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A bi-partite Ferdynandovian succession from Łuków, Eastern Poland: a new palynostratigraphic approach

Irena Agnieszka PIDEK and Marzena MAŁEK

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The paper presents a new approach to the Middle Pleistocene lacustrine deposits at the Łuków site (Łuków Plain, E Poland). The results of pollen analysis document a rarely found complete Ferdynandovian pollen succession with evidence of two warm periods of interglacial rank and two cold ones. New geological and palynological data are presented and interpreted against a background of earlier research by Rühle and Sobolewska from 1969, including a comparison with the nearest complete Ferdynandovian succession at Zdany (Siedlce Upland) and with the stratotype section of Ferdynandów. The proposed division of the Łuków sequence into two warm periods separated by a succession typical of glacial periods has been based on a new division of Ferdynandovian pollen succession applied for the first time to the Podgórze B1 pollen profile. Two warm units and the intervening cold one in the Łuków pollen sequence correspond to the climatostratigraphical units Ferdynandovian 1 and 2 separated by the cooling/glaciation (Ferdynandovian 1/2) and can be related to the Cromerian Complex.

Irena Agnieszka Pidek, Institute of Earth Sciences, M. Curie-Skłodowska University, al Kraśnicka 2 c/d, PL-20-718 Lublin, Poland, e-mail: i.pidek@poczta.umcs.lublin.pl; Marzena Małek, Polgeol S.A. Geological Enterprise in Warsaw, Lublin Office, Budowlana 26, PL-20-469 Lublin, Poland, e-mail: lublin@polgeol.pl *(received: December 29, 2008; accepted: February 8, 2010).*

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INTRODUCTION

The profile of Middle Pleistocene deposits in Łuków (E Poland), known since the end of the 1960s due to geological investigations (Rühle, 1969) and palynological analysis (Sobolewska, 1969), is one of the best-known, oldest interglacial sites in the Łuków Plain (Fig. 1). In this region, and also in the adjacent Żelechów Plateau, numerous palaeolake basins occur. They are filled with very well preserved organogenic deposits from several different interglacials: Ferdynandovian (Cromerian – following Lindner *et al*., 2004 and Ber *et al*., 2007), Mazovian (Holsteinian) and Eemian. They were examined during geological surveys conducted as part of the completion of the *Detailed Geological Map of Poland 1:50 000*, i.e. the following sheets: Siedlce Południe (Małek, 2004), Stanin (Małek and Buczek, 2005), Łuków (Małek and Buczek, 2006), Żelechów (Żarski, 2001; Krupiński *et al*., 2004), Okrzeja (Żarski, 2003), Adamów (Żarski, 2006) and Krzesk (Brzezina, 2000). Palaeolake districts from the Mazovian Interglacial were discussed, among others, by Małek and Pidek (2007), and – including Eemian interglacials – by Żarski *et al*. (2005).

Geological work on the Łuków sheet of the *Detailed Geological Map of Poland* (Małek and Buczek, 2006) gave a unique chance to re-study the deposits in the Łuków profile. The organogenic succession from Łuków was first related to the Mazovian (Holsteinian) Interglacial though not excluding a Cromerian age (Sobolewska, 1969). Later reinterpretations led to recognition that the organogenic deposits from Łuków are of Ferdynandovian age, both from a geological and a palynological point of view (Janczyk-Kopikowa *et al*., 1981). However, it was not known whether the succession examined by Sobolewska (1969) was overlain only by deposits from a cold period or, just as in the complete Ferdynandovian profiles, also by those from another warm period and from the early part of the Sanian 2 (Elsterian) Glaciation. In 1996 detailed palynological investigations of the Podgórze B1 profile (Mamakowa, 1996) shed light on the Ferdynandovian sequence, which showed a clear bi-partite nature, to containing two warmings of interglacial rank and a cooling of glacial character separating them. In the new profile from Łuków, the

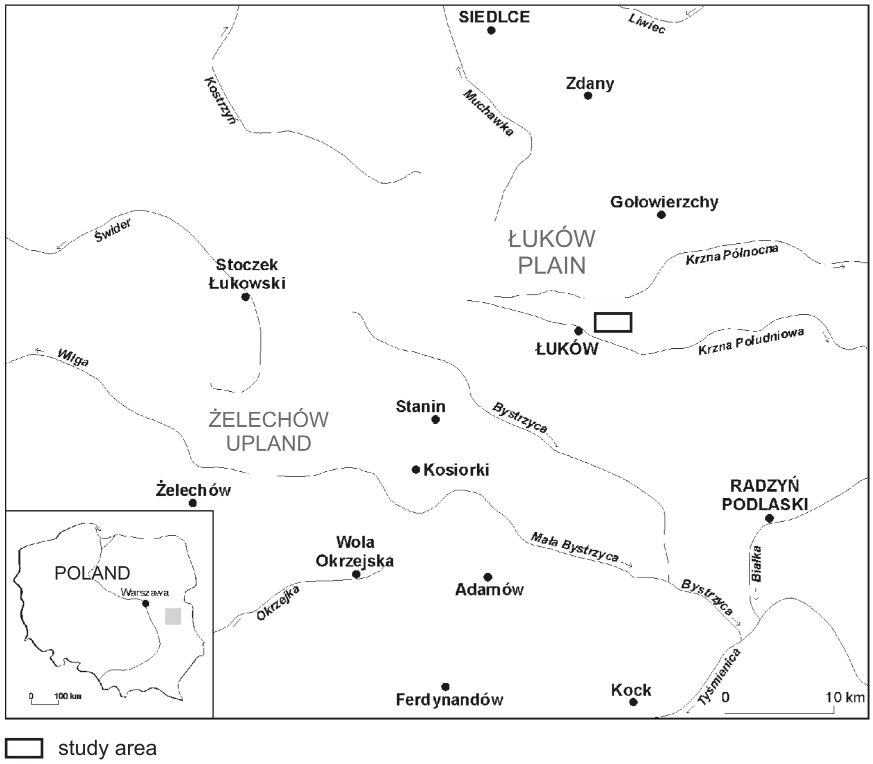

Fig. 1. Location of the study area

occurrence of mud deposits with traces of plant macroremains in the succession examined previously by Sobolewska, encouraged us to carry out a new, more detailed study of the Łuków profile. The importance of this profile for the Pleistocene stratigraphy of Poland and of Europe results from the supposed completeness of the pollen sequence and from the fact that whereas the Mazovian and Eemian are well recognized, the Ferdynandovian pollen sequence, and its division and position within Cromerian Complex, are still a matter of debate (*cf.* Lindner *et al.*, 2004; Ber, 2005). Turner (1996) and Zagwijn (1996) stressed that the early Middle Pleistocene sequences in the stratotype areas (Netherlands, Eastern England) are quite fragmentary and need reinterpretation. Zagwijn (1996) added that in comparison to the Netherlands other European areas (where interglacial lakes were formed) are better suited to the preservation of complete interglacial sequences. The significance of the Łuków profile for the stratigraphy was mentioned among others by Janczyk-Kopikowa *et al.* (1981), Lindner (1992), Rzechowski (1996), Lindner *et al.* (2001) and Mojski (2005).

In this paper, against a background of archival data from the Łuków 105 profile (Rühle, 1969; Sobolewska, 1969) we report new geological data and the results of palynological and lithological and petrographic examinations of samples taken from this profile, and discuss their relation to the stratigraphy at neighbouring sites. In the light of new data, we reinterpret their geological and stratigraphical position, demonstrate their Ferdynandovian age and give more detailed palynostratigraphic and palaeoclimatic interpretations of the interglacial succession. The conclusions are supported by the results of correlation with the Ferdynandovian pollen profile from NE – most Ferdynandovian site in Poland at Zdany (Pidek, 2003; Małek, 2004; situated in the adjacent Siedlce Plateau region) and with the data from Podgórze B1 (Mamakowa, 1996, 2003).

THE GEOMORPHOLOGICAL SETTING OF THE STUDY AREA

The town of Łuków is situated in the western part of the Łuków Plain – the mesoregion belonging to the South Podlasie Lowland (Kondracki, 2001). The environs of Łuków were covered by an ice sheet during the Odranian (Drenthe) Glaciation and were in the southern foreland of the ice sheet maximum extent during the Wartanian (Warthe) Glaciation (Terpiłowski, 2001; Lisicki, 2003; Harasimiuk *et al.*, 2004; Marks, 2004; Żarski, 2004). Elongated, strongly denuded hills of accumulation end moraines occur in the SE, SW and N of Łuków. They form trains along a WNW–ESE direction and mark one of the retreat phases of the Odranian (Drenthe) Glaciation (Mojski, 1971, 1972; Małek and Buczek, 2006). Łuków is situated on the moraine plateau in the upper valley of the Krzna Południowa River that flows through the town (Fig. 2). A strongly denuded, flat moraine plateau is composed of tills from the Odranian (Drenthe) and Sanian 2 (= Wilga = Elsterian 2) glaciations separated by fluvioglacial and

