



A 90 m-thick coal seam in the Lubstów lignite deposit (Central Poland): palynological analysis and sedimentary environment

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Durska E. (2008) — A 90 m-thick coal seam in the Lubstów lignite deposit (Central Poland): palynological analysis and sedimentary environment. *Geol. Quart.*, 52 (3): 281–290. Warszawa.

A 90 m-thick brown coal seam, the result of organic matter deposition in a fault-trough, is exploited in an open cast mine at Lubstów (Central Poland). Palynological analysis was conducted in order to determine which plants were the source of organic matter forming such a thick coal bed. The pollen spectrum is dominated by the gymnosperm pollen *Inaperturopollenites*, produced by trees closely related to the extant genera *Taxodium* and *Glyptostrobus*, the dominant constituents of swamp forests in SE North America and SE Asia today. However, the lack of xylites and preserved tissues in the coal does not support the conception of a swamp forest as the peat-producing community. There is also a significant percentage of angiosperm pollen in the coal, mainly from the groups: *Castaneoideapollis*, *Tricolporopollenites exactus* and *T. pseudocingulum*. The plants producing these pollen were probably the main constituent of the peat-producing community. The community shows signs of a shrub swamp with local tree islands and a low water table. Evidence for this also includes the detrital type of coal, the lack of preserved plant tissues and the presence of fungal remains. These characteristics show the existence of aerobic zones at the time of peat production. The peat was probably derived from angiosperms. Dome-shaped forms in the upper part of the deposit are the remains of tree islands. As detritus accumulation is very rapid on the surfaces of present-day tree islands, a similar rate of deposition may have taken place during peat production at Lubstów. This, combined with subsidence in the fault-trough, explains the great thickness of the coal bed.

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Key words: Miocene, Konin region, pollen, swamp, tree islands.

INTRODUCTION

In the vicinity of Konin, Central Poland, there are numerous brown coal seams (Fig. 1). The majority of these are coeval and belong to the Middle Polish Lignite Seam (Kremp, 1949; Mamezar, 1960; Sadowska and Giża, 1991; Ważyńska *et al.*, 1998). The geological setting is different at Lubstów, located 25 km NE from Konin. Two brown coal seams are exposed in an active open cast mine there. The upper seam is correlated with the Middle Polish coal beds from the Konin region, whereas the lower one is an older seam that belongs to the 2nd Lusatian Lignite Seam (Ciuk and Grabowska, 1991; Ważyńska *et al.*, 1998).

The subject of the present study is the 90 m thick lower brown coal seam. The coal (belonging to the detrital type) is very homogenous but with an almost total lack of clastic intercalations, devoid of plant macro-remains but with a rich assemblage of perfectly preserved sporomorphs.

Due to its economical importance, the lower brown coal seam in Lubstów has been thoroughly investigated (Chlebowski *et al.*, 1979; Matl *et al.*, 1979; Skała, 1992). Its tectonic setting has been described by Wiedera (2000). Kasiński *et al.* (1994) investigated the genesis of the deposit, and invoked that a domed peat bog. Palynological analyses were conducted by Domagała (in Matl *et al.*, 1979), Ciuk and Grabowska (1991), and Kasiński *et al.* (1994). The aim of these studies was to determine the stratigraphic position of this brown coal seam. Besides the work by Kasiński *et al.* (1994), that pertained only to the bottom interval of the seam, there have been no studies of the plant communities, that were present at the time of coal formation.

The aim of the present paper is an attempt to reconstruct the plant communities and determine which plants were the source of material for the formation of such a thick brown coal seam, by means of palynological analysis.

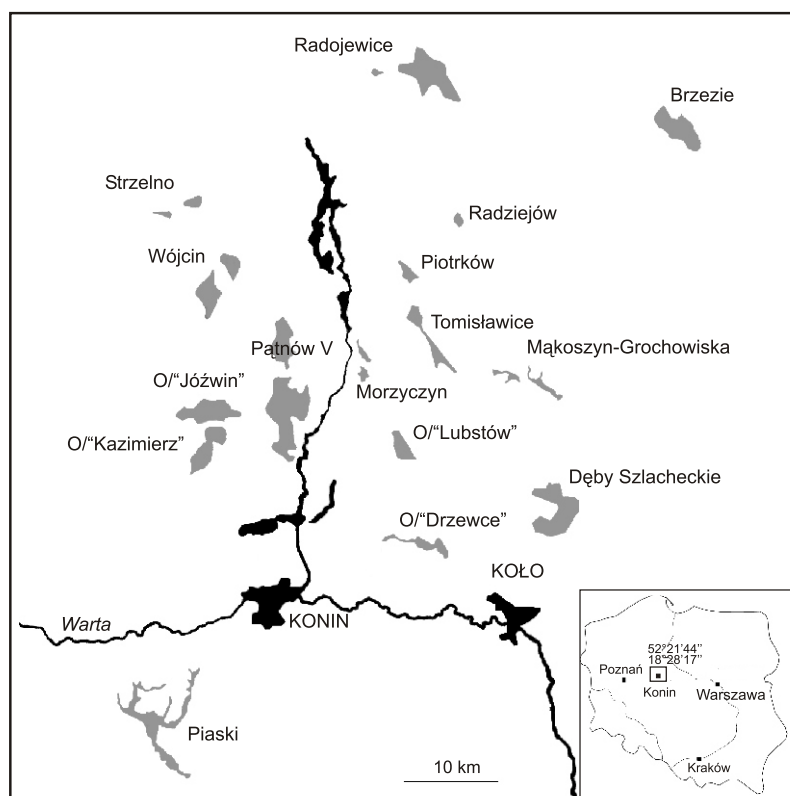


Fig. 1. Lignite deposits in the vicinity of Konin (after Włodarczyk *et al.*, 2002, changed) and location of the Konin region in Poland

