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Aspects of Weichselian Middle Pleniglacial stratigraphy and vegetation in central Poland

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Abstract

The basal member of the Piaski Formation in the Bełchatów outcrop of central Poland was deposited between 43 700 and 27 000 BP. It consists mostly of lacustrine deposits. Its lower part contains several organic layers, fluvial sands and slope deposits. Radiocarbon-dating places the organic horizons in the Moershoofd and Denekamp Interstadials. The first of these interstadials was probably characterized by forest-tundra or scrub-tundra conditions, but this needs to be confirmed since the analysed material may represent redeposited pollen. The Denekamp Interstadial was characterized by grass tundra (34 000–31 000 BP) and finally by discontinuous tundra of the subpolar desert (31 000–27 000 BP).

Introduction

Climatic conditions of the Weichselian (= Vistulian) Middle Pleniglacial in Poland are not known in detail. Their reconstruction is mainly based on permafrost indicators (Dylik 1969, Goździk 1973) or sedimentary features (Turkowska 1988, Krzyszkowski 1990, 1991a). Palynological data are available from a few sites only (Rotnicki & Tobolski 1969, Kozarski 1981, Baraniecka 1980, Pazdur et al. 1980, Manikowska & Balwierz 1987). Relatively mild conditions with birch forest are assumed for the period 45 000–41 000 BP (Pazdur et al. 1980) and scrub tundra for the period around 31 000 BP (Rotnicki & Tobolski 1969). However, new data from central Poland slightly disagree with these assumptions.

A tentative synthesis of the Weichselian Pleniglacial and Late Glacial stratigraphy and paleoclimates in central Poland was presented recently by Krzyszkowski (1990) on the basis of palynological data (Fig. 1). This paper supplements former investigations. It deals with Middle Pleniglacial deposits which infill small valleys. Organic layers intercalated in these deposits were found in several sections of the Bełchatów outcrop (Fig. 2). These layers were investigated for their pollen and plant-macrofossil content as well as for their radiocarbon ages in order to establish their stratigraphic position, vegetation and climatic conditions.

Middle Pleniglacial deposits in the Bełchatów outcrop

The Weichselian sediments under consideration belong to the basal member of the Piaski Formation (Fig. 1) and occur within the valley of the Świętojanka, a tributary of the Widawka in central Poland (Fig. 2). Their substratum is formed by the Rogowiec Formation of the Warthe stage (Krzyszkowski

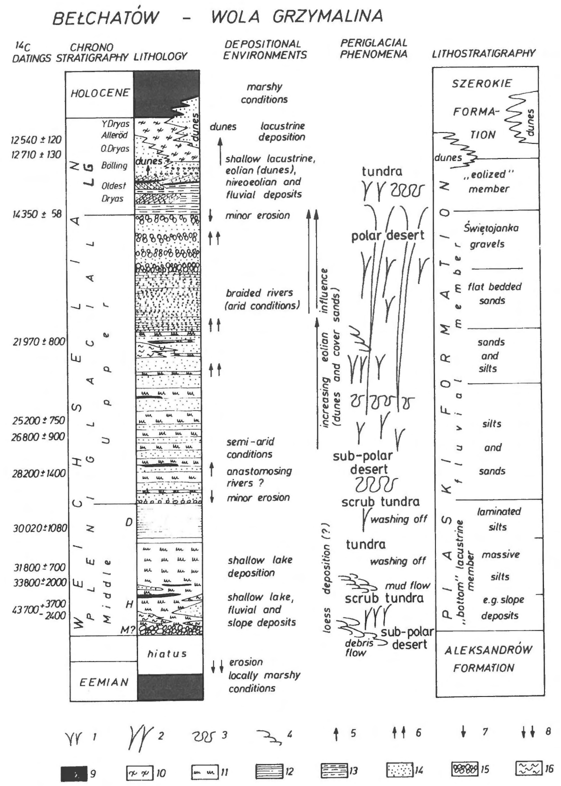


Fig. 1. Stratigraphy and paleoenvironments of the Weichselian deposits in central Poland (after Krzyszkowski 1990). 1. ice-wedge casts, 2. frost cracks, 3. involutions, 4. slope deposits, 5. moderate aggradation, 6. strong aggradation, 7. moderate incision, 8. deep incision, 9. peat, 10. lacustrine marl, 11. massive silt, 12. laminated silt, 13. eolian deposits, 14. sand, 15. gravel, 16. diamicton; LG – Weichselian Late Glacial, D – Denekamp Interstadial, H – Hengelo Interstadial, M – Moershoofd Interstadial.

1988, 1991b). They reach a thickness of 10–25 m and fill a SW–NE oriented paleovalley. The Świętojanka valley is located along this paleovalley and is much shallower (Krzyszkowski 1991a).

The Piaski Formation can be subdivided into three members: the basal or 'bottom', mainly lacustrine, the middle fluvial and the upper eolian member (Krzyszkowski 1990) (Fig. 1). The basal member, which is of Middle Pleniglacial age, comprises two units. The lower unit consists of a basal gravel lag and of interbedded fluvial sands, slope diamictons, lacustrine silts and organic layers. It is usually 0.5–2.0 m thick. The upper unit consists of lacustrine massive silts (1.0–6.0 m thick) and laminated silts (0.5–1.5 m thick; Fig. 1). The basal member occurs on the paleovalley floor, which is about 20 m below the ground surface near its mouth and only 3–7 m below the surface at the valleyhead, where it fills shallow depressions. The latter are nowadays very often dry valleys. The post-Eemian valley development is discussed in detail by Klatkowa (1989) and Krzyszkowski (1991a).

Generally, the Weichselian sedimentation was preceded by strong erosion, most probably of Early Glacial or Early Pleniglacial age. As a result, the older, interglacial deposits have been largely removed and are preserved only occasionally in the valley banks (Klatkowa 1989). The erosion phase is marked by the basal gravel lag of the Piaski Formation. Fluvial cross-bedded sands occur just above the gravels. Slope deposits as well as organic layers are common in the basal part of the formation whereas permafrost indicators are rare. This probably indicates relatively mild and moist climatic conditions (Krzyszkowski 1990). The overlying massive and laminated silts in the upper part of the basal member represent a shallow lake deposit with only limited peat bog accumulation near the lake margins. They also indicate a restricted supply of slope material. The lacustrine succession represents a redeposited loess, as indicated by grain size and mollusc fauna (Krzyszkowski 1990). It was formed, most probably, under relatively dry and cool climatic conditions. The lacustrine deposits were incised and partially removed during the next erosion phase. These events preceded the Late Pleniglacial fluvial sedimentation of the middle member; they are supposed to represent a recurrence towards generally milder and more humid conditions.

