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Are several profiles better than one? Multi-profile palynological study of the Eemian lacustrine sediments at the Wola Starogrodzka site (Garwolin Plain, Central Poland)

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ABSTRACT:

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Pollen analysis was performed on 14 profiles of fossil biogenic sediments from different parts of the vast depression near the Wola Starogrodzka village (Central Poland). The results allowed the determination of the time of their accumulation for the period from the end of the Odra Glaciation (Warta Stage, Saalian, MIS-6), through the Eemian Interglacial (MIS-5e), to the first interstadial of the Early Vistulian (Brørup, MIS-5c). In many studied profiles, we noted the incompleteness in the pollen record of the Eemian vegetation succession – hiatuses occur usually in the hornbeam (E5) and/or spruce phase (E6). Moreover, the thickness of the same pollen zone and the development of its palynological record are strongly differentiated between individual profiles, e.g. the hornbeam zone (E5) is contained in an exceptionally thick sediment layer (3.7 m) in the PWS1-19 profile, and the oak zone (E3) in the WH-123 and PWS2-19 profiles (1.0 and 1.2 m, respectively), while in other profiles they are represented only by single pollen spectra. If we only had a single profile with a hiatus and/or a poorly developed pollen record, it would be impossible to reconstruct a complete interglacial succession of vegetation. However, having several such imperfect profiles which complemented each other enabled us to do it.

Key words: Last interglacial: MIS-5e; Vegetation reconstruction; Pollen analysis; Palynostratigraphy; Hiatus.

INTRODUCTION

Although the Eemian pollen succession, the basis for palaeoecological and palaeoclimatic considerations during the last interglacial, is in Central Europe generally well recognized (e.g. Menke and Tynni 1984; Mamakowa 1989; Shalaboda 2001; Felde *et al*. 2020), the issue of changes in the environment (especially in vegetation and climate) in this part of our continent during the Eemian is still debatable (Hrynowiecka *et al*. 2021; Pidek *et al*. 2022 and many others). It is suspected, for example, that gaps may exist in the sedimentary record of the Eemian Interglacial (e.g. Rother *et al*. 2019). It is also suggested that rapid short-lasting climate fluctuations occurred within this interglacial, both during the hornbeam phase representing the interglacial optimum (e.g. Chedadi *et al*. 1998; Borisova *et al*. 2007), and during the pine phase closing the Eemian (e.g. Novenko *et al*. 2008; Boettger *et al*. 2009; Kupryjanowicz *et al*. 2016).

In Poland there are relatively many sites with Eemian pollen successions (e.g. Mamakowa 1989, 2003; Bruj and Roman 2007; Kupryjanowicz *et al*. 2018c). The majority of them occurs within the zone between the maximum range of the Vistula Glaciation (Weichselian, MIS-2) and the maximum range of the Oder Glaciation (Warta Stage, Saalian, MIS-6). Beyond this area, sites with Eemian lake and mire sediments are noted sporadically.

In many Polish sites, the pollen record of the Eemian succession of vegetation is incomplete (see Nalepka and Walanus 2018). This applies mainly to the hornbeam phase (E5 RPAZ) (Kupryjanowicz 2008). Sedimentation breaks (hiatuses) can be seen, especially at the end of this phase and at the beginning of the next phase, i.e. the spruce phase (E6 R PAZ). However, in the same profiles, the sediment accumulation was reactivated only in the pine phase (E7 R PAZ), and then it lasted for a significant part of the Vistula Glaciation (e.g. Kupryjanowicz 2008; Kupryjanowicz *et al*. 2021). Only in a few sites the record of the Last Interglacial is preceded by the record of changes before its start (Bińka and Nitychoruk 2003; Kupryjanowicz *et al*. 2021) and after its end (Jastrzębska-Mamełka 1985; Kupryjanowicz 1991, 2008; Granoszewski 2003; Kołaczek *et al*. 2012; Majecka 2014; Malkiewicz 2018).

For these all above reasons, each new site recording changes in the environment during the last interglacial (and the glaciations that preceded and followed it) is still very valuable. Therefore, when relatively thick Eemian lacustrine sediments were discovered at the Wola Starogrodzka site in Central Poland, they were subjected to palynological investigations. The overriding goal of this study is to reconstruct the main changes in vegetation of Central Poland during the Eemian Interglacial. In this paper, we present almost all the obtained results of pollen analysis, but in a very abridged form. First of all, we want to draw attention to the large number of profiles examined at this site and their great diversity in terms of the pollen record contained in individual profiles. In addition, the compilation of all pollen profiles illustrates some phenomena that would be more difficult to see based on individual profiles. Our intention here is only to signal some research problems related to the site we are examining. Palynological studies are currently supplemented by other paleoecological analyses (including analysis of plant macroscopic remains, Cladocera analysis, geochemistry). Some of the profiles presented here will be studied in more detail in our subsequent work in the context of specific problems concerning the Eemian Interglacial. So far, only two profiles have been subject to such a more detailed study, which formed the basis for reconstruction of environmental changes of the stadial-interstadial-stadial type at the end of the Saalian (Kupryjanowicz *et al*. 2021).

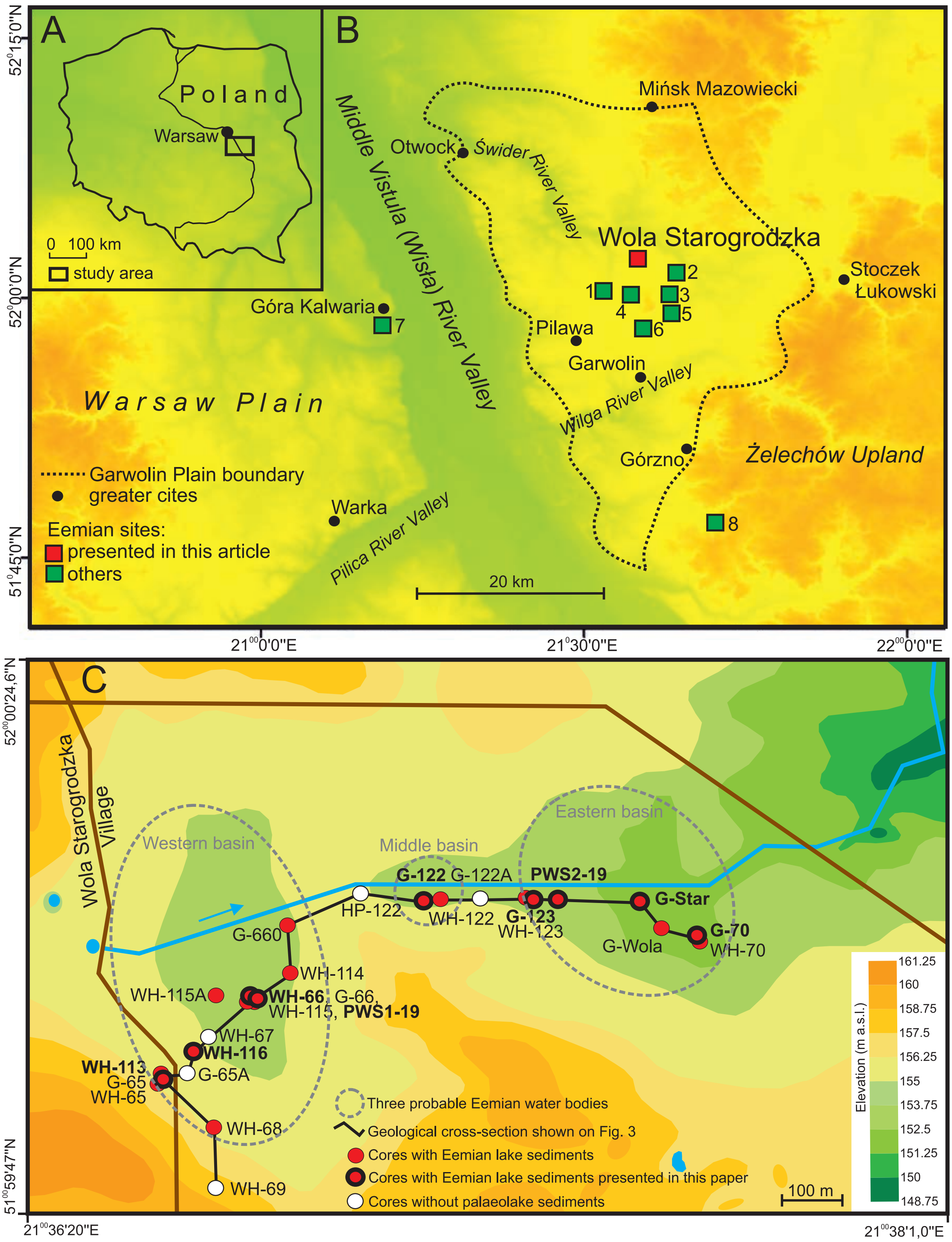
STUDY AREA AND SITE

The Wola Starogrodzka site is located in central Poland, within the Garwolin Plain (Text-fig. 1A, B) that constitutes part of the Masovian Lowland (Solon *et al*. 2018). The Garwolin Plain covers an area of about 900 km^2, sloping northwest from about 140 to 130 m a.s.l. It lies on the eastern side of the Middle Vistula Valley, between the Mienia River Valley (Świder tributary) in the north and the Okrzejka River Valley in the south, and borders neatly on the east with the Kałuszyn Upland and the Żelechów Plateau (Kondracki 2002).

