



INQUA
PeriBaltic Working
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INQUA



International Field Symposium
***“Glacials and interglacials
of the Middle and Upper Pleistocene
in central Poland”***

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EXCURSION GUIDE



June 28 – July 3, 2026, Łódź, Poland



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Geological and morphological background

Danuta Dzieduszyńska^a, Robert Sokołowski^b

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The sub-Quaternary geological structure of Central Poland is determined by the formation, development and subsequent disappearance of the Polish Basin, which formed part of the Permian–Mesozoic system of epicontinental basins in Western and Central Europe, the so-called Central European Basin System (Littke et al., 2005). From the Permian through the entire Mesozoic, subsidence occurred, followed by subsequent inversion and uplift within the axial part of the Polish Basin, namely the Mid-Polish Trough (Resak et al., 2008). Tectonic inversion took place at the Cretaceous–Paleogene boundary and was triggered by Alpine tectonic movements. As a result, a complex of uplifts (the Mid-Polish Trough) and surrounding depressions (the Marginal Synclinorium, the Szczecin–Miechów Synclinorium and the Fore-Sudetic Monocline) was formed. Tectonic movements within these structures continued throughout the Palaeogene and Neogene, resulting in the formation of numerous salt diapirs, as well as tectonic grabens and uplifts (Krzywiec, 2012). Within the tectonic depressions, intensive sedimentation of deposits, including lignite seams, took place from the early Oligocene onwards. Examples of such structures include the Kleszczów Graben and the Adamów Graben, as well as the graben and semi-graben of the Konin region (Kleczew Graben, Tomisławice Graben) (Gotowała and Hałuszczak, 2002; Widera and Hałuszczak, 2011). These structures also underwent subsidence during subsequent advances of the Scandinavian Ice Sheet (SIS), as a result of which they are filled with Quaternary sediments of thicknesses significantly greater than those of the surrounding areas (Krzyszowski, 1992; Wachocki et al., 2024).

Central Poland lies within a zone of continuous Quaternary sediment cover. Genetically, these deposits are associated with repeated advances of the SIS (Fig. 1), periglacial climatic conditions, and the temperate climate of interglacial periods and the Holocene (e.g., Klatkova, 1965, 1996, 1997; Dylík, 1967; Turkowska, 1988, 2006; Goździk, 2007; Roman, 2010). The thickness of Quaternary deposits varies, typically reaching several tens of meters, but locally, within depressions of the sub-Quaternary surface, it may reach 150–200 m. Maximum thickness occurs in the Kleszczów Graben, where the most complete Quaternary succession is preserved. In the southern part of the region, the Quaternary cover is thin, and numerous outcrops of Mesozoic rocks occur. Zones of glaciotectonic deformation are also present, best developed along a roughly meridional axis south of city of Łódź and within the edge/marginal zone of the Łódź Plateau to the northeast of the city,

The surface geological structure is dominated by a mosaic of clastic sediments of glaciogenic origin deposited by the SIS in the Saalian Stage (MIS 6) and Weichselian Stage/Vistulian (MIS 2; tills, glaciofluvial sands and gravels, and glaciolacustrine silts), periglacial deposits formed during the Vistulian (slope and fluvial silts and sands, aeolian sands), and Holocene temperate deposits (organic muds and peats, as well as fluvial silts and sands). Glacial deposits cover the largest area, whereas



Holocene deposits are the least extensive, being largely confined to present-day valley floors and small depressions (Klatkova, 1972; Turkowska, 2006).

Central Poland is part of the northern Central European Lowlands. The relief of the area is predominantly flat or slightly undulating. Elevations range from approximately 300 m a.s.l. to below 80 m a.s.l. Except for southern areas, where relief is strongly controlled by the characteristics of the bedrock (Sadłowska, 1982), the region is dominated by glacial landforms. Their diversity results from variations in the rate and direction of ice-sheet advance (including the influence of the Mesozoic substratum), as well as the relations between landforms created during transgression and recession phases, including different modes of the latter (areal retreat, oscillations, and surging of the retreating ice sheet).

Glacial relief is preserved mainly on uplands, where it is generally denuded. In the area covered by the ice sheet during the Saalian Stage glaciations most recently, periglacial climatic conditions prevailed in various forms: from arctic desert with continuous permafrost to park tundra and even boreal pine–birch forests for most of the subsequent period (Dylik, 1956; Klatkova, 1996). The most important landforming processes under Pleistocene periglacial conditions include slope processes (wash, solifluction, creep), fluvial processes, and aeolian processes, all of which are reflected there in the present-day relief.

In the Holocene, active morphogenetic processes became largely restricted to valley floors. Under temperate climatic conditions and in areas with relatively low initial relief diversity, geomorphological changes have been limited.

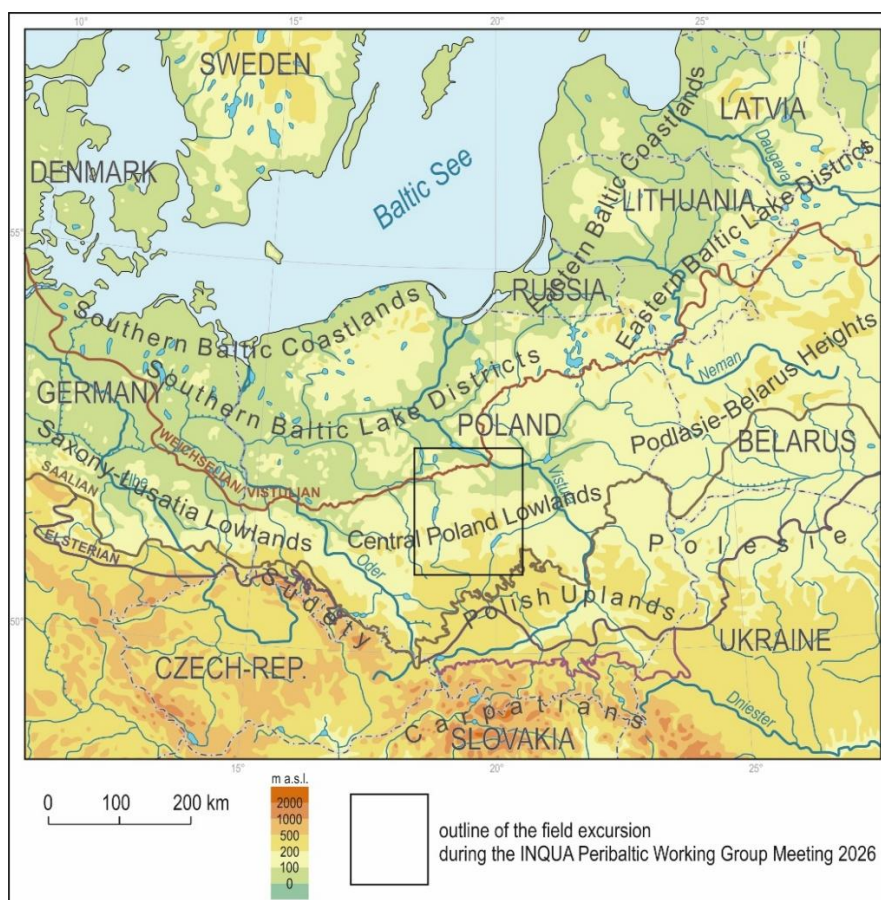


Fig. 1. Physiographic setting of the southern Baltic region and the outline of the field excursion area



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Legend to the geological map

Quaternary geological units (explanations)

- gyttja, chalk, sands and lake silts, and peat
- sands, silts (alluvium) and river peat
- aeolian sands
- lake sands, silts and clays
- sands, silts (alluvium) and recent river peat
- gravels, sands and tills of dead-ice moraines
- sands, silts, clays and kame gravels
- sands and gravels of eskers and crevasse forms
- gravels, sands and tills of end moraines
- sands, silts and lake-glacial clays
- younger glaciofluvial sands and gravels
- glacial sands and gravels
- glacial tills
- sands, gravels and silts (alluvium) of river origin
- gravels and sands of dead-ice moraines
- sands, silts and gravels of kames
- sands and gravels of eskers and crevasse forms
- gravels, sands and tills of end moraines
- younger lake-glacial sands, silts and clays
- younger glaciofluvial sands and gravels
- glacial sands and gravels
- younger glacial tills
- glacial tills

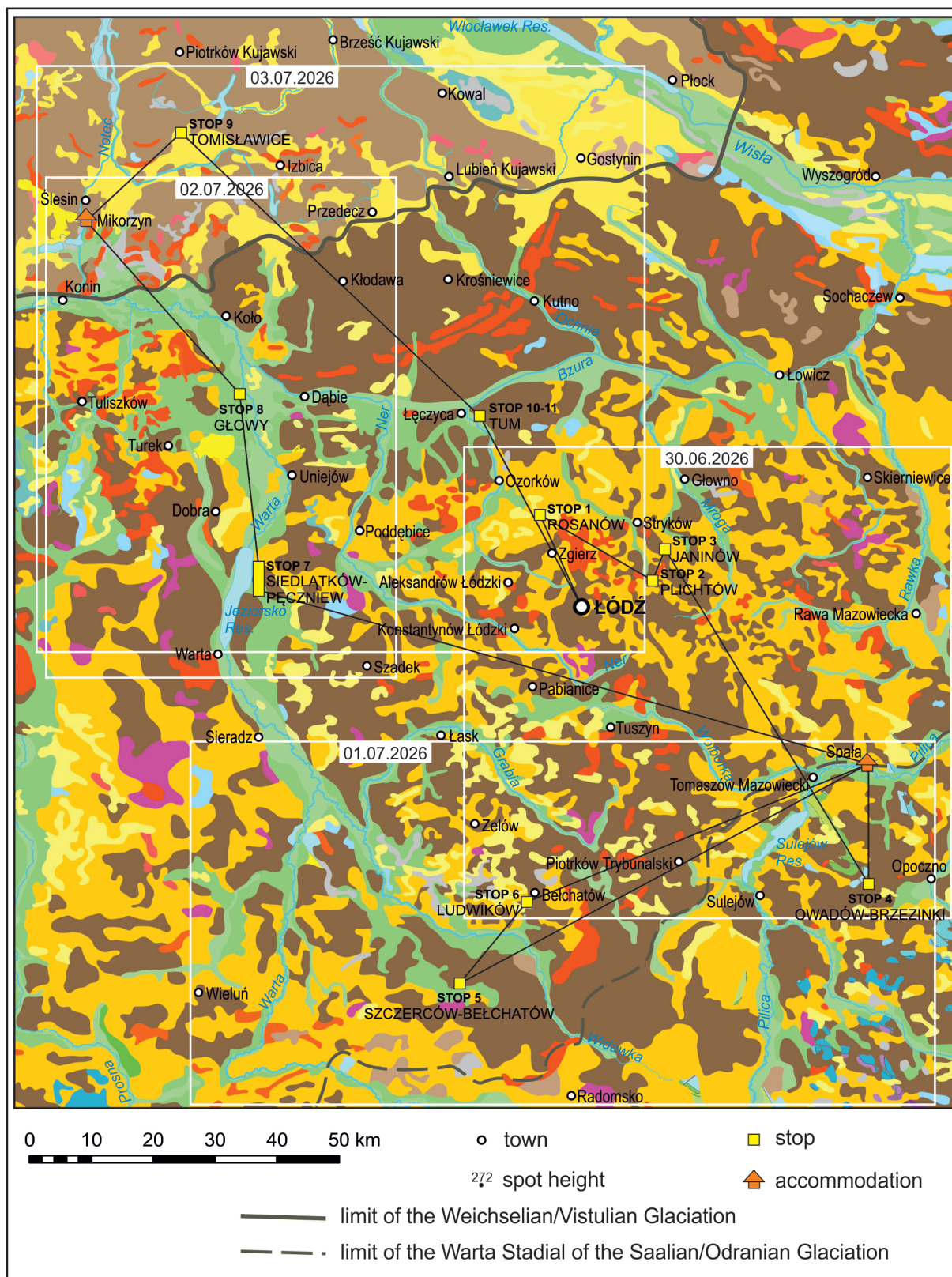
geological units of the Cenozoic basement (stratigraphy)