Section Wola Grzymalina 35

This section is located in the north of the Bełchatów outcrop, in the upstream part of a small valley, which is a tributary of the main Świętojanka valley (Fig. 2). The sediments of the Piaski Formation fill a 7 m-deep and about 50 m-wide incision formed in the glacial substratum (Fig. 3). The basal, lacustrine member of the Piaski Formation is about 4 m thick and comprises almost all units known from other

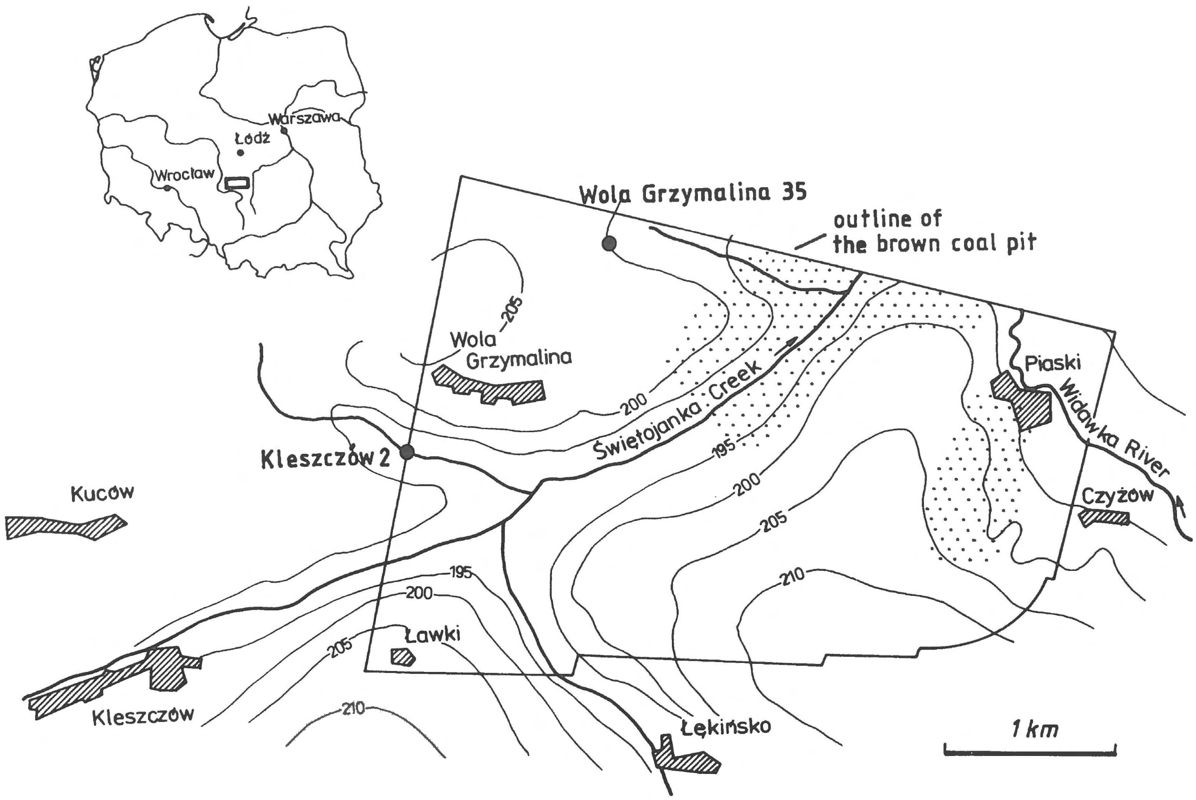


Fig. 2. Location of sites investigated in the Bełchatów outcrop. Dotted areas indicate regions with former investigations and radiocarbon datings of Weichselian deposits (see Fig. 8).

sites (Krzyszkowski 1990), i.e. from bottom to top: lowermost gravel lag, cross-bedded sands, slope diamictons, massive silts and laminated silts (Fig. 4). The massive silts are usually homogeneous and contain about 50% or more of the coarse silt and very fine sand fraction (0.05–0.1 mm). Only the basal part of these silts comprises relatively thick sandy layers. It also contains several organic horizons consisting

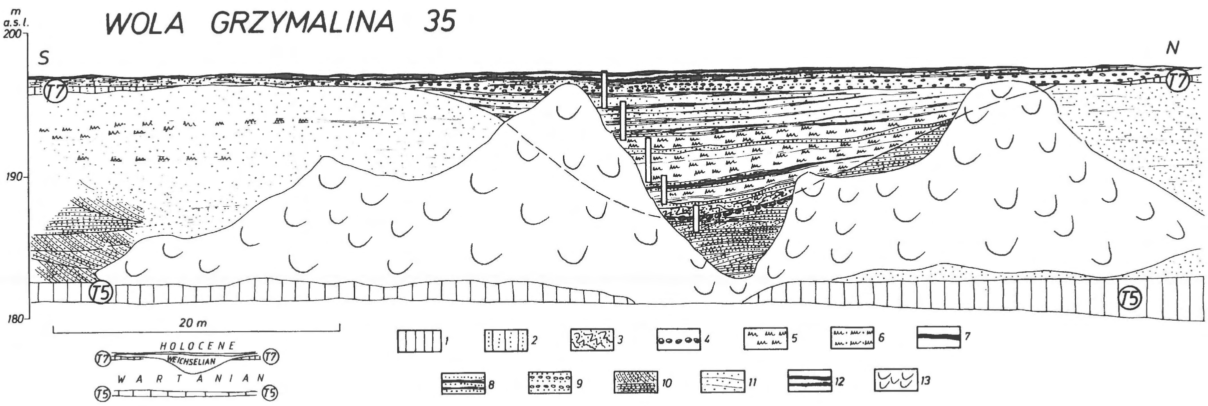


Fig. 3. The Wola Grzymalina 35 section (location in Fig. 2). 1. fresh till, 2. weathered till, 3. slope deposits, 4. gravel lag, 5. massive silt, 6. laminated silt, 7. peat, 8. interbedded sand and silt beds, 9. horizontally bedded sand and gravel, 10. cross-bedded sand, 11. structureless sand, 12. podzolic soil, 13. talus; T5 – lower Wartanian till, T7 – upper Wartanian till; White vertical bars: sampled section shown in Fig. 4.

