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MIDDLE AND UPPER WEICHSELIAN PLENIGLACIAL FLUVIAL EROSION AND SEDIMENTATION PHASES IN SOUTHWESTERN POLAND, AND THEIR RELATIONSHIP TO SCANDINAVIAN ICE SHEET BUILD-UP AND RETREAT

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Abstract: The sequence of Weichselian sediments and processes in SW Poland is almost identical to that of central Poland. Generally, three fluvial units occur, comprising silts and sands coarsening upwards to silts, sands and gravels, with aeolian deposits on top. This suggests very uniform processes throughout the palaeogeographic zone. To the south of this zone, there was extensive loess deposition and glacial deposition to the north. Climatic conditions during the Middle and Upper Weichselian Pleniglacial in SW Poland were similar to those in central Poland and northwestern Europe, though the period of 47–43 kyrs BP was slightly milder in SW Poland (shrub tundra, forest-tundra). Climatic conditions during the periods 38–27 kyrs BP and 23–18 kyrs BP were very uniform throughout central Europe, including SW Poland, though there may have been a strong north-south climatic gradient during the former period, as data from the loessic zone indicate at least patches of boreal forest or forest-tundra conditions in SW Poland at that time. It is also possible that there was a Middle Weichselian Pleniglacial interstadial with a lower age boundary at 25,900 ± 700 years BP, characterised by *Pinus-Picea* forest with no heliophytes. This interstadial represents the last mild period before the advance of the late Weichselian ice sheet into SW Poland. The Weichselian fluvial deposition of SW and central Poland may have been punctuated by at least three major erosional phases, characterised by similar incision depths during the cold stages. Erosion took place, with certainty, at around 75–60 kyrs BP (Lower Pleniglacial) and 27 kyrs BP, very probably at around 23/22 kyrs and possibly at around 40 kyrs BP, and valley aggradation occurred during the milder stages. The Upper Pleniglacial was characterised by valley aggradation, associated with southward ice sheet advance and restricted fluvial outflow. However, the frequent Middle Pleniglacial Weichselian climatic oscillations did not initiate sedimentation and erosion, they controlled only river discharge and type of fluvial sedimentation and aeolian activity. The occurrence of the erosional and aggradational phases were controlled by the changes in ice volume in Scandinavia, ice sheet build-up and retreat, respectively.

Key words: Pleistocene, Weichselian, fluvial erosion and sedimention, pollen analysis, ^{14}C dating, SW Poland.

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INTRODUCTION

Three palaeogeographical zones with different sediments and stratigraphic sequences occurred during the Upper Pleistocene in Poland. These were: a loess zone in the south, a glaciated area in northern Poland, and a wide intermediate zone which was characterised mainly by fluvial, but also by lacustrine and aeolian (loess, coversand, dunes) deposition in valleys, as well as by strong periglacial processes. In western Poland, the last zone is condensed to a 40–60 km wide belt between the Trzebnica Hills, with the northernmost loess, and the Leszno region, where the southernmost Upper Pleniglacial Weichselian end moraines occur (Leszno=Brandenburg phase) (Fig. 1). This palaeogeography suggests strong climatic gradients in the extraglacial areas, as the corresponding zone in central and eastern Poland is 200–250 km wide. Moreover, in contrast to central and eastern Poland, western Poland was characterised by a highly oscillatory ice margin during the Upper Weichselian Pleniglacial. There are several recessional moraines, 50–70 km apart, with new ice margins formed almost every 1,000–2,000 years (Kozarski, 1986, 1988) (Fig. 1). The extensive outwash plains and pradolinas (ice-marginal streamways, *Urstromtäler*) were formed south of the end moraines and drained westwards (Keilhack, 1899; Woldstedt, 1927, 1931; Kozarski, 1962, 1965, 1986, 1988).

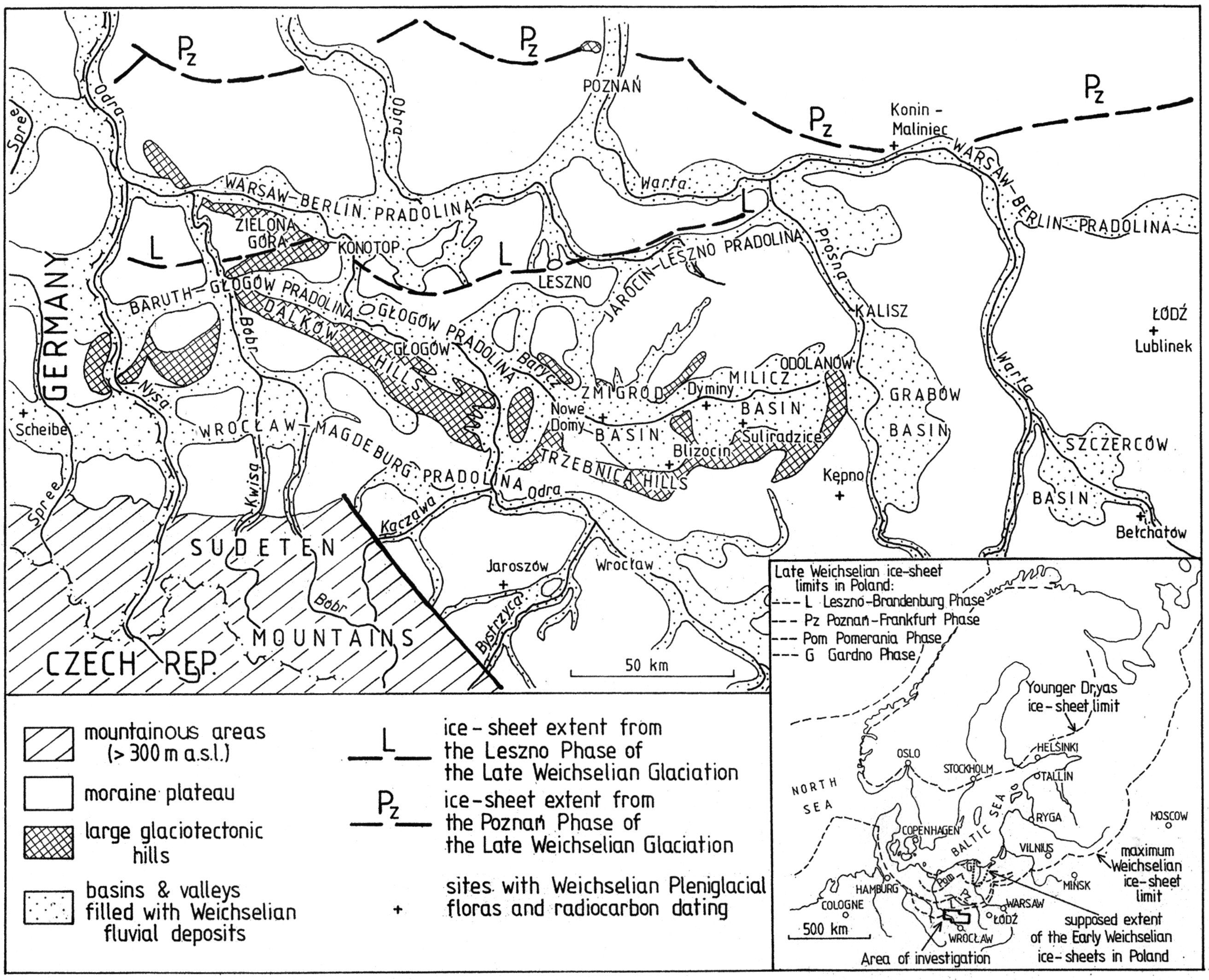

Fig. 1. Location of the study area against the background of Weichselian fluvial valleys and ice margins in SW Poland; see text for discussion of position of sites with floras and radiocarbon dating

A large part of SW Poland is occupied by Weichselian fluvial valleys, forming extensive basins along the Barycz River (Milicz and Żmigród basins), the Odra River near Głogów (Głogów Pradolina), and their tributaries (for instance, the Jarocin-Leszno Pradolina) (Fig. 1). This valley system forms the eastern end of the Głogów-Baruth Pradolina (*Urstromtal*) that drained the region to the west when the Upper Pleniglacial Weichselian ice sheet was at its maximum (ca. 20,000 yrs BP; Leszno-Brandenburg phase). Later, during the Poznań-Frankfurt phase (ca. 18, 500 yrs BP), a new outflow was formed farther north, along the Warsaw-Berlin Pradolina (Fig. 1).

This paper concentrates on Weichselian Pleniglacial stratigraphy of the extraglacial regions of SW Poland, which lies entirely within the intermediate palaeogeographical zone. We discuss phases of fluvial aggradation and erosion, their response to base level changes in relation to ice-sheet advance and decay, and especially their relation to ice-marginal sedimentation during the last glacial maximum. In addition, the paper discusses possible climatic oscillations and climatic gradients as four new sites with Weichselian floras have been documented. These are compared with some other Weichselian sites of the intermediate zone from SW Poland (Kępno, Jaroszów) (Rotnicki & Tobolski, 1969; Rotnicki, 1987; Krzyszkowski *et al.*, 1995, 1999), SE Germany (Scheibe) (Mol, 1997a, 1997b; Kasse, 2003), and central Poland (Kozarski, 1980; Pazdur *et al.*, 1981; Krzyszkowski, 1990a; Krzyszkowski *et al.*, 1993; Balwierz, 1995) (Fig. 1). We do not intend to provide a comprehensive synthesis on the Weichselian stratigraphy and palaeoclimate in Poland. Discussion on Weichselian fluvial processes and palaeoclimate from the entire Poland or from the loessic zone can be found elsewhere (Mamakowa & Środoń, 1977; Kozarski, 1980; Jersak *et al.*, 1992; Starkel, 1988, 1995; Starkel *et al.*, 1999).

The analysis is based on 20 borehole logs located along the Barycz and middle Odra river valleys (Fig. 2). The logs have been described sedimentologically in terms of general lithology and sedimentary structures and then characterised by their grain size, heavy mineral content (0.1–0.25 mm), quartz grains characteristics (0.5–1.0 mm), and calcium carbonate content. These characteristics have been supple-

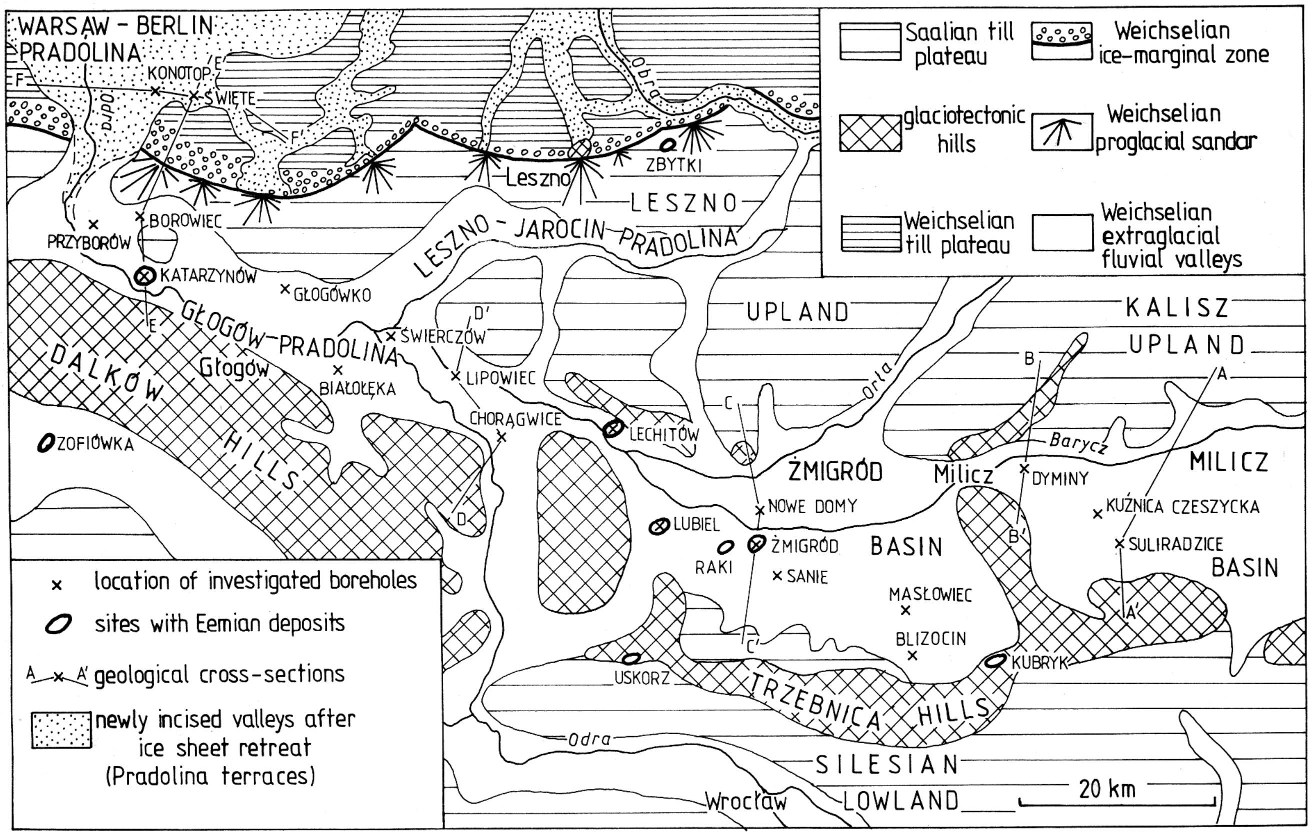

Fig. 2. Simplified geomorphological map of the area along Barycz and middle Odra rivers, SW Poland, with positions of investigated boreholes (Lateglacial and Holocene terraces omitted)

mented by surficial data taken from geological maps (Czerwonka *et al.*, 1997).

