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A multidisciplinary approach to reconstruct the Late Oligocene vegetation in central Europe

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Abstract

An interdisciplinary approach has been taken in the evaluation of the paleobotanical record of Late Oligocene vegetation in the Thierbach member of the Weißelster basin, Germany. Sedimentological, paleopedological, paleobotanical (megafloral and carpological), palynological and palynofacies, and biogeochemical investigations have been coordinated on an abandoned channel-fill sequence in order to develop a comprehensive data base from which to reconstruct this setting. The benefits of using multidisciplinary data sets are outlined including how these data sets may not only be complementary or contradictory, but also how independent data sets amplify and validate interpretations. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

Northern hemisphere climate deterioration near the end of the Eocene resulted in a phytogeographic change (Wolfe, 1978, 1980, 1992). Floristic changes in the early Oligocene were not simply a cooler version of the middle and late Eocene, but substantially different (80–90% of high-latitude genera became extinct in North America; Wolfe, 1992). Oligocene lowlands experienced inequable microthermal climates, resulting in range expansion and diversity

enrichment of broad-leaved, deciduous angiosperm taxa (Wolfe, 1972) into the mid-latitudes. By inference based upon palynological data, megathermal and mesothermal vegetation were restricted to the most equatorial position at this time. Renewed warming in the Late Oligocene allowed for regional expansion of mesothermal taxa and by Early to Middle Miocene, the middle latitudes of the northern hemisphere were characterized by broad expanses of humid to mesic broad-leaved deciduous forests. Wolfe (1986) acknowledged that, when compared with the Oligocene, the subsequent diversity in the Neogene was high particularly with respect to arcto-tertiary families. This diversity has been ascribed

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to the extension of geographic ranges, subgeneric diversification of broad-leaved deciduous Oligocene taxa, the adaptation of some mesothermal groups, and long-distance dispersal mechanisms (Wolfe, 1986).

Late Oligocene floras of central Europe have been investigated for more than a century and a half, and continue to be the focus of study (e.g., Kovar, 1982; Mai and Walther, 1985; Givulescu, 1989; Haby, 1989; Konzalová and Berger, 1989; see contributions in Knobloch and Kvaček, 1989). These investigations have provided a wealth of information about either the megafloras, carpo-floras, or palynofloras, but there has been little overlap or integration of data sets from a single collecting locality. The geological context of these floras often has been neglected, and there has been little synthesis to provide an overview of the taphonomic 'snapshot in time'.

The objective of this manuscript is to demonstrate the utility of a multidisciplinary approach in the study of the Upper Oligocene strata in Tagebau Bockwitz, Weißelster basin, Germany. The project was designed to overcome the limitations of previous attempts at gathering the data used in the reconstruction of Tertiary vegetation by obtaining the highest fidelity data sets that are complementary and integrative. Results of that multidisciplinary investigation are presented herein as a model for future studies.

2. Locality

Data concerning the regional geology of the Weißelster basin have recently become available due to the reunification of Germany. The general stratigraphy is established for the basin and a general sedimentological model has been proposed (Eißmann, 1968). Tagebau Bockwitz is an abandoned open cast

mine located near Borna, Saxony, situated within the eastern part of the Weißelster basin (Fig. 1). Mining operations began in the mid-1970's, with extremely restricted access, and ceased in late 1991. Tagebau Bockwitz was chosen as the site for this present pilot project because one member of the research team (Dr. Harald Walther) had excavated, processed, and curated large quantities of material during the mid-to late 1980's. As a result of reunification, the mine has been slated for reclamation within the next few years requiring the development of a timely program.

We have focused our efforts on the Upper Oligocene Thierbach member, which lies unconformably over the Upper Eocene (Oberflöz II) and Lower Oligocene (Oberflöz IV) lignites (Fig. 1; Brause et al., 1989). It is interpreted as a fluvial-sand-dominated unit deposited within a fully terrestrial setting (Eißmann, 1968; Kunzmann, 1995). The unit thickness is variable across the basin, but may be greater than 10 m east of Gestewitz, thinning eastward and westward towards the edges of the basin. The Thierbach member is overlain by Quaternary deposits.

3. Research strategy

A well-exposed section of the opencast tagebau highwall was worked in detail during the Fall of 1991, while a reconnaissance survey of the remainder of the mine was completed thereafter (Pöppelreiter, 1992). Sedimentological and stratigraphical data have been compiled using a combination of photo-mosaics coupled with vertical section descriptions in sites where there is obvious stratigraphical and sedimentological variability. These data have been used to establish the geological framework (the generalized terrestrial setting) in which the plant fossils

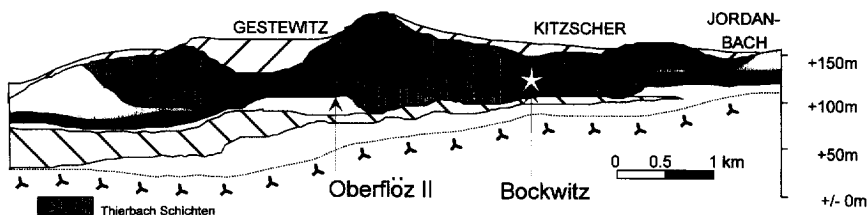


Fig. 1. Generalized geologic cross section of the Weißelster basin indicating the distribution of the Thierbach Schichten (after Eißmann, 1968).

are preserved. Paleosols have been treated separately from other terrestrial depositional settings, and preliminary paleopedological analyses have been conducted to characterize the features of these substrates. Mega- and microfloral investigations of these rooted beds provide data, unavailable through physical and textural characterization, to evaluate the genesis and development of these vegetated substrates. In addition, the variety of autochthonous plants that once inhabited these soils can be identified by studying anatomical sections of lignified or pyritized roots recovered *in situ*. Inorganic geochemical characterization of these paleosols produce data that may provide insights into the requirements for growth of these plants.

Plant taphonomic data, coupled with sedimentology of megafloral-bearing beds, has been used to establish the basis for an understanding of plant part occurrence. Once the assemblage can be identified as being either autochthonous, parautochthonous (remains having been transported from the death or discard site but remaining within the original habitat; Behrensmeyer and Hook, 1992), or allochthonous, the preserved flora can be evaluated in context. Bedding surfaces on which megafloral components are preserved were exposed sequentially throughout the sequence, forming the basis of the subsequent subsampling and the data that will be integrated in this study.

Megafloral components have been identified utilizing discrete morphological features that include cuticle analyses. These have been compared with systematically identified collections (Mai and Walther, 1991) that were made from the Thierbach complex prior to German unification. These collections, curated in the Staatliches Museum für Mineralogie und Geologie, Dresden, are extensive and consist of more than 15,000 leaves and leaf fragments concentrated on the exposed surface area of more than 21 m² of a single depositional environment, an abandoned channel fill (Gastaldo et al., 1996). More than 2500 specimens of fruits and seeds have been recovered through washing and sieving of selected blocks that represent somewhere between 200 and 300 kg of this same terrestrial setting. These parts have been systematically identified (Mai and Walther, 1991). Complementary palynological and palynofacies data sets, derived from the same sample

horizons as macrofloral data, are used to differentiate between local and regional elements (Table 1). In addition, both palynological and biogeochemical information derived from megafloral sample loci provide insights into plant successional data that may not be preserved in the megafloral assemblage. Biogeochemical data, complementary to the macro- and microfloral data, have been gathered (Otto et al., 1995) on individual taxa as well as the dispersed lipid fraction preserved within the section.

4. Thierbach member, Tagebau Bockwitz

4.1. General sedimentology

The Thierbach member exposed in Tagebau Bockwitz is composed of at least two coarse-clastic fluvial complexes (Fig. 2). The lower fluvial complex is in erosional contact with the Upper Eocene Oberflöz II brown coal; the upper fluvial complex is in erosional contact with a paleosol overlying the lower fluvial complex. It is within the upper fluvial complex that plant fossil assemblages are well preserved, and these are the focus of the present project.

The fluvial complexes are composed of at least seven distinct lithofacies (Pöppelreiter, 1992). The basal contact overlying Oberflöz II is sharp and erosional, and the lithologies directly overlying the contact are variable along the strike of the highwall. These include coarse granule-supported (average -1.31ϕ : samples 3 and 4, Fig. 2) pebble conglomerates and cross-bedded sands that range in grain size from very coarse (-0.48ϕ : sample 1, Fig. 2) through medium (0.25ϕ : sample 2, Fig. 2) to very fine ($\phi = 3.5$; Pöppelreiter, 1992). The section fines upward from lenticular bodies of cross-bedded pebble-conglomerates and pebbly-sand through coarse to fine sand. Soft sediment deformation, including convolute bedding, may occur in the finer sands and some of these deposits may be deeply rooted (Pöppelreiter, 1992, figs. 37, 39). A sharp contact exists with overlying very fine silt (8ϕ ; Paläoboden of Pöppelreiter, 1992) or clay (10ϕ ; Thierbacher Ton of Pöppelreiter, 1992) that are bioturbated by rooting structures. Very fine silt (7ϕ ; Altwasserton of Pöppelreiter, 1992) and clay (10ϕ) are restricted within small channel-form structures, three of which are seen along the highwall

Table 1
Summary of the probable life forms, dispersal mechanisms and physiognomic signatures of the Bockwitz taxa, based on the representation of the different plant parts in the assemblages

Family	Genus	Leaves	Pollen/ spores	Diaspores	Primary dispersal mechanism	Life form	Deciduous/ Evergreen	Leaf margin entire
BRYOPHYTES								
Sphagnaceae	<i>Sphagnum</i>	x	x		wind	hydrophyte		
FERNS AND FERN-ALLIES								
Lycopodiaceae	<i>Lycopodium</i>		x		wind	chamaephyte		
Osmundaceae	<i>Osmunda</i>		x		wind	hemycryptophyte		
Polypodiaceae	gen. indet.		x		wind	geo-/hemycryptophyte		
Salviniaceae	<i>Salvinia</i>	x	x		nautochory	hydrophyte		
Selaginellaceae	<i>Selaginella</i>		x		wind	chamaephyte		
GYMNOSPERMS								
Cephalotaxaceae	<i>Cephalotaxus</i>	x		x	endozoochory	phanerophyte	E	
Cupressaceae s.s.	<i>Taxodium</i>	x		x	wind	phanerophyte	E	
	gen. indet.		x		wind	phanerophyte	E	
Ginkgoaceae	<i>Ginkgo</i>		x		endozoochory	phanerophyte	D	
Pinaceae	<i>Abies</i>		x	x	wind	phanerophyte	E	
	<i>Cathaya</i>		x		wind	phanerophyte	E	
	<i>Picea</i>	x	x	x	wind	phanerophyte	E	
	<i>Pinus</i>		x(div.)	x(4)	wind	phanerophyte	E	
	<i>Pseudolarix</i>		x	x	wind	phanerophyte	D	
	<i>Pseudotsuga</i>		x	x	wind	phanerophyte	E	
	<i>Tsuga</i>		x(2)	x	wind	phanerophyte	E	
Sciadopityaceae	<i>Sciadopitys</i>		x		wind	phanerophyte	E	
Taxodiaceae s.s.	' <i>Athrotaxis</i> ' †	x		x	wind	phanerophyte	E	
	<i>Cunninghamia</i>			x	wind	phanerophyte	E	
	<i>Glyptostrobus</i>			x(2)	wind	phanerophyte	D	
	<i>Sequoia</i>			x	wind	phanerophyte	E	
	<i>Taxodium</i>	x		x	wind	phanerophyte	D	
	gen. indet.		x		wind	phanerophyte	D/E	
ANGIOSPERMS								
DICOTYLEDONS:								
Aceraceae	<i>Acer</i>	x(3)	x	x	wind	phanerophyte	D/(E)	yes(1)/no(2)
Alangiaceae	<i>Alangium</i>		x		endozoochory	phanerophyte	D/E	yes
Altingiaceae	<i>Liquidambar</i>	x	x	x	wind	phanerophyte	D	no
Anacardiaceae	<i>Rhus</i> s.l.		x		endozoochory	phanerophyte incl. liana	D/E	yes/no
Aquifoliaceae	<i>Ilex</i>		x(2)	x	endozoochory	phanerophyte	D/E	yes/no
Araliaceae	<i>Aralia</i>			x	endozoochory	chamae-/hemycrypto-/phanerophyte	D	yes/no
	<i>Pentapanax</i>			x	endozoochory	phanerophyte	E	yes/no
	<i>Schefflera</i>			x	endozoochory	phanerophyte incl. liana	E	yes/no
	gen. indet.		x		endozoochory	phanerophyte incl. liana	(D)/E	yes/no

