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THE PALAEOECOLOGY OF THE LOWER AND MIDDLE EOCENE AT HELMSTEDT, NORTHERN GERMANY – A STUDY IN CONTRASTS

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ABSTRACT. The lignite-bearing Eocene sediments at Helmstedt are divided into a Lower Eocene and a Middle Eocene unit separated by a partially marine bed of about 40 m in thickness. Lignites occur in both units in several seams varying somewhat in number, composition and thickness due to lateral and vertical facies variation. In each unit the lower seams are separated by more or less marine deposits while the upper seams are associated mainly with fluvial sediments. The general environmental setting in either unit is rather similar, characterized by an alternation of peat forming and marginal marine to fluvial clastic environments located on a coastal plain. The seams, however, are totally different in petrographic constitution as well as palynological and palaeobotanical content.

The seams of the Lower Eocene have a high content of fusain and woody tissue including marked tree stump horizons. The 10 m thick main seam ("Hauptflöz") and seam 1 in the Lower Eocene in particular are characterized by rapidly changing palynofloras with pronounced peaks of Sphagnaceae, fern spores, Taxodiaceae and palms. In contrast, the seams in the Middle Eocene are almost devoid of fusain layers and finely dispersed fusinite and recognizable woody tissue is rare while the Fagaceae and Juglandaceae form the dominant element in the palynoflora.

In the Lower Eocene, environments of peat formation appear to have been frequently disrupted by a fluctuating water table allowing for periodic or episodic fires and floods, while peats in the Middle Eocene grew under the influence of a rather persistent intermediate water table and a very equitable perhumid climate. In contrast, climatic and environmental conditions during the Lower Eocene appear to have been significantly less stable and slightly cooler.

KEY WORDS: lignite, plaeoecology, organic petrology, palynology, palaeobotany, peat formation, palaeoclimate, Eocene, Northern Germany

INTRODUCTION

One of the most striking and immediately visible features of the Eocene lignites at Helmstedt is the difference in macropetrographic appearance between the Lower Eocene and the Middle Eocene seams, called the lower seam group and the upper seam group respectively. This difference is all the more surprising since both groups of seams were deposited under very similar palaeogeographic conditions in a low lying coastal plain environment and since the age difference and possible climatic gradient is of little significance. Palaeogeographically, the Helmstedt deposit is situated near the mouth of a broad estuary feeding into a warm shallow sea the temperature of which was largely controlled by the varying intensity of currents coming in from the Tethys and which occupied most of the area of the North German plain and the southern Baltic Sea (Fig. 1). During the past five years the sedimentology, organic petrology and palynology of these lignite bearing sequences have been studied in detail through a series of individual investigations by the authors of this paper forming a basis to summarize the difference in various parameters and to reflect on the possible causes.

GEOLOGIC SITUATION

The Helmstedt lignites occur in a complex synclinal structure extending over a length of 70 km between Helmstedt in the northwest to Staßfurt in the southeast. The structure parallels a series of synclines and anticlines in the so-called Subhercynian Basin between the Harz Mountains and the Flechtingen Rise (Wilkening & Adler 1981, Look 1984). The Helmstedt structure is divided into two narrow, strictly parallel synclines separated by a salt diapir of about 2 km in width which rose from the deeply buried Zechstein salt during the Paleogene (Fig. 2). Formation of the diapir and subsidence of the marginal synclines including the deposition of the lignites were undoubtedly contemporaneous and syngenetic (Manger 1952). Whether both synclines formed a uniform depositional system (Lietzow 1991), however, remains questionable.

The Tertiary sequence (Fig. 3) begins with early Eocene, perhaps even with latest Paleocene sediments (Lietzow *et al*. 1990). In the eastern syncline they reach a thickness of 430 m near Helmstedt. The lower seam group has been formed during the early Eocene and begins in either syncline with a seam of about 10 m in

