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The development of Late Glacial and Holocene vegetation and human impact near Grodzisko Nowe in the Lower San Valley (Sandomierz Basin, south-eastern Poland)

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ABSTRACT. Vegetation changes in the Lower San Valley close to the Wisłok and San river confluence has been reconstructed from at least 12 700 cal. yr BP to the present on the basis of a palynological analysis of the Grodzisko Nowe profile supplemented with radiocarbon dating. During the Younger Dryas chronozone vegetation was characterized by high tree cover, which significantly exceeded the area of forest nowadays. Radiocarbon datings (AMS technique) confirmed the palynologically established Late Glacial/Holocene boundary, which is demonstrated by a decrease in *Artemisia*, *Larix*, and *Juniperus* curves with a decline in NAP. A rapid expansion of *Pinus* probably related to edaphic conditions caused the disappearance of *Betula* from most habitats at the beginning of the Preboreal chronozone (before 11 387–11 126 cal. yr BP). However, the latter taxon dominates in the Holocene part of the profile. In the pollen assemblages the probable influence of the Mesolithic groups (Janisławicka Culture) and the Tarnobrzeska Group of the Lusitanian Culture on the local vegetation has been recorded by visible rises in NAP. Sediments which represent the activity period of the Przeworska Culture, underlie modern sediments which makes interpretation difficult. The pollen profile from Grodzisko Nowe, like most of the profiles from the Sandomierz Basin, presents discontinuous sediment sequences, which is reflected in a lack of records from the late Boreal/early Atlantic chronozone up to the late Subboreal/early Subatlantic chronozones, and the older part of the Subatlantic chronozone.

KEYWORDS: pollen analysis, vegetation history, human impact, Late Glacial, Holocene, Sandomierz Basin, Poland

INTRODUCTION

The Sandomierz Basin is one of the most important areas for research into the south-eastern route of the expansion of different taxa into Poland during the Holocene. Although a relatively large amount of palynological research has been carried out, this area does not have a main reference profile for the Holocene. Most profiles simply record discontinuous sequences of sediments, which present local vegetation, and there is no radiocarbon data for the majority of them. The main reason for this is the lack of ombrotrophic peat bogs and lakes of suitable size, so that the only source of material for pollen analysis are fens or poor fens developed on palaeomeanders and various depressions of unknown origin.

The first palynological studies in the Sandomierz Basin were performed in 1934 and referred to the mires from the early Holocene in sinkholes located in Grodzisko and Wola Żarczycka near the San river (Trela 1934). The first complete palynological research into a history of vegetation based on pollen analysis in this area was carried out by Mamakowa (1962). In the Lower San Valley only a profile from Kopki located around 30 km north of Grodzisko Nowe, which represents the Late Holocene succession, has been palynologically investigated (Bałaga & Taras 2001). Recently in the Grodzisko Dolne (Nowe) area, south of the last site, a profile reaching Late Glacial sediments in the basal part was collected from one of the Wisłok palaeomeanders (Gębica et al. 2008). Other studied profiles located west of Grodzisko Nowe which recorded the Late Glacial succession in the basal part are Wola Żyrakowska (Starkel & Granoszewski 1994), Wolica Ługowa (Madeja 2002, Starkel et al. 2002), and Krasne (Kołaczek 2007).

The profile from Grodzisko Nowe (Fig. 1) was collected in 1997 during preparations of "The Detailed Geological Map of Poland 1: 50 000, Jarosław sheet" (Malata & Wójcik 1998). A preliminary analysis of basal sediments was performed by K. Szczepanek who pointed to the early Holocene as the beginning of sedimentation (Wójcik et al. 1999).

The main aim of this research paper is a reconstruction of the development of vegetation in the Lower San Valley in the vicinity of the confluence of the Wisłok and the San during the Late Glacial and the Holocene, based on pollen analysis supported by radiocarbon dating. This paper is based on a part of the PhD thesis (Kołaczek 2010).

CHARACTERISTICS OF THE AREA STUDIED

GEOLOGY AND GEOMORPHOLOGY

The Lower San Valley is a broad erosive rill between the San valley near Przemyśl to its junction with the Wisła near Sandomierz (Kondracki 2002).

According to Gębica (2004) the bottom of the Wisłok valley is made of a three-step system of terraces. The highest level, at a height of 10 m above the riverbed level, is represented by sandy terrace incisions into Middle Polish Glacial terraces. The second terrace, at a height of 6–7 m above the riverbed, consists of a meandering palaeochannels system. There is also a flood terrace 4–5 m above the riverbed, which is assigned to the Holocene.

SOILS

The higher Holocene terrace of the San valley is covered by various types of sandy soils e.g. podsolic, brown podsolic and acid brown podsolic (Kursa et al. 1988). Pseudosolic soils and brown soils developed on loamy light sands,

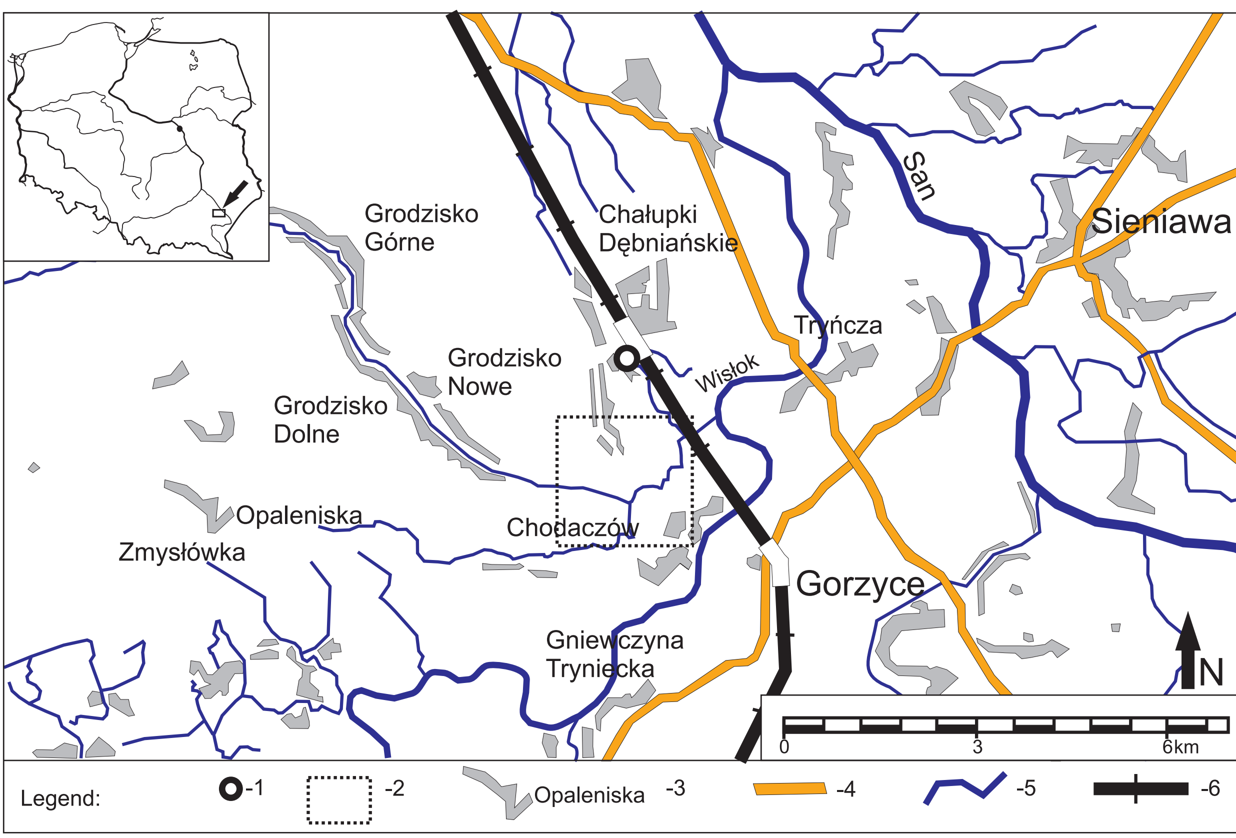

Fig. 1. Map of site locations in Grodzisko Nowe. **1** – site of profile collection, **2** – location on the map of archaeological sites presented at Fig. 2; **3** – villages and towns, **4** – roads, **5** – rivers and streams, **6** – railways

on peaty and organic-rich soils are limited to small areas (Bałaga & Taras 2001).

