Annales Societatis Geologorum Poloniae (1996), vol. 66: 17 - 33.

STRATIGRAPHIC POSITION AND SEDIMENTARY FEATURES OF THE TERTIARY UPPERMOST FLUVIAL MEMBER IN THE KLESZCZÓW GRABEN, CENTRAL POLAND

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Krzyszkowski, D. & Winter, H., 1996. Stratigraphic position and sedimentary features of the Tertiary Uppermost Fluvial Member in the Kleszczów Graben, central Poland. *Ann. Soc. Geol. Polon.*, 66: 17-33.

Abstract: The Uppermost Fluvial Member of the Neogene sequence of the Kleszczów Graben represents a thick sand body which was deposited by a "threshold" river, with some characteristics of sinuous rivers, though with no point bars and limited overbank deposition. Dominating lithofacies are very large-scale troughs, up to 6 m deep and 25 m wide. These troughs represent palaeochannels, which have been filled with large- and medium-scale cross bedded sands and less common thin and discontinuous fine sands, clayey-silt or peat/organic mud and clay lenses. The sandy material comes mainly from the redeposition of the underlying older Neogene deposits, and locally from Jurassic sands from the graben margins. The age of the member is late Middle Miocene to Upper Pliocene, and pollen analysis has indicated thermophilous forest (late Middle Miocene) at the lower and middle parts of the series and relatively cooler conditions, though still with forest (late Pliocene) in the uppermost part of the series. Formation of the Uppermost Fluvial Member was tectonically controlled. At first it is because of the unexpected sedimentary environment and formation of a sand body despite dense vegetation cover. On the other hand, the Uppermost Fluvial Member represents the lower part of the youngest sedimentary mega-cycle of the Neogene sequence in the Kleszczów Graben, which is interpreted as entirely tectonically controlled sedimentary sequence.

Abstrakt: Najwyższa Seria Fluwialna w sekwencji osadów neogeńskich rowu Kleszczowa reprezentowana jest przez grubą serię piaszczystą, deponowaną w warunkach rzeki progowej, tj. rzeki mającej pewne cechy rzeki krętej, lecz bez wykształconych odsypów meandrowych i prawie bez sedymentacji pozakorytowej. Dominującą litofacją są wielkoskalowe rynny, do 6 m miąższości i 25 m szerokości. Rynny te reprezentują dawne koryta, wypełniane osadami piaszczystymi z warstwowaniami przekątnymi w dużej i średniej skali oraz lokalnie przez osady drobnoziarniste (pyły, iły) i organiczne (torf, węgiel brunatny, muły organiczne). Materiał piaszczysty pochodzi głównie z redepozycji niżej leżących serii starszego neogenu, ale lokalnie także z redepozycji osadów jurajskich z obrzeży rowu. Opisana seria była deponowana od późnego środkowego miocenu do późnego pliocenu. Analiza pyłkowa wykazała las ciepłolubny (późny środkowy miocen) w dolnej części serii i stopniowo chłodniejsze warunki w stropie serii, lecz ciągle ze zwartą pokrywą leśną (późny pliocen). Depozycja najwyższej serii rzecznej w rowie Kleszczowa była uwarunkowana tektonicznie. Seria ta tworzy część najmłodszego megacyklu sedymentacyjnego neogenu w rowie Kleszczowa i posiada ona nietypowe wykształcenie osadów w postaci grubej serii piaszczystej, mimo zwartej pokrywy roślinnej w dorzeczu.

Key words: Neogene stratigraphy, fluvial sedimentology, Bełchatów

Manuscript received 24 May 1995, accepted 1 March 1996

INTRODUCTION

The Tertiary deposits of the Bełchatów open pit, central Poland, (Fig. 1) have not been investigated intensively until recent time (Ziembińska-Tworzydło, 1966; Nowicki, 1971; Ciuk, 1975; Ciuk & Piwocki, 1980; Hałuszczak, 1987). The latest results of both geological and palaeobotanical investigations have changed the formerly established stratigraphy (Głazek & Szynkiewicz, 1987; Stuchlik *et al.*, 1990), generally finding older age of the sequence: Eggenburgian to Ottangian for the Main Coal Seam, and Karpatian to Pannonian for the Clayey-coal Unit (Table 1). Also, the Pliocene/Pleistocene boundary was biostratigraphically defined, as the Reuverian C and Prae-tiglian floras were determined in one profile in superposition (Krzyszkowski & Szuchnik, 1995).

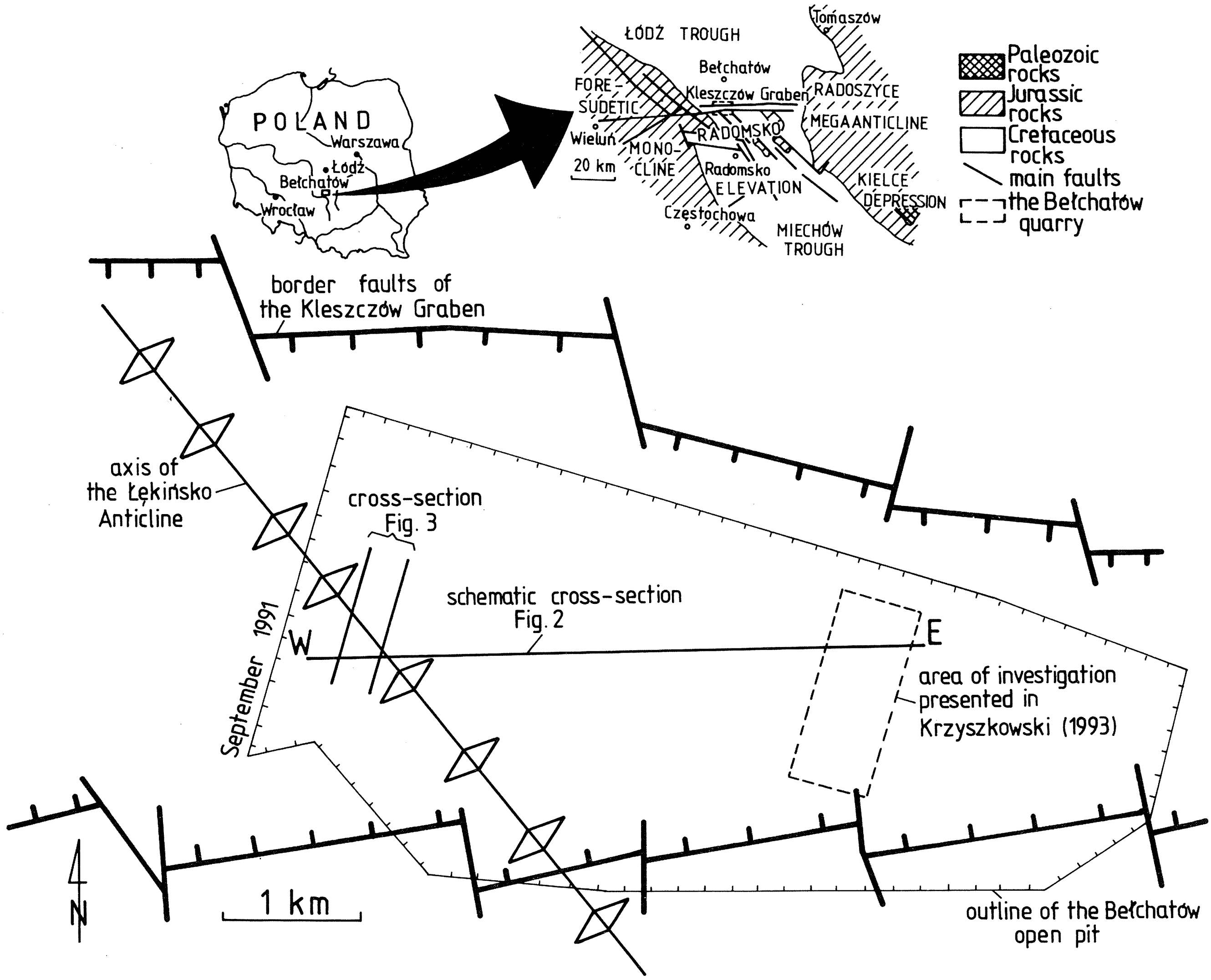

Fig. 1. Location of the area of investigation and major tectonic elements of the Kleszczów Graben

This paper presents the litho- and biostratigraphic position, and sedimentary features of the youngest Tertiary deposits of the Bełchatów open pit - the Clayey-sandy Unit, and especially the Uppermost Fluvial Member (Table 1). The pit during the investigation was 250 m deep and about 3 - 4 km wide. The continuing progress of exposures has allowed to study new sections every year. Recently, the Clayey-sandy Unit has been well exposed as a ca. 30 m thick sandy suite, unknown in former sections, with numerous silty-clayey lenses, suitable for palaeobotanical studies.

GEOLOGICAL SETTING

The Bełchatów pit is located within the Kleszczów Graben (Fig. 1). The E-W stretching Kleszczów Graben occurs at the intersection of a number of main tectonic units (Błaszkiewicz *et al.*, 1968; Pożaryski, 1971, 1977; Znosko, 1960, 1962) (Fig. 1). It is located at the intersection of two major lineaments: the NW-SE trending Poznań-Rzeszów lineament and the E-W fault system of Kodrąb-Wieluń. The latter was renewed during the Alpine deformation. The Kleszczów Graben originated at this tectonic line during the late Palaeogene. The graben is about 40 km long, and 3 - 4 km wide. The stratigraphic throw along the border faults varies from 150 to 400 m. The Mesozoic bedrock contains several paralell, NW-SE trending, synclinal and anticlinal zones which cross the graben area. The investigated area is located directly in the crest of one of such anticlinal zone, the Łękińsko Anticline (Fig. 1).