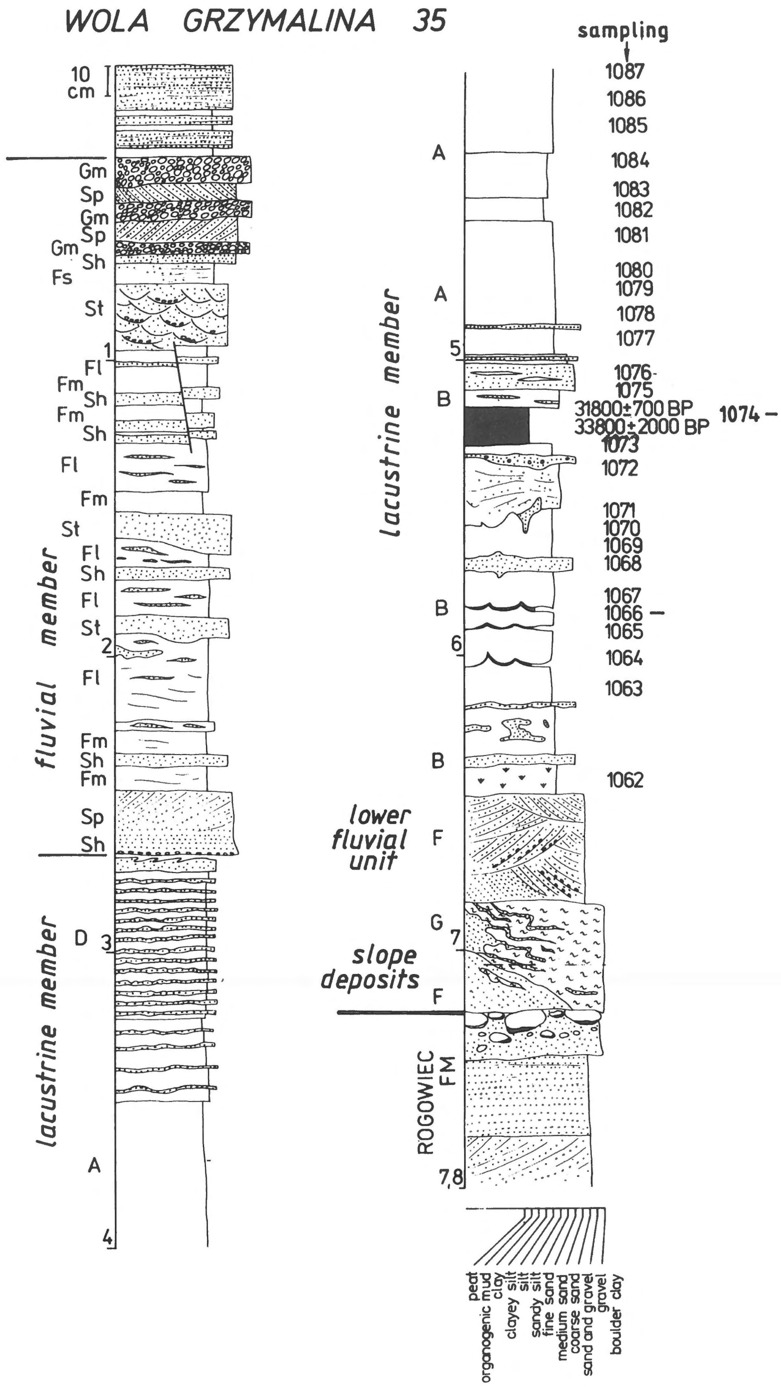
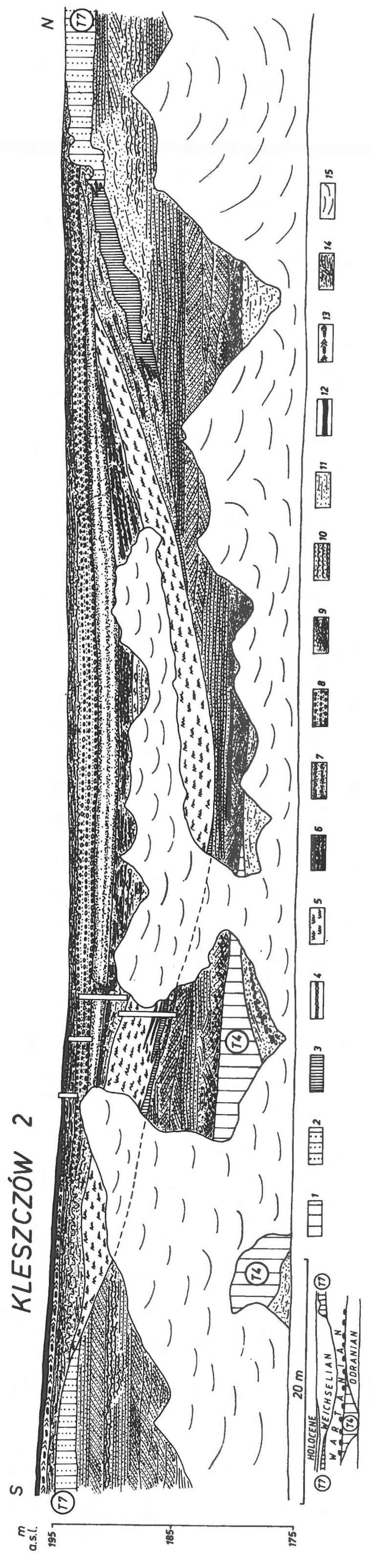


Fig. 4. Graphic log of the Piaski Formation in Wola Grzymalina 35 (location in Figs 2, 3). *Basal lacustrine member:* A – massive silt, B – massive silt with organic laminae, D – laminated silt, F – fluvial sand, G – slope diamicton. *Upper fluvial member:* Gm – massive to poorly bedded gravels, St – trough cross-bedded sands, Sp – planar cross-bedded sands, Sh – horizontally bedded sands, Fl – laminated silt, Fm – massive silt.



of humic loam and peat. The peat is 5–20 cm thick and occurs as a continuous layer at about 188–189 m above sea level (Fig. 3). The lower humic loam layers are only 1–2 cm thick and often deformed.

From the peat layer two radiocarbon dates are available: 33 800 ± 2 000 BP (Gd 2890) and 31 800 ± 700 BP (Gd 5371) (Fig. 4). Manikowska (1985) found in the same valley another peat layer which was radiocarbon-dated at 32 700 ± 900 BP (Lod 317). Only a few periglacial structures were observed in the basal member: a single ice-wedge cast in the lower fluvial sands and involutions in the humic loam horizons and laminated silts.