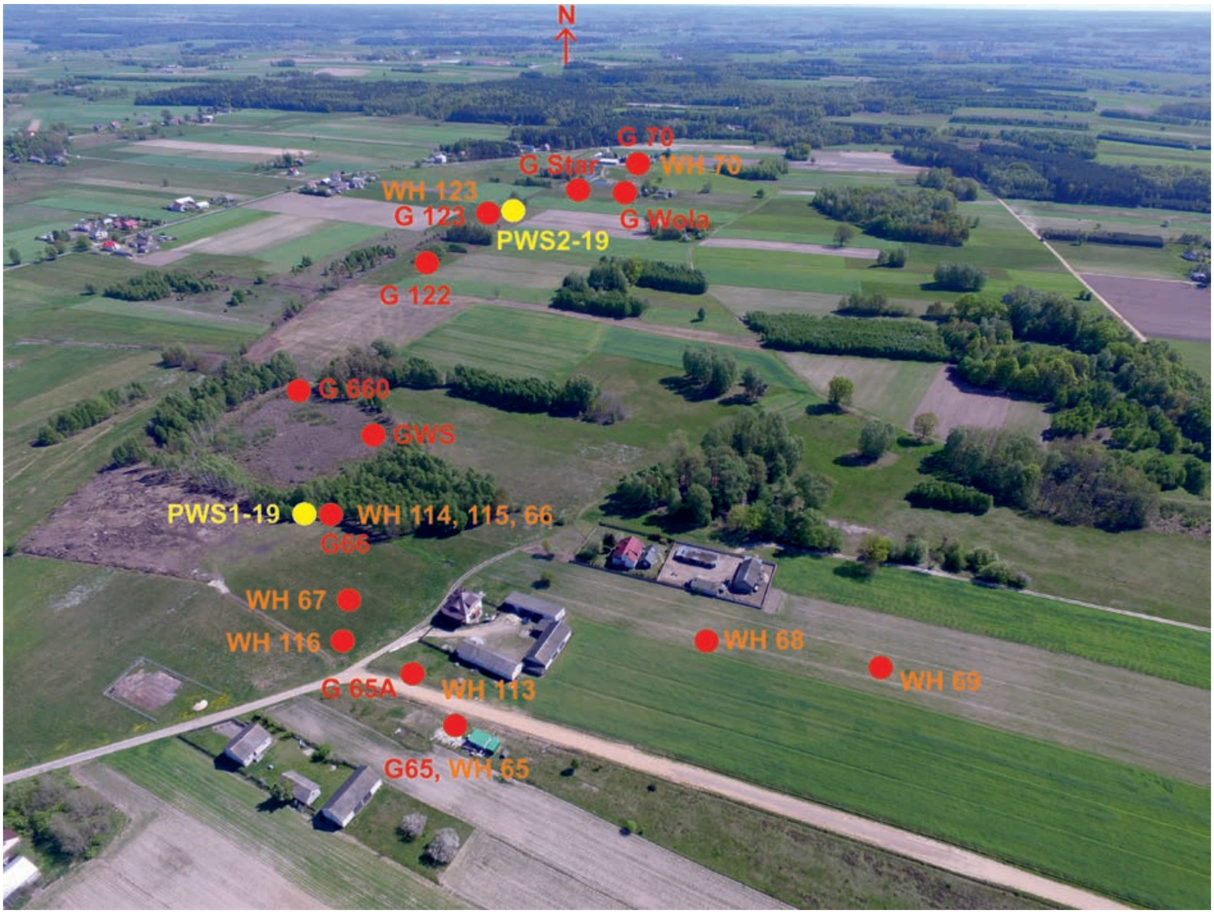
This region is situated outside the range of the Vistulian (Weichselian) Glaciation (Marks 2011), and the surface relief was here formed during the Warta Stage of the Odra Glaciation (Late Saalian, MIS 6). A feature of the landform are quite numerous drainless depressions, which were created mainly as a result of the melting of dead-ice blocks buried in the glacial deposits at the end of the Saalian Glaciation (Żarski 2020).

The Wola Starogrodzka site is located ca. 10 km north-east of Pilawa city (Text-fig. 1B). It lies within the valley of small periodically active watercourse (Text-fig. 1C). This depression was created at the end of the Late Saalian as a result of the melting a lump of dead ice (Żarski 2020). The length of this depression is about 1 km, and its width is up to 0.5 km.

During cartographic work for the updating of the Garwolin sheet of the Detailed Geological Map of Poland at a 1:50000 scale, more than 20 profiles with biogenic sediments of the Eemian Interglacial were identified in the Garwolin Plain (Żarski 2020). Around this region, only single sites with Eemian sediments have been previously documented, including Kletnia Stara (Żarski 1989), Wola Okrzejska (Żarski *et al*. 2005) and Kontrowers (Kupryjanowicz *et al*. 2003). This area is located in the south-eastern part of the zone with numerous Eemian sites (Bruj and Roman 2007; Kupryjanowicz *et al*. 2018c).



Text-fig. 1. Location of the study area (A), positions of the Wola Starogrodzka site and other localities of the Eemian Interglacial in the study area (B), and location of the boreholes made in the depression at the Wola Starogrodzka site (C). 1 – Puznówka (Żarski 2018), 2 – Kozłów (Żarski 2018; Pidek *et al.* 2021a; Suchora *et al.* 2022), 3 – Parysów (Żarski 2018), 4 – Struga (Żarski 2018; Bober *et al.* 2018; Zalat *et al.* 2021), 5 – Żabieniec (Żarski 2018; Pidek *et al.* 2021b), 6 – Jagodne (Żarski 2018; Pidek *et al.* 2021b; Bober *et al.* 2021), 7 – Góra Kalwaria (Sobolewska 1961), 8 – Kontrowers (Kupryjanowicz *et al.* 2003). G – profiles sampled with a Geoprobe vibracorer, PWS – profiles sampled with a Powerprobe vibracorer, WH – profiles sampled with a hydraulic probe, HP – profiles sampled with a hand probe.



Text-fig. 2. Aerial photo of the Wola Starogrodzka site with marked locations of drillings made in this basin. G – profiles sampled with a Geoprobe vibracorer, WH – profiles sampled with a hydraulic probe, PWS – profiles sampled with a Powerprobe vibracorer.

MATERIAL AND METHODS

Coring

The Wola Starogrodzka site was sampled with a Geoprobe and Powerprobe vibracorers as well as with hydraulic and hand probe (Text-figs 1C, 2, 3; drillings with the symbol G, PWS, WH and HP, respectively). In total, about twenty boreholes were made in different parts of the site. Based on the obtained cores, it was possible to determine the spatial distribution of fossil lacustrine sediments – they occur in three palaeobasins probably isolated from each other: western, central and eastern. Seven cores with palaeolake deposits (G-70, G-Wola, G-Star, G-123, PWS2-19, WH-70, WH-123) come from the eastern palaeobasin, four (G-122, G-122A, WH-122, HP-122) from the central one, and eleven (G-65, G-66, G-660, PWS1-19, WH-65, WH-66, WH-68, WH-113, WH-114, WH-115, WH-116) from the western one (Text-fig. 1C).

Core segments obtained as the result of drilling with a Geoprobe vibracorer were 1 m long and about 5 cm in diameter. Cores from hydraulic and hand probes were cut in the field into 5 cm thick slices and stored in plastic bags.

Pollen analysis

Pollen analysis was performed on 14 sediment profiles, including: 5 from the eastern, 2 from central, and 7 from western basin (Text-fig. 1C, Table 1). In the laboratory, 1 cm^3 samples were collected from the cores (in 1–2 cm intervals), and from the each of the large samples (5 cm thick), into which the some cores were cut in the field. Each sample was washed with hot 15% HCl, boiled in 10% KOH and finally treated by the Erdtman's acetolysis (Berglund and Ralska-Jasiewiczowa 1986). The minimum terrestrial pollen count was 1000 per sample. The nomenclature of pollen taxa is given according to Beug (2004).

No	Profile	Geographical coordinates	Elevation [m a.s.l.]	Number of samples	Stratigraphic resolution [cm]	Number of taxa
Eastern basin						
1	PWS2-19	52°00’05.6” N, 21°37’20.2” E	152.0	96	5–10	124
2	WH-123	52°00’05.7” N, 21°37’20.2” E	153.5	59	5–40	130
3	G-123	52°00’05.7” N, 21°37’20.3” E	153.5	9	4–16	61
4	G-70	50°00’02.4” N, 21°37’34.6” E	152.0	118	4–10	114
5	G-Star	52°00’04.6” N, 21°37’30.0” E	152.0	54	4–16	141
Central basin						
6	G-122	52°00’04.7” N, 21°37’12.1” E,	153.5	67	1–26	137
7	WH-122	50°00’05.3” N, 21°37’12.5” E	153.5	18	1–10	107
Western basin						
8	PWS1-19	51°59’59.4” N, 21°36’52.0” E	153.5	69	5–10	93
9	WH-65	51°59’55.2” N, 21°36’47.6” E	154.7	8	20	68
10	WH-66	51°59’59.4” N, 21°36’52.3” E	153.5	33	20–30	83
11	WH-113	51°59’55.2” N, 21°36’47.5” E	155.7	32	8	120
12	WH-114	51°59’59.4” N, 21°36’52.3” E	153.5	5	12	55
13	WH-115	51°59’59.3” N, 21°34’25.9” E	153.5	23	30–63	67
14	WH-116	51°59’57.0” N, 21°36’48.6” E	153.5	5	12	72

Table 1. Basic information about the pollen analyses performed for palaeolake sediments at the Wola Starogrodzka site. Profiles, the pollen of which diagrams are not included in this paper, are marked in grey (see text for more explanations).

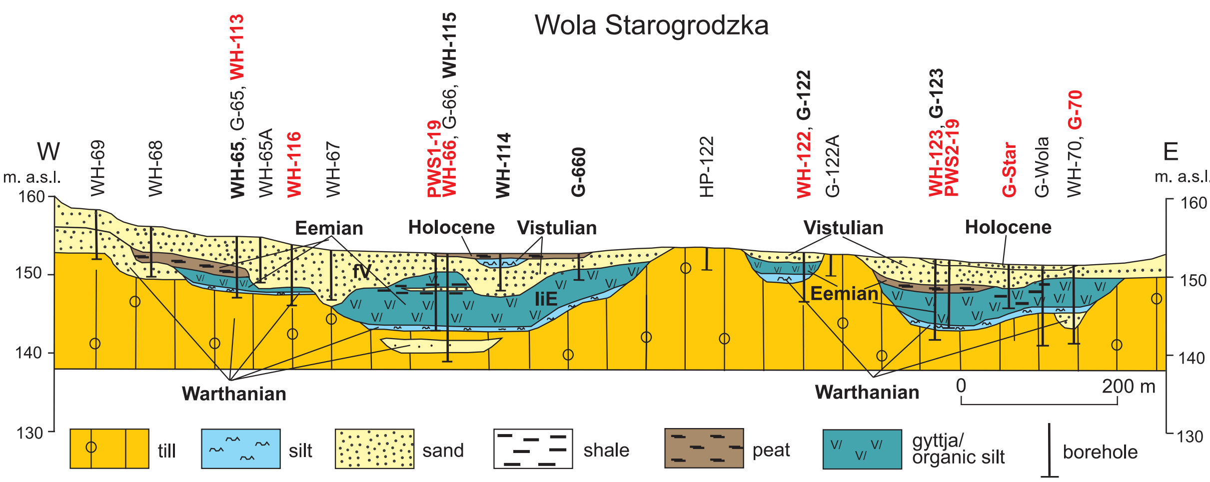
In total, 596 samples were studied by the pollen analysis method. The number of analysed samples and the stratigraphic resolution of pollen analysis vary between profiles (Table 1).