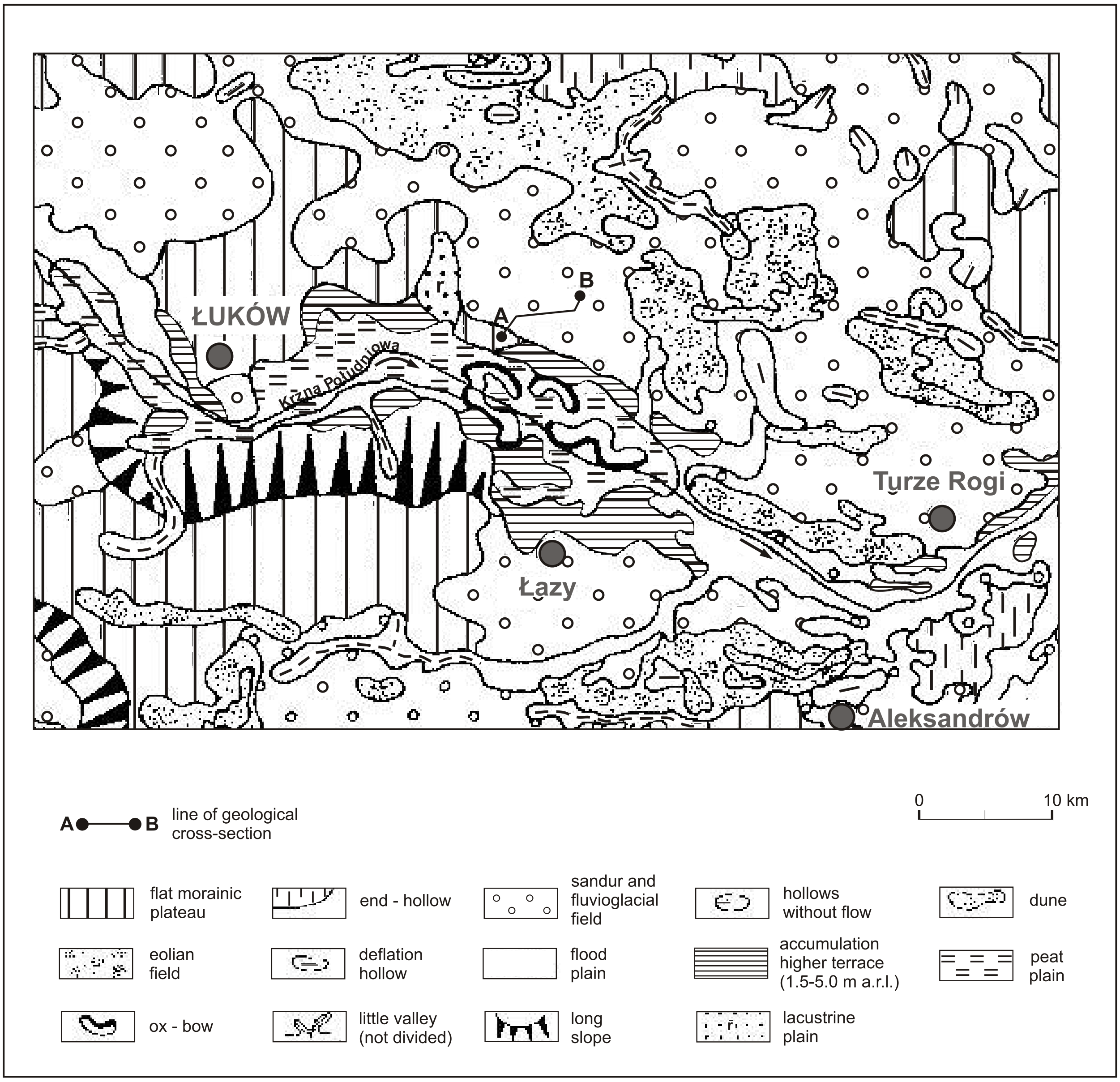

Fig. 2. Geomorphological situation of the area examined

fluvio-periglacial deposits, which are related to these glaciations. The plateau surface rises 160–165 m a.s.l. and is covered by deposits of weathering-aeolian origin. Fluvioglacial plains, composed of sandy and sandy-gravelly deposits related to the Wartanian (Warthe) Glaciation ice sheet retreat, occur in the northern and eastern part of the town (Mojski, 1971; Małek and Buczek, 2006). Around Łuków the outwash surface reaches 158–165 m a.s.l. and generally descends to the SE. Small patches of fluvioglacial deposits are also preserved along the Krzna Południowa River valley, which was one of the important routes for water from the melting ice sheet front of the Wartanian (Warthe) Glaciation. The valley bottom of the Krzna Południowa River in Łuków (from 0.5 to 1.0 km wide) is filled with Holocene sands and humic muds, alluvia and peats forming a floodplain. Discontinuous fragments of a higher accumulation terrace up to 0.5 km wide are preserved at 1.5–3.0 m above the river level, downstream of the Łuków centre. Near the surface of this terrace (to a depth of 3.0 m), mostly in the near-slope parts of the tributary valleys of the upper Bystrzyca River and in dry small valleys, 15 sites of lacustrine deposits from the Mazovian (Holsteinian) Interglacial have been examined (Małek and Buczek, 2006; Małek and Pidek, 2007). The discovery of these Mazovian deposits, occurring at exceptionally shallow depths under the ground surface, changed opinion concerning the age of the underlying tills that emerge to the plateau surface south of Łuków. At present, these tills are considered to be older, i.e. from the Sanian 2 (Elsterian 2) Glaciation. Younger Odranian glaciogenic deposits were probably mostly eroded from this area by meltwater during the Wartanian (Warthe) ice sheet deglaciation.

Both the boreholes: the archival one (105) and the new one (3a) were drilled in the eastern part of Łuków (Zapowiednik quarter), on the fluvioglacial plain to the north of the Krzna Południowa River valley (Fig. 2) and reach into deposits below the Sanian 2 (Elsterian 2) tills.

HISTORY OF RESEARCH ON CORE 105

In 1952, during coring of borehole 105, organic deposits were found at a depth of 29.10–36.20 m (Fig. 3) and their thickness was 7.10 m in total (Rühle, 1969). The geological profile of the archival borehole 105 and its stratigraphic interpretation according to Rühle (1969) are shown in Figure 4. It should be mentioned that Rühle based his interpretation only on lithological and depositional features of the deposits (laboratory petrographic examinations were not made). These are silts and clayey silts with plant remains, which are replaced upwards by strongly compressed black mud and "silty humus loam".

Taking into account palynological data and the geological situation of the profile in question, Rühle (1969, 1970) assigned the lacustrine deposits at Łuków to the Łuków Interstadial (specially distinguished in this site), which was supposed to separate the oldest known advance (Krzna Stadial) of the Middle Polish Glaciation from its maximum advance. Therefore, according to Rühle (1969, 1970) the Łuków Interstadial should be younger than the Mazovian (Holsteinian) Interglacial.

Thus, the lacustrine deposits in question, assigned by Rühle (1969, 1970) to the so-called Łuków Interstadial, would represent a deep facies deposited in a subglacial channel formed near the end of the Krzna Stadial. They are directly underlain by a 65 m thick succession of sands, with intercalations of silt and gravels assigned by Rühle to four sedimentation cycles of fluvial and lacustrine deposits of the Mazovian (Holsteinian) Interglacial. These Quaternary deposits are underlain by quartzose and glauconitic sands of the Lower Oligocene as well as by marls and limestones of the Lower Paleocene (Danian).

Borehole 105 documents the thickest (104.3 m) profile of Quaternary deposits that has been penetrated in Łuków and its vicinity to date. The Rühle's borehole was located over a depression of the sub-Quaternary surface – in a fossil valley, the direction of which (SE–NW) is determined by a longitudinal dislocation parallel to the edge of the Precambrian platform/marginal trough (Żelichowski, 1979). The tectonics of the bedrock in the edge zone of the Precambrian platform undoubtedly affected the development of neotectonic (or possibly isostatic or glaciotectonic) movements initiating erosion and facial differentiation of the deposits. In the region described, the narrow and deep fossil valley is filled almost exclusively with deposits of fluvial origin – with one thin layer of till now related to the Odranian (Drenthe) Glaciation. As correctly observed, among others by Rühle (1969), Mojski (1971) and Ruszczyńska-Szenajch (1976), this indicates that the base-level of erosion changed several times, and the valley was active from the end of the Neogene throughout almost the whole Quaternary.

Sobolewska (1969) examined only the bottom part of the lacustrine succession from a depth of 34.10 to 36.20 m (20 samples). Pollen spectra represented interglacial vegetation from the climatic optimum, without the initial and final phases (Sobolewska, 1969). However, those palynological studies did not resolve the question of deposit age. The pollen