CLIMATE

The climate of the Sandomierz Basin was put by Romer (1949) into the category of the piedmont climates of lowlands and basins. The area may be divided into two, with a more oceanic western part and a more continental eastern part (Okołowicz 1973–1978). The investigated site is located in the eastern part. From the 1996–2000 the mean annual temperature for the site was 8°C (17.5°C – mean July temperature, –3°C – mean January temperature), and mean annual rainfall ranged from 700 to 800 mm (Lorenc ed. 2005). According to Gumiński (1948) the growing season in the Sandomierz Basin area lasts 210–220 days.

RECENT VEGETATION

The distribution of forest communities in the Sandomierz Basin area is mainly related to the terraced morphology of the valleys (Szafer 1972). Patches of beech-fir and mixed forests e.g. *Fagetum carpaticum*, *Querco-Carpinetum*, *Pino-Quercetum*, and *Carici elongatae-Alnetum glutinosae* in damp depressions and near streams have survived on the highest levels of the geomorphological units. The Pleistocene terrace is occupied by *Vaccino myrtilli-Pinetum* forests, *Pino-Quercetum* forests, and various meadow and mire plant communities. The Holocene terraces are periodically flooded, hence meadows and willow thickets are the main communities in this area with accompanying single aspens and poplars which are the only trees there.

Within the 10×10 km square (ATPOL grid) where the palaeochannel is located 447 species of vascular plants were identified (Dubiel et al. 1979).

SETTLEMENT HISTORY

The first information about human activity in the Grodzisko Nowe environs goes back to the Late Palaeolithic epoch. In Grodzisko Dolne (Fig. 2, site 22) chert tools with the features of

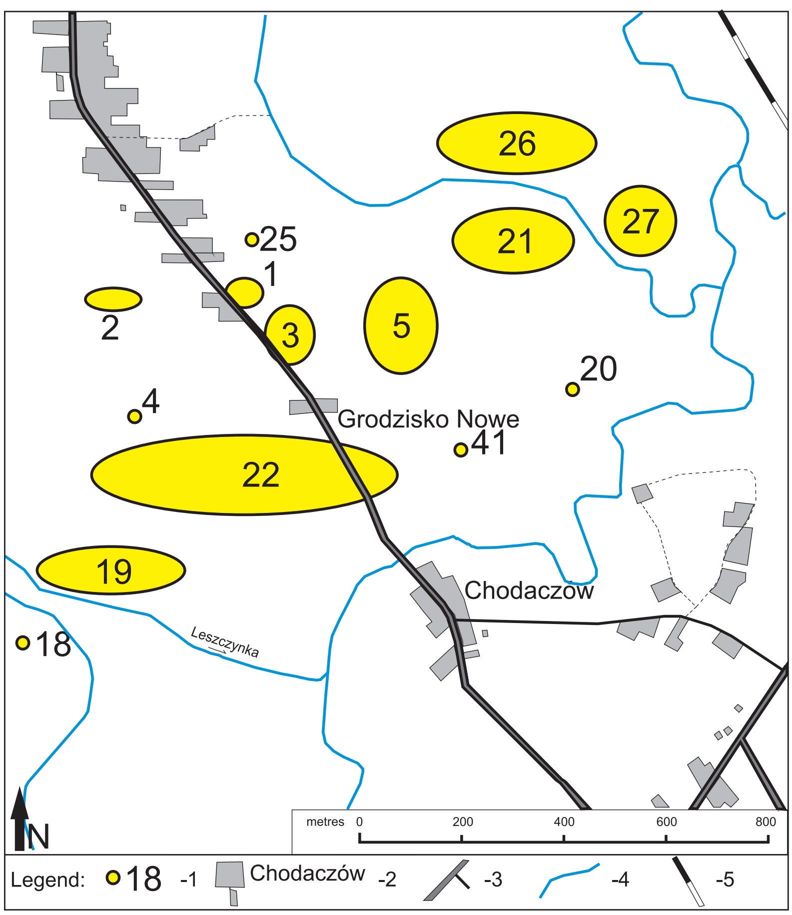

Fig. 2. Location of archaeological sites. **1** – archaeological site, **2** – villages, **3** – roads, **4** – rivers and streams, **5** – railways

the Świderska Culture were found and dated at 9950–10 950 cal. yr BP (Czopek & Podgórska-Czopek 2007). At site 22 in the Wisłok valley, a camp with many huts was discovered that is probably a trace of presence of the Janisławicka Culture (7950–5950 cal. yr BP, Czopek 2007).

Sites 1, 21, and 22 (Fig. 2) in Grodzisko Dolne confirmed the existence there of the Funnel Beaker Culture. Findings at site 22 point to the presence of a camp or a small village there (Czopek & Podgórska-Czopek 2007). These represent either the traces of two camps or of small short-lived villages (probably connected with tribes from the transition of the Corded Ware Pottery Culture and the Early Bronze Age). In the vicinity of Grodzisko Dolne, Chodaczów and Zmysłówka the existence of the Mierzanowicka Culture was detected, this being a direct continuation of the Corded Ware Pottery Culture (Czopek & Podgórska-Czopek 2007).

The Older Bronze Age (3750–3250 cal. yr BP) is represented by the Trzciniecka Culture, from which a cemetery was found on a sandy dune. The presence of this archaeological culture was also confirmed by findings at sites in Grodzisko Górne and Chodaczów.

The period of the decline of the Trzciniecka Culture (3250–3050 cal. yr BP) is the time of the origin of the Tarnobrzeska Group of the Lusitanian Culture (Czopek 1998). The settlement of these people was characterized by good organization. They occupied sandy grounds on the higher terrace levels of river valleys, where villages and long used cemeteries were established. There was a mixed economy based mainly on agricultural activities (Czopek 2003). There is local evidence of the earliest phase of this culture, along with the cemetery in Chodaczów and the necropolis in Grodzisko Dolne (Fig. 2, site 1). At site 22 traces of a village from the early Iron Age as well as a cemetery from the same time as at site 2 were detected. The age of both sites is estimated at 2550–2350 cal. yr BP. The village occupied an area of 2 ha, and consisted of several farms and was active for a long time. Its inhabitants had a settled life style, and likely had a pasture-agriculture economy supplemented with hunting and gathering.

The Roman Period brought visible economic and social development to the lower Wisłok and San valleys. Probably the trade route which led along the San river to the south and afterward east to the Black Sea passed through the area. At site 22 (Fig. 2), traces of the village dated back to the time of activity of the Przeworska Culture were found (2250–1450 cal. yr BP, Czopek & Podgórska-Czopek 2007). The settlement of this culture was concentrated along river valleys, mostly on the edges of the terraces, and according to Godłowski (1985) it had an expansive character in the Sandomierz Basin area. The population at this site was multiethnic with an evident Vandal element.