The percentage pollen diagrams were constructed using Polpal software (Nalepka and Walanus 2003). The diagrams included in this paper, due to their large number, have only a very simplified form (Text-figs 4–12). They show only the pollen curves of selected trees and shrubs as well as the percentage ratio of trees and shrubs (AP) and herbaceous plants and dwarf shrubs (NAP), which is sufficient to identify the record of the interglacial pollen succession, to determine the relative age of the studied sediments and to reconstruct the main changes in vegetation. More complete pollen diagrams from the most complete profiles presented in this paper will be shown in our subsequent works.

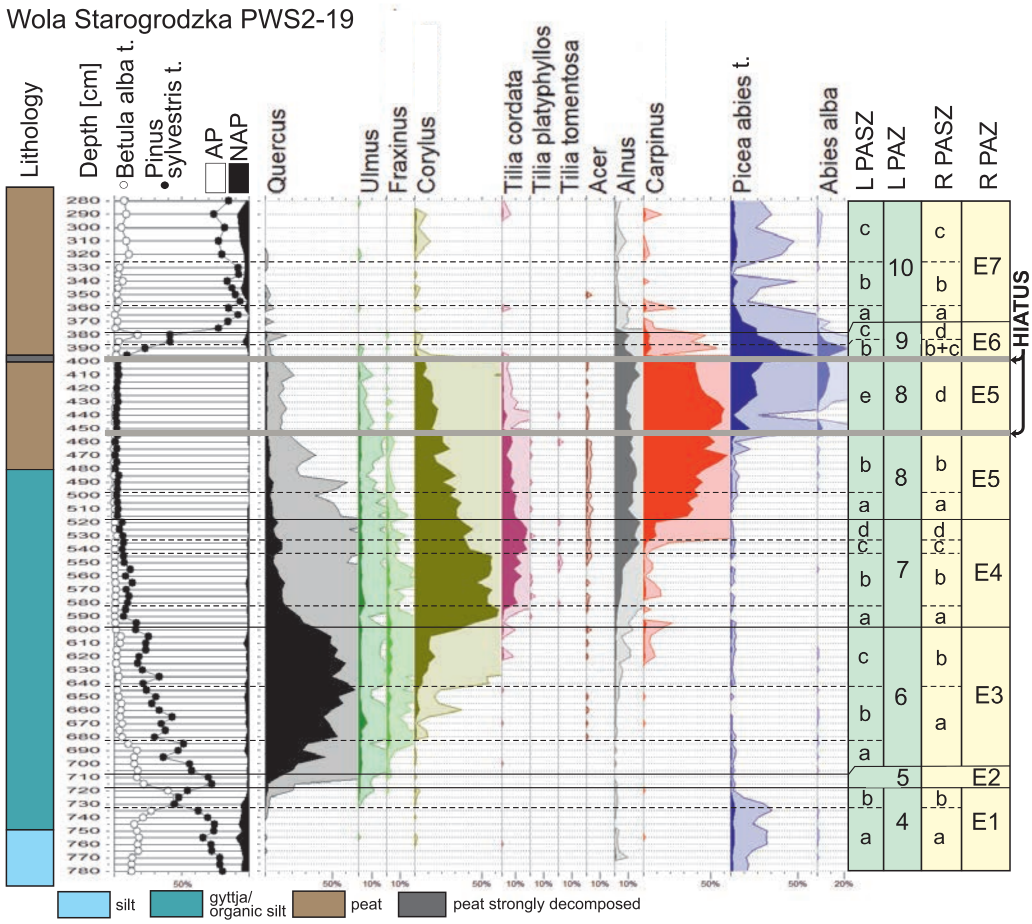
RESULTS

Lithology

Palaeolake sediments found at the Wola Starogrodzka site fill a vast depression in the Saalian (Warthanian, Odranian) till (Text-fig. 3). They are represented by Eemian gyttjas and organic silts



Text-fig. 3. Geological cross-section of the depression at the Wola Starogrodzka site; the names of the profiles presented in this article are marked in red, and the names of the other profiles analyzed palynologically – in bold.



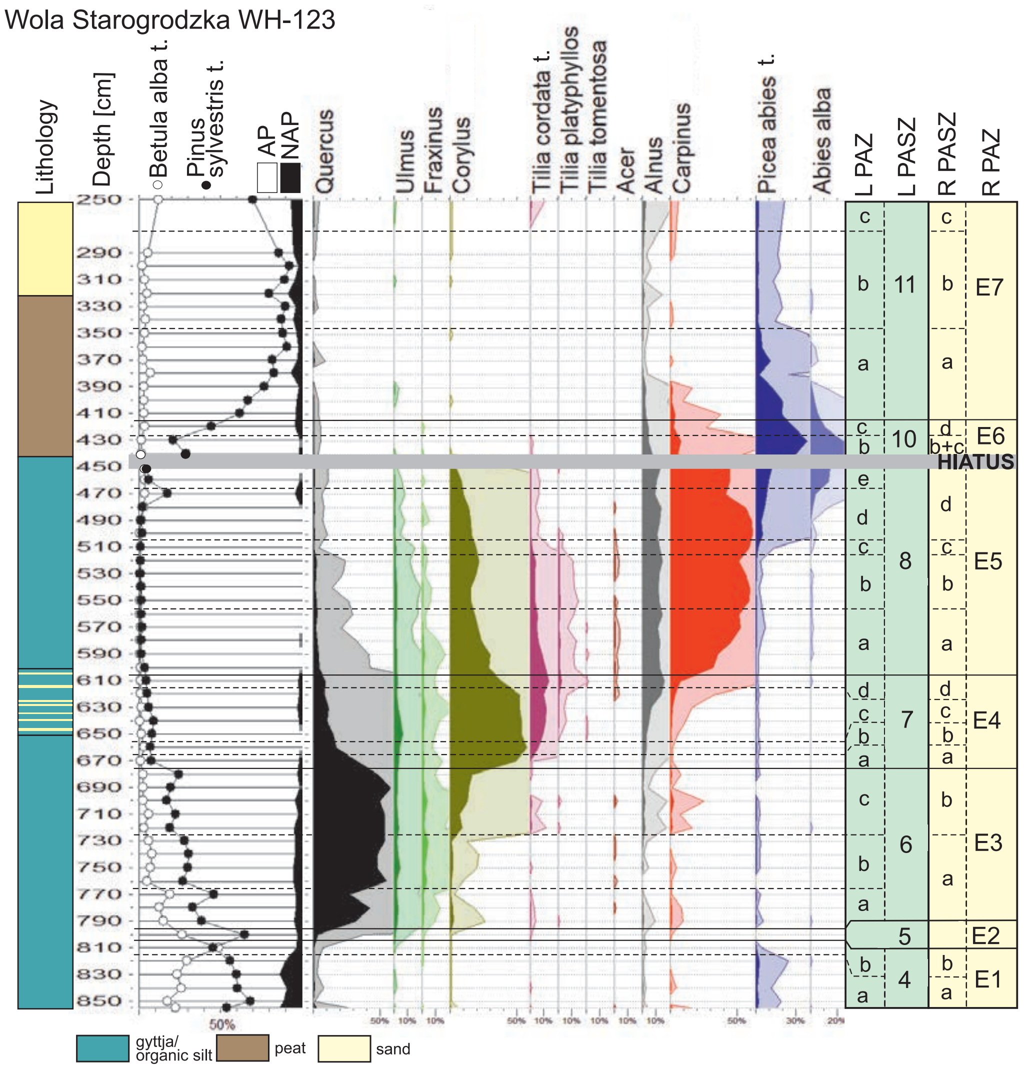
Text-fig. 4. Wola Starogrodzka PWS2-19 profile. Simplified pollen percentage diagram. Regional pollen assemblage zones (R PAZ) according to Mamakowa (1989), and subzones (R PASZ) according to Kupryjanowicz and Granoszewski (2018).

which are underlain by Warthanian silts or sands, and covered by Eemian peats, Vistulian sands and Holocene peats or sands.

Local palynostratigraphy

The local palynostratigraphy was developed on the basis of pollen data from 9 analysed profiles (Table 1). Pollen diagrams from the other 5 analysed profiles were not used in this work. The G-123 pollen profile turned out to be only a repetition of the short top section of the WH-123 profile. Profiles G-122 and WH-122 were published in an earlier paper (Kupryjanowicz *et al*. 2021). In order to present the complete pollen data from the Wola Starogrodzka site in the current work, only one of them, the more complete G-122 profile, is quoted here. Profiles WH-114 and WH-116 were developed only briefly, and their pollen records are very similar to that of the WH-65 profile, which is shown in Text-fig. 11. Also the pollen diagrams from profiles WH-66 and WH-115 are very similar to each other. Significant sediment disturbances were recorded in both of these profiles – younger pollen zones and subzones occur below the older ones. This makes it impossible to use these profiles for any paleoecological reconstructions. Thus, only one of them (WH-66 – Text-fig. 12) is shown in this work; at least in its top part, where the pollen record sequence characteristic of the Eemian Interglacial is preserved.

Each pollen diagram included to this paper was divided into local pollen assemblage zones (L PAZ) (Text-figs 4–12). Most of these zones were subdivided into subzones (L PASZ). Local pollen zones and subzones determined in individual profiles correlate well with each other. Due to the high similarity of the corresponding L PAZ and L PASZ registered in different profiles from the Wola Starogrodzka



Text-fig. 5. Wola Starogrodzka WH-123 profile. Simplified pollen percentage diagram. Explanations as in the Text-fig. 4.

site, we developed one unified local palynostratigraphy for this locality. Nine L PAZ and twenty seven L PASZ are distinguished in this collective palynostratigraphy (Text-figs 4–12). Table 2 contains their short descriptions, and Text-fig. 13 shows their occurrence in individual profiles.

The occurrence of the local palynostratigraphic units distinguished in individual profiles against the background of the regional pollen stratigraphy developed for the area of Poland by Mamakowa (1989) and then supplemented by Kupryjanowicz and Granoszewski (2018) is shown on Text-fig. 13. Not every one of the obtained pollen diagrams contain all the local palynostratigraphic units distinguished at the site. Sometimes this results from the presence of a sedimentation gap (hiatus), sometimes from too low stratigraphic resolution of the pollen analysis, and sometimes from the lack of sediments of the initial or final phase of the studied basin development (depending on the moment of the beginning or the end of biogenic sedimentation in this particular place).

