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The problem of the Last Glaciation extent in Central Poland

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The maximum extent of the last ice sheet near Konin, Koło and Turek has been controversial. Investigations carried out in the Warta River has shed light on this problem. The Krzyżówki, Koźmin and Smulsko sites show fluvial deposits laid down in an extraglacial, periglacial environment during the Vistulian Glaciation. The northernmost site, Krzyżówki, shows an influence of proglacial waters, expressed by the supply of fluvioglacial material. The findings suggest that the last ice sheet did not overpass the Berlin-Warsaw Pradolina east of Konin and thus did not enter the Turek Plateau or the Uniejów Basin.

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INTRODUCTION

In geomorphological and palaeogeographical investigations of the Warta River valley, in the segment between Uniejów and Konin and the surrounding area, there has been much discussion regarding the extent of the Vistulian Glaciation. Two schools of thought exist. Some researches have argued that the last ice sheet did not overpass the Berlin-Warsaw Pradolina between Konin and Koło, while others suggest that it did. This paper reviews this problem and the basis on which the various concepts have been developed.

Geological investigations at three exposures in the Adamów opencast mine (Władysławów, Smulsko, Koźmin) have been conducted since the early 1990s by the researchers from the Department of Quaternary Research of Łódź University. Initially researches tended to discount the possibility of the presence of the last ice sheet in this area (e.g. Klatkowa, 1993, 1995). Subsequent work has focused on the Warta River valley between Uniejów and Konin, where sandy Vistulian Glaciation deposits of extraglacial fluvial origin may be assumed. Three sites: Krzyżówki, Koźmin and Smulsko, which show contrasting depositional patterns, are considered here.

PREVIOUS INTERPRETATIONS

The extent of the Leszno Phase between Zielona Góra and Dolsk and the extent of the Poznań Phase between Sulęcin up to Poznań and Gniezno were determined as early as the beginning of the 20th century. These limits are generally accepted, unlike the course of the Leszno Phase east of Dolsk and of the Poznań Phase east of Gniezno. A review of the opinions prevailing at that time was made by Mikołajski (1927). He suggested that the marginal geomorphic forms between Powidz to Konin belong to the Poznań Phase (Fig. 1). These studies concerned the maximum limit of the Last Glaciation to the south of the Berlin-Warsaw Pradolina in the area to the east and south of Konin. The origin and the age of the hills of the Turek Plateau remained obscure. Both Mikołajski (1927) and Lencewicz (1927) considered that these forms were fashioned during the Last Glaciation, and according to Mikołajski (1927) belonged to the Poznań Phase.

Woldstedt (1932) held a different opinion. The criterion he used as an indicator of the extent of the Last Glaciation was that of the presence of glacial lakes. In Woldstedt's (1932) opinion the Leszno ice sheet did not overpass the Berlin-Warsaw Pradolina to the east of Żerków, while the extent of the Poznań