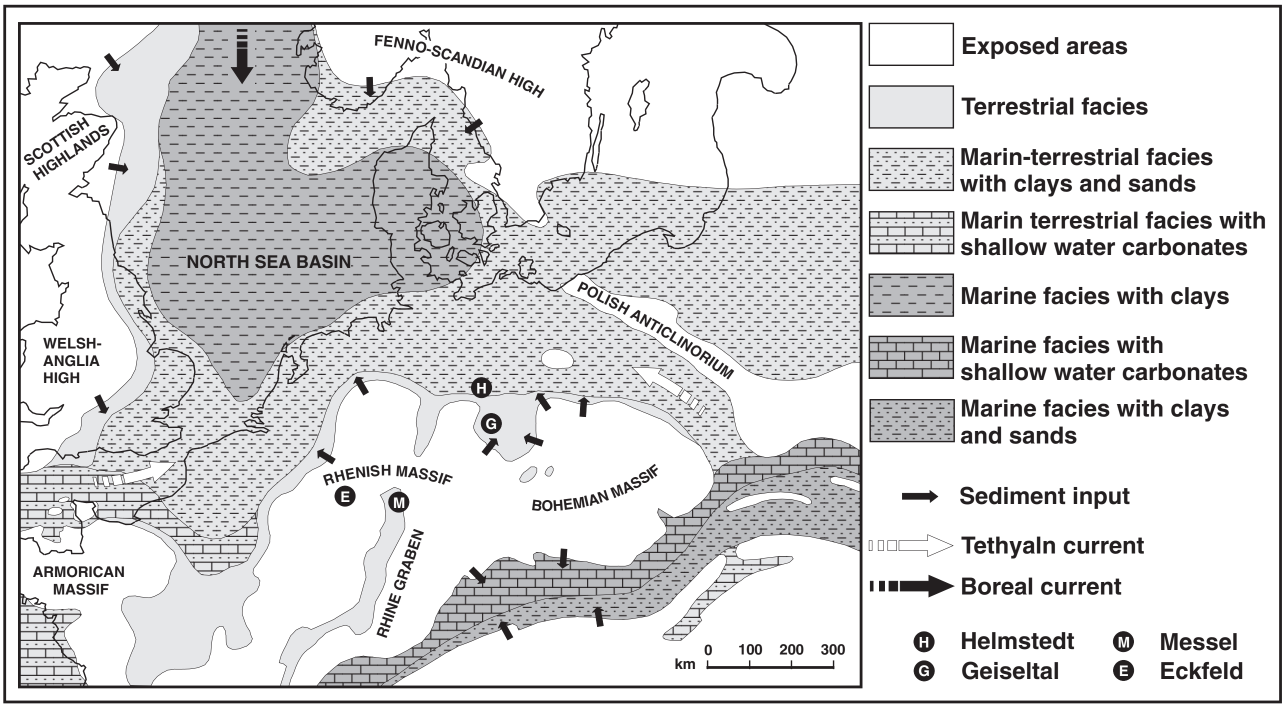

Fig. 1. Palaeogeographic map of central and northwestern Europe during the Eocene with location of Helmstedt and other major sites of Eocene floras (adapted from Ziegler 1990)

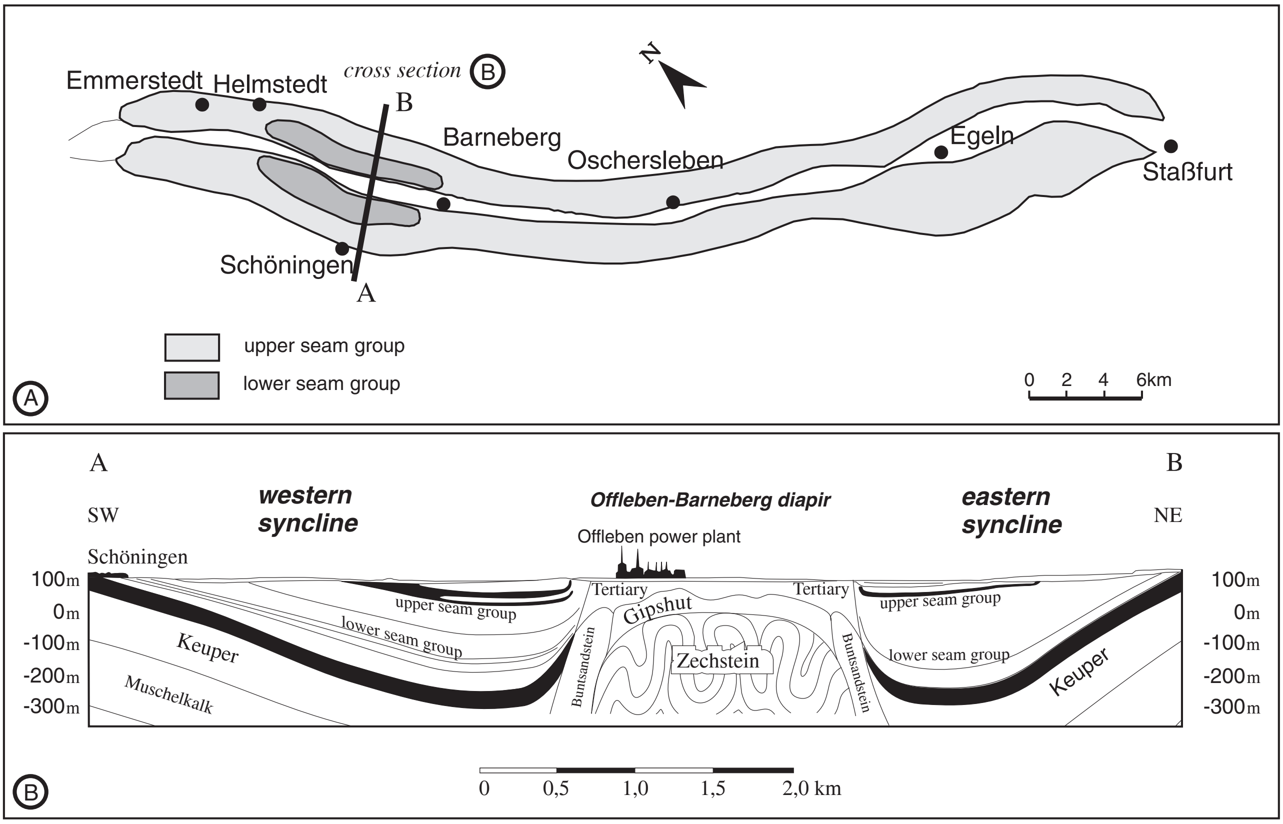

Fig. 2. Map (A) and cross section (B) showing extent and structure of the Helmstedt lignite deposit (adapted from Look 1984)

thickness (“Glückauf” seam in the eastern, “Prinz Wilhelm” seam or “Hauptflöz” in the western syncline). 7 to 8 thinner seams separated by clastic interbeds showing various degrees of marine influence follow above. About 40 to 50 m of sandy and clayey, in part even gravelly beds including a distinctly marine glauconitic sand hori-