Exploited (e.g. O/'Lubstów — open-cast mine "Lubstów") and unexploited (e.g. Strzelno) lignite deposits are marked grey; rivers, lakes and towns (Konin, Koło) are marked black

GEOLOGICAL SETTING

The Neogene deposits in Lubstów were formed in a NW–SE fault-trough 3 km long and 1.5 km wide located on the SE limb of the Gopło Anticline. The trough resulted from crustal movements caused by salt tectonics (Widera, 2000). It is filled with Neogene deposits. Currently, the area worked is located in the NW part of the Lubstów fault-trough.

Sands and coal-bearing sands of the lower Miocene Rawicz Formation represent the base of the succession (Fig. 2). They are overlain by the lower brown coal seam, belonging to the middle Miocene Ścinawa Formation (about 20 m in the currently exploited part of the deposit). In the axial part of the fault-trough, where exploitation has already ceased, the coal thickness reached up to 91.4 m (Matl *et al.*, 1979). The lower and upper brown coal seams are separated by sands and coal-bearing sands, with a rich assemblage of cones, seeds and fruit (Kowalski, 2006), belonging to the middle Miocene Adamów Formation. The upper 12.2 m-thick brown coal seam is already part of the middle Miocene Poznań Formation. The xylite-rich coal from the upper seam differs significantly from the lower coal. Strongly glaucitectonically-deformed late Miocene-early Pliocene multicoloured clays, also belonging to the Poznań Formation, are locally preserved above the upper

brown coal seam. The uppermost part of the profile consists of Pleistocene glacial tills, most often deposited directly on the eroded surface of the upper brown coal seam.

MATERIALS AND METHODS

The material studied originated from the currently mined, 24 m-thick lower brown coal seam. The material for research was sampled from brown coal, and from underlying and overlying coal-bearing sands (Fig. 2). Palynological analysis of 62 samples (odd numbers from 7 to 129) was performed. No sporomorphs were found in the sands underlying the coal seam studied. In the overlying sands they were only detected in sample 129.

The samples were macerated using the acetolysis method (according to Erdtman, 1952, with later modifications). Sand samples were floated prior to maceration, using KJ+ CdJ₂, in order to separate organic and mineral fractions.

Sporomorphs with abundant fungal remains and less frequent algal and plant tissue remains (cuticles, xylem) are the dominant plant micro-remains in the material studied. The preservation state is very good.

The palynological analysis was conducted by means of a light microscope using x600 and x1000 magnifications. Only pollen grains and spores were counted in the analysis. The rarefaction curve, representing the relation of the number of newly occurring taxa to the total number of counted grains (excluding bisaccate pollen; Bruch and Mosbrugger, 2002) was plotted for every sample (Raupp, 1975). Counting was stopped if the curve was flattening. The number of sporomorphs counted in particular samples ranged from about 300 to over 1000.

PALYNOLOGICAL ANALYSIS RESULTS

A total of 75 taxa were recorded. Detailed results of the analysis are presented in the form of a diagram (Fig. 3). The taxa in the diagram were grouped according to their affiliation to the following plant communities: mixed mesophytic forest (MMF), shrub swamp, and swamp forest (both of these communities occur today in habitats of different degrees of humidity, however, numerous plant taxa occur in both environments, which hinders their separation in the fossil record), and water plants. A group of herbaceous plants was also distinguished; they could have been associated both with MMF, and with shrub swamp and swamp forest. A basis for this distinction and for all considerations referring to plant communities and environments has been an assumption that there are close relatives of Miocene plants among the present-day flora (e.g. Nagy, 1969, 1985; Ziemińska-Tworzydło, 1974; Planderová, 1990;