Table 1 (continued)

Family	Genus	Leaves	Pollen/ spores	Diaspores	Primary dispersal mechanism	Life form	Deciduous/ Evergreen	Leaf margin entire
Betulaceae s.l.	<i>Alnus</i>	x	x	x(2)	wind	phanerophyte	D	no
	<i>Betula</i>		x	x	wind/endozoochory	chamaephyte/phanerophyte	D	no
Caprifoliaceae	<i>Carpinus</i>	x	x	x	wind	phanerophyte	D	no
Cercidiphyllaceae	<i>Sambucus</i>		x	x	endozoochory	hemicyptophyte/phanerophyte	D	no
Chenopodiaceae	<i>Cercidiphyllum</i>	x	x		wind	phanerophyte	D	no
	gen. indet.		x		wind/endozoo-/exozoo-/ nautochory	(hemicypto-/phanero-)/ therophyte	H	H
Ebenaceae	<i>Diospyros</i>		x		endozoochory	phanerophyte	D/E	yes
Ericaceae	<i>Rhododendron</i>		x		autochory/wind	chamaephyte/phanerophyte	D/E	yes
			x			incl. epiphytes		
Fagaceae	gen. indet.		x		autochory/wind	chamaephyte/phanerophyte	D/E	yes/no
	<i>Eotrigonobalanus</i> †		x	x	dyschory	phanerophyte	D/E	rarely
	<i>Fagus</i>	x	x	x	dyschory	phanerophyte	D	yes
	<i>Quercus</i>	x	x(3)	x	dyschory	phanerophyte	D/E	no
	<i>Trigonobalanopsis</i> †	x	x		dyschory	phanerophyte	E	yes
Flacourtiaceae	<i>Poltiothrysis</i>		x	x	wind	phanerophyte	D	no
Hamamelidaceae s.s.	<i>Dispyllum</i>	x	x		autochory	phanerophyte	E	yes
	gen. indet.		x		autochory/wind	phanerophyte	D/E	yes/no
Hypericaceae	<i>Hypericum</i>		x	x	?	chamae-/hemicypto-/phanero-/ therophyte	D/E	yes
Illiciaceae	<i>Illicium</i>		x	x	autochory?/endozoochory?	phanerophyte	E	yes
Juglandaceae	<i>Carya</i>		x		dyschory	phanerophyte	D	no
	<i>Cyclocarya</i>	x	x	x	wind	phanerophyte	D	no
	<i>Engelhardtia</i>	x	x		wind	phanerophyte	D/E	no
	<i>Pterocarya</i> s.l.		x		wind	phanerophyte	D	no
Lamiaceae (Labiatae)	<i>Collinsonia</i>		x	x	myrmecochory	hemicyptophyte	H	H
Lauraceae	<i>Daphnogene</i> †	x		x	endozoochory	phanerophyte	E	yes
	<i>Laurocarpus</i> †		x		endozoochory	phanerophyte?	D/E	yes
	<i>Laurophyllum</i> †	x		x	endozoochory	phanerophyte	D/E	yes
Loranthaceae s.l.	<i>Arcuthobium</i>		x		autochory	chamaephyte	H	H
	<i>Viscum</i>	x		x	endozoochory	phanerophyte	E	yes
	<i>Decodon</i>		x	x(2)	auto-/endozoo-/nautochory	hemicyptophyte	H	H
Lythraceae	<i>Microdipiera</i> †		x	x(2)	nautochory?	hydrophyte	H	H
Magnoliaceae	<i>Liriodendron</i>		x	x	wind	phanerophyte	D	yes
	<i>Magnolia</i>		x	x(2)	endozoochory	phanerophyte	D/E	yes
	<i>Manglitia</i>		x	x	endozoochory	phanerophyte	E	yes
Mastixiaceae	<i>Mastixia</i>		x	x	endozoochory	phanerophyte	E	yes
Moraceae	<i>Ficus</i>		x	x	endozoochory	phanerophyte—liana	(D)/E	yes/no
Myricaceae	<i>Comptonia</i>		x	x(2)	endozoochory	phanerophyte	D	no
	<i>Myrica</i>		x		endozoochory	phanerophyte	D/E	yes/no
Nyssaceae	<i>Nyssa</i>	x(2)	x	x(2)	endozoochory	phanerophyte	D	yes(1)/no(1)
Oleaceae	<i>Fraxinus</i>		x	x	wind	phanerophyte	D	yes/no

Table 1 (continued)

Family	Genus	Leaves	Pollen/ spores	Diaspores	Primary dispersal mechanism	Life form	Deciduous/ Evergreen	Leaf margin entire
Plantaginaceae	gen. indet.		x		wind/endozoo-/exozoo-/ myrmecochory	chamae-/hemicrypto-/therophyte	H	H
Platanaceae	<i>Platanus</i>	x	x	x	wind	phanerophyte	D	no
Rhamnaceae	<i>Ziziphus</i>		x	x	endozoochory	phanerophyte	D/E	no
Rosaceae s.l.	<i>Prunus</i>		x	x	endozoochory	(hemicrypto-)/phanerophyte	D/E	yes/no
	<i>Rubus</i>		x(4)		endozoochory	liana	D/E	no
	gen. indet.		x		wind/endozoo-/exozoochory	chamae-/hemicrypto-/phanero-/ therophyte	D/E	yes/no
Rutaceae	<i>Zanthoxylum</i>		x		endozoochory	phanerophyte	D/E	yes/no
Salicaceae	<i>Populus</i>	x(2)			wind	phanerophyte	D	no
	<i>Salix</i>	x			wind	chamaephyte/phanerophyte	D	no
Sapindaceae	<i>Sapindospermum</i> †		x	x	wind/endozoochory/nautochory	(hemicrypto-)/phanerophyte	D/E	yes/no
Sapotaceae	gen. indet.		x		endozoochory	phanerophyte	D/E	yes
Saururaceae	<i>Saururus</i>		x	x	endozoochory/? nautochory	hydrophyte	H	H
Styracaceae	gen. indet.		x		wind/dys-/endozoochory	phanerophyte?	D/E	yes/no
Symplocaceae	<i>Sphenotheca</i> †		x	x	endozoochory?	phanerophyte?	?	?
	<i>Symplocos</i>		x	x(2)	endozoochory	phanerophyte	(D)/E	yes/no
Theaceae	<i>Eurya</i>	x			endozoochory	phanerophyte	E	yes/no
	<i>Ternstroemites</i> †	x			endozoochory	phanerophyte	E	yes/no
Tiliaceae	gen. indet.		x		wind/endozoo-/exozoo-/ nautochory	(chamae-/hemicrypto-)/ phanerophyte	D/E	rarely
Ulmaceae	<i>Ulmus</i>	x(2)	x		wind	phanerophyte	D	no
	<i>Zelkova</i>		x		wind	phanerophyte	D	no
Viaceae	<i>Ampelopsis</i>		x	x	endozoochory	phanerophyte—liana	D	no
	<i>Parthenocissus</i>		x(2)		endozoochory	phanerophyte—liana	D/(E)	no
	<i>Vitis</i>	x	x(2)		endozoochory	phanerophyte, mostly liana	D/(E)	no
	gen. indet.		x		endozoochory	phanerophyte, mostly liana	D/(E)	no
MONOCOTYLEDONS:								
Araceae	<i>Epipremites</i> †			x	endozoochory?	hemycryptophyte?		
Areaceae (Palmae)	gen. indet.		x		endozoochory/nautochory	phanerophyte incl. liana		
Cyperaceae	<i>Cladiocarya</i> †			x(2)	endozoochory/ nautochory/hemycryptophyte			
	<i>Scirpus</i>		x		endozoo-/exozoo-/nautochory	geophyte/hemycryptophyte		
Hydrocharitaceae	<i>Stratiotes</i>		x		nautochory	hydrophyte		
	<i>Vallisneria</i>		x		endozoochory/? nautochory	hydrophyte		
Poaceae (Gramineae)	gen. indet.		x		wind/endozoo-/exozoochory	geo-/hemicrypto-/phanero-/ therophyte		
Smilacaceae	<i>Majanthemophyllum</i> †	x			endozoochory?	phanerophyte?		
Sparganiaceae	<i>Sparganium</i>			x(2)	endozoochory/nautochory	hydrophyte		
Zingiberaceae	<i>Spirematospermum</i> †			x	endozoochory	hemycryptophyte		

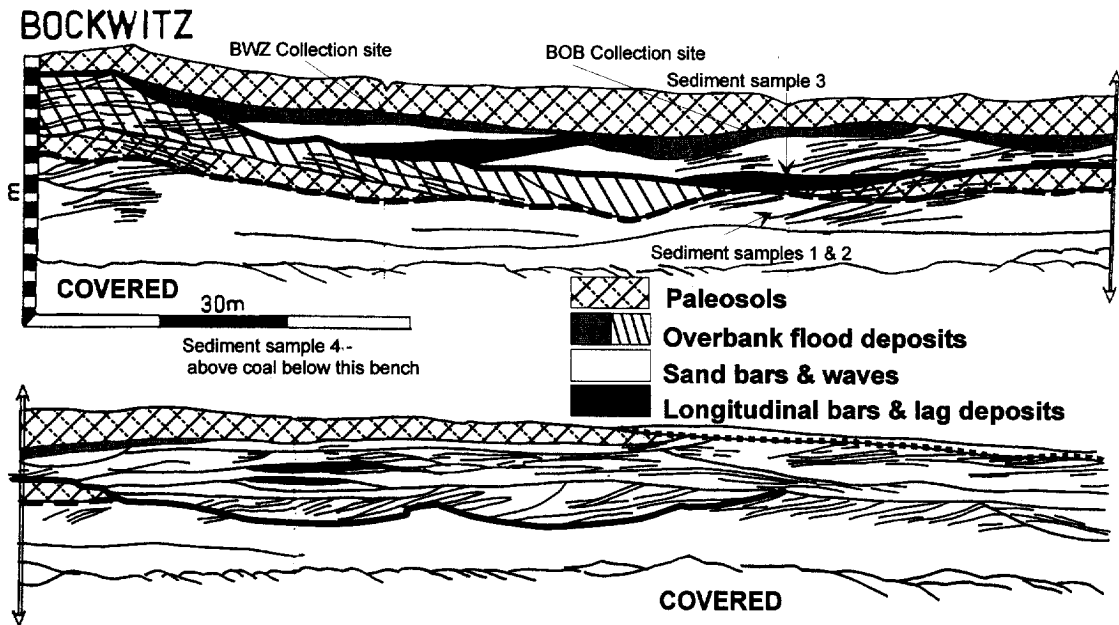


Fig. 2. Line illustration traced from a photomosaic of the highwall in Tagebau Bockwitz taken in October 1991. Lithofacies interpretations are based on the identification of fluvial architectural elements after Miall (1977, 1978). Locations of sediment samples referred to in the text are indicated, as well as the collection sites for palynological sections. Four channel systems can be seen in the highwall, the bases of three are indicated by (1) a thick dashed line, (2) a thick solid line (sediment sample 3), and (3) a thick dotted line. The basalmost channel system overlies Oberflöz II (sediment samples 1, 2, and 4).