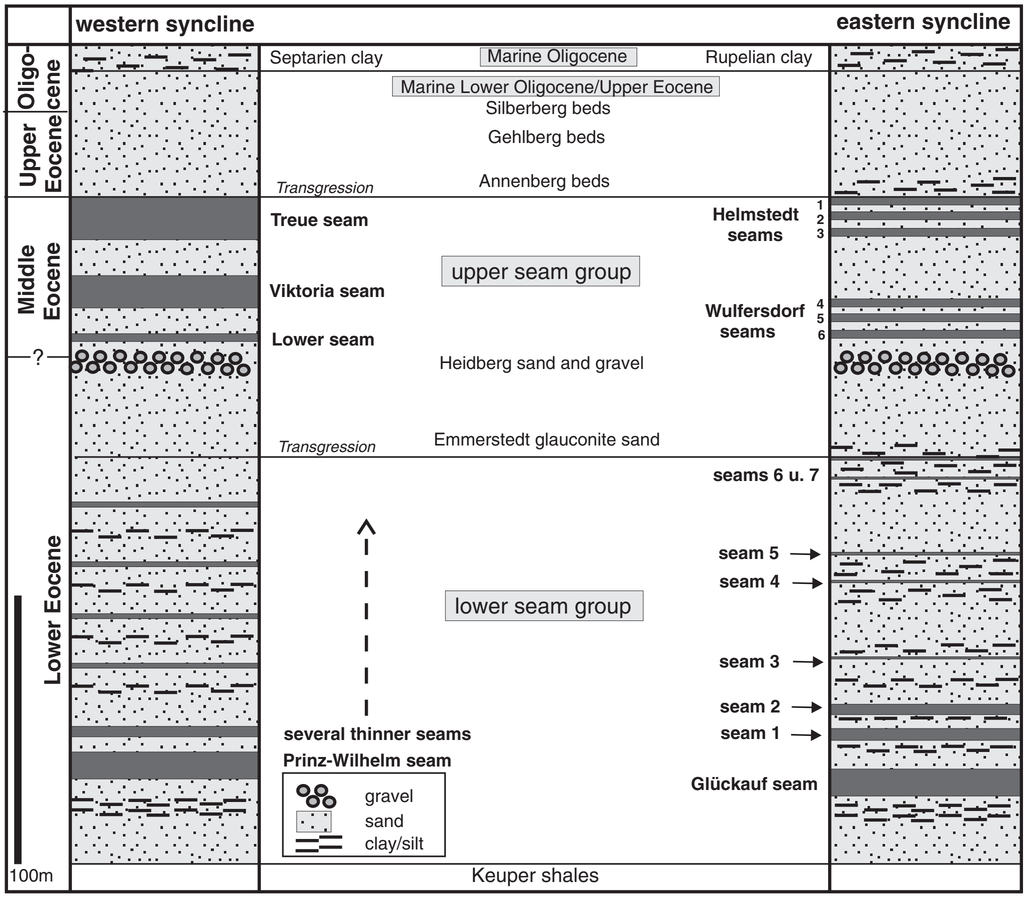

Fig. 3. Generalized stratigraphic section through the Tertiary sequence of the western and eastern syncline at Helmstedt (adapted from Look 1984)

zon separate the lower seam group from the Middle Eocene upper seam group.

The sequence making up the upper seam group is somewhat different in the two synclines. In the western syncline there are only three seams of which the upper one was the most important with a thickness of locally more 20 m. All the coals of the upper seam group are now totally mined out in this western syncline. In the eastern syncline there are 6 seams the lower three of which, the Wulfersdorf seams (seams 4 to 6), are rather uniform in thickness (in general 3 to 5 m) and separated by interbeds deposited in an estuarine environment (Bullwinkel 1996, Lenz 1999). The upper three seams, the Helmstedt seams (seams 1 to 3), are highly variable in thickness (up to 10 m) and lateral extent while the interbeds clearly exhibit features of fluvial sedimentation. The change from marginal marine, estuarine to fluvial sedimentation takes place at the top of seam 4 (top of the Wulfersdorf group).

The seams of the Wulfersdorf group are particularly well studied by the authors. Thus seam 4 of the upper seam group is selected for closer comparison with seam 1 of the lower seam group (Fig. 4) since both are of similar thickness and originated in a comparable marginal marine environmental setting.

PETROGRAPHIC COMPARISON

The macropetrographic constitution is the most striking distinguishing feature of the two seam groups. Figure 4 shows macropetrographic seam sections of the two selected seams in juxtaposition. Seam 1, as most of the seams of the lower seam group are mainly made up of lithotypes rich in recognizable remains of various tissues especially those of roots. Near the bottom of the seam leaf fragments are common but leaves are not entirely preserved. Xylites are common especially in the middle part of the seam and tree stumps occur in several horizons. One of the most important characteristics of coals from the lower seam group is the frequent occurrence of fusain layers. In seam 1 they are mainly concentrated in the upper part of the seam. Fusain also occurs finely dispersed within the other lithotypes. The overlying clay/silt alternation is root penetrated. The dominant colour of coal lithotypes is dark brown to black indicating a high degree of gelification.