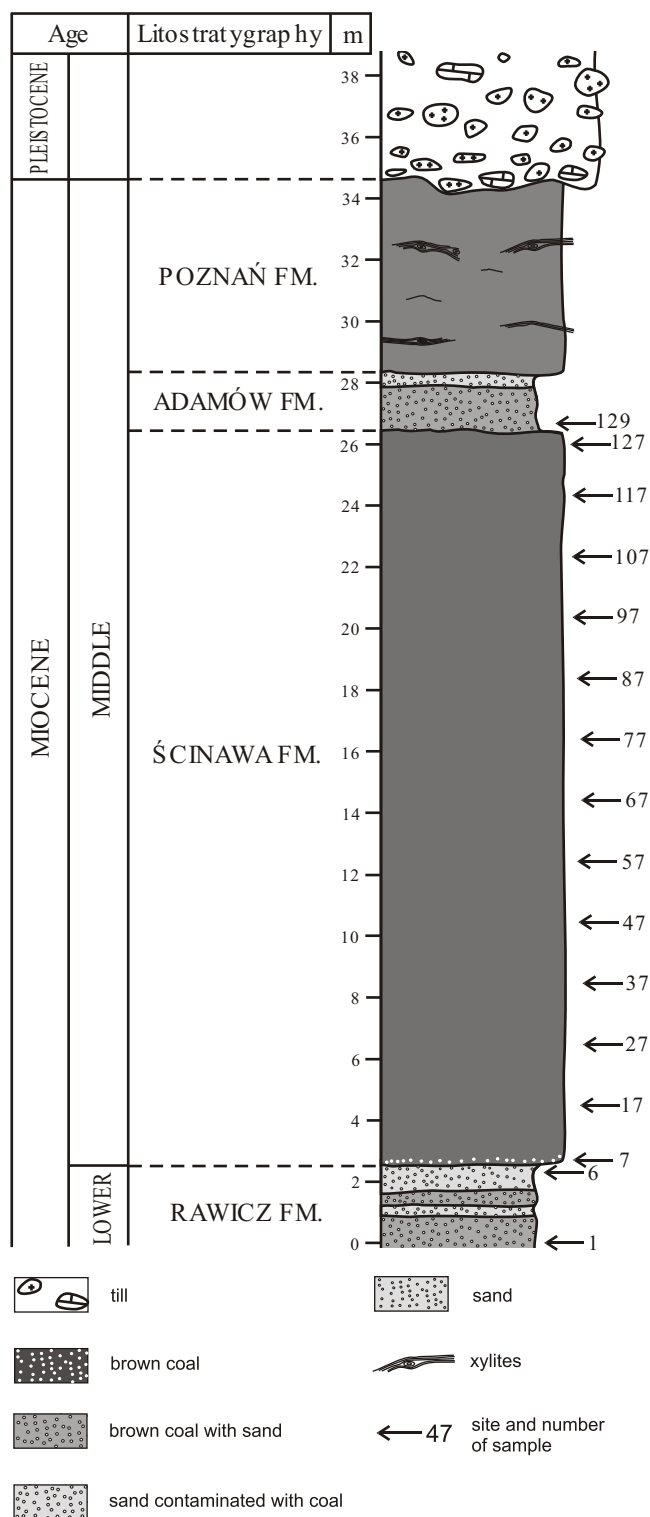


Fig. 2. Geological profile from the Lubstów brown coal mine, with sample locations marked

Kohlman-Adamska, 1993; Stuchlik *et al.*, 1994, 2001, 2002; Mai, 1995). The list of fossil taxa and of their extant analogues is given in Table 1. The environments of the extant taxa occurrences were determined based on the papers by Kearney (1901), Wang (1961), Krüssmann (1976–1978), Stuchlik *et al.* (2001, 2002), Willard *et al.* (2001) and Podbielkowski (2002).

Beside species and genera, groups of taxa were also included in the diagram. Such groups were designated in cases when two or more morphological species distinguished in the fossil record were associated with the same extant plant taxon or taxa. *Castaneoideapollis oviformis* and *Castaneoideapollis pusillus*, whose extant relatives are thought to be the following three genera: *Castanea*, *Castanopsis*, and *Lithocarpus*, were included in the group *Castaneoideapollis*. The group *Tricolporopollenites exactus* contains *T. brühlensis*, *T. exactus* and *T. megaexactus*, associated with the families Clethraceae and Cyrillaceae. The group *Tricolporopollenites fallax* comprises two species: *T. fallax* and *T. liblarensis*, associated with the present-day families Fabaceae, Combretaceae and Verbenaceae (Stuchlik *et al.*, 1994). The following morphological species were included in the *Tricolporopollenites pseudocingulum* group: *Tetracolporopollenites andreamus*, *Tricolporopollenites dolium*, *T. leonensis*, *T. lubstovensis*, *T. scutulensis*, *T. theacoides*, *T. villensis*, *T. pseudocingulum*. All of these belong to the family Fagaceae (according to Kohlman-Adamska and Ziembińska-Tworzydło, 2000), however it is impossible to determine their relationships at lower systematic levels (Kohlman-Adamska and Ziembińska-Tworzydło, 2000). The sporomorph assemblage is dominated by coniferous plant pollen (76%). Broadleaf plant pollen has a much lower percentage equal to 23% with the remaining 1% consisting of herbaceous plant sporomorphs. Such percentage relationships show that the sediment was deposited in an open space, easily accessible by the easily wind-transported coniferous plant pollen. Pollen of most broadleaf plants is heavy and distributed over small areas, therefore coniferous plant pollen grains dominate in the sediment.

The percentage of pollen of most taxa in individual samples does not exceed 1%, and in the entire assemblage studied only a few taxa have percentages exceeding 5% in individual samples. These are the coniferous plant pollen: *Cathayapollis* sp., *Inaperturopollenites* sp., *Pinuspollenites* sp., *Sciadopityspollenites* sp., *Sequoiapollis* sp. and the broadleaf plant pollen: *Castaneoideapollis* group, *Tricolporopollenites exactus* group, *Tricolporopollenites pseudocingulum* group.