Section Kleszczów 2

This section is located in the west of the Bełchatów outcrop, in the upstream part of another small valley (Fig. 2). The Piaski Formation fills a 10 m-deep and about 100 m-wide incision formed in glacial sediments (Fig. 5). The thickness of the basal member of the formation is slightly reduced (2 m), but comprises all sedimentary units, except for the upper laminated silts. The sediment succession closely resembles that of the Wola Grzymalina section and shows from bottom to top: gravel lag, cross-bedded sand, slope diamicton, silt with several humic loam layers and massive silts (Fig. 6). The humic loam layers are thin (up to 3–4 cm) and discontinuous and they lie at about 186–187 m above sea level. No periglacial structures have been found in the member, though the overlying fluvial deposits have many frost cracks, ice-wedge casts and involutions.

From two humic loam layers the radiocarbon dates are available: 29 200 ± 1 100 BP (Gd 2930) and 26 900 ± 500 BP (Gd 5413) (Fig. 6). These ages are rather surprising, as they were expected to be older

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Fig. 5. The Kleszczów 2 section (location in Fig. 2). 1. fresh till, 2. weathered till, 3. slope diamicton, 4. gravel lag, 5. massive silt, 6. interbedded silt and sand beds, 7. horizontally bedded sand, 8. horizontally bedded sand and gravel, 9. cross-bedded sand, 10. eolian sand and silt, 11. structureless sand, 12. peat, 13. lacustrine marl, 14. large ice-wedge cast, 15. talus; T5 – lower Wartanian till T7 – upper Wartanian till; White vertical bars: sampled section shown in Fig. 6.

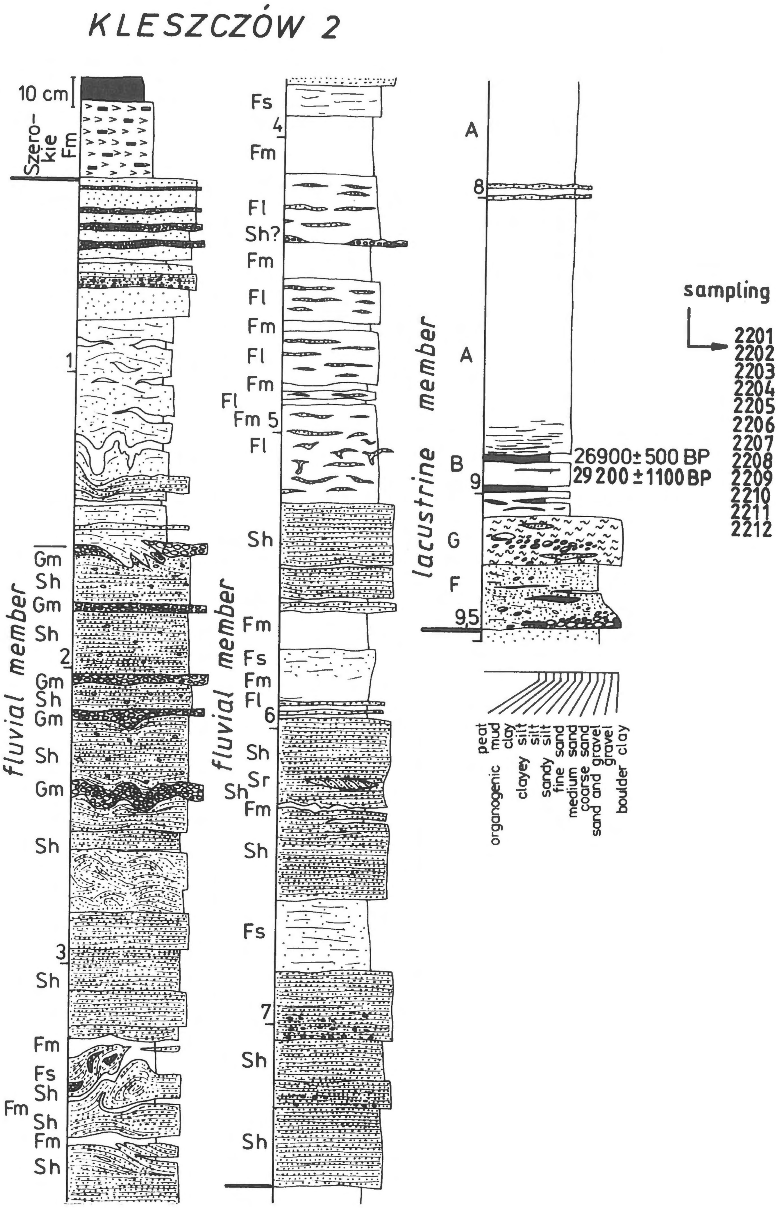


Fig. 6. Graphic log of the Piaski Formation in Kleszczów 2 (location in Figs 2, 5; symbols in Fig. 4).

and similar to those of the Wola Grzymalina section, taking into account the virtually identical position (shallow, upstream parts of the valley) and sediment succession of both sections (Figs 4, 6). Thus, the lacustrine member appears to be diachronous. The difference in topographic position of the organic deposits in the Wola Grzymalina and Kleszczów sections seems to be due to differential compaction and thus is not relevant for the stratigraphic interpretation.

Pollen analysis

Methods

Pollen samples were taken from organic layers as well as from the intervening massive silts. Only ten samples contain sporomorphs: five from Wola Grzymalina 35 and another five from Kleszczów 2. The samples were treated with KOH and then heated in hydrofluoric acid and acetolised (Erdtman 1943, Faegri & Iversen 1966). The material was then embedded in glycerine jelly. The slides studied are 8 cm^2 (Wola Grzymalina) and 4 cm^2 (Kleszczów) in size. In the pollen diagram (Fig. 7), the percentages have been calculated on the basis of the sum of the AP (arboreal pollen) and 'dry' NAP (non-arboreal pollen), excluding aquatic and swamp plants, spores of mosses and ferns and undetermined grains (corroded and Varia). Because of the small number of pollen grains, the data from Kleszczów are presented in Table 1, rather than in a diagram.