- Maastrichtian
- Campanian
- Santonian
- Turonian-Santonian
- Albian-Santonian
- Albian-Cenomanian
- Lower Cretaceous
- Upper Jurassic
- Middle Jurassic
- Lower Jurassic
- Upper Triassic
- Middle Triassic
- Lower Triassic

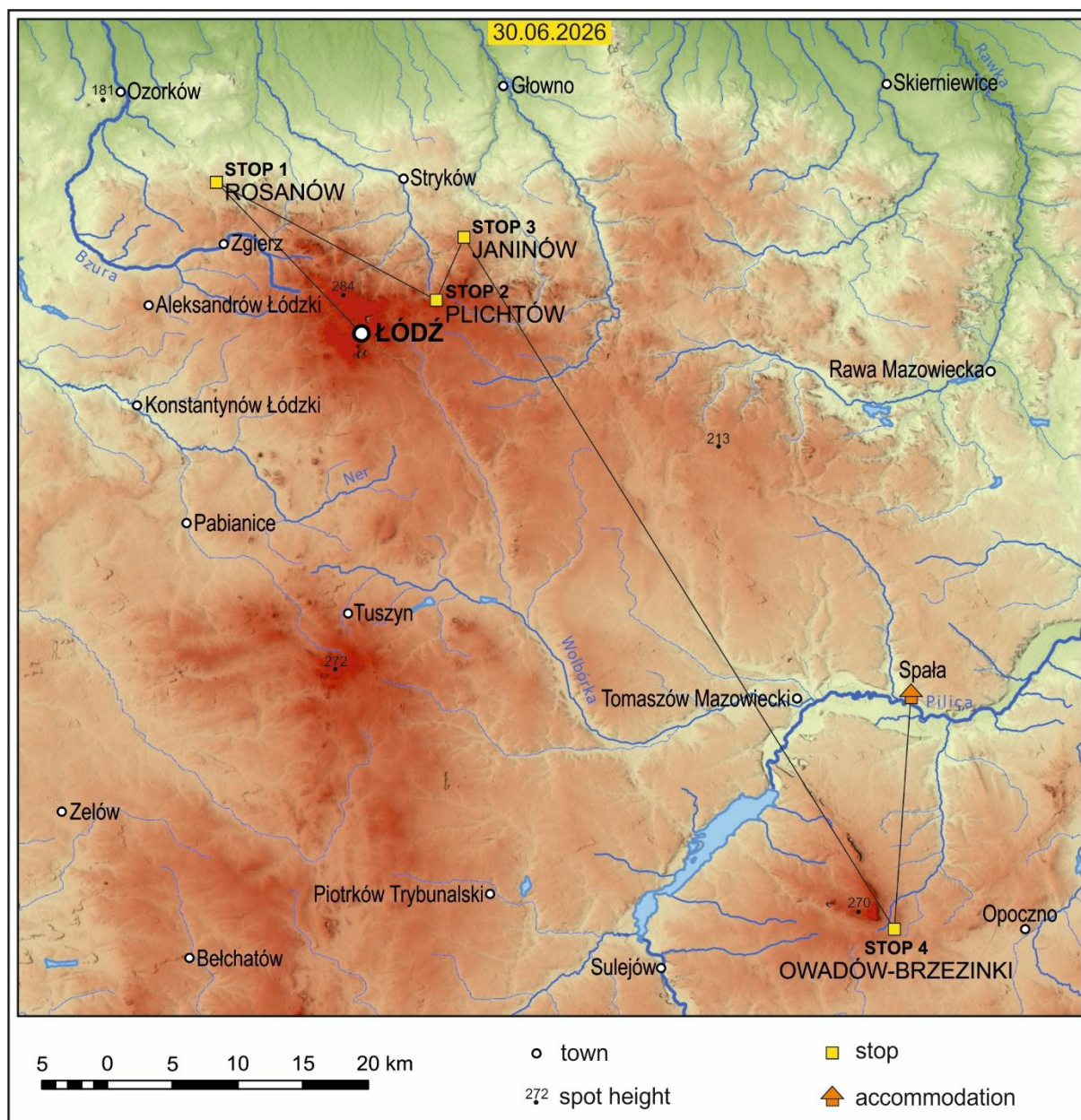
geological units of the Cenozoic basement (explanations)

- marls, limestones, gault, chalk and clastic rocks
- marls, opoka, gault, limestones and clastic rocks
- quartz sandstones
- opoka, marls, chalk, limestones and sandstones
- limestones, opoka and marls
- limestones and marls, and sandstones
- sandstones, siltstones, claystones, limestones and marls
- limestones, marls, siltstones and claystones
- claystones, shales, siltstones, sandstones and dolomites
- sandstones, siltstones and claystones
- claystones, siltstones, sandstones, dolomites and gypsum
- limestones, marls, dolomites, siltstones and sandstones
- sandstones, claystones and clastic rocks, and evaporites

Geological map of the field trip area



acc. Marks L., Grabowski J., Stępień U. (eds) 2022. Geological Map of Poland at a scale of 1:500,000.
 Polish Geological Institute – National Research Institute, Warsaw





STOP 1 – ROSANÓW

Edge zone of the Łódź Plateau

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STOP 1.A. THE MORPHOGENETIC ROLE OF GLACIOTECTONIC PROCESSES

To the north and northeast of Łódź extends a zone of glaciotectionic thrust structures, associated with a distinctive relief characterized by considerable elevation differences and steep slopes, generally north-facing. This area constitutes the so-called „edge/marginal zone”, forming a transitional belt between the surface of the Łódź Plateau and the Warsaw-Berlin ice-marginal spillway. Areas of the steepest gradients and greatest topographic diversity are interspersed with terrain of markedly gentler morphology. The terrain descends north through a series of broad flat levels separated by narrower and steeper faces up to 10° or more in angle. Along a section of less than 50 km of the meridional profile, the heights decrease by nearly 150 m, from over 250 m a.s.l. to less than 100 m a.s.l. A characteristic geological feature of this area is the exceptionally high concentration of glaciotectionic structures involving unconsolidated Palaeogene, Neogene, and Quaternary deposits, particularly along the faces of each morphological level, with their abundance increasing toward the higher levels. They commonly occur just beneath the present-day surface. The lithology is predominantly composed of ablation till and glaciofluvial sand. The evolution of the area has been studied thoroughly in the investigations by H. Klatkova (1972, 1996).

The highest morphological level is formed by the surface of the Łódź Plateau, which slope gently southward from their northern margin. Their northernmost face is deeply dissected by valleys, including dry periglacial ones, into a series of peninsulas and isolated hillocks, contributing to the pronounced relief diversity of the area.

The first morphological level below – the Smardzew level – is a relatively flat surface situated at elevations of 185–210 m a.s.l., with higher absolute elevations occurring in the western part and gradually decreasing eastward. This area is dissected into smaller fragments by river valleys trending approximately meridionally. The transition to the next, lower morphological level is marked by the face with slope inclinations reaching up to 8°. The dominant structural style in this area is represented by monoclinial glaciotectionic structures, in which dip angles locally reach as much as 90°. The uplifted and deformed sequences are composed predominantly of glaciogenic material, together with older deposits, including Miocene clays and also chalk marl.

The second, lower morphological level – the Stryków level – occurs at elevations of 165–189 m a.s.l. and reaches its greatest extent in the central part of the marginal zone. In terms of geological composition, this level is characterized by a reduced proportion of gravels relative to sands. From a structural perspective, glaciotectionic deformation remains an important feature; however, it is no longer as dominant or as pervasive as on the higher morphological level.

The third morphological level – the Katarzynów level – extends at 140–160 m a.s.l., with elevations in the western part approaching the upper limit of this range, while in the eastern part they are generally

closer to the lower boundary. This level extends considerably southward along river valleys and disappears in the central sector, where it merges with the preceding, higher Stryków level. Its geological structure includes glaciotectionic features developed in the form of folds accompanied by secondary deformation structures, formed within glaciofluvial deposits.

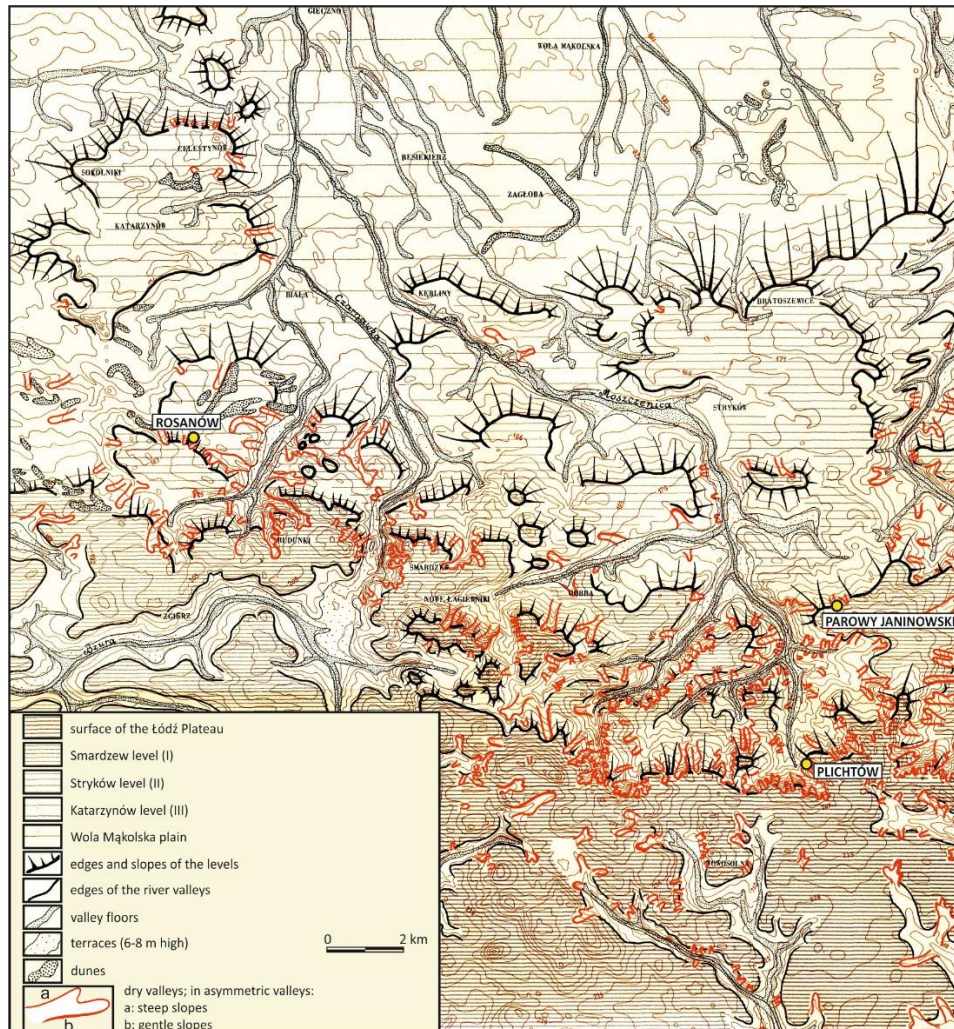


Fig. 1. Morphological levels of the edge zone of Łódź Plateau (Klatkova, 1965)

A common feature linking the morphological levels is the presence of glaciotectionically derived structures in the basement. This area marks the boundary between two major Mesozoic structural units: the Kujawy Segment (part of the Mid-Polish Anticlinorium) and the Łódź Segment (part of the Szczecin–Miechów Synclinorium), which together form a domal uplift. This basement culmination, characterized by a fault-block structure, constituted a significant barrier to the advancing Scandinavian ice sheets. The origin of the marginal zone and the associated glaciotectionic thrust structures developed in the foreland of the Łódź Plateau is interpreted as being closely related to the presence of faults in the Cretaceous basement oriented perpendicular to the direction of ice-sheet movement (Klatkova, 1972, 1996).

The transgressing Saalian ice sheet advanced over terrain underlain by a Mesozoic structural high, flanked to the north by sequences of unconsolidated Cenozoic deposits. According to Klatkova (1972), such an obstacle, together with material detached from the substratum and thrust up in front of the ice margin, impeded further ice-sheet advance until renewed ice influx increased the driving force and

reactivated forward movement. The basal part of the ice sheet, subjected to the greatest frictional resistance against the substratum, remained largely steady state, whereas the overlying ice masses were displaced farther along shear planes, levelling the surface of the thrust-up deposits at a slightly higher elevation. The cause of this irregularity in ice movement has also been attributed to the episodic nature of ice sheet advance, expressed in the form of ice-sheet surges. Subsequent studies by K. Turkowska (1993) and J. Petera (1996) indicate that glaciotectonic deformations in this region may also be associated with oscillations of the retreating ice sheet.