GEOLOGICAL AND GEOMORPHOLOGICAL BACKGROUND

The area of investigation is located along the Barycz and middle Odra rivers, between Odolanów and Konotop (Figs 1, 2). This area comprises three large fluvial basins: the Milicz and Żmigród basins, and the Głogów Pradolina. The last one is about 100 km long and 20–30 km wide, whereas the two first are ovate and extensive, about 40x60 km. The basins are filled surficially with extensive alluvial deposits and are separated from each other by narrow reaches. The valley/basin surfaces lie from 130 m a.s.l. in the Milicz Basin to 57 m a.s.l. downstream near Konotop, and are generally about 15–20 m lower than the surrounding Late Saalian till plateau. The Saalian glaciotectonic hills decline from 250–280 m a.s.l. at the southern margins of the basins to 190 m a.s.l. at the northern margins (Fig. 2). Moreover, the ice-marginal landforms of the Upper Pleniglacial Weichselian glaciation (Leszno/Brandenburg), such as end moraine hills, kames, eskers and sandurs, are superimposed on the till plateau in the northern part of the region (Fig. 2), forming a 2–5 km wide zone with up to 20 m high hills, often disrupted by tunnel valleys.

Dyjor and Kuszell (1975) considered that the basins along the Barycz and middle Odra rivers were erosional landforms, now filled mainly with Holsteinian and Eemian fluvial deposits covered by a thin veneer of Weichselian/Holocene sediments. Krygowski (1967, 1975) and Rotnicki (1967) interpreted these basins as glaciotectonic depressions formed during the late Saalian (Wartanian), and Brodzikowski (1987) suggested that they were formed by multi-stage deformation throughout the Pleistocene. All these authors claimed the absence of older deposits within the basins, with only a thick Upper Pleistocene fluvial sequence. Recent investigations (Czerwonka *et al.*, 1997) have shown that the basins have more complex history, with up to five till horizons, three Elsterian and two Saalian ones (Fig. 3). Holsteinian deposits have not been found yet, but several Eemian sites were subsequently discovered. This suggests, that the basins were formed due to glacial and not fluvial erosion, and probably during the early Elsterian, as a till of that age occurs usually at the bottoms of all basins. Then, the basins were sequentially filled and partly eroded during the following glaciations (Fig. 3). As the basins lie beyond the late Weichselian ice limit, the basins and surrounding till plateau may preserve post-Saalian morphology. Indeed, there are five Eemian sites within these basins: Żmigród, Raki, Lubiel, Lechitów, and Katarzynów (Fig. 2) (Skompski, 1983; Krzyszkowski *et al.*, 1994; Kuszell, 1980; Kuszell & Sadowska, 1994; Malkiewicz, 1998). There are several other Eemian sites in the surrounding till

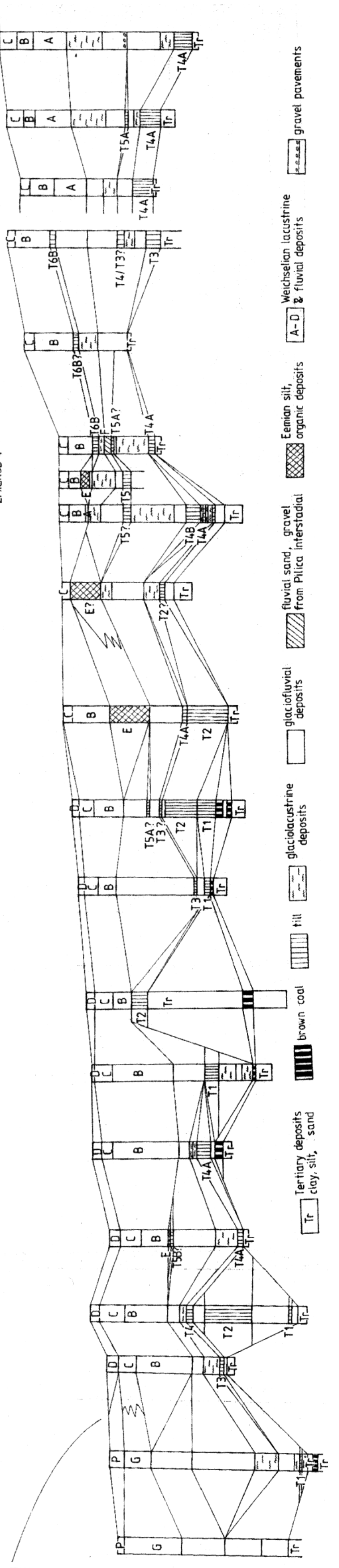

Fig. 4. Correlation of Pleistocene deposits along the Barycz and middle Odra river valleys (after Czerwonka *et al.*, 1997) and position of Weichselian Pleniglacial fluvial deposits (Suliradzice Formation); note that sediments of Unit C interdigitate with glaciofluvial deposits of Unit G and that a part of Unit D (aeolian deposits) may be the age equivalent of Unit P (Pradolina terrace). T1-T4 – Elsterian tills, T5A & B – early Saalian tills, T6A & B – late Saalian tills (after Czerwonka *et al.*, 1997)

plateau, which almost lie at the ground surface. All these Eemian sites represent lacustrine sequences formed either in kettle holes or in tunnel valley lakes (Kuszell, 1997).

The uppermost fluvial series lies on top of Eemian and Late Saalian (Wartanian) deposits. Eemian deposits are well preserved in the Milicz and Żmigród basins, but they are almost absent along the Głogów Pradolina (Fig. 3). The fluvial series is 10–50 m thick, with its base at 17 m a.s.l. at Przyborów (Figs 2 and 4). At the surface, it forms distinct terraces, the highest and most extensive of which are associated with the Weichselian Pleniglacial, which we discuss in this paper, and other terraces, which increase in number downstream. Conventionally, in this region these are interpreted as terraces from the ice sheet retreat (Unit P in Figs 3 and 4), as well as Upper Pleniglacial Weichselian (Unit D in Figs 3 and 4) and Holocene terraces (Rotnicki, 1987).

DESCRIPTION AND INTERPRETATION OF DEPOSITS

The Weichselian Pleniglacial fluvial series varies from silts to occasional pebble sands and thin organic layers (peat, organic mud). The series is defined from boreholes using various criteria. In several profiles it occurs above Eemian deposits or comprises organic layers with cold floras and/or finite radiocarbon dates, especially in the Milicz and Żmigród basins (Figs 5 and 6). Downvalley, its lower boundary is less well defined, as organic-poor fluvial deposits lie directly above glacial deposits, including glaciofluvial sands. Lithological and mineralogical criteria have been used here, as the fluvial deposits usually contain significantly more garnet and always more rounded quartz grains (Figs 5–8; Table 1) (Czerwonka *et al.*, 1997). Similarly high contents of garnet and well rounded-quartz grains have commonly been reported from Weichselian extraglacial sequences in Poland. These high contents have been interpreted as the result of aeolian activity *in situ* and/or fluvial redeposition of aeolian material (Goździk, 1980; Krzyszkowski, 1990a, b; Stankowski & Krzyszkowski, 1991). The mineralogically defined lower boundary of the Weichselian Pleniglacial series in the Głogów Pradolina was confirmed later by the discovery of Eemian deposits at Katarzynów (Figs 4 and 8). The upper boundary of the series is at the terrace surface.

The series described above was named the Suliradzice Formation, after the Suliradzice borehole (Fig. 2), which comprises all sedimentary units in the log, as well as radiocarbon dated deposits at its base and top (Fig. 5). The Suliradzice Formation includes three lithostratigraphic units, informally named A, B and C, which differ in their grain size characteristics, garnet and well-rounded quartz contents (Table 1). However, deposits from all three units differ greatly from the Weichselian proglacial sequences found in the tunnel valleys and sandurs (unit G; Fig. 4) and from the older glacial deposits, mainly in terms of quartz grain roundness, *i.e.* only extraglacial deposits (units A, B, C) have an aeolian component (Table 1).

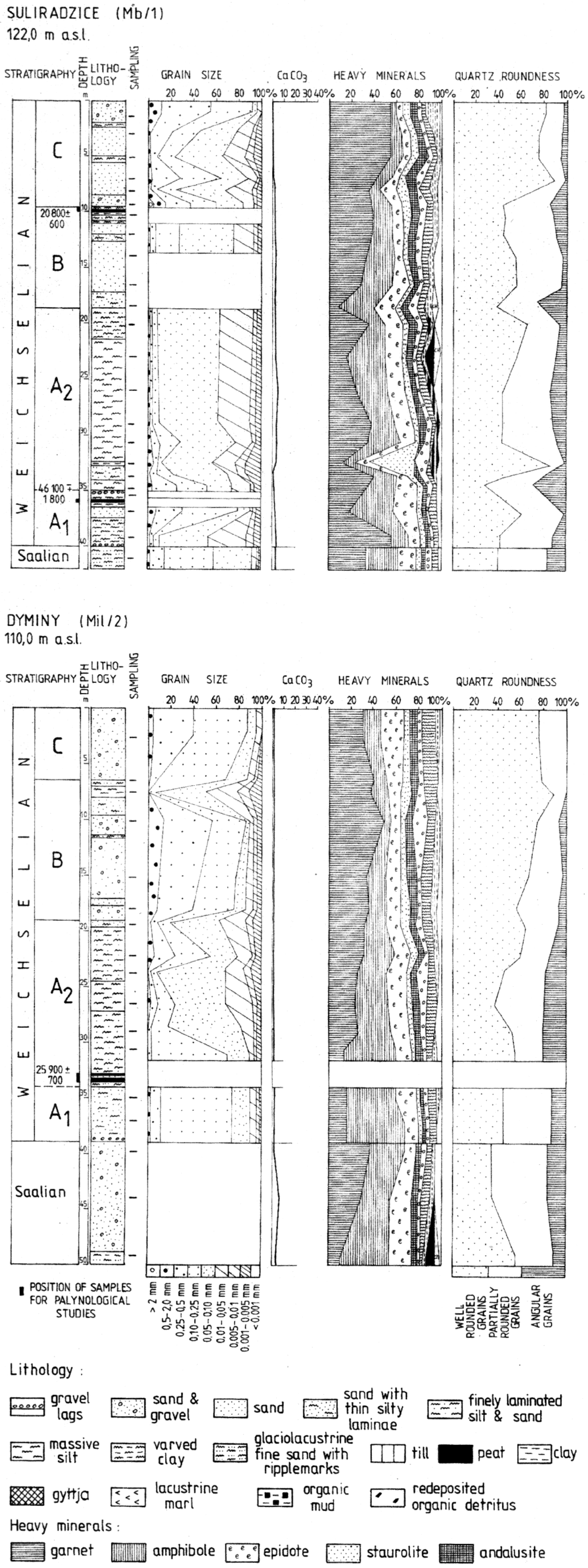

Fig. 5. Sedimentary logs, sediment properties and lithostratigraphy of Weichselian deposits of the Suliradzice and Dyminy boreholes; note the occurrence of gravel lag between A_1 and A_2 Sub-units at Suliradzice. Location of boreholes in Figure 2