The Early Slavonic Period (tribal) began in about the 5th century AD (1550–1450 cal. yr BP) with the coming of the first Slavs from the east. They occupied the areas abandoned earlier by communities of German-origin. Early Slavic traces were detected within sites 3 and 22, and there was probably one wide-spread settlement or a village (Czopek & Podgórska-Czopek 2007). The finding of a bronze coin dating back to 613/614 AD also confirms broad contacts between its inhabitants and other groups of Slavs which had reached the Byzantine Empire. The period between the 5th and the 7th century AD (1550–1250 cal. yr BP) was characterized by a slightly sluggish but stable economy based on agriculture (Czopek 1998).

The tribal period of early medieval times showed relatively unsophisticated and gradual cultural development up to the establishment of the first national structures and spanned the period between the 7th and the10th century AD (1350–950 cal. yr BP). The population of this period made a living from agriculture and cattle breeding. The tendency to exploit fertile soils was distinguishable, even those in the lower parts of the valleys (Czopek 1998). The traces of this settlement are composed of three inhabited structures at site 22, the inhabitants of which probably moved to the central part of Grodzisko Dolne after a relatively short period of time. These developments were caused by both political and economical changes that led to the establishment of the better-organized communities which could be the building blocks of more national units. All this intensified the need for building a fortified settlement (Czopek & Podgórska-Czopek 2007).

MATERIAL AND METHODS

The drilling of the profile from Grodzisko Nowe was performed in 1997 by A. Wójcik (Polish Geological Institute, Carpathian Branch) using an Instrorf

(Russian type) sampler. The remains of the core, after sampling at intervals of 5 cm, were destroyed and the author received material only as subsamples.

Altogether 36 subsamples (1 cm^3 volume) were selected and prepared with modified Erdtman acetolysis with an addition of hydrofluoric acid (Faegri & Iversen 1989). To every sample a weighed *Lycopodium* tablet was added for further calculations of pollen concentration (Stockmarr 1971). More than 500 arboreal pollen grains (occasionally 200 in samples with low pollen concentration) per sample were counted at 400× and 1000× magnification.

The pollen taxa were determined with the assistance of the modern pollen slide collection of the Władysław Szafer Institute of Botany, Polish Academy of Science, and special keys and manuals (Punt 1976, Faegri & Iversen 1989, Moore et al. 1991, Reille 1992, Beug 2004). The taxa were identified to the highest possible level and the nomenclature follows a compilation of taxa names from the above-mentioned keys and manuals, for example according to Beug (2004) pollen of different *Pulsatilla* species (without *Pulsatilla alpina*) is included in *Ranunculus acris* type, whereas Moore et al. (1991) classify these species as the pollen taxon *Ranunculus* type (nevertheless, point to the fact that grains of *Pulsatilla vulgaris* are distinct in this type), what is more pollen grains of *P. vulgaris*, *P. patens* and, *P. pratensis* are very similar (personal observation) hence this type of pollen was ascribed to *Pulsatilla* in the diagram.

The percentage values of individual taxa were calculated in the ratio to AP+NAP excluding telmatophyte (with Cyperaceae) and limnophyte pollen as well as the spores of Pteridophyta and *Sphagnum*. The percentages of excluded taxa were calculated in the ratio to AP+NAP+taxon. Pollen diagrams were plotted using POLPAL software (Nalepka & Walanus 2003). Additionally, a dendrogram of the similarity between pollen spectra prepared using the ConSLink method and a diagram of the Rarefacted number of taxa which reflects palynological richness were also plotted using a program within POLPAL software.

RADIOCARBON DATINGS

Radiocarbon datings were done in the Poznań Radiocarbon Laboratory and were calibrated using the OxCal v 4.10 program (Bronk Ramsey 2009), according to the calibration curve IntCal 04 (Reimer et al. 2004). The results are presented in Table 1.

PROFILE DESCRIPTION

The place of the profile drilling was situated at an altitude of 177.8 m a.s.l. (50°09′55″N, 22°30′35″E), within a palaeomeander of the Wisłok river on the sandy terrace. The sediments of the analysed core were described by A. Wójcik.

0–20 cm	Silty peat
20–195 cm	Peat with wood particles
195–250 cm	Peat with a predominance of loam and lacustrine marl
250–305 cm	Laminated lacustrine marl
305–400 cm	Sand

DESCRIPTION OF POLLEN ZONES

Pollen diagram (Fig. 3) was divided into local pollen assemblage zones (L PAZ) according to Birks (1979, 1986) and Janczyk-Kopikowa (1987) with the support of the ConSLink dendrogram. The diagram was also divided into chronozones proposed by Mangerud et al. (1974). The results are presented in Table 2 and Figure 3.

VEGETATION HISTORY

GN-1 *Pinus-Betula-Artemisia* L PAZ

The *Betula* frequency increases in forest communities after an initial *Pinus* domination. Perhaps it was affected by local flood phenomena which positively influenced the expansion of birch on degraded sites. The lowest terrace levels were occupied by willow thickets, which were expanding. In the GN-1c subzone were recorded the highest larch (*Larix*) pollen percentage values which indicate its local presence. Light demanding juniper (*Juniperus*) thickets probably covered only small areas, and its percentage values are similar to the pattern from 12 800–11 250 cal. yr BP for south-eastern Poland (Okuniewska-Nowaczyk et al. 2004). Open areas were also

Table 1. Radiocarbon dates from the Grodzisko Nowe profile

Laboratory code	Depth (cm)	Material	Age (^{14}C BP)	Callibrated age – 95.4% probability (cal. BP)
Poz-26442	30	Unidentified wood	1845±30	1865–1712
Poz-27935	195	*Phragmites australis* stem (fragment)	9810±60	11 387–11 126
Poz-26444	315	Unidentified plant remains	10 430±60	12 637–12 092

Table 2. Grodzisko Nowe. Description of local pollen assemblage zones (L PAZ)