Results

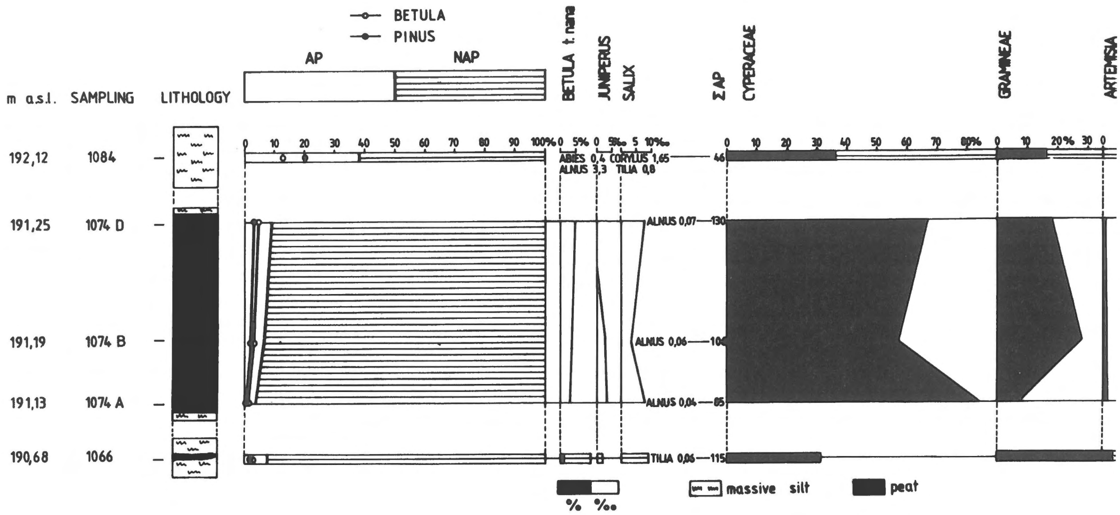
The humic loam (sample nr. 1066) and peat (sample nrs 1074A, 1074B and 1074D) from Wola Grzymalina 35 contain many pollen grains. Corroded grains account for only 5% of the total. The pollen diagram (Fig. 7) is characterized by low percentages of AP (max. 9.1%), with continuous *Betula* and *Pinus* curves. Also *Betula nana, Juniperus* and *Salix* are relatively common. The percentages of NAP are high as *Cyperaceae* reach up to 82.7% and *Gramineae* up to 27.2%. *Artemisia* and *Cruciferae* are less common, not exceeding 3–4%. The other herbaceous plants are represented by single grains (*Campanula, Saxifraga oppositifolia, Polygonum aviculare*) or are very rare (below 1%: *Caryophyllaceae, Chenopodiaceae, Rosaceae* – type *Potentilla, Helianthemum, Polygonum bistorta/viviparum, Thalictrum, Rubiaceae* – type *Cerastium, Ranunculus*). Small admixtures of plants such as *Helianthemum, Polygonum aviculare, Polygonum bistorta/viviparum* and *Saxifraga oppositifolia* clearly show the cold, arctic climate during peat formation. Most probably, the organic deposits of Wola Grzymalina were deposited during a period of open vegetation: grass tundra with scattered scrubs of *Juniperus, Salix* and *Betula nana.* The *Pinus* and *Betula* sporomorphs represent a far-distance admixture, most likely originating from forested areas of southernmost Poland (Środoń 1977).

Table 1. Total number of pollen grains in basal lacustrine member of Piaski Formation in Kleszczów 2 section (Fig. 6).

Pollen type	Sample nr. 2202	2205	2207	2209	2211
Pinus	4	4	12	3	1
Salix	2	–	2	–	–
Betula	5	–	5	19	5
Corylus	1	–	1	–	–
Carpinus	1	–	–	–	–
Ulmus	1	–	–	–	–
Alnus	–	–	–	–	1
AP:	14	4	22	22	7
Cyperaceae	56	3	43	9	8
Gramineae	21	1	3	9	6
Artemisia	1	–	1	–	2
Rubiaceae	1	–	–	–	–
Thalictrum	1	–	–	–	–
Cruciferae	–	1	1	–	–
NAP:	80	5	48	18	16
Lycopodium clavatum	3	1	1	–	1
Botrychium	2	–	–	–	1
Selaginella selaginoides	3	–	5	–	–
Sphagnum	–	–	–	1	–
Corroded grains	85	11	72	132	100

AP: arboreal pollen. NAP: non-arboreal pollen.

The uppermost sample from Wola Grzymalina (nr. 1084, taken from the massive silts) and all samples from Kleszczów (humic loam, massive silt) have a very low frequency of pollen grains, with most of the grains being corroded. Generally, the lower frequency strongly correlates with a high number of corroded grains and the occurrence of thermophilous trees (*Corylus, Carpinus, Ulmus;* Fig. 7, Table 1). *Pinus* and *Betula* are very rare. *Cyperaceae* and *Gramineae,* on the other hand, are quite common. Also, single grains of *Artemisia, Rubiaceae, Thalictrum, Cruciferae, Lycopodium clavatum, Botrychium, Selaginella selaginoides* and *Sphagnum* are found. All taxa, and especially *Artemisia* and *Selaginella selaginoides,* suggest the open vegetation of a cold, arctic climate. The relatively large number of redeposited material, which probably derives from older, Eemian deposits, indicates that the vegetation cover was not continuous. Most probably, the upper part of the basal member of the Piaski Formation was deposited in a subpolar desert, with sparse vegetation.



Plant macrofossils

Methods

Two samples (nrs 1066 and 1074), each of about 0.5 kg, were taken from the Wola Grzymalina exposure and examined for their macrofossil content. They were soaked in water for several days and then treated with KOH and boiled. The suspended material was finally rinsed using a 0.35 mm mesh. The keys of Szafran (1961) and Kac et al. (1977) have been used for the identification of the macrofossils.

Results

The total number of macrofossils is large, but the number of genera is limited. The lower sample (nr. 1066) contains mostly fragments of mosses: *Drepanocladus* sp. and *Calliergon* sp. (about 70%). The remaining fragments belong to *Cyperaceae* and *Gramineae.* Additionally, one specimen of *Equisetum* sp. was found. The upper sample, taken from the peat layer (nr. 1074), on the other hand, contains many *Cyperaceae* fragments (50%), including six fruits of *Carex hudsonii* and four of *Carex gracilis,* as well as a large number of root fragments of *Carex* sp. Moreover, mosses (*Drepanocladus* sp., *Calliergon* sp.) and *Gramineae* are common (Table 2).

Table 2. Plant macrosfossils from basal lacustrine member of Piaski Formation in Wola Grzymalina 35 (Fig. 4).

Sample nr.	Deposit	Type of fossil	*Drepanocladus* sp.	*Calliergon* sp.	*Equisetum* sp.	*Carex hudsonii*	*Carex gracilis*	*Carex* sp.	Gramineae
1074	peat	stems	*	*					#
		leaves	*	*					
		roots						*	*
		fruits				#	#		
1066	humic loam	stems	*	*	+				#
		leaves	*	*					
		roots						*	*

+ single occurrence, # rare, * common.