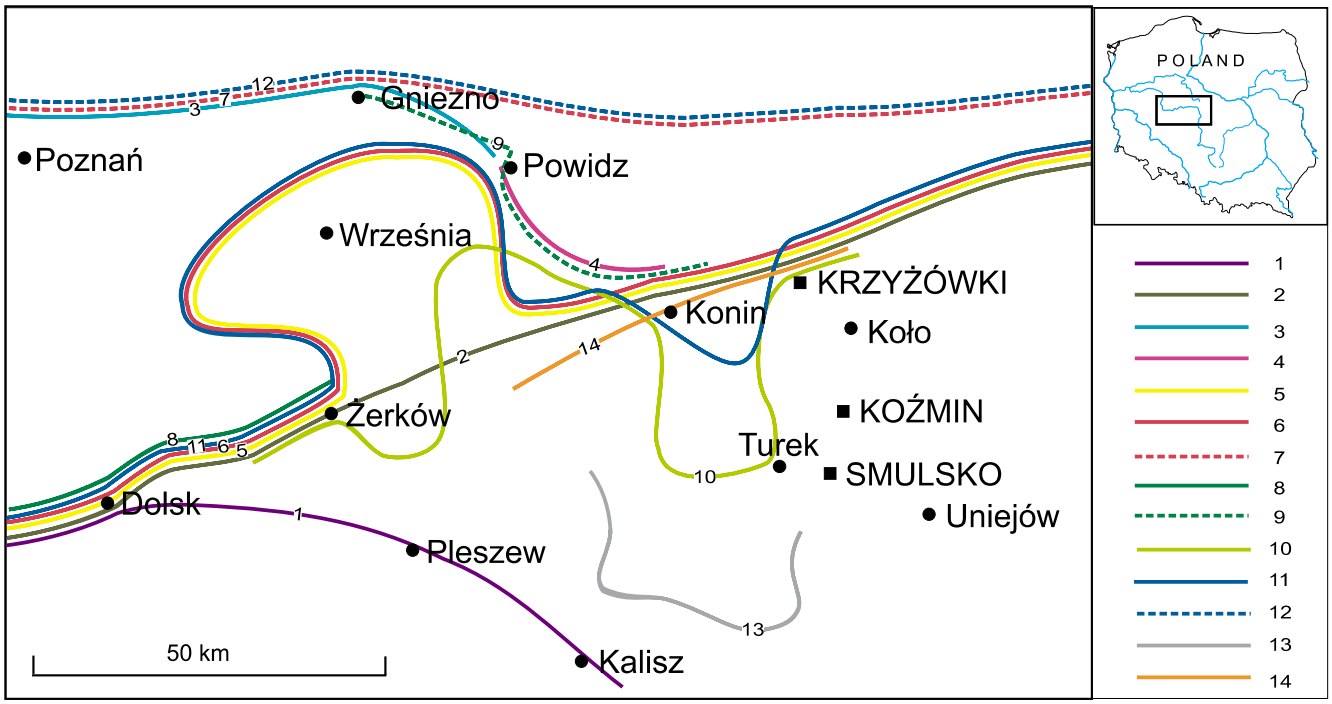

Fig. 1. Previous interpretations of a maximum ice sheet limit of the Leszno Phase and Poznań Phase of the Last Glaciation in Wielkopolska Lowland

1 — Keilhack and Berendt (1894, after Mikołajski, 1927) — Leszno Phase; 2 — Behre and Tietze (1911, after Mikołajski, 1927) — Leszno Phase; 3 — Korn (1912, after Mikołajski, 1927) — Poznań Phase; 4 — Mikołajski (1927) — Poznań Phase; 5 — Majdanowski (1950) — Leszno Phase; 6 — Galon (1956, 1957) — Leszno Phase; 7 — Galon (1956, 1957) — Poznań Phase; 8 — Rotnicki (1963) — Leszno Phase; 9 — Rotnicki (1963) — Poznań Phase; 10 — Domosławska-Baraniecka (1969*b*, after Łyczewska, 1960) — Leszno Phase; 11 — Krygowski (1972, 1974) — Leszno Phase; 12 — Krygowski (1972, 1974) — Poznań Phase; 13 — Mańkowska (1980, 1983) — Leszno Phase; 14 — Stankowski (1982) — Leszno Phase

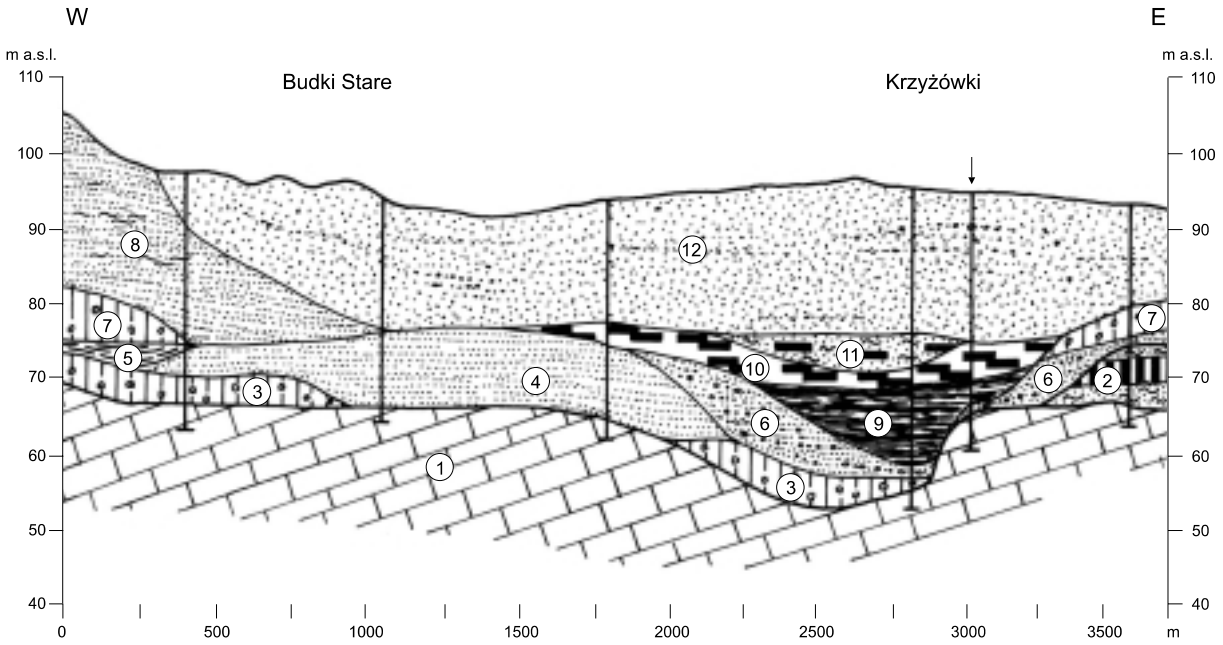

Fig. 2. Geological cross-section — Krzyżówki (after Szałamacha and Skompski, 1999, changed)