STOP 1.B. SEDIMENTARY ARCHITECTURE OF THE STRYKÓW LEVEL IN ROSANÓW

The elevation of the Stryków level in Rosanów reaches 185.5 m a.s.l. and towards the Katarzynów level it descends by a slope with an inclination of up to 5°. In the geological structure, sands and sands with gravels dominate – upper glaciofluvial deposits – overlying Warta Stadial till (Fig. 2) (Klatkowska et al., 1991). A small pit located on the slope of the Stryków level makes it possible to gain insight into details of the geological structure down to a depth of about 15 meters (Fig. 3).

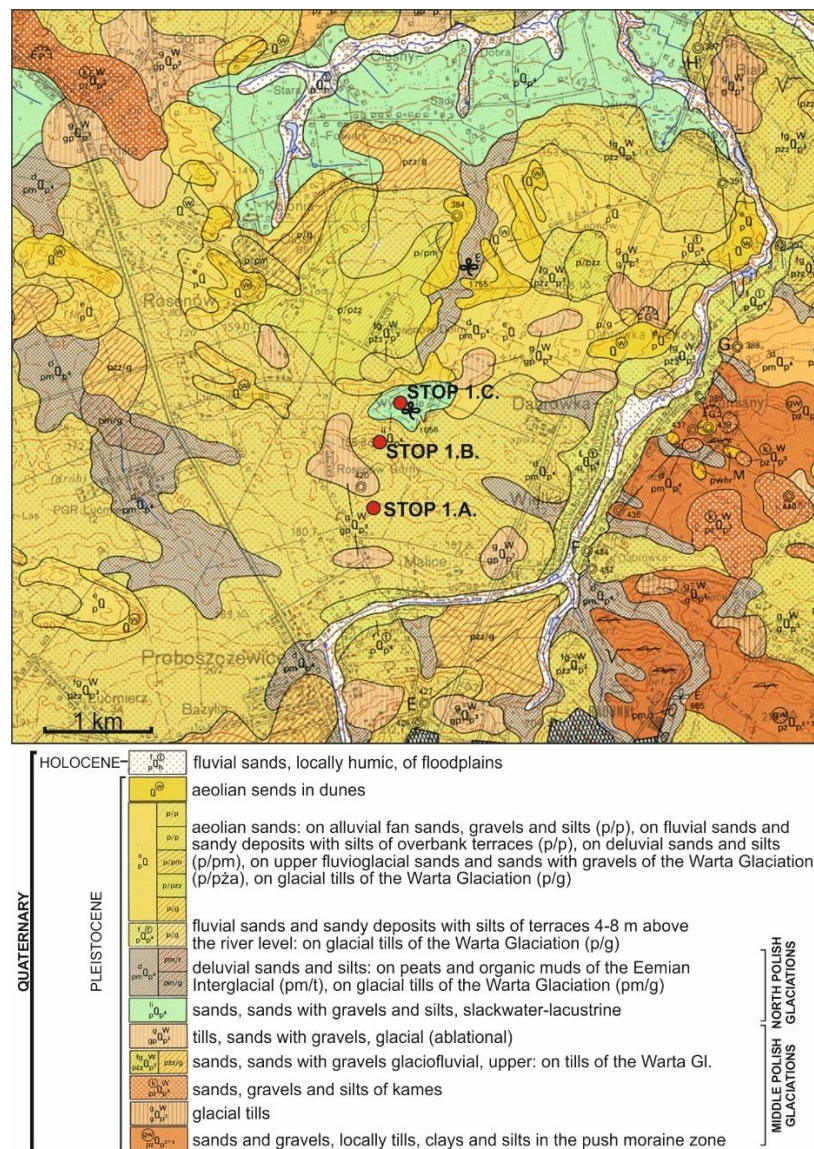


Fig. 2. Fragment of the Detailed Geological Map of Poland 1:50,000, sheet Zgierz (Klatkowska et al., 1991)

In the western and north-western part of the exposure, deposits dominated by lithofacies of sands or sands with gravels, horizontally stratified and low-angle cross-stratified, are exposed, with a documented thickness of up to 7 meters (unit A). Individual lithofacies have a small thickness, ranging from several to several tens of centimeters. In places, massive deposits occur, as well as ripple lamination in sand and silty sand. Small scour pools filled with trough cross-stratified deposits also occur. The described sedimentary features indicate deposition under variable dynamic flow conditions. Transitions occurred from dynamic conditions of subcritical flow states or supercritical flow under upper plane-bed conditions to deposition from rhythmic bedload transport during periods of reduced flow dynamics. The sedimentological features of the deposits, as well as the geomorphological context, suggest that this series was formed as a kame terrace. It should be noted, however, that according to Zieliński (1992), a similar sedimentological record characterizes a medial or distal glaciomarginal fan.

The entire Series A exhibits an inclination of approximately 10° towards the NNE. Closer to the margin of the landform, normal faults with throws ranging from several to several tens of centimeters occur within the sediments. Faults dipping towards the SW predominate. The dominant dip angles range between 40° and 75°.

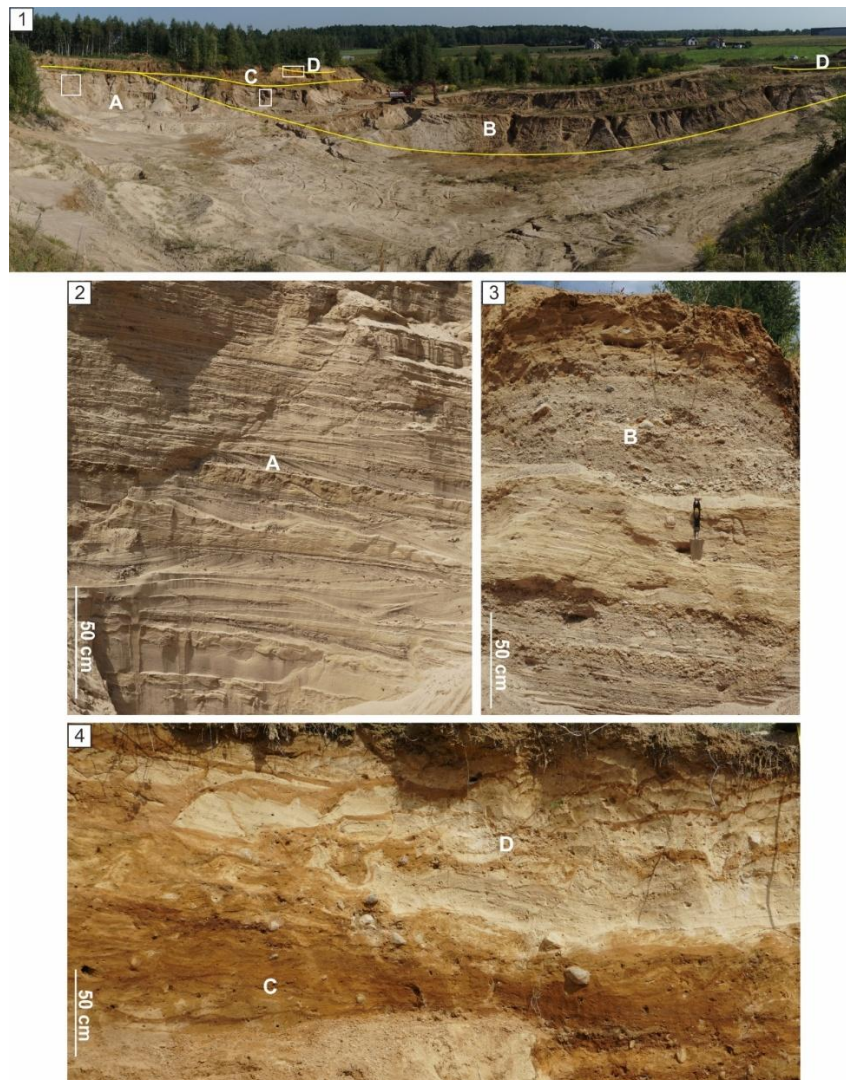


Fig. 3. Deposits documented in Rosanów site
 (1) general view with boundaries of units; (2) sands and sandy gravels of unit A; (3) gravels and sands of unit B; (4) ablation till (unit C) and thinly laminated deposits with deformations (unit D)



Sedimentary series – unit B (Fig. 3), exposed in the northern and north-eastern part of the outcrop, is composed of markedly coarser-grained deposits, with a minimum thickness of 8 m. The succession is dominated by coarse gravels, with the occurrence of isolated boulders. The deposits are predominantly massive or exhibit internally organised structures in the form of horizontal stratification and low-angle cross-stratification; in places, the primary depositional structures are poorly discernible. This series also includes thicker facies sets of gravelly sands and massive sands, as well as horizontally stratified and low-angle cross-stratified sands and gravelly sands. Individual lithofacies typically attain thicknesses of several tens of centimeters. Diamicton facies are also present within this sedimentary series. The deposits were accumulated under highly dynamic but temporally variable flow conditions, as indicated by the wide grain-size spectrum. The depositional environment was characterized by intensive, probably shallow sheet-like flows, transporting large volumes of poorly sorted, polymodal sediment, which underwent rapid accumulation. Hydraulically overloaded flows were episodically interrupted by cohesive debris flows, with deposition through flow freezing, resulting in diamicton units. The sedimentary characteristics of this series are typical of a proximal glaciomarginal fan (sensu Zieliński, 1992).

In Series B, an inclination of strata is also observed, with the dominant direction towards the NE. The layers dip at an angle of approximately 13°. In the eastern part of the exposure, strongly deformed sediments occur. The deformation is mainly plastic in character and affects sediments with a minimum thickness of 6 m. The structures include folded sediments, flexure-type deformation, and locally vertically oriented strata. In most layers, the sediments retain their internal structure; however, in the upper part of the profile, finer-grained deposits have been disturbed. Normal faults dipping towards the SW or NE are also present within the sediments.

The inclination of the sedimentary layers may result from the disappearance of ice support to the NE of the kame terrace. The intense disturbance observed in the eastern part of the exposure most likely represents glaciotectonic deformations. Stress related to the south-westward movement of the ice sheet caused plastic deformation of water-saturated sediments.

Unit C consists of a diamicton with a thickness of approximately 1 m. The diamicton is characterized by a high proportion of sandy matrix, the presence of clasts within the boulder-size fraction, and the occurrence of streaking (Fig. 3). These deposits were emplaced by cohesive debris flows and represent ablation till.

Sedimentary series A, B and C are genetically related to the presence of the last ice sheet in this area during the Saalian Glaciation and record successive depositional phases closely linked to the ice margin. The subsequent near-surface sedimentary series (D) is associated with Vistulian morphogenesis. It occurs on slopes and within dry valleys as the uppermost infilling unit of these forms.

The youngest sedimentary unit (D), with a thickness of approximately 1 m, consists of thinly laminated mineral material with an admixture of coarser grains accentuating the lamination. A distinctive feature of this series is its discontinuous deformation manifested by pronounced faulting and fissuring. These structures include minor reverse and normal faults as well as unrotated blocks (Fig. 3). The origin of this series is attributed to deposition on frozen snow patches preserved for more than one season, formed by processes of wash, mudflow and aeolian activity, whereas the development of collapse structures resulted from denivation processes. Due to the approximate geochronological control of these features, climatic conditions of the Late Vistulian suggest that the Younger Dryas cold phase was the most favourable period for the formation of the oversnow depositional series (Klatkova, 1984; Dzieduszyńska, 2011; Dzieduszyńska and Petera-Zganiacz, 2018). However, recently obtained OSL age determinations place the deposition of these sediments in earlier phases of the Late Vistulian.