L PAZ. Depth (cm)	Description of pollen spectra	Top boundary description
GN-1. *Pinus-Betula-Artemisia.* 335–210	Gradual increase in *Betula* undiff., constant decrease in *Pinus sylvestris* type (38.5–79%), the highest percentage values of *Salix* undiff. (0.2–1.9%), *Larix* (0.6–2%), *Juniperus* (0–0.8%) and *Pinus cembra* type (0–0.7%) in the diagram, *Betula nana* type occurs in most of assemblages; *Artemisia*, Apiaceae undiff., and Chenopodiaceae reach their maximum. *Myriophyllum verticillatum*, *Potamogeton* subgen. *Eupotamogeton*, and *Lemna* type are the main limnophytes. Numerical analysis ConSLink confirms spectra grouping into one L PAZ, as well as confirming the division into subzones.	Decrease in *Betula* undiff., rapid rise in *Pinus sylvestris* type and Filicales monolete.
GN-1a. *Pinus.* 335–315	Dominance of *Pinus sylvestris* type (71–79%), maximum of *Salix* undiff. (1.9%); Cyperaceae undiff. (4–6.5%), Poaceae undiff. (2.6–4.8%), *Artemisia* (2–4.5%), Apiaceae undiff., and Chenopodiaceae are the main herb taxa; single grains of *Pleurospermum austriacum*. Single spores of *Selaginella selaginoides* and *Botrychium*. Maximum of *Potamogeton* subgen. *Eupotamogeton* (0.1–1.5%); single grains of *Typha angustifolia*. Frequency of corroded grains between 0 and 5% and shows increasing trend.	
GN-1b. Apiceae undiff. 315–252.5	Increase in *Betula* undiff. (10.5–16.5%), *Pinus sylvestris* type values after a steady decrease; *Juniperus* and *Pinus cembra* type (0.1–0.7%) reach their maximum in the profile, Sharp increase in Apiaceae undiff. values (11.5–16%), culmination of *Artemisia* values (5.3%), regular curves of Cyperaceae undiff. (4.8–8.7%), Poaceae undiff. (3.9–6.4%), Chenopodiaceae, *Thalictrum*, and *Filipendula*; singular: *Plantago major*, *Pleurospermum austriacum*, *Polemonium coeruleum*, *Helianthemum* undiff., and *Plantago media*. Increase in *Equisetum* percentage values (0.5–1.8%). Regular occurrence of *Myriophyllum verticillatum, Potamogeton* subgen. *Eupotamogeton*, *Lemna* type, and *Sagittaria sagittifolia*; *Typha angustifolia* in most of the assemblages. Corroded sporomorphs: 0.8–3.7%.	
GN-1c. *Betula.* 252.5–210	Rapid rise in *Betula* undiff. curve (19–50.5%), decrease in *Pinus sylvestris* type (38.5–58.5%); maximum of *Larix* percentages in the profile (2%), second culmination of *Salix* undiff.; single pollen grain of *Hippophaë rhamnoides.* Decrease in Apiaceaea undiff.; fluctuation of Cyperaceae undiff., decreasing trend of *Artemisia* and Chenopodiaceae curves; single grains of *Pleurospermum austriacum*, *Dryas octopetala*, *Bupleurum*, and *Helianthemum* undiff. Filicales monolete and *Equisetum* occur at every level (3.9%, max. in profile); single spores of *Botrychium* and *Pteridium aquilinum*. Maximum values of *Nuphar* (0.8%) and *Lemna* type (1.4%); *Myriophyllum vericillatum* curve disappears after its maximum (15.2%); *Typha latifolia* and *T. angustifolia* occur in single grains. Corroded grains frequency: 0.5–3.5%. Maximum pollen concentration in the diagram recorded in the upper part ($4.2{\times}10^5$ pollen grains/cm^3).	
GN-2. *Pinus-* Filicales monolete. 210–120	Increase in *Pinus sylvestris* type (93% max. in profile, curve fluctuation) correlated with sharp decrease in *Betula* undiff. (1.3–9.9%); single occurrences of: *Betula nana* type, *Juniperus*, *Populus*, *Larix* and *Pinus cembra* type. Decrease and fluctuations in NAP in the upper part of zone. Domination of Filicales monolete (81%, max.), curve of *Thelypteris palustris* culminates in the profile (11%, in basal part); decrease in *Equisetum*; Disappearance of pollen of aquatic taxa. Fluctuations in corroded grains frequency: 1.2–19.5%. Numerical analysis ConSLink confirms spectra grouping into one L PAZ.	Rise in *Corylus* curve.
GN-3. *Pinus-Corylus.* 120–95	Moderate values of *Pinus sylvestris* type (61–85.5%); increase in *Corylus avellana* (2.8–5.4%) and *Ulmus* (1.5–3.3%, max. in profile) frequency. Fluctuation in NAP curve. High frequency of Filicales monolete spores (20–43.5%), regular occurrence of *Pteridium aquilinum* (2.8%, max. in diagram). Regular occurrence of *Phragmites australis* type. Frequency of corroded grains 4.7–11.5% increases in the upper part. Numerical analysis ConSLink confirms spectra grouping into one L PAZ and points to similarity to GN-2 zone.	Rise in *Alnus* undiff. percentage values and decrease in *Pinus sylvestris* type.
GN-4. *Alnus-Pinus.* 95–30	Decrease in *Pinus sylvestris* type (29.5–51.5%) correlated with increase in *Alnus* undiff. (19.5–32.5%, max. in profile); culmination of *Tilia cordata* type (0.8–7.7%), *Quercus* (1.2–5.7%), *Carpinus betulus* (0–4.5%) and *Picea abies* (0.6–3.9%); decrease in *Corylus avellana* frequency after its curve reaches its maximum at a depth of 90 cm (7%); appearance of *Fagus sylvatica* (0–0.7%), *Abies alba* (1.5%, max. in profile) and *Acer*. Single occurrence of *Viscum* and *Juglans* grains. Percentage values of NAP first increase then decrease in the upper part. Low-percentage curve of Cerealia type (0–0.4%) and single grains of *Secale cereale*, *Plantago lanceolata* and *Centaurea cyanus.*	Rise in NAP percentage values

Fig. 3. Percentage pollen diagram from the Grodzisko Nowe profile. **1** – silty peat, **2** – peat, **3** – peat with loam and lacustrine marl, **4** – lacustrine marl, **5** – sand

Table 2. Continued

L PAZ. Depth (cm)	Description of pollen spectra	Top boundary description
GN-4. *Alnus-Pinus.* 95–30	Fluctuations of Filicales monolete (11.5–59.5%) frequency; regular occurrence of *Pteridium aquilinum*; The highest values of corroded sporomorphes in the diagram (11–31%). Numerical analysis ConSLink confirms spectra grouping into one L PAZ.	Rise in NAP percentage values
GN-5. NAP 30–0	Decrease in most of tree taxa percentages occur in the GN-4 zone; but increases in *Fraxinus excelsior* (0.3–0.9%), *Salix* undiff., *Fagus sylvatica* (0.2–1.5%) and *Abies alba* (0.4–0.8%); *Juglans* and *Viscum* are detected. Frequency of NAP exceeds 50% in some spectra. Culmination of Cerealia type (3.4–8.4%), *Secale cereale* (2.4–3.5%), *Rumex acetosa* type (1.1–8.2%), *Plantago lanceolata* (0.1–2.2%), Cichorioidae (0.1–3.4%), Brassicaceae undiff. (0.1–3.0%), and *Centaurea cyanus* (0.1–1.1%); appearance of *Polygonum aviculare*, *Fagopyrum esculentum* type (max. 0.3%), *Hordeum* type (max. 0.5%), and *Triticum* type (max. 0.7%). Regular occurrence of Filicales monolete (17–29%) and *Pteridium aquilinum* (0.6–1.4%); maxima for *Anthoceros* (0.8%) and *Phaeoceros* (0.3%). Corroded sporomorphes: 9.9–14%. At the depth of 15 cm charcoal particles reach their maximum of concentration in the profile (2400/cm^3). Rarefacted number of taxa analysis shows the highest values in the profile. Numerical analysis ConSLink confirms spectra grouping into one L PAZ and points to its similarity to GN-4 zone.	

covered by steppe vegetation patches where *Artemisia* was a dominant component. The detected presence of spruce pollen grains (at about 0.5%) is identical to isopollen maps and corresponds to the Younger Dryas chronozone (Obidowicz et al. 2004). This indicates its scarce occurrence, which might be further supported by Harmata (1987) who found spruce macrofossils along with a frequency of pollen of less than 0.5%.

The increase in the frequency of Apiaceae undiff. was probably due to the local occurrence of a species colonizing the palaeochannel, as it silted up.

The littoral zone of the basin was dominated by *Myriophyllum verticillatum* and *Potamogeton* subgen. *Eupotamogeton*, and the water body was fringed with a belt of rushes formed by Cyperaceae, Typhaceae with an admixture of *Sagittaria* and *Sparganium*. *Filipendula* may have occurred on the edge of these communities. The presence of *Typha latifolia* pollen indicates 13°C as a mean June temperature (Isarin & Bohncke 1999), and the *Typha angustifolia* pollen detected in this zone, according to Hoek (1997), suggests that the temperature was not lower than 14°C.