Not in all profiles is the record of individual pollen zones and subzones complete and well developed. For this reason, a so-called type profile (or at most 2 profiles) has been selected for each local pollen zone. In such a profile, the pollen record of this zone is the best (the most complete and developed) among all studied profiles: for L PAZ-1, L PAZ-2 and L PAZ-3 it is the G-122 profile, for L PAZ-4, L PAZ-6 and L PAZ-7 – the PWS2-19 and WH-123 profiles, for L PAZ-5 – the G-122 and WH-113 profiles, for L PAZ-8 – the PWS1-19 profile, for L PAZ-10 – the G-Star profile,

L PAZ/L PASZ Number and Name	Description
12 *Pinus-Betula*-NAP	Domination of *Betula alba* t., following by domination of *Pinus sylvestris* t.; relatively high values of NAP (to 10%). The zone is divided into 2 subzones.
12b *Pinus*	High culmination of *Pinus sylvestris* t. (60-90%); *Betula alba* t. below 20%.
12a *Betula*	Peak of *Betula alba* t.; very low values of *Pinus sylvestris* t. (below 5%).
11 NAP	High frequency of NAP (to 50%); *Betula alba* t. values oscillating (5-20%); consequent decrease of *Pinus sylvestris* t.; still occurrence of single pollen grains of *Alnus*, *Carpinus*, *Quercus*, *Tilia cordata* t. and *Corylus – probably redeposited.*
10 *Pinus*	Absolute prevailing of *Pinus sylvestris* t. (50-90%). The zone is divided into 5 subzones.
10e *Pinus-Betula*	Depression in NAP proportion (ca. 10%); next peak of *Pinus sylvestris* t. (ca. 70%).
10d NAP	Culmination of NAP (20-35%).
10c *Betula*	Increase in frequency of *Betula alba* t. and NAP (to ca. 15% and 10%, respectively).
10b *Pinus*	High peak of *Pinus sylvestris t. (70-90%).*
10a *Pinus-Picea*	Rising proportion of *Pinus sylvestris* t. (to 60-80%); relatively high values of *Picea abies* t. and *Abies alba*.
9 *Picea-Pinus-Abies*	*Picea abies* t. domination (ca. 40%); values of *Pinus sylvestris* t. about 20%; increase of *Abies alba* to 10%; relatively high values of *Alnus* (ca. 10%); fall of *Carpinus* below 10%. The zone was divided into 2 subzones.
9b *Pinus*	Gradual fall of *Picea abies* t. and *Abies alba* frequencies; consequent increase in *Pinus sylvestris* t. values.
9a *Picea-Abies-Carpinus-Alnus*	Culminations of *Picea abies* t. and *Abies abies* (30-40% and 10-20, respectively); rather high proportion of *Carpinus* (to 25%) and *Alnus* (to 25%); relatively low values of *Pinus sylvestris* t. (to 15%).
8 *Carpinus-Corylus-Alnus*	Absolute domination of *Carpinus (35-70%); high values of Alnus* (to 22%); gradual decrease of *Corylus* to 10% and *Tilia cordata* t. to 1%; rise of *Picea abies* t. to 15% and of *Abies alba* to 15-17%; still very low proportion of *Pinus sylvestris* t. and *Betula alba* t. The zone is divided into 5 subzones.
8e *Picea-Abies*	High values of *Picea abies* t. (to 20%) and *Abies alba* (to 3%).
8d *Picea*	*Carpinus slightly lower than in previous subzone (35-50%); Alnus* similar as previously; further decrease of *Corylus*; *Tilia cordata* t., *Ulmus*, *Acer* and *Fraxinus* below 1%; clear increase of *Picea abies* t.; slight rise of *Abies alba*.
8c *Carpinus*	Maximum of *Carpinus* (50-70%); high values of *Alnus* (12-26%); further fall of *Corylus*; *Tilia cordata* t. generally below 1%; slight increase of *Picea abies* t.
8b *Corylus*	Proportion of *Corylus* similar as in the previous subzone, while values of *Tilia cordata* t. very lower than previously; relatively high values of *Alnus* (12-26%).
8a *Corylus-Tilia*	High values of *Corylus* (14-18%), *Alnus* (12-21%) and *Tilia cordata* t. (ca. 10%); occurrence of *Tilia platyphyllos* and *Tilia tomentosa*; increasing tendency of *Carpinus*.
7 *Corylus-Tilia-Alnus-Carpinus*	Absolute domination of *Corylus* (to 65%); high values of *Tilia cordata* t. (to 20%); regular occurrence of *Tilia platyphyllos* and *Tilia tomentosa*; rise of *Alnus* above 10%, and *Carpinus* above 5%; very low proportion of *Pinus sylvestris* t. and *Betula alba* t. The zone is divided into 4 subzones.
7d *Carpinus*	Further decrease of *Corylus*; rise of *Carpinus* to ca. 10-20%; still high values of *Tilia cordata t. and Alnus*.
7c *Tilia-Alnus*	Fall of *Corylus* to ca. 30-40%; culmination of *Tilia cordata* t.; increase of *Alnus* to ca. 20%.
7b *Corylus-Tilia*	Values of *Corylus* only slightly lower than in previous subzone; important increase of *Tilia cordata* t. (to 10%); fall of *Quercus* below 10%.
7a *Quercus*	Maximum of *Corylus*; high values of *Quercus* (to 20%); low frequency of *Tilia cordata* t. (below 2%).
6 *Quercus-Pinus*	Maximum of *Quercus* (50-70%) together with maximum of *Fraxinus* (5%); still presence of *Ulmus*; decreasing values of *Pinus sylvestris* t. and *Betula alba* t. The zone is divided into 3 subzones.
6c *Corylus*	Rise of *Corylus*; proportion of *Pinus sylvestris* t. significantly lower than in previous subzone.
6b *Pinus*	Still relatively high values of *Pinus sylvestris* t. (30-40%), but *Betula alba t. rapidly decreased below 10%.*
6a *Pinus-Betula*	Relatively high values of *Pinus sylvestris* t. (40-60%) and *Betula alba* t. (ca. 20%).
5 *Pinus-Betula-Quercus-(Picea)*	Increase of *Pinus sylvestris* t. to 60-70%; slight rise of *Quercus* and *Ulmus*; rather high values of *Betula alba* t. (to 35%); *Picea abies* t. below 1% and NAP generally below 5%.
4 *Betula-Pinus-Picea*	Culminations of *Pinus sylvestris t., and then Betula alba* t.; relatively high values of *Picea abies* t. and NAP. The zone is divided into 2 subzones.
4b *Betula*	Peak of *Betula alba* t. (50-60%); decreasing values of NAP; fall of *Picea abies* t. and *Pinus sylvestris* t.
4a *Pinus-Picea*	Peaks of *Pinus sylvestris* t. (70-80%) and *Picea abies* t. (3-12%); values of *Betula alba* t. between 10% and 20%; NAP below 10%.

L PAZ/L PASZ Number and Name	Description
3 NAP-*Betula-Pinus-Picea*	High values of NAP (10-25%); *Pinus sylvestris* t. slightly lower (40-60%), while *Betula alba* t. (5-20%) and *Picea abies* t. (2-10%) slightly higher than in previous zone. The complete record of the zone is noted only in the G-122 profile, where it is divided into 2 subzones. In remaining profiles only the uppermost section of 3b subzone is represented.
3b *Betula*	Increase of *Betula alba t. to ca. 30%; declines of* Betula nana t. and *Picea abies* t.
3a *Betula nana*	Relatively high proportion of *Betula nana* t. (to 5%) and *Picea abies* t. (to 5%).
2 *Pinus*-NAP	High values of *Pinus sylvestris* t. (65-92%); decline in NAP proportion below 10%. In the G-122 profile it is divided into 2 subzones.
2b *Pinus*	High culmination of *Pinus sylvestris* t. with maximum of 92%.
2a *Picea*	High peak of *Picea abies* t. (25%).
1 NAP-*Pinus-Betula*	High NAP values (to 30%); relatively high amount of redeposited pollen of thermophilous trees and shrubs (*Carpinus, Tilia cordata* t.*, Alnus, Corylus, Quercus*).

Table 2. Characteristics of the local pollen assemblage zones (L PAZ) and subzones (L PASZ) distinguished in the profiles from the Wola Starogrodzka locality; in stratigraphic order – from bottom up, as in the pollen diagrams (Text-figs 4-12).

for L PAZ-11 – the G-Star and G-70 profiles, and for L PAZ-12 – the G-70 profile (see Text-fig. 13). L PAZ-9 is very problematic, as it does not have a complete pollen record of the spruce phase (E6 R PAZ) in any of the examined profiles.

Age of the studied sediments

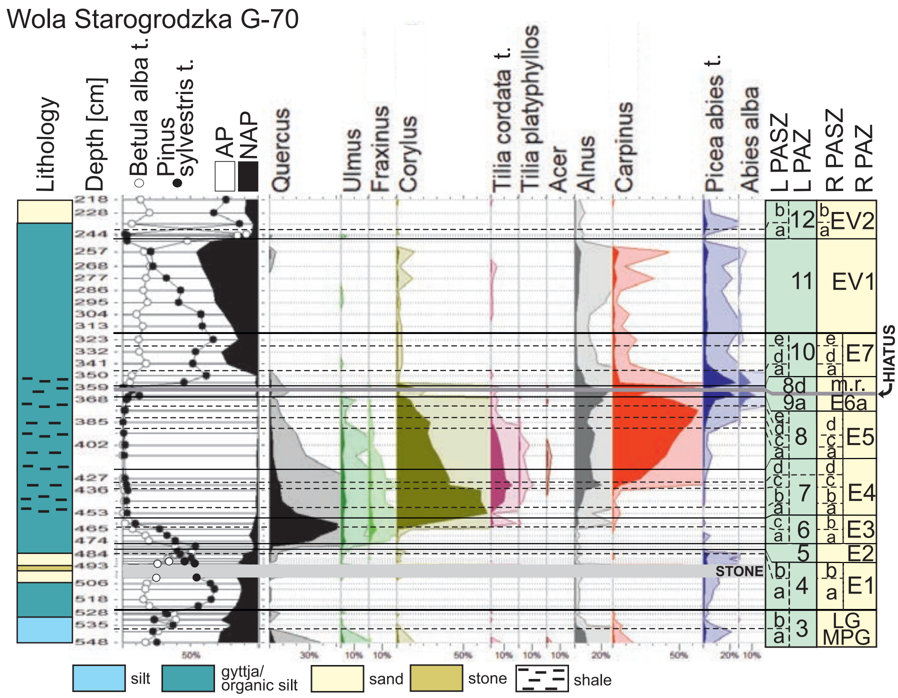
Seven local pollen assemblage zones determined in profiles at the Wola Starogrodzka site, from L PAZ-4 to L PAZ-10 (Text-figs 4–12), represent the interglacial succession of vegetation. Its typical features include: very high pollen values of *Corylus*, the expansion of trees and shrubs in particular sequence, i.e. *Betula–Pinus*, *Ulmus*, *Quercus–Fraxinus*, *Corylus*, *Alnus*, *Tilia*, *Carpinus*, *Picea* and a marked increase in the *Carpinus* pollen presence coupled with high co-occurrence of those of *Corylus*, that allows it unquestionably to be correlated with the Eemian Interglacial (see Mamakowa 1989). The Eemian local pollen assemblage zones and subzones from the analysed profiles correlate very well with the regional pollen zones and subzones distinguished for the area of Poland (Text-fig. 13). In three of the studied profiles (PWS2-19, G-70, WH-123), almost a complete palynological record of the Eemian succession of vegetation was recorded, and the local palynological units distinguished in these profiles represent (at least fragmentarily) all regional pollen zones of the last interglacial.