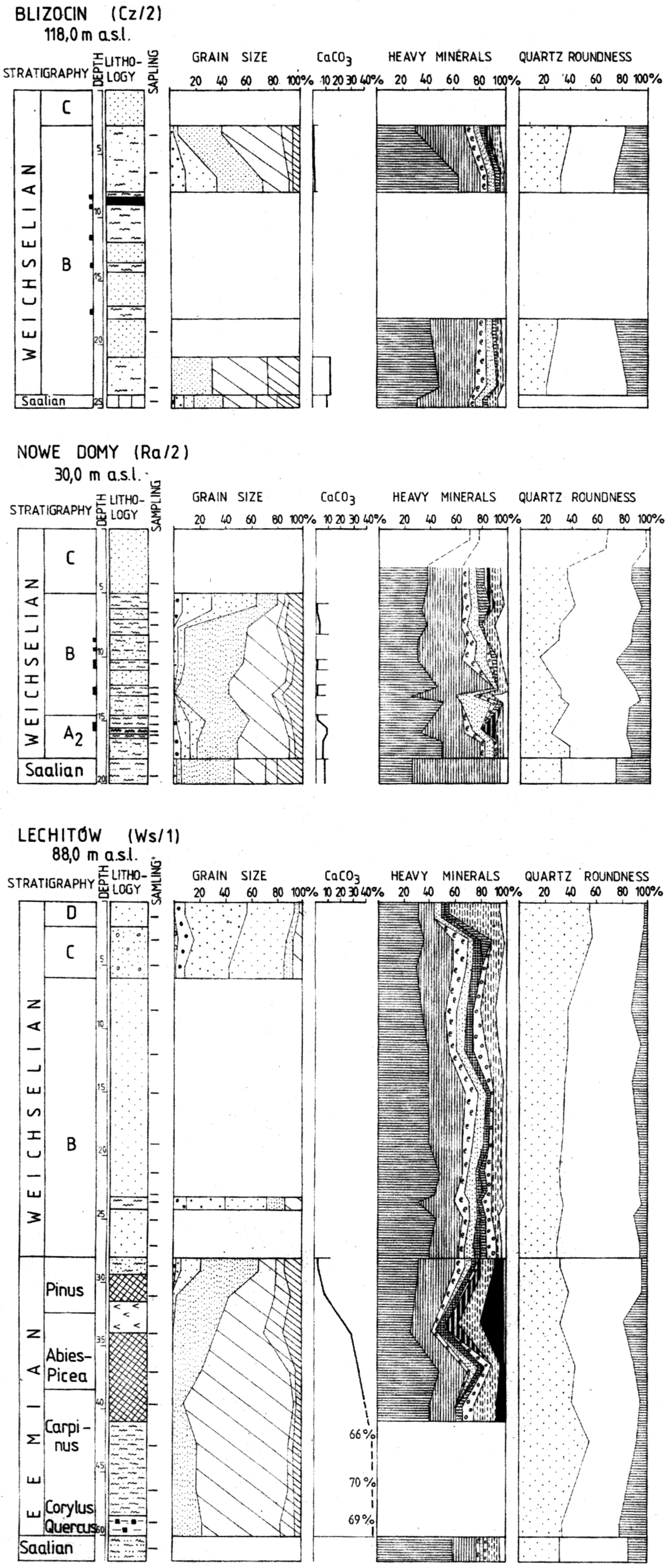

Fig. 6. Sedimentary logs, sediment properties and lithostratigraphy of Weichselian deposits from the Blizocin, Nowe Domy and Lechitów boreholes; note a complete Eemian sequence at the base of Weichselian deposits at Lechitów (pollen zones after Malkiewicz, 1998). Location of boreholes in Figure 2; captions in Figure 5

Table 1

General granulometric and mineralogical characteristics of sediments of the Middle and Late Pleniglacial Weichselian age along the Barycz and middle Odra rivers

Sedimentary Unit	Mean size (ϕ scale)	Sorting (ϕ scale)	Garnet content (%)	Well rounded quartz (%)
D	2.62. 13 - 3.03	1.2 0.67 - 1.00	41 30 - 51	44 30 - 58
G (sandurs)	0.8 -2.0 - 1.9	1.6 0.6 - 1.8	38 25 - 45	35 30 - 40
G(tunnel valleys)	1.8 1.00 - 2.98	1.2 0.81 - 1.78	40 30 - 45	28 25 - 30
C	2.00 0.34 -4.49	1.3 0.39 - 3.22	38 30 - 56	52 40 - 80
B	2.68 1.11 -5.39	1.3 0.50 - 2.84	35 30 - 46	38 30 - 60
A	4.30 2.47 - 5.24	1.8 0.99 - 2.39	35 15 - 55	49 38 - 60

Upper numbers indicate mean values within the units; lower numbers indicate range of variability

Description of sedimentary units

Unit A

The sedimentary sequence of unit A, occurring only in the Milicz and Żmigród basins (Figs 3–5), comprises mainly massive to finely laminated green silt and occasionally, especially in its lower part, thin layers of silty sand and sand. Organic deposits are from a few centimetres to 0.7 m thick and are present throughout the unit (Figs 5 and 6). The lower boundary of the unit is erosional (Fig. 3). Unit A may be subdivided into two sub-units. The lower sub-unit (A_1) is up to 8 m thick and comprises massive and laminated silts and frequent sandy layers. The upper sub-unit (A_2) is up to 20 m thick and comprises only massive to laminated, poorly sorted silts. The boundary between sub-units A_1 and A_2 is erosional at Suliradzice, marked by 0.5 m thick gravel lag (Figs 3 and 5), but in other profiles the gravels are absent (Figs 3, 5, 6). The upper boundary of the unit A is very distinct in all boreholes, marked by a rapid change in sediment lithology from cohesive silts to loose sandy silts, sands or pebble sands of the overlying unit; although there is no gravel lag, it may represent an erosional boundary.

Unit A is characterised by a variable garnet content, from 15% to 55%, often with the glacially-derived amphibole as the dominant mineral in the lower sub-unit and with a continuous increase of garnet in the upper sub-unit. In both sub-units, the mean content of garnet is *ca* 35%, which is only slighty greater than in the underlying glacial deposits. Aeolian-derived, well-rounded quartz grains are dominant in both sub-units, varying from 38 to 60% (Table 1).

Unit B

This unit, 8–36 m thick, comprises mainly fine- to coarse- grained sands or silty sands with some silty beds and it was present in all the boreholes (Fig. 4). It lies on top of the unit A deposits in the Milicz and Żmigród basins, or directly above Eemian or glacial deposits in the Głogów Pradolina. The latter may suggest an erosional phase before sedimentation of Unit B, during which the older Weichselian deposits of unit A were partly removed. The upper boundary of unit B has no erosional features and is less distinct. It seems to be a transitional one.

The sediments of unit B are lithologically variable along the valley. Unit B of the Milicz and Żmigród basins contains alternating sand and silt beds, where the silty beds are from a few decimetres to 3 m thick and are very similar to those of Unit A, *i.e.* they contain a large admixture of coarse silt and are poorly sorted. Sandy deposits are usually fine- to medium-grained, moderately to poorly sorted. Occasionally, some 10–40 cm thick layers of organic mud are present (Figs 5 and 6). The unit B of the Głogów Pradolina is formed mainly of moderately well to moderately sorted, medium-to coarse-grained sand, with only few silty beds, up to 0.5 m thick (Figs 6–8, Table 2).

The heavy mineral content and quartz grain characteristics are uniform throughout the unit. Garnet varies from 30 to 46%, with an average about 35%, *i.e.* only slighty greater than in the underlying glacial deposits. The number of well-rounded grains is slightly less than in Unit A, but still more than in typical glacial deposits (Figs 5–8; Table 1).

Unit C

This unit is 3–14 m thick and comprises medium- to coarse sand and occasionally pebbly sand, with thin beds of sandy silts in the Milicz Basin (Fig. 5). The sediments of Unit C occur in all the studied boreholes (Fig. 4), but they vary slightly down the valley, from poorly sorted, medium-grained sands in the Milicz and Żmigród basins, to well through moderately well sorted, coarse-grained sands or pebble sands. The coarsest and best sorted deposits occur in the western part of the Głogów Pradolina (Table 2), which is probably connected with their position close to the

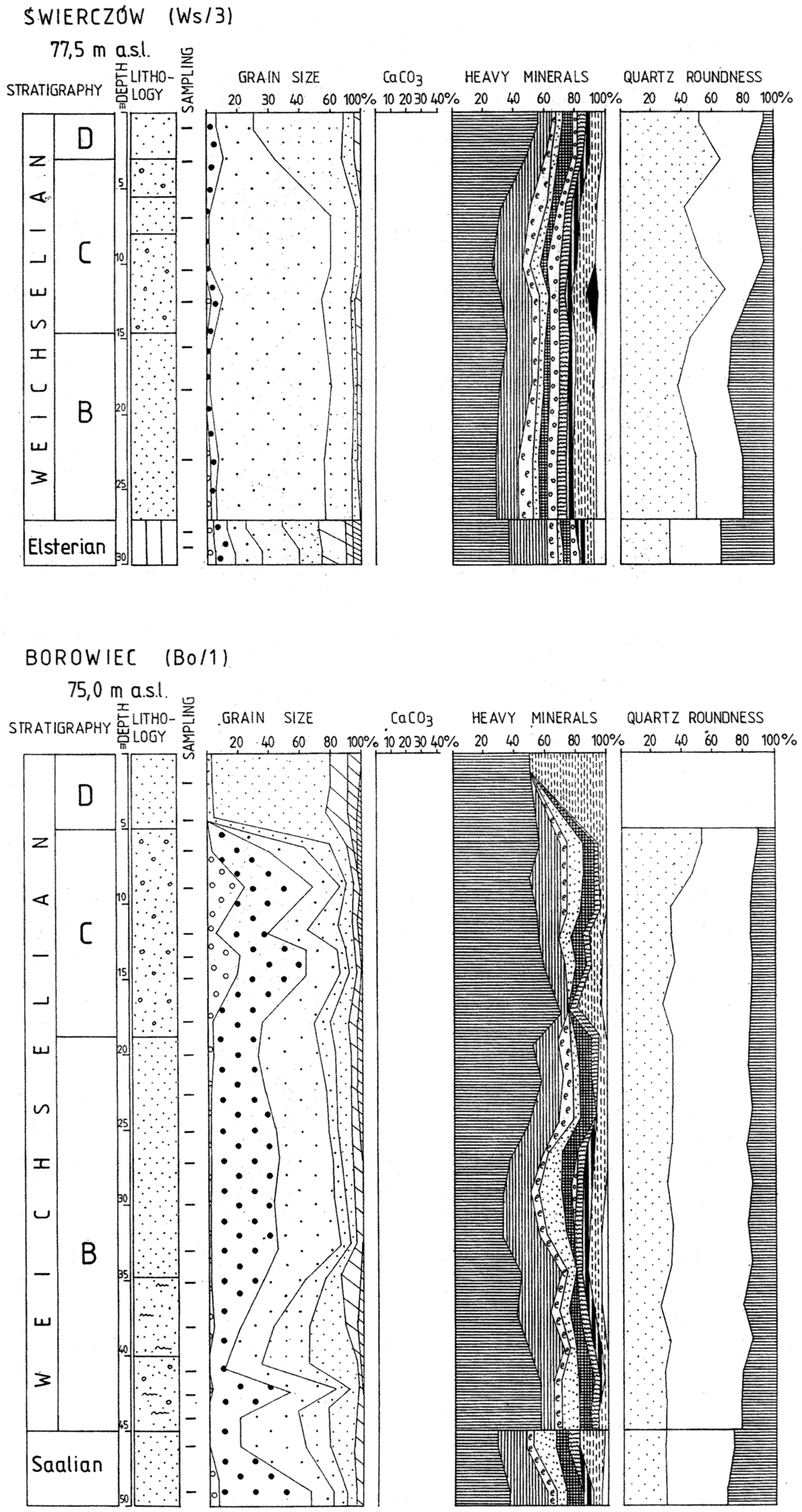

Fig. 7. Sedimentary logs, sediment properties and lithostratigraphy of Weichselian deposits at Świerczów and Borowiec; note that Weichselian sediments of these logs are the coarsest among the investigated sequences. Location of boreholes in Figure 2; captions in Figure 5