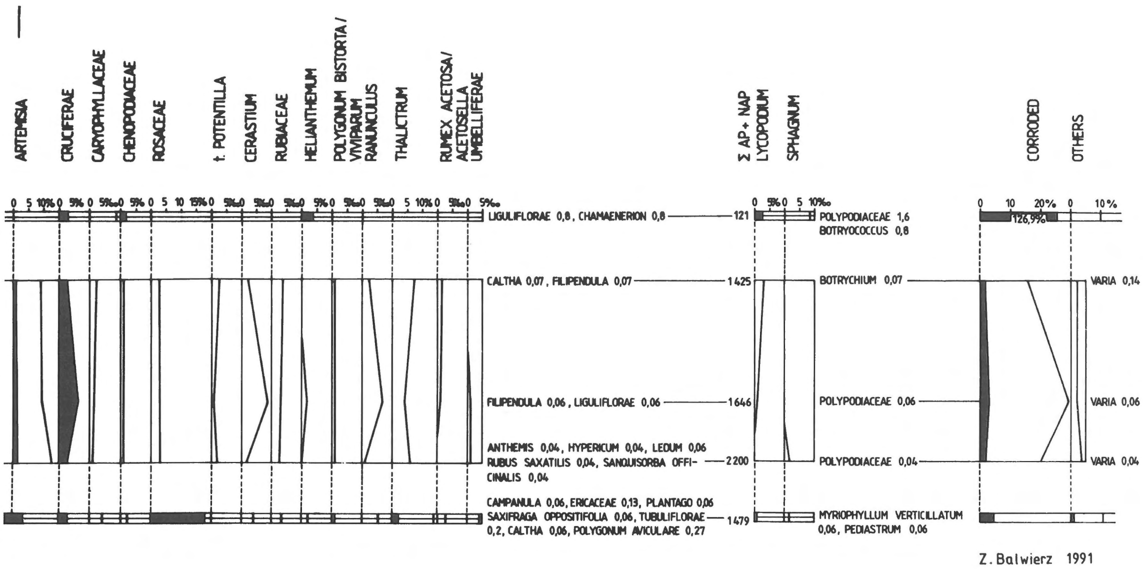


Fig. 7. Pollen diagram of basal lacustrine member of Piaski Formation in Wola Grzymalina 35 (Fig. 4).

From the above it follows that the organic layers of Wola Grzymalina represent the moss-sedge peat of a permanently wet lowland moor. The upper peat, however, was deposited under drier conditions, as is indicated by higher pollen and macrofossil percentages of *Cyperaceae* (Table 2, Fig. 7). The data suggest that trees were absent.

Discussion

The organic deposits of the basal, lacustrine member of the Piaski Formation occur always near its lower boundary, just above the lower fluvial sands and/or slope diamictons. Surprisingly, these deposits have quite different radiocarbon ages in the investigated sections (Table 3). Thus, in spite of a similar lithostratigraphic position, these deposits accumulated apparently during different stages of valley infilling. The complete sequence, including the oldest strata, occurs only near the present-day mouth of the valley; the presence of the youngest sediments of the member seems to be restricted to the valley's headwater portion. Peat-bog conditions recurred during progressively younger stages of aggradation near the shallow lake margins (Fig. 8).

Table 3. Radiocarbon datings of the Weichselian Middle and Upper Pleniglacial deposits of the Piaski Formation in the Bełchatów outcrop.

Stratigraphy	Lithology	Kleszczów 2 Distance from valley mouth: 4.0 km	Wola Grzymalina 35 Distance from valley mouth: 2.5 km	Other sites Distance from valley mouth: 0.5–2.0 km
Middle fluvial member (Upper Pleniglacial)	fluvial sands and silts 1)			26 800 ± 900 BP 28 200 ± 1400 BP
Basal lacustrine member (Middle Pleniglacial)	laminated silts			30 020 ± 1080 BP
	massive silts with organic layers	26 900 ± 500 BP 29 200 ± 1100 BP	31 800 ± 700 BP 32 700 ± 900 BP 33 800 ± 2000 BP	43 700 (+ 3700/– 2400) BP

1) Oldest ages only.

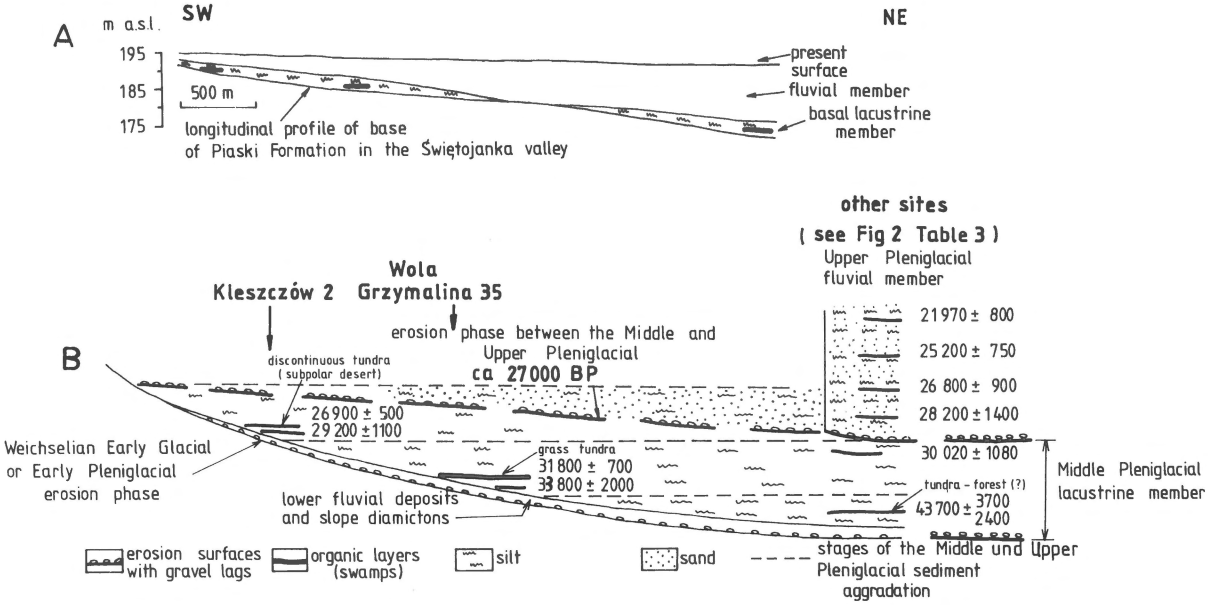


Fig. 8. A model of lacustrine deposition in the Świętojanka palaeovalley during the Weichselian Middle Pleniglacial. Radiocarbon ages in years BP (see text 'Discussion'). A – Simplified geological cross-section along the Świętojanka paleovalley, B – Interpretation of radiocarbon dates and stages of the palaeovalley infilling during the Middle and Late Pleniglacial.