The bottom three local pollen zones, from L PAZ-1 to L PAZ-3, with a high percentage proportion of herbs and dwarf shrubs represent the late glacial directly preceding the Eemian Interglacial (Odranian, Warta Stage, Saalian, MIS-6).

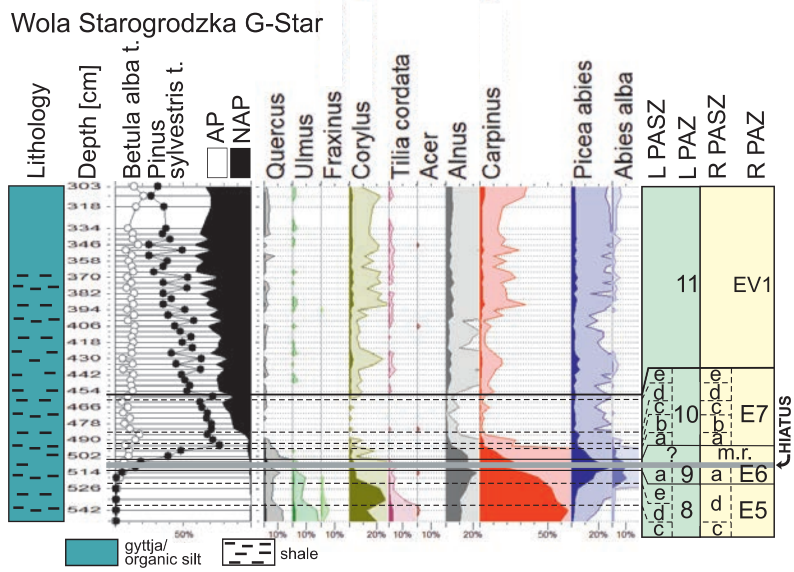
All three Late-Saalian pollen zones were distinguished only in the G-122 profile. Their pollen record reflects a change in climate from a cold (arctic) climate documented by L PAZ-1 (high NAP proportion), throughout a somewhat warmer climate recorded by L PAZ-2 (high values of *Pinus sylvestris* t. pollen, depression of NAP) to again a colder climate recognized by the L PAZ-3 (values of NAP are twice as high, and of *Pinus sylvestris* t. pollen are clearly lower than in L PAZ-2). This change represents the transition stadial-interstadial-stadial conditions during the Late Saalian (Kupryjanowicz *et al*. 2021).

For area of Poland, Mamakowa (1989) placed the Late Saalian/Eemian boundary at the fall in pollen values of herbs (NAP) and shrubs and the rise of *Pinus* pollen values with simultaneous relatively high values of *Betula* pollen. In our opinion, the Late Saalian/Eemian boundary defined in this way, falls in profiles at the Wola Starogrodzka site between L PAZ-3 and L PAZ-4. In some profiles (G-122, G-70, WH-123, PWS2-19, WH-113), above this boundary, the values of NAP remain above 10% until the beginning of the L PAZ-6 representing the oak phase of the Eemian (E3 R PAZ). Such a pollen record is typical for eastern and north-eastern Poland – similar high NAP values throughout the Early Eemian are also recorded, for example, at Szwajcaria (Borówko-Dłużakowa and Halicki, 1957) and Ludomirowo (Bitner 1957) as well as at some sites from the Garwolin Plain (I.A. Pidek, personal communication).

The uppermost two local pollen zones distinguished at the Wola Starogrodzka site (L PAZ-11 and L PAZ-12) represent the early glacial of the glaciation following the Eemian Interglacial (Weichselian, Vistulian). The L PAZ-11 with high proportion of non-arborescent pollen (NAP) corresponds to the Polish regional zone EV1 (Text-fig. 13) and represents the first post-Eemian cooling of the climate. It may be correlated with the German Herning stadial (Erd 1973; Menke and Tynni 1984, Behre and Lade 1986)



Text-fig. 6. Wola Starogrodzka G-70 profile. Simplified pollen percentage diagram. m.r. – redeposited material; other explanations as in the Text-fig. 4.

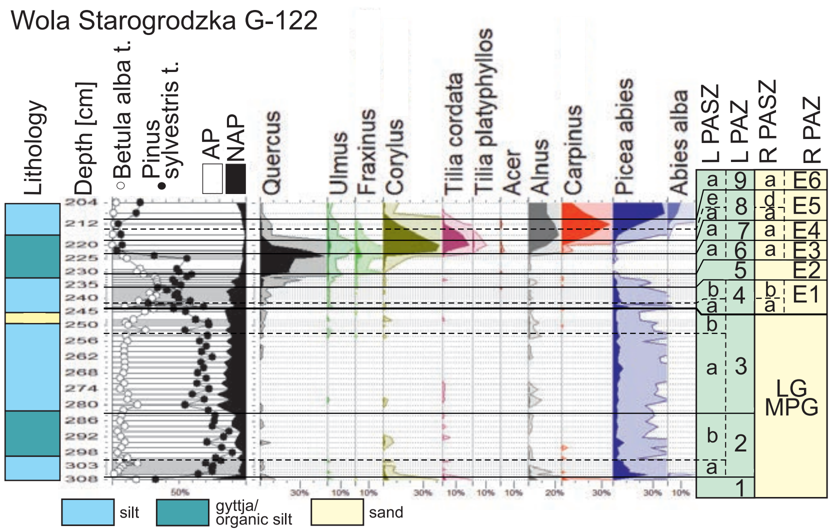


Text-fig. 7. Wola Starogrodzka G-Star profile. Simplified pollen percentage diagram. m.m. – mixed material of L PASZ-9b (from below hiatus) and L PASZ-10a (from above hiatus); other explanations as in the Text-fig. 4.

and MIS 5d. The L PAZ-12 characterised by high percentage values of pine and birch pollen represents the Polish regional zone EV2, which was correlated with the first interstadial of the Early Vistulian, i.e. German Brørup *sensu lato* (Erd 1973; Menke and Tynni 1984, Behre and Lade 1986) and MIS 5c.

Intra-Eemian hiatuses

Particularly noteworthy is the incompleteness in the pollen record of the Eemian vegetation succession registered in all studied profiles at Wola Starogrodzka (Text-fig. 13). The vast majority of sedimentary gaps



Text-fig. 8. Wola Starogrodzka G-122 profile. Simplified pollen percentage diagram. Explanations as in the Text-fig. 4. For more complete pollen diagram of this profile see Kupryjanowicz *et al*. (2021).

(hiatuses) occur in the spruce phase (L PAZ-9, E6 R PAZ) and cover it entirely (in the PWS1-19 profile; Text-fig. 9) or only its older (in the PWS2-19 and WH-123 profiles; Text-figs 4 and 5, respectively) or younger part (in the G-70 and G-Star profiles; Text-figs 6 and 7, respectively). Only in the profile PWS2-19 does this hiatus fall on a thin layer of highly decomposed peat occurring within the thicker layer of peat with a low degree of decomposition (Text-fig. 4, Table 2). In the remaining profiles, the hiatus does not manifest itself macroscopically in the lithology (Text-figs 4–11, Table 2).

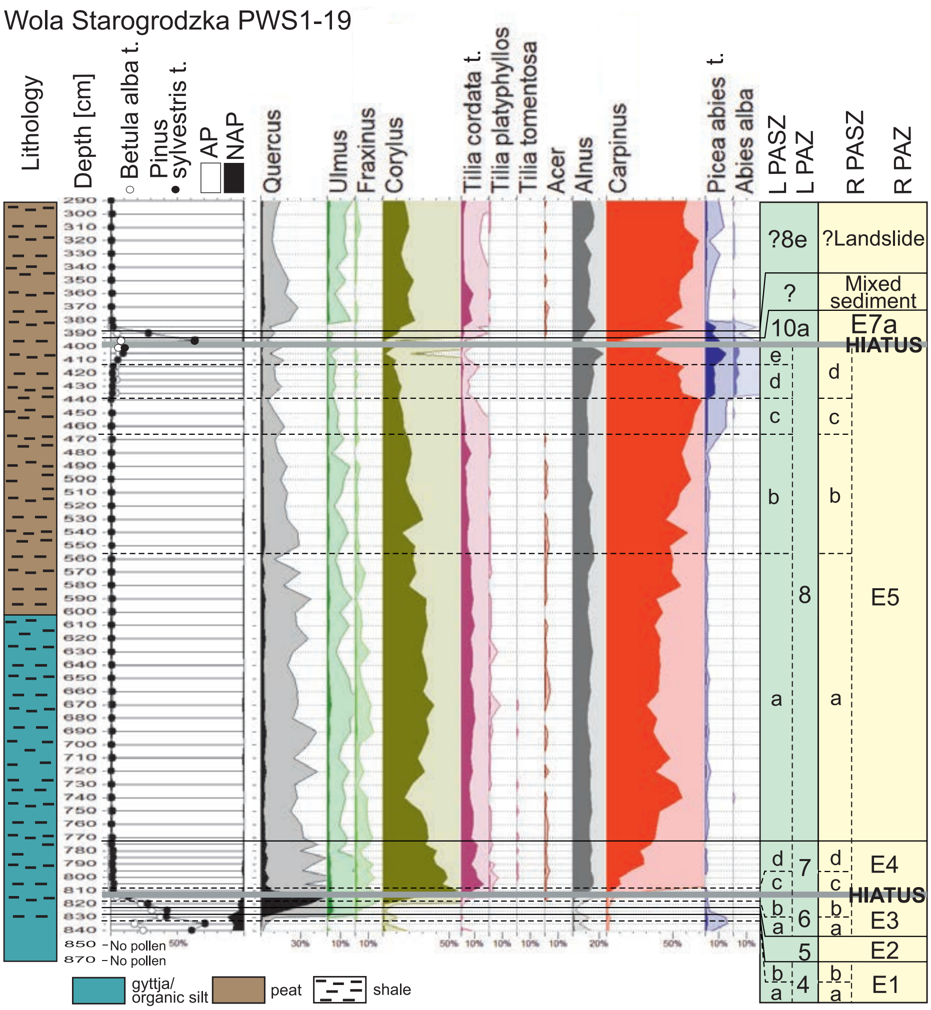
Hiatuses within the Eemian biogenic sediments were recognised also at some other sites in Garwolin Plain. They occur there most often at the E5/E6 R PAZ transition – examples of such hiatuses are in profiles at the site of Jagodne (Bober *et al*. 2021a) and Żabieniec (Pidek *et al*. 2022). Intra-Eemian hiatuses are also common in profiles in northern Podlasie and many other regions of Poland (Kupryjanowicz 2008, and references therein). However, in those regions they usually span the entire hornbeam phase of the Eemian (E5 R PAZ) or its younger part and older part of the spruce phase (E6 R PAZ). According to Kupryjanowicz (2008) these hiatuses are one of the effects of the lowering of the groundwater level at that time.