In contrast, seam 4 of the upper seam group consists almost entirely of a finely detrital organic matrix forming matrix-dominated lithotypes. Root penetration is

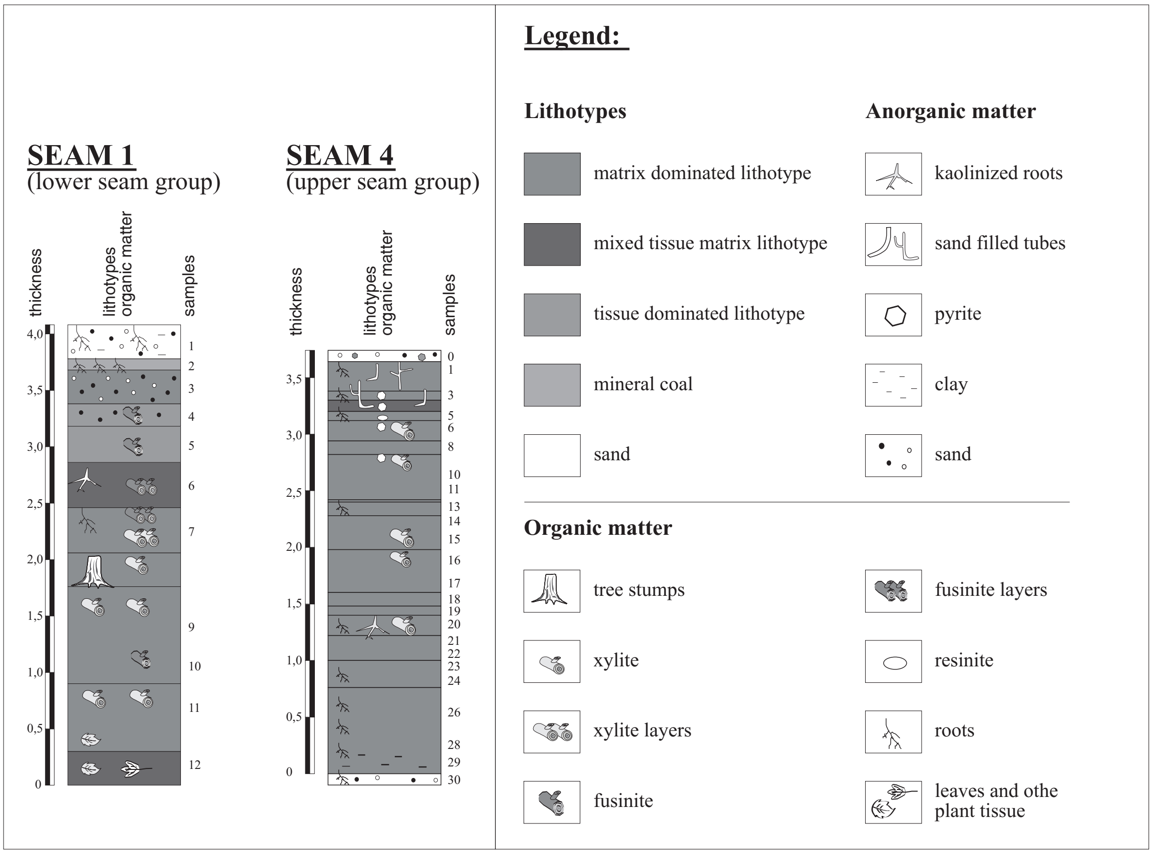

Fig. 4. Macropetrographic comparison between the lower seam group (seam 1) and the upper seam group (seam 4)

common and particularly well visible since the black gelified root traces contrast more sharply than in the lower seam group with the medium to light brown colour of the homogeneous matrix. Leaf remains are virtually absent. However, traces of woody tissue within the matrix are not uncommon though discrete xylites are exceedingly rare. Even more significant appears the total lack of fusain layers and finely dispersed fusain. The seam is overlain by a medium fine sand with lignite clasts indicating fluvial sedimentation. However, the presence of clay-filled bioturbation tubes at the seam top as well as pyritization of root traces in the upper part of the seam indicate that seam formation has been terminated by marine ingression the corresponding sediments of which have been removed later by fluvial erosion.

The main distinguishing macropetrographic parameters between the two seam groups are summarized in table 1. Maceral analysis shows that micropetrographic composition closely corresponds to the macroscopic aspect of the lignites. Telinite and corpohuminite is very common in lignites of the lower seam group while attrinite together with highly flourescing matrix and liptodetrinite vastly dominates the upper seams (Bode 1994). The most striking difference, however, is again the abundance and lack of fusinite respectively in the lower and upper seam group.

Table 1. Contrasting petrographic parameters of lower and upper seam group

LOWER EOCENE LOWER SEAM GROUP	MIDDLE EOCENE UPPER SEAM GROUP
tissue-rich lithotypes	matrix-dominated lithotypes
light lithotypes rare	light lithotypes common
xylites frequent	xylites rare
permineralized xylites common	permineralized xylites rare
tree stump horizons common	tree stump horizon very rare
fusain layers abundant	fusain layers absent
dispersed fusain/fusinite common	dispersed fusain/fusinite very rare
very heterogeneous seam structure	homogeneous seam structure

PALYNOLOGICAL COMPARISON

Pflug (1952) first noted the difference in palynological assemblages between the lower and upper seam group and emphasized the stratigraphic implications of these differences. Our concern has been more devoted to the ecological aspects which are superimposed on the extinction and first appearance data. A more rigorous evaluation of the palynological difference between the two seam groups will be carried out after completion of palynological investigations still in progress. However,