STOP 1.C. FOSSIL LACUSTRINE SYSTEMS IN DRY VALLEYS OF THE ŁÓDŹ PLATEAU

Individual morphological levels of the Łódź Plateau are dissected by numerous dry valleys. A characteristic feature of these valleys is the axial occurrence of fossil, closed-basin lacustrine systems in their upper reaches. The origin of closed-basin may vary (Klatkova, 1989). These form chains of paleolakes separated by thresholds within the glacial tills. The basins are typically several tens to several hundreds of meters in diameter and reach depths of several to over a dozen meters. Although often indistinct in present topography, they are locally expressed by temporary ponds during periods of increased moisture. In the geological record, they occur as distinct packages of organic deposits of variable thickness within depressions of the glacial surface.

The basins functioned as local, denudational base. The highest basins commonly remain disconnected from the valley drainage system, forming closed basin within watershed zones and preserving the most complete sedimentary records. Their infillings document morphogenesis under temperate climatic conditions, including the Saalian lateglacial (MIS 6a), the Eemian Interglacial (MIS 5e), and the Early Vistulian, with evidence of the Brørup (MIS 5c) and Odderade (MIS 5a) interstadials.

In Rosanów site, the highest palaeobasin is the Wymokłe site, below which an even smaller depression has been documented, located in the axis of a dry valley oriented northward, perpendicular to the Ciosenka River valley. Dune deposits associated with the late glacial of the Vistulian occur transversely to the axis of the basins on the surface between them (Fig. 2, 4).

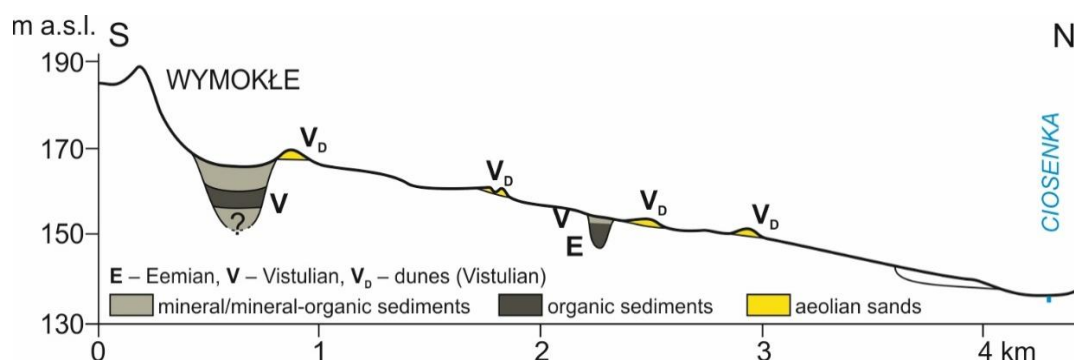


Fig. 4. Longitudinal profile of the dry valley at the Rosanów site (acc. to Klatkova, 1997)

These basins formed the original denudation bases in zones predisposed to the development of open valley systems along them. In both basins, Eemian organic deposits have been documented at their bases, covered more (in the upper basin – Wymokłe) or less (in the lower basin) by a complete series of Vistulian sediments (Fig. 4).

The Eemian interglacial succession in Łódź Plateau sites demonstrates essentially the same regional pattern of vegetation development, differing only in local details and record completeness. The lateglacial record of the Saalian is characterized by the dominance of park tundra communities and scattered patches of pine-birch forest, which progressively displace communities of open habitats. The significant share of redeposited pollen is evidence of soil instability and intensive erosional processes. The Eemian interglacial begins with the expansion of pioneer pine-birch communities, through the hornbeam-lime optimum, and finally the final spruce-fir and pine phase. The climatic optimum is distinguished by very high percentages (up to 79%) of *Corylus avellana*, high *Tilia* undiff., and the early appearance of *Carpinus betulus* (Majecka, 2014). The regional records show a complete Early Vistulian with two interstadial periods – the older Brørup and the younger Odderade (Rudunki interstadial according to Jastrzębska-Mamełka, 1985). The absence of younger deposits in the lake fillings provide

the evidence of definitive disappearance lake basins from the landscape at the end of the Early Vistulian.

The best-documented sites in the region include Zgierz-Rudunki (Fig. 5), Bychlew, Dąbrowa, Ślaskowice, Wągry and Żabieniec Południowy (Jastrzębska-Mamełka, 1985; Klatkova, 1989; Majecka, 2014). Based on these records, a diagram of the functioning of the upper sections of the valleys in closed and open denudation systems was developed (Fig. 6). The Eemian and early Vistulian periods played a key role at the onset of the transformation of the original glacial relief of Łódź Plateau, expressed by the infilling of closed depressions with thick organic sediments. Subsequent periglacial morphogenesis led to complete infilling of depressions and their integration into an open denudational valley system. As a result, Vistulian deposits are frequently incomplete and exhibit evidence of erosion.

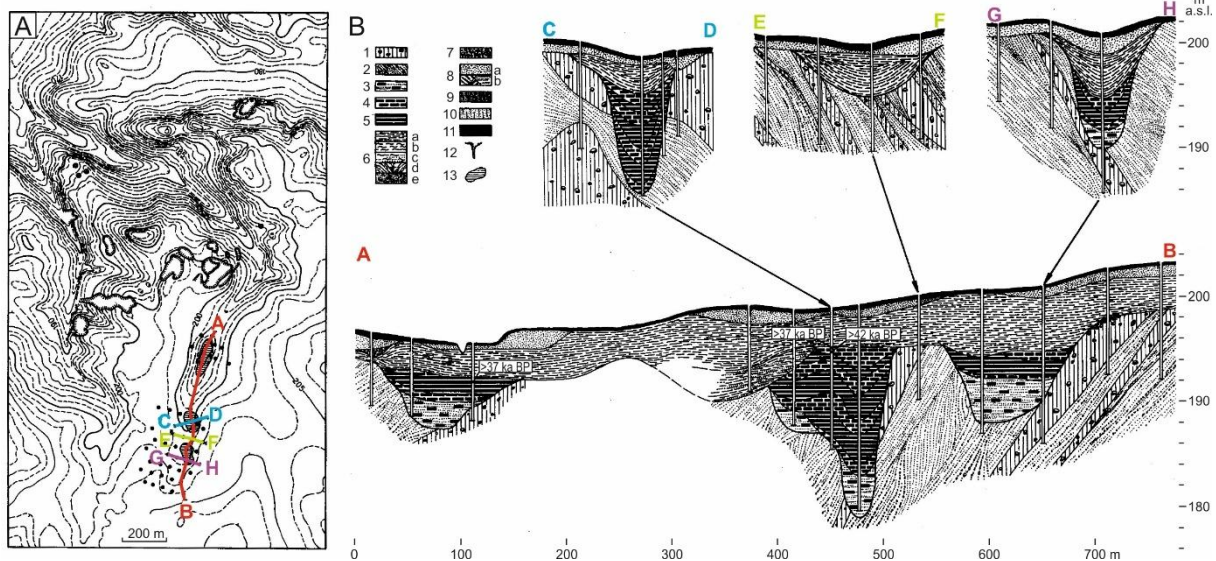


Fig. 5. Zgierz-Rudunki. Geological documentation of the site (acc. to Klatkova, 1989)

(A) hypsometric sketch of the dry valley, (B) transverse and longitudinal geological cross-sections; Warta stadial: 1 – till, 2 – glaciofluvial sands and gravels; Eem-Vistulian: 3 – aeolian sands, 4 – organic silts, 5 – peats, 6 – sandy-silty deposits: a – not distinguished on cross-sections, b – silts, c – parallel-laminated sandy silts, d – silts with syngenetic frost disturbances, e – silty sands with soil traces; Upper Plenivistulian: 7 – gravel-stone horizon, 8 – finely laminated sands, a – on cross-sections, b – on the profile; Late Vistulian – Holocene: 9 – horizon of iron compound accumulations, 10 – silty, aeolian sands, 11 – horizon of modern soil accumulation, 12 – pseudomorphs after thermal contraction cracks (Upper Plenivistulian), 13 – extent of fossil lake basins

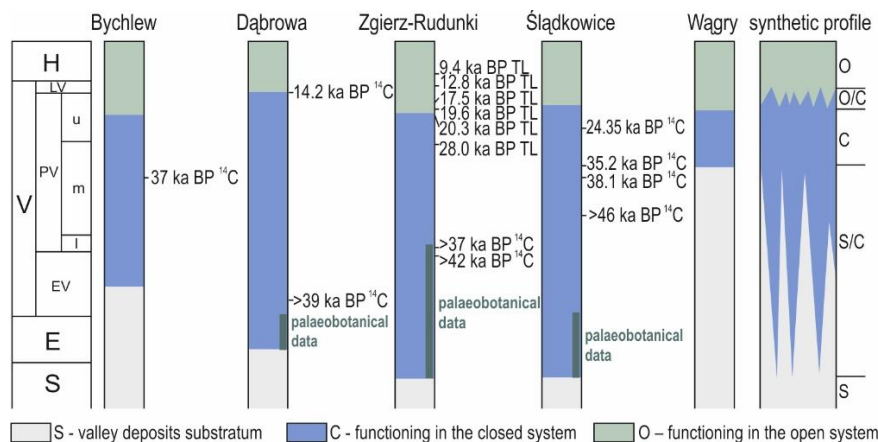


Fig. 6. The scheme of functioning of the upper valley sections in the closed and open denudational systems (acc. to Klatkova, 1989)



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STOP 2 - PLICHTÓW

Periglacial relief transformation: the case of dry valleys and dells

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Dry valleys in the context of landforms developed under periglacial conditions are concave landscape features dissecting margins of various origin, created primarily by periglacial denudation ensuring transport transverse to the form axis and periodically operating longitudinal transport processes leading to the removal of material. Morphological characteristics of dry valleys include clearly defined slopes and flat-floored, relatively wide bottoms with no active channel in them. Closely related to dry valleys are dells: shallow, unchanneled hillslope hollows that are commonly bowl- or paddle-shaped and usually distinctly smaller than dry valleys.

Development of dry valleys in the Central Polish lowlands is connected with the Vistulian, when the extraglacial area of the last SIS was subject to periglacial conditions of different intensity over time and different duration. The fundamental studies of dry valleys have been carried out since the 1960s by Professor Halina Klatkova (1965, 1989, 1997) on the basis of nearly 800 features over the area of approximately 800 km² of the so-called "marginal zone" of the Łódź Plateau. The dry valleys and dells are key landforms here and provide the best record of past periglacial environmental conditions in the landscape. Their abundance is an external expression of the intensity of periglacial denudation.

The most common dry valleys are integrated with currently active river valleys, either as concavities within valley slopes corresponding to the Vistulian terraces or as their headward extension without a stream channel. Besides, there are also quite numerous cases when dry valleys cutting a steep slope terminate in the flattening stretching below.

Dry valleys and dells are distributed irregularly over the area, with their density locally attaining 20 features per km². They occur either as single features or in groups of several forms. Where one big valley occurs near a few small dells, the bottoms of the tributary dells hang above the valley bottom. Equivalent forms may be combined and create extensive dell-like valleys. Dry valleys and dells do not reveal any relation with an active fluvial system and nowadays only brief, episodic runoff without morphological impacts is likely to occur. Dry valleys and dells are distinguished on the basis of morphometry: dells are up to 300 m long, small valleys are between 300 and 800 m long, and large valleys 800–1500 m. Their width ranges from 8 to 400 m. Bowl-like features that have a width greater than their length are mostly dells; the valleys are definitely narrower and their bottoms are not clearly exhibited. The hillslope profiles are characterized by long and distinctly marked concave parts in the lower slope unit and convex parts in the upper one. Most of the dry valleys display symmetrical cross-profiles, with angles varying from 0.5° to 20° (most frequently 2–6°). Some of the slopes of larger valleys are asymmetrical, with south- and west-facing slopes tending to be steeper than north- and east-facing sections, but differences between opposite slopes are not significant. In longitudinal profile, valleys have relatively straight or gently concave floors with gradients of 0.5–10°, which typically follow host slope parameters. The formation of dry valley and dell systems depended largely

upon topography. The favored location is on hillslopes steeper than 2° ; dells by values of $8\text{--}10^\circ$, and larger forms of $2\text{--}4^\circ$. Lithological conditions do not determine their occurrence.