The causes of the hiatuses recorded in the individual profiles at the Wola Starogrodzka site and in the entire region of the Garwolin Plain will be analysed in more detail in our subsequent articles devoted to the evolution of paleolakes occurring at this site.

DISCUSSION

Late Saalian (Warta Stage, Odranian, MIS 6)

Pollen data for the reconstruction of changes in vegetation around Wola Starogrodzka during the Late Saalian (Warta Stage, Odranian, MIS-6) are taken mainly from the profile G-122 (Text-fig. 8; see Kupryjanowicz *et al*. 2021 for its extended version). Three stages of these changes were determined. The first stage (L PAZ-1) was of stadial character, with open vegetation indicating rather low temperatures during both warm and cold months. During the second stage (L PAZ-2), being slightly warmer than the previous one and correlated with the Zeifen Interstadial (Jung *et al*. 1972; Seidenkranz *et al*. 1996), boreal pine-birch forest with admixture of spruce and alder developed around the studied locality. The youngest stage (L PAZ-3) was the stadial corresponding to the Kattegat Stadial (Seidenkranz 1993; Seidenkranz *et al*. 1996), when the forest communities were slightly reduced in their area or the pollen production of the trees forming these communities decreased, and climatic conditions were similar to those occurring during the earlier stadial represented by L PAZ-1. Vegetation dynamics during the three stages of the Late Saalian were characterised by alterations of the proportion of the area occupied by forest and open plant communities, at the same time the floristic composition of the plant cover did not change radically (Kupryjanowicz *et al*. 2021). In



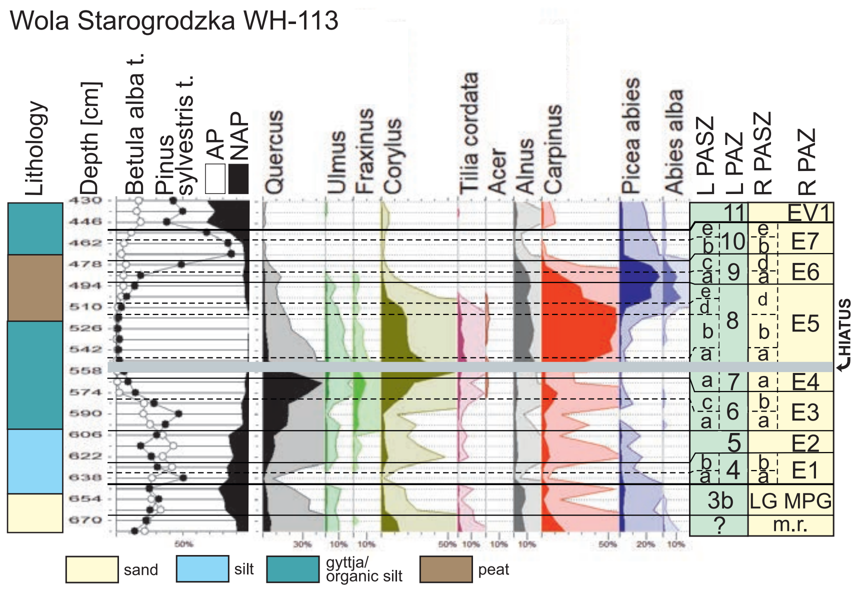
Text-fig. 9. Wola Starogrodzka PWS1-19 profile. Simplified pollen percentage diagram. Explanations as in the Text-fig. 4.

addition to pine and birch, spruce was a very important component of Late Saalian plant communities. It appeared in the studied area at the beginning of the Zeifen Interstadial, and then survived the cooling during the Kattegat Stadial, although this caused a marked reduction in its area.

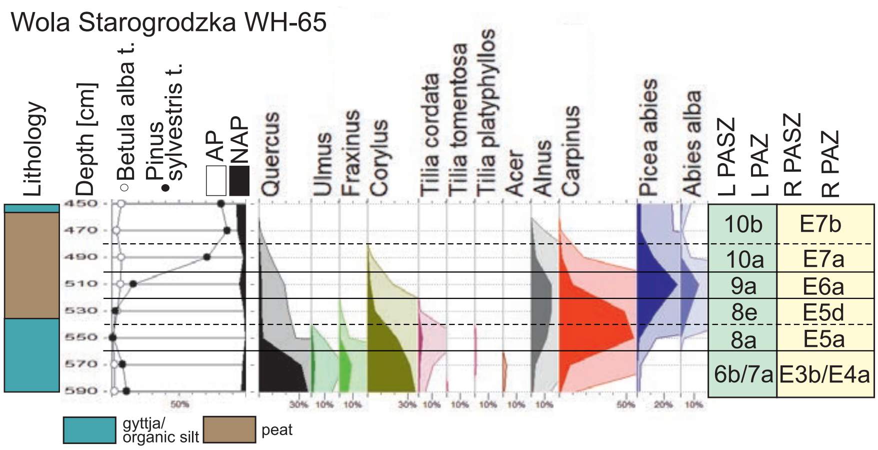
Eemian Interglacial

Due to the high-resolution pollen record of the L PAZ-6 (E3 R PAZ) in the PWS2-19 and WH-123 profiles (Text-figs 4 and 5, respectively) and L PAZ-8 (E5 R PAZ) in the PWS1-19 profile (Text-fig. 4) providing new information on the vegetation succession in Central Poland during the oak and hornbeam phases of the Eemian Interglacial, only these two periods will be described in more detail. Other phases of the Eemian, of which the pollen record at the Wola Starogrodzka site is less developed or has been recognized with a low stratigraphic resolution, will be dealt with only in token.

Pine-birch phase (L PAZ-4, E1 R PAZ): Already during the initial phase of the Eemian Interglacial, forests again spread widely around the Wola Starogrodzka site (high AP values). However, their species composition was very poor. Pine played the leading role and absolutely dominated in the forests during the older part of this phase (high values of *Pinus sylvestris* t. pollen in the L PASZ-4a). Instead during its younger part (L PASZ-4b), birch became of great importance in the forest structure (high proportion of *Betula alba* t. pollen). Perhaps purely birch forests developed. These must certainly have been



Text-fig. 10. Wola Starogrodzka WH-113 profile. Simplified pollen percentage diagram. m.r. – material redeposited. Explanations as in the Text-fig. 4.



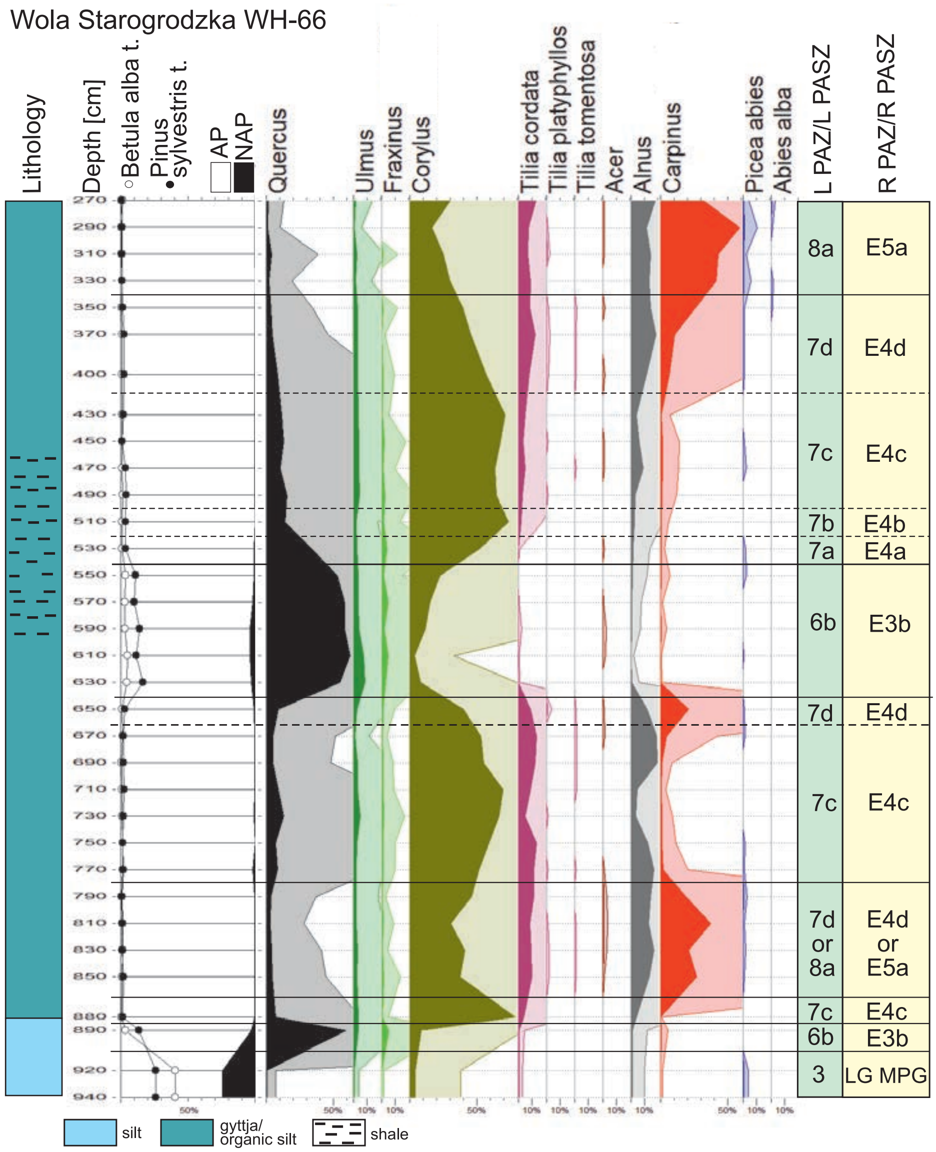
Text-fig. 11. Wola Starogrodzka WH-65 profile. Simplified pollen percentage diagram. Explanations as in the Text-fig. 4.

scattered and sunlit communities of the birch swamp wood type; today similar phytocoenoses occur in the north-western Europe (Matuszkiewicz 2001).