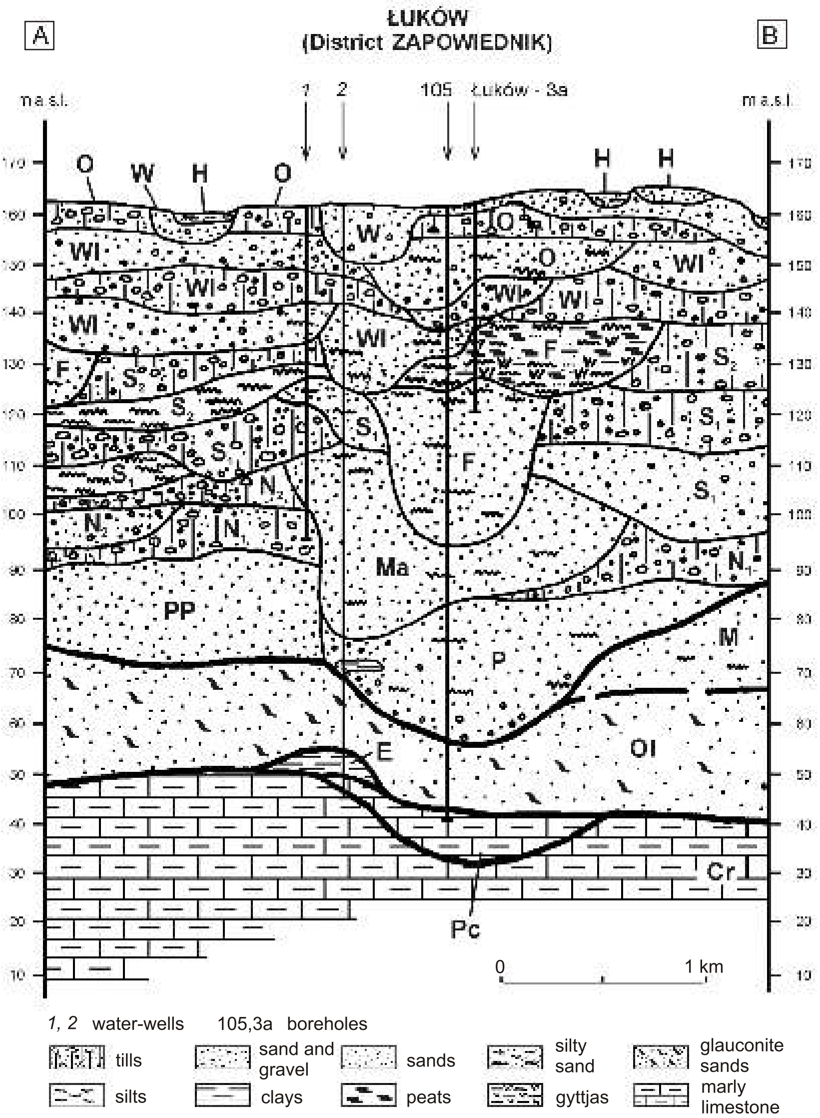

Fig. 3. Geological and stratigraphical situation of the Łuków 105 profile by Rühle (1969) in reinterpretation according to Małek and Buczek (2006) and new Łuków-3a profile by Małek and Buczek (2006)

A–B corresponds to A–B transect in Figure 2; PP – preglacial, M – Middle Miocene, Ol – Lower Oligocene, E – Upper Eocene, Pc – Lower Paleocene, Cr – upper Maastrychtian; interglacials: H – Holocene, F – Ferdynandovian, Ma – Malopolanian, P – Podlasian; glaciations: W – Wartanian, O – Odranian, Wl – Sanian 2 (Wilga), S_2 – upper stadial of the Sanian 1, S_1 – lower stadial of the Sanian 1, N_2 – upper stadial of the Nidanian, N_1 – lower stadial of the Nidanian

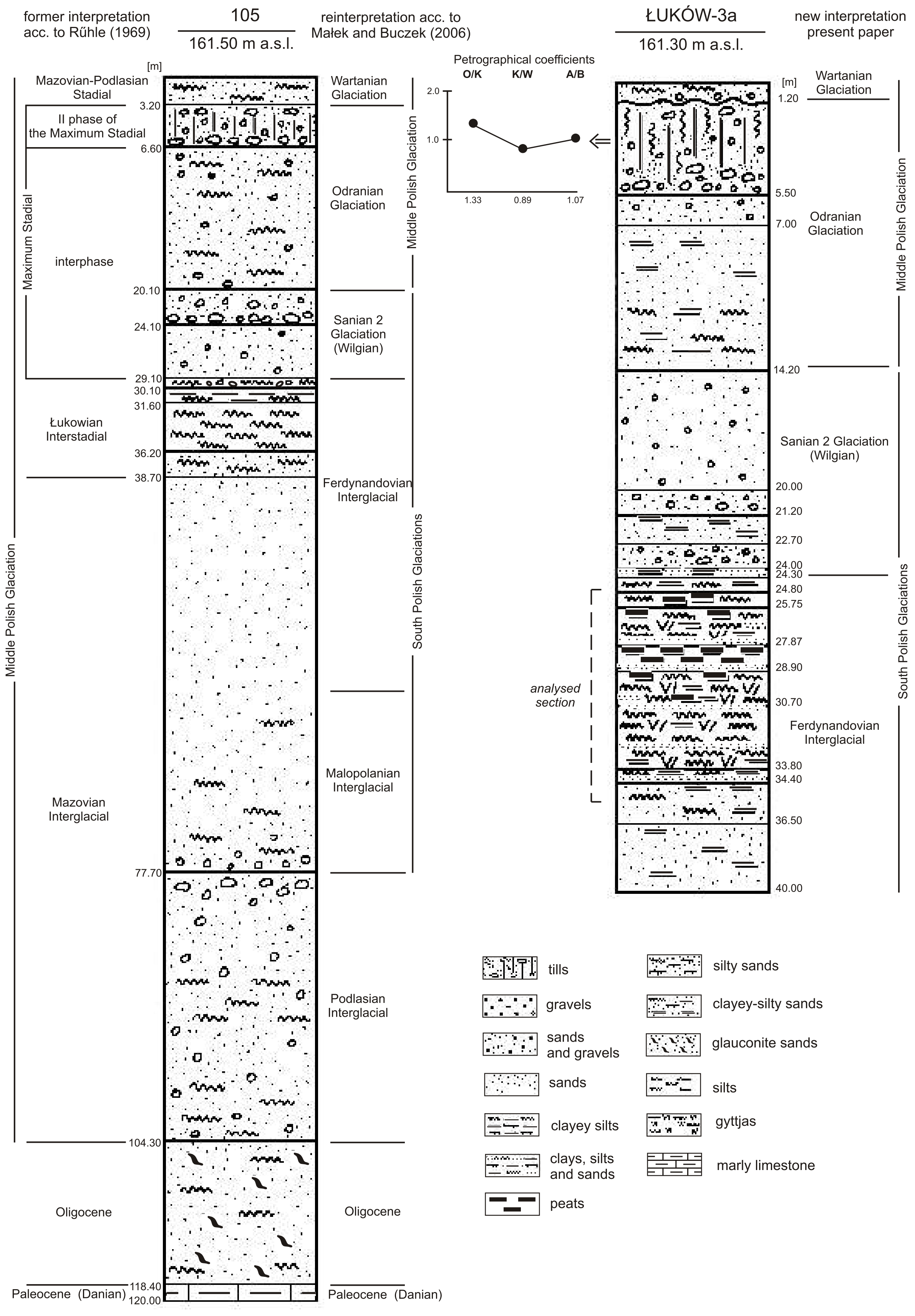

Fig. 4. Geological and stratigraphical interpretation of the archival Łuków 105 profile according to Rühle (1969) in reinterpretation according to Małek and Buczek (2006) against the geological and stratigraphical interpretation of the Łuków-3a profile according to Małek and Buczek (2006)

Petrographic coefficients are calculated for gravel clasts of Scandinavian rocks, 5–10 mm in diameter, collected from tills: O/K – the ratio of sedimentary rocks to crystalline rocks together with quartz, K/W – the ratio of crystalline rocks together with quartz to limestones and dolomites, A/B – the ratio of rocks non-resistant to weathering to rocks resistant to weathering succession was similar to that found in the Ferdynandów profile (which at that time was considered to be a Mazovian Interglacial site – Janczyk-Kopikowa, 1963), though being different from the sequences regarded as typical of the Mazovian Interglacial, e.g. those from the following profiles: Syrniki (Sobolewska, 1956*a*), Olszewice (Sobolewska, 1956*b*) and Nowiny Żukowskie (Dyakowska, 1952). Therefore Sobolewska (1969) also suggested a Cromerian age for the organic deposits from Łuków and Ferdynandów, i.e. that they were older than the Mazovian Interglacial.

THE NEW PROFILE FROM ŁUKÓW

LITHOLOGICAL AND STRATIGRAPHIC PROFILE

The full-core survey borehole Łuków-3a was made using a URB 2.5 device during fieldwork in the Łuków sheet of the *Detailed Geological Map of Poland* (Małek and Buczek, 2006), about 100 m of the archival profile 105 (Figs. 2 and 3). Drilling stopped at a depth of 40.0 m, after penetration of organogenic deposits. The profile obtained is similar to the archival one but the succession of organic deposits is more complete (Fig. 4). Lacustrine deposits with a thickness of 10.10 m occur at a depth of 24.30–34.40 m (Fig. 3). Their bottom part consists of grey silts with intercalations of silty sand. They are overlain by dark grey and brown silts, with intercalations and lenses of gyttja. Thin layers of peat appear from a depth of 24.80 to 30.70 m, and at a depth of 27.87 m the peat layer is black, strongly decomposed in the bottom part, and reddish-brown and, weakly decomposed in the top part. The overlying silts contain many thin layers of peat and gyttja, as well as sand laminae. Dark brown clayey silts form the uppermost part of the lacustrine deposits.

The lacustrine deposits are overlain by fluvial-periglacial deposits 3.10 m thick from the beginning of the Sanian 2 (Elsterian 2) Glaciation (clayey, medium-grained sands, with intercalations of sands of variable grain-size). Higher, at a depth of 14.20–21.20 m, there occur medium-grained, layered sands with gravels and scattered pebbles, these being fluvioglacial deposits from the end of the Sanian 2 (Elsterian 2).

The deposits from the South Polish Glaciations are directly overlain by deposits of the Odranian (Drenthe) Glaciation, i.e. fluvioglacial medium-grained sands, clayey in places (at a depth of 5.50–14.20 m) and a 4.00 m thick layer of till (at a depth of 1.20–5.50 m). According to this interpretation, Mazovian Interglacial deposits are lacking. The till is compact, with few gravel layers or pebbles. Its petrographic composition (Fig. 4) is similar to those typical of tills from the Odranian (Drenthe) Glaciation in this area (among others, Lisicki, 2003; Żarski, 2004). The petrographic composition of gravels indicates the predominance of crystalline rocks (39.2%) over limestones (34.8%) and dolomites (13.9%). Local rocks constitute the rest (Małek and Buczek, 2006).