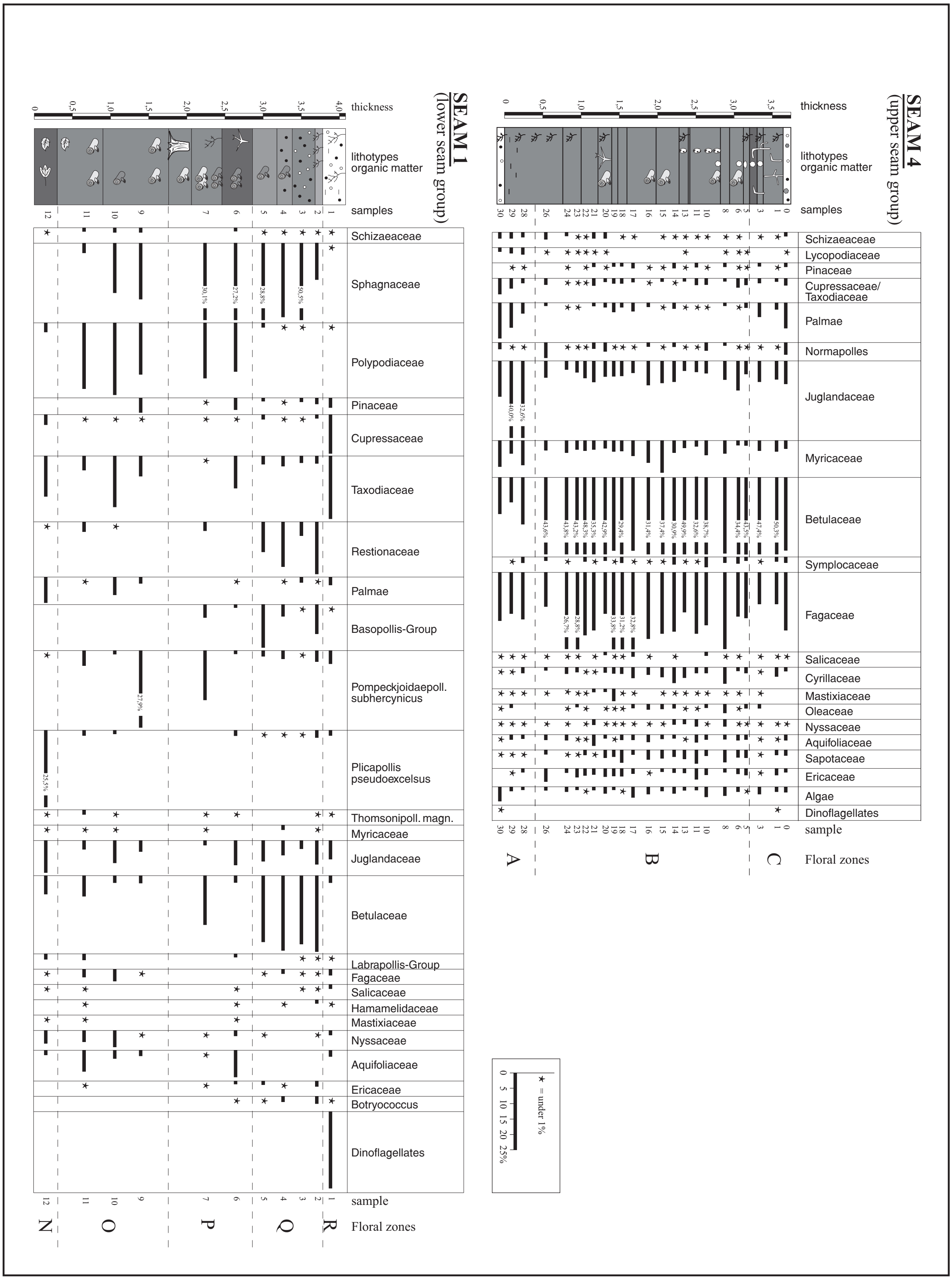

Fig. 5. Simplified palynological diagram of seam 1 (lower seam group) and seam 4 (upper seam group) showing difference in composition and succession of assemblages (data of seam 1 from Hammer-Schiemann 1998; data of seam 4 from Hammer 1996)

Table 2. Contrasting palynological parameters of lower and upper seam group

LOWER EOCENE LOWER SEAM GROUP	MIDDLE EOCENE UPPER SEAM GROUP
Taxodiaceae-Nyssaceae association significant	Taxodiaceae-Nyssaceae association absent
Fagaceae rare	Fagaceae abundant
Betulaceae only locally abundant	Betulaceae abundant
Sphagnaceae-fern association significant	Sphagnaceae-fern association absent
Mangrove association absent	Mangrove association common and diverse
Restionaceae (marsh element) significant	Restionaceae (marsh element) reduced
High Normapolles diversity	Low Normapolles diversity
Thomsonipollis magnificus abundant	*Thomsonipollis magnificus* nearly absent
Sapotaceae nearly absent	Sapotaceae common
Pollen assemblages highly variable	Pollen assemblages homogeneous within seams
Botryococcus locally abundant	*Botryococcus* rare

a general assessment of the more apparent distinguishing parameters can already be given here. Figure 5 presents a generalized quantitative composition of assemblages from seam 1 (lower seam group) and seam 4 (upper seam group).

A general palynological difference between the two seam groups constitutes the relative homogeneity of assemblages in seams of the upper seam group versus the highly variable succession of assemblages in the seams of the lower seam group (Table 2). At the bottom (zone A) and top (zone C) of seam 4, for instance, assemblages transitional between those of the interbeds and the seam itself can be recognized (Fig. 5). The bottom assemblage is dominated by Juglandaceae pollen. Palm pollen form a significant element in both, the bottom and top assemblages, in which dinoflagellates also occur occasionally indicating the marine influence bounding the beginning and the end of peat formation. More than three quarters of the total seam thickness are characterized by a fairly stable assemblage (zone B) of mainly Betulaceae and Fagaceae pollen. A few other elements such as Cyrillaceae, Sapotaceae and Ericaceae are somewhat more common in this zone than outside, but generally low in proportion.