(Fig. 2). The greatest width of these channel-forms is approximately 35 m.

The channel-fill sequence within each of these scours fines upward (Fig. 3). The basal part of the fill is composed of a bed (up to 7 cm) of poorly sorted fine sand (Munsell color 5 Y 6/1) in which isolated ripples and isolated coarse-sand clasts occur. In addition, small quartz pebbles may be dispersed throughout this bed. Evidence for soft-sediment deformation includes micro-flame structures. Overlying the basal bed are fining upward, generally planar laminations of fine-sand and/or silt (Munsell color 5 Y 6/1) alternating with clay. Light (Munsell colors 5 Y 6/1 and N6) and dark (Munsell color N5) clay beds occur, with dark-colored beds concentrated near the top of the preserved portion of the channel-fill. Fine lamination characterizes the clay fraction, whereas low amplitude ripple crests may be present at the contact between coarser and finer sediments. Horizontal and shallow vertical burrows filled with clean sand occur near the base of the channel fill. The silt and clay fractions increase vertically, with fine sand found in isolated beds up to 0.5 cm thick or starved ripples.

Higher in the preserved section, starved ripples are composed of very fine sand and coarse silt. These may be slightly burrowed. The uppermost portion of the channel-fill sequence has been homogenized by intense rooting originating from the overlying mudstone.

A thick mudstone, 10 to 19 m, overlies this channel complex and is heavily bioturbated by rooting. It is not possible to trace the edges of the three smaller channels into this overlying unit. Primary sedimentary structures are no longer visible, but secondary features, such as slickensides, are common.

4.2. Paleosols

Two paleosols have been identified in the studied interval (Fig. 2), each of which represents the culmination of alluvial plain aggradation. The first, found at the top of the lowermost fluvial complex, is just a remnant of a laterally extensive soil that attains a maximum thickness of 1.7 m. The second, found at the top of the section, is a very thick and laterally extensive soil.

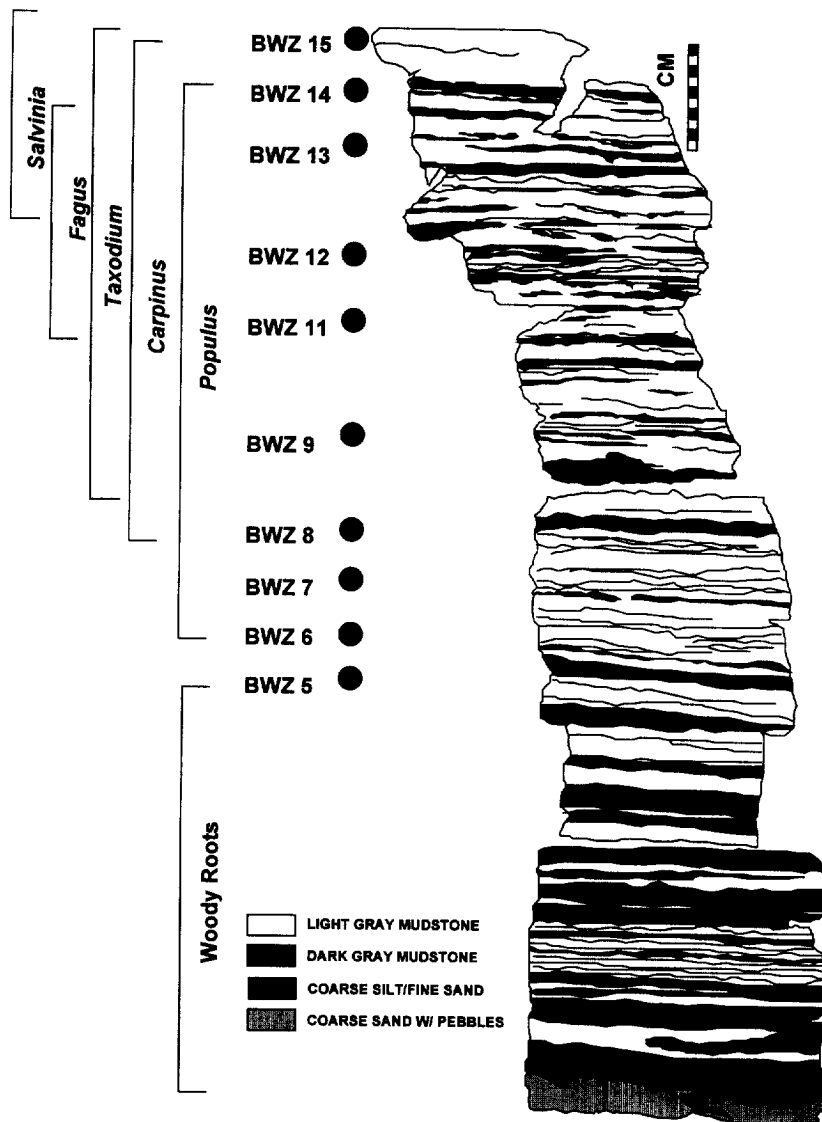


Fig. 3. Sedimentological detail of the basal 1.10 m of channel-fill sequence. The locations of palynological samples are indicated and the range of preserved megafloral taxa are noted. See Gastaldo et al. (1996) for details of the sedimentology and megafloral distribution.

Sedimentologically, the lowermost paleosol (Fig. 4) is a mixture of silt and clay that fines upwards to an organic-rich horizon. No primary sedimentary structures are present as the sediment has been homogenized, and there are no diagnostic pedogenic properties. Small, claystone clasts are scattered within the unit. Large diameter (>1 cm) woody roots may penetrate vertically through the soil and penetrate the underlying sandy barform (Pöppelreiter, 1992). At least one tree base has been identified

in situ. Because it is possible to differentiate soil horizons, this silt-clay paleosol is interpreted as an Inceptisol (after Retallack, 1990).

The uppermost paleosol (Thierbacher Ton) can be divided into two distinctive zones, the Altwasserton and the Kaolinton of Pöppelreiter (1992). The basal 2 m, or the Altwasserton, represents the initial aggradation phase of abandoned channel fill, or oxbow lake (Gastaldo et al., 1996). It is characterized by a fining upwards sequence of alternating sand, silt,

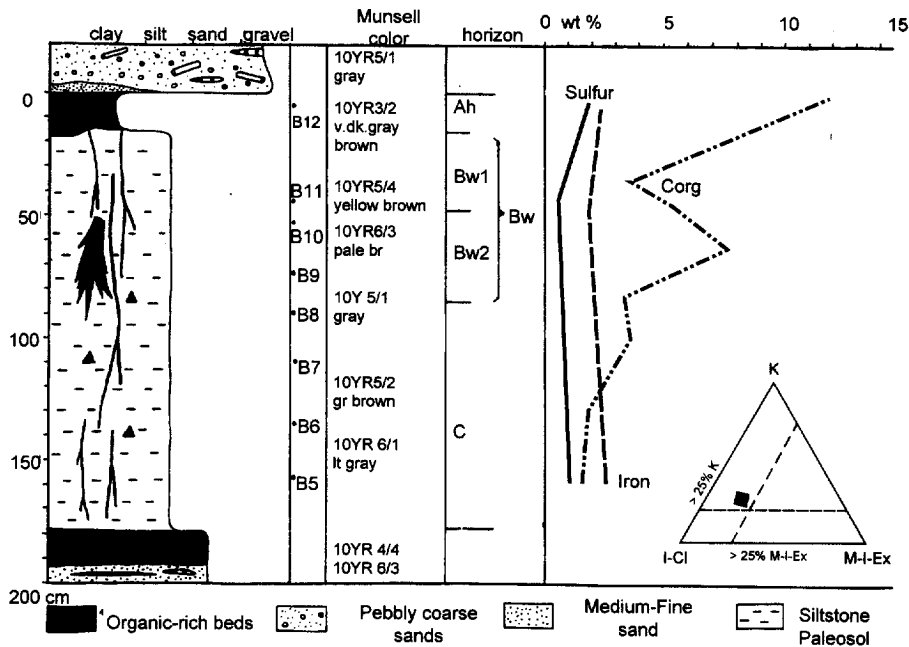


Fig. 4. Details of the lowermost paleosol identified in Fig. 2. The ternary diagram plots the clay mineralogy of the Thierbach Clay. Symbols: A = soil forming processes that are mainly organic; B = soil-forming processes that are mainly inorganic; h = alluvial accumulation of organic matter; w = colored by weathering or other soil-forming processes.

and clay (that may represent seasonal varves) with an admixture of phytoclasts (Fig. 3; see below). The remaining paleosol is a very thick (ranging from 8 to 17 m), whitish-gray to bluish-gray kaolinitic (Bellmann et al., 1982) fine silt (7.5ϕ ; Pöppelreiter, 1992) that is devoid of any primary structures. Large diameter woody roots penetrate both zones, but only the uppermost zone is completely homogenized. Slickensides are a common feature of this paleosol. Detailed mineralogical analyses have not been conducted to determine whether or not there has been any significant accumulation of either clay minerals or elements in the B-horizon. This soil preserves features that were caused by seasonal swelling and shrinking of clay minerals, resulting in slickensides, the destruction or homogenization of the substrate, and the destruction of primary sedimentary structures. Based upon these physical features, this soil is interpreted as a vertisol (Retallack, 1990). Vertisols are very young soils that develop under dry conditions in a subhumid to semi-arid climate, where there is a well established wooded grassland.