The regular occurrence of *Picea abies* t. pollen in all pollen spectra of the L PAZ-4 suggests that spruce was a component of some stands during the whole initial phase of the Eemian Interglacial. Its presence at that time is a characteristic feature of north-eastern Poland (e.g. Kupryjanowicz 2008), Belarus (e.g. Shalaboda 2001) and Lithuania (e.g. Seiriene *et al.* 2014). It was probably Siberian spruce (*Picea obovata*), whose cones were found in the bottom of Eemian sediments at the Szwajcaria site (Borówko-Dłużakowa 1975) and at several Belarusian localities (e.g. Bremówna and Sobolewska 1950; Środon 1950).

Despite the spread of forest area, it seems that, especially in the older part of the phase (L PASZ-4a), open communities of herbaceous plants still played an important role in the landscape (relatively high proportion of NAP).

Pine-birch-oak phase (L PAZ-5, E2 R PAZ): Rapidly expanding pine became a dominant tree taxon in woodland communities in most of the area around the Wola Starogrodzka site (high peak of



Text-fig. 12. Wola Starogrodzka WH-66 profile. Simplified pollen percentage diagram illustrating disorders of sediments in the lower part of the profile (below the depth of 630 cm). Explanations as in the Text-fig. 4.

Pinus sylvestris t. pollen within the L PAZ-5 in the PWS2-19, G-122, G-70 and WH-123 profiles), where it occurred together with birch. However, in some places, birch has retained its importance in the tree stand (L PAZ-5 with high values of *Betula alba* t. pollen in the PWS1-19 and WH-113 profiles). Elm, oak and ash started to occupy some habitats. Generally, a further decline in the area of open herb and shrub plant communities took place. The high values of NAP are noted for this phase only in the WH-113 pollen profile (Text-fig. 10). They are chiefly connected with the increase in Cyperaceae pollen frequency and are related probably with local expansion of waterlogged habitats in this part of the lake.

Oak phase (L PAZ-6, E3 R PAZ): In many Polish sites, the pollen record of the oak phase (E3 R PAZ) is recorded in sediments of small thickness, and in some profiles there are hiatuses covering a significant part of this phase (e.g. in Starowlany and Choroszczewo profiles in northern Podlasie – Kupryjanowicz 2008). Against this background, two profiles from Wola Starogrodzka, PWS2-19 and WH-123, which are characterized by a large

	Poland (R PAZ and R PASZ)		Wola Starogrodzka (L PAZ and L PASZ) PWS2-19		G-70		WH-123		G-Star		G-122		PWS1-19		WH-65		WH-113	
EW	EV2 *Pn-Be*	EV2b *Pn*			12b	12												
		EV2a *Be*			12a													
	EV1 Po-*Ar-Bn*				11				11								11	
Eemian Interglacial	E7 *Pn*	E7e *Pn-Be*			10e				10e								10e	
		E7d NAP			10d				10d								*	
		E7c *Be*	10c		*	10	10c		10c	10							*	10
		E7b *Pn*	10b	10	*		10b	10	10b						10b		10b	
		E7a *Pn-Pc*	10a		10a		10a		10a				10a		10a	10	*	
	E6 *Pc-Ab-Al*	E6d *Pn*	9c		Hiatus		9c		Hiatus				Hiatus		*		9c	
		E6c *Pc*	9b	9			9b	9							*	9	*	9
		E6b *Pc-Ab*																
		E6a *Pc-Cr*	Hiatus		9a	9	Hiatus		9a	9	9a	9			9a		9a	
	E5 *Cr-Co-Al*	E5d *Cr-Pc*	8e		8e		8e		8e		8e		8e		8e		8e	
			Hiatus		8d		8d		8d	8	*		8d		*		8d	
		E5c *Cr*		8	8c	8	8c	8	8c		*	8	8c	8	*	8	*	8
		E5b *Cr-Co*	8b		*		8b				*		8b		*		8b	
		E5a *Cr-Co-Ti*	8a		8a		8a				8a		8a		8a		8a	
	E4 *Co-Qu-Ti*	E4d *Cr-Ti* (reg.)	7d		7d		7d				*		7d		*		Hiatus	
		E4c *Ti-Ta*	7c	7	7c	7	7c	7			*	7	7c	7	*	7		
		E4b *Co*	7b		7b		7b				*		Hiatus		*			
		E4a *Qu-Ul-Fr-Ti* (reg.)	7a		7a		7a				7a				?7a		7a	7
	E3 *Qu-Fr-Ul*	E3b *Co*	6c		6c		6c				*				?6c	6	6c	
		E3a *Pn*	6b	6	*	6	6b	6			*	6	6b	6			*	6
			6a		6a		6a				6a		6a				6a	
	E2 *Pn-Be-Ul*		5		5		5				5		5				5	
	E1 *Pn-Be*	E1b *Be*	4b	4	4b	4	4b	4			4b	4	4b	4			4b	4
		E1a *Pn*	4a		4a		4a				4a		4a				4a	
LS	LG MPG				3b	3					3b	3					3b	3
					3a						3a							
											2b	2						
											2a							
											1							

Text-fig. 13. Correlation of the local pollen assemblage zones (L PAZ) and subzones (L PASZ) distinguished in profiles from the Wola Starogrodzka site with regional pollen assemblage zones (R PAZ) (acc. to Mamakowa 1989) and subzones (R PASZ) (acc. to Kupryjanowicz and Granoszewski 2018) determined for the area of Poland. *Ab – Abies*, *Al – Alnus*, *Ar – Artemisia*, *Be – Betula*, *Bn – Betula nana*, *Co – Corylus*, *Cr – Carpinus*, *Fr – Fraxinus*, *Hi – Hippophaë*, *Ju – Juniperus*, NAP – no arborescent pollen, *Pc – Picea*, *Pn – Pinus*, Po – Poaceae, *Qu – Quercus*, red. – redeposited pollen, reg. – regionally, *Ta – Taxus*, *Ti – Tilia*, *Ul – Ulmus*; * – no pollen record due to the low resolution of pollen analysis (not due to hiatus); LS – Late Saalian (in Poland: Late Odranian or Warta Stage), EW – Early Weichselian (in Poland: Early Vistulian), LG MPG – Late Glacial of the Middle Poland Glaciation. Gray – the presence of a particular local pollen zone or subzone in the profile; dark gray – the presence of a particular local pollen zone with pollen record the most complete and developed among all profiles.

thickness of this zone (1.05 m and 1.15 m, respectively), stand out as really exceptional. Thanks to this, within L PAZ-6 correlated with E3 R PAZ, it was possible to perform pollen analysis with a high stratigraphic resolution and to divide this zone into 3 subzones. Thus, a reconstruction more precise than before of vegetation changes in Central Poland during the oak phase of the Eemian Interglacial was carried out – the three-stage nature of these changes was documented.

Oak dominated in terrestrial habitats throughout the E3 phase. According to Granoszewski (2003), these trees grew mainly in fertile wetlands at that time, forming multi-species riverine forests similar to the modern *Ficario–Ulmetum* association (Matuszkiewicz 2001). These communities probably did not only occupy river valleys (as did those in the Holocene), but also floodplain terraces.

During the oldest part of this phase (L PASZ-6a), oak consistently expanded its acreage in wetlands. In much drier habitats pine and pine-birch woods still persisted in the vicinity of Wola Starogrodzka (relatively high proportion of *Pinus sylvestris* t. and *Betula alba* t. pollen), which had dominated here during the previous phase. Beside pine and birch, spruce formed their tree stands (the occurrence of *Picea abies* t. pollen). Forest of this type gradually disappeared at that time and its closing stage is well documented by a clear decrease in the percentage values of birch and pine pollen at the transition of the L PAZ-6a and L PASZ-6b subzones. Moreover, pine together with oak could build forests similar to the contemporary *Querco roboris–Pinetum* association (cf. Matuszkiewicz 2001). It seems they occupied sandy soils on washed out areas that were most conspicuous in the region.

At the top of the L PASZ-6a subzone, a depression in the *Quercus* pollen and a simultaneous peak of *Pinus sylvestris* t. pollen are registered. This record may reflect some short climate fluctuation related to change in temperature (?cooling) or solely in humidity (?drying out). It cannot be excluded that they illustrate changes interrelated with the switch of generations in mature oak-pine forests (see Kupryjanowicz 2008, pp. 77–79 and references therein).

As the pollen record of L PASZ-6b (Text-figs 4, 5) suggests, during the middle part of the oak phase, oak consistently spread not only in wetlands, but also in much drier habitats, where it won the competition with pine (gradual increase of *Quercus* and decrease of *Pinus sylvestris* t. pollen). *Fraxinus* and *Ulmus* were important trees – they grew together with oak in riverine forests at that time, reaching their maximal development within the Eemian Interglacial. The great increase in pollen proportion of *Quercus* coupled with the simultaneous drop in values of *Pinus sylvestris* t. and *Betula alba* t. points out a surge in oak significance in forest assemblages which subsequently resulted in habitats previously occupied by pine being overtaken by this species. That constituted a continuation in changes that were noticed for the previous subzone. It resulted in furthermost oak spreading during the Eemian Interglacial.

In the youngest part of the oak phase (L PASZ-6c), the rapid spread of hazel took place (increase in values of *Corylus* pollen) which gave rise to a large-scale reconstruction of forest communities in the direction of lime-hornbeam woods. The appearance of *Corylus avellana* in forests around Wola Starogrodzka in the youngest part of the oak phase (L PASZ-6c) points out the beginning of large-scale and long-term renewal of forest communities that went on throughout the entire next phase.

Throughout the oak phase, open vegetation covered a very small area around Wola Starogrodzka.