A problem is posed by the conflicting radiocarbon ages for the youngest beds of the basal lacustrine member and the overlying fluvial member. The oldest radiocarbon age of the fluvial member is 28 200 ± 1 400 BP (Krzyszkowski 1990) and the youngest radiocarbon age of the lacustrine member is 26 900 ± 500 BP. Field evidence shows that these two members are separated by an erosion surface and that the lacustrine deposits above the dated organic horizons are about 1.5–2.0 m thick. The explanation might be that fluvial sedimentation started at the minimum age, i.e. 26 800 BP, and that lacustrine sedimentation ended at the maximum age, i.e. 27 400 BP. Another explanation might be that the samples from the fluvial member suffered contamination, e.g. by reworking of older organic material. Also, it is possible that fluvial sedimentation locally had begun, whilst elsewhere lacustrine deposition continued. Here, it is proposed that the boundary between the lacustrine and fluvial members be placed around 27 000 BP. This boundary is marked by a local erosion phase and a rapid change of the sedimentary environment (Krzyszkowski 1990), and probably represents the boundary between the Middle and Late Pleniglacial.

From its radiocarbon dating it is clear, that the basal, lacustrine member of the Piaski Formation was deposited during a large part of the Weichselian Middle Pleniglacial: from 43 700 (+ 3700/– 2400) to 27 000 BP (Fig. 1). The Bełchatów outcrop is the only place in central Poland where a complete sequence of this Middle Pleniglacial can be observed. The outcrop shows a succession of several sharply bounded organic beds in the basal lacustrine member. These Middle Pleniglacial organogenic layers are of particular regional importance since similar layers are not found elsewhere in central Poland. The abiotic aspects of the paleoenvironment under consideration were discussed in detail in Krzyszkowski (1990).

Palynologically, the oldest organic horizon of the Piaski Formation (43 700 years BP) is characterized by high percentages of AP (usually 22–45%, max. 64%), with mostly *Pinus* (16–32%, max. 48%), *Betula* (5–11%), *Picea* (1–4%) and *Alnus* (1–4%) and with single grains of *Abies*. Herbaceous plants predominate, however, because most samples contain abundant (35–78%) *Cyperaceae* and *Gramineae*, as well as *Caryophyllaceae, Artemisia, Compositae, Chenopodiaceae, Umbelliferae, Cruciferae, Arme-*

ria, Thalictrum, and heliophytes like *Polemonium coeruleum, Oenotheraceae, Helianthemum,* and *Selaginella selaginoides.* The presence of *Lycopodium suntinum* clearly indicates the occurrence of forest (Baraniecka 1980, Janczyk-Kopikowa 1980, Krzyszkowski 1990). The pollen spectra point to conditions of an open *Pinus* forest to a scrub tundra.

The Moershoofd Interstadial in the Netherlands, which is of comparable age, shows only a treeless, open tundra environment (Zagwijn & Paepe 1968, Zagwijn 1974, Kolstrup & Wijmstra 1977). Also from the Netherlands, Vandenberghe (1985) has described the Riel Interstadial dated at 48 480 (+ 3200/– 2300) BP to 45 200 (+ 1980/– 1600) BP, i.e. almost of the same age as the Moershoofd Interstadial and containing large percentages of *Pinus* (about 20–40%). The oldest organic layer of the Piaski Formation contains redeposited material: single grains of *Carpinus, Corylus, Ulmus, Nyssa, Tilia, Sequoia,, Sciadopithys* and other thermophilous types. It is not sure in how far this layer represents redeposited material. The Moershoofd flora from the Maliniec I section in western Poland indicates only birch, open-forest to scrub-tundra conditions (AP: 45.8%, birch: 37%; Pazdur et al. 1980), similar to the Glinde and Oerel Interstadials in Germany (Behre & Lade 1986, Behre 1989) and many other, older Middle Pleniglacial floras in the Netherlands (Van der Hammen et al. 1967, Zagwijn 1974, Kolstrup & Wijmstra 1977, De Gans & Cleveringa 1981, Brinkkemper et al. 1987, Ran et al. 1990).

The younger organic horizons of the basal member of the Piaski Formation show grass-tundra conditions (34 000–32 000 BP) followed by discontinuous tundra conditions of a subpolar desert (29 000–27 000 BP). These horizons may be related to the Denekamp Interstadial. Similar floras have been described from Kalinko in central Poland (28 300 ± 900 BP; Manikowska 1985) and from Bełchatów (32 700 ± 900 BP; Manikowska, pers. comm.). Rotnicki & Tobolski (1969), on the other hand, described scrub-tundra conditions for the period around 31 400 ± 1 100 BP for western Poland. Also, the Denekamp Interstadial in the Netherlands is characterized by scrub tundra and/or open birch forest (Van der Hammen et al. 1967, Zagwijn & Paepe 1968, Zagwijn 1974, Kolstrup & Wijmstra 1977).

From the above it follows, that the Weichselian Middle Pleniglacial climatic succession of central Poland cannot be directly correlated with those recognized in more western areas. In central Poland, the early Middle Pleniglacial was probably characterized by forest-tundra or scrub-tundra conditions, but so far this is not confirmed beyond doubt. The late Middle Pleniglacial, on the other hand, was characterized by grass-tundra conditions and finally by discontinuous tundra (subpolar desert). The characteristic feature of the Middle Pleniglacial is a lack of organic sediments within the timespan of the Hengelo Interstadial. Similar features were recognized also in western Poland (Kozarski 1981). Most probably, this period was drier than the Moershoofd and Denekamp Interstadials, and swamp formation was restricted. It is also imaginable, that the difference in vegetation between sites in central Poland and those more to the west was controlled by local factors of hydrology and geomorphology rather than by climate.