4.3. Depositional setting

The Thierbach Schichten have been interpreted to represent deposition in a river system (Eißmann, 1968) that was braided (Pöppelreiter, 1992; Kunzmann, 1995). It flowed in a northwesterly direction over low-grade metamorphosed Paleozoic rocks, Zechstein (Permian), and Buntsandstein (Triassic; Fig. 5). Its provenance was in the western Erzgebirge from which quartz, topaz, rutile, anatase, and tourmaline were supplied to the basin (Rost, 1933, as cited in Pöppelreiter, 1992). It is also possible that the kaolinitic character of the paleosols was derived from weathering products of Cretaceous siliciclastics. The presence of Erzgebirge-type heavy minerals in the Thierbach member accompanies clasts of an allochthonous weathering crust. This weathering crust is interpreted to have developed on Lower Cretaceous rocks exposed in the early Tertiary.

The identified lithofacies can be assigned to four of the fluvial architectural elements of Miall (1977, 1978): (1) Gm consisting of massive or crudely bedded gravels that may be clast supported; (2–3) Sp

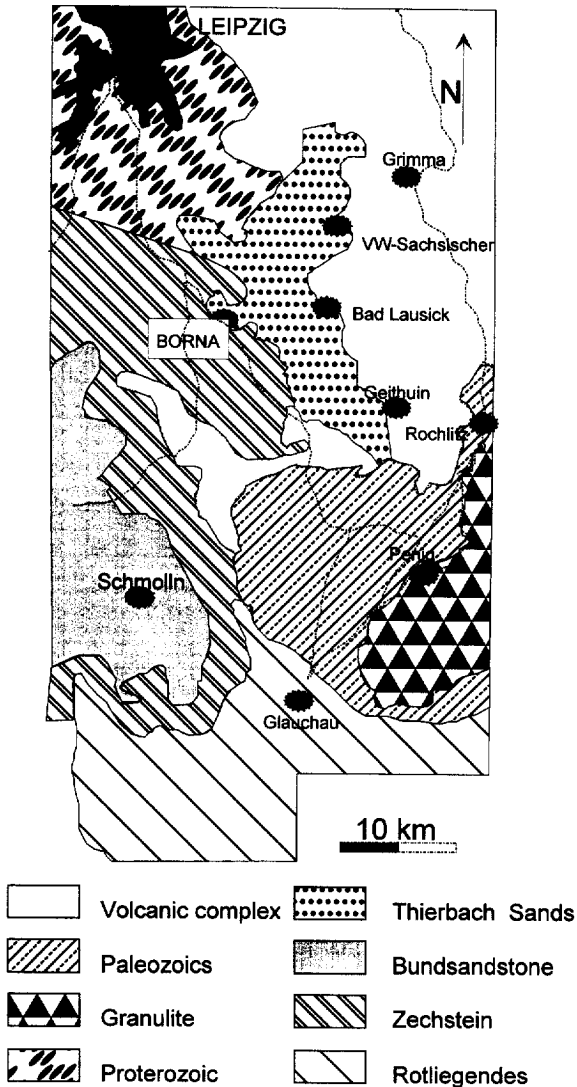


Fig. 5. Geologic map and distribution of the Thierbach member in the Weißelster basin (after Lauer, 1984).

and St consisting of very coarse to medium planar cross-stratified (Sp) or trough cross-stratified (St) sand that may be pebbly; and (4) Fl characterized by very fine sand, silt and clay that may be interbedded (Fig. 2). These architectural elements can be interpreted as representing longitudinal bars and channel lag deposits (Gm), subaqueous dunes (St) and sand waves (Sp) formed within the lower flow regimes, linguoid bars (Sp) formed within the upper flow regime, and overbank or waning flood deposits (Fl).

All structures may have the possibility of becoming stabilized through colonization in modern settings, but only the latter lithofacies are rooted in Bockwitz.

The Thierbach Schichten in Tagebau Bockwitz represents at least two depositional cycles of alluvial braidplain within the basin. Each of these cycles reflects several principle sedimentological events. The main controlling event was sporadic (aperiodic) flooding that resulted in (1) a variety of superposed bar forms that developed under decreasing discharge velocities, (2) reoccupation of channels causing cut and fill structures to form, and (3) overbank deposition of the fines with aggradation of the alluvial plain. Small-scale bedforms developed in response to periodic discharge resulting in accretion of lateral bars and point bars. Finally, channel aggradation resulted in the filling of abandoned channels due to waning energy and ultimately in the colonization and merging of these settings with the alluvial plain. The superposition of each braided floodplain is most probably due to subsidence caused by tectonic loading of the Alps to the south.

5. Distribution of phytological components

5.1. Megafossils

Autochthonous, allochthonous, and parautochthonous plant parts have been identified within the Thierbach Schichten (Fig. 6). Autochthonous megafossils are restricted primarily to the paleosols. This suite consists of lignitized and pyritized vertical to sub-horizontal rooting structures. Degraded OM and the base of an erect small shrub/tree have been found at the top of the lowermost paleosol where the interpreted Ah horizon exists (Fig. 5). The only other plant fossils that represents autochthony are complete specimens of the aquatic *Salvinia reusii* on bedding planes within the upper 0.5 m of the channel-fill sequence (Fig. 3). It is possible that autochthonous fruits and seeds are preserved in either the Ah horizon of the Inceptisol or the kaolinite-dominated B horizon of the uppermost paleosol, but these sites of accumulation have not been sampled to date.

Allochthonous megafossils are found as concentrated leaf litters that drape cross-set beds within river-channel deposits. The fossil suite includes lig-

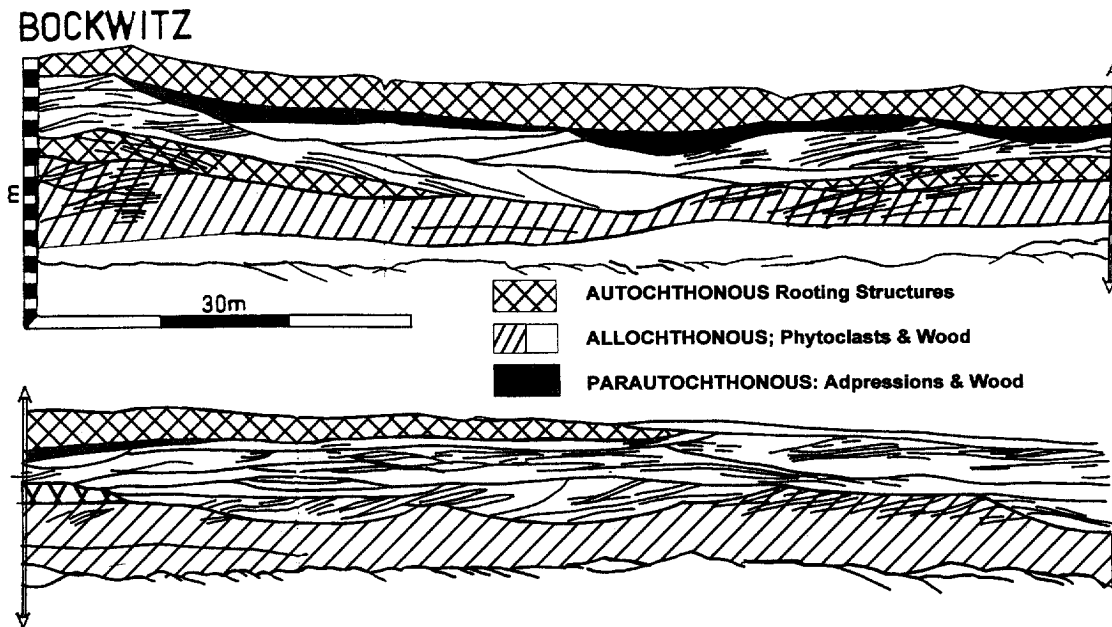


Fig. 6. Distribution of autochthonous, allochthonous, and parautochthonous megafossil assemblages in the sediments of Tagebau Bockwitz. Note that the parautochthonous assemblages that represent abandoned channel fills are also rooted from the paleosol lying above.

nitized wood and branches, some with attached bark, coriaceous leaves (typically lauraceous; H. Walther, pers. commun., 1992), seeds, and fruits. Based upon observations of the small exposures available, there appears to be no preferred orientation of these phytoclasts on the bedding surface, reflecting emplacement during waning discharge rather than deposition and alignment during flow. Basal lags of wood (Coarse Woody Debris; Robison and Beschta, 1990) may be present above the scour contact of channel-fill sequences. These probably represent allochthonous elements deposited prior to the abandonment and infilling of the channel. Leaf, fruit, and seed collections have been made from both the sandy barforms and the infill of the abandoned channels, but depositional site-specific assemblages have not been published. Rather, the generalized floristics of the locality have been documented (Mai and Walther, 1985, 1991).

The vast majority of plant megafossils have been interpreted to represent parautochthonous elements preserved within abandoned channels (Gastaldo et al., 1992). This interpretation is based upon the characterization of single bedding planes or leaf

accumulations that represented a single cluster of leaves within the abandoned channel fill sequence (Fig. 7). Gastaldo et al. (1996) evaluated these channel fills to determine: (1) whether or not entire leaves were size-sorted indicating an assemblage biased by transport; (2) whether or not leaf-size distribution of individual taxa might indicate that certain taxa may have had different transport histories; (3) whether or not the leaf population exhibited any preferential orientation thereby indicating abiotic influence(s) on the assemblage; and (4) whether or not any specific taxa may have different depositional histories. These authors have developed a set of criteria that are critical in identifying these phytoclasts as being parautochthonous. The criteria include: (1) a log-normal distribution of leaf sizes in the assemblage; (2) a log-normal distribution of leaf size in all dominant taxa; (3) a random directional orientation of leaves and, in the case of taxodiaceous conifers, branchlets with attached leaves on any particular bedding surface; and (4) a biased leaf-surface orientation that appears to be taxon-dependent.