Cretaceous: 1 — marl; Tertiary (Miocene): 2 — brown coal, silt and sand; Quaternary — Sanian Glaciation: 3 — till; Masovian Interglacial: 4 — sand; Wartanian Glaciation: 5 — ice-dam silt, 6 — sand with gravel, 7 — till, 8 — sand with silt interbed; Eemian Interglacial: 9 — organic silt, 10 — peat; Vistulian Glaciation: 11 — organic silt with sand, 12 — poorly sorted sand

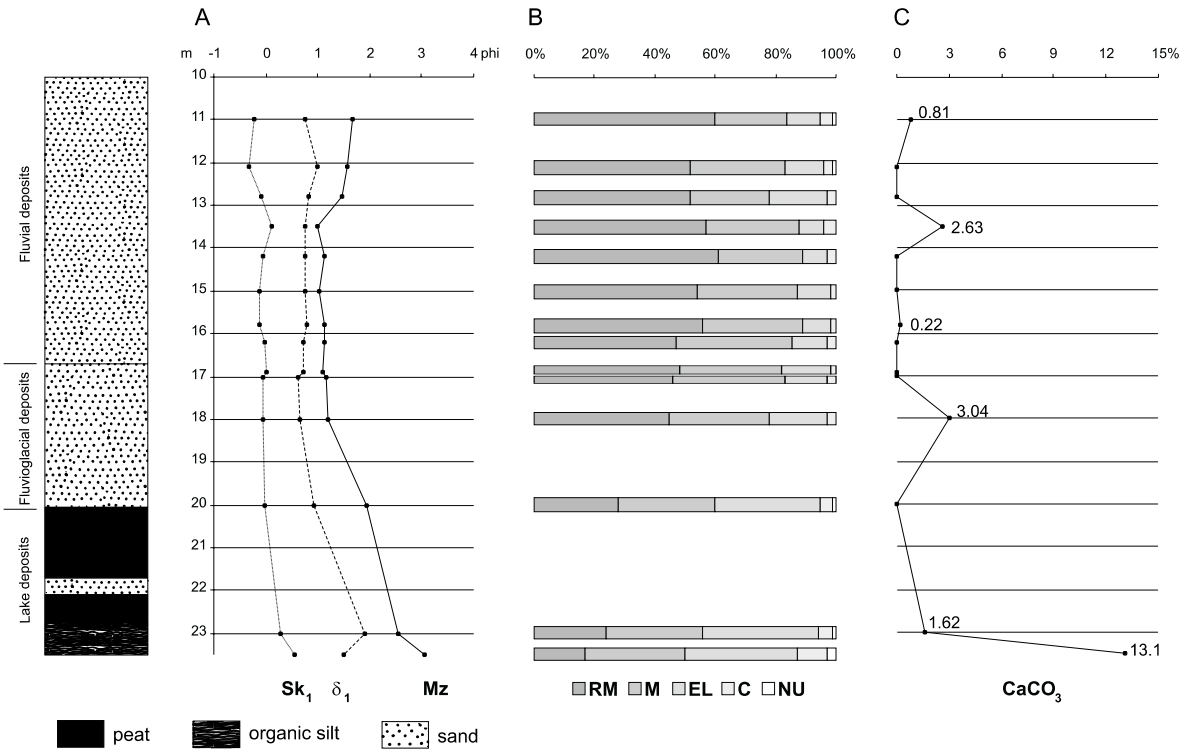

Fig. 3. Krzyżówki site: A — grain-size distribution, B — quartz-grain abrasion, C — $CaCO_3$ content

RM — round mat grains (rounds-mats), M — rounded, partly mated grains (mats), EL — blunt, glossy grains (emousses-luisants), NU — fresh, sharpedged grains (non-uses), C — grains initially rounded and then crushed (casses)

Phase was traced by him to the east of Gniezno through Powidz, Golina and Konin. Later observations (Majdanowski, 1950) concerning the occurrence and the density of lakes and subglacial channels generally corroborated Woldstedt's (1932) conclusions (Fig. 1). The problem of the so-called Września "bay", where there are neither lakes nor subglacial channels, arose.

In the 1950's the opinion that the Leszno ice sheet had not overpass the Berlin-Warsaw Pradolina east of Konin became dominant, and consequently, the origin of the hillocks between Konin, Koło and Turek was not atributed to the Last Glaciation. The extent of the Leszno Phase was delimited through the Poznań–Gniezno–Lipno line to the east. This was based on the occurrence of fresh glacial landforms and the glacial provenance of deposits (Galon, 1956, 1957) (Fig. 1), from the courses of terminal moraines and of outwash plains expanding southwards and from ice-marginal valley (Krygowski, 1958).