In contrast, seam 1 of the lower seam group shows much greater variation and some rather isolated peaks of otherwise rare and unusual elements. This makes division into zones rather difficult. But at least five zones have been distinguished here. *Plicapollis pseudoexcelsus* is often found to be associated with mangrove elements and only frequent at the immediate base of the seam. It is used as the basis for identifying zone N. Spores of polypodiaceous ferns are most abundant in the next zone (zone O) where ferns may have formed a reed-like vegetation dotted with isolated stands of the source plant of *Pompeckioidaepollenites subhercynicus*, a probable member of the Juglandaceae. Most striking is the great abundance of *Sphagnum*-type spores (*Stereisporites* spp.) in the subsequent zones P and Q where they are closely associated with a massive occurrence of fragments of fusinitized woody tissue in the palynological preparations. Frequent occurrence of polypodiaceous spores is the basis for separating zone P from zone Q in which they are replaced by Restionaceae and Betulaceae pollen. The frequency of Taxodiaceae pollen and dinoflagellate cysts characterizing zone R probably results from a incidental mix washed together in the clastic sediments overlying the seam. Both elements originate from environments which are mutually exclusive, for instance, in the modern Florida Everglades (Riegel 1965).

In general, taxodiaceous pollen form a regular, locally even abundant element in the lower seam group suggesting that *Taxodium* mire forests contributed significantly to coal formation during the Lower Eocene at Helmstedt. The same may be true for Sphagnaceae and polypodiaceous ferns. These elements are insignificant in all parts of the upper seam group. Particularly noteworthy is the very low representation of Fagaceae in the lower seam group whereas they reach one third of the total assemblage for instance in seam of the upper seam group. Another important point of difference is the obvious presence of mangrove fringe at the bottom transition, rarely, too at the top of seams of the Wulfersdorf group, represented by *Rhizophora* and *Avicennia* type pollen as well as *Nypa* (*Spinizonocolpites echinatus*). Due to their low number and very restricted occurrence they have not been included in the quantitative diagrams of Fig. 5. No indication of a mangrove zone has yet been established for the lower seam group.

Other noteworthy differences are the presence of *Thomsonipollis magnificus* in the lower and its absence from the upper seam group. Sapotaceae pollen, on the other hand, are largely restricted to the upper seam group. The major distinguishing palynological parameters are summarized in table 3.

RECONSTRUCTION OF ENVIRONMENTS

Before looking into the reasons causing the described difference between the Lower and the Middle Eocene lignites a reconstruction of environments involved in their formation is attempted. For this all relevant sedimentological, organic petrological and palynological evidence currently available is considered. The Wulfersdorf seams of the upper seam group will be treated first since the current status of their investigation is more complete.

Table 3. Main elements of plant associations in the lower and upper seam group

LOWER EOCENE	LOWER SEAM GROUP	MIDDLE EOCENE	UPPER SEAM GROUP
Costal zone	◆ *Plicapollis pseudoexcelsus* ◆ Hamamelidaceae ◆ Juglandaceae	Mangrove zone 1	◆ *Rhizophora* ◆ Prasinophytes ◆ Dinoflagellates
		Mangrove zone 2	◆ *Avicennia* ◆ *Diporoconia iskaszentgyoergyi*
		Mangrove zone 3	◆ *Nypa* (*Spinizonocolpites baculatus*)
		Brackish marsh	◆ *Plicapollis pseudoexcelsus* ◆ Restionaceae (*Milfordia* spp.)
Freshwater marsh and hammocks	◆ Polypodiaceae ◆ *Pompeckjoidaepollenites subhercynicus*	Freshwater marsh	◆ Pompeckjoidaepollenites subhercynicus ◆ Sparganiaceae/Typhaceae ◆ Restionaceae (*Milfordia* spp.)
Disturbed fresh water marsh and hammocks	◆ Sphagnaceae ◆ Polypodiaceae ◆ Restionaceae ◆ *Taxodium* ◆ *Botryococcus*		
Mire forest 1	◆ Betulaceae ◆ Juglandaceae ◆ *Thomsonipollenites magnificus*	Mire forest 1	◆ *Dicolpopollis kockeli* ◆ Pinaceae (*Pityosporites* spp.)
Mire forest 2	◆ *Taxodium*, *Nyssa* ◆ Palms ◆ Polypodiaceae	Mire forest 2	◆ Betulaceae (*Triporopollenites robustus, T. rhenanus, T. megagranifer*) ◆ Ericaceae (*Ericipites* spp.) ◆ Sapotaceae (*Tetracolporopollenites* spp.)
		Mire forest 3 (open mire association)	◆ Fagaceae (*Tricolpollenites liblarensis, Tricolporopollenites cingulum*) ◆ Taxodiaceae (*Inaperturopollenites* spp.) ◆ Plankton (*Botryococcus, Planctonites stellarius*)

The Wulfersdorf seams (upper seam group)

Intensive bioturbation and the regular presence of dinoflagellate cysts are the most convincing evidence of marine influence in the interbeds of the Wulfersdorf seams (seam 4 to 6). A sedimentological analysis (Bullwinkel 1996) suggests that they were deposited under estuarine conditions. The seams thus represent stages of terrestrialization in an estuarine environment initiated by a mangrove fringe. This is indicated by the regular though infrequent combined occurrence of *Nypa, Rhizophora* and *Avicennia* type pollen at the base of the seams. Isopollen maps (Fig. 6) have been constructed from a thin, highly carbonaceous band within the interbed between seams 4 and 5 which could be traced in the mine high wall over a distance of nearly 2 km and is considered to represent an isochronous horizon. The distribution of mangrove elements in this horizon clearly shows that the shoreline was to the northwest and advanced from there inland to the southeast. A fourth element, *Diporoconia iskaszentgyoergyi*, is restricted in distribution and closely associated with the other known mangrove types and therefore considered here to be part of the mangrove fringe substantiating the previous contention of Frederiksen *et al.* (1985). High resolution sampling at the base of some seam sections even indicates that a succession similar to recent mangrove fringes from the seaward *Rhizophora* to the landward *Nypa* zone with *Avicennia* in the center existed in central Europe during the Middle Eocene.