In the profile Łuków-3a, at a depth of 34.40–40.00 m (the base of the borehole), under the lacustrine deposits, there occur fine-grained sands, interlayered with medium- and varigrained sands with intercalations of clayey silt as well as dispersed humus. This represents the top part of the fluvial deposits which filled the fossil valley at the end of the Sanian 1 (Elsterian 1)/ the beginning of the Ferdynandovian Interglacial (Fig. 3). Moderately sorted sands, almost without carbonates ($CaCO_3$ content up to 0.42%), were deposited by a river characterized by variable but rather high current velocity (Małek and Buczek, 2006). As is reported by Ruszczyńska-Szenajch (1976), their thickness is estimated at about 30 m (*cf*. Fig. 3), and the fossil valley continues through the centre of Łuków and extends to the east (Szymański and Buła, 1999), and to the north (Brzezina, 2000; Małek, 2004).

POLLEN ANALYSIS OF THE LACUSTRINE DEPOSITS

Pollen analysis was applied to the Łuków-3a organogenic deposits from a depth of 24.53–34.60 m. In the preliminary stage, the pollen succession was examined across the entire organogenic succession. Palynological investigations of 20 samples taken from a depth of 24.66–34.35 m show unambiguously that the lacustrine deposits examined formed in the Ferdynandovian Interglacial *s.l.* (Pidek, 2004). In order to obtain more detailed palynostratigraphy, 69 additional samples were taken for pollen analysis from the section between 27.15 and 34.60 m covering the deposits of two warm periods. The samples were treated according to standard palynological procedures used in the analysis of lacustrine sediments – HCl, KOH, HF, Erdtman's acetolysis. Pollen spectra were counted on at least two slides. The percentage pollen diagram (Fig. 5) was made based on the *POLPAL* software worked out by Walanus (Walanus and Nalepka, 1994). The calculations of pollen percentages were based on the sum of pollen grains of trees and shrubs (AP) and of terrestrial herbs and dwarf shrubs (NAP). The percentages of aquatic and lake-shore vegetation pollen, of Pteridophyta and Bryophyta spores, and of redeposited and non-determined taxa were calculated in relation to the sum including AP + NAP + the examined taxon.

The resulting pollen diagram (Fig. 5) includes the part of the profile examined from the bottom of the lacustrine deposits (at a depth of 34.60 m) to a depth of 27.15 m. The samples were taken at different intervals, depending on lithology, but usually the distance between them did not exceed 10–15 cm. The top part of the organogenic succession (from a depth of 24.53 to 27.15 m), containing the pollen succession of the early part of the Sanian 2 Glaciation, is in the course of detailed examination.

VEGETATION DEVELOPMENT: RESULTS AND INTERPRETATION

The pollen diagram of the Łuków-3a profile (Fig. 5), divided into 16 local pollen assemblage zones (L PAZ), reveals the vegetation history of a bi-partite interglacial sequence in the Łuków region. The description of L PAZ has been included in Table 1.