Hazel phase (L PAZ-7, E4 R PAZ): The expansion of hazel, which probably built dense homogenous thickets and/or short-stemmed forests, led to a change in deciduous forest structures and limited oak area. Patches of woodland with oak and elm probably overgrew only the places where ground water restricted the existence of hazel (cf. Granoszewski 2003).

Four steps can be distinguished in the vegetation succession during the hazel phase. In the forests of the first subphase (L PASZ-7a), oak was still of great importance, while lime was not yet present. During the next subphase (L PASZ-7b), alder spread in the wetlands, while lime became a subdominant in mixed deciduous forests formed mainly by hazel. Apart from *Tilia cordata*, also *Tilia tomentosa* and *Tilia platyphyllos* grew as an admixture in these communities. Then (L PASZ-7c), both lime and alder reached the maxima of their interglacial distribution, and the importance of hazel decreased somewhat. Finally, at the end of the hazel phase (L PASZ-7d), hornbeam appeared in the forests and quickly gained in importance. This was mainly at the expense of the hazel, while the lime retained its current acreage. The alder area did not change at that time.

In almost all profiles from Wola Starogrodzka, we noted the presence of *Tilia tomentosa* pollen, similarly as in profiles from numerous other Polish sites (Kupryjanowicz *et al*. 2018b, and reference therein). This proves that silver lime, whose northern limit of range is now in southeastern Europe, during the Eemian Interglacial occurred in Central Europe. So, there is a high probability that also some currently south-European species of the genera *Fraxinus*, *Corylus* and *Carpinus* could grow here together with silver lime.

Hornbeam phase (L PAZ-8, E5 R PAZ): The L PAZ-8 local pollen zone was divided in the profiles from Wola Starogrodzka into four sub-zones, which represent subsequent stages of vegetation development; each of them was characterised by only slightly different edaphic and climatic conditions.

In the oldest sub-phase (L PASZ-8a), rapidly expanding hornbeam, which might have established pure stands in most areas, replaced the greater part of communities with hazel and lime. Despite that, both these species were a quite important component of forests until the end of the sub-phase. Alder still occupied damp and moist habitats, from which it displaced other trees with high moisture requirements already at the end of the hazel phase. Due to this, riverine woodlands with oak, ash and elm occupied only very small areas.

In the next sub-phase (L PASZ-8b), hazel still remained a rather important component of forests dominated by hornbeam, while the occurrence of lime was clearly limited, probably mainly due to the slight decrease in temperatures and increase in moisture, which resulted in the appearance of spruce. Nevertheless, small-leaved lime was still quite a component of forests, and was accompanied by *Tilia platyphyllos* and *Tilia tometosa*. The role of elm and oak was less significant than in the previous period, while the role of alder carrs grew slightly (higher pollen values of *Alnus*). This also points to an increase in moisture at that time. *Abies alba* occurred for the first time in stands. Forest density was the highest in the whole of the interglacial (the deep depression in values of NAP).

At the beginning of the third sub-phase (L PASZ-8c), the hazel area was visibly restricted, and then its further gradual reduction took place. Hornbeam reached its interglacial maximum. There was a small increase in the area of spruce. The role of lime was much less significant than in the previous sub-zone, but it was constantly present in forests as an admixture. The area covered by alder carrs was still large.

In the fourth part of the hornbeam phase (L PASZ-8d), the role of forests dominated by hornbeam decreased slightly. There was a further decrease in the area of hazel. Lime, elm and ash disappeared from local forest stands. Alder carrs still prevailed in wetland habitats. Spruce and fir was slightly more frequent in wood stands than before.

During the last subphase of the hornbeam phase (L PASZ-8e), spruce and fir significantly expanded their areas, but despite this, hornbeam remained the dominant tree.

Vegetation changes recognised at the Wola Starogrodzka site indicate a gradual decrease in temperature and simultaneous slow increase in humidity during the hornbeam phase of the Eemian Interglacial. These were processes typical of the post-optimal part of all the Pleistocene interglacials (cf. Iversen 1964; Andersen 1966, 1994; Birks and Birks 2004). There is no evidence in the pollen record for a cold oscillation of the climate at that time, similarly to some other sites of the Garwolin Upland (e.g. Pidek *et al*. 2021b) and northern Podlasie (e.g. Kupryjanowicz *et al*. 2018a).

Spruce-pine-fir phase (L PAZ-9, E6 R PAZ): An expansion of boreal forest composed mainly of spruce, pine and fir replaced the hornbeam forests. These processes were probably induced by environmental changes typical of the post-optimal part of the interglacial (cf. Iversen 1964; Andersen 1966, 1994; Birks and Birks 2004). Fir and spruce reached their maximal spread during the Eemian Interglacial. Fir role in forest stands of the Wola Starogrodzka region, like in the whole of Central Poland (Mamakowa 1989), was very important, which is documented by the high percentage value of *Abies alba* pollen. Nonetheless, patches of hornbeam woodlands were still present in the landscape.

The slight increase in the percentage values of herb pollen (NAP) points to the formation of places with relatively good light conditions under canopies.

Pine phase (L PAZ-10, E7 R PAZ): The pine zone (E7 R PAZ) represents the latest stage of the Eemian succession of vegetation. The increase in humidity and further cooling of the climate resulted in the change of habitat quality and the character of plant communities as well. Pine became the dominant tree. It formed thick boreal forests, probably diversified into different types of communities. The expansion of pine forests was prompted by the decline of all other types of forest communities. The steady and relatively high values of *Picea abies* t. pollen indicate that spruce played a major role in the forest community. The alder carrs finally disappeared. They were most likely replaced by marshy pine forests or spruce forests.

Early Vistulian (Weichselian)

Herning stadial (L PAZ-11, EV1 R PAZ): The increase in landscape openness triggered the spread of open plant communities. The pollen spectra failed to reflect a gradual cool shift demonstrated by a progressive rise in NAP and fall in *Pinus sylvestris* t. As regards tree species, only pine and birch were possibly present at that time, which is exhibited by continuous pollen curves of these trees. They most likely formed small patches in otherwise open plant communities. It is noteworthy that the pollen of *Alnus*, *Carpinus*, *Tilia cordata* t. and *Corylus* was probably transported for a long distance from the south and/or redeposited from older Eemian deposits occurring in the peripheral zone of the studied palaeolake, which were eluted due to fluctuations in the lake water level. The pollen record of the Herning stadial vegetation registered in the Wola Starogrodzka profiles is typical for this stadial recognised in various regions of Poland (Jastrzębska-Mamełka 1985; Mamakowa 1989; Kupryjanowicz 2008).

Brørup interstadial (L PAZ-12, EV2 R PAZ): At the Wola Starogrodzka site, the pollen record of the Brørup interstadial is limited to 6 pollen spectra in the G-70 profile (Text-fig. 6). This allows only very general remarks concerning the vegetation of that period in the studied area, and does not reflect the complex climate and vegetation changes of this interstadial documented in many European profiles, including from Poland (e.g. Jastrzębska-Mamełka 1985; Mamakowa 1989; Granoszewki 2003; Kupryjanowicz 2008; Kupryjanowicz *et al.* 2021), Germany (e.g. Erd 1973; Behre 1989; Hahne *et al*. 1994; Müller *et al*. 2003), France (e.g. Reille *et al*. 1992), and Sweden (e.g. Robertsson 1988).

At that time the dominant community around Wola Starogrodzka was boreal forest resembling today's taiga. The vegetation succession of the Brørup interstadial can be here divided into two parts. During the older part of the interstadial (L PASZ-12a), this area was occupied by tree birches, which is expressed by rapid rise in values of the *Betula alba* t. It is possible that they formed clusters of parkland-steppe being scattered in otherwise open vegetation, though the existence of denser birch forests should not be excluded which in turn is suggested by very low NAP proportion. The area covered with open communities considerably diminished.

In the younger part of the Brørup interstadial (L PASZ-12b), after the most prosperous time for birch presence, forest communities transformed into pine-birch assemblages, a tendency being accentuated by Scots pine dominance. Larch and spruce reappeared becoming relatively important elements of pine-birch forests in the region. A very high proportion of trees and shrubs (95–98%) would support both forests with remarkable closeness of canopy, as well as no-forest communities, occupying quite limited areas at that time. The regular occurrence of *Picea abies* t. pollen suggest the presence of spruce and larch in those forests. The role of open plant communities was still insignificant.

SUMMARY

Pollen analysis was performed on 14 profiles of palaeolake sediments collected in different parts of the vast depression located near the village of Wola Starogrodzka in the Garwolin Plain (Central Poland). Based on pollen data, the time of accumulation of these sediments was defined as the period from the end of the Odra Glaciation (Warta Stage, Late Saalian, MIS-6), through the Eemian Interglacial (MIS-5e), to the first interstadial of the Early Vistulian (Early Weichselian, MIS-5c). Particularly noteworthy is the incompleteness in the pollen record of the Eemian Interglacial noted in almost all the studied profiles. The sedimentation gaps (hiatuses) usually cover the various parts of the spruce phase (E6 R PAZ).

Only in four of the studied profiles (PWS2-19, G-70, WH-123, WH-113) was the palynological record of the almost complete Eemian succession of vegetation registered. However even in these profiles, there are hiatuses, and some local palynological subzones represent regional pollen zones of the last interglacial only fragmentarily. Therefore, in order to reconstruct the complete Eemian succession of vegetation in the area of Wola Starogrodzka, it was necessary to create a compiled pollen profile consisting of the well-developed and complete local zones and subzones originating in various profiles. The very extensive pollen record of the E3 R PAZ included in the PWS2-19 and WH-123 profiles allowed the documentation of 3 stages of changes in vegetation during the oak phase of the Eemian, while transformations in plant cover during the hornbeam phase could be reconstructed in detail only from the pollen record of E5 R PAZ in the PWS1-19 profile. So, when the pollen record in a single profile is incomplete and/or poorly developed, it is good to have several profiles from the same locality – then the deficiencies existing in individual profiles can compensate for each other.

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Author contributions

M. Kupryjanowicz was an author of the article concept as well as text and figures outline. The sediment cores were collected, described and interpreted by M. Żarski. Samples for pollen analysis were macerated by E. Żuk-Kempa. Pollen analysis was carried out mostly by M. Fiłoc, and partly by M. Kupryjanowicz. Pollen diagrams was performed by M. Fiłoc and M. Kupryjanowicz. All authors contributed in the discussion and interpretation of the results as well as working with the text of the manuscript. I confirm that all authors have approved the final version of the manuscript.

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