Phytoclasts that comprise these parautochthonous assemblages include logs, branches, leaves, fruits,

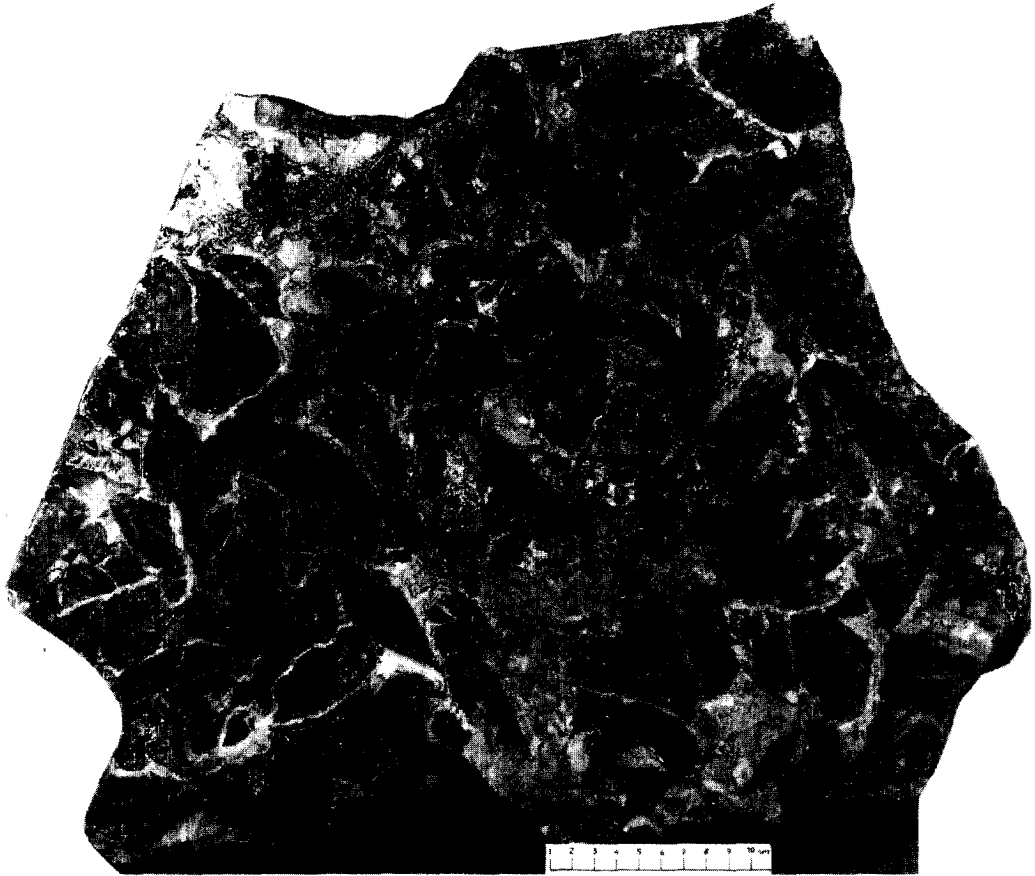


Fig. 7. Photograph of bedding plane exposure of parautochthonous channel-fill assemblage BOB 2252:1 (curated in the Staatliches Museum für Mineralogie und Geologie, Dresden) on which *Alnus rostaniana*, *Carpinus grandis*, *Taxodium dubium/balticum*, *Fagus saxonica*, *Ulmus carpinoides*, *U. drepanodonta*, *Populus germanica*, *Cyclocarya cyclocarpa*, *Liquidambar europaea*, and *Acer haselbachense* are preserved.

seeds, and rare flowers. The wood component increases up section as smaller diameter (up to 3 cm) lignitized branches become more abundant near the top. Those that have been examined in the field are variously orientated and are not found to be concentrated on any single bedding surface or horizon. Overall, the wood component does not comprise a quantitatively significant proportion of the assemblage.

Angiosperm leaves and taxodiaceous branchlets with attached leaves make up the vast majority of preserved specimens, but are not distributed evenly through the sequence (Fig. 3). Scattered leaf fragments are first seen where there is an increase in the proportion of clay-sized sediment. Leaves are virtu-

ally absent in the relatively coarser, basal channel fill. The first cluster of leaves is preserved within a thick (1.8 cm) homogenous light-gray claystone 0.43 m above the channel base. This leaf cluster is not directly overlying or associated with coarser clastics and is indicative of suspension load deposition probably related to dehiscence from riparian vegetation established along the channel margins. Leaf clusters are preserved from this point upwards to the top of the moderately bioturbated channel fill. There is an increasing density of leaves per linear centimeter upsection (Gastaldo et al., 1996). Rarely are leaves found within or draping coarse silt- or fine-sand ripples or planar laminae, and they are not found to be more clustered in the darker-gray clay beds.

Concentrated leaves occur within clusters up to as many as 8 leaves (generally clusters are comprised of 3–5 leaves), and appear in the form of overlapping individual leaves when bedding planes are exposed (Fig. 7). Leaves comprise the greatest plant part component. Fruits and seeds are interspersed within the leaf assemblage and constitute a small fraction of total biomass, although the diversity (the number of species within a collection) of this fossil suite is higher than that of the leaves (Table 1; Mai and Walther, 1991).

Within the vertical section that we have examined in detail, it appears that there is also a discrete distribution with respect to the predominant leaf taxa (Fig. 3). *Populus* and *Carpinus* are initially encountered in the first leaf clusters, with an increase in diversity 13 cm higher in the section. The number of taxa remains relatively constant until 0.71 m above the basal contact where two new elements, *Cyclocarya* and *Salvinia*, appear for the first time. This distribution may reflect either community enhancement (increasing number of plants inhabiting the channel margins over time) or localized taphonomic factors/filters (which would include either a restricted contribution of marginal plants at the time of early infill, or a more representative sampling of the vegetational mosaic that lined the channel margins at this particular sampling site during accumulation).

5.2. Microfossils

Palynomorphs and palynodebris are found throughout the Thierbach member. Samples have been analyzed from the range of depositional settings (Riegel et al., 1992) and two channel-fill sequences (Figs. 8–10). Pollen of taxa identified from the leaf collections have been categorized separately within the counts to determine if their representation within the section display wide variation (Plates I and II). Statistically, there is no variation in systematic representation throughout the channel fills with the exception that *Carpinus* is more abundant in the BWZ channel fill sequence (Table 2; Fig. 2). Diversity increases upsection where leaf assemblages are first preserved (which may be the result of reduced water flow through the channel and local concentration of pollen). The lowest samples differ from the remainder of the section by the absence of *Sciadopitys*.

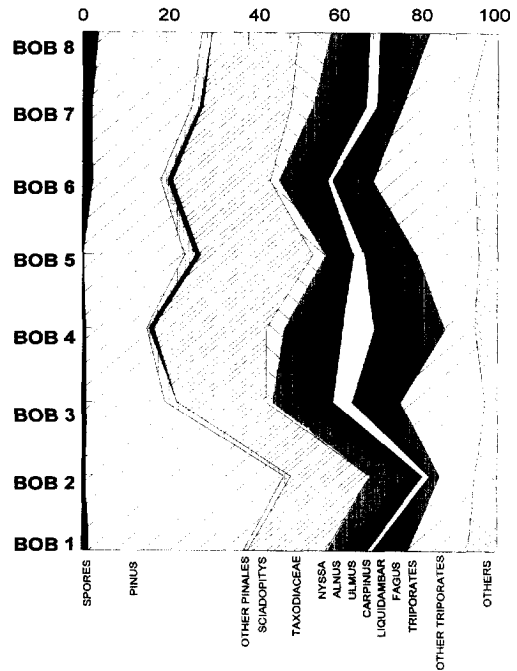


Fig. 8. Palynological spectrum of channel section BOB through one channel-fill sequence. See Fig. 1 for location of samples.

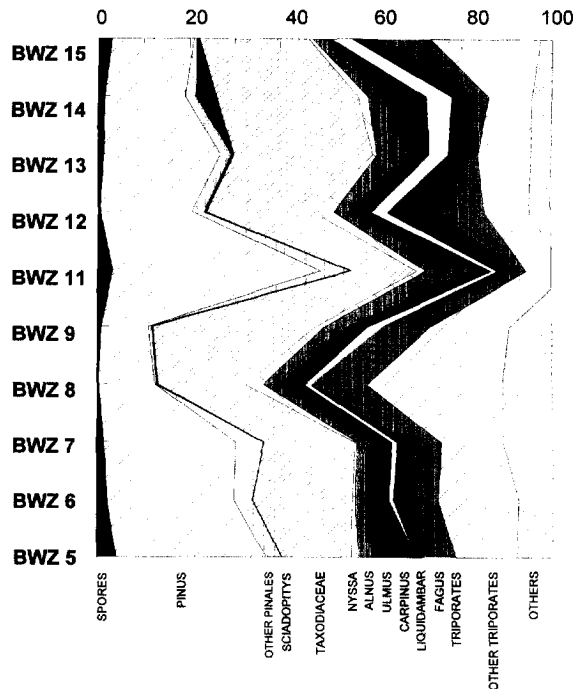
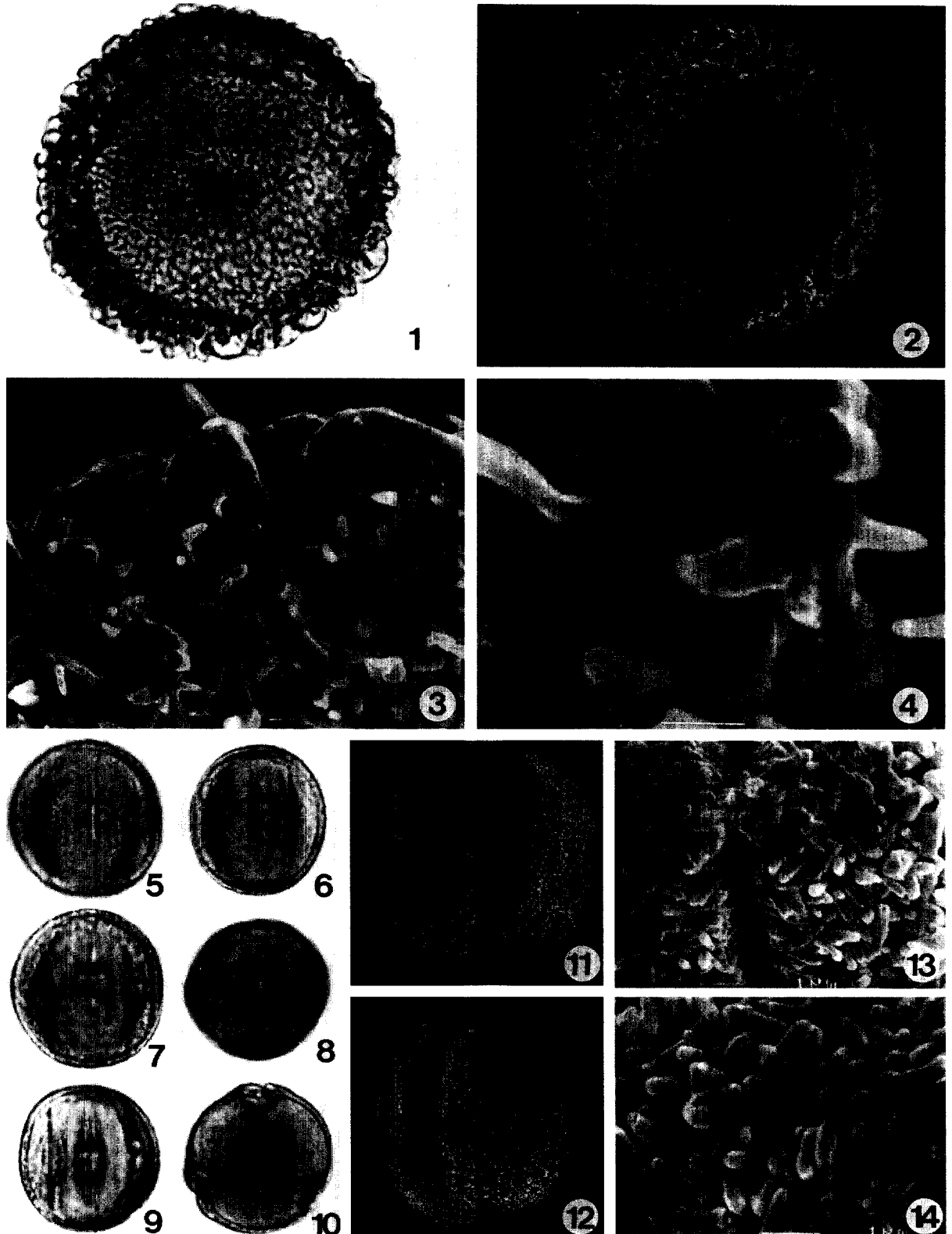


Fig. 9. Palynological spectrum of channel section BWZ through one channel-fill sequence. See Fig. 1 for location of samples.