The profile studied is quite homogenous as regards its palynology. There are no rapid changes in percentages of pollen produced by plants belonging to separate assemblages. There are, however, some clear tendencies which allow distinction of five phases (Fig. 3). Phase I comprises the lowest part of the seam, between 2.5 and 2.7 m (sample 7). It is distinguished by a relatively high percentage of broadleaf plant pollen taxa, and a relatively low content of *Inaperturopollenites* sp. pollen, from the shrub swamp and swamp forest community. It also shows a significant share of *Corrugatisporites* sp. and *Leiotriletes* sp. spores belonging to the group of herbaceous plants, and *Cathayapollis* pollen from the MMF (Mixed Mesophytic Forest) community. Phases II (from 2.7 to 7.1 m, samples 9–29), III (between 7.1 and 18.3 m, samples 31–85) and IV (from 18.3 to 25.1 m, samples 87–119) are distinguished by a very high percentage of *Inaperturopollenites* sp. pollen. Their dissimilarity is mainly shown by changes of percentage within the *Castaneoideapollis* group and, partially of *Pinuspollenites* sp. The most distinct one is phase V (from 18.5 to 26.9 m, samples 121–129) in which there is a significant in-

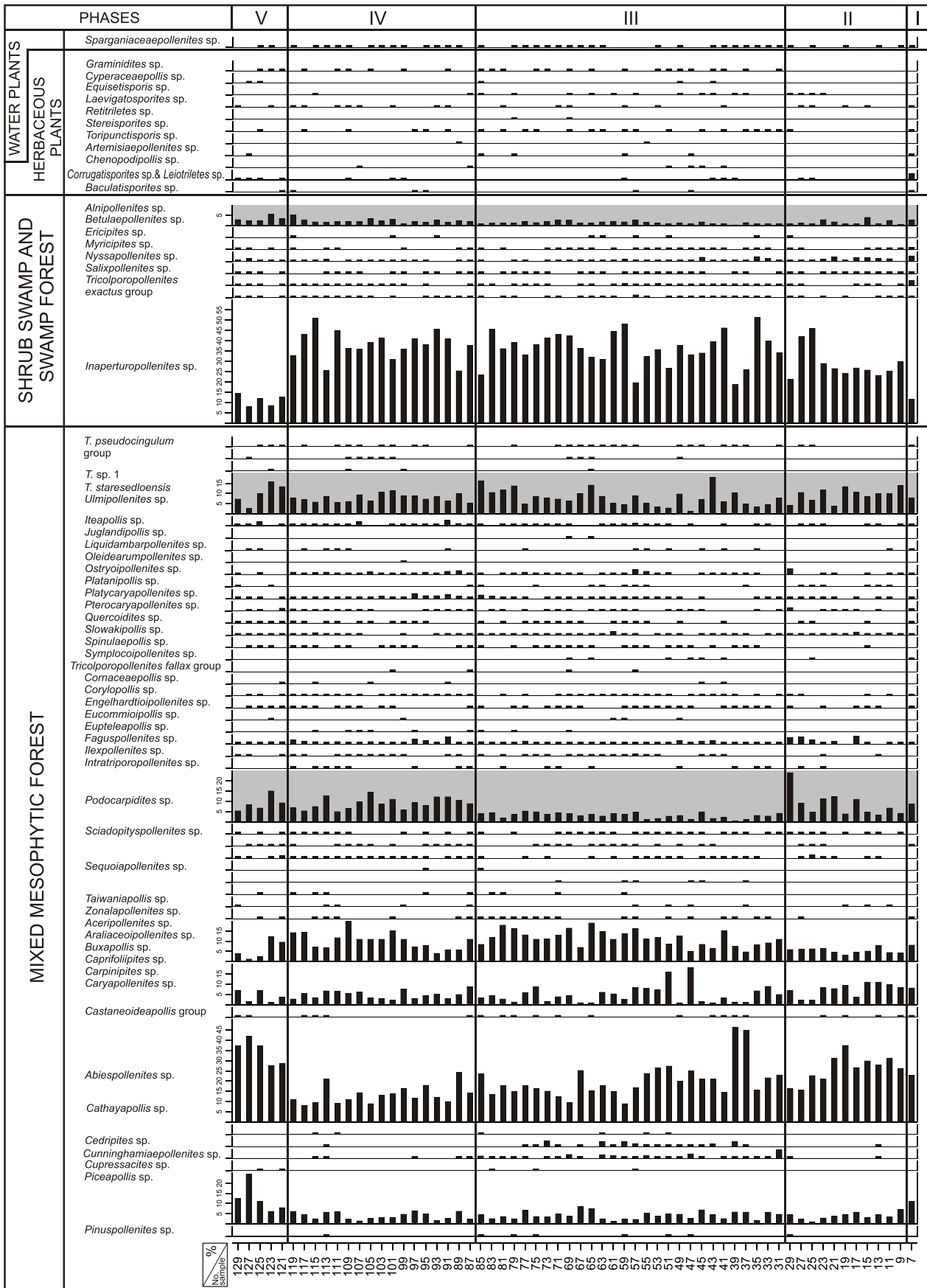


Fig. 3. Sporomorph percentage diagram — habitative list

I–V — distinguished phases, explanations in text; taxa/groups which are probable main constituents of the peat-producing community are marked grey; taxa with percentage equaling 1% or less are shown as 1%

Table 1

Tab. 1 cont.