The opinion that the ice sheet overpassed the Berlin-Warsaw Pradolina in the vicinity of Konin returned in 1960 in work by J. Łyczewska. Her conclusion was inferred from the internal structure and freshness of landforms. Łyczewska (1960) also considered that the Poznań Phase reached the hillocks in the Turek Plateau. Łyczewska's (1960) opinion was accepted, and quoted by Galon and Roszkówna (1961), Rutkowski (1967), Domosławska-Baraniecka (1969*a*, *b*) and Krygowski (1972, 1974; Fig. 1). Krygowski (1972, 1974) held the opinion that the Leszno Phase extended to the northern part of the Złota Góra massif and that the Ostaniec Kolski originated during the Wartanian Glaciation whereas the landforms of Leszno Phase age followed the older terminal moraines leaving in their background a Vistulian till and small kame hillocks. The interpretation of the results of pollen analysis at the Konin-Marantów site by Borówko-Dłużakowa (1969, 1979) was critical to supporting this opinion. According to Borówko-Dłużakowa (1969, 1979), organic and organic-mineral deposits overlain by till at Konin-Marantów were laid down during the Brörup Interstadial. This correlation was controversial and eventually negated (Lindner and Brykczyńska, 1980; Tobolski, 1991).

The problem of the maximum extent of the last ice sheet in Central Poland has been discussed by Rotnicki (1963), who considered that there is no reason to retain the Września "bay" outside the Last Glaciation limit. On the basis of examinations of the outwash plain levels on the Września Plain it appeared that the Powidz-Konin terminal moraines are not of Leszno age but trace the Poznań Phase extent (Fig. 1). Rotnicki (1963) also drew attention to the unresolved problem of the age of the hillocks in the Turek Plateau.

The authors of subsequent publications tended to assert that the last ice sheet did not over-ride the Berlin-Warsaw Pradolina to the east of Konin (e.g. Bartkowski, 1964; Roszko, 1968), they did not mark the Września "bay", and Mojski (1968) and Rühle and Mojski (1968) and Kozarski (1962, 1981), for example, determined the Poznań Phase to the east of Gniezno, in a lobate form, up to Konin. Investigations into the distribution of ventifacts, carried out between Turek and Konin, suggested that this area remined within the periglacial realm during the Last Glaciation (Kubiś, 1978).

On the Detailed and Review Geological Maps of Poland the maximum extent of the last ice sheet includes the hillocks of the Turek Plateau (Mańkowska, 1980, 1983*a*, *b*, 1987;

Fig. 4. Geomorphological sketch of a fragment of the Uniejów Basin and Turek Plateau

Mańkowska and Gogołek, 1988; Trzmiel, 1996) (Fig. 1). In the legend for this map the authors (Ciuk and Mańkowska, 1981; Mańkowska, 1983*b*) stated that the Vistulian Glaciation ice sheet over-rode the Berlin-Warsaw Pradolina and covered the low surfaces of the Pyzdry and Uniejów Basins with ice, the Złota Góra massif forming the morphological divide between the lobes. Morainic hillocks on the slopes of the massif were regarded as the marginal zone of the Pyzdry and Uniejów lobes. Similar views are expressed in Mańkowska (1975) and Gogołek and Mańkowska (1989).

Detailed investigations into the the internal structure of marginal forms in the area between Konin, Koło and Turek, carried out by Kłysz (1981, 1985) and by Kłysz and Stankowski (1986) led to the conclusion that the last ice sheet did not enter the Turek Plateau, and that these forms are polygenetic. According to Krysz the landscape is of Wartanian Glaciation age, with patches of lodgement till and forms of areal deglaciation: kame plateaux, kame terraces, kames and eskers.

According to Stankowski (1982), no lithostratigraphic evidence exists from which to infer the presence of the Vistulian ice sheet to the east of Konin. West of here to the Powa Mouth, the ice sheet occurrence is proved by thin patches of Leszno Phase tills, though ice marginal landscapes are absent (Stankowski, 1982; Stankowska and Stankowski, 1983) (Fig. 1). The extent of the Poznań Phase to the east of Konin was determined on the basis of remains of outwash plain streams which locally dissect the outwash plains of the maximum phase (Stankowska and Stankowski, 1983). The extent of the Leszno Phase west of Konin is traced to the south of the Berlin-Warsaw Pradolina. To the northern-east of Konin, near Babiak, limits of the Leszno and Poznań Phases coincide, both being directed eastwards up to Budki Stare then further northwards and north-eastwards (Stankowski, 1982; Stankowska and Stankowski, 1983; Stankowski and Krzyszkowski, 1991; Stankowski *et al*., 1995).