Immediately above, respectively behind the mangrove zone pollen of Restionaceae and Sparganiaceae as well as fern spores are more abundant than elsewhere in the seam section suggesting that a reed-like vegetation with ferns and aquatic herbs developed here under rather wet conditions. The frequency of Juglandaceae pollen, especially of *Plicapollis pseudoexcelsus* and *Pompeckioidaepollenites subhercynicus*, as well as palm and taxodiaceous pollen indicates that trees and shrubs may have been intimately associated with the herbaceous plants or dotted the reed-like vegetation with tree islands (hammocks). A hammocky distribution of corresponding plants is indicated f.i. by the isopollen map for *Arecipites convexus* (Fig. 6).

The main peat forming vegetation, however, was a mire forest which changed from a domination by Fagaceae to a Betulaceae dominated forest. In the upper part of the seams there may be a local increase of Ericaceae and certain palm pollen (e. g. *Dicolpopollenites kockeli*). Even bisaccate pollen, usually very rare in the Helmstedt Eocene in general, may reach a few percent. The succession of assemblages represented here suggests

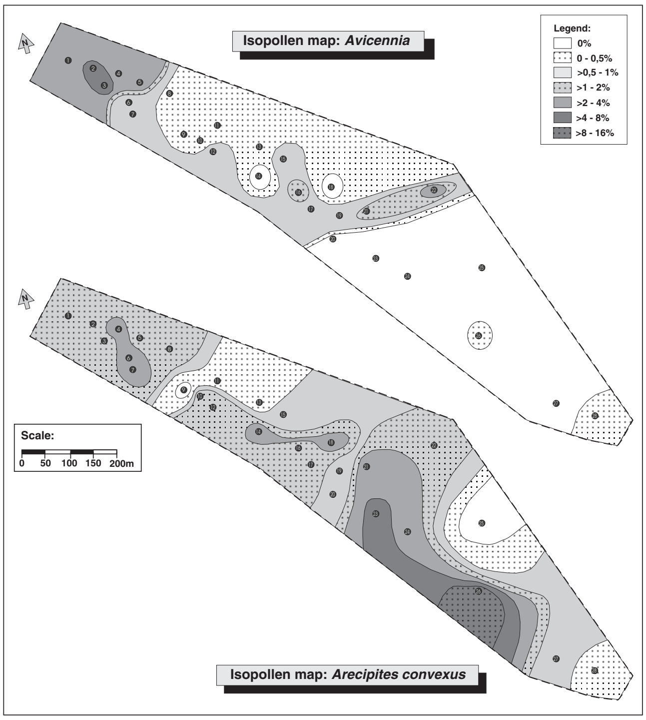

Fig. 6. Isopoll maps of *Avicennia* and *Arecipites convexus* in coaly layer of interbed between seam 4 and 5 of the upper seam group. The two maps are selected to demonstrate the relationship between the distribution of pollen and the source vegetation: Mangrove fringe in the northwest and tree hammocks with palms in the southeast of the studied area (from Lenz 1999; in preparation)

a continued trend toward drier and nutrient deficient conditions even within the mire forest. This trend is finally interrupted by a renewed marine transgression. That surface conditions, especially in the mire forest, were relatively dry is also borne out by the finely detrital petrographic constitution of the coal which is commonly assumed to be the result of intensive microbial degradation. In particular, the light coloured, matrix-dominated lithotypes may be derived from intensive white rot of woody tissue under sustained aerobic conditions (Klein-Reesink 1984). On the other hand, the nearly total lack of fusinite in the seams of the upper seam group requires that droughts with significant lowering of the water table and subsequent forest and peat fires did not occur, neither in the mire itself nor in the immediate surroundings.

Lower seam group

Seams in the lower seam group are, like their counterparts in the upper seam group, sandwiched between partially marine beds of probable estuarine origin. *Plicapollis pseudoexcelsus* is abundant only at the base of the seams. Although it clearly occurs in succession with mangrove elements in the upper seam group it can not by itself taken as a signal of a mangrove fringe here since all other mangrove elements are missing. The lower part