List of taxa of the lower brown coal seam in Lubstów identified by palynological investigation, and their closest extant relatives

Taxon	Nearest living relative
<i>Abiespollenites</i> sp.	<i>Abies</i>
<i>Aceripollenites</i> sp.	<i>Acer</i>
<i>Alnipollenites verus</i>	<i>Alnus</i>
<i>Araliaceoipollenites</i> sp.	Araliaceae
<i>Artemisiaepollenites</i> sp.	<i>Artemisia</i>
<i>Baculatisporites</i> sp.	<i>Osmunda</i>
<i>Betulaepollenites</i> sp.	<i>Betula</i>
<i>Buxapollis</i> sp.	<i>Buxus</i>
<i>Caprifoliipites</i> sp.	Caprifoliaceae
<i>Carpinipites</i> sp.	<i>Carpinus</i>
<i>Caryapollenites</i> sp.	<i>Carya</i>
<i>Castaneoideaepollis oviformis</i>	<i>Castanea</i> + <i>Castanopsis</i> + <i>Lithocarpus</i>
<i>Castaneoideaepollis pusillus</i>	<i>Castanea</i> + <i>Castanopsis</i> + <i>Lithocarpus</i>
<i>Cathayapollis</i> sp.	<i>Cathaya</i>
<i>Cedripites</i> sp.	<i>Cedrus</i>
<i>Chenopodipollis</i> sp.	Chenopodiaceae
<i>Cornaceapollis</i> sp.	Cornaceae
<i>Corrugatisporites</i> sp.	<i>Lygodium</i>
<i>Corylopollis</i> sp.	<i>Corylus</i>
<i>Cunninghamiaepollenites</i> sp.	<i>Cunninghamia</i>
<i>Cupressacites</i> sp.	Cupressaceae + Taxaceae
<i>Cyperaceapollis</i> sp.	Cyperaceae
<i>Engelhardtioipollenites</i> sp.	<i>Engelhardia</i>
<i>Equisetisporites</i> sp.	<i>Equisetum</i>
<i>Ericipites</i> sp.	Ericaceae
<i>Eucommioipollis</i> sp.	<i>Eucommia</i>
<i>Eupteleapollis</i> sp.	<i>Euptelea</i>
<i>Faguspollenites</i> sp.	<i>Fagus</i>
<i>Graminidites</i> sp.	Poaceae
<i>Ilexpollenites</i> sp.	<i>Ilex</i>
<i>Inaperturopollenites</i> sp.	<i>Taxodium</i> + <i>Glyptostrobus</i>
<i>Intratropipollenites</i> sp.	<i>Craigia</i> + <i>Tilia</i>
<i>Iteapollis</i> sp.	<i>Itea</i>
<i>Juglandipollis</i> sp.	<i>Juglans</i>
<i>Laevigatosporites</i> sp.	Polypodiaceae <i>sensu lato</i>
<i>Leiotriletes</i> sp.	<i>Lygodium</i>
<i>Liquidambarpollenites</i> sp.	<i>Liquidambar</i>
<i>Myricipites</i> sp.	<i>Myrica</i>
<i>Nyssapollenites</i> sp.	<i>Nyssa</i>
<i>Oleidearumpollenites</i> sp.	Oleaceae
<i>Ostryoipollenites</i> sp.	<i>Ostrya</i>
<i>Tricolporopollenites</i> sp.	<i>Parrotia</i>
<i>Piceapollis</i> sp.	<i>Picea</i>
<i>Pinuspollenites</i> sp.	<i>Pinus</i>
<i>Platanipollis</i> sp.	<i>Platanus</i>
<i>Platycaryapollenites</i> sp.	<i>Platycarya</i>
<i>Podocarpidites</i> sp.	<i>Podocarpus</i>
<i>Pterocaryapollenites</i> sp.	<i>Pterocarya</i>
<i>Quercoidites</i> sp.	<i>Quercus</i>