Dry valleys are considered to initiate and develop by two different paths. According to the first, the valleys have foundations in glacial bedrock which began to develop in the Saalian termination. Isolated depressions in the land surface left by the ice sheet, which resulted from dead-ice decay or uneven glacial accumulation or the uneven surface resulting from glaciotectonic processes, were used by the developing drainage. Intensive post-glacial erosion in the presence of permafrost occurred at the end of the Saalian and continued throughout the early Eemian Interglacial, deepening the valleys and leaving the network of currently dry features. In their bottoms survived an erosional lag, named the "lower gravelly stone pavement". The second path assumes that water bodies situated on gently sloping surfaces after enlarging and filling up with clastic sediments, drained and became incorporated into an open morphological system. Under permafrost conditions, this created a landscape dominated by dry valleys with long convexo-concave hillslopes.

The process of infilling of dry valleys with periglacial deposits started at the Denekamp Interstadial ($\sim 32\text{--}28$ ^{14}C ka BP). Within the valleys, concentrated slope wash operated under humid-climate conditions associated with extant permafrost. The resulting sediments are rhythmically stratified ("sandy-silty series"), and developed in alternating aerobic and gleyed conditions above impermeable frozen ground. Typically, the thickness of this first fundamental sedimentary unit infilling the dry valleys is 1.5–2 m. Age determinations from its bottom have provided results from thermoluminescence (TL) dating of ~ 28.0 kyr and from radiocarbon (^{14}C) dating of ~ 28.1 ka BP for a muddy soil horizon. Deposits above contain cryogenic structures such as fine syngenetic fissures and permafrost-related involutions. The latter are thought to reflect the raising of the former permafrost table, which, by retaining water on the surface, promoted sediment loading. The formation of the disturbed section occurred in the period between ~ 20.3 kyr and ~ 19.6 kyr, based on TL dating.

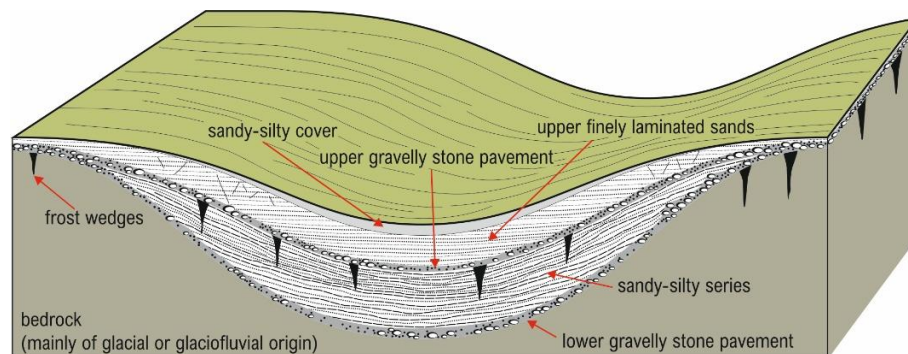


Fig. 1. Model of dry valley sedimentary infilling of the Łódź Plateau (Dzieduszyńska et al., 2025)

Overlying the sandy-silty rhythmically stratified series is an allochthonous "upper gravelly stone pavement" whose material was derived from upslope or from uplands. It consists of unstratified and heterogeneous deposits in the form of gravel or pebbles in an iron-enriched sandy matrix. Some large clasts which display polishing and facetting by wind abrasion are ventifacts. Nevertheless, the origin of the deposit is linked primarily to valley-side solifluction activated by freeze–thaw cycles within an active layer above permafrost. The stratigraphical position of most pavement horizons was indirectly established by TL dating of the underlying deposits at ~ 17.5 kyr; thus the formation of the pavement horizons followed the Upper Pleniglacial cold period. Evolution of the dry valleys under permafrost conditions through the Upper Pleniglacial is recorded in their infills by common and large epigenetic ice-wedge pseudomorphs developed from the upper gravelly stone pavement downwards and

truncating the sandy-silty series. The pseudomorphs often contain subsided fragments of the pavement or glacial till moved by solifluction over the slope.

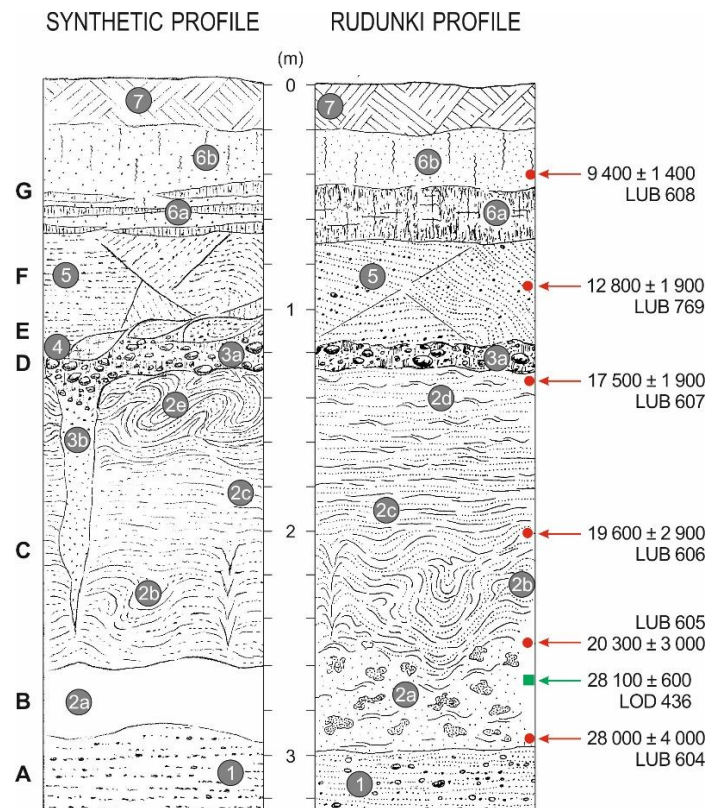


Fig. 2. Scheme of processes and deposition succession in dry valleys of the Łódź Plateau since the Denekamp Interstadial (Klatkowska, 1997).

Lithological description: 1 – bedrock, 2a – soil level of weathering, 2b – zone of syngenetic deformations: involutions and frost fissures, 2c – horizontally stratified sandy-silty series, 2e – strongly deformed sandy-silty series, 3a – stone pavement, 3b – epigenetic ice-wedge cast, 4 – loamy gravely gelifluction lobes, 5 – finely-laminated sands, 6a – sandy-silty deposit with limonitic streaks, 6b – sandy-silty deposit with high amount of wind abraded grains, 7 – humus.

A – bedrock (mainly of Saalian Stage), B – traces of soil-weathering processes (from Denekamp Interstadial), C – traces of slopewash (silty-sandy series) over frozen substrate with cryoturbation structures synchronous with the series formation (from Denekamp Interstadial onwards) and major generation of epigenetic ice-wedges (Upper Pleniglacial cold maximum),

D – upper gravely-stone pavement (first warming after Upper Pleniglacial cold apogee), E – traces of solifluction (first warming after Upper Pleniglacial cold apogee), F – deposition of vari-grained and genetically-varied clastic material of sandy-silty series, including facies differentiation (Lateglacial), G – eolian structureless sandy-silty cover (Lateglacial/Early Holocene). Red dots indicate TL dates; green square indicates radiocarbon date.

Activated slope processes formed the next fundamental unit infilling dry valleys, the “upper finely-laminated sands”. This unit is up to 1.5 m thick and forms the most extensive sedimentary succession filling the dry valleys. It is medium- and fine-grained horizontally stratified sand, often with aeolian sediment and pebbles. Deposition is attributed to slopewash. A distinctive variation of this series is an oversnow deposit of a thickness varying from 0.3 m upslope to 0.8 m downslope. It contains an admixture of chaotically spaced pebbles and cobbles up to 10 cm in diameter; the horizontal lamination is disturbed by small folds and faults. The origin of this unit is attributed to deposition on long-lasting frozen snow patches by wash, mudflow and wind. Discontinuous deformations were created by material collapse activated by denivation (i.e., snowmelt), while disturbances of the lamination might have resulted from deposition over an uneven slope surface under cold though non-permafrost conditions. The series was TL dated to ~12.8 kyr, pointing to a Lateglacial age.



The sedimentary succession within dry valleys is capped by a structureless sandy-silty cover of aeolian origin TL dated to ~9.4 kyr, i.e., to the Lateglacial/Holocene boundary.

The history and origin of broad, shallow dells are also strictly Vistulian and periglacial, though shorter than the history of dry valleys. In the infills of dells, neither the sandy-silty series nor the older series have been found anywhere. Locally, dells are mantled with the finely-laminated sands or the upper gravelly stone pavement occurs. But most often they are devoid of the Vistulian covers and the bedrock reaches the present-day surface. According to Klatkova (1965), dells that have a hanging position above the floors of large dry valleys connect with the surface at the top of the sandy-silty series, and therefore may have developed through slopewash over frozen subsoil. Following a concept by French (2007), dells are considered to be periglacial landforms that resulted from snowmelt erosion under cold-climate conditions.

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STOP 3 – JANINÓW

Janinów gullies – an example of Neo-Holocene landscape transformation

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The area located north of Łódź is characterised by the occurrence of a relatively large number of young erosional forms – gullies. More than 200 forms can be indicated here, ranging from small, shallow gullies several tens of metres long to mature, branched erosional systems with lengths of several kilometres. The total length of the gullies north of Łódź amounts to approximately 32.1 km, and their density reaches 0.11 km/km², which corresponds to a moderate (II) degree of gully erosion intensity (Józefaciuk and Józefaciuk, 1990). The gullies mostly dissect river valley slopes (in total 60% of the forms), while the remaining nearly 40% are associated with incisions within dry valleys and dells. These periglacial forms created favourable conditions for the concentration of episodic runoff originating from intense rainstorms and rapid thaw events, especially those occurring on frozen ground. Among the gullies incised into periglacial denudational systems, 28% of all forms occur in large dry valleys, 5% of the gullies north of Łódź dissect small dry valleys (these are forms with lengths below 300 m), and 4% of the gullies dissect the smallest, gently outlined dells (Twardy, 1995).

The largest gully system in the vicinity of Łódź, located 18.5 km NE of Łódź, occurs in the area of the villages of Anielin, Lipka and Janinów. The Janinów gully system consists of two large gullies: a more strongly branched western gully and a slightly smaller eastern gully, devoid of more significant lateral branches (Fig. 1). The gullies have a total length of nearly 4,000 m and a density of 4.62 km/km², which makes them comparable to the smaller and less plan-complex classical gullies of the Lublin–Volhynian Upland (SE Poland), which dissect thicker loess covers. The volume of material eroded from the Janinów gullies amounts to approximately 100,530 m³. The width of the gullies locally reaches 50-60 m, and the maximum incision depths attain 7 m.

In terms of morphology, the Janinów gullies correspond to forms described in former Russia and the USSR as “dolinnyj owrag” (долинный овраг). This term was used to denote large, branched erosional forms, drained only episodically, which are incised into dry valley systems (Sobolew, 1948). The main arms of the Janinów gullies usually have a sinuous course and are characterised by local fluctuations in volume, i.e. short, narrower and shallower sections with reduced volumes occur (Fig. 2), alternating with longer, widened and often deeper sections with larger volumes. Such a “beaded” form of the gullies is most probably a distant reminiscence of the functioning of initial incisions of dry valleys, which only in the final stage became connected into a single drainage route, while still preserving traces of uneven erosion in the past. This resembles the mechanics of development of so-called discontinuous gullies, described from other climatic zones (Leopold et al., 1964). The remaining conditions of gully erosion, apart from relief, were discussed in earlier studies (Twardy, 1995, 2005).

As stated above, the Janinów gullies dissect the floor of a branched system of large Vistulian dry valleys, which connect on the left side to the Mrożyca River, a fourth-order stream (a left-bank tributary of the Mroga River, which flows into the Bzura River, which in turn is a left-bank tributary of the Vistula River).

The aforementioned dry valleys are associated with considerable relief amplitude: their headwater sections reach elevations of 220 m a.s.l., while their outlet into the floor of the Mrożyca valley occurs at an elevation of approximately 151 m a.s.l. It is evident that, given such significant relief differences and valley gradients for lowland conditions, episodic gully erosion had favourable conditions for development. The eastern gully reached the highest elevation (up to 205 m a.s.l.), and the point at which the two main forms (i.e. the western and eastern gullies) merge is located at an elevation of about 177.5 m a.s.l. At this point, deep infilling with eroded sediments occurs – the gullies vanish within their own accumulation zones.