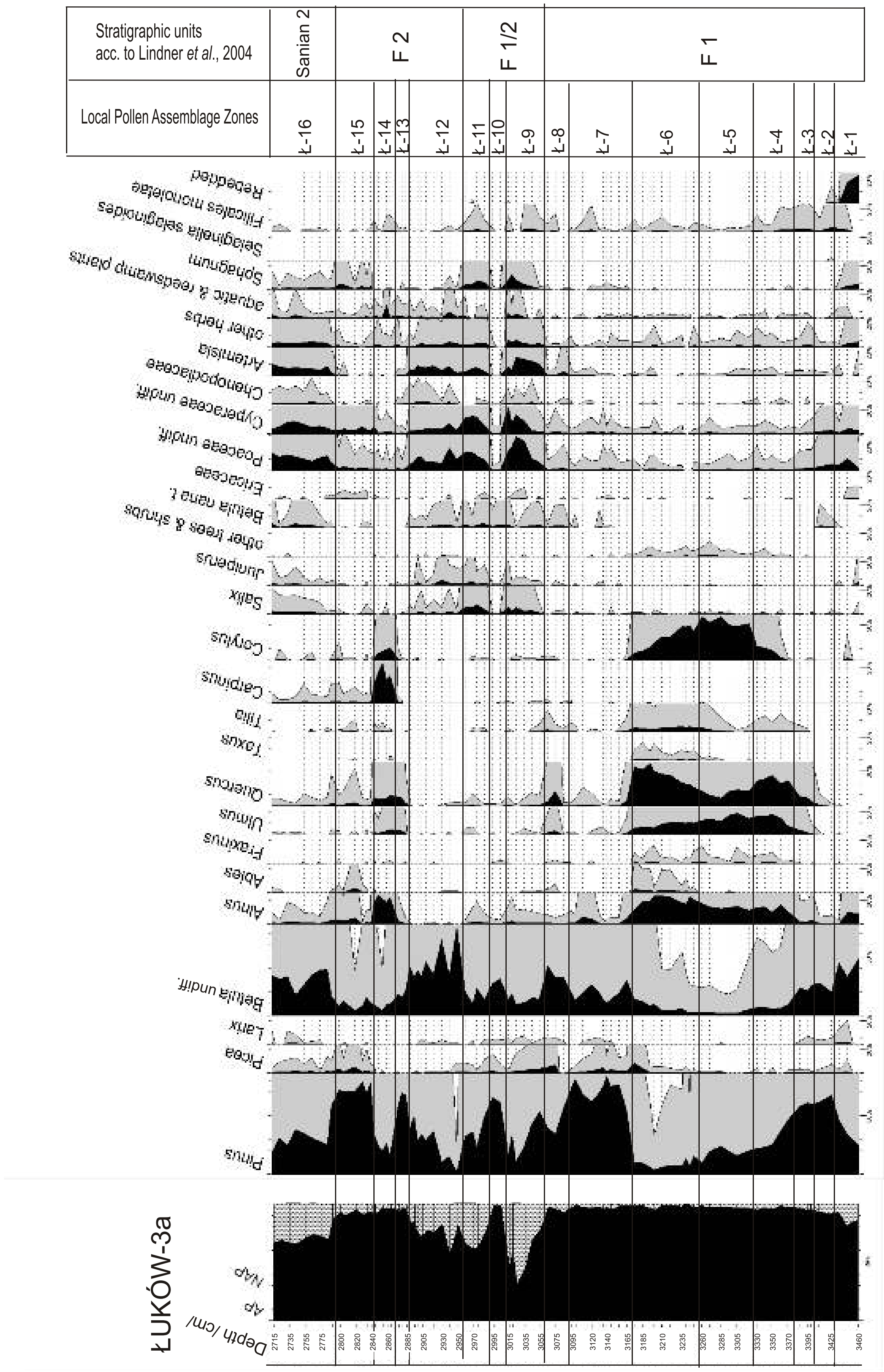

Fig. 5. Percentage pollen diagram from the Łuków-3a profile

Analysis by Pidek 2004–2007

Table 1

Description of pollen assemblage zones of the Łuków-3a sequence

Number of L PAZ	Samples depth [m]	Main features of pollen spectra
Ł-1	34.35–34.60	*Pinus* pollen values range from 24.5 to 46.0%; those of *Betula* undiff. – from 33.0 to 48.5%; *Larix* percentages up to 2.0%; *Alnus* – up to 9.5%; *Picea* – up to 1%; frequent *Salix* pollen; single grains of *Ulmus* and *Fraxinus*; Cyperaceae – up to 4.0%; Poaceae – up to 10.5%; frequent pre-Quaternary sporomorphs
Ł-2	34.10–34.25	Percentage values of *Quercus* increase to 1.1%; those of *Pinus* – up to 67.5%; *Betula* undiff. falls to 27.5%; single pollen grains of *Alnus*, *Ulmus*, *Larix*; Cyperaceae and Poaceae percentages decrease to *ca*. 3–5%; *Betula nana* t. pollen forms continuous curve
Ł-3	33.85–34.00	Pine pollen values *ca*. 60%; those of birch-range from 21.0 to 25.5%; *Alnus* and *Ulmus* – *ca*. 2–4%; *Quercus* values rise to 8.5%; first pollen grains of *Tilia* and *Corylus* appear; Poaceae and Cyperaceae values fall to *ca*. 1–2%; *Betula nana* t. pollen disappears
Ł-4	33.30–33.70	Decrease of *Pinus* pollen to 22.0%; those of *Betula* – to *ca*. 5–6%; considerable rise of *Quercus* percentages (up to 26.5%), *Alnus* and *Ulmus* – up to 16%; *Fraxinus* and *Tilia* – up to 1.0–1.5%, *Corylus* – up to 12.0%; frequent *Acer* pollen; Poaceae and Cyperaceae – below 1%
Ł-5	32.60–33.20	Increase of *Corylus* values up to 37.0% in the upper part of the zone; the values of *Ulmus*, *Quercus* and *Alnus* range from *ca*. 7 to 17%; *Tilia* percentages rise to 3.3% and those of *Acer* – to 0.9%; *Pinus* values fall to less than 10%; those of *Betula* undiff. – to *ca*. 2%; presence of *Ligustrum* and *Buxus* pollen
Ł-6	31.75–32.50	Maximum of *Tilia* pollen – 4.5%; continuous pollen curves of *Taxus*, *Abies* and *Picea*; maximum of spruce pollen – 8.5%; fir – up to 2.7%; *Alnus* percentages – up to 24%; those of *Quercus* – to 36.5% in the upper part of the zone; *Ulmus* and *Corylus* values fall simultaneously to *ca*. 6%; pollen of *Acer* – frequent; sedges and grasses appear sporadically; *Ligustrum*, *Hedera* and *Ilex* pollen occurs
Ł-7	30.95–31.65	Pine pollen values range from 54.0 to 84.0%; those of birch – from 10.5 to 30.0%; *Larix* appears again; *Picea* pollen – more frequent in the lower part of the zone, in the upper part – falls to 0.4%; percentages of all thermophilous taxa and alder fall considerably
Ł-8	30.65–30.85	*Betula* undiff. pollen more frequent than in the previous zone (up to 42.0%); *Tilia*, *Ulmus* and *Larix* form again continuous pollen curves; *Picea* and *Quercus* percentages increase (to 7 and 12.5%, respectively) in the sample 30.75 m; presence of *Carpinus*, *Fraxinus* and *Corylus* pollen; NAP and *Betula nana* t. – more frequent
Ł-9	30.15–30.55	*Pinus* pollen values range from 11.0 to 53.5%; those of *Betula* undiff. – from 9.5 to 18.5%; percentages of *Picea* gradually fall to 0.2%; single grains of thermophilous taxa; *Salix* and *Juniperus* – more frequent (up to 5.3 and 2.1%, respectively); increase of NAP values; Cyperaceae – up to 22.5%, Poaceae – up to 29.0% and *Artemisia* – up to 16.0%
Ł-10	29.95–30.05	Pine pollen percentages increase to 65.5%; birch – range between 20.0 and 27.5%; frequencies of Cyperaceae, Poaceae and *Artemisia* are less than 1% each
Ł-11	29.60–29.85	AP percentages fall sharply again; *Pinus* values range from 23.5 to 49.0%; *Betula* undiff. percentages fall to 9.5%; *Salix* and *Juniperus* pollen reach their maxima (8.0 and 3.5%, respectively); *Betula nana* t. – frequent; NAP increase considerably again; Cyperaceae and Poaceae reach 15–16% each; values of *Artemisia* range from 3.3 to 7.0%
Ł-12	28.90–29.50	Birch pollen values increase to 76% in the lower part of the zone; those of pine – in the upper part; NAP percentages (mainly Poaceae and Cyperaceae) fall towards the upper part of the zone; *Artemisia* pollen high values throughout the zone (max 8.7%); Chenopodiaceae pollen forms continuous curve (values range from 0.5 to 2.3%)
Ł-13	28.75–28.85	*Pinus* pollen dominates (59.0–69.0%); *Betula* undiff. percentages fall to *ca*. 15%; values of *Alnus*, *Ulmus* and *Quercus* rise considerably (up to 2.5, 4.1 and 7.8%, respectively); continuous pollen curve of *Carpinus* forms; *Corylus* pollen more frequent again; values of NAP, *Salix*, *Juniperus* and *Betula nana* t. fall
Ł-14	28.45–28.65	Distinct decrease of pine and birch pollen values; simultaneous increase of *Alnus* (up to 24.5%) and *Carpinus* (up to 33.5%); percentages of *Ulmus*, *Fraxinus* and *Quercus* pollen – similar to previous zone; *Tilia* and *Acer* pollen occur again; *Corylus* percentages reach 11.0% in the upper part of the zone and fall to 2.1% in the lower part
Ł-15	28.00–28.40	*Pinus* pollen up to 78.5%; increase of *Picea* percentages towards the upper part of the zone; continuous curve of *Abies* pollen; fall of *Carpinus* values (less than 2%); simultaneous fall in percentages of *Alnus*, *Ulmus*, *Quercus* and *Fraxinus*; pollen of Ericaceae, Poaceae and Cyperaceae – more frequent
Ł-16	from 27.90 m upwards	Fall of pine and simultaneous rise of birch pollen values; larch and spruce pollen form continuous curves; thermophilous taxa – sporadic; increase of Poaceae, Cyperaceae, *Artemisia* and Chenopodiceae percentages (up to 15, 10, 10 and 2.3%, respectively); more frequent *Betula nana* t., *Salix* and *Juniperus*

The outline of the vegetation history, presented below, has been divided into four units which represent warm and cold climatostratigraphical units distinguished in the pollen succession (Fig. 5). Local pollen assemblage zones have been grouped as follows: Ł-1–Ł-8, Ł-9–Ł-11, Ł-12–Ł-15 and Ł-16.

Zones Ł-1–Ł-8. The Ł-1 L PAZ, with considerable values of NAP and *Betula* undiff., abundant *Pinus* and *Alnus* and continuous percentage curves of *Picea* and *Larix*, indicate that open birch and probably pine-birch forests, with an admixture of spruce and larch, occurred in the surroundings of the Łuków site. Pre-Quaternary sporomorphs are redeposited. Part of the alder pollen and individual grains of thermophilous trees may be derived from Neogene deposits. The next zone (Ł-2 L PAZ), dominated by *Pinus*, still contains considerable pollen values of *Betula* undiff. and various herbs. These features indicate transformation of forest communities of the protocratic phase of the interglacial towards pine-dominated ones. Continuous pollen curves of *Quercus* and *Ulmus* provide evidence of spread of elm and oak in wetter places. Tundra communities with *Betula nana* may still have persisted in the landscape.

Pollen of trees with higher thermal and edaphic requirements predominates in the next zones: Ł-3–Ł-6 L PAZ. The Ł-3 LPAZ, marked by a considerable rise of *Ulmus*, *Quercus* and *Alnus*, indicates spread of elm-oak riverine forest and alder communities. *Quercus* and *Picea* trees were probably also scattered in pine forest with a birch admixture. *Corylus* and *Tilia* began to spread on more fertile habitats. In the Ł-4 L PAZ the *Quercus* pollen culmination indicates that oak may have been abundant among various other forest types. *Tilia*, *Acer* and *Ulmus* formed admixtures in oak woods. Hazel was abundant in the understorey and in forest margins. High *Ulmus* percentages, moderately high of *Alnus* and a continuous *Fraxinus* pollen curve testify to further spread of rich riverine forests of various types. In the Ł-5 LPAZ the maximum of *Corylus* pollen (37%) suggests that hazel occurred not only in the understorey but may have formed thickets of hazel communities with *Ligustrum* as an admixture. According to Janczyk-Kopikowa (Janczyk-Kopikowa *et al*., 1981; Janczyk-Kopikowa, 1991), such a sequence of pollen zones represents the first part of the climatic optimum of the Ferdynandovian succession.

In zone Ł-6, which belongs to the younger part of the climatic optimum, the rise in pollen values of *Abies*, *Taxus* and *Picea* provide evidence of increasing proportions of these taxa in the forests. Maxima of *Tilia* and *Quercus* pollen, frequent *Acer* and presence of *Ligustrum*, *Hedera* and *Ilex* indicate that riverine forests and dry-ground communities on fertile soils were very rich. Indicator taxa of a warm climate – *Celtis, Hedera, Vitis, Ligustrum* and *Humulus* (*vide* Mamakowa, 2003) – are present in zones Ł-4–Ł-6. In Ł-7 L PAZ a sharp increase of *Pinus* percentages and a considerable fall in values of all thermophilous taxa indicate pine forest expansion (with birch admixture) in most habitats. Rich riverine forests and dry-ground communities must have been strongly limited, probably due to climate cooling and decreasing fertility of soils.

In the upper part of zone Ł-8 *Betula* undiff. predominates, a continuous curve of *Betula nana* t. starts and frequencies of NAP gradually increase. This indicates a change in the succession of forest communities, which was typical of the last, i.e. terminocratic part of the interglacial. After disappearance of deciduous trees with climate cooling, dense pinewoods (Ł-7) followed by slightly more open birch-pine forests (Ł-8) encroached on their habitats. Higher values of *Picea* (up to 7%), *Quercus* (up to 12.5%) and also pollen of *Ulmus* and *Tilia* are recorded in the sample from 30.75 m. They may indicate redeposition processes. However, it cannot be excluded that they might be connected with general habitat changes around the site as the lithological boundary appears in the deposits at a depth of 30.70 m (Fig. 4).

Zones Ł-9–Ł-11. In zone Ł-9, pollen values of herbs (NAP) suddenly rise and slightly exceed 64%. The increasing values of Poaceae (=Gramineae), *Artemisia*, Cyperaceae and Chenopodiaceae provide evidence of a great change in plant communities. The simultaneous increase in pollen values of *Betula nana* t., *Juniperus*, *Salix*, and the frequencies of *Sphagnum* spores show an expansion of vegetation of open communities, including also tundra, steppe and mire ones, which resulted from a strong cooling. Such features of pollen spectra are typical of glacial periods when total retreat of thermophilous trees is observed. However, tree birch, pine, larch and spruce might have persisted in small patches as can be shown by other early glacial sequences (*vide* Granoszewski, 2003; Mamakowa, 2003). The continuing presence of pine in these spectra may be partly the result of long-distance transport of its pollen across an open landscape.

A distinct change of the pollen spectra character occurs in the Ł-10 L PAZ, which is dominated by *Pinus* with a considerable admixture of *Betula*. The values of NAP decrease to several per cent. These changes indicate that boreal pine-birch forests expanded on open habitats. *Larix* was probably present as an admixture in these communities. Development of boreal forest indicates slight climate amelioration. However, patches of tundra communities with *Betula nana* may have persisted in a mire zone around the lake. The next rise of NAP in zone Ł-11, up to 40% (conditioned by the high values of Poaceae, Cyperaceae and *Artemisia*), continuing high percentages of *Betula nana* t. and maxima of *Juniperus* and *Salix*, indicate that the landscape was again open but to a lesser degree than in zone Ł-9. These were probably still boreal pine-birch forests but considerably less dense, and again with a high proportion of tundra and steppe vegetation patches.