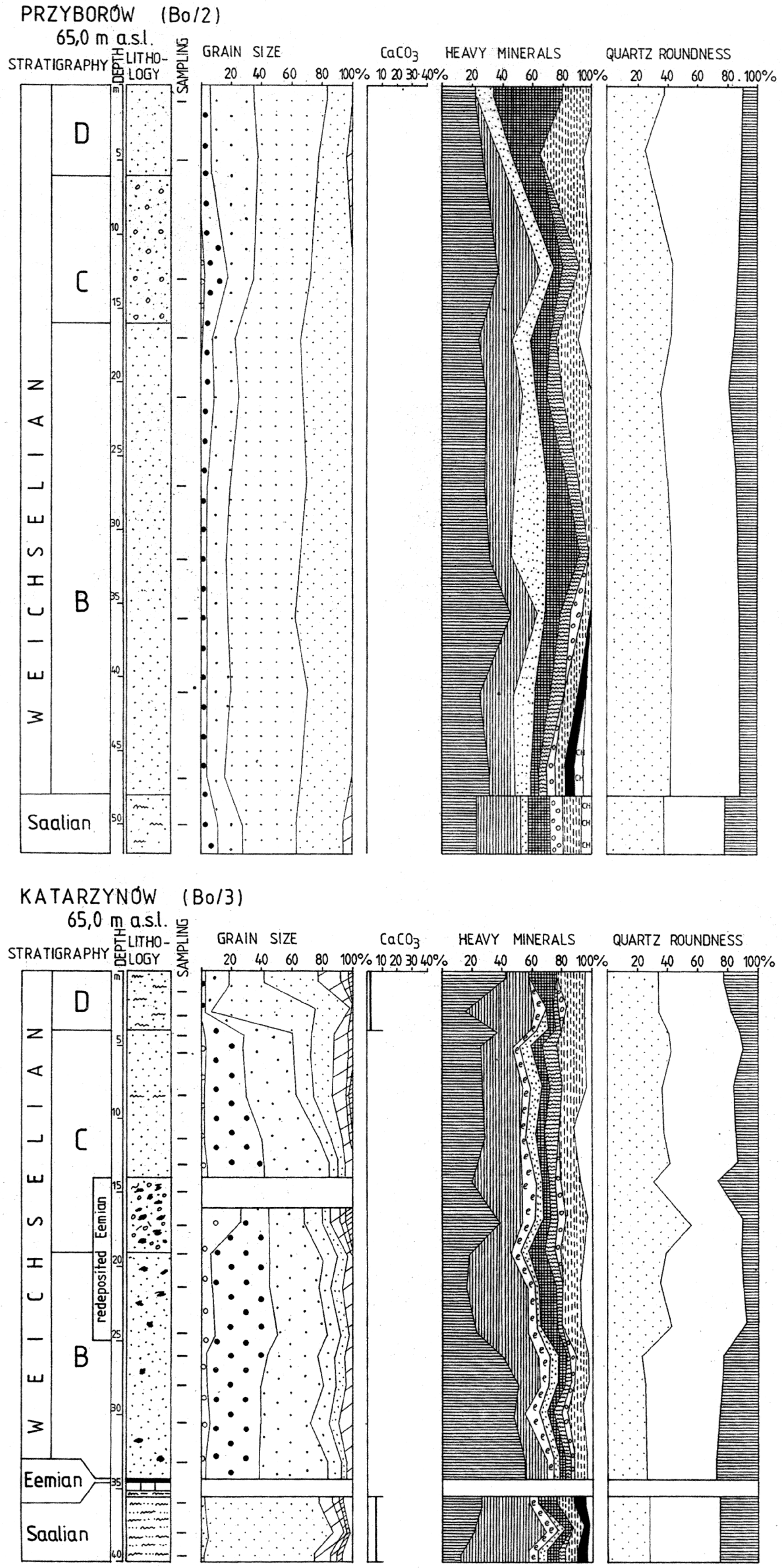

Fig. 8. Sedimentary logs, sediment properties and lithostratigraphy of Weichselian deposits at Przyborów and Katarzynów; note that the base of Weichselian sequence at Przyborów is at 17 m a.s.l. and the sequence is 48 m thick. Location of boreholes in Figure 2; captions in Figure 5

Table 2

Variability of granulometric characteristics of the Middle and Upper Weichselian Pleniglacial deposits along the Barycz and middle Odra river valleys

Sedimentary Unit	Western part of the Głogów Pradolina		Eastern part of the Głogów Pradolina		Żmigród Basin		Milicz Basin	
	M_z	σ	M_z	σ	M_z	σ	M_z	σ
C	1.4	1.9	1.5	0.7	2.5	1.6	2.6	1.2
B	2.0	1.2	1.8	0.6	3.4	1.5	3.5	1.7
A	–	–	–	–	4.4	2.0	4.1	1.6

M_Z – mean size, σ – sorting

Upper Pleniglacial Weichselian proglacial sandur and the Jarocin-Leszno Pradolina (Fig. 2).

The sediments of unit C are characterised by a high garnet content (up to 56%; average *ca* 40%) and the highest content of well-rounded quartz grains (up to 80%, average *ca* 50%) among the various fluvial units. Angular grains are usually less than <10% or do not occur at all (Figs 5–8).

Weichselian proglacial deposits (Unit G)

The Weichselian Upper Pleniglacial (Leszno Phase) glacially-derived fluvial deposits occur in the ice marginal tunnel valleys and sandurs (Kasprzak & Kozarski, 1989; Krzyszkowski & Gratzke, 1994) (Figs 2–4). They are represented by moderately to poorly sorted, medium- to fine-grained sands in the tunnel valleys, and coarse-grained sands and pebble sands in the sandur sequences (Table 1). The garnet content varies from 25% to 45% and the grain size characteristics and garnet content are very similar to those of Unit C of the Głogów Pradolina, except that the sediments of the sandur are coarser (Tables 1 and 2). The quartz grain characteristics are, however, markedly different, being less well rounded up (25–30%), with a high content of angular quartz grains (usually 20–35%, in contrast to extraglacial fluvial deposits with less than 20%) (Table 1).

Interpretation and correlation of deposits

The valley-fill sediment succession (units A, B and C) and mineralogical features are very similar to those found in the well-dated Weichselian sequences of the Bełchatów outcrop (Goździk, 1980, 1995; Krzyszkowski, 1990a,b, 1998; Goździk & Zieliński, 1996) and other Weichselian sequences of central Poland (Goździk, 1981; Pazdur *et al.*, 1981; Rotnicki, 1987; Turkowska, 1988; Stankowski & Krzyszkowski, 1991). In central Poland, the valley-fill succession is threefold, with thick massive to finely laminated silts at the base (equivalent to unit A), sands with silty beds in the middle (equivalent to unit B), and sands and gravels at the top (equivalent to unit C). The age of these sediments is Middle and Upper Weichselian Pleniglacial, as indicated by radiocarbon dating (Kozarski, 1980; Pazdur *et al.*, 1981; Rotnicki, 1987; Krzyszkowski, 1990a, 1998). The same age of valley-fill sequences has been discovered in SW Poland, as the organic beds have been dated back to 46,100 ± 1800 yrs BP (Gd-7252) at the base of sub-unit A_1 to ca 25,900 ± 700 yrs BP (Gd 6790) in sub-unit A_2, and 20,800 ± 600 yrs BP (Gd 6787) from the upper part of Unit B (Fig. 6; Table 3). Also, there is usually a progressive increase of garnet and well-rounded quartz in the younger units, with maximum values, *i.e.* the largest aeolian supply, in the coarsest deposits (Unit C; Table 1) in both regions. In central Poland, the Middle and Upper Pleniglacial deposits are usually superposed by Lateglacial aeolian coversands, dunes and related deposits. Along both the Barycz and Odra river valleys, dunes have been observed commonly at the top of Weichselian Pleniglacial terrace (Pernarowski, 1958) and the Lateglacial fluvial terrace (Unit D in Figs 3–8).

It is quite difficult to interpret the type of fluvial regime and dominating processes from a few boreholes. The borehole logs contain only limited sedimentological data, and lack information about lateral erosion and facies transitions. However, great similarity among the sediment successions and valley gemorphology of SW and central Poland, as well as their position in the same intermediate palaeogeographical zone, suggests that the fluvial processes were similar, if not the same. Hence, the interpretation of the Weichselian Middle and Upper Pleniglacial sedimentary environments of SW Poland will be supplied by data from well-exposed sections of the Bełchtów outcrop in central Poland (Krzyszkowski, 1990a, 1991, 1998; Goździk, 1980, 1995; Goździk & Zieliński, 1996). It is commonly accepted that vertical aggradation dominated during the Weichselian Pleniglacial in central Poland, with limited channel facies and complete absence of lateral erosion and deposition. In contrast, in SE Poland (loessic zone), is lateral channel migration of sinuous rivers occurs (Starkel, 1995; Starkel *et al.*, 1999).

The massive and laminated silts (equivalent of Unit A) represent either a shallow lake or a floodplain (Krzyszkowski, 1990b, 1998; Goździk & Zieliński, 1996), which in part may represent redeposited loess (loess fraction content is up to 30–40%) (Goździk, 1995). The organic deposits of this unit may represent swamps, either from near-shore parts of lakes or from floodplain basins. The sandy-silty sediments (equivalent of Unit B) were deposited in a fluvial environment, where the sands may represent the channel zone and/or high-energy flood deposits of the main channel, and the silty and organic beds floodplain or lateral-marginal flood deposition. Krzyszkowski (1990a, 1991) suggested that the Weichselian Pleniglacial sandy-silty deposits in central Poland were formed in a highly aggrading, ephemeral river system of semi-arid climate. In the Barycz and middle Odra river valleys, the downvalley increase in stream energy may also be assumed from the grain size characteristics (Table 2). The sandy sediments (equivalent of Unit C) were deposited in a high-energy fluvial environment. Krzyszkowski (1990a, 1991), suggested that the coarse-grained units of the Weichselian Pleniglacial successions were formed by highly aggrading, ephemeral to braided rivers of arid climate. Also, the deposits of Unit C of the Barycz and middle Odra river valleys indicate a downstream increase in water discharge. The occurrence of coarser material in units B and C of the Głogów Pradolina (Table 2) may suggest that this part of the valley represented the main river of the region, i.e. the Odra River, being presumably characterised by a larger water discharge than local rivers of the Milicz and Żmigród basins (Figs 1 and 2). Moreover, an additional supply of coarse material from the Jarocin-Leszno Pradolina or directly from proglacial streams is also possible during the deposition of unit C (Fig. 2).

POLLEN ANALYSIS

The material for pollen analysis was prepared in two ways. The silty deposits were at first boiled in HF and the organic deposits in 10% KOH, both were acetolized using Erdtman's (1943) method. Ninety-one samples from four profiles were analysed: Suliradzice, Dyminy, Blizocin and Nowe Domy, although only fifty-one samples contained significant pollen for interpretation. The percentage calculation was based on the pollen sum of trees, shrubs, dwarf shrubs and herbs plants (AP + NA). Aquatic plants and cryptogams were excluded from the basic sum (AP +NAP). The results of analyses are presented in Figures 10–13.

Description of local pollen assemblage zones (L PAZ)

Suliradzice

Analyses of the massive silts and organic deposits were carried out at depths of 39.25–38.00 m, 36.10–34.10 m, 32.40–32.10 m, and 9.85–9.60 m (Fig. 5). Only organic deposits (peat) at 36.00–35.90 m and 9.80–9.60 m did contain pollen and the pollen assemblages are presented in diagram Figure 9.

S-(1) Pinus L PAZ (depth 36.0–35.9 m). This zone contains up to 78.1% *Pinus*. *Betula* and *Picea* are characterised by very low frequencies, 4.5% and 1.1%, respectively. NAP ranges between 19.0–24.45%, where Poaceae and Cyperaceae predominate and *Valeriana officinalis* has a low frequency. *Sphagnum* and Polypodiaceae occur sporadically.

S-(2) NAP-Pinus L PAZ (depth 9.80–9.75 m). This pollen zone is characterised by high frequency of *Pinus* (46%) and herbaceous plants (49%). *Betula* is 4.5%, *Larix* 3.2% and *Juniperus* 0.3%, but *Picea* is absent. Among the herbs, Cyperaceae and Poaceae predominate.

S-(3) NAP (Cyperaceae-Poaceae) L PAZ (depth 9.75–9.60 m). This pollen zone is dominated by herbs (60–70%). Among them Cyperaceae (max. 31.1%) and Poaceae (18.6%) are dominant, although heliophytes are also very frequent, with *Artemisia* up to 15.6% and less frequent Caryophyllaceae, Chenopodiaceae, Asteraceae and *Helianthemum*. Among other herbs, Ericaceae and *Thalictrum* are quite common. Trees are infrequent, with only *Betula* (max. 10.1%) and *Pinus* (max. 27.9%). Some aquatic plants are present, as *Typha-Sparganium* and *Sagittaria*, as well as *Equisetum*, which reaches up to 20.4%.

Dyminy

Pollen analysis was carried out in the massive silts and organic deposits at 34.5–32.84 m (Fig. 5). Pollen material was present only in finely laminated peat and sand at 33.48–32.84 m (Fig. 10).

D-(1) NAP-Pinus L PAZ (depth 33.48–33.40 m). This pollen zone is characterised by a high frequency of herbs (max. 46.5%), with abundant trees, mainly *Pinus* (max. 48.2%) and *Betula* (8.2%). Among other trees, some *Larix*, *Picea* and *Juniperus* pollen occur. Herbs are represented mainly by Poaceae , Cyperaceae and *Artemisia*.

D-(2) Pinus-Picea L PAZ (depth 33.40–32.84). This pollen zone is *Pinus* dominated (88.9%). Among other trees, *Picea* (8.9%) and *Betula* (7.9%) are frequent, and *Alnus* has a low-frequency (<1%), but continuous presence. *Larix* and *Salix* occur sporadically. Herbs are represented mainly by Cyperaceae and Poaceae, ranging between 2.1% and 17.3%. Polypodiaceae are common, as well as *Sphagnum* among swamp plants.

Nowe Domy

Pollen analyses were carried out in the massive silts and sandy silts at 16.0–5.6 m. Only some fragments of this profile contained pollen (Fig. 6): 15.5–15.2 m, 13.0–12.4 m, 11.0–10.3 m, 9.4–9.5 m, and 8.9–8.7 m (Fig. 11). Two different pollen zones have been distinguished: the lower one at 15.5–15.3 m, and the upper one, comprising a fragment between 15.3 and 8.7 m with similar floras.