The lowest sample from the GN-1a subzone probably corresponds with the youngest part of the Allerød chronozone. Most of the zone spans the Younger Dryas period with the highest sample belonging to the Preboreal chronozone.

GN-2 *Pinus*-Filicales monolete L PAZ

In this area pine expanded rapidly and clearly displaced birch from most of its sites and limited its occurrence to the lowest valley terraces. Perhaps edaphic factors (sandy ground) encouraged these processes. Spruce and elm may have been occasionally present in wooded areas, but the low incidence of the latter shows it was not a significant presence (comp. Huntley & Birks 1983). In the upper part of the zone the number of *Quercus*, *Corylus avellana*, and *Fraxinus excelsior* pollen grains increase slightly, but values of the last two do not indicate their *in situ* presence (Miotk-Szpiganowicz et al. 2004a, Milecka et al. 2004). A few patches of dwarf birch (*Betula nana*) may have survived in some communities in the vicinity and/or in the area of the fen. Ferns from the Polypodiaceae family (in the diagram represented by Filicales monolete) dominated forest groundcover. Open area communities were strongly reduced by expanding forests and could have been represented by scarce patches of xeric vegetation overgrown by Poaceae and *Artemisia* with the addition of thickets with *Rhamnus catharticus*.

During this period the palaeochannel was fragmented into small ponds occupied by *Potamogeton* subgen. *Eupotamogeton* and Lemnaceae (at the beginning of the zone). Those processes triggered an expansion of *Thelypteris palustris* accompanied by *Phragmites australis* and *Typha latifolia* across the surface of the basin.

This zone is probably correlated with the Preboreal and the older phase of the Boreal chronozones.

GN-3 *Pinus-Corylus* L PAZ

Hazel (*Corylus avellana*) expanded visibly and became dominant in the light understorey of pine forests – the main component of the landscape. The expansion of deciduous taxa e.g. *Quercus*, *Fraxinus excelsior*, *Tilia cordata*, and *Alnus* in woods was brought about by an improvement in edaphic and climatic conditions. In the floodplain woods *Ulmus* was becoming a more frequent taxon. The groundcover was still dominated by ferns from the Filicales monolete group and by bracken (*Pteridium aquilinum*) whose occurrence might indicate forest clearings. This pioneering species is also considered to be a good indicator of light conditions, because it does not tolerate shade (Emmingham 1972 followed by Madeja et al. 2004).

This zone is correlated with the younger phase of the Boreal chronozone.

GN-4 *Alnus-Pinus* L PAZ

Alder spread rapidly and formed woodland on the lowest terrace levels, where spruce could occur in small numbers as well. The forests, which had covered the upper Holocene and Pleistocene terraces, were still dominated by *Pinus*. However, *Tilia cordata*, *Quercus*, and *Carpinus betulus* may have been a more frequent component in those forests. The highest frequency of hornbeam grains coincided with the appearance of beech (*Fagus sylvatica*) and fir (*Abies alba*), both of which may have been linked to anthropogenic disturbances of forest communities, which favoured the expansion of this taxa (Ralska-Jasiewiczowa & van Geel 1998).

Open herb communities, which expanded their distribution, were composed of Poaceae, Asteraceae, and *Rumex*. The simultaneous appearance of indicators of human activity, such as Cerealia type, *Secale cereale*, and *Centaurea cyanus,* points to the presence of arable fields.

This zone is characterized by a non-linear sediment record with strongly corroded pollen material in a spectrum at a depth of 80 cm.

The lowest sample may be correlated with the older phase of the Atlantic chronozone, whereas the remaining part of the zone could be ascribed to the younger phase of the Subboreal and the Subatlantic chronozone.

GN-5 NAP L PAZ

The strongest deforestation recorded in the whole profile is in this zone. Fragments of mixed woods, which survived on the higher terraces, were composed of pine together with oak and lime. The floodplains were still occupied by alder woods accompanied by ash, birch, poplar and/or aspen that coexisted with willow thickets, where *Urtica* and *Solanum dulcamara* probably occurred in the ground layer.

Arable fields with cereals and *Fagopyrum* (*F. esculentum* type), which apperared in this zone, were a very important element of the landscape. Weed and ruderal communities also played an important role in habitats affected by human activity. They were composed mainly of Polygonaceae (*Polygonum aviculare* and *Polygonum persicaria* type), Brassicaceae, Chenopodiaceae together with *Artemisia*, *Spergula*, *Scleranthus*, *Centaurea cyanus*, and *Convolvulus arvensis*. Deforested parts of the valleys were occupied by mown meadows and/or pastures.

On the dried-out palaeomeander Cyperaceae and *Phragmites australis* spread. This zone coresponds to the youngest part of the Subatlantic chronozone.

THE ANALYSIS OF SETTLEMENT PHASES

Phase A (130–80 cm). The first decline in AP percentage values, which could be connected with deforestation caused by human activity, is visible at depths of 145 cm, 115 cm, and 90 cm (Figs 3, 4). Additionally, at a depth of 115 cm a maximum of *Pteridium aqulinum* spore frequency was detected (Fig. 4). Soil acidifcation after fires favours the germination of these spores, so that young plants appear in great numbers on soils fertilized by ash (Page 1986, Oberdorfer 1990). An increase in the number of spores might indicate fire clearance to improve hunting (Smith 1970, Hicks 1972, Jacobi et al. 1976 after Behre 1988). The lack of agriculture and grazing indicators may point to the activity of Mesolithic tribes in the Wisłok and San valley area which was probably an intensive hunting ground for small groups of hunters whose archaeological remains were detected