The Kleszczów Graben was an active sedimentary basin during the Neogene. It was filled with up to 400 m thick sequence of coal and clastic deposits, both Neogene and Quaternary in age. The deposits were also strongly folded and faulted during different phases of tectonic activity (Nowicki, 1971; Ciuk, 1980; Ciuk & Piwocki, 1980; Gotowała, 1982, 1987; Hałuszczak, 1987). The Neogene sequence contains three main units: lower, middle (the Main Coal Seam) and upper (Nowicki, 1971; Ciuk & Piwocki, 1980; Hałuszczak, 1987; Stuchlik *et al.*, 1990). Detailed

Table 1

General stratigraphy of the Neogene sediments within the Kleszczów Graben

Lithostratigraphy		Genesis	Chronostratigraphy
Łękińsko Formation (Łk)* [Ławki 18A]		fluvial (cyclic suite)	Lower Pleistocene (Prae-tiglian)
Clayey-sandy Unit (I-P) [Ławki 18F & 17] [Kuców 1]	Green Clays*	lacustrine	Upper Pliocene to late Middle Miocene
	Uppermost Fluvial Member* (White and Brown Sand)	fluvial (sand body)	
	Upper Gravels*	erosion phase	
Conglomeratic Unit	Upper Member (Gr 1)	alluvial fan	late Middle Miocene to Lower Miocene
[Stawek 1 & 3] Clayey-coal Unit Upper Member (I-W$_g$)	Upper Fluvial Member*	fluvial (cyclic suites)	
	Shales with leaves	lacustrine	
	Middle Fluvial Member	fluvial (sand body)	
	Black Gravels	erosion phase	
Clayey-coal Unit Middle Member (I-W$_{śr}$)	I Coal Seam	swamp	Lower Miocene
	Lower Fluvial Member	fluvial (cyclic suites)	
	Lowermost Sandy Member	fluvial (sand body)	
	Lowermost Gravels	erosion phase	
Conglomeratic Unit	Middle Member (Gr 2)	alluvial fan	
Clayey-coal Unit Lower Member (I-W$_g$)	II Coal Seam	swamp	
	Black Clays	lacustrine	
	III Coal Seam	swamp	
Conglomeratic Unit	Lower Member (Gr 3)	alluvial fan	
Carbonate Unit (W-W)		lacustrine	
Main Coal Seam (W)		swamp	
Sub-coal sands (PW)		fluvial (sand body)	

* - suites discussed in the paper; [Stawek 1 & 3] - position of sites investigated palynogically; arrows indicate sedimentary megacycles

lithostratigraphy of the upper unit has been presented by Hałuszczak (1987) and Krzyszkowski (1993). Generally, four sedimentary cyclothems including fluvial and lacustrine deposits have been found above the Main Coal Seam, which are separated by conglomeratic slope deposits at the southern margin of the trough. This paper describes mainly the Uppermost Fluvial Member of the Neogene sequence, belonging to the youngest sedimentary cycle (Clayey-sandy Unit), as well as deposits from units directly below and above (Table 1).

The tectonic history of the Kleszczów Graben is very complex. Generally, its southern and northern parts have quite different tectonic evolution, with continuous subsidence and repeated subsidence and uplift, respectively. This profoundly influenced sedimentary processes, e.g. some units, including the Main Coal Seam, occur only or in majority in the southern zone of the graben. Also, fluvial sequences change laterally their lithofacial architecture (Krzyszkowski, 1993). This picture is complicated additionally in the W-E direction, where other sedimentary basins with differing subsidence rates trough time were created above the synclines and anticlines of the Mesozoic bedrock.

The varying subsidence rates in W-E direction, along the graben, controlled the thickness and stratigraphic se-

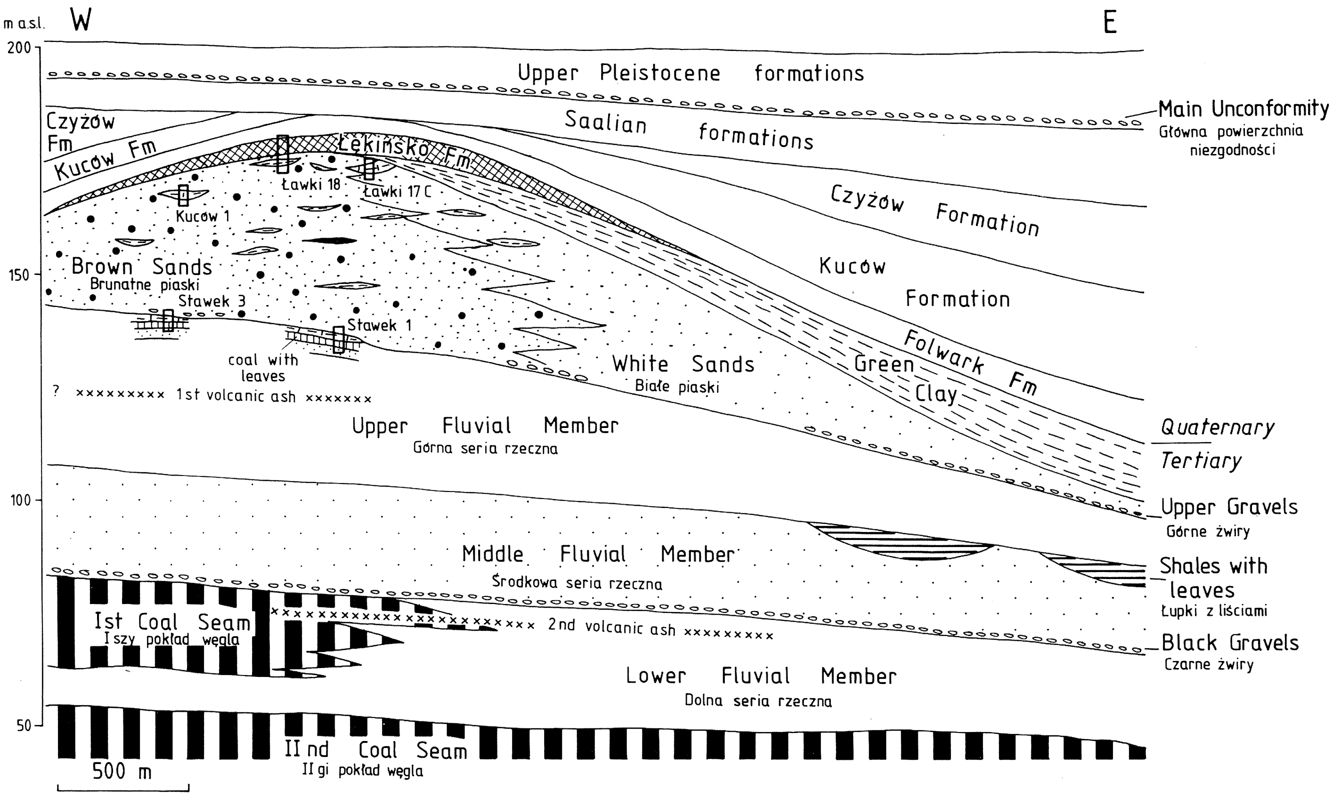

Fig. 2. Schematic stratigraphic successions of the uppermost part of the Tertiary sequence in the Kleszczów Graben and position of sites of palaeobotanical studies

quence of the Clayey-sandy Unit (Fig. 2). This Unit was only up to several metres thick in the eastern part of the pit and contained White Sands and up to 10 m thick Green Clay (Krzyszkowski 1993). In the area of the Łękińsko Anticline, the Clayey-Sandy Unit is at least 30 m thick. The Green Clay disappeared or is represented by only 1 - 2 m thick and discountinuous clayey lenses. The sandy bed has thickened and changed the colour (the Brown Sands) (Fig. 2).

LITHOSTRATIGRAPHY

Lithostratigraphic position of units described below was determined on two levels: +125 and +150 of the Bełchatów quarry (Fig. 3), in the middle part of the graben (Fig. 1). The summary sequence is presented in figure 4.

Upper Fluvial Member

This unit was earlier described in detail by Krzyszkowski (1993) and interpreted as the facies association of a meandering river. This fluvial suite contained thin and continuous coal or clay beds up to 10 - 15 cm thick (fine members), which were interstratified with the laterally extensive, 0.5 - 2.0 m thick, sheet sands (coarse members). New profiles (Fig. 5) have contained more thick fine members, up to 2 m, which usually contained layers of silt, clay and coal with some fine sand intercalations. The coarse members were still laterally extensive and contained medium-scale and occasionally small-scale cross trough bedded sands. The thicknees of the coarse members was usually between 2 - 4 m.

The main heavy mineral of sandy deposits of the Upper Fluvial Member is zircon (40 - 70%), which is associated with garnet, staurolite, tourmaline and kyanite (Fig. 4).

The uppermost clayey-coal bed of the Upper Fluvial Member was sampled for palaeobotanical investigations at two sites: Stawek 1 and Stawek 3 (Fig. 5). At the first site, the coal layer contained leaves (Figs 6A & B). This horizon dates back the lower age boundary of the Uppermost Fluvial Member, which is discussed in detail in this paper.

Uppermost Fluvial Member

The boundary between the Upper and the Uppermost Fluvial Members is erosional. This is documented in many places by distinct scours in the fine grained topmost deposits of the first unit. However, the gravel lag appears only occasionally (Upper Gravels, Table 1) and it is not visible in sections recently investigated (Fig. 3, 5), except the clay balls at site Stawek 3.