N-(1) Pinus-Picea L PAZ (depth 15.5–15.3 m). This zone is *Pinus* dominated (up to 86%), with frequent *Picea* (5.1%) and *Betula* (8.2%); and low but continuos *Alnus* has a low (<2%). *Abies* and *Salix* occur sporadically. Herbs are represented mainly by Cyperaceae and Poaceae, ranging between 2.8% and 11%. Polypodiaceae are relatively common.

N-(2) NAP-Pinus L PAZ (depth 15.3–8.7 m). This pollen zone is characterised by a high frequency of NAP, up to 55.1%. The tree pollen are dominated by *Pinus* (33.0–82.0%) and *Betula* (5.6%–27%). *Picea* and *Alnus* are relatively common (1–2%) but *Larix*, *Abies*, and *Salix* occur only sporadically. Among the herbs, Poaceae and Cyperaceae are dominant with small admixture of *Artemisia* (1–2%). Polypodiaceae are common (up to 21%) as well as *Sphagnum* among swamp plants.

Blizocin

Pollen analyses were carried out in the massive silts and sandy silts at 17.6–8.4 m. Only some fragments of this profile contained pollen (Fig. 6), *i.e.* massive silts at 17.6–17.4 m, 14.0 m, 11.8–11.6 m, and 9.2 m, all of them indicating

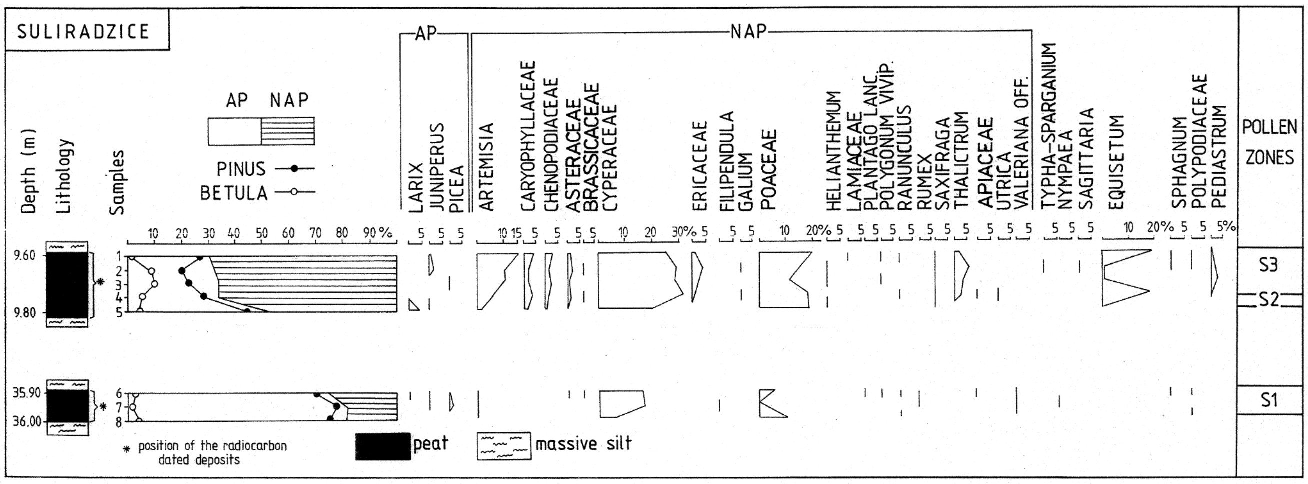

Fig. 9. Pollen diagram of Weichselian organic deposits at Suliradzice, Milicz Basin, SW Poland

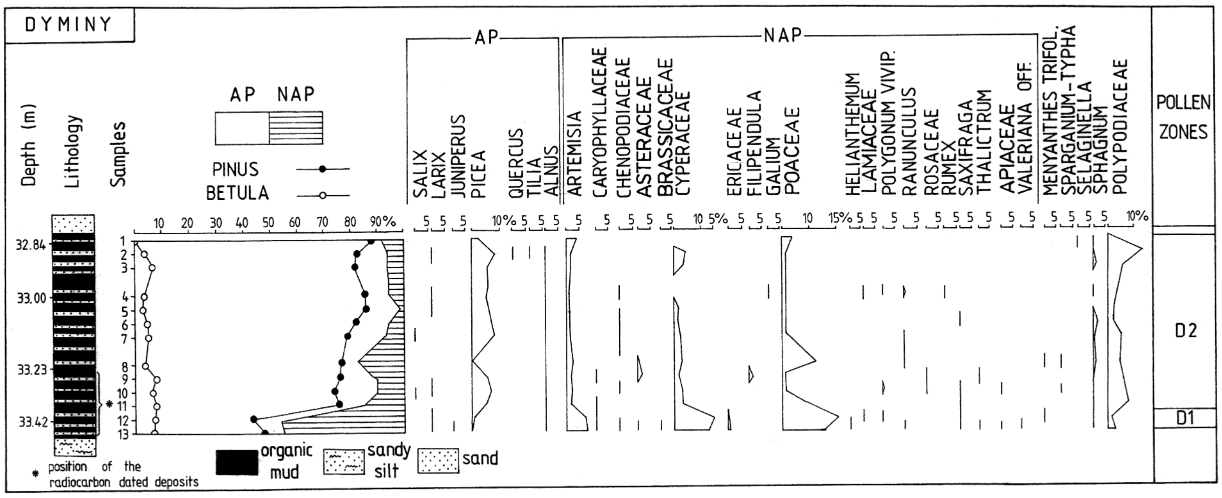

Fig. 10. Pollen diagram of Weichselian organic deposits at Dyminy, Milicz Basin, SW Poland; note that radiocarbon dated sediments are located in the lower part of the organic bed, *i.e.* at the lower boundary of the Dyminy Interstadial

similar floras, and silts with thin organic layers at 8.9–8.4 m, with a slighty different pollen assemblage (Fig. 12).

B-(1) NAP-Pinus L PAZ (depth 17.6–9.2 m). This zone is characterised by a high frequency of NAP (45–60%) and *Pinus* (28–41%). *Betula* is up to 15.1% and *Alnus* up to 2.5%; *Picea* occurs only sporadically. Among herbs, Cyperaceae and Poaceae predominate, with Ericaceae up to 5.5% in one sample and with infrequent *Artemisia*, Chenopodiaceae, Caryophyllaceae and *Thalictrum* in almost all samples. *Selaginella selaginoides* is present in two samples and reaches up to 3%. Polypodiaceae and *Sphagnum* are also quite common.

B-(2) NAP (Poaceae) L PAZ (depth 8.9–8.4 m). This pollen zone is characterised by a high frequency of herbs (up to 73.3%). Poaceae are the most abundant, with frequent Cyperaceae and *Artemisia*, but Chenopodiaceae, Caryophyllaceae and *Thalictrum* are less frequent. *Pinus* reaches only 20–30% and *Betula* 5–6%. Other trees, such as *Alnus* and *Salix*, occur sporadically. Polypodiaceae and *Sphagnum* are also relatively frequent.

CORRELATION OF POLLEN DIAGRAMS AND CLIMATIC INTERPRETATION

It seems likely that pollen zones D2 and N1 (*Pinus-Picea*), S2, B1 and N2 (NAP-*Pinus*) and S3 and B2 (NAP) correlate with each other. This correlation is also in a good agreement with their lithostratigraphic position in the upper part of units A and B. Consequently, pollen zones D1 (NAP-*Pinus*) and S1 (*Pinus*) must be older (Fig. 13).

The sediments of the Sub-unit A_2 and Unit B most probably comprise a complete pollen succession from 25,900 ± 700 yrs BP to 20,800 ± 600 yrs BP. Even if strata with pollen data occur discontinuously throughout the profiles, the continuity of the pollen succession can be deduced from the positions of the D1/D2 and N1/N2 boundaries at the lower and upper parts of Sub-unit A_2 and from the very uniform floristic evidence throughout Unit B (Fig. 13). Moreover, other sites in central Poland and SE Germany that contain chronostratigraphic equivalents of Unit B are characterised by closely similar floristic evidence (Table 3) (Pazdur *et al.*,

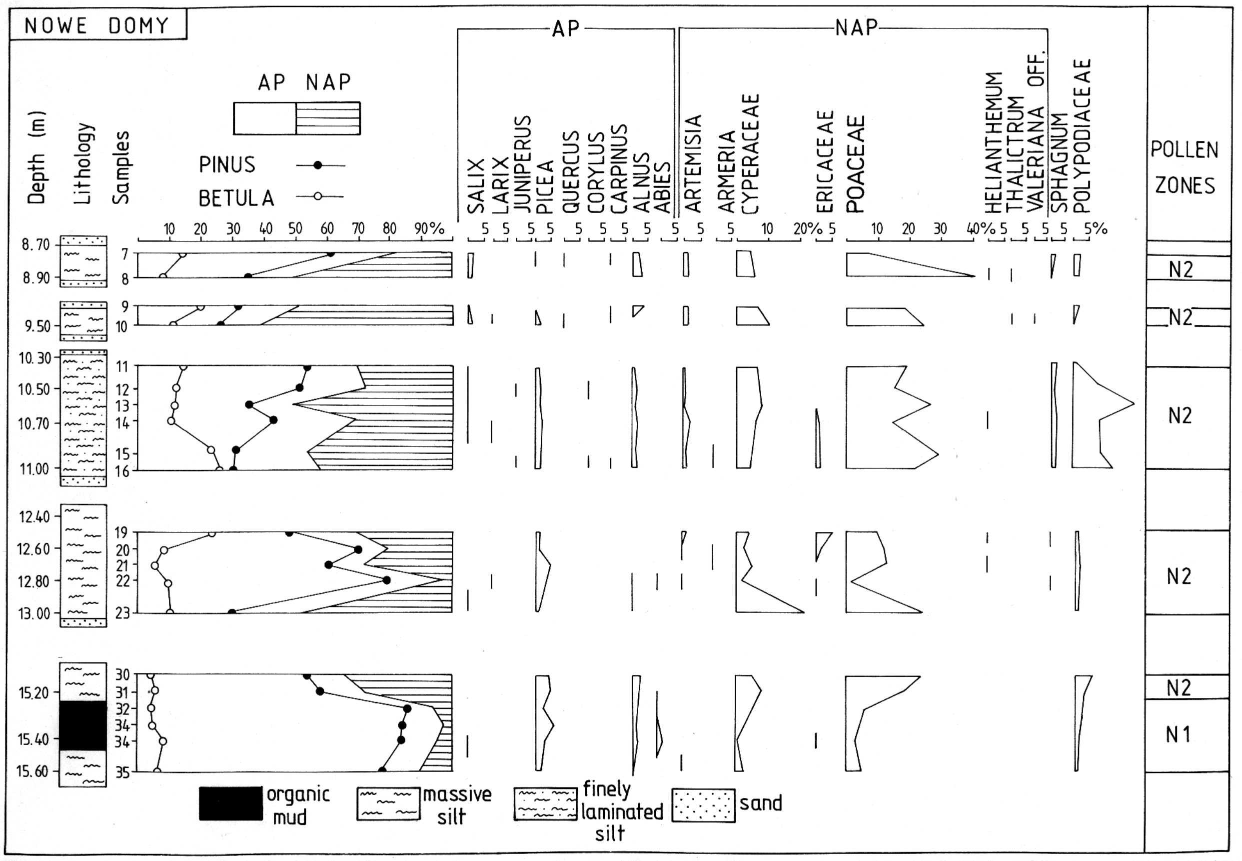

Fig. 11. Pollen diagram of Weichselian organic deposits and massive silts at Nowe Domy, Żmigród Basin, SW Poland

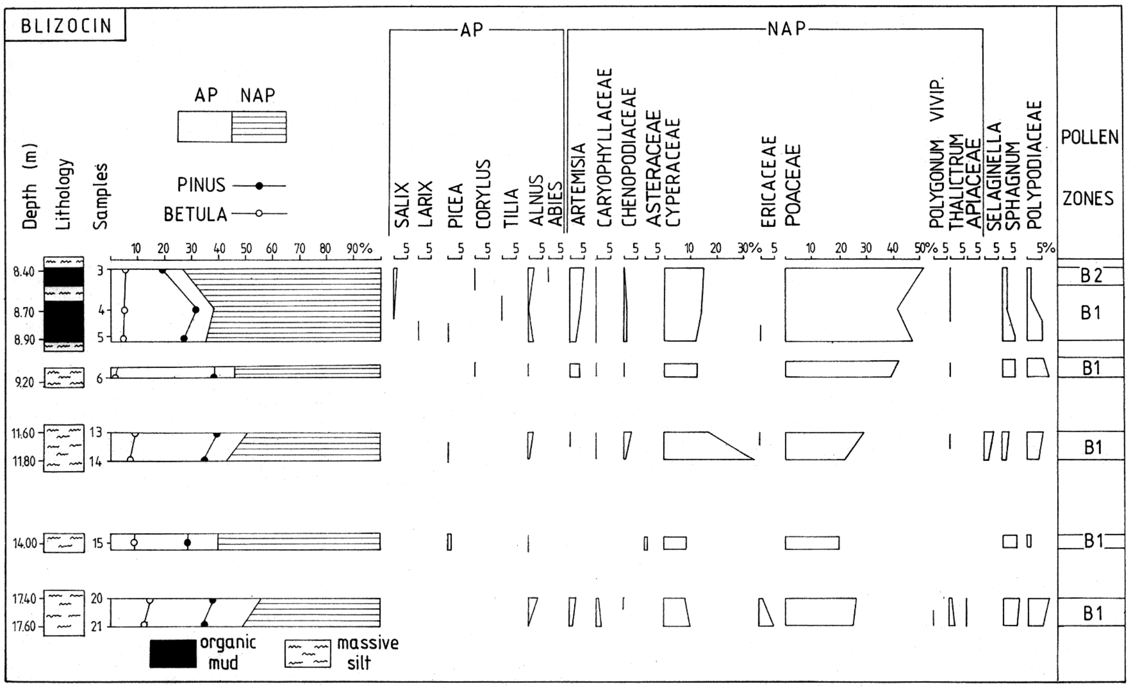

Fig. 12. Pollen diagram of Weichselian organic deposits and massive silts at Blizocin, Żmigród Basin, SW Poland