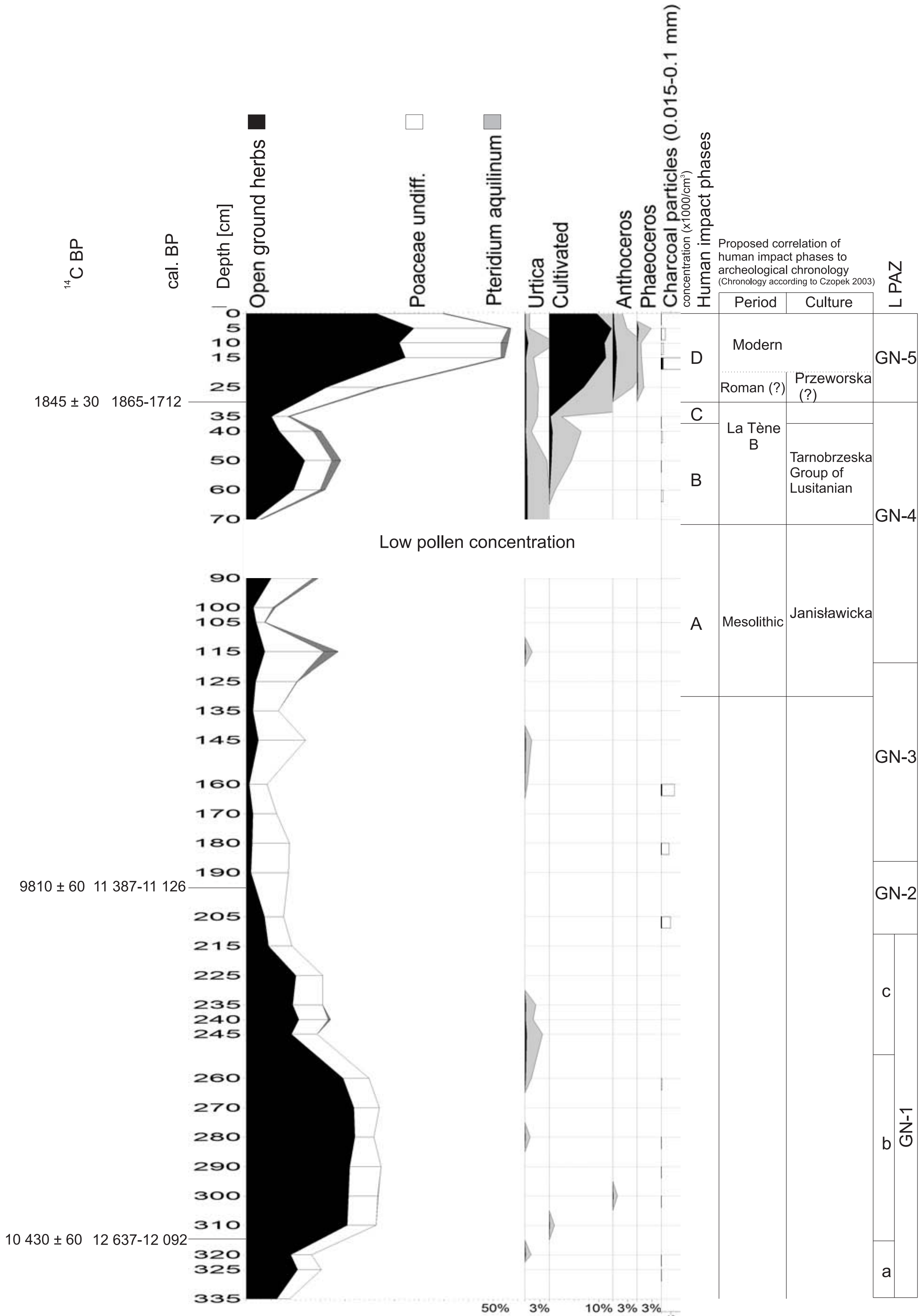

Fig. 4. Summary diagram of human impact from the Grodzisko Nowe site

in numerous places on sandy terraces close to the Kolbuszowa Plateau (Czopek & Podgórska-Czopek 2007). At a depth of 90 cm the first grain of *Juglans*, probably from long distance transport, was identified.

Phase B (70–30 cm). The first regular occurrence of Cerealia type signifies the presence of cultivated fields (Fig. 3). This phase is characterized by noticeable deforestation shown by higher values of NAP (in the 35–70 cm section it reached 20%). An increase in the *Rumex acetosa* type and the number of Cichorioidae grains may have been caused by an expansion of areas exploited as mown meadows and grazing areas. A rise in the *Artemisia*, Brassicaceae undiff., and *Urtica* curves is evidence of the development of synanthropic plant communities. Bracken was still the main component of forest clearings. This phase may be correlated with the time when the Tarnobrzeska Group of the Lusitanian Culture occupied this area (Fig. 4). Phase B probably reflects processes recorded in the *Pinus-Alnus-Carpinus* (*Fagus*) zone from the Grodzisko Dolne (Nowe) profile (Gębica et al. 2008) which is characterized by an increase in cereals dominated by *Secale cereale* pollen. Although that profile was collected closer to the archaeological site (site 22) the frequency of herb taxa is similar in both levels (comp. Gębica et al. 2008). In the Kopki profile significant activity of the Tarnobrzeska Group was recorded between the 14th and the 8th century BC, which is visible in the high values of herb taxa where Poaceae, Cerealia, *Plantago lanceolata*, and *Rumex* were dominant. A distinct peak of *Carpinus* (>15%) is a characteristic feature of this part of the profile (Bałaga & Taras 2001), and the highest values of *Carpinus betulus* in the Grodzisko Nowe profile are also typical of Phase B.

Phase C (37.5–30.0 cm). A visible reduction in open habitats reflected in a decrease in open ground herbs values (Fig. 4) and a decline in cereals curves coincided with the expansion of *Alnus* (Fig. 3), which was probably effected by a lessening of human activity. A radiocarbon date from a depth of 30 cm pointed to 1865–1712 cal. yr BP (85–239 AD) which might be correlated with an interruption of settlement between the activity of the Tarnobrzeska Group of the Lusitanian Culture and the beginning of dominance of the Przeworska Culture in the region, which is estimated to between the 4th century BC and the 1st century AD (S. Czopek pers. comm.).

Phase D (30–0 cm). A strong increase in the values of open ground herbs signifies highly intensive deforestation, which is demonstrated by the highest frequency of Poaceae undiff (Fig. 4). The high accumulation of *Plantago lanceolata*, Cichorioidae, and *Ranunculus acris* type (Fig. 3) may suggest the expansion of mown meadow communities (comp. Makohonienko et. al. 1998). The highest values of Brassicaceae undiff. in the profile could have been caused by the dispersion of weed species from this family by root vegetable cultivations and/or the appearance of rapeseed (*Brassica napus*) cultivation. A rapid increase in *Rumex acetosa* type, which might also have contained *Rumex acetosella* pollen grains (Fig. 3), combined with regular findings of *Polygonum aviculare* and *Scleranthus* confirms strong ruderalization in the vicinity of the palaeomeander in this phase. The pollen assemblages point to the most significant development in cereal cultivation recorded in the whole pollen profile, which is supported by the highest values of *Centaurea cyanus* (>1%, Fig. 3). A new component in agriculture was buckwheat (*Fagopyrum esculentum* t.), whose pollen regularly occurred in this zone.

Occurrences of *Juglans* (in three spectra) and *Vitis vinifera* (in a single spectrum) grains may confirm their cultivation for economic purposes. The highest concentration of *Vitis vinifera* occurrences is observed in the last 250 years in pollen diagrams from Poland (Granoszewski et al. 2004). According to historical information, the regular cultivation of walnuts started in medieval times (Lityńska-Zając & Wasylikowa 2005).

Taking into consideration the high NAP percentage values, which exceeded 50% between depths of 5 cm and 15 cm, as well as relatively very high *Rumex acetosa* type percentage values (up to 8%) in the 0–10 cm section, the age of this upper part of the phase might be estimated as 240–0 cal. yr BP. Values for these taxa are very similar to the patterns presented in the isopollen maps for this period (comp. Harmata et al. 2004,

Miotk-Szpiganowicz et al. (2004b). The occurrence of *Ambrosia artemisifolia* type pollen in this zone is probably an effect of the expansion of American taxa of this genus in southern and central Europe after the World

War I and also confirms the age of this section of the profile (comp. Makra et al. 2005). Unfortunately, the lack of macrofossil plant remains and the small volume of materials made it impossible to carry out any dating from this part of the profile.