The Uppermost Fluvial Member constitutes itself as the 20 - 30 m thick, laterally extensive sand body (Figs 3, 7). This sand body is uniform from its bottom to top as well as laterally, and it is formed mainly with large and medium trough cross bedded sands, rarely sands with pebbles. Occa-

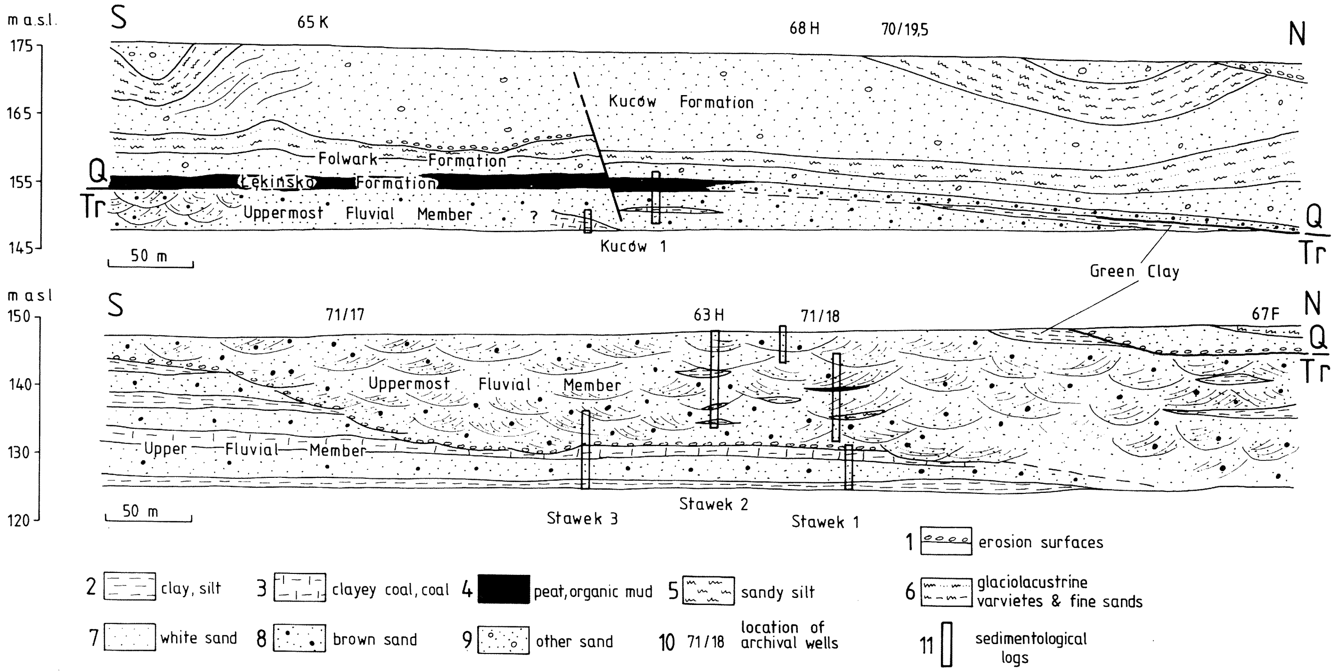

Fig. 3. Geological cross sections of the levels +125 and +150 of the Bełchatów open pit (location in Fig. 1)

sionally, at trough bottoms, occur silty, clayey or peat lenses.The latter are from several centimetres up to 1.4 m thick (Figs 3, 5). The number of silty-clayey lenses increases slighty upwards. Two silty-clayey beds in the uppermost part of the member have indicated Reuverian flora (sites Łękińsko 18F and 17; Krzyszkowski & Szuchnik, 1995).

The main heavy minerals of the Uppermost Fluvial Member (White Sands) from the eastern part of the pit are staurolite, garnet, amphibole, zircon, kyanite, tourmaline and andalusite (ca 15%) (Krzyszkowski, 1990). The main heavy minerals of the Brown Sands from western part of the pit (Krzyszkowski & Szuchnik, 1995) are staurolite, zircon, kyanite, tourmaline, garnet and some amphibole, but andalusite almost does not occur (0 - 4%). It was inferred, that brown sands of the Uppermost Fluvial Member come from the redeposition of older Tertiary fluvial sequences, because the latter deposits contain the same minerals. In turn, it was also supposed that the white sands of the Uppermost Fluvial Member contain some admixture of Jurassic sands (sandstones), which are exposed at the graben margins (Krzyszkowski & Szuchnik, 1995). New sections, presented in this paper, embrace interbedded laterally both brown and white sands (Fig. 3). Moreover, there are found some large troughs which contain both brown and white sands on the opposite sides of the trough. Except for two samples, almost all sandy deposits, both brown and white, have only small amount of andalusite, being overdominated by zircon, staurolite, tourmaline, garnet and kyanite (Fig. 4). The andalusite-bearing deposit, with 20 - 25% of andalusite, occur within one trough structure, with sands of different colours (Fig. 4). Hence, the colour of sands is not directly dependent on the "Jurassic admixture", but the occasional and lenticular occurrence of andalusite-bearing deposits within the Uppermost Fluvial Member indicates for rather short-distance transport of this mineral, presumably from margins of the graben.

One site, Kuców 1, sampled for palaeobotanical investigations contains: 1.4 m thick layer with alternating silt, clay, peat and fine sand (Figs 3, 5). The Kuców 1 is located only ca 5 - 10 m below the top of the sand body and simultaneously ca 5 - 10 m below the deposits with earlier documented Reuverian floras (Figs 3, 8, 9).

The Green Clay

Green Clay occurs only occasionally in the sections investigated (Fig. 3). This unit is up to 1 - 2 m thick and lies between the Uppermost Fluvial Member and the Łękińsko Formation. In case, where the Green Clay does not occur, both fluvial units are in superposition (Fig. 3) (Krzyszkowski & Szuchnik, 1995).

The Łękińsko Formation

This formation was described in detail by Krzyszkowski (1990) and Krzyszkowski & Szuchnik (1995). The Łękińsko Formation represents the fluvial sequence, most probably deposited by a meandering or anastomosing river, and it contains organic deposits (peat, organic mud, organic detritus) and grey, horizontally or medium-scale cross bed-

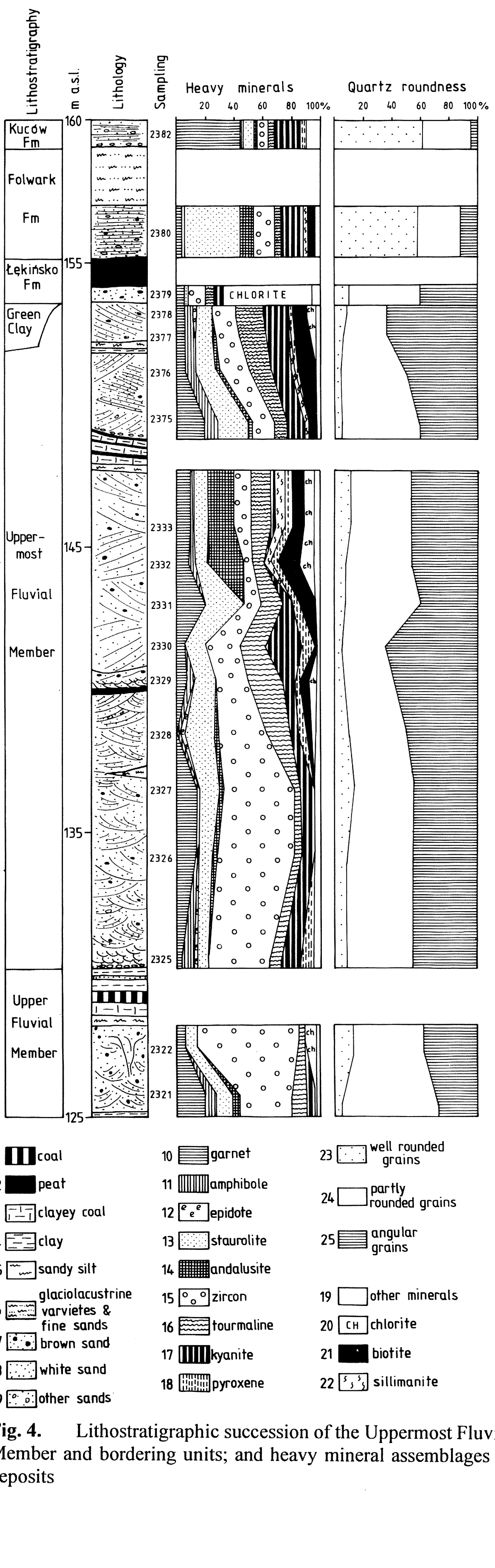

Fig. 4. Lithostratigraphic succession of the Uppermost Fluvial Member and bordering units; and heavy mineral assemblages of deposits

ded sands (Krzyszkowski, 1990). The lower and upper boundary of the formation are distinct, although they do not indicate traces of erosion. The age of the Łękińsko Formation was inferred to represent the Prae-tiglian (site Łękińsko 18A; Krzyszkowski & Szuchnik, 1995) and this horizon gives the upper age boundary for the Uppermost Fluvial Member.

The Folwark Formation, overlying the Łękińsko Formation, is supposed to represent the Elsterian glaciation. Thus, there is a hiatus, ca 2 mln years long, between the Łękińsko Formation and the next Quaternary deposit. In turn, the transition from the Uppermost Fluvial Member to the Łękińsko Formation is rather continuous because the Reuverian C floras were determined in the clay layer lying directly below both the Łękińsko Formation and the Green Clay (Krzyszkowski & Szuchnik, 1995).

Heavy minerals of the Łękińsko Formation are usually the same as those of the underlying Tertiary deposits, except for the increase in garnet (Krzyszkowski & Szuchnik, 1995). An important difference in comparison to the Tertiary deposits is the quartz roundness characteristics. Generally, the Łękińsko Formation contains more rounded grains than the Uppermost Fluvial Member of the Tertiary sequence (Fig. 4), due to possible admixture of aeolian grains (Krzyszkowski & Szuchnik, 1995).

PALYNOSTRATIGRAPHY

Methods of pollen analysis

The samples were boiled with 7% KOH. Then, the mineral and organic fractions were separated using the aqueous solution of the cadmium and potasium iodides with density of ca. 2.1. Finally, the organic material was acetolised with the Erdtman method.

The percentages of particular taxa were calculated from the total consisting of pollen of trees, shrubs, terrestial herbaceous plants, aquatic plants, and spores (100%). In relation to this sum, the percentages of pollen of the of non-Tertiary plants and plankton were calculated. Results of the pollen analysis are presented in three pollen diagrams (Figs 10 - 12).

Results

Stawek 1 (Fig. 10)

Phase I *Pinus-Sequoia-Picea* (samples 2236 - 2240)

Pinus dominates within the coniferous trees (max. appearance above 36% in sample 2239). Also, *Picea* and *Sequoia* have their maximal values of pollen in this phase, 15.23% (sample 2240) and 7.53% (sample 2240), respectively. The pollen of other coniferous trees, such as *Sciadopitys*, *Abies*, *Tsuga* and others, is rare. Main decideous trees are *Quercus*, *Fagus* and *Ulmus*; their percentage contents do not exceed 10%.