Zones Ł-12–Ł-15. The Ł-12 L PAZ represents the first part of the second warm period. A sudden rise of tree birch pollen which is visible in the cumulative curve of *Betula* undiff. and a decrease in pollen values of *Pinus, Salix,* Poaceae and Cyperaceae provide evidence of a new spread of boreal birch forest. These were probably quite open communities as reflected by continuing high values of *Artemisia*, together with a continuous curve of Chenopodiaceae and *Betula nana* t. In zone Ł-13, a sudden rise of *Pinus* frequencies and a decrease in *Betula* undiff. indicate that the area was again overgrown by pine-birch and pine forests replacing birch forests. Pollen of *Betula nana* t. disappears and NAP values decrease significantly providing evidence of a diminished importance of open communities in the landscape. In the upper part of the Ł-13 L PAZ, increasing values of thermophilous trees (*Quercus*, *Ulmus*) and *Alnus*, together with sharply rising pollen curves of *Corylus* and *Carpinus*, indicate transformation of forest communities and a progressive climate warming. Oak-elm riverine forests may have expanded at the beginning, followed by oak-hazel communities with an increasing admixture of hornbeam.

The climatic optimum of this second warm period is best expressed in zone Ł-14, which is definitely dominated by *Carpinus* pollen reaching a high maximum of 33.5%. Simultaneously, pollen values of *Corylus* and *Alnus* considerably increase, *Quercus* and *Ulmus* reach their maxima and a continuous pollen curve of *Tilia* appears. These features indicate that multispecies deciduous forests expanded in the area near Łuków. Hornbeam, as well as hazel and oak, played an important role in these forests, which might have resembled present-day dry-ground forests. Lime and maple also appeared as components of these communities. Wet habitats were mostly occupied by alder carrs and riverine forests composed of elm with an admixture of ash trees.

A considerable rise of the *Pinus* curve, more frequent occurrence of *Picea* pollen in the next zone (Ł-15) and a decrease in pollen values of thermophilous taxa (*Carpinus*, *Quercus*, *Ulmus*, *Fraxinus* and *Corylus*), indicate that climatic conditions became again more severe. This zone belongs to the final, terminocratic phase of the second warm period. Thermophilous deciduous forests were replaced by pine forests, and spruce expanded in wetter places. However, it cannot be excluded that trees of hornbeam, oak, alder and lime survived in these communities. More frequent Ericaceae and NAP and reappearance of *Betula nana* t. pollen provide evidence of open areas occupied by dwarf-shrubs and herbaceous vegetation.

Zone Ł-16 marks the beginning of the next sequence of glacial nature. The increasing pollen values of tree birches (*Betula* undiff.), NAP (mostly Poaceae and *Artemisia*), and the reappearance of *Betula nana* t. pollen indicate that pine communities of the terminocratic period of the interglacial were replaced by open boreal birch forests with wide areas of herbaceous vegetation. Willow and juniper played an important role in the landscape.

DISCUSSION

STRATIGRAPHICAL POSITION OF THE ŁUKÓW-3A POLLEN SEQUENCE

In the light of palynostratigraphic criteria, the pollen succession in the Łuków-3a profile starts with the birch phase (Ł-1) that marks the beginning of the first interglacial which is represented by eight pollen zones (Ł-1–Ł-8). The next pollen zones (Ł-9–Ł-11) record the stadial-interstadial changes during a glacial period, after which the successive warm sequence of the second interglacial appears in the zones Ł-12–Ł-15 (Table 1). The next long sequence of pollen zones, starting from zone Ł-16, is of glacial nature, and is partly shown in the diagram (Fig. 5).

Here, we follow the palynostratigraphic division of the Ferdynandovian pollen sequence into two interglacial successions separated by a cold unit of a glacial character, as initially suggested by Mamakowa (1996, 2003), who based the new division on detailed examination of the Podgórze B1 profile. According to this division, the first stadial of the cooling, separating two interglacial warmings, is characterized by a domination of Poaceae, Cyperaceae and *Artemisia* and the presence of taxa typical of open communities (*Helianthemum* t. *nummularium*, *Rumex* t. *acetosella*, *Betula* t. *nana*). The second stadial represents the repeated expansion of tundra and steppe communities with patches of tree birch, pine and larch. The two stadials are separated by the interstadial expressed by an increase in birch and pine pollen values (Mamakowa, 1996, 2003).

In the present paper, the climatostratigraphic scheme of Lindner *et al*. (2004) is used for correlation with the pollen zonation distinguished in the Łuków-3a succession. According to this scheme, the pollen sequence from Łuków represents the following units: Ferdynandovian 1 and 2 interglacials with a cooling/glaciation separating them (Ferdynandovian 1/2) and the early glacial of the Sanian 2 (Elsterian 2) Glaciation (Table 2). These units correspond with the lower and upper climatic optima separated by a phase of open boreal forests distinguished by Janczyk-Kopikowa *et al*. (1981) in the stratotype profile from Ferdynandów.

THE POLLEN SUCCESSION OF ŁUKÓW-3A IN RELATION TO ŁUKÓW 105

This research has confirmed the Ferdynandovian age of the deposits from Łuków, both from the geological and palynostratigraphical point of view. It has been shown that the organogenic succession is more complete than originally supposed on the basis of investigations carried out by Sobolewska (1969).

Pidek reinterpreted the original pollen diagram by Sobolewska (1969) according to the new division of the Ferdynandovian pollen sequence into two interglacial periods with a cooling/glaciation separating them. The table of raw pollen counts published by Sobolewska (1969) allowed calculation of percentages and the production of a pollen diagram not only for the tree taxa distinguished but for the main herbs (Poaceae, Cyperaceae, *Artemisia*, Chenopodiaceae) as well. As shown in Figure 6, the pollen zones distinguished by Pidek in the reinterpreted diagram of Sobolewska can be correlated with corresponding zones of the new Łuków-3a pollen diagram. The pollen succession of the old profile (105) from Łuków represents only the first warm period with very high pollen values of *Betula* at the beginning (Fig. 6). The climatic optimum ends with the pine pollen zone with a significant proportion of birch.

In the new profile (Łuków-3a) no pollen grains of *Ulmus* and *Quercus* were recorded in the birch phase (Ł-1), while Sobolewska found considerable amounts of both oak and elm pollen in the lowermost samples. The culmination of *Quercus* follows that of *Ulmus* in the Łuków-3a pollen diagram, so it occurs later and its value is higher (36.5%) in comparison with the results obtained by Sobolewska (about 25%). The curves of *Corylus* have quite a different shape in the profiles in question. In the diagram by Sobolewska, high pollen values of *Corylus* (over 30%) occur twice, and between them the hazel frequency falls to several per cent. In the new profile (Łuków-3a), such a large decrease does not occur in the hazel curve. After the first, very high culmination (37%), the pollen values of *Corylus* fall gradually.

According to Sobolewska, the pollen values of *Abies* and *Picea* are considerably lower. They fluctuate from 0.1 to 0.2%, while in the new profile the range is from 2.7 to 8.6%. The very beginning of the post-optimum cooling is represented by the upper part of the diagram published by Sobolewska (1969), with the NAP values reaching *ca*. 10%. This section can be related to the pollen zone Ł-8 of the new profile. Quite sparse sampling by Sobolewska, especially between 34.5 and 34.1 m and with no samples available above this section, made further comparisons with the old pollen diagram impossible.

Table 2

Correlation of local pollen assemblage zones in the diagrams of Łuków-3a (this paper), Podgórze B1 (Mamakowa, 1996) and Zdany (Pidek, 2003) with Ferdynandovian phases according to Janczyk-Kopikowa (1975), in relation to the division of Ferdynandovian pollen sequence (according to Janczyk-Kopikowa *et al*., 1981), new division of Ferdynandovian pollen succession by Mamakowa (1996, 2003), stratigraphic units by Ber *et al*. (2007), Lindner *et al*. (2004), Zagwijn (1996) and Rylova and Savchenko (2005)