Conclusions

1. The basal, lacustrine member of the Piaski Formation at Bełchatów accumulated during different stages of paleovalley infilling. The member is complete only near the mouth of this valley; its youngest sediments are restricted to the valley's headwater portion.
2. The member was deposited during the Weichselian Middle Pleniglacial from 43 700 (+ 3700/ – 2400) to 27 000 BP and contains three organic layers dated at approximately 44 000, 33 000 and 28 000 BP. These horizons may be related to the Moershoofd (44 000 BP) and Denekamp (33 000–28 000 BP) Interstadials.
3. The pollen spectra of the lowermost organic bed (44 000 BP), show open *Pinus* forest-tundra to scrub-tundra conditions. The younger organic horizons show grass–tundra conditions (33 000 BP) and discontinuous tundra conditions of a subpolar desert (28 000 BP).
4. The Weichselian Middle Pleniglacial climate of central Poland produced mostly treeless environments and differed slightly from that recog-

nized in more western areas. This is probably due to drier conditions in central Poland.

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References

Baraniecka, M.D. 1980 Osady stadiału Warty i młodsze osady plejstoceńskie w odsłonięciu kopalni wegla brunatnego Bełchatów – Kwart. Geol. 24: 841–856

Behre, K-E. 1989 Biostratigraphy of the Last Glacial period in Europe – Quat. Sci. Rev. 8: 25–44

Behre, K-E. & U. Lade 1986 Eine Folge von Eem und 4 Weichsel – Interstadialen in Oerel/Niedersachsen und ihr Vegetationsablauf – Eiszeitalter und Gegenwart 36: 11–36

Brinkkemper, O., B. van Geel & J. Wiegers 1987 Palaeoecological study of a Middle-Pleniglacial deposit from Tilligte, The Netherlands – Rev. of Palaeobotany Palynology 51: 235–269

De Gans, W. & P. Cleveringa 1981 Stratigraphy, palynology and radiocarbon dating of Middle and Late Weichselian deposits in the Drentsche Aa Valley system (Drenthe, The Netherlands) – Geol. Mijnbouw 60: 373–384

Dylik, J. 1969 Slope development under periglacial conditions in the Łódź region – Biul. Peryglacjalny 18: 381–410

Erdtman, G. 1943 An Introduction to Pollen Analysis. Verdoorn, Mass., U.S.A., 239 pp

Faegri, K. & J. Iversen 1966 Textbook of Pollen Analysis. 2nd ed. Munksgaard, Copenhagen, 287 pp

Goździk, J. 1973 Geneza i pozycja stratygraficzna struktur peryglacjalnych w środkowej Polsce – Acta Geographica Lodziensa 31: 1–117

Janczyk-Kopikowa, Z. 1980 Flory osadów jeziornych w Piaskach. In: W. Barczyk (ed.): Przewodnik 52 Zjazdu Polskiego Towarzystwa Geologicznego: 321–322

Kac, N., S. Kac & E. Skobyeyeva 1977 Atlas rastityelykh ostatkov v torfakh – Niedra, Moskva, 371 pp

Klatkowa, H. 1989 Póznowarciańskie kształtowanie górnych odcinków dolin. Przykłady z wyżyny Łódzkiej – Acta Geographica Lodziensa 59: 61–74

Kolstrup, E. & T.A. Wijmstra 1977 A palynological investigation of the Moershoofd, Hengelo and Denekamp interstadials in The Netherlands – Geol. Mijnbouw 56: 85–102

Kozarski, S. 1981 Stratygrafia i chronologia Vistulianu Niziny Wielkopolskiej – Polska Akademia Nauk, Oddział w Poznaniu, Seria Geografia 6: 4–44

Krzyszkowski, D. 1988 The Rogowiec Formation in a Kleszczów Graben, a new view for the Wartanian (Warthe) glaciation in central Poland – Bull. Pol. Acad. Sci., Earth Sciences 36: 287–298

Krzyszkowski, D. 1990 Middle and Late Weichselian stratigraphy and palaeoenvironments in central Poland – Boreas 19: 333–350

Krzyszkowski, D. 1991a Vistulian fluviatile sedimentation near Bełchatów, central Poland – Bull. Pol. Acad. Sci., Earth Sciences 39, 311–329

Krzyszkowski, D. 1991b Saalian sediments in the Bełchatów outcrop, central Poland – Boreas 20: 29–46

Manikowska, B. 1985 O glebach kopalnych, stratygrafii i litologii wydm Polski środkowej – Acta Geographica Lodziensa 52: 1–137

Manikowska, B. & Z. Balwierz 1987 Analiza vistuliańskiego wypełnienia suchej doliny w północnej części odkrywki Bełchatów. In: Baraniecka, M.D., K. Brodzikowski & L. Kasza (eds): Quaternary of Bełchatów region, 2nd Symposium, Guide Book, Wydawnictwa Geologiczne, Warszawa: 161–164

Pazdur, M., W. Stankowski & K. Tobolski 1981 Litologiczna i stratygraficzna charakterystyka profilu z kopalnymi utworami organogenicznymi w Malińcu koło Konina (doniesienie wstępne) – Bad. Fizjogr. nad Pol. Zach. 33: 79–88

Ran, E., S. Bohncke, J. van Huissteden & J. Vandenberghe 1990 Evidence of episodic permafrost conditions during the Weichselian Middle Pleniglacial in the Hengelo Basin (The Netherlands) – Geol. Mijnbouw 69: 207–218

Rotnicki, K. & K. Tobolski 1969 Stanowisko Interstadiału Paudorf w Kępnie (południowo – zachodnia Wielkopolska) – Bad. Fizjogr. nad Pol. Zach. 23: 119–127

Środoń, A. 1977 Szata roślinna Polski. Roślinność Polski w czwartorzędzie. Państwowe Wydawnictwo Naukowe, Warszawa

Szafran, B. 1961 Mchy (Musci), vol. II. Państwowe Wydawnictwo Naukowe, Warszawa, 405 pp

Turkowska, K. 1988 Rozwój dolin rzecznych na Wyżynie łódzkiej w w późnym czwarto rzędzie – Acta Geographica Lodziensa 57: 1–157

Vandenberghe, J. 1985 Palaeoenvironment and stratigraphy during the Last Glacial in the Belgian-Dutch border region – Quat. Res. 24: 23–38

Van der Hammen, T., G.C. Maarleveld, J.C. Vogel & W.H. Zagwijn 1967 Stratigraphy, climatic succession and radiocarbon dating of the last glacial in the Netherlands – Geol. Mijnbouw 46: 79–95

Zagwijn, W.H. 1974 Vegetation, climate and radiocarbon datings in the late Pleistocene of the Netherlands. Part II: Middle Weichselian – Meded. Rijks Geol. Dienst 25-3: 101–111

Zagwijn W.H. & R. Paepe 1968 Die Stratigraphie der weichselzeitlichen Ablagerungen der Niederlände und Belgiens – Eiszeitalter und Gegenwart 19: 129–146