These conclusions have been supplemented with lithological analyses of Quaternary deposits of the southern scarp of the Berlin-Warsaw Pradolina, in Konin (Paluszkiewicz, 1995). Glaciogenic deposits of the Vistulian Glaciation are absent here, though on the opposite scarp these have been recorded (Stankowska and Stankowski, 1983). Their lack is assumed to be due to erosion by meltwaters during the last ice sheet recession.

KRZYŻÓWKI SITE

The northernmost site is Krzyżówki — a borehole drilled in the course of geological mapping, published by Szałamacha (1998), Noryśkiewicz (1999) and Szałamacha and Skompski (1999). The site is located in the Berlin-Warsaw Pradolina north of Koło (Fig. 1), a few kilometres from the contemporary Warta channel. Two sedimentary units were reported there. The first, organic suite, at the depth of 25.8–20.6 m (Fig. 2), consists largely of peats and gyttja. Pollen analysis proved its Eemian Interglacial age (Noryśkiewicz, 1999), although the record in the upper part of the diagram differs from the schemes accepted for this period, probably due to post-depositional disturbance. The Eemian

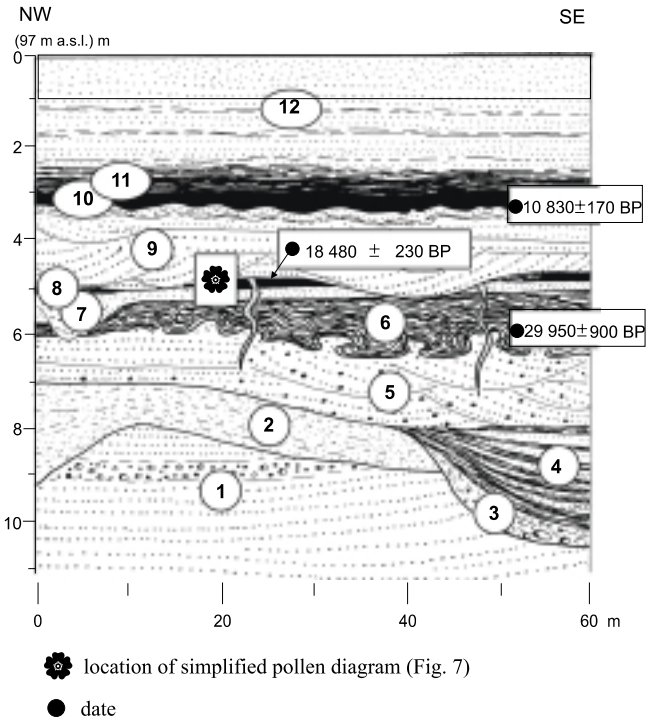

Fig. 5. Koźmin site

Deposits older than the Vistulian Glaciation: 1 — sand and gravel, 2 — sand and silt; Vistulian Glaciation: 3 — poorly sorted deposit, 4 — organic silt with sand interbed, 5 — sand with gravel, 6 — organic silt, 7 — sand with silt, 8 — peat, 9 — sand, 10 — peat, 11 — gyttja, 12 — sand with silt interbed

Interglacial age was supported by faunal analyses (Szałamacha and Skompski, 1999). It must be emphasised that this is as yet the only site with biogenic Eemian Interglacial sediments deposited within the valley of a large river in this region. The overlying deposits, reaching the present-day surface, comprise sands with gravels. Szałamacha and Skompski (1999) described the basal part (17.0–20.0 m) as fluvioglacial sediments, and its upper part as fluvial relating to the Vistulian Glaciation. Core sediment samples were analysed as regards grain size composition, by the modified Cailleux method and for calcium carbonate content. The monotonous grain size composition suggests a flowing water environment. Most samples contain no $CaCO_3$ at all, except for samples at 18.0 and 13.5 m depth with *ca*. 3% concentration of $CaCO_3$ (Fig. 3), whereas the fluvial sands of the same age at the nearby Koźmin site in the Warta River valley are completely decalcified. A quartz-grain analysis of the 0.63–0.8 mm fraction showed an increase of RM grains, from 45% at a depth of 18.0 m up to 61% at 14.2 m, whereas contents of EL grains decrease from 19.0 to 8%, respectively (Fig. 3). A similar trend has been registered for the Upper Plenivistulian at many sites in middle Poland. Both the results of the laboratory analyses and the site location suggest that the site lies beyond the Vistulian ice sheet extent but probably close to its margin, since part of the succession may have been deposited by proglacial waters. The bulk of the succession accumulated quickly by extraglacial waters which lost their carrying capacity because of ice blockage. Therefore, the deposition of these