Western European Stratigraphy (according to Lindner *et al*., 2004 and reference therein)	Palynostratigraphical correlation of Łuków-3a sequence with Eastern European palynostratigraphy (according to Rylova and Savchenko, 2005; in accordance with Zagwijn, 1996)	Correlation with Marine Oxygen Isotope stages (MIS) (according to Lindner *et al*., 2004; Ber, 2006)	Stratigraphy (according to Ber *et al*., 2007)	Stratigraphy (according to Lindner *et al*., 2004)	New division of Ferdynandovian pollen sequence (according to Mamakowa, 2003)	Podgórze B1 (according to Mamakowa, 1996)	Ferdynandovian phases (according to Janczyk-Kopikowa, 1975)	Division of Ferdynandovian pollen sequence (according to Janczyk-Kopikowa *et al*., 1981)	Zdany (according to Pidek, 2003)	Łuków-3a (this paper)	Corresponding zones of Łuków 105 analysed by Sobolewska (1969; zonation by Pidek, this paper)
Elsterian 2		12	Sanian 2 (Elsterian 2)	Sanian 2 (Elsterian 2)	Sanian 2 Early Glacial	Pg14–Pg16	9–11	Sanian 2 Early Glacial	Zd19–Zd25	from Ł-16 upwards	
Interglacial IV of Cromerian Complex	Cromerian III (Rosmalen)	13	Ferdynandovian	Ferdynandovian 2 Interglacial	Interglacial 2 (upper)	Pg12–Pg13	8	upper climatic optimum	Zd17–Zd18	Ł-15	
						Pg11	7		Zd16	Ł-14	
									Zd15	Ł-13	
						Pg9–Pg10	6	cooling (spread of open boreal forests)	Zd13–Zd14	Ł-12	
Glacial C		14		Ferdynandovian 1/2 cooling/ glaciation	glaciation	Pg 5–Pg 8			Zd12	Ł-11	
									Zd10–Zd11	Ł-10	
									Zd9	Ł-9	
Interglacial III of Cromerian Complex	Cromerian II (Westerhoven)	15		Ferdynandovian 1 Interglacial	Interglacial 1 (lower)	Pg 4			Zd8	Ł-8	Ł-8
						Pg 3	5	lower climatic optimum	Zd7	Ł-7	Ł-7
						Pg 2	4		Zd5–Zd6	Ł-6	Ł-5/6
						Pg 1	3		Zd4	Ł-3–Ł-5	Ł-3/4
							2		Zd3	Ł-2	Ł-2
							1		Zd2	Ł-1	Ł-1
Cromerian Glacial B (Elsterian 1)		16	Sanian 1 (Elsterian 1)	Sanian 1 (Elsterian 1)	Sanian 1 Late Glacial				Zd1		

THE POLLEN SUCCESSION OF ŁUKÓW-3A IN RELATION TO THE ZDANY SEQUENCE

In the light of new palaeobotanical data, the site at Łuków adjoins the sites representing a full bi-partite Ferdynandovian pollen succession, rare in Poland. The pollen sequence and the lithological and stratigraphical context of the organogenic deposits can be compared with the site of Zdany (Pidek, 2000, 2003; Małek, 2004; Siedlce Plateau) neighbouring Łuków.

The Zdany profile is situated in the central part of the Siedlce Południe sheet of the *Detailed Geological Map of Poland*, about 19 km to the NE of Łuków. The flat moraine plateau is composed of tills from the Wartanian (Warthe) Glaciation, and near Zdany its surface occurs at 164.00 m a.s.l. Lacustrine organic deposits (lithological profile published in Pidek, 2000), reaching a thickness of 13.80 m, were found at a depth of 28.90–42.70 m (121.30–135.10 m a.s.l.). These deposits are underlain by a 0.7 m thick layer of sandy-gravelly deposits of fluvial origin. Together they fill a fossil depression eroded in till from the last stadial of the Sanian 1 (Elsterian 1) Glaciation. The erosion took place at the beginning of the interglacial (Małek, 2004). This sandy till with a thickness of 5.1 m is calcareous ($CaCO_3$ content – up to 14.8%), rich in pebbles, among which crystalline rocks (41.0%) predominate over Scandinavian limestones (32.1%). The content of dolomite clasts is moderate (5.4%). The lacustrine deposits are covered by a 15.6 m thick sandy till ($CaCO_3$ content – up to 18.6%;

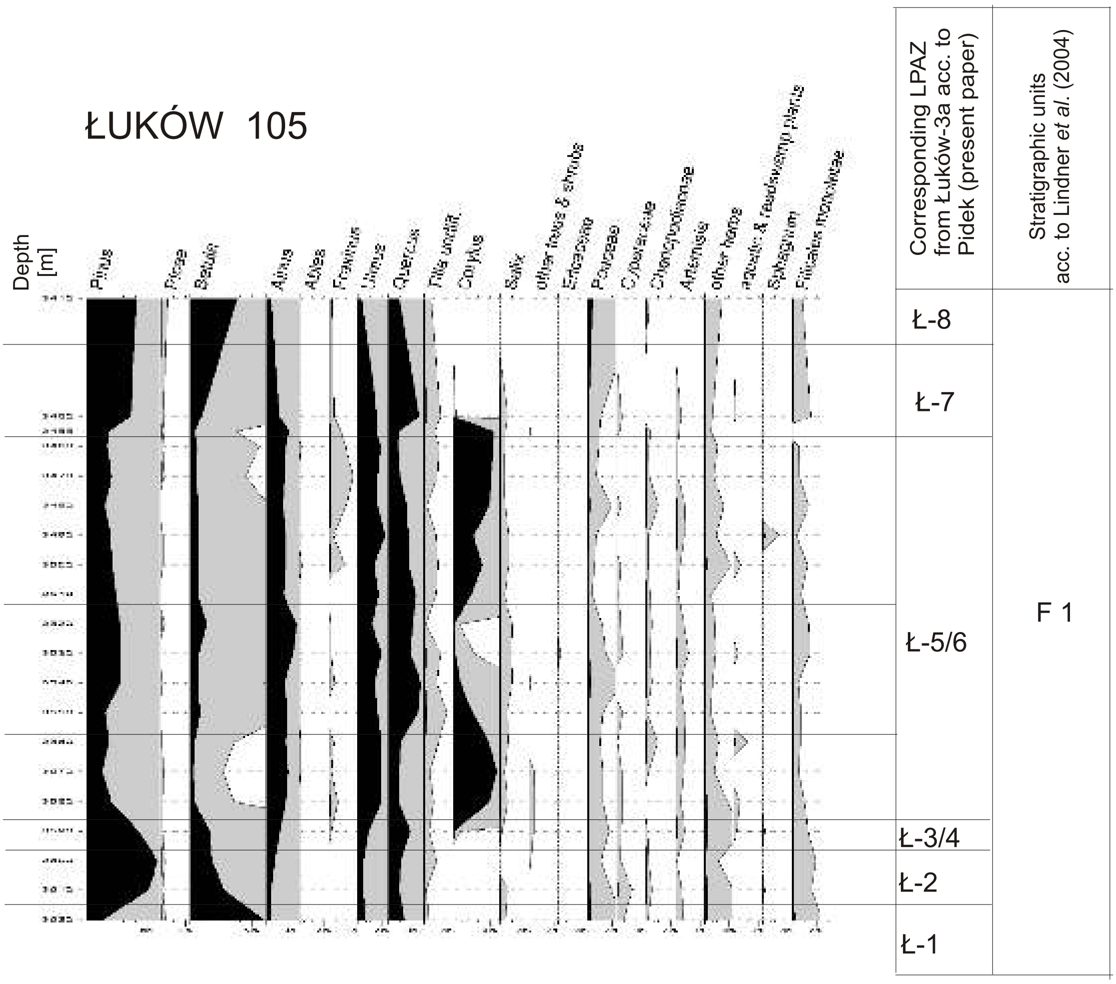

Fig. 6. Percentage pollen diagram from the Łuków 105 profile

Pollen zonation and reinterpretation by Pidek; analysis by Sobolewska (1969)

among gravels, Scandinavian limestones – 43.7%; crystalline rocks – up to 33.6%; dolomite – up to 7.7%). Petrographic compositions of the lower till correspond to those obtained for tills of the Sanian 1 (Elsterian 1) Glaciation and for the overlying till – those of the Sanian 2 (Elsterian 2) Glaciation by Lisicki (2003; *vide* Małek, 2004). Additionally, within the lacustrine deposits at Zdany, in layers corresponding to cooling/glaciation F1/2, a considerable increase of clayey-sandy admixture in gyttja was observed.

Palynological studies of the Zdany profile (94 samples collected from a depth of 29.00–37.15 m) allow one to assign unambiguously the deposits to the Ferdynandovian Interglacial, and to reconstruct in detail the climatic-vegetational changes from the end of the Sanian 1 Glaciation, through two warm periods (climatic optima) of interglacial rank separated by a cold unit of glacial character, to the early glacial of the Sanian 2 (Elsterian 2) Glaciation (Pidek, 2000, 2003).

The comparison of local pollen zones from the Łuków and Zdany profiles against a background of the new division of the Ferdynandovian succession is shown in Table 1. In both the profiles, a new division of the Ferdynandovian pollen succession was used, published for the first time by Mamakowa (1996, 2003). The new division differs from the one of the stratotype Ferdynandów site (Janczyk-Kopikowa, 1975).

The first pollen zone corresponding to the late glacial of the Sanian 1 (Elsterian 1) Glaciation was not distinguished in the Łuków-3a pollen diagram. The diagram starts with the birch phase corresponding to the expansion of open birch boreal forest at the beginning of interglacial warming. The zones (Ł-1–Ł-15) i.e. those representing the first and second warm periods and the cold unit between them, have their equivalents in both the profiles concerned (Table 2). The distance between Łuków and Zdany is rather short (19 km), so the course of organic-mineral sedimentation and vegetation development was similar in these sites, as reflected in the geological profiles and vegetation history recorded in the pollen diagrams. In general, the number of pollen zones distinguished and pollen percentages of the main taxa are similar within each period. Small differences in the percentage values of individual taxa probably resulted from different local conditions on the Łuków Plain and

Siedlce Plateau, both in terms of vegetation development and pollen deposition. Depending on relief and water-soil conditions, slightly different vegetation communities could have predominated in each of these regions (especially at climatic optima), though the vegetation history was generally very similar. A detailed comparison of the pollen succession from Zdany, which is the most complete among the palynologically examined Ferdynandovian successions in Poland, with the succession from the stratotype profile from Ferdynandów was published by Pidek (2003). In the light of the present study, Łuków-3a adjoins the sites with complete bi-partite pollen sequences of this age.