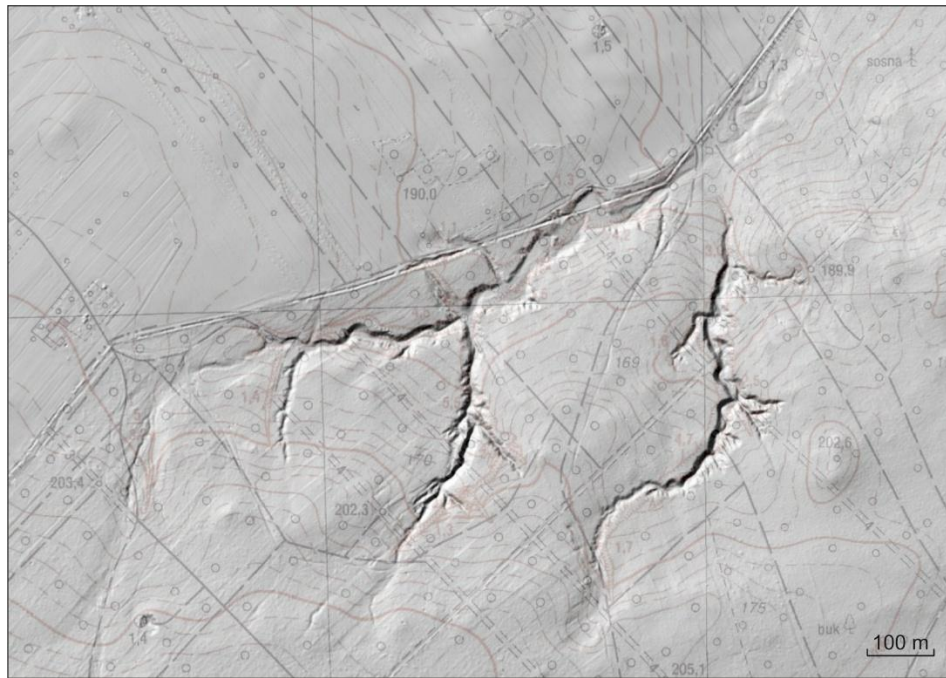


Fig. 1. Janinów gully complex in the context of the surrounding terrain morphology



Fig. 2. Morphology of the upper part of the eastern gully (Photo: J. Twardy, 2008)

The relative age of the gullies is determined by their relationship to the periglacial sediments infilling the dry valleys (Fig. 3, phase I). It is known that the gullies incise into or completely cut through all units of the dry-valley infill: the Plenivistulian sandy-silty series, the Late Vistulian upper finely-laminated sands (Klatkova, 1965), as well as loess-like deposits of unspecified origin. The Vistulian infill of dry valleys was formed until the transition between the Late Vistulian and the Holocene, that is, until the development of forest formations in Central Poland. Consequently, the development of incision processes into the Vistulian units must have taken place already in the Holocene, during periods when forest communities were more intensively exploited and removed by humans. The development of gullies in Central Poland was preceded by environmental transformations under conditions of increasing anthropogenic pressure (Fig. 3, phase II). These environmental changes resulted in the activation of denudation on deforested slopes and the accumulation of deluvium deposited, among other places, on the floors of dry valleys (Fig. 3, phase III). Incision into the dry-valley infill and the initial phases of gully erosion occurred at the beginning of the SA-2 subphase of the Subatlantic (Twardy, 2008, 2011). According to archaeological chronology, which is based on shorter time intervals, this can be related to the Roman period of the Iron Age (ca. 2000-1600 years BP) and linked to the already more drastic environmental pressure exerted by communities of the Przeworsk Culture.

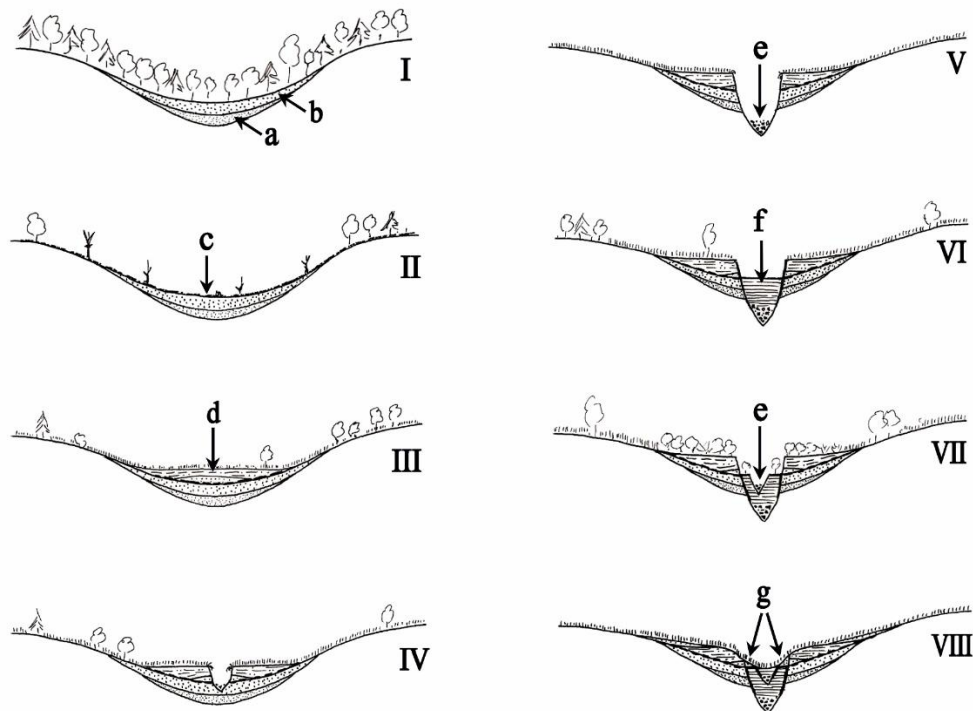


Fig. 3. The phases of gully development in the Łódź Plateau

Main sediment series; Vistulian; a – sandy-silty deposits of dry valleys infill; Late Glacial: b – fine-laminated sands of dry valleys infill; Neoholocene: c – fire horizon, d – deluvial sands and clays, e – stony pavement, f – sands and gravels of gully fills, g – tillage diamictons.

The Janinów gullies appear to be somewhat younger – the oldest radiocarbon date documenting vigorous incision of the eastern gully (Fig. 3, phases IV and V), combined with mass movements of material from steep slopes, is $1,490 \pm 100$ years BP ($1,514-1,298$ cal BP; 68.3% conf. int.; LOD 519). On the gully floors, an erosional pavement was deposited, composed of pebbles with diameters up to 30 cm, as well as large boulders eroded from morainic material and preserved as a residuum. Subsequently, together with the spatial development of the gully system, the gully floors were covered by diversified, most often poorly and very poorly sorted sands, gravels and silts (Fig. 3, phase VI).



Subsequent datings – 570 ± 80 years BP (645–492 cal BP; 68.3% conf. int.; LOD 520) and 480 ± 70 years BP (623–469 cal BP; 68.3% conf. int.; LOD 518) – indicate a certain stabilisation of gully-erosion processes (Fig. 3, phase VII) and the development of initial soils colonising fresh deposits displaced by gully erosion. The development of the Janinów gully system thus had at least a 1,000-year history and falls within the Migration Period and the entire long Medieval Period. In the Modern Period, the gully system was excluded from agricultural use and afforested. Therefore, phase VII characterised by the gradual obliteration of erosional relief under conditions of intensive agriculture did not take place in the development of the Janinów gullies (Fig. 3).

The question remains as to where the sediments removed by gully erosion from the Janinów gullies are located. Part of them was accumulated on the floor of the dry valley below the point where the gullies merge (cf. Fig. 1). This valley, however, should be treated primarily as a transport section, linking the Janinów gullies with the local erosional base – the floor of the Mrożyca River valley. Thus, the material mobilised by gully erosion may have become part of the Neo-Holocene alluvial cover, which covers the floors of small river valleys in the Łódź Plateau with a layer approximately 0.5 m thick (Kamiński, 1993). An estimate of the volume of sediments eroded from the two largest gully systems in the Mrożyca valley (that is, the Janinów gullies and the slightly smaller, higher-situated gully in the town of Brzeziny), related to the area of the river-valley floor, indicates that the eroded material could theoretically have formed there a uniformly distributed layer about 6 cm thick, which corresponds to approximately one-eighth of the thickness of the alluvia. Therefore, gully erosion, which in the Neo-Holocene stripped ancient Vistulian surface-runoff pathways, may have had a relatively significant impact on the youngest sedimentary units occurring in river valleys.

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STOP 4 – OWADÓW-BRZEZINKI

The exceptionally well-preserved Late Jurassic ecosystem of Owadów–Brzezinki, Central Poland

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The Owadów–Brzezinki quarry is an active open-pit marl and limestone mine (Fig. 1C) located in Central Poland, on the northwestern margin of the Holy Cross Mts (Łódzkie Voivodeship, Opoczno County; Fig. 1B). The rocks exposed in the quarry belong to the uppermost stage of the Upper Jurassic – the Tithonian, and have been independently correlated with the local East European Substage – the Middle Volgian. Moreover, multi-phase karst sinkhole deposits present in the Owadów–Brzezinki quarry contain Lower Cretaceous (Valanginian) sands and clays, as well as Miocene siliceous sinter, coal clay, and speleothem fragments (Wierzbowski et al., 2026). These strata are truncated and overlain by Quaternary deposits reaching a thickness of several meters (approximately 4-5 m). The site has produced some of the most important palaeontological discoveries in Poland in recent years (Kin et al., 2012, 2013; Błażejowski et al., 2016, 2023a, b). Excavation work at the site – carried out systematically since 2013 by the Institute of Paleobiology PAS in Warsaw as part of research projects supported by the Polish National Science Centre – has involved undergraduate students, doctoral students and scientists from all over the world. Remarkably well-preserved fossils of marine and terrestrial organisms of Late Jurassic age, many of them new to science, have proved invaluable for the study of ecosystem taphonomy, the evolution and migration of taxa, and palaeoenvironmental changes (cf. Błażejowski et al., 2016, 2019; Wierzbowski et al., 2016).

OVERVIEW OF TOP PALAEOLOGICAL FINDS

The palaeontological site of Owadów–Brzezinki has been described as a new “taphonomic window” into the Late Jurassic, providing insights into the evolution of life on Earth (Fig. 2). New species endemic to the site are continually being discovered, such as lobster-like decapod crustaceans (Feldmann et al., 2015; Błażejowski et al., 2016; Fig. 3) and xiphosuran arthropods (Kin and Błażejowski, 2014; Błażejowski, 2015; Błażejowski et al., 2019, 2020; Fig. 4), constituting one of the largest accumulations of Jurassic horseshoe crabs discovered to date. The most notable vertebrate taxa discovered so far include the ichthyosaur *Cryptopterygius kielanae* (Tyborowski, 2016; classified as *Undorosaurus* by Zverkov and Jacobs, 2021), the pancryptodiran turtle *Owadovia borsukbialynicka* (Szczygielski et al., 2018), the carapace of a marine turtle (Thalassochelydia indet.; Fig. 5), and isolated plesiosaur teeth (Weryński and Błażejowski, 2023). Other vertebrate taxa are represented by Actinopterygii and Elasmobranchii (Kin et al., 2013; Błażejowski et al., 2015; Weryński et al., 2023), with additional shore fauna including insects – beetles, dragonflies and orthopterans (Michalska and Błażejowski, 2026; *in review*; Fig. 6), terrestrial crocodylomorphs (Błażejowski et al., *manuscript in preparation*), and possibly pterosaurs (Kin et al., 2013).

The Owadów–Brzezinki section is located within both the Brzostówka marls of the topmost part of the Pałuki Formation (Fm) and the overlying limestones of the Kcynia Fm (Błażejowski et al., 2016; Fig. 1A). The uppermost part of the Pałuki Fm and the overlying limestones of the Kcynia Fm – including the Sławno Limestone Member (Mb), “*Corbulomima* limestones”, and a horizon of “serpulid” beds – are exposed in the section (Kutek, 1994). The sedimentary pattern observed in the Owadów–Brzezinki section indicates a gradual marine regression, reflected in a transition from offshore to coastal and lagoonal settings. However, its uppermost part was deposited during a short-term marine transgression and subsequent reappearance of coastal environments (Błażejowski et al., 2016; Wierzbowski et al., 2016).