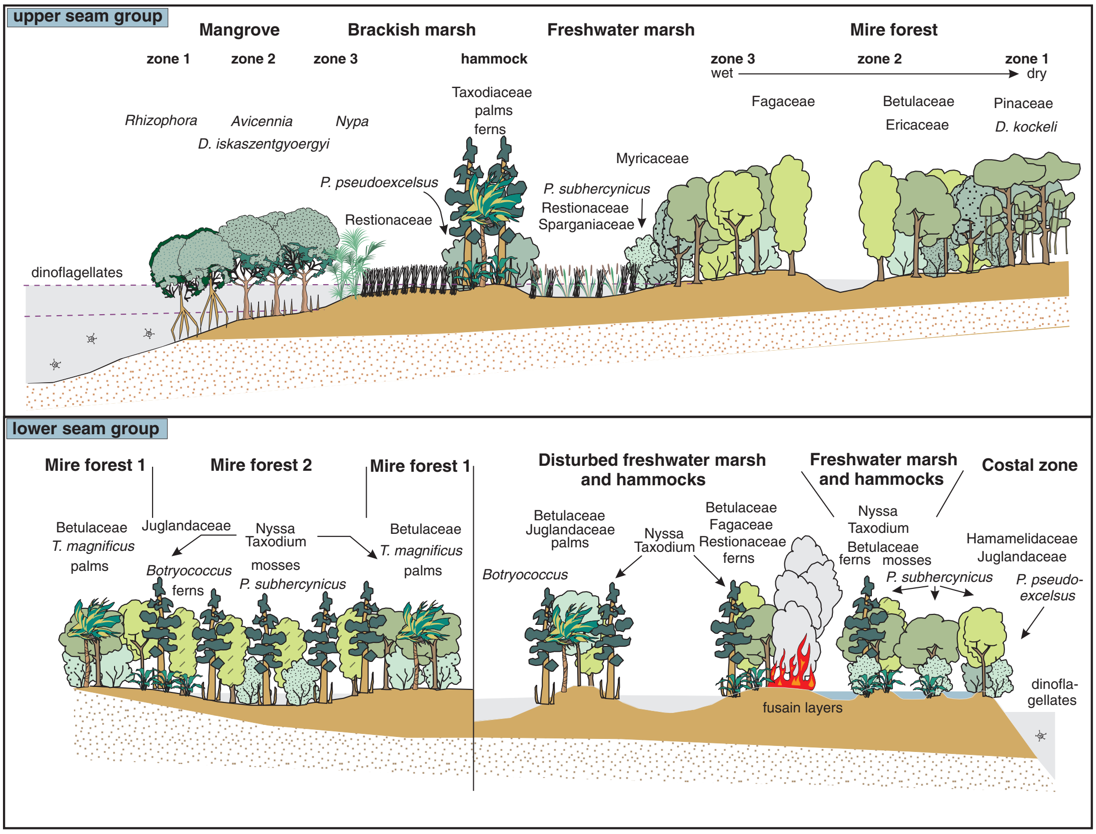

Fig. 7. Reconstruction of floral successions in the lower and upper seam group (Lower and Middle Eocene respectively) at Helmstedt. Note in particular the presence of a mangrove fringe and the continuous development towards a relatively dry mire forest in the upper seam group versus the disturbed development and absence of a mangrove fringe in the lower seam group

of the seams thus far studied seems to be formed by a *Nyssa-Taxodium* mire forest under rather wet conditions. Clearings or drier areas may have been occupied by ferns respectively Juglandaceae as indicated by high values of polypodiaceous spores and occasional peaks of *Pompeckioidaepollenites subhercynicus*. The upper part of the seams appears to be particularly disturbed. The unusual frequency of *Sphagnum* type spores (*Stereisporites* spp.) in association with numerous fusain horizons are a signal of highly disturbed environments caused or at least closely connected with forest and peat fires. Significantly, *Botryococcus* begins to occur regularly indicating the presence of ponds and a water table rising above the peat surface perhaps caused by loss of volume following fire. The frequency of Restionaceae and Betulaceae in this upper part of the seams may be derived from repopulated disturbed areas and remnants of undisturbed mire forests respectively. Apparently during this stage of peat formation a mosaic of aquatic, burned, mire forest and naturally reclaimed environments existed synchronously and succeeded each other in relatively short intervals (Fig. 7).

CAUSES OF THE DIFFERENCE

In the lower seam group the frequent occurrence of fires and disturbed peat forming vegetation with evidence of intermittent open water areas is clear evidence of a highly fluctuating water table. In a low coastal plain environment such as that represented by the Helmstedt Lower and Middle Eocene two possible causes may be responsible for the fluctuations of the water table: A seasonal change of wet and dry with episodic droughts leading to catastrophic events in the mire system, or fluctuations of the sea level in the adjacent sea. In the latter case the problem remains to relate the high frequency of fire events to any orbital control. Sea level changes on a larger scale are assumed to underly the seam/interbed alternation (Lietzow *et al*. 1990). A third possible cause may be periodic subsidence and elevation of the basin surface due to pulses of salt migration in the subsurface.

The homogeneous character of seams in the upper seam group requires rather homogeneous conditions of peat formation such as a homogeneous climate and substrate conditions supporting a stable peat forming vegetation. The seeming conflict between the high degree of degradation of plant tissues and the lack of fusinite can be explained by assuming very high atmospheric moisture and precipitation supporting raised mires with a fairly well drained peat substrate and preventing fires in the mire as well as in the surrounding perhumid rain forest. The presence of Sapotaceae, *Nypa* and a few other tropical elements in the Middle Eocene suggests that the climate was nearer to tropical here than previously in the Lower Eocene. This is in agreement with the first order climatic cycle reconstructed for the Eocene of Central Germany by Krutzsch (1992). However, his second order cycle shows a slight reversal for the Middle Eocene. Macrofloral evidence from other localities in Central Europe do not seem to substantiate significant climatic changes from the Lower to the Middle Eocene (Mai 1995). Our results from Helmstedt definitely do not support previous reconstructions and models according to which the climatic optimum is in the Early Eocene (e. g. Barron 1987, Hubbard & Boulter 1983, Rea *et al*. 1990, Wolfe, 1989).

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