The phase I is characterized by a mixed forest with dominant arctotertiary elements and only minor admixture

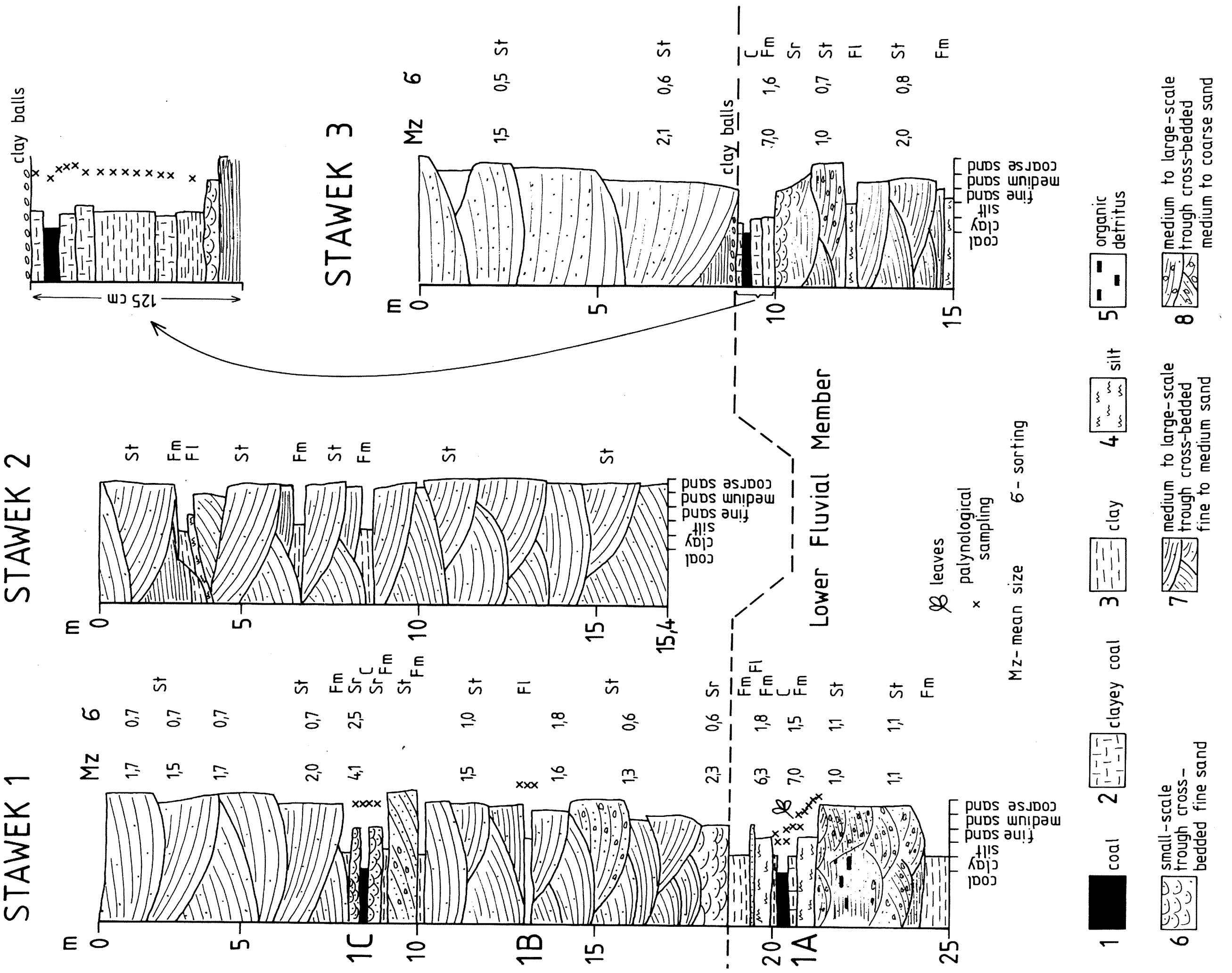

Fig. 5. Lithofacies succession in the Uppermost Fluvial Member at sites Stawek 1, 2 and 3

of palaeotropical elements. The latter is mainly represented by *Symplocos*, *Platycarya* and *Ilex*. Swamp forest took little part and was mainly represented by *Alnus*.

Phase II *Fagus*, *Carpinus*, *Betula* (samples 2241 - 2243)

This phase is characterized by a rapid decrease of *Pinus* and *Picea*, with simultaneous increase values of deciduous trees such as *Fagus*, *Quercus*, *Carpinus* and *Betula*. These deciduous trees reached their maximal appearance in the profile (*Fagus* 18.10% in sample 2241, *Quercus* 17.10% in sample 2242, *Carpinus* 8.57% in sample 2242, *Betula* 10.84% in sample 2242) during the phase II. Also, percentages of pollen of other deciduous trees increase, especially *Ulmus* and *Carya*. A swamp forest is predominated by *Taxodiaceae-Cupressaceae*.

The phase II is characterized by a mixed forest, with highly decreased palaeotropical elements and coniferous trees. The swamp forest was only subsidiary.

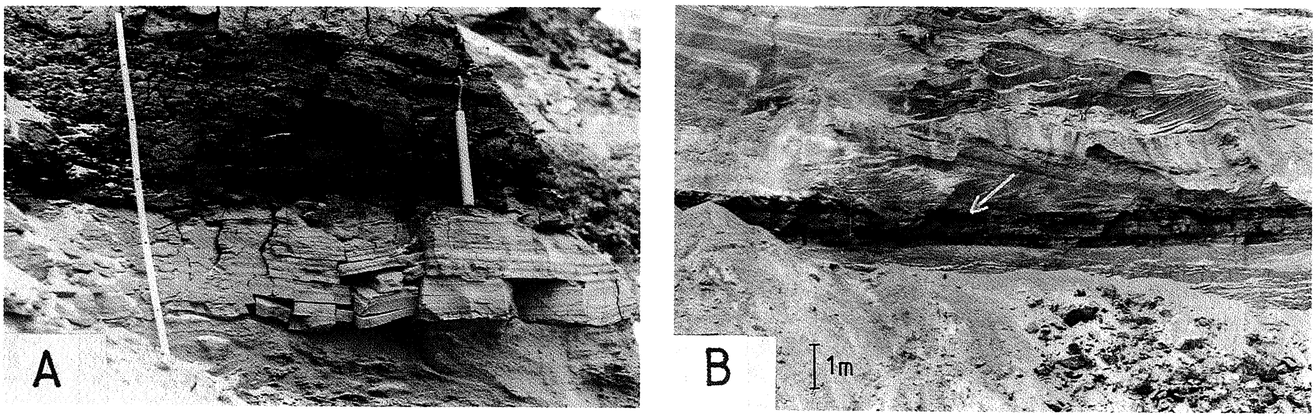

Fig. 6. A - clayey coal and coal with leaves from Stawek 1 (Upper Fluvial Member), B -clayey coal - coal bed at Stawek 3 (compare with Fig. 5). Scale 1 m in all sections. Arrows indicate the top surface of the Upper Fluvial Member

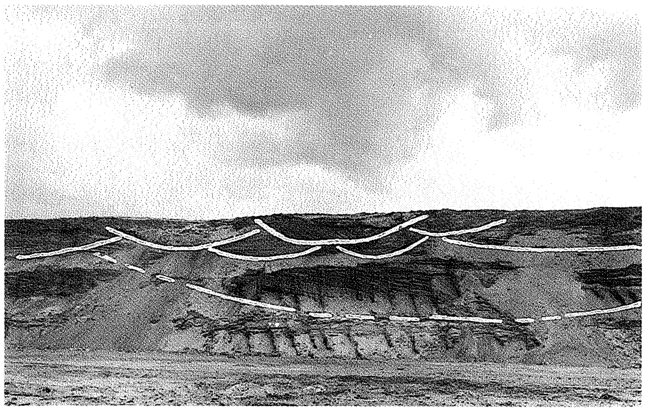

Fig. 7. The thick sandy unit of the Uppermost Fluvial Member. Note the very large scale trough cross bedded structures (palaeochannels). The section is 20 m high

Phase III *Alnus*, *Pterocarya* (sample 2246)

This phase is characterized by a rapid increase of *Alnus* (max. ca 40%) and *Pterocarya* (up to 15.21%). The pollen of other trees decreases. Another characteristic of this phase is an extensive development of the swamp forest with *Alnus-Pterocarya*; dry areas were mixed decideous-coniferous forest with *Pinus*, *Picea*, *Quercus* and *Fagus*.

Phase IV *Pinus*, *Ulmus* (sample 2247)

In this phase, values of *Alnus* and *Pterocarya* drastically decrease, with simultaneous increase values of *Ulmus* (max. 18.88%) and *Pinus*. This phase is characterized by the mixed forest with *Pinus*, *Fagus* and *Quercus* in dry habitats and the swamp forest with *Ulmus* and *Alnus* in wet conditions.

Generally, the pollen spectrum of the profile Stawek 1 is predominated by arctotertiary elements (e.g. *Quercus*, *Fagus*, *Carpinus*, *Ulmus*, *Sequoia*) with minor palaeotropical elements such as *Symplocos*, *Ilex*, *Platycaria*, *Padocarpus*, *Reevesia* and others. The mixed mesophitic deciduous-coniferous forest was dense and dominant of that time. The trees were accompanied by some shrubs as *Corylus*, *Rosaceae* and *Salix*. Undergrowth is represented mainly by *Polypodiaceae, Ericaceae* and *Gramineae*. Marshy habitats are predominant by the swamp forest with *Alnus* and *Taxodiaceae-Cupressaceae*.

Stawek 3 (Fig. 11)

Phase I *Taxodiaceae-Cupressaceae*, *Quercus*, *Fagus* (samples 2420 - 2430)

This phase is characterized by a high percentage of *Pinus* (max. 37.86% in sample 2430) and the highest value of *Picea* (max. 11.71% in sample 2420), but the value of *Picea* pollen systematically decreases. Pollen of other coniferous trees such as *Abies*, *Tsuga*, *Sequoia* and *Sciadopitys* are infrequent and do not exceed 4%. Main deciduous trees are *Fagus* (max. 14.14% in sample 2424), *Quercus* (max. 14.23% in sample 2422), *Ulmus* (max. 9.22% in sample 2421) and *Betula* (max. 9.21% in sample 2423).