PLATE I



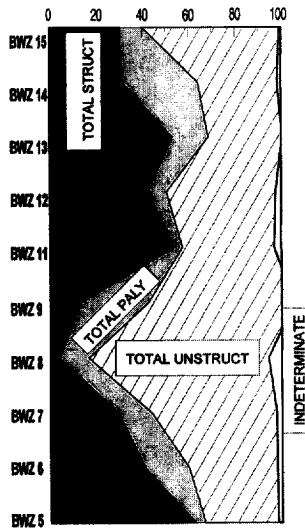


Fig. 10. Distribution of first-order palynofacies categories throughout the BWZ channel-fill section.

Palynofacies assemblages (Fig. 10) are also relatively consistent throughout the channel fill sequence, with the exception of an increased amount of Total Unstructured OM in sample BWZ 8. Structured OM consists mainly of other plant tissues that may include high proportions of peridermal cells (secondarily introduced into the sediments through rooting), degraded tissues (structured indeterminate), and fungal remains (Table 3). The Palynological components are comprised of sporomorphs, algae, fungal spores, and bacterial aggregates. Finely Dispersed (<5 μm diameter) Unstructured OM pre-

Table 2

Results of Mann–Whitney nonparametric analyses comparing the rank order abundance of palynological spectra in two adjacent channel fills, BOB and BWZ. Refer to Fig. 2 for location in the highwall

	Spores	<i>Pinus</i>	Other Pinales
BOB:BWZ	$z = 0.49; p = 0.63$	0.18; 0.86	1.24; 0.24
	<i>Sciadopitys</i>	Taxodiaceae	<i>Nyssa</i>
BOB:BWZ	0.36; 0.72	0.36; 0.72	0.66; 0.50
	<i>Alnus</i>	<i>Ulmus</i>	<i>Carpinus</i>
BOB:BWZ	0.44; 0.65	10.11; 0.27	20.17; 0.03
	<i>Liquidambar</i>	<i>Fagus</i>	<i>Triporates</i>
BOB:BWZ	0.31; 0.76	0.97; 0.33	10.28; 0.20
	other <i>Triporates</i>	indeterminate	
BOB:BWZ	0.57; 0.56	0.13; 0.89	

dominates this palynofacies category, with accessory amounts of homogenous and ‘fluffy’ OM.

5.3. Biochemical markers

Otto et al. (1995) subjected samples from the channel-fill sequence to biogeochemical analyses. They found that air dried samples that were Soxhlet-extracted with dichloromethane and derivatized with BSTFA/pyridine yielded series of *n*-alkanes, *n*-alkanols, and *n*-carboxylic acids along with several terpenoids. When they compared the extracted chemical compounds and the megafloral record preserved within the channel fill, they found a relationship between biomarker occurrence and fossil occurrence (Fig. 11). The terpenoid, simonellite (reported to be an alteration product of abietic acid; Simoneit et al., 1986), occurred only in the *Taxodium*-bearing leaf clusters while alkanes, alkanols, carboxylic acids and β -amyryn were present throughout the entire profile. The lipid fractions recovered from the sediments originated mainly from epicuticular waxes of the megafloral components and from the roots.

6. Benefits of multidisciplinary data sets

6.1. Paleobotanical-sedimentological

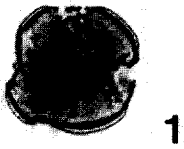
Isolated and disarticulated plant parts can be considered as sedimentary organic particles, or phyto-

PLATE I

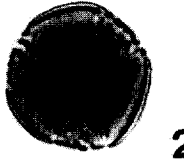
Selected pollen grains from Tagebau Bockwitz.

- 1–4. *Tsuga* sp.
 1. Distal view, LM. $\times 850$.
 2. Proximal view, SEM. $\times 850$.
 3. Detail of saccus area, SEM. Note the spinules characteristic of Holocene eastern Asiatic species. $\times 4000$.
 4. Detail of the sculpture of the proximal surface. $\times 14,000$.
- 5–14. *Fagus bockwitzensis* Walther et Zetter.
 - 5–9. Equatorial view, LM. $\times 850$.
 10. Polar view, LM. $\times 850$.
 - 11–12. Equatorial view, SEM. $\times 1400$.
 13. Detail of the exine in the aperture region, SEM. $\times 8000$.
 14. Detail of the exine in the mesocolpium, SEM. Note the short, rod-like twisted elements characteristic of the genus. $\times 10,000$.

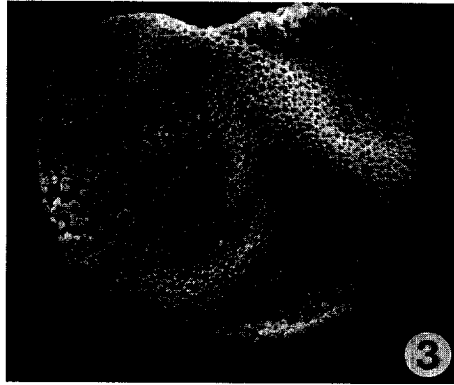
PLATE II



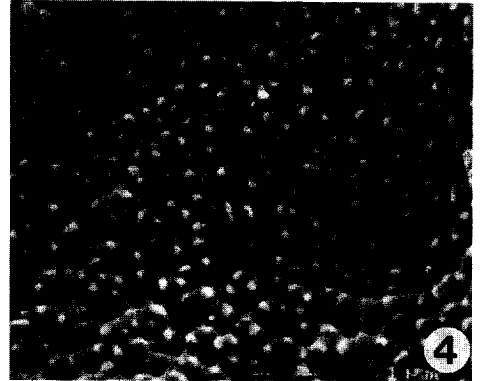
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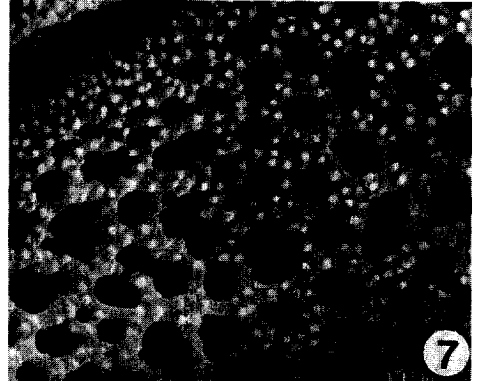
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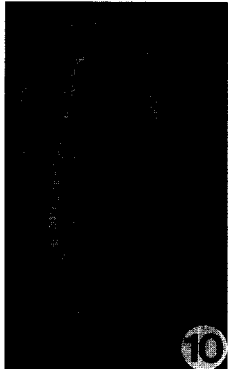
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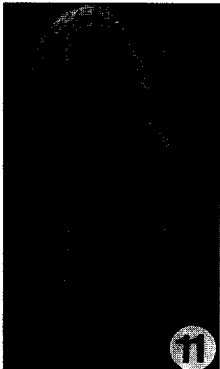
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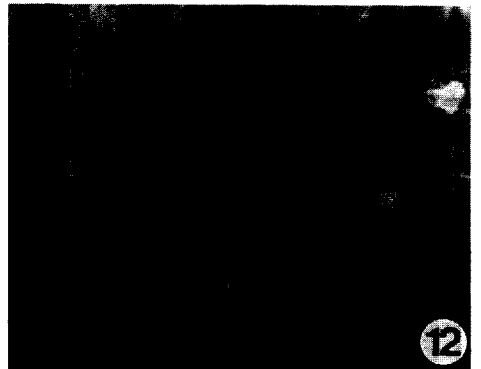
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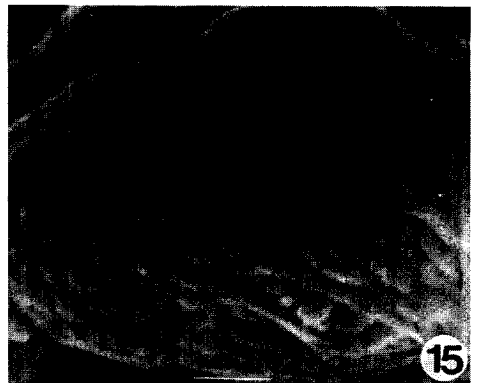
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14



15

clasts. Each clast is affected by the hydrodynamic system in which it resides during the biostratigraphic phase prior to burial (see Traverse, 1994). Just as sedimentary structures reflect a great variation in hydrologic conditions operating during their development and emplacement, the same is true for the megafloreal and microfloreal assemblages that are incorporated within. Sedimentological and paleobotanical data sets compliment each other because characteristics of the fossil assemblages can be directly related to physical conditions under which they were transported (or grew), deposited, buried and preserved (Gastaldo, 1988; Spicer, 1989; Greenwood, 1991). In the case of autochthonous or parautochthonous assemblages, an understanding of the clay mineralogy of the matrices preserving the fossils provides insight into the physico-chemical conditions operating in the regime that may be a direct reflection of paleoclimate (see: Retallack, 1990). Each different physical setting will provide a slightly different data set from which specific information

can be derived. This is particularly true for the palynological fraction, the composition of which has been shown to correlate well with grain size (see Traverse, 1994). An assessment of the fossils recovered from all the depositional settings within one particular environment of deposition (for example, the carpological, megafloreal, and microfloreal elements from all sites within a fluvial complex) will allow the researcher to better define the diversity of autochthonous, parautochthonous, or allochthonous assemblages. Multivariate analyses applied to such data taken within depositional context may provide a basis from which to interpret communities (e.g., Burnham, 1990).

Some data sets may be contradictory with regard to which floristic elements are present and characterize a specific depositional site. It has been well demonstrated that the hydrologic constraints under which floristic assemblages form, even within a single cross bed set, change within the regime (e.g., Spicer, 1980; Spicer and Wolfe, 1987). The types of phytoclasts that can be recovered and the 'significance' attributed to them from collections made from only one of all possible sites can be extremely biased without integration of the sample site(s) into a depositional framework. The discrepancies in the presence or absence of a unique form/taxon is particularly true in palynological data. Here, the overall assemblage may be significantly influenced by the presence of water-borne phytoclasts, presenting the appearance of a heterogenous mix of diverse taxa (that may reflect an extrabasinal contribution). This contrasts with pollen and spore assemblages that originated through air-borne dispersal and may appear more uniform in composition because of the local or regional character of the contributing vegetation.

Processing for dispersed organic matter (paly-nofacies) and its biogeochemical characteristics in sedimentary facies where there are no macrofloral elements provides a potential data set that amplifies cryptic information. It is possible to obtain data that reveal the physical and biological development of the environment, such as the presence of phytoplankton in poorly developed soils (vertisols or inceptisols) indicating lacustrine fill and hydrosere evolution (Riegel et al., 1992). Such information can also be obtained from the OM lipid fraction with the

PLATE II

Selected pollen grains from Tagebau Bockwitz.