INTERPRETATION OF THE LATE GLACIAL/HOLOCENE BOUNDARY IN THE POLLEN PROFILES FROM THE EASTERN PART OF THE SANDOMIERZ BASIN

One of the most important problems in the stratigraphy of pollen profiles from the Sandomierz Basin is the proper establishment of the Late Glacial/Holocene (LG/Ho) boundary. In a lot of them this boundary was established on the basis of the composition of pollen assemblages, without comparing the results of pollen analysis with radiocarbon dating. What is more, in most of those profiles different pollen indicators were chosen to establish it (Mamakowa 1962, Starkel et al. 2002, Starkel & Granoszewski 1994, Madeja 2002, Kołaczek 2007, Gębica et al. 2008) In the Grodzisko Nowe profile a decrease in the percentage values of *Artemisia* (the most visible one), *Larix*, and *Juniperus*, which is simultaneous with an increase in AP values determine this transition, which might be confirmed by a radiocarbon date from a depth of 195 cm (11 387–11 126 cal. yr BP). Furthermore palynological records from Lake Perespilno (Goslar et al. 2000, Bałaga 2004), which is the nearest site to the Sandomierz Basin where annual lamination has been recognized, also show a clear decline in the *Artemisia* curve at the transition between the Late Glacial and the Holocene dated back to 11 550–11 501 cal. yr BP. Lake Perespilno is located about 180 km north-east of Grodzisko Nowe. Those facts suggest that the decline in *Artemisia* curve with the simultaneous increase in AP values is a reliable benchmark for the establishment of the LG/Ho boundary in the Sandomierz Basin. Hence this boundary in the profiles from Rzemień, Obary and Podbukowina should be reconsidered (Figs 5, 6), because Mamakowa (1962) assigned similar decreases in *Artemisia* values to the Preboreal or even to the Boreal chronozone. On the other hand, the Świlcza profile is the only one where the LG/Ho boundary seems to be established correctly among the sites analysed by Mamakowa (1962). Nevertheless, there is no visible increase in AP correlated with the rise in *Artemisia* in most diagrams presented by Mamakowa (1962), the only exception is the diagram from the Obary site. Probably incorporating of Cyperaceae pollen to the total pollen sum, contrary to the Grodzisko Nowe diagram, caused this fact (comp. Mamakowa 1962). In the pollen profile from Wola Żyrakowska (Starkel & Granoszewski 1994) in the Wisłoka valley the radiocarbon plateau of the Late Glacial/Holocene transition was recorded, thus radiocarbon datings have not shown a clear LG/Ho boundary. Despite this fact, the YD/PB chronozone is more closely related to the Younger Dryas chronozone considering the shape of the *Artemisia* curve (comp. Starkel & Granoszewski 1994). Declines in *Pinus cembra* and *Larix* values are also simultaneous with *Artemisia* fall in the Wolica Żyrakowska profile which further confirm this suggestion. In this profile Cyperaceae pollen was included to the total pollen sum and there is no visible rise in AP values at the beginning of the Holocene (comp. Starkel & Granoszewski 1994). Another radiocarbon dating from the potential LG/Ho transition comes from the Grodzisko Dolne (Nowe) profile (Gębica et al. 2008) and shows 7460 ± 120 ^{14}C BP. This dating is not reliable in the light of palynological analysis and was not taken into consideration in the interpretation of this profile (K. Szczepanek personal comm.). In this profile the LG/Ho boundary is not clearly determined, but the decline in *Artemisia* coincides with the increase in NAP and seems to point this boundary (Fig. 6, comp. to Gębica et al. 2008). A different situation was recorded in the profiles from Krasne located in the Rzeszów Foothills (Kołaczek 2007) and Wolica Ługowa located west of Krasne, (Madeja 2002, Starkel et al. 2002) where the *Artemisia* percentage values fluctuate, because this makes it impossible to pinpoint clearly a decline in its curves. However, radiocarbon dating and changes in values of other taxa related to the Late Glacial period (mainly decline in *Larix*) confirm the establishment of the LG/Ho boundary at Krasne (comp. Kołaczek 2007), whereas in the Wolica Ługowa profile radiocarbon datings present incoherent results, and the boundary is established on the basis of the composition of pollen assemblages (fall in *Larix* and *Pinus cembra*; comp. Madeja

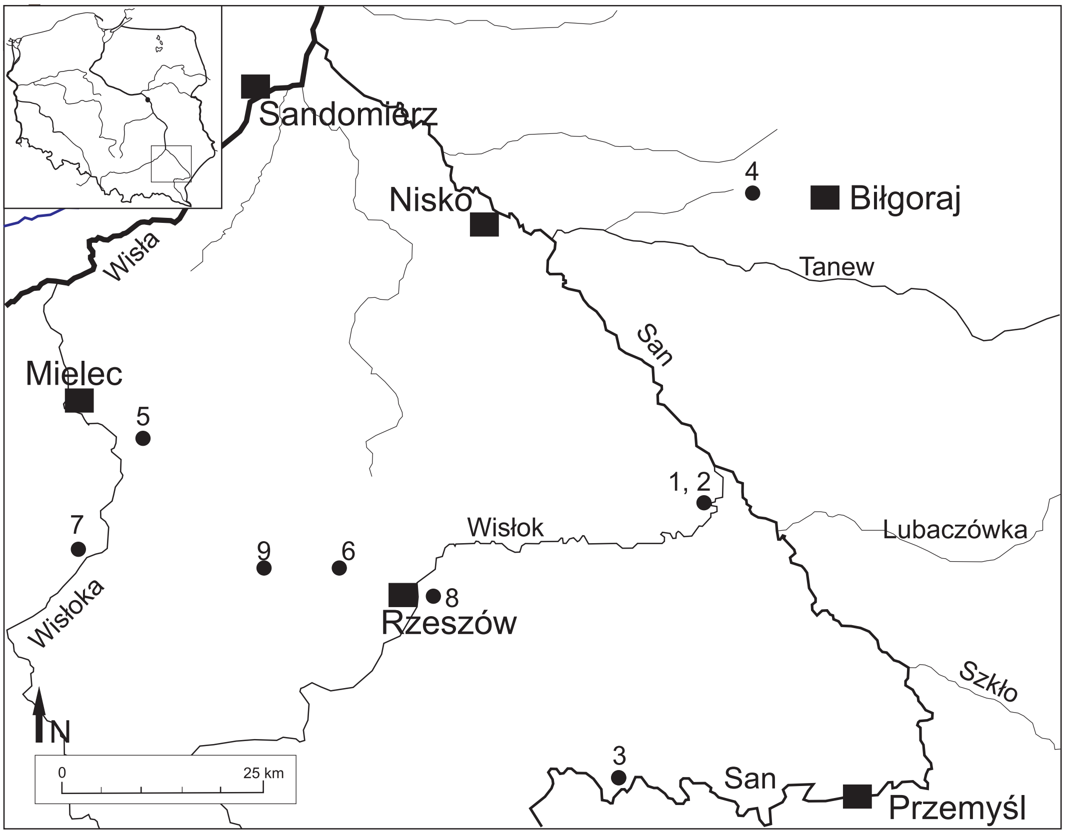

Fig. 5. Map of sites with numbers of profiles as in Figure 6

2002, Starkel et al. 2002). Neither Krasne, nor Wolica Ługowa profiles show the rise in AP percentages at the beginning of the Holocene.

THE PROBLEM OF SEDIMENT DISCONTINUITIES IN THE GRODZISKO NOWE PROFILE

Another vital problem connected with the interpretation of the Grodzisko Nowe profile is discontinuity of sediments reflected in a shortened section correlated with the Atlantic (or the younger part of the Boreal) and the Subboreal chronozones, as well as in a hiatus between a layer probably from the Roman period (GN-5 zone) and modern times. Discontinuity was also detected in the Grodzisko Dolne (Nowe) profile (Gębica et al. 2008) where it is demonstrated by the lack of a Preboreal-Boreal section, but the authors have not explained causes of this fact. The strong corrosion of pollen grains reflected in the Grodzisko Nowe profile (in the Atlantic section) is characteristic of a lot of sequences originating in the Holocene climate optimum e.g. in pollen profiles from the Western Carpathians (Rybničková et al. 1989) and Starunia in the Ukraine, where profiles No 4 and VL-1 recorded deterioration of pollen material preservation in the Boreal and Atlantic chronozones (Stachowicz-Rybka et al. 2009). This phenomenon was caused by the desiccation and subsequent aeration of peat (Rybničková et al. 1989). Another potential cause was an expansion of alder woods on mires and the start of the accumulation of alder peat. This kind of peat is characterized by poor pollen preservation (Barthelmes et al. 2006). According to Kulczyński (1940) occurrence of forest associations, including that of alder woods on a peat bog surface may stop or limit the growth of a peat layer. Both these effects may probably have occurred and caused the discontinuity in the Boreal-Subboreal section in the Grodzisko Nowe profile, because this phenomenon took place after *Alnus* expansion in the site vicinity. On the other hand fluctuation of water level, which is typical of fens developed in palaeochannels, may have led to the increase in aeration of peat and subsequent corrosion of pollen. Similar situation was observed in Krasne (Kołaczek 2007) where the profile was collected from the peat bog, which developed on the Wisłok palaeochannel and