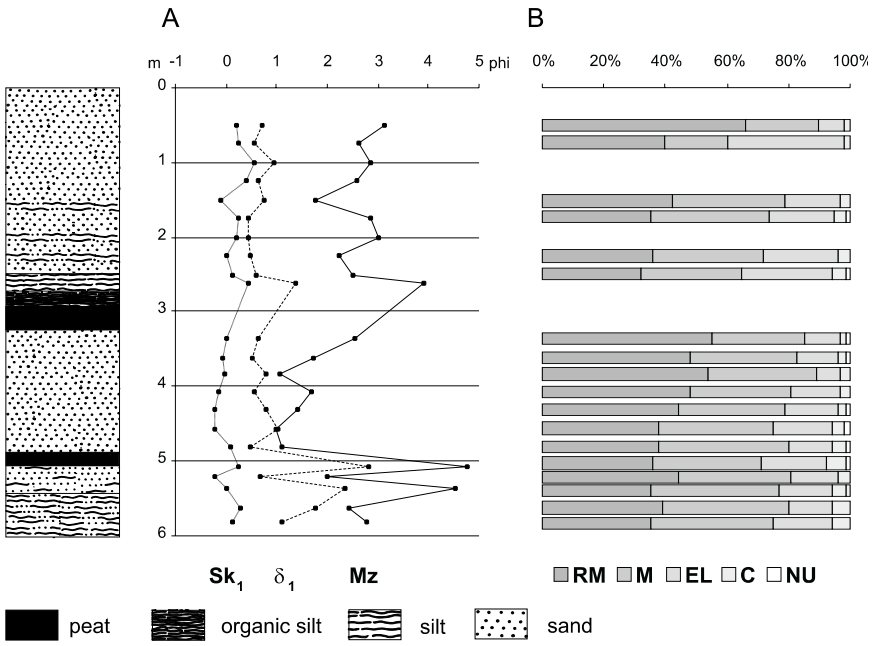

Fig. 6. Koźmin site

A — grain-size distribution, B — quartz abrasion; for other explanations see Figure 3

deposits occurred during the maximum extent of the Vistulian Glaciation in a periglacial river environment.

KOWMIN SITE

The Koźmin outcrop (the Adamów Tertiary coal opencast mine) is situated in the northwestern part of the Uniejów Basin, in the Berlin-Warsaw Pradolina (Fig. 4). The Vistulian Glaciation succession has been studied in detail by us (e.g. Klatkowa, 1996; Forysiak *et al*., 1999; Petera and Forysiak, 1999; Turkowska *et al*., 2000; Forysiak and Petera, 2001; Petera, 2002). The situation in 1999 is given below.

The Upper Plenivistulian sequence is underlain by organic silts, and is interbedded with peat, revealing involutions (Fig. 5, series 6). These sediments are ^{14}C dated to 29 950±900 years BP (Lod 769) and 26 290±580 years BP (Lod 879) (Petera and Forysiak, 1999; Petera, 2002).

The overlying deposits are represented by three units of different origin, structure and textural features. The oldest unit, at a depth of 5–6 m (Fig. 5, series 7), is made up of medium- and fine-grained sands with an admixture of silt or with silty beds up to 80 cm thick. These are predominantly massive deposits. They possess a mean content of 47.8% of aeolian (RM) grains (Fig. 6). Deposition of this unit occurred in a fluvial, overbank environment, but with aeolian processes involved.

Subsequently, the peaty layer, *ca*. 10 cm thick, radiocarbon-dated at 18 480±230 years BP (Lod 768), was formed (Fig. 5, series 8). Pollen investigations of the peat indicate cold, progressively more severe climatic conditions (according to the analysis by Miotk-Szpiganowicz, Fig. 7). The content of trees decreases upwards (from 30 to below 10%), and most pollen could have been derived by long-distance transport. NAP is dominated by Cyperaceae and Gramineae. Epigenetic ice wedge pseudomorphs which appear in the peat layer are evidence for contemporaneous permafrost.

The third unit is 2.0–4.5 m thick, is assigned to the period of the maximum extent of the main stadial ice sheet, and comprises sands, occasionally with gravels. Its top occurs at a depth of 2.5–3.0 m (Fig. 5, series 9). This units either overlies the peat or fills erosional hallows reaching up to 2.5 m below the peat level. Tabular and trough bedding as well as horizontal and ripple lamination are present. This unit was deposited in a sandy braided river system, which was characteristic of the widened Warta River valley, as demonstrated by Petera (2002). The role of aeolian processes in the modelling of textural features of the sediment is shown by the content of wind-abraded grains (42 to 60% — Fig. 6). The percentage of unabraded grains (NU) is low (1.3%). Such textural features suggest that the sediment was formed in an extraglacial, periglacial environment.

The Koźmin deposits, correlated with the Leszno and Poznań Phases, represent deposition in a fluvial environment, possibly with marginal waters involved, but taking into account the distance from the ice margin a glacial provenance may be excluded.