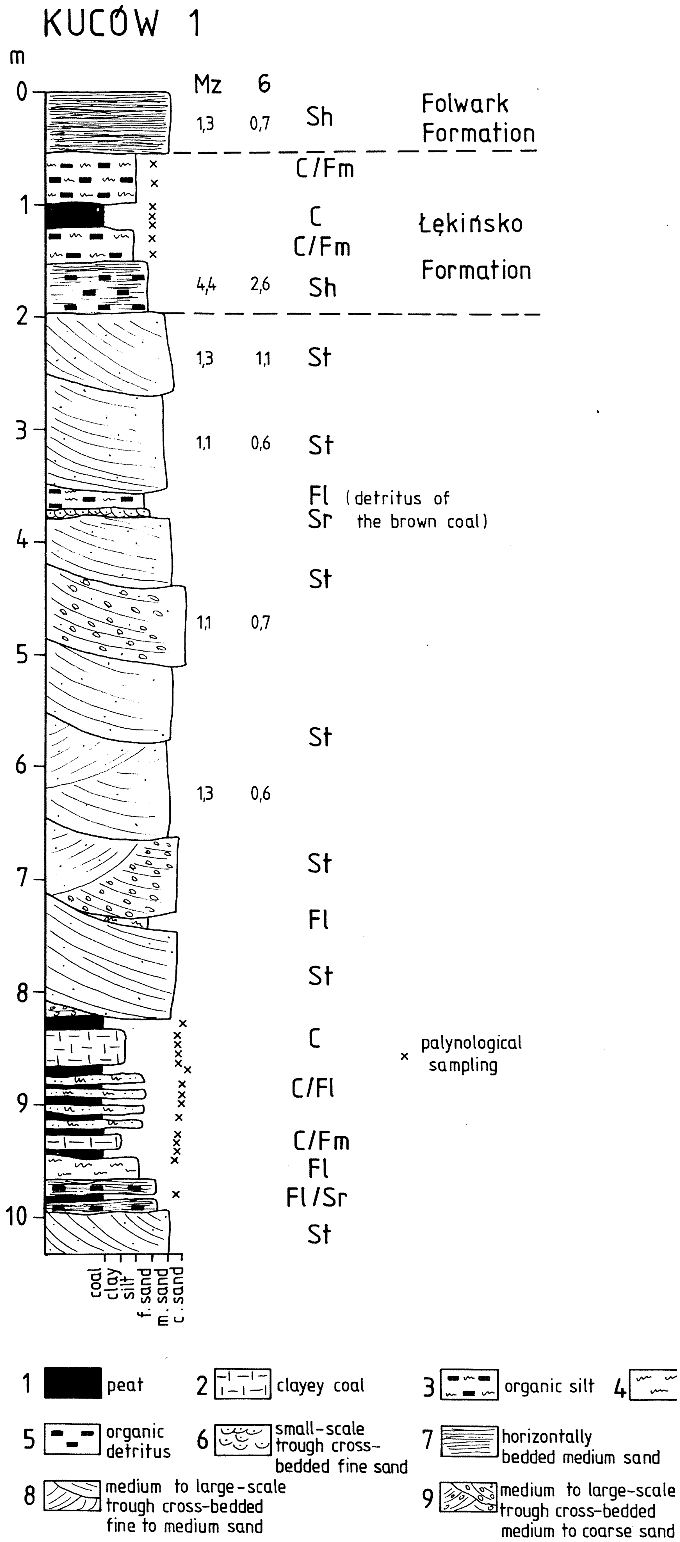

Fig. 8. Lithofacies succession of the Uppermost Fluvial Member and the Łękińsko Formation at site Kuców 1

This phase is dominated by the mixed forest with *Pinus*, *Picea*, *Fagus*, *Quercus*, *Ulmus* and *Betula*; the wet habitats were dominated by the *Taxodiaceae-Cupressaceae* forest with admixture of *Alnus*.

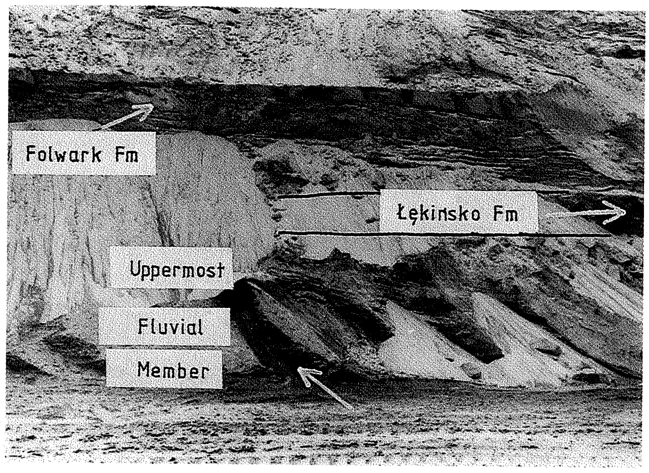

Fig. 9. General overview for site Kuców 1; note the superposition of the Kuców 1 site (lower arrow) and the Łękińsko Formation

Phase II *Alnus*, *Picea*, *Itea* (samples 2431 - 2434)

This phase is characterized by a rapid increase of *Alnus* pollen, with its maximal appearance up to 57% (sample 2432). Almost all other trees decrease, especially of *Quercus* and *Betula*. Simultaneously *Liquidambar* increases its pollen content. Pollen of *Itea* appears in this pollen zone and reaches the highest value in sample 2433 (3.27%).

The phase II is characterized by a predomination of the swamp forest, mainly with *Alnus* and with admixture of *Taxodiaceae-Cupressaceae*. However, the mixed forest with *Pinus*, *Fagus* and *Quercus* is still important in the vegetation cover.

Generally, the pollen spectrum of the profile Stawek 3 represents the mixed forest with almost equal amounts of coniferous and deciduous trees, with some brushes such as *Corylus* and *Rosaceae*. This forest transforms into the swamp forest with *Alnus* and *Taxodiaceae-Cupressaceae*. The Stawek 3 profile shows distinct presence of the palaeotropical elements, represented by *Itea*, *Tricolporopollenites pseudacingulum* (ancient species, probably from family *Anacardiaceae*), *Araliaceoipollenites edmundi* (*Araliaceae*), *Symplocos*, *Ilex*, *Tricolporopollenites satzveyensis*, and *Irillaceae*.

Kuców 1 (Fig. 12)

Phase I *Pinus*, *Sequoia*, *Abies* (samples 2400 - 2405)

This phase is characterized by a high value of *Pinus* pollen. Besides *Pinus*, coniferous trees are represented by *Sequoia* (max. 6.25% in sample 2400), *Abies*, *Tsuga*, *Picea* and *Sciadopitys*. In terms of deciduous trees, the highest value is reached by *Ulmus* (max. 7.36% in sample 2401). Values of other deciduous trees such as *Quercus*, *Betula*, *Fagus*, *Carya* and *Carpinus* do not exceed 3%.

Phase I is characterized by the mixed forest with dominant coniferous trees, mainly *Pinus*, and with admixtures of *Ulmus*, *Quercus*, *Betula* and *Fagus*. Marshy habitats were occupied by the *Taxodiaceae-Cupressaceae* forest with *Alnus*.

Phase II *Pinus*, *Taxodiaceae-Cupressaceae*, *Carpinus* (samples 2406 - 2408)

As in the phase I, *Pinus* is a dominant taxon. Value of pollen of *Sequoia* decreases. The main deciduous tree is *Carpinus* which attains the highest value of 9.65% in sample 2406. Other important deciduous trees are *Fagus*, *Ulmus* and *Betula* (max. 6.03% in sample 2407). Marshy vegetation is represented mainly by *Taxodiaceae-Cupressaceae*.

The phase II is also characterized by a mixed forest with dominant coniferous trees, mainly *Pinus*, but values of deciduous trees significantly increase. The *Taxodiaceae-Cupressaceae* forest with *Alnus* was dominant in the marshy regions.

Phase III *Pinus*, *Fagus*, *Quercus* (samples 2409 - 2414)

In this phase *Pinus* pollen reaches its maximum value, up to 61% (sample 2413) and is absolutely dominant among the trees. Other coniferous trees are *Abies* and *Picea*. Deciduous trees are represented mainly by *Fagus* (max. 17.45% in sample 2414), *Pterocarya* (max. 6.12% in sample 2412), *Quercus* (max. 4.50% in sample 2412) and *Ulmus*. Also, *Taxodiaceae-Cupressaceae* reaches 8.64% in sample 2414.

During the phase III, the dominant is the mixed forest with *Pinus* and *Fagus*, with an addition of *Ulmus*, *Quercus* and *Pterocarya*. Marshy habitats are occupied by the *Taxodiaceae*- Cupressaceae forest.

In conclusion, the pollen diagram of the profile Kuców 1 shows the predominance of coniferous forest, with only subsidiary deciduous trees. Vegetation changes are distinct mainly in the latter group. At the begining, the dominant tree is *Ulmus*, than *Carpinus* and finally *Fagus*, *Quercus* and *Pterocarya*. The mixed forest with *Parthenocissus*, *Caprifoliaceae* and *Vitis* documented in Kuców 1 represents dry habitats. Besides *Polypodiaceae* in the undergrowth of the forest, *Graminae* and other herbaceous plants occurred. The palaeotropical elements were rare – *Symplocos*, *Tricolporopollenites libarenae*, *Reveesia* and very rare *Tricolporopollenites pseudoangolum* and *Tricolporopollenites satzveyensis*.

Age of deposits

Two plant communities have been recognized in the profiles investigated: swamp forests and mixed forests. The last one is only important in the stratigraphic discussion. The mixed forest is dominated by *Pinus*, *Picea* and *Abies*, with less frequent *Sequoia*, *Tsuga* and *Sciadopitys*. These trees were accompanied by deciduous trees, first of all *Fagus*, *Carpinus*, *Ulmus*, *Quercus*, *Carya*, *Pterocarya*, and other belonging to arctotertiary floras.