- 1–4. *Distylium* sp.
1. Tetracolpate pollen grain, polar view, LM. $\times 850$.
2. Tricolpate pollen grain, polar view, LM. $\times 850$.
3. General view, SEM. Note the broad aperture with membrane composed of fused verrucae. $\times 2100$.
4. Detail of the mesocolpium, SEM. Note tectum perforatum with nanoverrucate sculpture. $\times 10,000$.
- 5–7. Hamamelidaceae gen. indet.
5. Tricolpate pollen grain, LM. $\times 850$.
6. The same grain, SEM. $\times 1600$.
7. Detail of the mesocolpium, SEM. Note the transition between the tectum perforatum next to the aperture and the heterobrochate reticulum in the middle of the mesocolpium. The broad muri with numerous nanoverrucae are similar to those of the genus *Fortunearia*. $\times 6000$.
- 8–12. *Eotrigonobalanus eizmannii* Walthers et Zetter.
- 8–9. Equatorial view, LM. $\times 850$.
- 10–11. Equatorial view, SEM. Note the variation in shape. $\times 2200$.
12. Detail of the mesocolpium displaying a tectum perforatum with a sculpture consisting of radially orientated short striae. SEM. $\times 12000$.
- 13–15. *Lithocarpus* sp.
13. Equatorial view, LM. $\times 850$.
14. Equatorial view, SEM. $\times 5500$.
15. Detail of the mesocolpium, SEM. Note the rugulate ornamentation. $\times 10,000$.

Table 3
 Palynofacies analyses of BWZ channel fill

	BWZ 15	BWZ 14	BWZ 13	BWZ 12	BWZ 11	BWZ 9	BWZ 8	BWZ 7	BWZ 6	BWZ 5
Woody	0	0.5	2.7	3.1	5.4	0	0.6	0	1.4	0.6
Epid/cuticle	1.2	0	3.6	0.6	0.3	0.6	0	2.9	1.1	0.6
Other plant	13	6.7	16.1	8.7	21.7	4.5	1.9	8.3	9.7	42.6
Fungal	0.3	0.3	2.4	4.7	5.4	0	0	0.3	6.8	7.1
Indeterminate	16.1	24.2	28.5	25.5	21.3	8.6	1.9	18	22	11.9
Total struct	30.6	31.7	53.3	42.6	54.1	13.7	4.4	30	41	62.8
Spores	7.4	18.8	5.5	3.1	2.6	6.1	3.2	10	15.8	1.3
Algae	0	0.5	1.5	0	0	1.3	0	0.9	0.3	1
Fungal sp.	0	0	1.8	2.5	0.6	0.3	0	1.2	2.7	0.6
Bacterial	2.2	13.2	6.4	2.2	0	21.1	9	1.7	0	1
Total paly	9.6	32.5	15.2	7.8	3.2	28.8	12.2	14	18.8	3.9
Homogenous	0.9	4.8	12.4	14	22.9	8	4.2	9.5	9	3.9
Heterogenous										
Fluffy	2.2	2.7	2.4	5.6	1.9	7	27	9.2	9	6.7
Finely dispersed	56.2	27.2	17	28.3	15.6	46.6	48.2	36	20.7	21.5
Total unstruct	59.3	34.7	31.8	47.9	40.4	61.6	79.4	55	38.7	32.1
Indeterminate	0.6	1.1	0	1.9	2.2	0	2.9	1.7	1.6	1.3
Total struct	30.6	31.7	53.3	42.6	54.1	13.7	4.4	30	41	62.8
Total paly	9.6	32.5	15.2	7.8	3.2	28.8	12.2	14	18.8	3.9
Total unstruct	59.3	34.7	31.8	47.9	40.4	61.6	79.4	55	38.7	32.1
Indeterminate	0.6	1.1	0	1.9	2.2	0	2.9	1.7	1.6	1.3

recognition of algal-derived lipids, but such interpretations could not be made on sedimentological and paleopedological data alone.

6.2. Paleobotanical–palynological

In a perfect world theoretically there should be a 1:1 correlation between the megafloreal and the microfloreal records. In reality, there are such vast differences in the vegetative and reproductive productivity of taxa and the taphonomic filters through which each must pass, that paleobotanical and palynological data sets from the same sediment often provide a very different floristic picture (Table 1). For instance, the following families are still only known in this locality from the megafossil record: Araceae, Cephalotaxaceae, Cyperaceae, Flacourtiaceae, Hydrocharitaceae, Hypericaceae, Illiciaceae, Lamiaceae, Lauraceae, Magnoliaceae, Moraceae, Rhamnaceae, Sapindaceae, Saururaceae, Smilacaceae, Sparganiaceae, Theaceae, and Zingiberaceae. Conversely, the presence of the Alangiaceae, Anacardiaceae, Arecaceae, Chenopodiaceae, Ebenaceae, Ericaceae, Ginkgoaceae, Oleaceae, Plantaginaceae, Poaceae, Rutaceae, Sapotaceae, Sciadopityaceae,

Styracaceae, and Tiliaceae is based solely upon the pollen record. Megafloreal elements of a particular taxon may be quantitatively underrepresented or absent when compared to its representative share in the pollen spectrum, or vice versa. Thus, while ferns are moderately well represented by spores, these life forms are all but missing from the megafossil record. On the other hand, more species of Aceraceae and Vitaceae are documented by leaves and seeds, respectively. Leaves of a taxon may be confined to a short vertical interval (where physico-chemical conditions were favorable for preservation), while the spores/pollen of the same taxon are found throughout the lithology, or vice versa. Do either of these cases mean the taxon extended its range into the site at the time when its leaves were preserved (as defined by first occurrence)? Or, does it just mean that the taxon was a local or regional inhabitant and that when conditions for preservation were conducive, the phytoclasts were spared deterioration (see Burnham, 1993; This question may also be approached through the evaluation of palynofacies components within the section under study)? Do we presume within a single genetic rock sequence that the vegetation is systematically homogenous in the short

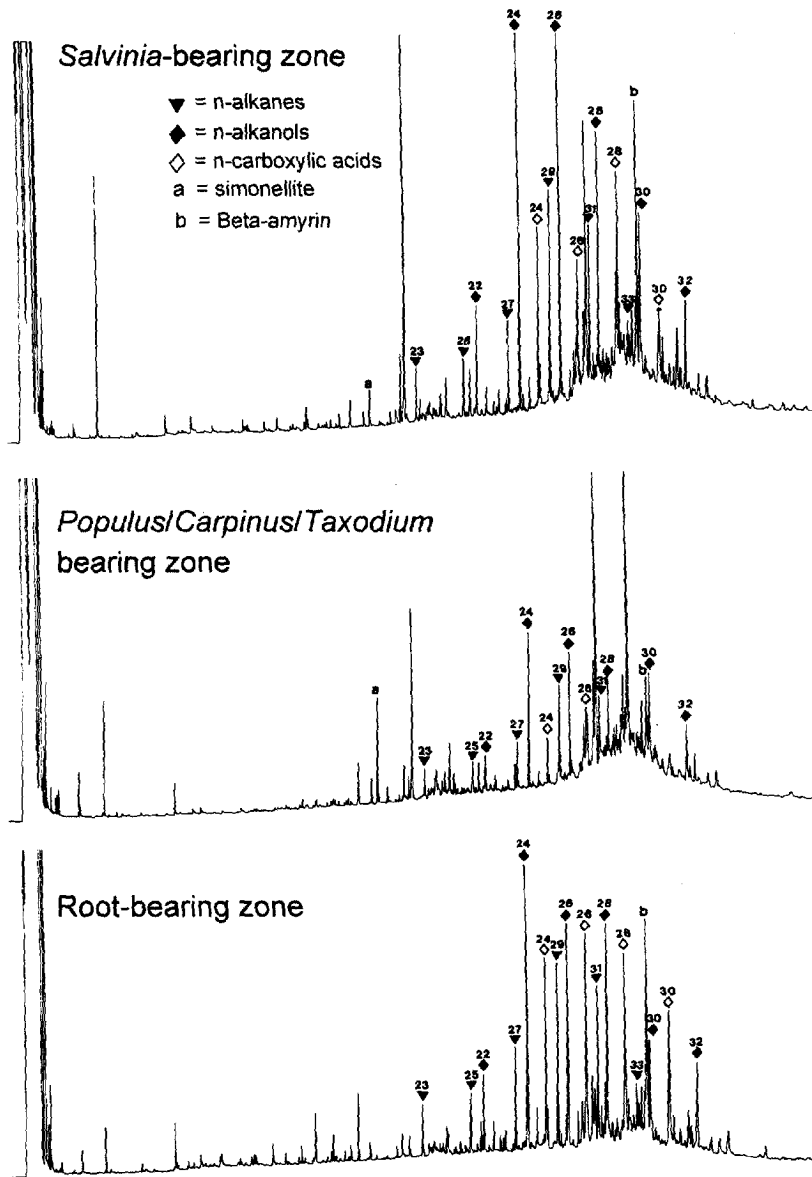


Fig. 11. Gas chromatograms of derivatized (BSTFA) total extract of three samples representing the three megafloreal zones in the lake fill (see Fig. 3). Series of *n*-alkanes (▼), *n*-alkanols (◆) and *n*-carboxylic acids (◇) are marked by their carbon chain length. The *n*-alkanes show a strong odd over even predominance, whereas the *n*-alkanols and *n*-carboxylic acids are dominated by even numbered homologues. The distribution profiles of *n*-alkanols and *n*-alkanes are similar to those found in many recent sediments (Rieley et al., 1991). Compound (a) represents simonellite and compound (b) is β -amyrin. Chromatographic features have been described elsewhere (Otto et al., 1995).

geological time represented by the sediment accumulation? Or do we assume that temporal replacements are inherent in the ecosystem or community, have equal probability of occurrence in the fossil record, and, when first occurrences are documented,

they represent taxonomic range extension (that might be the result of many different ecological, climatological or evolutionary factors)? Discussion of such questions is beyond the scope of the present paper.

Paleobotanical and palynological data sets are essential for the development of ecosystem reconstructions because each provides important complementary and amplifying data. The presence of both megafloral and microfloral remains in autochthonous or parautochthonous assemblages provides unequivocal evidence for the taxon having lived in or near the preservational site. The absence of either a macrofloral or microfloral component does not necessarily mean that the taxon is an allochthonous element. Many taxa have a very low probability of becoming fossilized even when growing adjacent to or within the depositional site (e.g., Burnham, 1989, 1994), and the absence in the fossil record of one or more plant parts is to be expected. The presence of non-arboreal pollen or spores of a taxon in such settings provides insights into contribution from local sources, and compensates for the potential absence of megafloral remains. The presence of arboreal pollen, on the other hand, may be more an indication of regional or extrabasinal contributions (e.g., Dupont and Agwu, 1991) than that of local origination.