STRATIGRAPHIC CORRELATIONS

Besides new palaeobotanical data, the pollen succession from Łuków, similarly to the successions from Podgórze (Mamakowa, 1996, 2003) and Zdany, provides further evidence of the fact that the Ferdynandovian succession contains two pollen intervals representing warm periods which are separated by one with features typical of a glacial period. The palynological picture of the cold unit is very similar at Łuków, Zdany and Podgórze, and the stadial-interstadial oscillations, which are the most important for the new division of the Ferdynandovian succession, occur in the section represented by the pollen zones Ł-9–Ł-11 in Łuków and Zd-9–Zd-12 in Zdany, which correspond to Pg-5–Pg-8 in Podgórze (Table 2). This section contains two cold oscillations of stadial character, which represent steppe-tundra vegetation separated by the interstadial expansion of boreal birch and pine-birch forest. The common features occurring in this cold unit in the three profiles under consideration include a high NAP proportion (mostly over 40%), presence of indicator taxa for open steppe-tundra communities, a low frequency of sporomorphs and lithological changes, i.e. considerable amixture of clayey-sandy material (Zdany and Łuków) or lamination occurring in gyttja deposits (in Podgórze B1). The first cold oscillation in the Podgórze B1 profile, represented by zone Pg-5, is characterized by slightly lower values of NAP than those for the corresponding zones at Łuków (Ł-9) and Zdany (Zd-9). The second cold oscillation in the Podgórze (Pg-8) section is more distinct than its equivalents at Łuków (Ł-11) and Zdany (Zd-12). Pollen spectra separating the cold oscillations record the development of boreal birch-pine forests of interstadial vegetation type. The whole section representing the glacial cooling is not very thick both in the Łuków and Zdany profiles (about 80–90 cm). In Podgórze B1 it encompasses *ca*. 1.1 m of the succession. It is possible that in the stratotype profile from Ferdynandów (Janczyk-Kopikowa, 1975) the section representing the glacial cooling was not distinguished because of rather sparse sampling. NAP values reaching 28.6% in this section were considered by Janczyk-Kopikowa (1975) as representing vegetation of open boreal forests.

Besides Łuków-3a, Zdany and Podgórze B1, the pollen sequence from Białobrzegi (Janczyk-Kopikowa, 1991) covers two warm periods separated by significant cooling expressed in the pollen diagram by the rise of NAP to 37%. When referring to the Ferdynandovian sequence from Sosnowica Janczyk-Kopikowa (1991) concluded that it covers not only the “lower climatic optimum” with the late glacial part preceding it but also the subsequent cooling and part of the “upper optimum”. The unit separating the two optima in Sosnowica was related by Mojski (2005) to distinct Ferdynandovian cooling observable in stratotype profiles of this age.

Other published Ferdynandovian pollen sequences in Poland encompass only the first (= lower) interglacial which probably lasted *ca*. 20 thousand years (Krzyszkowski *et al*., 1996). These are: Wola Grzymalina and Ławki 7 (Kuszell, 1991), Popioły (Winter, 1992), Buczyna pod brukiem (Janczyk-Kopikowa, 1991), Stanisławice (Janczyk-Kopikowa and Żarski, 1995), Falęcice (Lindner *et al*., 1991) and Podlodów (Janczyk-Kopikowa and Rzechowski, 1980).

The early correlation of the Ferdynandovian succession with the stratigraphic schemes of Eastern Europe by Janczyk-Kopikowa (1975) indicated its resemblance to the Shklovian double-optimum interglacial in western Russia, and to the succession from the Nizhninsky Rov profile in Belarus. Lindner (1992) correlated also the lower optimum of the Ferdynandovian sequence with the Muchkapian Interglacial in Russia, and the upper one with the Glazovian Interglacial.

However, taking into account palynological criteria, the correlation with Belorussian profiles is the most tentative due to great similarities of pollen successions which are quite numerous there (Rylova, 1998; Rylova and Savchenko, 2005). The Belorussian stratigraphic scheme agrees with the new division of the Ferdynandovian pollen sequence into two separate interglacials (Velichkevich *et al*., 1996; Mamakowa *et al*., 2000; Sanko *et al*., 2005). The older of these with elm and oak domination is called the Belovezhian Interglacial and palynologically corresponds well to the lower warm unit of the Ferdynandovian succession. The younger one (Mogilevian Interglacial) with a distinct hornbeam phase corresponds to the upper optimum of the Ferdynandovian succession.

Taking into account studies on sections of glacial deposits, corresponding loesses and interglacial organic deposits of Poland, Belarus and Ukraine Lindner *et al*. (2004) distinguished 10 glaciations or coolings within the Mid and Late Quaternary, separated by 9 interglacials or warmings. According to this climatostratigraphical scheme the Ferdynandovian belongs to megainterglacials with two separate warmings (F1 and F2) and cooling between them F1/2. The Ferdynandovian is situated between the Sanian 1 and Sanian 2 (Elsterian 1 and Elsterian 2) glacials and corresponds to the Belovezha Complex in Belarus, with two warmings of the Belovezhian 1 and 2 and a cooling Belovezhian 1/2 (Lindner *et al*., 2004).

The pollen sequence of the stratotype profile from Ferdynandów, containing two warm units called climatic optima, in the recent stratigraphic schemes is related to the oxygen isotope stages 15–13 and situated between the Sanian 1 (Elsterian 1) and Sanian 2 (Elsterian 2) glaciations (among others, Lindner and Marks, 1994; Lindner *et al*., 2002, 2004; Mojski, 2005; Ber, 2006). Timescales for this part of the early Middle Pleistocene cover the period *ca*. 480–630 ka (Ber, 2006). However, according to Ber (2005, 2006) and Ber *et al*. (2007) the Ferdynandovian should be considered chronostratigraphically as one unit even if climatostratigraphically it can be divided into two warn units (F1 and F2) and a cold one (F1/2).

The distinguishing of two interglacials in the Ferdynandovian succession is consistent with the interpretation of the pollen diagram from Ferdynandów by Zagwijn (1996) and with the opinion by Turner (1996). Both these authors unequivocally related the Ferdynandovian sequence to the oxygen isotope stages 15–13 and placed it within the Cromerian Complex (Turner, 1996; Zagwijn, 1996). However, referring to Western European stratigraphy, Zagwijn (1996) correlated the lower warm period from Ferdynandów with the Cromerian II (Westerhoven), and the upper one with the Cromerian III (Rosmalen). Lindner *et al.* (2004) and Ber *et al.* (2007) were also of the opinion that the Ferdynandovian sequence should be related to the Cromerian Complex. However, they correlated the first warm unit with the Cromerian III, and the second one with the Cromerian IV. Detailed palynostratigraphical correlation with West European stratigraphy is not easy due to the fragmentary nature of the pollen data. This fact was stressed strongly by Zagwijn (1996) and Turner (1996). Based on similarities in the pollen succession of Poland and Belarus it seems probable that F1 corresponds to Cromerian II (Westerhoven) and F2 to Cromerian III (Rosmalen) (see also Rylova and Savchenko, 2005). In such a case the cooling/glaciation beetween them would correspond to glacial B in the Cromerian Complex of the Netherlands (Zagwijn, 1996).

More data is needed to solve these problems and there is no place in this paper to re-open the discussion, but it is worth noting that one result was an attempt at a new interpretation of the Ferdynandovian succession proposed not only by Lindner *et al.* (2004) but also by Winter (2006). The last author discussed the Ferdynandovian and the Augustovian long pollen sequences as bi-interglacials separated by a cold stage comprising stadial and interstadial intervals. Winter (2006) proposed the division of the Ferdynandovian long pollen sequence into two interglacials (the older one denoted by F I and the younger one by F II) separated by glacial cooling denoted by F I/II. In the discussion, she raised the problem (after Janczyk-Kopikowa, 1987) of distinguishing cold units based on palynostratigraphy only. In her opinion, chronostratigraphic cold units can only be distinguished and named on geological criteria, but within one chronostratigraphic unit named Ferdynandovian three climatostratigraphic ones (F I and F II of interglacial rank and glaciation *s.l.* – F I/II, between them) can be distinguished. Mojski (2005) remarked that the proposed of new division of the Ferdynandovian pollen sequence is not meaningless because it touches the topical issues of definition of a glacial stage both from the palaeogeographical and palaeobotanical points of view. The new findings in the Łuków profile strongly support this opinion.

CONCLUSIONS

The new data from the Łuków site show unambiguosly that it belongs to the rarely found bi-partite Ferdynandovian sequences. The first warm succesion in its optimal phase represents development of deciduous forests with a considerable proportion of oak, elm, hazel and without hornbeam. The second warm succession represents expansion of hornbeam with significant percentages of some other deciduous trees. The cold unit separating the two warmings represents the spread of steppe-tundra communities with intervening phases of development of boreal birch and pine-birch forest.

From a palynostratigraphical point of view the Łuków sequence can be divided into two separate interglacials with cooling/glaciation between them. Such a conclusion follows earlier findings at the Podgórze B1 profile by Mamakowa (1996, 2003) and Zdany (Pidek, 2003) and is supported by numerous pollen sequences of this age in Belarus (Rylova and Savchenko, 2005).

The new division of the Ferdynandovian sequence can be correlated with new climatostratigraphical units of the Middle Pleistocene where F 1 (I), F 2 (II) and F1/2 (FI/II) can be found (Lindner *et al*., 2004; Winter, 2006). These units reflect two warmings of interglacial vegetation separated by a cooling/glaciation. The two warm periods are correlated with oxygen isotope stages 15 and 13 and placed within the Cromerian Complex.

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