The pollen diagrams of Stawek 1, Stawek 3 and Kuców 1 have been compared with other pollen diagrams of the Miocene and Pliocene deposits in Poland. They are very similar to floras of the site Bełchatów VI (Stuchlik *et al.*, 1990) and Sośnica (Stachurska *et al.*, 1973). Floras of the

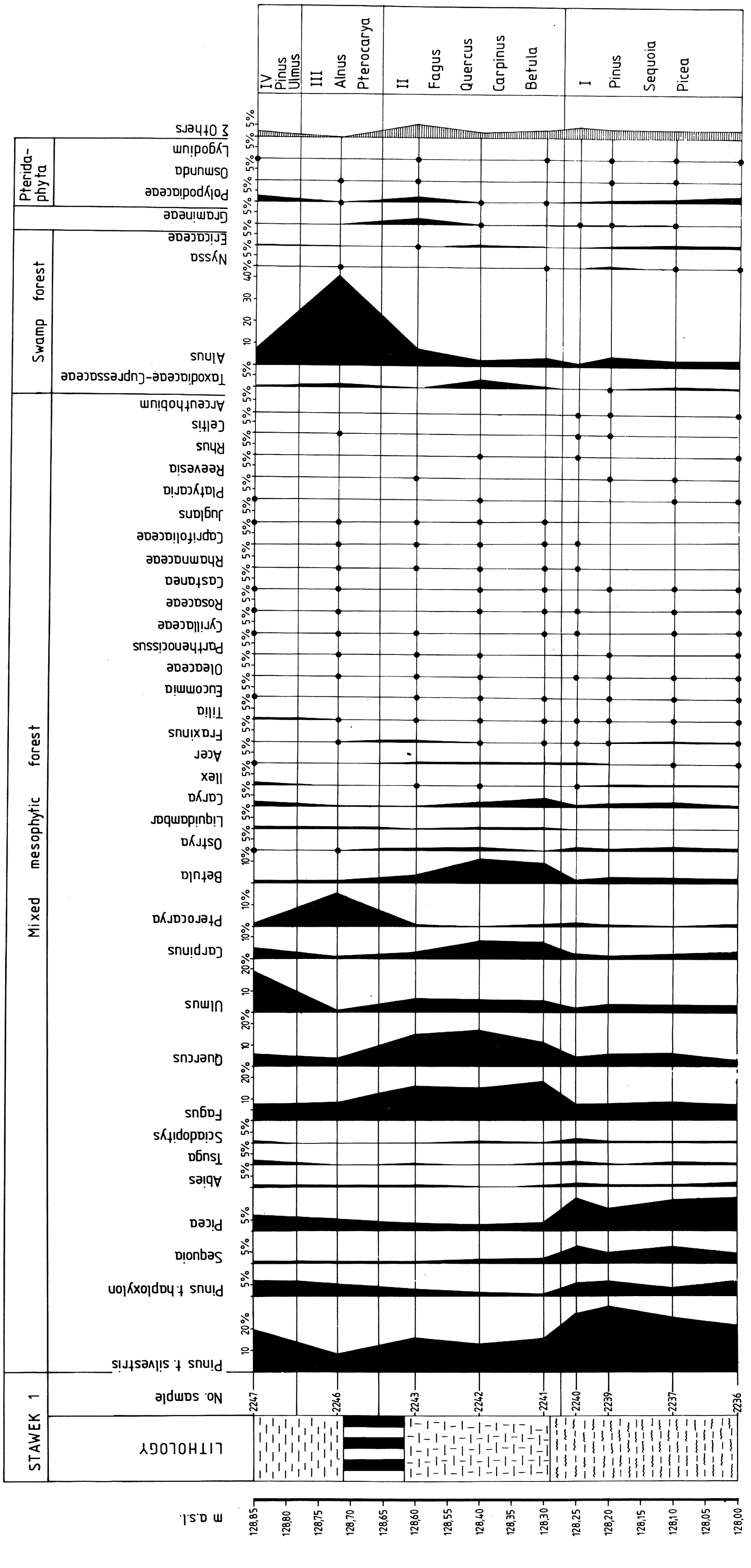

Fig. 10. Pollen diagram of the profile Stawek 1 at Bełchatów outcrop

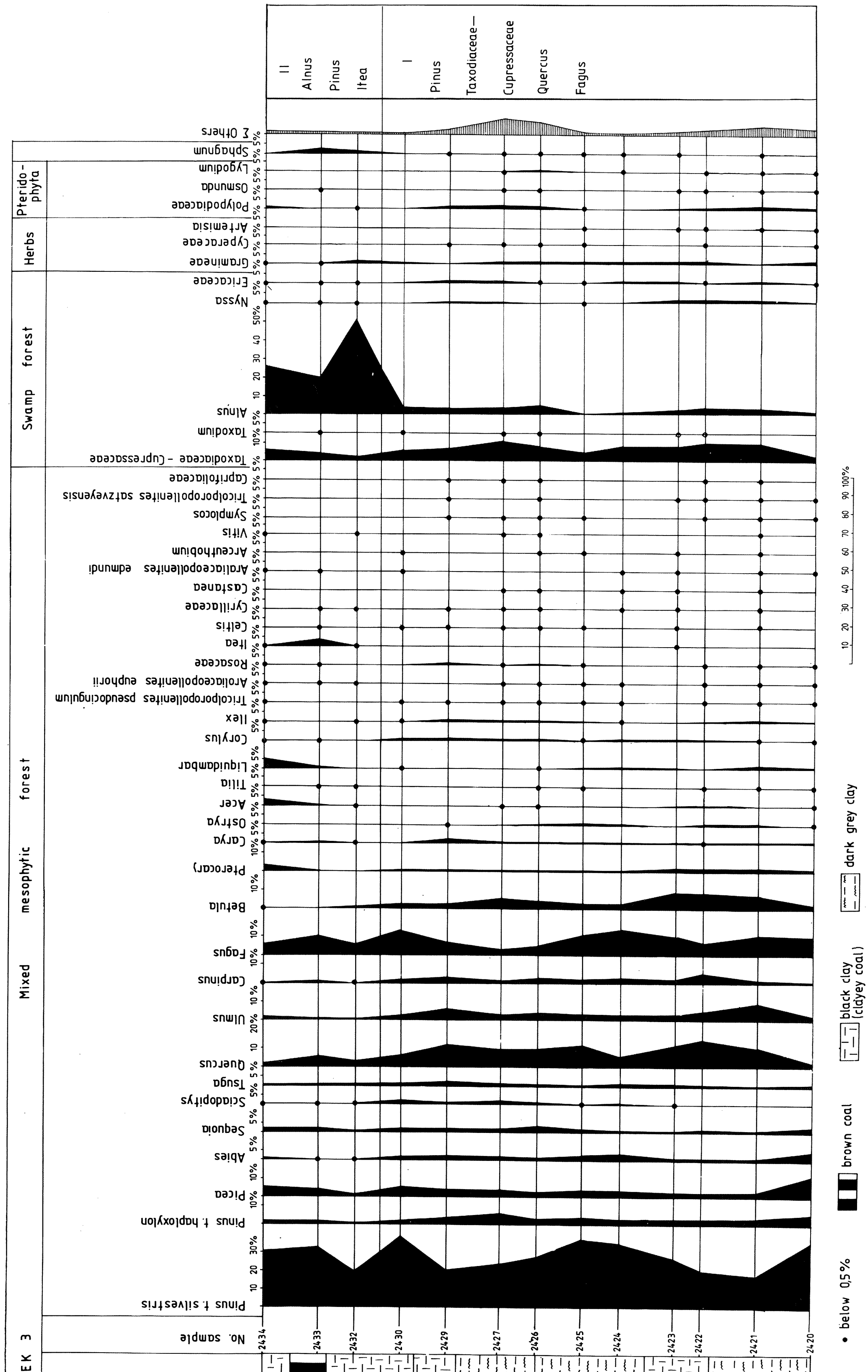

Fig. 11. Pollen diagram of the profile Stawek 3 at Bełchatów outcrop

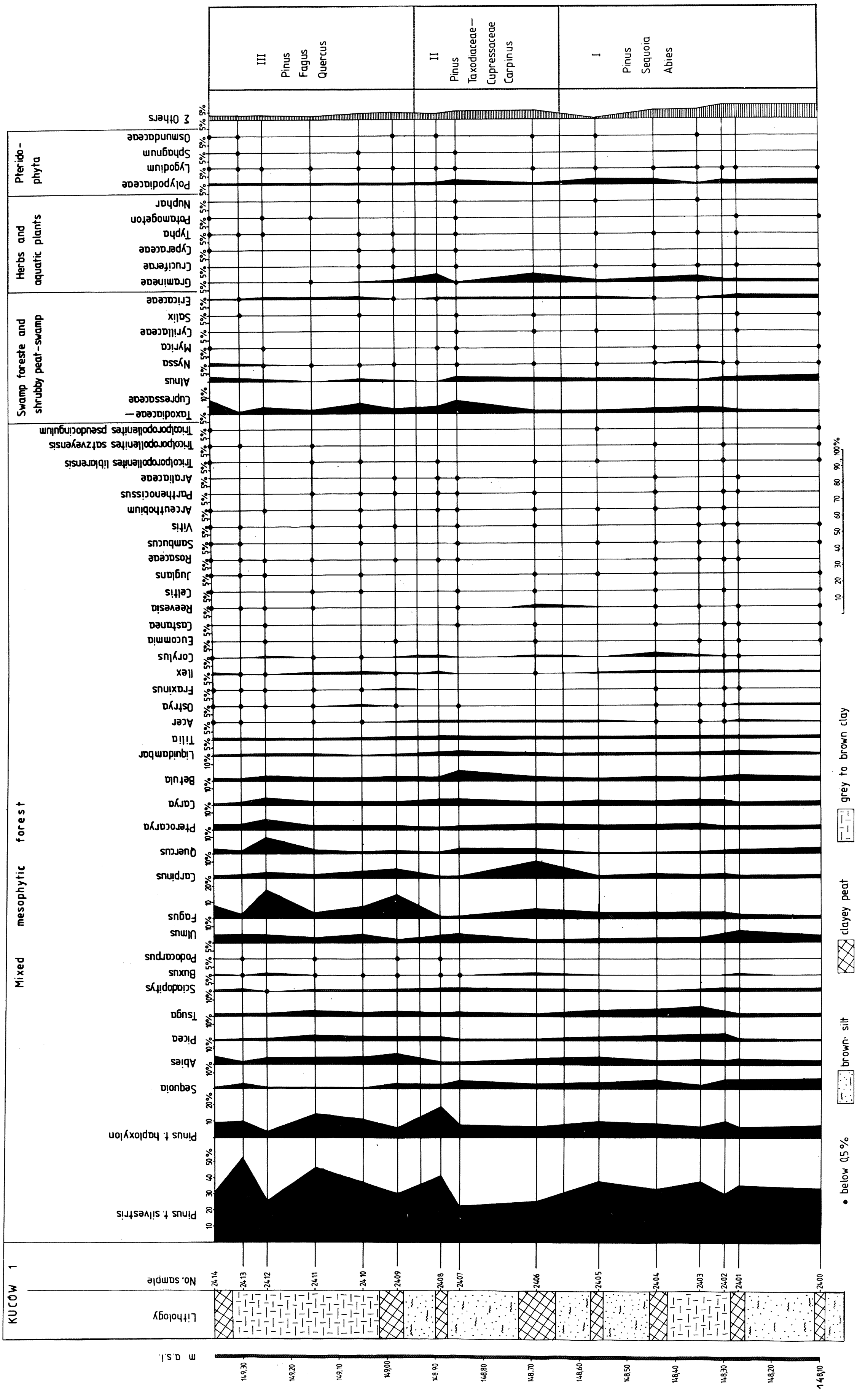

Fig. 12. Pollen diagram of the profile Kuców 1 at Bełchatów outcrop

Bełchatów VI have been interpreted as the Middle Miocene (Pannonian), and floras of Sośnica as the Early Pliocene. The floras presented in this paper are most probably older then those of Sośnica. It may be indicated by larger values of palaeotropical elements, e.g. *Araliaeaepollenites edmundi*, *Symplocos*, *Reevesia*, and by the occurrence of *Itea* and continuous presence of *Sequoia*. The presence of the *Itea* phase in Stawek 3 may suggest the Middle Miocene age of deposits, especially the VIIth pollen zone described by Ziembińska-Tworzydło (in press). However, a general floral characteristics suggests rather younger, Late Miocene age. Grabowska (1983) has described similar floras at the Buczyna profile, which were interpreted by her as belonging to the latest Middle Miocene or early Late Miocene.

More precise dating is impossible and general conclusion is that the floras of sites Stawek 1, Stawek 3 and Kuców 1 all represent the late Middle Miocene to early Late Miocene. From the lithostratigraphic position it is clear, that floras of the Kuców 1 are somewhat younger than two other, despite similarity of the floras.

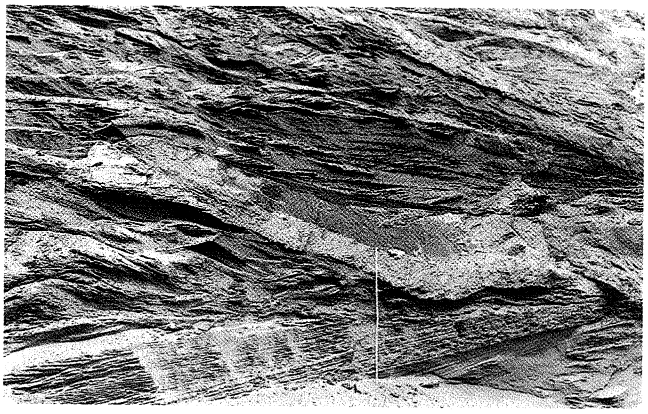

Fig. 13. Large to medium-scale trough cross-bedded brown sands at site Stawek 2. Scale 1 m

SEDIMENTARY FEATURES OF THE UPPERMOST FLUVIAL MEMBER

Lithofacies

Very large scale troughs (palaeochannels)

The individual troughs may reach depth up to 6 m and width up to 25 m; in average they are 2 - 3 m deep and 5 - 15 m wide and contain in majority brown or white, medium to fine-grained sand, only occasionally containing pebbles, moderately well to moderately sorted. The large troughs occur throughout the unit described. They may form single coset of large scale cross-bedding (Fig. 7) or may be filled with more complex sequences containing lithofacies listed below.

Medium to large scale trough cross bedded sand (St)

This is brown, locally white, medium to fine-grained, moderately well to moderately sorted, trough cross bedded sand (Fig. 13). The troughs are large or medium-sized, varying in depth from 0.3 to 2.0 m and with typical width of 1 - 3 m. They are filled with cosets up to few metres thick and commonly contain detritus of the lignite and clay balls.

Small scale trough cross bedded sand (Sr)

This is white to brown, medium to very fine-grained sand, moderately to poorly sorted. Sands display cross-lamination both at 3-dimensional troughs and ripple-drift lamination. The size of individual trough structures is about 5 cm. This facies is defined as cosets up to 1 m thick, usually 20 - 30 cm thick, of limited lateral extent. This facies is usually associated with the massive to laminated sandy silt, occurring at their bottoms.

Massive to laminated sandy silt (Fm, Fl)

This is grey to brown, very fine sand or coarse silt, moderately to very poorly sorted, massive or crudely laminated. The thickness of sets is up to 0.5 m, usually several centimetres. Their lateral extent is changing from several centimetres up to few metres. Massive and laminated silts occur usually at bottoms of the very large troughs and often together with small-scale cross bedded finesands.

Massive clay (brown to dark grey) (C)

This is organic-rich sediment (clayey coal) varying in grain size from clayey silt to clay (with more than 60% of clay fraction). The clay is massive, although with changeable colour from dark grey to brown within one layer. In many places, it also indicates platy structure (shale). The latter, most probably, was originated due to differentiated organic content and dehydration. The facies is up to 1 m thick. The massive clay occurs most often at bottoms of the very large troughs, forming laterally-limited lenses.

Peat or clayey peat (C)

This is brown to dark brown, fibrous, strongly decomposed peat, in places more clayey peat (clastic admixture). It forms layers or lenses up to 20 cm thick, usually only a few centimetres thick, intercalated with other organic or fine grained deposits.

Green clay (massive to brecciated)