Paleobotanical assemblages that are allochthonous represent potential contributions from local, regional, and extrabasinal vegetation (Gastaldo et al., 1987; Gastaldo and Huc, 1992). The admixture of these phytoclasts depends, in part, upon the depositional setting within the ancient landscape and the biostratigraphic factors responsible for the accumulation. To unravel the complexities inherent in these assemblages requires the collection of time-equivalent taphocoenoses from all available depositional settings within a single genetically related depositional sequence. The use of multivariate statistical analyses may provide a means to discriminate local from regional contributors, but only single data sets (either megafloral or microfloral) have been used where this has been successfully applied (e.g., Kovach, 1988; Burnham, 1990; Boulter et al., 1993; Kovach and Batten, 1994).

6.3. *Paleobotanical–biogeochemical*

The concept of geochemical biomarkers is based on the understanding that certain organic compounds are uniquely distributed in the plant kingdom (Summons, 1993; De Leeuw and Largeau, 1993). The

presence of this lipid fraction within sediments may ultimately allow for the identification of floristic components in depositional settings where no megafloral elements are preserved. To date, where paleobotanical and biogeochemical data sets have originated from the same samples (Otto et al., 1995), there has been very good correlation between specific biomarkers and individual taxa. This is also true with regard to the distribution of those taxa within the lithology, the lipid fraction tracks the megafloral trends. It must be noted that there is always the possibility of remobilization of the lipid fraction within the sequence, but the extent to which migration of these biomarkers can occur is not yet well documented in terrestrial environments. At this point in time, though, the paleobotanical record holds more promise as the framework for discriminating which biomarker belongs to which taxon than vice versa. Biogeochemical data, on the other hand, provides essential insights into the diagenetic environment to which the plant was subjected, the boundary conditions for diagenetic processes, and the reconstruction of catabolic and microbial biodegradational pathways.

7. **The multidisciplinary data set as applied to Tagebau Bockwitz**

When viewed together, the sedimentological, megafloral, microfloral, and biogeochemical data from the channel fill facies provide a means by which to more accurately reconstruct this Oligocene setting. The alluvial braidplain that developed in the Weißelster basin was comprised of moderate depth rivers (<10 m at bankfull stage) in which longitudinal and probably linguoid bars formed. These barforms are composed of a mixture of sand, granules, and pebbles in which there is evidence of erosion and subsequent deposition, and barform migration. These barforms are typically covered by megaripples and sandy trough cross bed sets that range from coarse to very fine sand. It is probable that chutes developed within the barforms during periods of high discharge, accounting for the scattered lenticular deposits of finer sands. The system apparently migrated across the alluvial plain, abandoning channels (and chutes within barforms) and allowing

for the passive infilling by overbank flooding of fine clastics including silt, clay, and phytoclasts. Once sediment aggradation reduced water levels to a depth in which aquatic and semi-aquatic vegetation could colonize (*Salvinia* zone), the organic matter fraction increased to more than 4.5% (Otto et al., 1995), sediment-grain size decreased, and non-woody rooting structures become more common. Complete channel filling resulted in the development of incipient paleosols colonized by woody vegetation. Rooting on the alluvial floodplain intensified, with woody roots penetrating meters into the soil horizon. Leaching of the overbank fines resulted in a deep weathering profile, kaolinite-rich soils, and the advent of slickensides. This soil horizon represents the longest interval of time in the section, whereas the channel-fill sequence represents the shortest overall amount of time (Burnham, 1993).

The first aquatic colonizers of the abandoned channel were algae (palynological record), *Salvinia* (known from whole plants and megaspores), and possibly other aquatic angiosperms (*Vallisneria*, *Stratiotes* known from the carpological record). We are hesitant to assign specific representatives from the fruit and seed record to positions within the landscape because, presently, it is difficult to state with certainty exactly which taxa have been recovered from the channel-fill. The published data (Mai and Walther, 1985, 1991) have not been presented with regard to the lithology or channel system from which the fruits and seeds have been collected in Bockwitz. Therefore, in the following discussion, it can be stated with certainty that specific taxa were present in the landscape, but it is not possible to indicate whether or not they represent parautochthonous or allochthonous contributions to the fossil record. An understanding of the parautochthonous fruits and seeds would allow for a more accurate reconstruction of the channel margin and backswamp vegetation (particularly seed banks recovered from paleosols).

The parautochthonous contribution from riparian vegetation in what has been interpreted as rhythmic leaf dehiscence pattern is of rather low diversity (Gastaldo et al., 1996). An admixture of wetland coniferous (*Taxodium*; leaf and carpological evidence) and flood-tolerant angiospermous (*Liquidambar*, *Platanus*, *Acer*, *Salix*, *Populus*, *Cyclo-*

carya and *Palaeocarya*, *Alnus*, *Fagus*, *Quercus*, *Ulmus*, and *Nyssa*) trees, all of which are represented by leaves, fruits and seeds, and pollen (Table 1; Figs. 8 and 9), formed a mosaic of greenery lining the margins of the channel. These taxa comprise the largest quantitative share of the assemblage, as modern arboreal members comprise the largest proportion of leaves in taphocoenoses (e.g., Gastaldo et al., 1987; Burnham et al., 1992). An understory or shrub/small tree canopy may have been composed of *Daphnogene*, *Laurophyllum*, *Trigonobalanopsis*, and others (represented by leaves and seeds, and probably pollen that has either not fossilized or has not been identified to date). These taxa are underrepresented in the channel fill, relative to the former group, and have been considered as minor leaf components in the assemblage. Speculation has arisen concerning the allochthony of these elements, but there is no indication in the sedimentological evidence that these taxa are associated with coarser-clastic (and, hence, flood-derived) input into the channel. There is no other phytotaphonomic evidence that would allow for an interpretation other than parautochthony for these elements. Their presence, then, may reflect: (1) the low probability of plant part transferral from the contributing parent (one close enough to the channel margin to provide the leaves) to the burial (and future collection) site; (2) spatial heterogeneity of taxa along the channel margin; (3) a possible evergreen strategy for these taxa; or (4) limited exposure and collection of the channel bedding surface. As in modern channel-margin communities, lianas proliferated and are represented in the leaf, pollen, and carpological record (*Ampelopsis*, *Parthenocissus*, *Vitis* and *Majanthemophyllum*). It is difficult to reconstruct a herbaceous understory due to the present lack of knowledge of the parautochthonous carpological record. The probability of these plants being recorded in the leaf assemblage is practically nil (Gastaldo, 1988, 1992), and only confirmation of their presence would be possible using correlative palynological and carpological data sets. For instance, it is only by undertaking a palynological study that the presence of the Chenopodiaceae, Plantaginaceae, and Poaceae has been revealed. Herbaceous taxa are known from carpological remains that are similar at the generic level to those inhabiting wetland swamps of the

present southeastern United States (Stout and Le-Long, 1981), arguing for a strong similarity in ground cover associations.

Relative degradation rates that would be a proxy for preservational potential within the channel can be extrapolated from the palynofacies data. Overall, it would appear there was a disproportionate probability that OM would be preserved throughout the channel fill (Fig. 10). Higher proportions of Unstructured OM occur in the lower part of the fill, reflecting higher rates of decay than in other parts of the channel fill. In this interval there is less recoverable megafloreal material than above, where higher proportions of Structured OM are recovered. In the uppermost part of the section, where pedogenesis has affected the sediment, there is again an increase in the amount of Unstructured OM. This parallels the loss of megafloreal elements in the fossil record. The highest quantitative share of Structured OM is found where the leaf litters are preserved, which is no surprise. This indicates that although degradation of OM continued in the system (either within the water column, at the sediment–water interface, or upon adjacent soils [as can be ascertained by the presence of fungal remains in megafossils and palynofacies preparations]) the rate at which decay proceeded in this part of the channel fill was low.

The inorganic geochemical record indicates that taphonomic conditions were optimal for the preservation of the megaflorea and the biogeochemical record reflects variations in the megafloreal composition. The lower section of the channel fill is dominated by *n*-tetracosanol, a compound that originates from wax esters (Püttmann and Bracke, 1995). It is present in the leaf-bearing part of the channel fill, and in higher abundance in the root-bearing zone. Where the leaf clusters are first preserved (and probably represent their first introduction to the channel based upon this biogeochemical evidence), there is an increase of β -amyrin, a biomarker known from many different angiosperms. Additionally, simonellite, a byproduct from the conversion of abietic acid, is a biomarker for conifers (Simoneit et al., 1986) and becomes part of the record where the first *Taxodium* leaves are preserved. The distribution of the alkanols and alkanes recovered from the channel fill (Otto et al., 1995) are similar to that observed in many other Recent sediments (Rieley et al., 1991).

8. Conclusions

The use of multidisciplinary approaches provides a more comprehensive and credible data base from which to propose reconstructions of Tertiary vegetation. The integration of sedimentology, paleopedology, phytotaphonomy, megafloreal systematics (including leaf and carpological investigations), palynology and palynofacies (dispersed organic matter), and biogeochemistry results in independent lines of evidence that help to corroborate or modify interpretations of the system under investigation. No single data set can contribute enough information from which a credible reconstruction can be developed. When interpreted within depositional context, (1) megafloreal leaves demonstrate which plants could contribute to the preservable flora, (2) carpological remains provide an enhanced signal for life forms generally not preserved as compressions–impressions, and (3) palynological debris, including an assessment of dispersed organic matter, not only confirms the presence of some, but not all, taxa represented by megafloreal and/or carpological evidence, but also adds information about the regional floral components. As paleobotanists begin to focus their attention on past ecosystem structure and the dynamics involved with ecosystem change, it is imperative that multidisciplinary data sets be used.

The ‘snapshot’ in time afforded by the fossil-plant assemblage found in channel-fill sediments at Bockwitz, taken within sedimentological context, allows for a better reconstruction of this Late Oligocene community. The ecosystem that provided detritus to the abandoned channel was multi-tiered, with canopy, subcanopy, liana screen, and herbaceous ground cover, similar to that now found in the southeastern United States wetlands (Archibald, 1995). These plants grew on a soil that was heavily and deeply leached (as affirmed by the presence of a kaolinite-rich soil) through interaction with seasonal fluctuations in climate (wet and dry periods are reflected by the presence of slickensides in the soil). Periodic rainfall and humidity must have been high, because of the presence of the very thick, kaolinite-rich soil below which the assemblage is preserved. These physical features correlate well with the interpreted Late Oligocene warm interval (Wolfe, 1992) under which subhumid to semi-arid conditions pre-

vailed in the northern hemisphere. The taxonomic composition at Bockwitz reflects vegetation adapted to subhumid conditions, rather than semi-arid conditions. Taxonomic enrichment can be documented within the deposit, which reflects immigration of taxa when conditions were favorable for colonization (e.g., *Salvinia* and other aquatics) as well as regional contribution to the site when physical conditions within the channel allowed for passive accumulation. Fungal activity within the ecosystem can be documented not only in palynofacies and palynological preparations, but also through examination of infected megafossils. The organic geochemical signature of the sediments correlates well with the plants within the deposits and, in the future, may be used to decipher community contribution to terrestrial environments in the absence of megafossils.

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