1981; Kozarski, 1981; Krzyszkowski *et al.*, 1993; Balwierz, 1995; Mol, 1997a,b; Kasse *et al.*, 2003). The pollen succession of Sub-unit A1 is incomplete and is represented from one organic bed dated to 46,160 ± 1800 yrs BP. Other organic layers in central and western Poland dated to the 43,700–26,900 yrs BP recorded floras different from the S1 pollen zone, generally indicating cooler conditions (Baraniecka, 1980; Kozarski, 1980; Pazdur *et al.*, 1981; Rotnicki

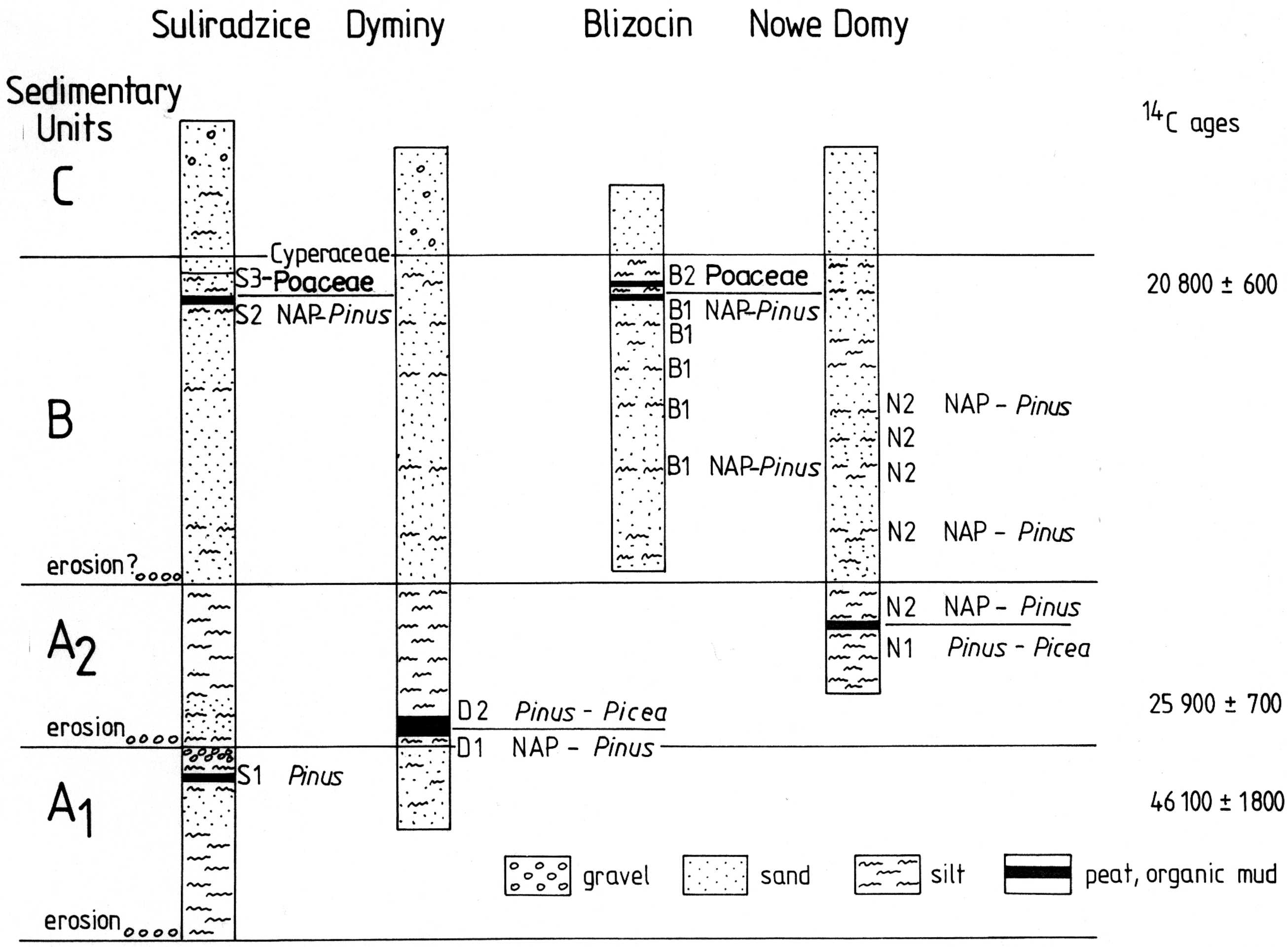

Fig. 13. Correlation of Local Pollen Assemblage Zones of the Weichselian sequences along the Barycz River valley and their lithostratigraphic position

& Tobolski, 1969; Krzyszkowski, 1990; Krzyszkowski *et al.*, 1993; Balwierz, 1995) (Table 3).

It follows from the above that the lowest part of Unit A (ca 46,000 yrs BP; Sub-unit A_1) was deposited during a relatively mild climate, with boreal forest to forest-tundra, which was characterised by complete absence of heliophytes (S1 pollen zone). This period most probably corresponds with the Moershoofd interstadial, which in SW Poland must have been slighty milder than in the Netherlands and Germany (Zagwijn, 1974; Behre, 1989). Correlation with Glinde Interstadial is less likely, as there is no substantial values of Ericaceae and more pine in the S1 pollen zone. Later, 44,000–27,000 yrs BP, climatic conditions were probably more severe, as indicated in central Poland (Table 3). This period was characterised by numerous climatic oscillations, where relatively milder periods (Hengelo and Denekamp interstadials) were characterised by shrub-tundra with common heliophytes or shrub-tundra with patches of birch forests, and cold periods represented sub-polar or polar deserts (no pollen, strong frost cracking, *etc.*).

In turn, much milder conditions could have occurred again slightly after 26,000 yrs BP (Sub-unit A_2). This period was characterised in SW Poland by pine-spruce boreal forest, with minor occurrences of alder and larch (pollen zones D-2 and N-1). This is the most temperate period in the sequence, which probably represents the last temperate period before the late Weichselian ice sheet advance to central Poland. This interstadial lasted approximately from 26,000 to 24,000 years BP. The above interpretation is based on only two sites with pollen records and a single radiocarbon dating, and thus is highly speculative. The radiocarbon dating of Dyminy profile may be inaccurate, as there are many Weichselian sites with reversed dates (Mamakowa & Środoń, 1977; Starkel, 1988; Starkel *et al.*, 1999; Krzyszkowski *et al.*, 1999). Also, such mild conditions have not been recorded during the Middle Weichselian Pleniglacial in Poland or elsewhere in central and northwestern Europe (Velichko, 1982; Huizer & Vandenberghe, 1998). However, there is some evidence to support a mild episode at that time. (1) There is a room for an interstadial period at around 26–24 kyrs BP, indicated by isotope measurements in Greenland (Dansgaard *et al.*, 1993) and the North Atlantic (Bond *et al.*, 1993). (2) An interstadial period at around this age occurred in Western Norway (Valen *et al.*, 1996). (3) There is at least one other site in SE Poland with documented forest to forest-tundra flora at around 26–24 kyrs BP (25,580±3,270/2,420; Łążek; cf. Mamakowa, 1968), although previously interpreted as older event in spite of dat-

Table 3

Age and type of vegetation cover at Weichselian sites with organic deposits in SW and central Poland

Radiocarbon date	Unit	Site	Other sites	Vegetation (pollen zones)
19,250 ± 310	**C**		Jaroszów	NAP-*Pinus*
	B	Suliradzice		Cyperaceae-Poaceae
20,800 ± 600		Blizocin		Poaceae
			Bełchatów	Poaceae
21,200 ± 220			Lublinek	Cyperaceae-Poaceae
21,720 ± 220			Konin-Maliniec	Cyperaceae-Poaceae
22,050 ± 450			Konin-Maliniec	Cyperaceae-Poaceae
22,230 ± 480		Blizocin		NAP-*Pinus*
		Nowe Domy		NAP-*Pinus*
	A$_2$		Bełchatów	Poaceae
24,590 ± 120		Nowe Domy		NAP-*Pinus*
				Pinus-*Picea*
25,900 ± 700		Dyminy		Pinus-*Picea*
				NAP-*Pinus*
35,000- 25,000	*hiatus*		Jaroszów	*Pinus-Betula-Picea*
26,430 ± 240			Bełchatów	Poaceae
26,900 ± 500			Bełchatów	Cyperaceae-Poaceae
29,200 ± 1,100			Bełchatów	Cyperaceae-Poaceae
31,400 ± 1,100			Kępno	NAP-*Betula*
32,700 ± 900			Bełchatów	Cyperaceae-Poaceae
32,600 ± 1,300			Bełchatów	Cyperaceae-Poaceae
33,900 ± 2,600			Bełchatów	Cyperaceae-Poaceae
31,800 ± 700			Bełchatów	Cyperaceae-Poaceae
33,800 ± 2,000			Bełchatów	Cyperaceae-Poaceae
33,370 ± 600			Scheibe	Cyperaceae-Poaceae
> 42,900	**A$_1$**		Konin-Maliniec	NAP-*Betula*
> 42,500			Konin-Maliniec	NAP-*Betula*
43,700 ± 3,700/2,400			Bełchatów	NAP-*Pinus*
> 44,600			Scheibe	Cyperaceae-Poaceae
46,160 ± 1,800		Suliradzice		*Pinus*

ing. (4) Krzyszkowski *et al.* (1999) have suggested that the entire period 35–25 kyrs BP in the loessic zone of SW Poland was characterised by the occurrence of at least patches of boreal forest or forest-tundra (Jaroszów, Sudetic Foreland; Fig. 1, Table 3). Site Dyminy lies only 60–70 km north of Jaroszów (Fig. 1), and thus the occurrence of boreal forest conditions shortly before the final advance of the Scandinavian ice sheet is not impossible.

At the end of the deposition of Sub-unit A$_2$ (pollen zone N-2), climatic conditions became severe and continued throughout Unit B (ca 25,000–22,000 yrs BP), with tundra or shrub tundra. A relatively high content of pine pollen in the zones N-2 and B-1 may have been due to long-distance wind transport or local redeposition. Grass tundra dominated in the region at around 21,000 yrs BP (the uppermost part of Unit B), with mainly Poaceae, Cyperaceae and *Artemisia* and some other heliophytes. Finally, the climate in the Barycz River region became very severe (sub-polar or polar desert), as Unit C does not contain any pollen, probably indicating absence or very scarce vegetation at that time (Fig. 13). At Jaroszów, climatic conditions were much milder at around the same time, enabling the formation of shrub tundra or even shrub tundra with patches of pine-birch forest (Krzyszkowski *et al.*, 1995, 1999) (Table 3).

DISCUSSION

The Weichselian sequences of the Suliradzice Formation indicate two, possibly three, phases of erosion separated by valley aggradation (Fig. 13). The initial phase of erosion, which resulted in removal of a large part of the late Saalian and Eemian deposits and formation of a new valley system, took place before 46,100 ± 1800 yrs BP (Fig. 5). This erosion cannot be older than the Early Weichselian, as a complete Eemian succession has been documented below Weichselian deposits at Lechitów (*Pinus* zone; Malkiewicz, 1998) (Figs 4 and 6). Several other Eemian sites in central Poland document continuous sedimentation from the early Eemian to the Odderade Interstadial (Jastrzębska-Mamełka, 1985; Goździk & Balwierz, 1993), suggesting that the major erosion phase throughout Poland occurred during the Lower Pleniglacial (*ca* 75,000–60,000 yrs BP) (Krzyszkowski, 1990a).