<i>Retitriletes</i> sp.	<i>Lycopodium</i>
<i>Tricolporopollenites</i> sp. 1	Rosaceae
<i>Salixpollenites</i> sp.	<i>Salix</i>
<i>Sciadopityspollenites</i> sp.	<i>Sciadopitys</i>
<i>Sequoiapollenites</i> sp.	<i>Sequoia</i> + <i>Sequoiadendron</i> + <i>Metasequoia</i> + <i>Cryptomeria</i>
<i>Slowakipollis</i> sp.	<i>Elaeagnus</i>
<i>Sparganiaceapollenites</i> sp.	<i>Sparganium</i>
<i>Spinulaepollis</i> sp.	<i>Arceuthobium</i>
<i>Stereisporites</i> sp.	<i>Sphagnum</i>
<i>Symplocoipollenites</i> sp.	<i>Symplocos</i>
<i>Taiwaniapollis</i> sp.	<i>Taiwania</i>
<i>Tetracolporopollenites andreanus</i>	Fagaceae
<i>Toripunctisporis</i> sp.	unknown
<i>Tricolporopollenites brühlensis</i>	Cyrillaceae + Clethraceae
<i>Tricolporopollenites dolium</i>	Fagaceae
<i>Tricolporopollenites exactus</i>	Cyrillaceae + Clethraceae
<i>Tricolporopollenites fallax</i>	Fabaceae, Combretaceae, Verbenaceae
<i>Tricolporopollenites leonensis</i>	Fagaceae
<i>Tricolporopollenites liblarensis</i>	Fabaceae, Combretaceae, Verbenaceae
<i>Tricolporopollenites lubstovens</i>	Fagaceae
<i>Tricolporopollenites megaexactus</i>	Cyrillaceae + Clethraceae
<i>Tricolporopollenites pseudocingulum</i>	Fagaceae (after Kohlman-Adamska and Ziemińska-Tworzydło, 2000)
<i>Tricolporopollenites scutulensis</i>	Fagaceae
<i>Tricolporopollenites theacoides</i>	Fagaceae
<i>Tricolporopollenites villensis</i>	Fagaceae
<i>Ulmipollenites</i> sp.	<i>Ulmus</i>
<i>Zonalapollenites</i> sp.	<i>Tsuga</i>

crease in frequency of the bisaccate pollen taxa *Cathayapollis* sp. and *Pinuspollenites* sp. from the MMF community, and, to a smaller extent, pollen from the *Tricolporopollenites exactus* group, belonging to the shrub swamp and swamp forest plant community. However, there is a distinct decrease of *Sequoiapollis* sp. pollen, from the MMF plant community, and *Inaperturopollenites* sp. pollen from the shrub swamp and swamp forest community.

DISCUSSION — BROWN COAL FORMATION

As already has been mentioned above, the lower brown coal seam in Lubstów is not a typical example of a coal bed. It shows a variable thickness, ranging from 20 to over 90 m. This difference results from different rates of subsidence within the fault-trough. The subsidence rate was much higher in the axial part of the trough, and it was compensated by phytogenic sedimentation (the plant biomass quantity was very high). The almost total lack of clastic intercalations indicates that the

Lubstów fault-trough was an extensive swamp when the lower brown coal seam was formed.

The coal, beside a high content of sporomorphs, is almost totally devoid of any plant macrofossils. There are no preserved tissues that would enable the identification of peat-producing plants. In the palynological profile there are no traces of peat bog overgrowing successions, typical of Neogene successions of the European Plain (Teichmüller, 1958). The pollen *Inaperturopollenites* sp. constitutes 33% of all sporomorphs found. It is associated with two extant genera of coniferous trees: *Taxodium* (cypress) and *Glyptostrobus*, both typically occurring in swamp forests of the SE part of North America and of SE Asia respectively. The cypress swamps of Florida have a high water level. Trees and shrubs occurring there live in a constantly flooded environment throughout most of the year (Kearney, 1901; Willard *et al.*, 2001). The genus *Taxodium* has developed a special adaptation to such conditions, i.e. pneumatophorae, a special type of respiratory root. In anoxic conditions, when the water level is constantly high, plant tissues do not decompose, but become fossilized. This refers especially to coniferous plants. Their remains degrade slowly because of the presence of impregnating resin (Brzyski, 1984) and guaiacyl lignin (Shearer *et al.*, 1995). It can be expected that peat produced in a *Taxodium/Glyptostrobus* swamp forest will contain fossilized tissues, both in the form of xylites and plant micro-remains. Modern observations of sediment from the cypress swamps of Okefenokee in Georgia, USA, support this. The sediment contains large woody tissues mainly of root origin (Dehmer, 1995). Plant tissues should also be present in coal formed from such a peat. The *Taxodium/Glyptostrobus* swamp forest was an important peat-producing plant assemblage in the Neogene, therefore numerous examples of coals (xylitic, xylodetritic and detro-xylitic) of this age are known to contain fossilized tissues, e.g. Oberdorf (Kolcon and Sachsenhofer, 1999), and Pątnów (Sadowska and Giża, 1991). Coals from these localities contain also significant quantities of the pollen *Inaperturopollenites* sp.

Plant tissues decompose when they remain in the aerobic zone. The process of intense degradation of plant material in aerobic conditions may take place either during deposition, or already after peat has been produced, as a result of water table oscillation. This causes changes, overprinting the earlier processes that took place during peat production (Moore and Shearer, 2003).

There are no tissues preserved in Lubstów coal. It is highly improbable that an area covered by *Taxodium/Glyptostrobus* swamp forest with a high ground water level was frequently subject to drying that so deeply penetrated the sediment that all coniferous trees tissues deteriorated without leaving any trace in the fossil record. Supposedly a cypress swamp forest was not the direct source of organic matter for the formation of the coal studied, even though the palynological analysis results indicate so. Rather, it was growing in close vicinity to the Lubstów sedimentary basin.