The green clay layers are from a few centimetres to few decimetres thick and occur in two sub-facies. More common are massive layers, with abundant slicks. They differ from the main body of Green Clay only in thickness and position. The breccia type clay is formed with small and angular clay balls which were homogenised and compacted, forming finally beds with well defined boundaries. Transitions between two above sub-facies were noticed. The green clay layers have limited lateral extents, from several centimetres to a few metres. They usually fill the bottoms of the large troughs, but some separate beds were also documented.

Lignite/clay/silt detritus

This lithofacies contains redeposited material, mainly the small (up to 2 cm) particles of lignite and occasionally also clay balls and silt admixture. The redeposited material form layers up to several centimetres thick, paralell to the trough cross bedding. When compacted, it may be recognized as the "lignite layer".

Distribution of lithofacies

Generally, the Uppermost Fluvial Member forms a laterally extensive, although varying in thickness, sand unit. The dominant facies is the very large scale trough cross-bedded sand (about 60 - 80% of the suite described) (Figs 5, 7, 8). Large to medium scale trough cross-bedded sand is less common (20 - 30%). The latter facies cannot be easily identified, as it may fill very large structures (palaeochannels) or form iregular lenses of medium to large scale trough cross-bedded sand in between palaeochannels. The value 20 - 30% is calculated for the latter case.

Other facies are much less common, together ca 5%, with an increase up to 10% in the uppermost part of the unit. These lithofacies form usually thin beds (up to 2 m) with limited lateral extents (up to few metres) (Fig. 2). Green clay and lignite detritus beds usually occur separately, forming isolated lenses or layers. Other lithofacies: cross bedded fine sands, massive to laminated silts, brown and dark grey clays and peat are usually connected with the very large troughs and often form sequences with alternating lithologies (Figs 5, 8) (Krzyszkowski & Szuchnik, 1995). They usually fill the bottoms of the very large troughs. Upper boundaries of these fine sand-silty-organic beds are erosional, and usually followed by large to medium scale cross bedded sands.

Sedimentary environment

The very large troughs may be interpreted as palaeochannel infills of the sinuous river environment. These palaeochannels may be filled with typically channel deposit formed in high energetic conditions (trough cross-bedding of different size) or with complex sequences containing both channel and overbank facies. The latter were deposited at bottoms of the abandoned channels during the vanning stages of floods. They represent typical shallow basin deposits (massive silts and clays), with sequences formed during occasional inflows (fine sands with ripplemarks, laminated silts). High admixture of organic deposits in these basins (brown to dark grey clay, peat) as well as their pollen content suggest dense vegetation on the river banks, and their expantion into the channels during low water stages. Pollen analysis (Kuców 1 and Łękińsko 18F, 17C profiles) has indicated coniferous to mixed forests in the neighbourhood of the river valley, together with swamp conditions (forest) on permanently wet alluvial plains.

The grain size of the coarsest deposits filling the channels is unusually small (medium to fine sand, occasionally fine pebble; the largest mean size observed – +1.1φ, the largest 1st centile – -2.48φ). This must be explained by specific local conditions, taking into account possible large erosional power of the river (formation of very large troughs). Most probably, sandy deposits were redeposited from older Tertiary sequences and/or Jurassic sands and sandstones, which both are fine to medium sized. Thus, the grain size is not indicative for the palaeohydraulic interpretations, being only the "available material". Local redeposition as a main process in formation of the Uppermost Fluvial Member may be confirmed also by the occurrence of lignite detritus and redeposited green clay layers (clay balls), both occurring in older deposits (lignite occurs only in the older strata) as well as by mineralogical characteristics of sediments.

On the other hand, fine grained deposits, though present, represent only a small admixture in the fluvial sequence. The fine grained deposits do not form distinct layers formed in floodplain conditions, but they are restricted only to the channel zone. The fluvial series is formed almost entirely as a laterally extensive sand body, which is unexpected for fluvial deposits formed by sinuous rivers in highly vegetated region of the temperate to warm climate. Some other Tertiary fluvial series at Bełchatów, which were formed in similar climatic conditions, have indicated typical fining upward sequences and/or extensive floodplain deposition (Krzyszkowski, 1993).