SMULSKO SITE

In the early 1990s the Smulsko exposure of the Adamów Tertiary coal opencast mine was available for detailed studies of Wartanian Glaciation deposits, mostly of the till succession (Klatkowa, 1993, 1994, 1995; Forysiak, 1994; Załoba and Czubla, 1995). The results showed that glaciogenic deposits

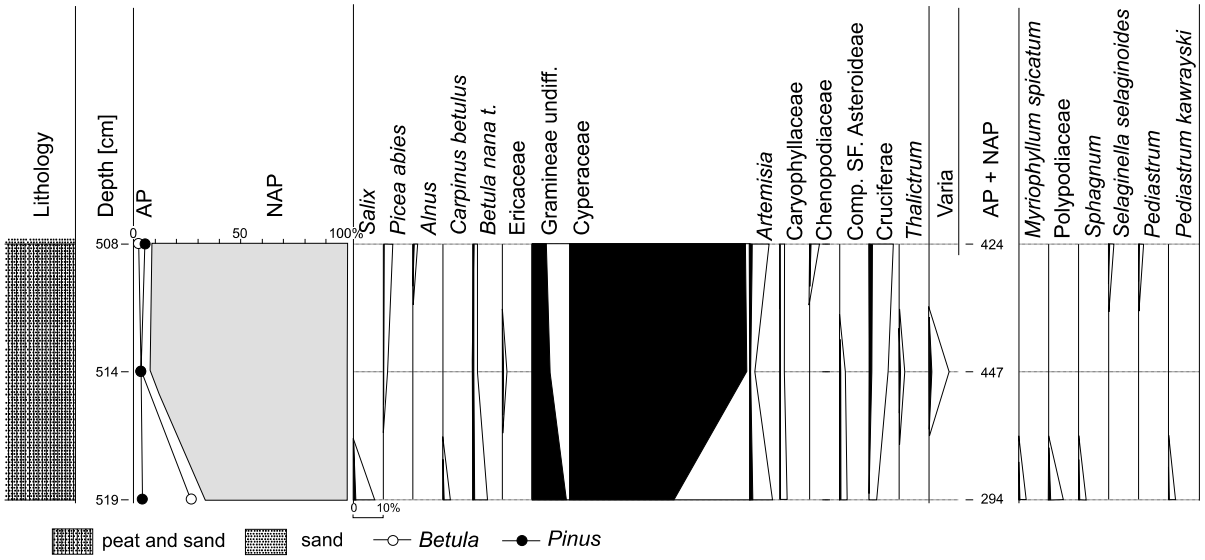

Fig. 7. Koźmin site, simplified pollen diagram

younger than these of the Wartanian Glaciation age are absent from the Turek Plateau. Progressive excavation works at the exposure have reached the area of an extensive sandy plain that is, according to e.g. Baranowski and Mańkowska (1970) and Czarnik (1972), a fragment of the higher terrace level of the Warta River valley or, as postulated by Trzmiel (1996), an outwash plain of the Vistulian Glaciation.

The sandy succession, up to 14 m thick, is situated in the eastern part of the exposure, and at present is available for the direct observation over a distance *ca.* 2 km. The profile selected for study shows thick sands separated by a peat layer (Fig. 8). These deposits rest on a till suggested to be of Wartanian Glaciation age (Czubla, 2001). The till has at its upper surface a continuous erosional pavement overlain by a gravelly-sandy bed (Fig. 8). The overlying sands with silts have been attributed by us to the Vistulian Glaciation. This succession has been divided into two parts. The bottom part, at a depth of 9.1–10.4 m, consists of grey-beige sands and silts with involutions obliterating the original structure. A thin (0.25 cm) peat layer is noticeable. A sample from its base gave a radiocarbon date of 24 400±470 years BP (Lod 1084), while a preliminary palaeobotanical study suggests that it represents a park tundra (Balwierz, pers. comm.). The content of RM grains varies between 41 and 59% (Fig. 9), which may suggest fluctuating depositional conditions.

At a depth of *ca.* 9.1 m an erosional surface is present. From there up to the ground surface there are sands which show evidence of cyclic accumulation. The sedimentary structures reflect varying-energy conditions during deposition. The lowest part is composed of medium sands with tabular cross-bedding, changing towards the top into horizontally laminated sands with silts (Fig. 8), which may suggest the transition from channel to overbank facies within a braided river. The frequency of aeolian grains (RM) increases from 42% at 9.0 m to 58% at 7.25 m (60% at 8.25 m), whereas the percentages of those abraded by water (EL) decrease (Fig. 9). The deposits between 6.75–3.5 m comprise cross-bedded sands, followed by horizontal laminated sands giving way to fine sands with silts. The silt layer at the depth of 4.25 m is of special interest, because it is the finest-grained deposit in the entire profile, and has the highest content of RM grains (64%). The top of this sandy succession, from 3.0 m up to the surface, is more complicated. The lithology (both sands with silts and a gravel bed) as well as quartz-grain analysis (RM grains vary between 43 and 56%, EL vary between 5 and 10% and C vary between 1 and 6%; Fig. 9) show that deposition occurred in fluctuating environmental