Other plant communities should be examined as possible sources of organic matter if the *Taxodium/Glyptostrobus* swamp forest is excluded as a peat-producing plant community. Angiosperms have also gained a peat-producing significance in the Neogene, equal to that of gymnosperms (Shearer *et*

al., 1995). Three angiosperm pollen groups are important in the palynological assemblage studied (Fig. 3): the *Tricolporopollenites exactus* group, the *T. pseudocingulum* group, and the *Castaneoideapollis* group. Representatives of two families, the Clethraceae and Cyrillaceae, the latter being a typical constituent of the present-day swamp shrubs in a warm-temperate climate of North America, belong to the first group. The group *Tricolporopollenites pseudocingulum* represents the pollen of extinct representatives of the family Fagaceae (Kohlman-Adamska and Ziemińska-Tworzydło, 2000). The *Castaneoideapollis* group pollen is associated with extant trees from the genera *Castanea*, *Castanopsis*, and *Lithocarpus*. It is unknown what the plants producing these types of pollen looked like; they might have been either trees or shrubs. Supposedly, because of an exceptionally high (for broadleaf plants) percentage of pollen belonging to those groups in the assemblage investigated, the plants producing it must have grown close to the sedimentary basin. They might have had a peat-producing significance (the two latter groups are traditionally included into MMF in Figure 3, due to a probable, though on confirmed, affiliation to the shrub swamp and swamp forest community). The quantity of pollen belonging to the three angiosperm groups mentioned above is smaller than that of *Inaperturopollenites* pollen; the disproportion might be a result of the more abundant pollen production of coniferous *Taxodium/Glyptostrobus* and a better adaptation of their pollen to aeolian transport.

Angiosperm tissues decompose faster than gymnosperm tissues: they do not contain resin, and their main constituent, syringil/guaiacyl lignin is considerably more degradable than guaiacyl lignin in gymnosperms (Shearer *et al.*, 1995). Despite the fact that angiosperm tissues are easily decomposed, their deposition within the aerobic zone (e.g. due to a low or frequently fluctuating water table) during peat production is a significant condition of angiosperm tissue decomposition. Such conditions facilitate degradation of plant material (Moore and Shearer, 2003). A good present-day example is the Moanatuatua peat bog in New Zealand, in which Moore and Shearer (2003) have observed a permanent aerobic zone. Highly decomposed material is located in its lower interval. A probable interpretation, considering the detrital type of coal and the almost complete lack of preserved tissues at Lubstów, is that the source of organic matter for coal was an ombrogenous peat bog with a low water table, overgrown with angiosperm shrubs and trees.

An interesting feature of the Lubstów brown coal deposit are dome-shaped structures in the top part of the lower seam, discovered by Kasiński *et al.* (1994). These structures inspired the depositional model created by those authors (Kasiński *et al.*, 1994). Sedimentation is thought to have started by the formation of a shallow eutrophic lake, surrounded by plants, remains of which were the source for biomass deposited in the bottom of the basin. Changes of hydrogeological conditions led to the transformation of the lake into a high peat bog, growing over the water table in the form of domes. According to Kasiński *et al.* (1994) such rapidly growing domes explain the significant thickness of coal. The idea is very interesting, but the authors did not indicate which plants might have formed the high peat bog domes.

Extant dome-shaped, high peat bogs are reported from numerous localities around the world, from cold through temperate to tropical climates (Cohen and Stack, 1996). An example of such dome-shaped peat bogs are tree islands occurring in shallow, flooded swamps in the warm-temperate climate zone of the SE part of North America. They seem to be a good actualistic analogue of the Lubstów peat bog.

Pup-up (battery) tree islands, occurring in Everglades in Florida (Willard *et al.*, 2001) and Okefenokee in Georgia (Cohen and Stack, 1996) are small (about 50 m in diameter; Cohen and Bailey, 1997) and round, dome-shaped, reaching a height of about 1 m above the water table (Cohen and Stack, 1996). They are thought to have formed after pieces of peat broke loose from the substrate and were redeposited (Cohen and Stack, 1996; Willard *et al.*, 2001).

The present-day tree islands are covered by small trees in the central part, and shrubs at the margin. Dominant among trees and shrubs in the Florida Everglades are such genera as: *Ilex*, *Myrica*, *Quercus*, *Salix* (Willard *et al.*, 2001); the genera *Cyrilla* and *Ilex* dominate at Okefenokee (Cohen and Bailey, 1997).

Cyrillaceae/Clethraceae type pollen, related to *Cyrilla* from the Okefenokee tree islands, is abundant in the Lubstów coal. The pollen of the other genera mentioned inhabiting the present-day tree islands (Fig. 3) is also present, however, in minor quantities. Besides these abundantly occurring pollen types from the groups *Castaneoideapollis* and *Tricolporopollenites pseudocingulum* might have been the constituents of fossil peat-producing plant communities.