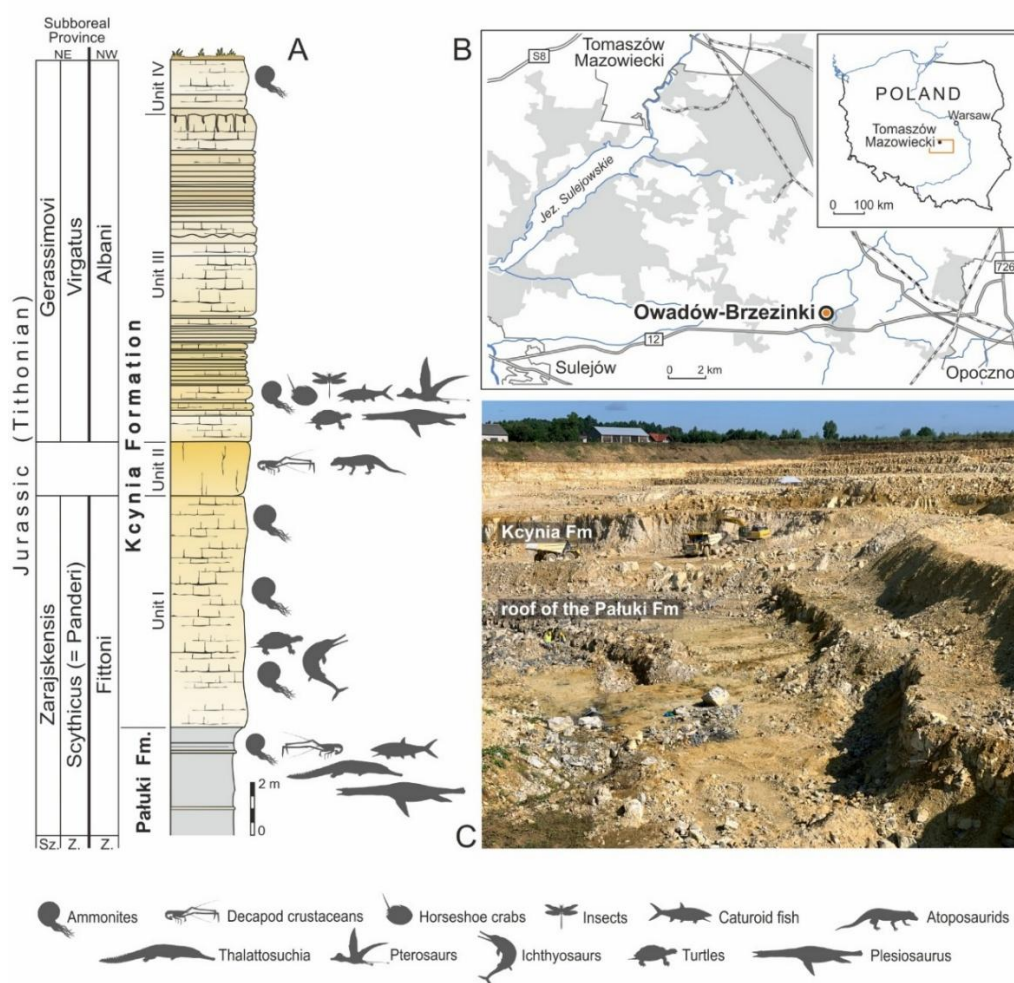


Fig. 1. Location of the site and lithological succession in the study area

(A) Lithological succession and biostratigraphy of the Owadów–Brzezinki Quarry. The topmost part of the Pałuki Fm and overlying limestones of the Kcynia Fm (Units I–IV). (B) Road map with the location of the Owadów–Brzezinki site and its proximity to Tomaszów Mazowiecki in Central Poland. (C) General view of the Owadów–Brzezinki section. Abbreviations: Fm, Formation; Sz., Subzone; Z., Zone.

The uppermost part of the Brzostówka Marl Mb of the Pałuki Fm from the Owadów–Brzezinki quarry (ca. 4 m thick) consists of black, blue-greyish, and yellow-bluish marls with intercalations of thin oyster-bearing and marly limestone beds (cf. Błażejowski et al., 2016; Wierzbowski et al., 2016). The marls have yielded abundant marine microfossils, bivalves, ammonites, decapod crustaceans, and fish (Błażejowski et al., 2016). The overlying limestones of the Kcynia Fm have been subdivided into four lithological units (Fig. 1A).

According to the stratigraphic studies of Kutek (1994) and Matyja and Wierzbowski (2016) based on the ammonite fauna (Fig. 7), the lower part of the Owadów–Brzezinki deposits is dated to the *regularis* horizon (the uppermost part of the Brzostówka Marl Mb of the Pałuki Fm) and the *zarajskensis* horizon (unit I of the Sławno Limestone Mb of the lowermost part of the Kcynia Fm) of the Zarajskensis Subzone of the Scythicus (Panderi) Zone of the Middle Volgian, as well as to the Fittoni Zone from the "Bolonian" zonation of England. The upper part of the Owadów–Brzezinki section (units III and IV belonging to the "*Corbulomima* limestones" and "serpulid" beds, respectively) has, in turn, been assigned to both the Gerassimovi Subzone of the Virgatus Zone of the Middle Volgian and the Albani Zone of the "Portlandian". Owadów–Brzezinki has recently attracted much attention not only due to the exquisite quality and quantity of preserved fossils, but also due to its palaeogeographic significance – it has been proposed that the site exemplifies an important area at the intersection of Boreal/Subboreal and Tethyan realms, where mixing of temperate and tropical faunal biota occurred (Błażejowski et al., 2023a; Fig. 8).

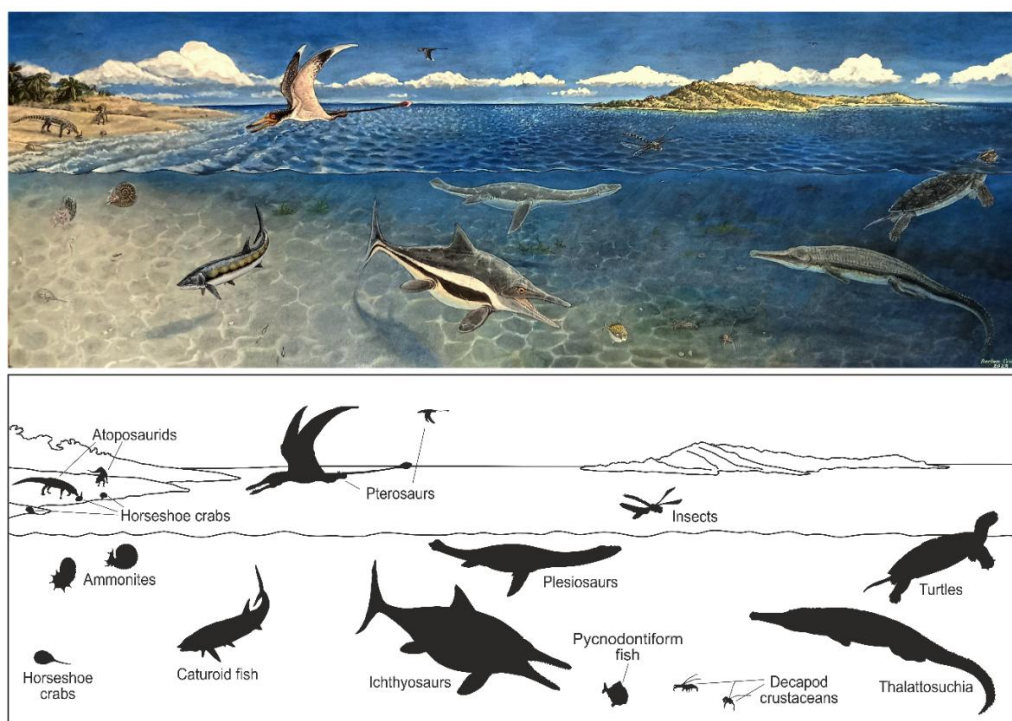


Fig. 2. Reconstruction of the paleoenvironment of the Owadów-Brzezinki site.
 Palaeoart drawn by Bartosz Czader; (Błażejowski et al., 2023b).



Fig. 3. Lobster-like decapod crustacean *Mecochirus* sp. nov. (ZPAL Cr.11/O-B/22/1).
 Upper Jurassic (Tithonian), Pałuki Formation.



Fig. 4. Horseshoe crab exoskeleton - *Crenatolimulus darwini* (Kin and Błażejowski, 2014).
 Upper Jurassic (Tithonian), Kcynia Formation (Unit III). Coin for scale.

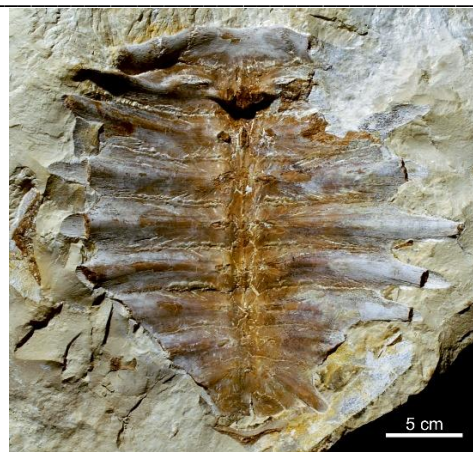


Fig. 5. The carapace of a marine turtle (*Thalassochelydia* indet.).
 Upper Jurassic (Tithonian), Kcynia Formation (Unit III).



Fig. 6. Forewing (tegmen) of an orthopteran from the extinct family Elcanidae (ZPAL I.1/O-B/49; Michalska and Błażejowski, 2026). Upper Jurassic (Tithonian), Kcynia Formation (Unit III).



Fig. 7. Ammonite *Virgatopavlovia*. Upper Jurassic (Tithonian), Kcynia Formation (Unit I).



Fig. 8. Palaeogeographical map of Europe at the end of Jurassic (acc. Błażejowski et al., 2023a)

THE OWADÓW–BRZEZINKI GEOEDUCATION AREA

This site is of importance not only for palaeontology as a scientific discipline and for the promotion of this field in Poland, but also for the development of the region and its local communities. For a number of years, workshops and lectures have been held in the Sławno Commune aimed at promoting knowledge of geology, and especially palaeontology, among the population of the region, fostering greater understanding of and respect for the natural environment. These activities are directed mainly at schoolchildren and young people, as well as at those interested in the study and protection of Poland's geological heritage. It is also a potential venue for national and international geological and palaeontological conferences. Of special importance for such activities is the palaeontological pavilion in the thematic geoeducation area (also known as the "Owadów–Brzezinki Geopark"; Fig. 9), under the supervision of the Sławno Commune, where fossils discovered here and reconstructions of the Jurassic animals they represent are on display (Fig. 10). The most spectacular specimens include life-sized ammonites, fish, and marine reptiles – ichthyosaurs, turtles, and crocodylomorphs – as well as flying pterosaurs. The scientific team examining the fossils from this site supervised the creation of the

museum's exhibition and the informative plaques positioned along the geoeucational path, running on the observation deck along the edge of the quarry. Telescopes placed on the terrace allow visitors to observe both the limestone mining activity carried out by the quarry operator (Nordkalk Company), and also the research and exploration camps of scientists. In the central part of the observation deck stands a 12-meter-long statue of an ichthyosaur, which has become a symbol of local palaeontological discoveries.

