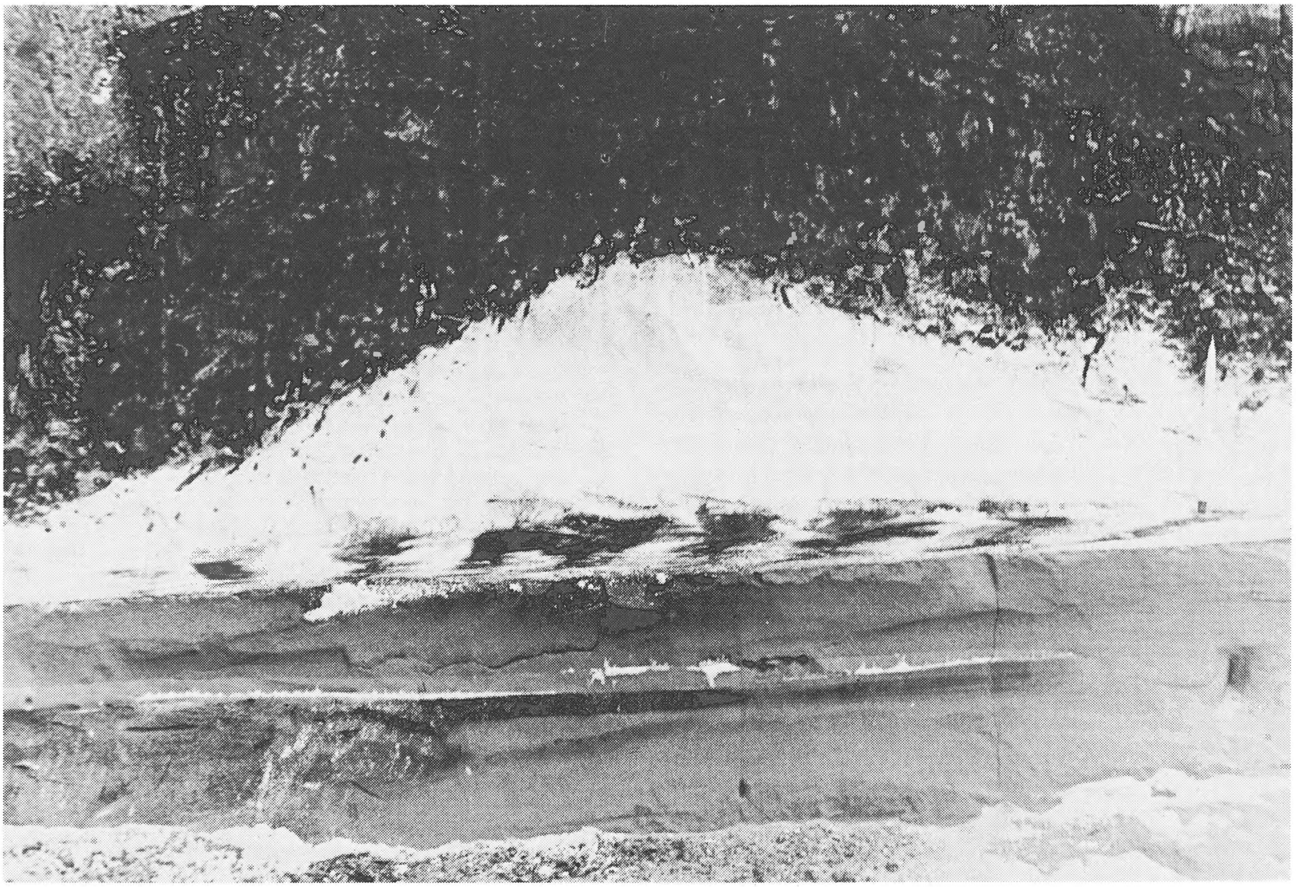


Fig. 11
A small dune-like elevation with rootlets at the top, overlain by sandy lignite and underlain by a thin sheet of dark-greyish faintly horizontally laminated sand.

The small dune-like elevations seem best interpreted as small wind-generated dunes which became stabilized by vegetation and in this way preserved.

The thin sandsheets intercalated with the sandy lignite are interpreted as representing wash-over fan sediments as described by Dickinson et al. (1972) and Howard et al. (1973). The local presence of small fragments of rolled lignite or sandy lignite (fig. 2), and the occurrence of horizontal lamination, both indicating high current velocities, support this interpretation. The upper portion of the wash-over fans may suffer from eolian reworking before finally becoming overgrown.

CONCLUSIONS

The occurrence of sandy lignite in association with lignite formed in coastal swamps characterized by an open mixed forest of conifers and angiosperms (Teichmüller, 1958; Van der Burgh, 1973) as well as with shallow marine and beach deposits makes it likely that the sandy lignite was formed on eolian flats as suggested in the palaeogeographical reconstruction (fig. 4). This interpretation is contrary to the one proposed by Gliese (1972/1973) who looked on the sand with lignite detritus as a lagoonal deposit partly on the assumption that the sediment did not possess any sedimentary structures. Sediments from recent eolian flats have been described by Dickinson et al. (1972) as non-laminated sand displaying gray mottling and containing soil horizons. The rather high content of lignite detritus in the sediment discussed here clearly indicates that the Miocene eolian flats were overgrown by a dense vegetation, which later decayed and formed the lignitic fraction of the sediment. The eolian sand blown in from the nearby dunes became easily trapped in the vegetation or on the moist surface of the flats, in the latter case often piled into small adhesion ripples.

The eolian flats and wash-over fans are incised by channels, one large and several smaller ones, interpreted to belong to a storm inlet. These channels became slowly filled up with sediments mainly from small ephemeral streams.

If the interpretation of the sandy lignite as an ancient eolian flat sediment holds true, its recognition in the field in geological settings similar to the one described above gives a useful hint for the reconstruction of ancient shorelines.

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