Peat is produced on the surface of the extant tree islands from plant remains (leaves, branches *etc.*) covering them. Due to a low water table (the domes rise about 1 m above water level and thus remain in the aerobic zone) the decomposition of these remains by microorganisms and detritophages is very significant (Cohen and Bailey, 1997). Fallen leaves are dried which causes the cuticle to separate from the internal tissues of a leaf, which in turn accelerates their decomposition by microorganisms and detritophages. Cohen and Bailey (1997) have recognized the presence of *Actinomycetales* — bacteria playing a major role in the process of organic matter humification in many horizontal strata in peat sampled in tree islands. Their presence evidences that the process took place in aerobic conditions (Cohen and Bailey, 1997). As discussed above, the peat in Lubstów was also produced in aerobic conditions, as shown by lack of preserved tissues in the coal studied.

Fungal microfossils are very abundant in the sediment from the Florida Everglades tree islands (Chmura *et al.*, 2006). They are most abundant in the aerobic zone on the surface of tree islands. These are probably the remains of mycorrhizal fungi which were associated with tree roots (Chmura *et al.*, 2006). Mycorrhizal fungi are also known from the fossil record from the Triassic and younger coals (Moore *et al.*, 1996). Fungal remains are also frequent in the coal studied from Lubstów, which indicates both the presence of an aerobic zone and a high number of shrubs or trees during peat production.

One more argument in support of the existence of tree islands at Lubstów during peat production is a high rate of detrital layer increase observed on the surfaces of the pres-

ent-day tree islands. Cohen and Bailey (1997) have measured a 20–30 cm increase in the quantity of a layer of detritus during 1.5 years under favourable climatic conditions (high humidity). The possibility of such a rapid increase in the quantity of organic matter quantity would allow the sedimentation to compensate subsidence in the Lubstów fault-trough. This explains the exceptional thickness of the brown coal seam as well.

The present-day tree islands occur in the warm-temperate climate zone. The coal at Lubstów was formed in similar climatic conditions. This is shown by the domination of taxa associated with a warm-temperate climate (43%), and a significant percentage of subtropical climate taxa (19%), with a minor share of typically tropical and typically cold-temperate climate taxa (Durska, 2005, 2006).

The taxonomic constitution of the sporomorph assemblage studied and the changes in the palynological profile correlate fairly well with the idea of an angiosperm shrub swamp/tree island plant community at Lubstów. Phase I distinguished in the palynological profile marks the beginning of a shrub swamp development (an increased percentage of pollen produced by trees and shrubs inhabiting swampy environments — Fig. 3). Phases II–IV are similar to each other and indicate a high humidity of the habitat. Phase V marks the process of drying, as shown by: a decrease in quantity of pollen produced by swamp forest plants (*Inaperturopollenites*), an increase in bisaccate pollen grain quantity, transported from greater distances, and high abundance of pollen produced by shrub swamp plants. Shrubs not dependent directly on the water table might have certainly developed well in the conditions in which the cypress forest was already starting to disappear.

CONCLUSIONS

A shrub swamp with tree islands (an actualistic model being Okefenokee and the Florida Everglades from the USA) seems the most appropriate model for peat production at Lubstów. Such an interpretation is confirmed by:

There are no tissues or coniferous wood preserved in the coal, which indicates that they were not the direct organic matter producers of the coal. However, the domination of pollen produced by plants from the *Taxodium/Glyptostrobus* swamp forest community indicates that such a community existed in the vicinity of the Lubstów peat bog.

The detrital type of coal without preserved tissues indicates angiosperm plants as the source material, and shows the existence of an ombrogenous peat bog in which rapid decomposition of plant tissues took place within the aerobic zone.

There is an exceptionally high percentage of pollen from the groups: *Castaneoideapollis* (*Castanea/Castanopsis/Lithocarpus*), *Tricolporopollenites pseudocingulum* (Fagaceae) and *T. exactus* (Cyrillaceae/Clethraceae) in the coal. The plants producing these types of pollen were probably the dominant constituents of the peat-producing plant community.

The dome-shaped structures in the top of the deposit, discovered by Kasiński *et al.* (1994) might be evidence for the presence of tree islands at Lubstów.

Numerous remains of fungi similar to present-day mycorrhizal fungi, found in tree island sediments, suggest the presence of trees and shrubs and an aerobic zone.

The great thickness of the brown coal seam at Lubstów is a result of a high subsidence rate in a fault-trough, and a high rate of organic matter deposition. A very rapid increase of detritus layer thickness is observed on the surfaces of the present-day tree islands overgrown by angiosperm plants. This allows one to suppose that similar fossil plant communities might have produced an amount of organic matter sufficient to compensate for the subsidence.

The coal was formed in warm-temperate climate conditions, similar to the climate zone in which extant tree islands occur in North America.

Acknowledgements. Most sincere thanks are due to Dr. M. Ziemińska-Tworzydło for her help with pollen identification and for inspiring discussions. The author is also very grateful to Prof. U. Radwańska and Prof. A. Radwański for critical reading of the manuscript and to Dr. M. Hottenrott and Dr. J. R. Kasiński for constructive comments. In addition I would like to thank M.Sc. K. Dembiczy for assistance with field work and figure preparation.

This work is supported by the University of Warsaw, Faculty of Geology (BW 1761/1).

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