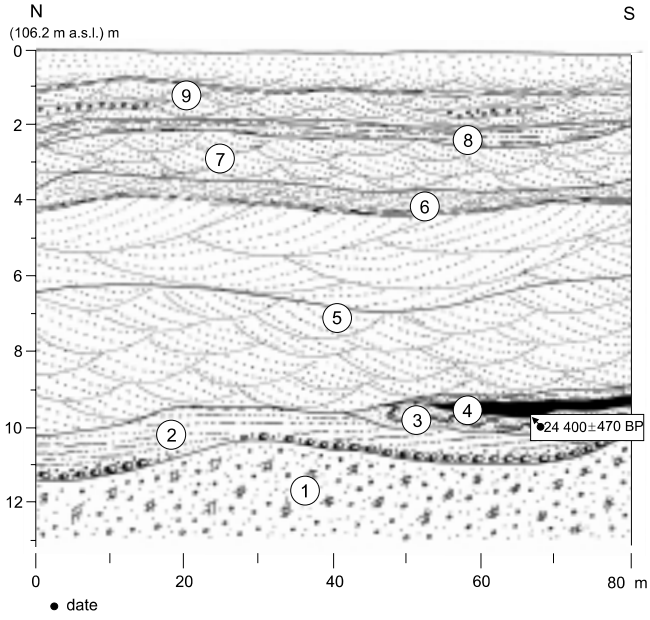

Fig. 8. Smulsko site: the exposure at the first exploitation level

Wartanian Glaciation: 1 — till; Vistulian Glaciation: 2 — sand with silt, 3 — sand with silt, with post-sedimentary deformations, 4 — peat, 5 — poorly sorted sand, 6 — fine-grained sand, 7 — medium-grained sand, 8 — sand with silt, 9 — poorly sorted sand with gravel interbed

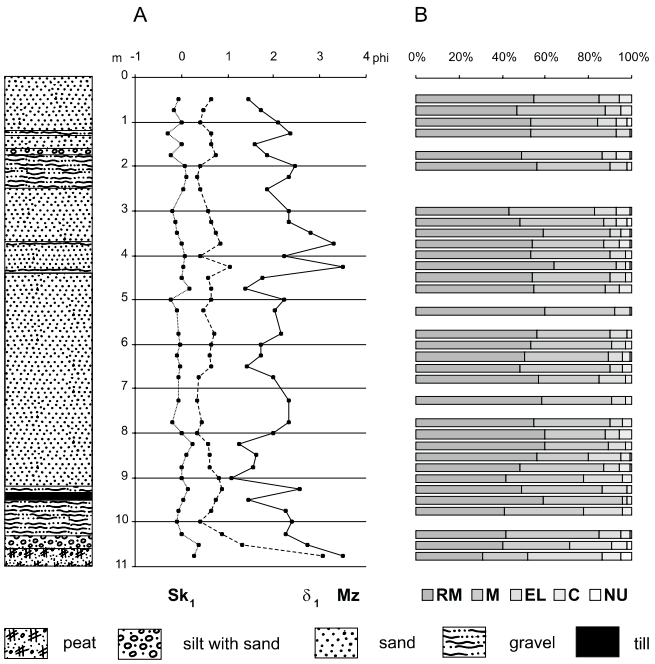

Fig. 9. Smulsko site

A — grain-size distribution, B — quartz-grain abrasion; for other explanations see Figure 3

conditions or in river channels supplied from different sources. Deposition took place during the Last Glaciation maximum. The sedimentological studies, showing the predomination of the southern sector, indicates that a fluvioglacial origin for them may be rejected.

CONCLUSIONS

Both the results of the laboratory analyses and the location of Krzyżówki site suggest that the site lay beyond the Vistulian ice sheet extent but probably close to its margin, because part of the sediments could have been deposited by proglacial waters. The bulk of the succession was deposited quickly by extraglacial waters which lost their carrying ability because of ice blockage. Therefore, the deposition of this sandy succession occurred during the maximum extent of the Vistulian Glaciation, in a periglacial river environment.

The Koźmin and Smulsko deposits, which correlate with the Leszno and Poznań Phases represent deposition in a fluvial environment. The accumulation terminated at the start of the downcutting of the Warta River at the turn of the Upper Plenivistulian and Late Vistulian, as suggested by Petera (2002). Textural features suggest that the sediment was formed in an extraglacial, periglacial fluvial environment. The measurements of sedimentary structures in Smulsko site within the succession show derivation from the south; thus a fluvioglacial origin may be excluded.

These three sites from the Warta River valley between Uniejów and Konin indicate a location beyond the limit of the Vistulian ice sheet. We thus support the opinion of the researchers who, in the vicinity of Koło, suggested a maximum extent line of the Last Glaciation to the north of the Berlin-Warsaw Pradolina.

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