The next erosion phase along the Barycz River valley occurred before 25,900± 700 yrs BP, as an organic bed of this age is present just above the A$_1$/A$_2$ erosional boundary. However, the age of this erosion phase can not be established precisely, yet. At Bełchatów, Krzyszkowski (1990a, b, 1991) and Krzyszkowski *et al.* (1993) recognised one major Middle Pleniglacial erosion phase at around 27,000 yrs BP and the second one, far less documented, at around 40,000 yrs BP. The 27 kyr BP erosion phase has also been identified in the Prosna River valley (Rotnicki, 1987), Konin area (Kozarski, 1980; Pazdur *et al.*, 1981), and at Jaroszów (Krzyszkowski *et al.*, 1999). The 40 kyr BP erosion phase has been recognised at Bełchatów and Jaroszów only (Krzyszkowski *et al.*, 1999). Current dating of the sequences suggests that the erosion phase in the Barycz River valley may represent either a 27 kyr BP or a 40 kyr BP event.

The youngest erosion phase took place after 25,900 ± 700 yrs BP but before Unit B was deposited (Fig. 5), possibly at around 22/23 kyrs BP, as an erosional phase of this age has been commonly documented in central Poland (Kozarski, 1980; Pazdur *et al.*, 1981; Rotnicki, 1987; Krzyszkowski, 1990a,b, 1991; Krzyszkowski *et al.*, 1993).

All the erosion phases took place during severe climatic conditions favourable to either polar desert (Lower Pleniglacial) or shrub tundra (NAP-*Pinus* pollen zones; erosion at the A_1/A_2 and the A_2/B boundaries; Fig. 13, Table 3). The youngest erosion phase incised less deeply than the previous phases. The middle erosion phase cut less deeply in the Milicz and Żmigród basins but more deeply in the Głogów Pradolina than the first erosion phase, as indicated by the preservation of Unit A in the former and its removal in the latter basin (Figs 3 and 4). The deepest erosion cut down to 17 m a.s.l. near Przyborów (Fig. 4), i.e. 50 m below the present-day valley surface and *ca* 60–70 m below the Late Saalian till plateau.

The Weichselian aggradation phases were usually connected with periods of relatively mild climate (S-1 pollen zone, lower part of A_1 Sub-unit; D-2/N-1 pollen zone of A_2 sub-unit), but the final aggradation phase occurred during severe climatic conditions (units B and C) (Fig. 13). Hence, the former aggradations may have occurred during interstadials (Fig. 14A/B), but the last one occurred during the late Weichselian ice sheet advance into central Europe (Fig. 14C).

The phases of Weichselian Pleniglacial erosion and aggradation in Poland correlate surprisingly well with the glaciation curve for Scandinavia (Larsen *et al.*, 1987; Mangerud, 1991a, b; Larsen & Sejrup, 1990; Valen *et al.*, 1995, 1996). The ice-sheet oscillations in Fennoscandia correspond well with global changes in the sea level and ice volumes during the Early and Upper Pleniglacial Weichselian (Martinsson *et al.*, 1987), but also indicate several short-term ice-sheet advances during the Middle Pleniglacial. These short ice-sheet advances occurred around 40,000 yrs BP (Andersen *at al.*, 1981) and 27,000–25,000 yrs BP (Valen *et al.*, 1996) (Fig. 15). Thus, the initial Polish Weichselian erosion phase can be correlated with the Lower Pleniglacial ice-sheet build-up (Schalkholz Stadial) and low sea level at that time (– 60 m; Chappel & Shackleton, 1986). By analogy, the erosion phases around 40 kyrs BP and 27 kyrs BP may be correlated with other phases of build-up of the Scandinavian ice-sheet (Fig. 15). Ice-free conditions in southern Baltic and northern Poland areas are, however, suggested for these time spans. The Middle Pleniglacial aggradation in SW and central Poland may have occurred during the mild periods dated to about 60–41 kyrs BP (Oerel, Glinde and Moershoofd interstadials), 39–27 kyrs BP (Hengelo and Denekamp interstadials) and 25–24 kyrs BP (Dyminy Interstadial), which were characterised by substantial ice sheet retreat in Scandinavia. The last period of erosion (22/23 kyrs BP) is connected with the build-up phase of the Upper Pleniglacial Weichselian ice sheet. The subsequent southward advance of the ice sheet impeded outflow of rivers, leading to the general cessation of erosion and increased aggradation in valleys (deposition of Unit C of the Suliradzice Formation; *ca* 20,000 yrs BP; Fig. 14C). During this ice sheet advance, the majority of Lower and Middle Pleniglacial valleys of northern Poland were destroyed due to glacial and glaciofluvial erosion (Fig. 3F-F`). Only few valleys are preserved, with the best example at Konin-Maliniec (Pazdur *et al.*, 1981; Kozarski, 1980; Stankowski & Krzyszkowski, 1991). In the latter case, an equivalent to Unit C of the Suliradzice Formation is a till (Maliniec Till; Czerwonka & Krzyszkowski, 1994; Krzyszkowski, 1994). The sediments of this unit interdigitated with glacial deposits of the ice-proximal zone (Figs 3 and 4) or contained a large admixture of glacial deposits (Table 2), indicating that they were formed at the front of the ice-sheet when it was at its maximum southerly position near Leszno (Figs 2 and 14C). Thus, the abundant occurrence of coarse-grained material in Unit C may reflect not only a climatic influence on river discharge (Krzyszkowski, 1990a, 1991) or position along a large river, but may also reflect an input of coarse-grained glacial material transported to the extra-glacial valley directly from proglacial sandur or along the Jarocin-Leszno Pradolina (Fig. 14C). At that time, rivers must have flown to the west, forming the Głogów-Baruth Pradolina system (Figs 1 and 14C). The aeolian cover from the top of the Suliradzice Formation formed during deglaciation, being partly correlative with erosion and deposition in the Warsaw-Berlin Pradolina fluvial system (roughly 19,000–18,000 yrs BP; Kozarski, 1986). A terrace level connected with the Warsaw-Berlin Pradolina has been observed in the northwestern part of the study area (Figs 4 and 14D), but its occurrence and extent upstream is not well documented.

The model of Weichselian Pleniglacial erosion and aggradation presented here assumes that erosion took place during the cold stages (ice sheet build-up) (Fig. 15). The incision during each phase, except the last, interrupted cold stage, was from several metres to more than 50 m. Incision increased downstream, at least along the Barycz and Odra river valleys (Fig. 4). The cause of these deep regional incisions is an open question. Possible causes include: climate (cold, arid), local lowering of base level (*e.g.* low water level in the isolated lake of the southern Baltic basin) or regional uplift (forebulge effect). Further discussion and comparisons with more western and eastern Weichselian successions are necessary.

This and other successions from the Weichselian intermediate palaeogeographical zone in Poland do not confirm the presence of short-term climatic events that may be related to Dansgaard-Oeschger events. This is in contrast to loessic zone and fluvial systems in NW Europe (Hatte *et al.*, 1988; Vandenberghe *et al.*, 1998; Vandenberghe, 2003).

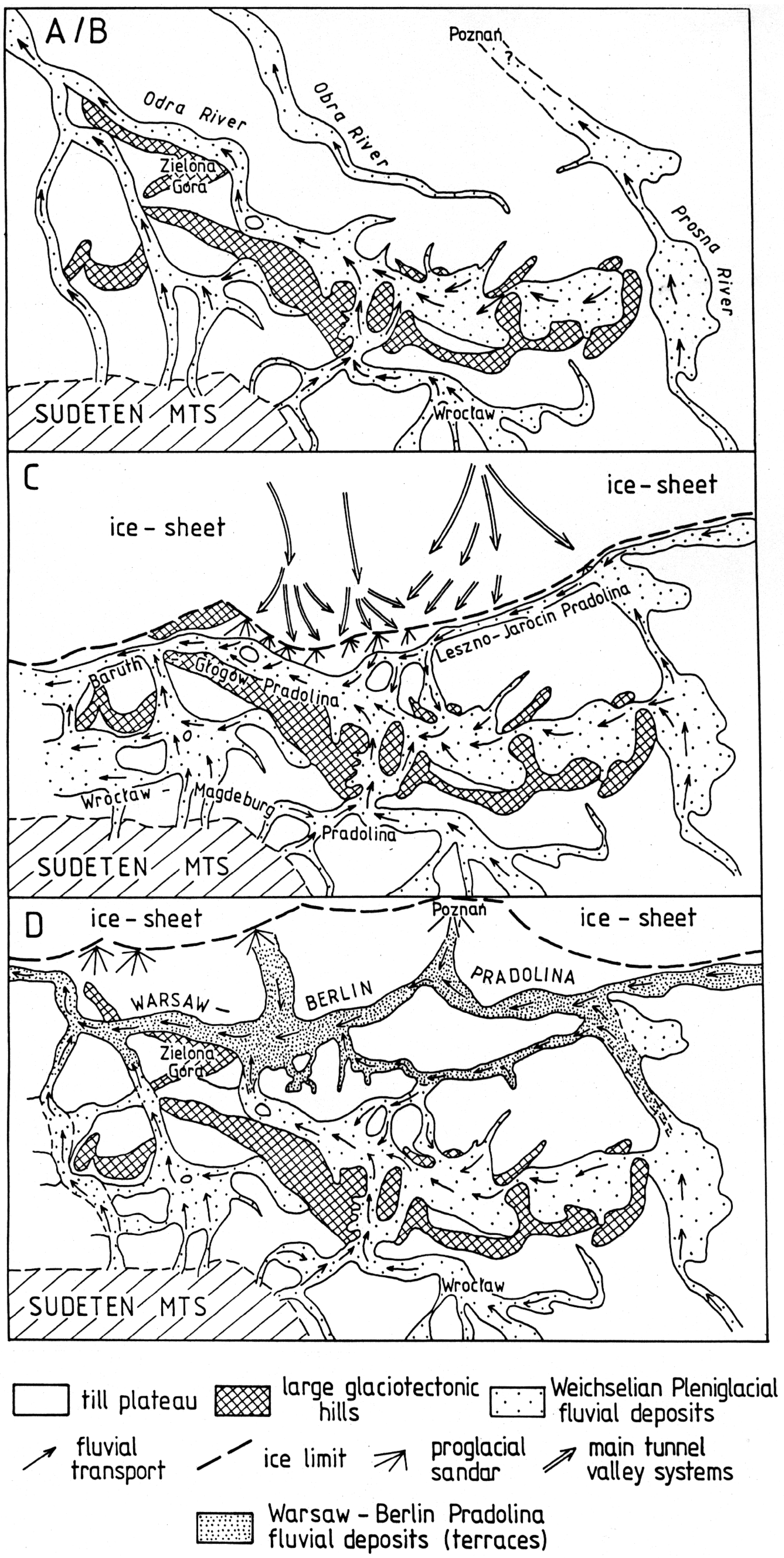

Fig. 14. Evolution of the Weichselian fluvial system in SW Poland: A/B – Lower to early Upper Pleniglacial (Units A and B), drainage to the western Baltic and/or North Sea; C – maximum extent of ice sheet during the Leszno-Brandenburg phase (Unit C; 20,000 yrs BP), drainage was along the Baruth-Głogów Pradolina supplied by subglacial water (position of tunnel valleys after Czerwonka & Krzyszkowski, 1994); D – late Upper Pleniglacial, ice sheet retreat to Poznań-Frankfurt phase position, drainage along the Warsaw-Berlin Pradolina. See also discussion in the text