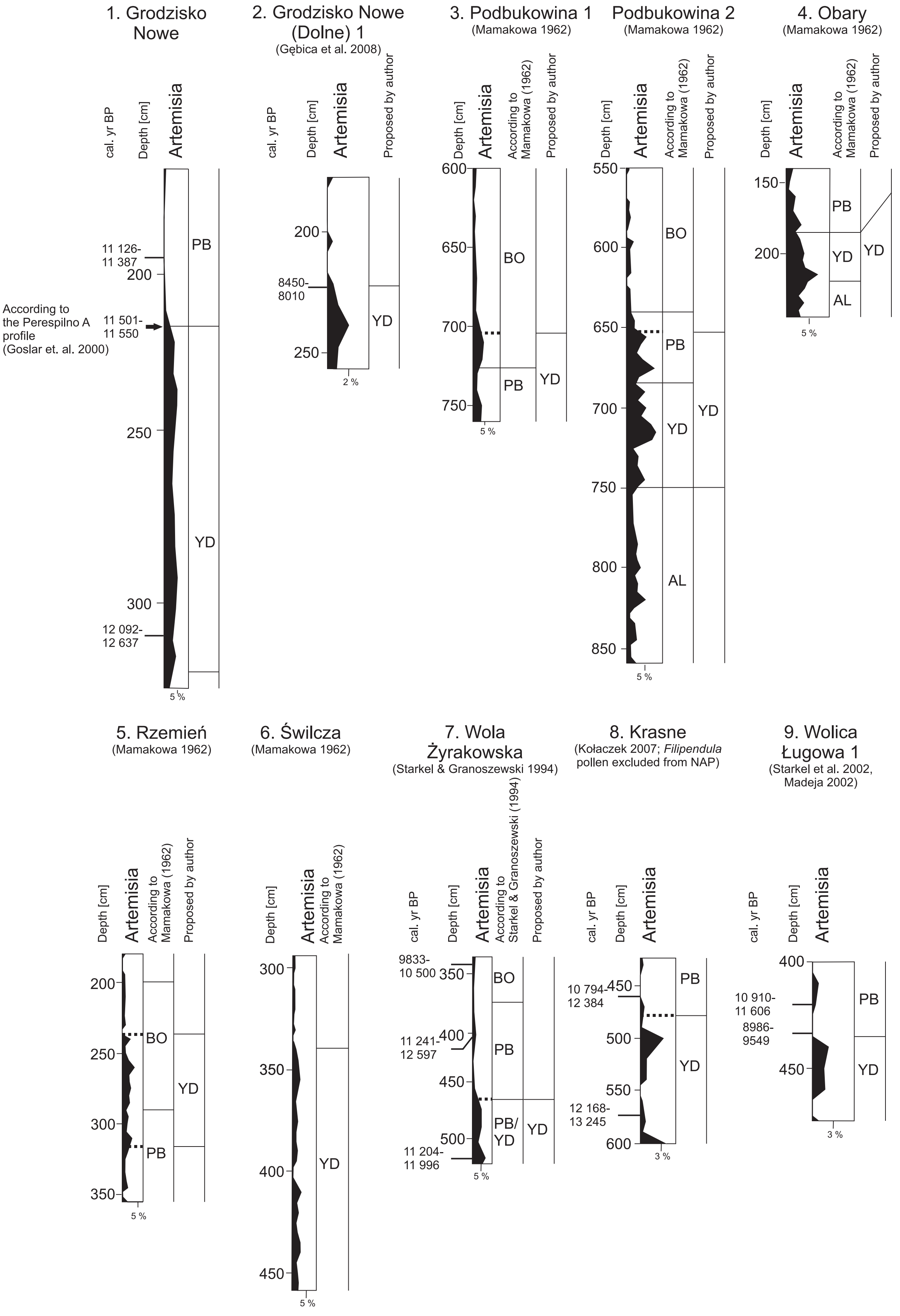

Fig. 6. Curves of the *Artemisia* percentage values changes during the Late Glacial/Holocene boundary from the pollen profiles from the eastern part of the Sandomierz Basin. In diagrams, where originally radiocarbon dates were not calibrated, datings were calibrated using OxCal v 4.10 program (Bronk Ramsey 2009), according to the calibration curve IntCal 04 (Reimer et al. 2004)

strong corrosion of pollen was recorded in the almost whole peat layer. Degradation of sporomorphs led to the visible fall in concentration of pollen grains and overrepresentation of *Pinus* and Filicales monolete in the diagram, which disturbed interpretation of that pollen diagram (comp. Kołaczek 2007). The discontinuity in the GN-5 zone was probably an effect of erosion which can be confirmed by presence of silt in peat. Unfortunately, the small volume of material samples was not sufficient to carry out any peat analysis in the Grodzisko Nowe profile.

CONCLUSIONS

1. The pollen profile from Grodzisko Nowe presents the succession from the beginning of the Younger Dryas up to the modern period. Pollen assemblages originating in the Late Glacial are characterized by relatively high AP values. This fact suggests the presence of great areas covered by forest in that period. Radiocarbon dating confirmed a palynologically established boundary between the Younger Dryas and the Preboreal chronozones in the profile, hence this profile may become a reference source for verifying the stratigraphy of this transition in the pollen profiles from the eastern part of the Sandomierz Basin which lacks radiocarbon dates. In the Preboreal chronozone, a strong decrease in *Betula* (dating at 11 387–11 126 cal. yr BP) along with a rapid increase in *Pinus* values was recorded, which reflects the dynamic expansion of pine on the sandy Wisłok terraces.

2. In the pollen profile from Grodzisko Nowe, as in many others from the Sandomierz Basin, a discontinuous Holocene sediment sequence has been detected. A large part of the section dating from 0–1500 cal. yr BP is probably missing, as well as the part between the late Boreal/early Atlantic and the Subboreal/ Subatlantic chronozones, which is represented by strongly decomposed and compressed peat with poorly preserved pollen grains.

3. Three phases of increases in human activity are recorded in the pollen profile. The first represents the activity of Mesolithic tribes reflected in a few episodes with declines in AP values, which coincide with an increase in Poaceae undiff. and the frequency of *Pteridium aquilinum*. The subsequent phase is probably connected with the activity of the Tarnobrzeska Group of the Lusitanian Culture, which is represented by a decrease in AP values correlated with an increase in the frequency of Cerealia type. The strongest deforestation, which was recorded in the uppest part of the profile is probably connected with the modern period, and is reflected in the highest values of Poaceae undiff., Cerealia type, *Secale cereale*, *Centaurea cyanus*, *Rumex acetosa* type, and *Plantago lanceolata*.

4. The paucity of radiocarbon datings caused by the small amounts of material collected from this profile, made it impossible to establish a detailed chronology of the profile and to carry out an exact correlation between phases of human activity and the archaeological chronology.

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