It seems, however, that the Uppermost Fluvial Member may have been deposited by the sinuous river, but with very changeable palaeodischarge. The latter may be assumed from repeating deep erosion and formation of very large troughs (channels) and afterwards filling of troughs by fines. This river may have indicated the threshold conditions: 1) during the high energetic (and erosional) stages it has characteristics very similar to braided rivers with possible formation of several channels; and, 2) during the low water stages it represents the low energetic sinuous river with limited overbank deposition (restricted to filling the abandoned channeals) and almost no point bars (Ethridge & Schumm, 1978; Maizels, 1983; Fergusson, 1987).

The sand body of the Uppermost Fluvial Member is ca 2 - 3 km wide. It suggests, that the original fluvial system could have similar width and was located only along the Kleszczów Graben. The palaeoflow directions measured in trough structures indicated the E-W trend, consistent with the elongation of the tectonic zone.

DISCUSSION AND CONCLUSIONS

The pollen analysis has indicated dense forest vegetation during the deposition of the Uppermost Fluvial Member. Such climatic/edaphic conditions are responsible for formation of fluvial sequences with extensive floodplain deposits (meandering or anastomosing rivers) rather than formation of sand bodies (Allen, 1964, 1965, 1970, 1974, 1978; Bridge & Leader, 1979; Campbell, 1976; Ethridge *et al.*, 1981; Gersib & McCabe, 1981; McLean & Jerzykiewicz, 1978; Moody-Stuart, 1966; Nemec, 1984; Walker & Cant, 1984). The cyclic fluvial deposits containing both channel and floodplain sequences were noticed within the Tertiary of the Kleszczow Graben (Krzyszkowski, 1993) and they come from stages with almost similar vegetation

(Stuchlik *et al.*, 1990). Hence, it seems that the formation of sand bodies deposited by "threshold" rivers cannot be related to "normal" sedimentary process. The tectonic influence must be inferred (Alexander & Leeder, 1987). The sand bodies occur regularly in the Tertiary sequence of the Kleszczów Graben and always at the lower part of the sedimentary megacycles defined by Krzyszkowski (1993) (Table 1). The sand bodies lie directly above the lower, erosional boundaries of the megacycles. Some of these erosion surfaces form distinct angular discordances, dividing strata with different tectonic history. The formation of sand bodies may be an answer of fluvial systems to decreased subsidence and sediment deformation in the graben. Increased erosion rates and redeposition of uplifted, older sediments is expected in this case and fit well with characteristics of the "threshold" rivers.

The Uppermost Fluvial Member represents the lower member of the youngest Tertiary sedimentary megacycle of the Kleszczów Graben. At least two other were described in older sequences (Table 1) (Krzyszkowski, 1993). The sand bodies are followed by lacustrine/swamp suites (in the youngest megacycle – the Green Clay), which show for the end of uplift and a phase of subsidence in the graben. The upper members of the megacycles are represented by cyclic fluvial sequences deposited by meandering rivers which suggest tectonic stabilization in the graben area and moderate subsidence (Table 1) (Krzyszkowski, 1993). In the youngest Tertiary megacycle, the end member is represented by the Lower Pleistocene Łękińsko Formation. It generally represents similar sedimentary environment as the older end members of megacycles, although it has also some specific features resulted from its Pleistocene age (Krzyszkowski & Szuchnik, 1995). The youngest sedimentary megacycle was formed during at least 5 - 10 million years, as their lower and upper age boundaries are placed in the late Middle Miocene/early Late Miocene (Pannonian) and in the Prae-tiglian stage of the Lower Pleistocene, respectively. However, a major part (20 - 25 m) of the sand body was deposited during the late Middle Miocene/early Late Miocene, as the profile Kuców 1 inferred to represent floras of this age, is located in the upper part of the sequence. Almost only the uppermost 5 - 10 m of the series was deposited during the late Late Miocene and Pliocene (Table 1, Fig. 2).

In conclusion it can be stated that the fluvial sedimentation within the Kleszczów Graben was predominatly influenced by the tectonic activity in this zone. The climatic factors were less important and played only a passive role in the evolution of fluvial systems. The tectonic evolution of the Kleszczów Graben created two major responses of the sedimentary sequences: formation of megacycles and constitution of specific fluvial environments, the "threshold" rivers which eroded and redeposited older sequences and formed thick sand bodies. These sand bodies were formed generally by sinuous rivers, though with limited overbank deposition and no point bars. Thus, the former interpretation of sand bodies of the Tertiary megacycles of the Bełchatów sequence as braided river sequences (Krzyszkowski, 1993) is revised, though general tectono-sedimentary history of the Kleszczów Graben presented in this paper is still valid.

Acknowledgements

Tomek Zieliński and Jurand Wojewoda offered very useful discussion on sedimentary features and their interpretations. Palynological results have been discussed broadly with M. Ziembińska-Tworzydło, I. Grabowska, A. Kohlman-Adamska, H. Ważyńska and B. Słodkowska. The authors are greatly indebted to them. Geological work was in part supported by the grant of the Polish Scientific Research Committee (KBN) No. 6 6265 91 02.

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Streszczenie

POZYCJA STRATYGRAFICZNA I CECHY SEDYMENTOLOGICZNE TRZECIORZĘDOWEJ NAJWYŻSZEJ SERII FLUWIALNEJ W ROWIE KLESZCZOWA, POLSKA ŚRODKOWA

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Najwyższa Seria Fluwialna reprezentuje jedno z najmłodszych ogniw sekwencji trzeciorzędowej w rowie Kleszczowa (odkrywka Bełchatów) (Fig. 1 - 3; Tabela 1). Była ona deponowana od późnego środkowego miocenu do późnego pliocenu, co jest udokumentowane palinologicznie. Ogniwo to występuje w postaci 20 - 30 m grubości serii piaszczystej o znacznym bocznym rozprzestrzenieniu (Fig. 2, 3, 5, 8). Dominują w niej wielkoskalowe rynny (palaeokoryta) o głębokości do 6 m i szerokości do 25 m. Rynny te są wypełnione bądź to piaskami z wielkoskalowym warstwowaniem przekątnym (Fig. 6, 7), bądź zestawami osadów zawierającymi średnio- i wielkoskalowe warstwowania przekątne rynnowe, warstwy piasków z riplemarkami, warstwy mułków, iłów i osadów organicznych (ił węglisty, torf, węgiel brunatny) (Fig. 5, 8, 9, 13). Miąższość osadów drobnoziarnistych i organicznych nie przekracza 1,4 m. Występują one w postaci soczew w spągu niektórych form rynnowych i stanowią nie więcej niż 5 - 10% całości serii. Osady piaszczyste tworzące pozostałe 90 - 95% serii są reprezentowane przez piaski drobne i średnie, z podrzędnymi wkładkami piasków grubych ze żwirami. Piaski pochodzą głównie z redepozycji starszych, dolnomioceńskich osadów rzecznych z rowu Kleszczowa, a podrzędnie też z redepozycji piasków i piaskowców jurajskich z krawędzi rowu. W obu przypadkach redepozycję udokumentowano na podstawie składu minerałów ciężkich w badanych seriach (Fig. 4), a w przypadku serii dolnomioceńskich także występowaniem toczeńców ilastych i ksylitowych.

Najwyższa Seria Fluwialna była deponowana przez rzekę "progową", zachowującą charakterystyki rzek krętych, lecz z ograniczoną sedymentacją pozakorytową i brakiem odsypów meandrowych. Powstanie takiego typu rzeki jest uwarunkowane tektonicznie. Warunki klimatyczne i edaficzne, w tym istnienie gęstej pokrywy roślinnej w czasie depozycji (termofilny las liściasty lub mieszany, oraz lasy bagienne (Fig. 10 - 12), sugerują raczej możliwość powstawania serii rzecznych o budowie cyklicznej, charakterystycznej dla rzek meandrujących. Takie serie są

notowane w rowie Kleszczowa z podobnych warunków klimatycznych jak te, udokumentowane w Najwyższej Serii Fluwialnej. Wydaje się więc, że osady rzeki progowej (Najwyższa Seria Fluwialna) powstawały w specyficznych warunkach – podczas wzmożonej aktywności tektonicznej rowu, w czasie której starsze osady były deformowane i erodowane. Najwyższa Seria Fluwialna jest fragmentem większego cyklu sedymentacyjnego, zawierającego: grubą serię piaszczystą ponad powierzchnią erozyjną (często dyskordancja), osady jeziorne i w stropie cykliczne osady rzeczne (piaszczysto-mułkowo-węglowe). W rowie Kleszczowa zaobserwowano kilka takich megacykli sedymentacyjnych (Tabela 1), co świadczy o cykliczności zjawisk tektonicznych w rowie, na przemian podnoszenia i deformacji osadów, wzmożonej subsydencji i warunków umiarkowanej subsydencji. Najwyższa Seria Fluwialna jest fragmentem najmłodszego megacyklu sedymentacyjnego w sekwencji trzeciorzędowej rowu Kleszczowa.

Appendix: description of samples investigated palynologically

Dodatek: opis próbek do badań palinologicznych

Sample no Próbka nr	Altitude m a.s.l. Wysokość m n.p.m.	Lithology Litologia
Stawek 1		
2236	128.00	clayey silt, grey
2237	128.10	
2238	128.15	
2239	128.20	
2240	128.25	
2241	128.30	clayey coal
2242	128.40	
2243	128.50	
2244	128.57	coal (lignite) with leaves
2245	128.65	
2246	128.72	clay, greyish-green
2247	128.85	clay, green
Stawek 3		
2420	130.05	clay, grey
2421	130.15	
2422	130.25	clay, black
2423	130.30	
2424	130.40	clay, grey
2425	130.47	
2426	130.55	
2427	130.62	
2428	130.70	
2429	130.75	clay, dark grey
2430	130.80	clay, black
2431	130.85	
2432	130.90	
2433	130.95	coal (lignite)
2434	131.05	clay, black
Kuców 1		
2400	148.10	silt, brown
2401	148.27	clayey peat
2402	148.30	clay, greyish-brown
2403	148.35	
2404	148.44	clayey peat
2405	148.56	
2406	148.69	
2407	148.85	silt, brown
2408	148.89	clayey peat
2409	148.98	
2410	149.05	clay, grey
2411	149.15	
2412	149.25	
2413	149.30	
2414	149.36	clayey peat