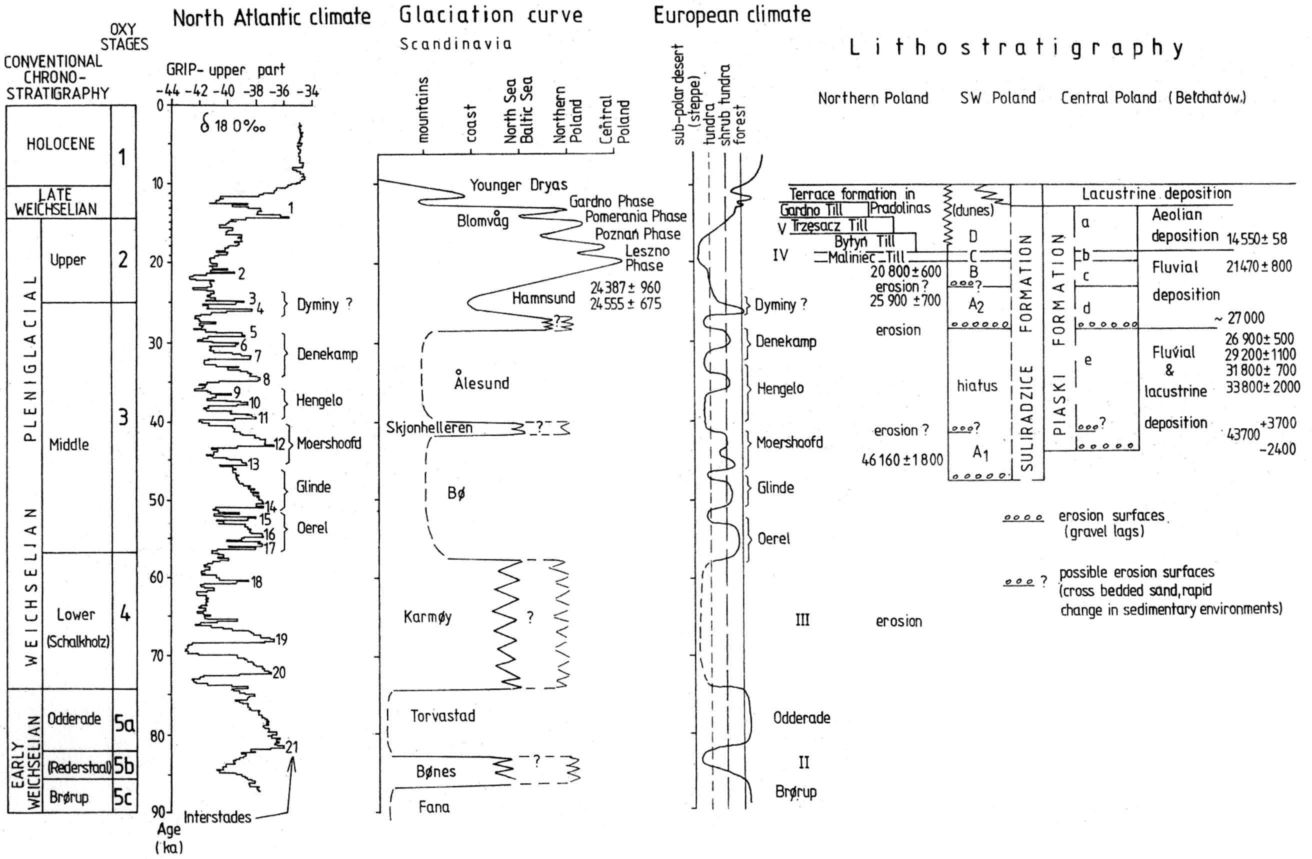

Fig. 15. Correlation of phases of erosion and aggradation in SW and central Poland with global climatic oscillations and Scandinavian ice sheet history. Greenland climatic curve after Bond *et al.* (1993); tentative correlation with European climatic curve after Behre (1989), modified according to Polish data; see discussion in the text. Glaciation curve after Mangerud (1991ab) and Valen *et al.* (1995, 1996), modified for Poland during the Weichselian Upper Pleniglacial

However, while it is possible that the climatic oscillations in SW and central Poland can be correlated with North Atlantic events, they may reflect rather longer-term cooling cycles (Bond *et al.*, 1993). The possibility of a new interstadial period at around 26–24 kyrs BP fits well with this suggestion (Fig. 15). The rare occurrence of deposits of this interstatial were removed during the subsequent erosional phase, but fortunately were presered occasionally.

The occurrence of a mild interstadial at around 26–24 kyrs BP at Dyminy (intermediate zone) and permanent mild conditions during the late Middle Pleniglacial (35–25 kyrs BP) at Jaroszów (loessic zone) in SW Poland may imply stronger north-south climatic gradients at those times. It appears that during the Weichselian Upper Pleniglacial ice sheet advance into the southern Baltic/northern Poland area, there were still patches of boreal forest in SW Poland, and consequently not a very severe climate. Only during the maximum extent of the ice sheet (20 kyrs BP) did the climate become extremely severe. On the other hand, evidence from Bełchatów, from two organic beds dated to 26,430 ± 240 and 24,590 ± 120 yrs BP, suggests extremely harsh, treeless climatic conditions (Kasse *et al.*, 1998). This dicrepancy may be explained in any of three ways: (1) there was no mild interstadial in SW Poland and radiocarbon dating at the Dyminy is wrong; (2) the interstadial was very short, lasting 1,000 years or less, and occurring within cold events documented at Bełchatów (25,900 ± 700 yrs BP); (3) there was a strong west-east climatic gradient in the intermediate palaeogeographical zone, with SW Polish sites belonging to the more mild, maritime sector, and those from central Poland and more eastern regions belonging to the more severe, continental sector. Further investigations should elaborate this problem in greater detail, but new sequences with deposits with radiocarbon dates at around 26–24 kyrs must be found.

CONCLUSIONS

It seems likely that despite incomplete record, the data from SW Poland have important implications requiring further investigation:

1. The sequence of the Weichselian sediments and processes in SW Poland are almost indentical to those of central Poland. Generally, three units occur showing progressive coarsening upwards of deposits (silts, sands and silts, sands and gravels), with aeolian deposits on top. This suggests very uniform processes throughout the intermediate palaeogeographical zone, *i.e.* the zone between the strong loess deposition in the south and the glacial deposition in the north.

2. The Weichselian valley-fill sequences of SW and

central Poland contain mainly fluvial deposits, with local lacustrine and aeolian deposits. A large aeolian admixture is observed throughout the sequences, especially in their younger parts. The fluvial sequences are punctuated by at least three major erosional phases, characterised by similar incision depths. Consequently, different valleys preserve sequences of various ages, although generally the succession of sedimentary environments, floral succession, and degree of aeolian activity indicate a gradual climatic deterioration (successively documented in Units A, B, and C).

3. Climatic conditions during the Weichselian Middle and Upper Pleniglacial in SW Poland were similar to those in central Poland and northwestern Europe (Huizer & Vandenberghe, 1998; Vandeberghe, 2003). It seems likely, however, that the Moershoefd Interstadial (47–43 kyrs BP) was a little bit milder in SW Poland (shrub tundra, forest-tundra). On the other hand, the climatic conditions during periods 38–27 kyrs BP and 23–18 kyrs BP were very uniform throughout the intermediate zone of central Europe, including SW Poland. However, it is likely that there was strong north-south climatic gradient during 38–27 kyrs BP period, as data from loessic zone in SW Poland indicate at least patches of boreal forest or forest-tundra conditions at that time.

4. A new Middle Weichselian interstadial is documented at two sites in SW Poland. Its lower age boundary is 25,900 ± 700 years BP. It is characterised by *Pinus-Picea* forest and no heliophytes. This interstadial represents the last mild period before the advance of the late Weichselian ice sheet into SW Poland (26–24 kyrs BP), and may be correlated temporarily with the Hamnsund Interstadial in western Norway. Whether the occurrence of such a mild interstadial of this age in Poland is possible or not must be proved by further investigations.

5. Erosion in the Weichselian valleys of SW and central Poland took place during the cold stages, with certainty at around 75–60 kyrs BP (Lower Pleniglacial) and 27 kyrs BP, very probably at around 23/22 kyrs and possibly at around 40 kyrs BP, and valley aggradation occurred during the milder stages, respectively. The Upper Pleniglacial was characterised by valley aggradation, connected with southward ice sheet advance and limited outflow (ice marginal Pradolina valley system).

6. It is likely that frequent Weichselian Middle Pleniglacial climatic oscillations did not initiate sedimentation and erosion. They only controlled river discharge and type of fluvial sedimentation and aeolian activity. The occurrence of erosion to aggradation phases are controlled rather by the changes in ice volumes in Scandinavia, ice sheet build-up and retreat, respectively.

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Streszczenie

FAZY SEDYMENTACYJNE I EROZYJNE ŚRODKOWEGO I GÓRNEGO PLENIVISTULIANU ORAZ ICH ZWIĄZEK Z TRANSGRESJĄ I REGRESJĄ LĄDOLODU SKANDYNAWSKIEGO W POŁUDNIOWO-ZACHODNIEJ POLSCE

Dariusz Krzyszkowski & Teresa Kuszell

Przedstawione w niniejszej pracy wyniki badań dotyczą zmian paleośrodowiskowych podczas pełnego vistulianu w południowo-zachodniej Polsce. Podstawą przeprowadzonych badań były osady pochodzące z 20 profili otworów wiertniczych. Analizowany obszar usytuowany jest wzdłuż doliny Baryczy i dorzecza środkowej Odry, pomiędzy Odolanowem i Konotopem. Obejmuje on trzy duże baseny rzeczne: milicki, żmigrodzki i Pradoliny Głogowskiej. Dwa pierwsze baseny zajmują powierzchnię około 40×60 km, natomiast basen trzeci ma około 100 km długości i 20–30 km szerokości. Badania geomorfologiczne i litologiczno-petrograficzne oraz datowania radiowęglowe w laboratorium ^{14}C w Gliwicach pozwoliły na przedstawienie szczegółowej chronostratygrafii osadów zachowanych w zbiornikach sedymentacyjnych. W sekwencji środkowego i górnego plenivistulianu można wyróżnić trzy jednostki sedymentacyjne pochodzenia rzecznego. Obejmują one mułki i piaski przechodzące ku górze w osady o większym stopniu uziarnienia (muły, piaski, żwiry) oraz osady pochodzenia eolicznego, występujące w najwyższym poziomie.

Warunki paleogeograficzne oraz procesy związane z powstaniem tych osadów są prawie identyczne, zarówno w południowo-zachodniej jak i centralnej Polsce. Plenivistulian był najdłuższym i zarazem najgłębszym kryzysem klimatycznym całego vistulianu. Znaczna część południowo-zachodniej Polski była w tym czasie zajęta przez doliny rzeczne, które ukształtowały się po interglacjale eemskim, we wczesnym vistulianie. Zmiana warunków klimatycznych na przełomie wczesnego i pełnego vistulianu spowodowała ożywienie peryglacjalnych procesów denudacyjnych na badanym terenie. Występujące rzeki nie miały w tym czasie uporządkowanego reżimu, stąd ich częste, sezonowe wylewy na równiny zalewowe, powodujące pionowy przyrost osadów. Główna faza wypełniania rozcięć dolinnych w południowo-zachodniej Polsce przypadała na plenivistulian. Sekwencja wypełnień tych dolin zawierała przede wszystkim osady rzeczne z lokalnie występującymi osadami jeziornymi, które powstały w sprzyjających warunkach klimatycznych oraz z cienkimi pokrywami eolicznymi. O klimatycznych warunkach jakie panowały podczas akumulacji osadów biogenicznych świadczą wyniki badań palinologicznych. Pozwoliły one przedstawić obraz szaty roślinnej w poszczególnych warstwach osadów oraz stwierdzić, że ku stropowi pogarszały się warunki klimatyczne. Przedmiotem badań metodą analizy pyłkowej były profile osadów z czterech stanowisk: Suliradzice, Dyminy, Nowe Domy i Blizocin. Z rozważanych czterech profili osadów zostało wykonanych kilka datowań. Najstarszymi datowanymi osadami plenivistulianu, są utwory biogeniczne, których wiek określono na 46 100±1800 BP w profilu Suliradzice. Młodszymi datowaniami jakie uzyskano są daty 25 900±700 BP z profilu Dyminy i 20 800 ± 600 BP z profilu Suliradzice.

W powiązaniu z uzyskanymi datami radiowęglowymi i wynikami badań litologicznych, przedstawiono związek procesów fluwialnych z warunkami klimatycznymi i szatą roślinną oraz określono wiek osadów w analizowanych zbiornikach. Sekwencje fluwialne charakteryzowały się zmiennym przebiegiem depozycji osadów. Badane profile zawierały nieciągłe sekwencje jeziorne, przedzielone osadami mineralnymi, związanymi z okresami erozji i depozycji fluwialnej, wskazujące na oscylacje klimatyczne. W profilach tych stwierdzono fazy erozji w krótkich okresach przejściowych, od klimatu stadialnego do interstadialnego i odwrotnie od interstadialnego do stadialnego.

W okresach chłodniejszych sekwencja osadów w dolinach rzecznych odznaczała się stopniowym wzrostem frakcji mineralnej i zmianą typu sedymentacji. Znaczna intensywność procesów denudacyjnych powodowała wypłycenie zbiorników. Po pewnym czasie, w sprzyjających warunkach klimatycznych, akumulacja osadów mineralnych została zahamowana i na powierzchni rozwijały się stosunkowo płytkie zbiorniki jeziorne, wypełniane utworami z przewagą frakcji organicznej. W plenivistuliańskich zagłębieniach sedymentacja jeziorna lub bagienna była co najmniej dwukrotnie przerywana, co zaznaczyło się erozją i depozycją piasków i żwirów. Wydaje się, że oscylacje klimatyczne wpływały głównie na wielkość przepływu rzecznego oraz na typ sedymentacji fluwialnej i na aktywność procesów eolicznych, natomiast nie odegrały większej roli w procesach sedymentacji i erozji.

Z przeprowadzonych badań wynika, że warunki klimatyczne interstadiałów plenivistuliańskich w południowo-zachodniej części Polski były podobne do panujących w centralnej Polsce i w północno-zachodniej Europie, zarówno w interstadiale Hengelo jak i w Denekamp. Pewne różnice – na badanym terenie – dotyczą jedynie interstadiału Moershoofd (47–43 ka BP), w którym klimat był nieco łagodniejszy. W badanych profilach nie zachowały się spektra pyłkowe sygnalizujące postępujące zwilgotnienie klimatu, które u schyłku interstadiału Denekamp jest zapowiedzią pogarszających się warunków klimatycznych w związku z nasuwającym się z północy lądolodem skandynawskim.