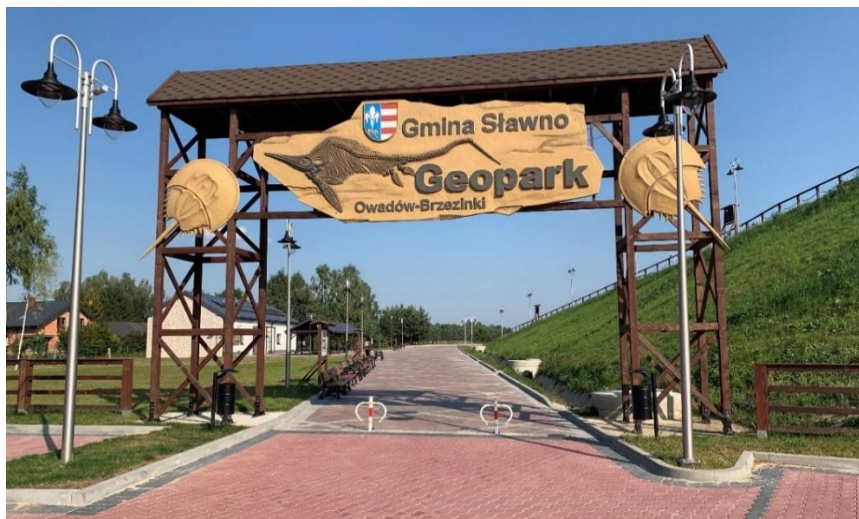


Fig. 9. The entrance gate to the Owadów-Brzezinki Geosite (geopark) in Sławno community



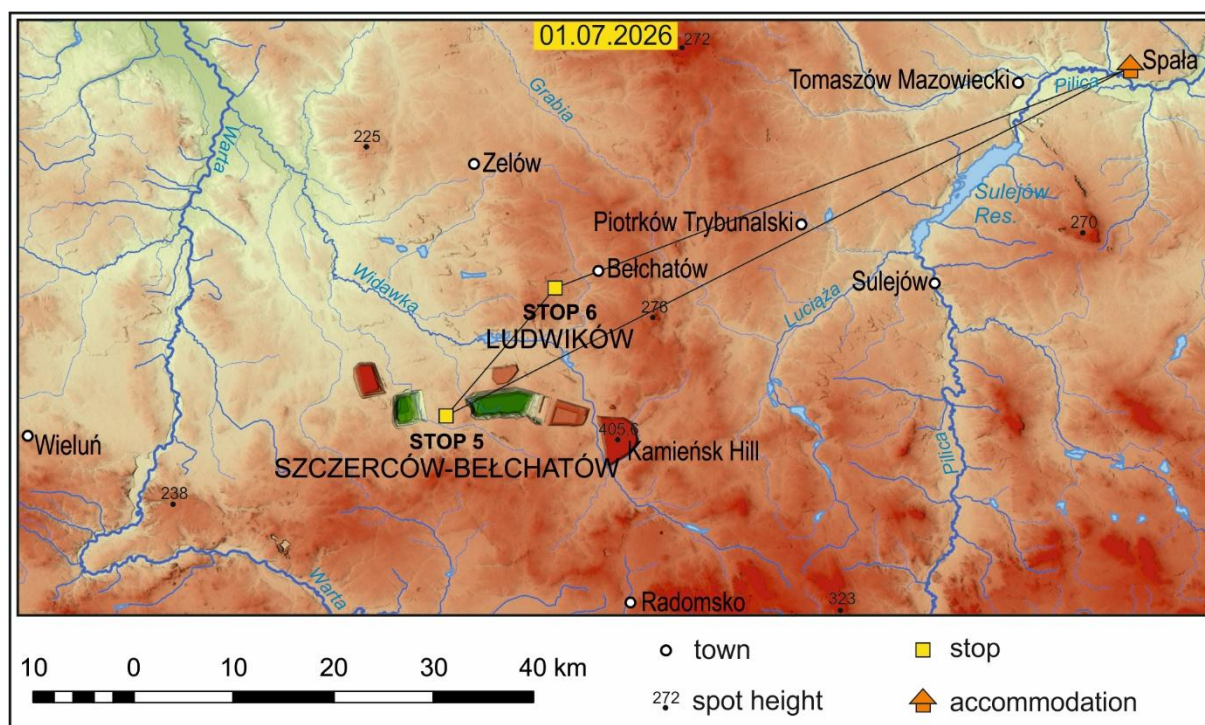
Fig. 10. The palaeontological pavilion presents fossils from the Owadów-Brzezinki quarry and life-size reconstructions of animals which inhabited the local seas and islands during the Late Jurassic

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STOP 5 – SZCZERCÓW-BEŁCHATÓW

Multi-proxy research of Quaternary palaeogeography of the Central Poland, case study from Szczerców-Bełchatów area (Bełchatów Open-Cast Mine)

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STOP 5.A. SZCZERÓW OUTCROP – PARCHLINY AND KUŹNICA SITES

Geological setting

About 150,000 years ago, the study area was covered by the Scandinavian ice sheet – Odranian Glaciation (Saalian), MIS 6 (Fig. 1A, Tab. 1). Toward the end of this period (MIS 6a, Warta Stadial), the ice sheet began to retreat, forming a diverse landscape with moraines, kames, eskers, and kettle depressions. In the Parchliny and Podlas areas, lakes developed — some connected, others isolated (Fig. 1B). Their presence indicates high ice-sheet dynamics, which also created the Szczerców Basin as a trace of the Widawka ice lobe. This is further confirmed by glaciotectionic deformation of sediments.

Due to open-cast mining (lignite), the Parchliny area is well-studied geologically. Several till layers, along with glaciolacustrine and glaciofluvial sediments, have been identified, as well as organic deposits from the Mazovian and Eemian interglacials. The Pleistocene deposits are often deformed, related to the location within the Kleszczów Graben and the presence of the Dębina Salt Dome (Fig. 2, 3).

This text presents results of investigations of Middle and Upper Pleistocene and Holocene deposits in the Parchliny area (Szczerców outcrop), based on analyses of several geological profiles. The aim is to



characterize the lithology, sedimentology, and stratigraphy of deposits from the last 140,000 years and to reconstruct past environmental and climatic changes. The sediments were investigated in several main profiles (see Fig. 1): Parchliny A, Parchliny B (Wachecka-Kotkowska et al., 2014), Parchliny C (Wachecka-Kotkowska et al., 2017), Parchliny 2012 (Kuszell and Iwanus, 2012), Parchliny 2014 (Wachecka-Kotkowska et al., 2018), Parchliny 2016 (Majecka et al., 2022; Płóciennik et al., 2023) and a synthesis (Wachecka-Kotkowska et al., 2024, 2026). Unfortunately, due to the ongoing work in the mine related to lignite extraction, since 2000 none of the above sites are available (see Fig 1B). We are currently presenting the research results for 2018-2019.

The Kleszczów Graben is an extensive tectonic structure that formed in the Polish Lowlands during the Early Miocene (Gotowała and Hałaszcak, 2002). It is quite long (approx. 80 km), but narrow (0.2-5.0 km) and deep (up to 250-400 m) as a result of reactivated older faults. Its importance is linked to lignite deposits exploited in the Bełchatów and Szczerców outcrops, which provide excellent conditions for studying Pleistocene sediments.

Table 1. Stratigraphic scheme of the glacial part of the Pleistocene in Poland with correlations to Western Europe and Marine Isotope Stages (MIS) (according to Marks et al., 2016).
 Glacial periods are marked in bold and gray.

AGE ka	STRATIGRAPHY		WESTERN EUROPE		POLAND		MIS		
11.7	Holocene		Holocene		Holocene		1		
130	Pleistocene	Upper Pleistocene	Weichselian	Late glacial	Vistulian	Late Vistulian	2- 5d		
				Pleni- glacial		Pleni- vistulian			
				Lower Weichselian		Early Vistulian			
Eemian			Eemian			5e			
420		Middle Pleistocene	Saalian	Warthe Drenthe		Odranian	Warta Odra		6
				Schöningen			Lublinian		7
					Krznanian		8		
			Wacken		Zbójnian		9		
			Fuhne		Liwiecian		10		
			Holsteinian		Mazovian		11		
			Elsterian		Sanian 2		12		
			Cromerian IV		Ferdynandovian		13- 15		
			Glacial C		Sanian 1		16		
			Cromerian III		Podlasian		17- 21		
Glacial B									
Cromerian II									
Glacial A									
Cromerian I									
780	Lower Pleistocene	Dorst		Nidanian		22			

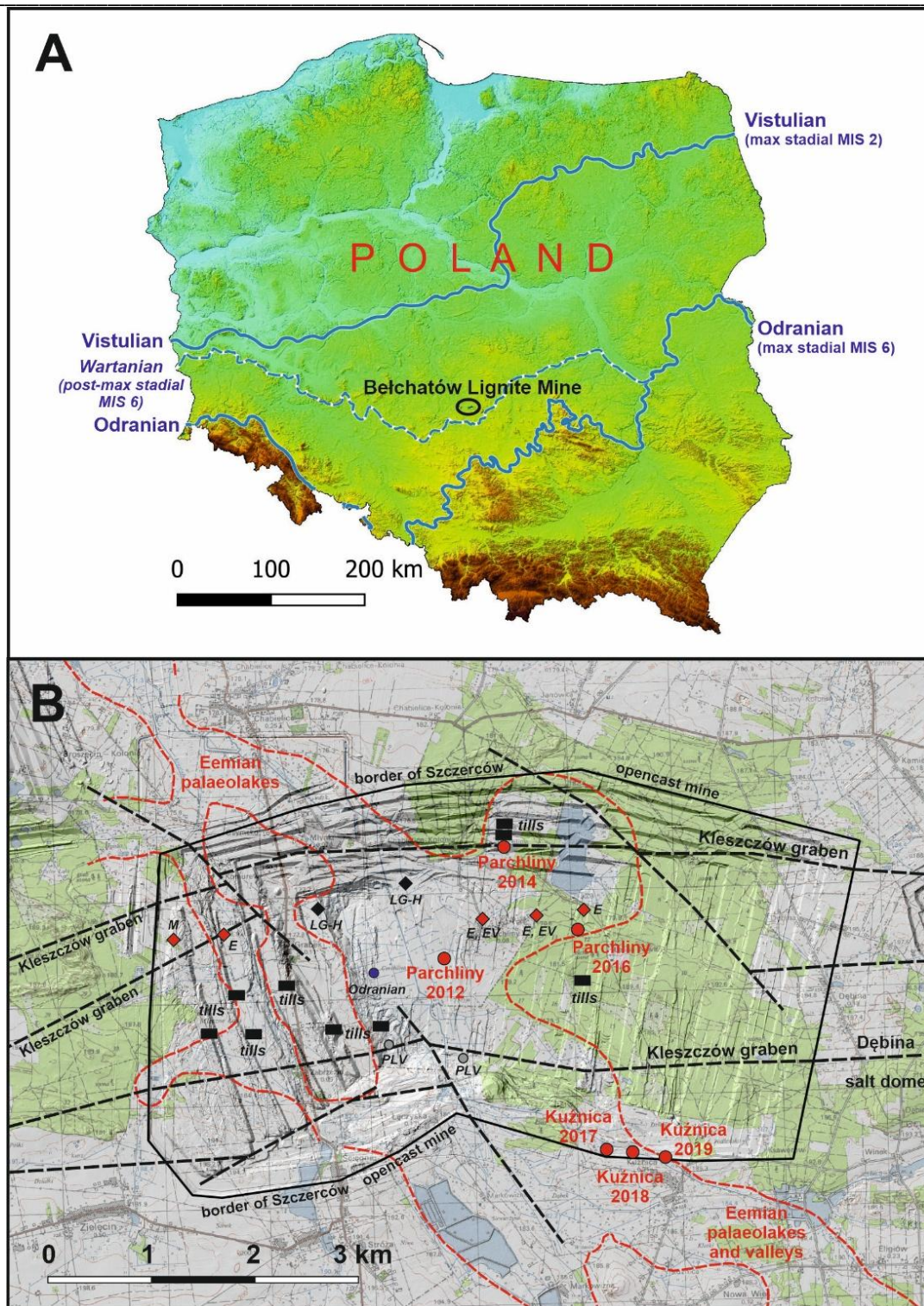


Fig. 1. The study area against the background of the limits of glaciations in Poland (acc. to Marks 2023 – map A) and against the background of a topographic map, digital terrain model (DTM), and the extent of the Kleszczów Graben (acc. to Wachecka-Kotkowska et al., 2026 – map B)

Explanations for map B: the red dashed line indicates extent of postglacial (MIS6) palaeovalleys and palaeolakes; **tills** – sites with study of glacial till; **M, E** – sites with deposits of Mazovian or Eemian Interglacial; **EV, PLV** – sites with deposits of Early Vistulian or Plenivistulian; **LG-H** – sites with deposits of Late Vistulian and Holocene; see table 1.

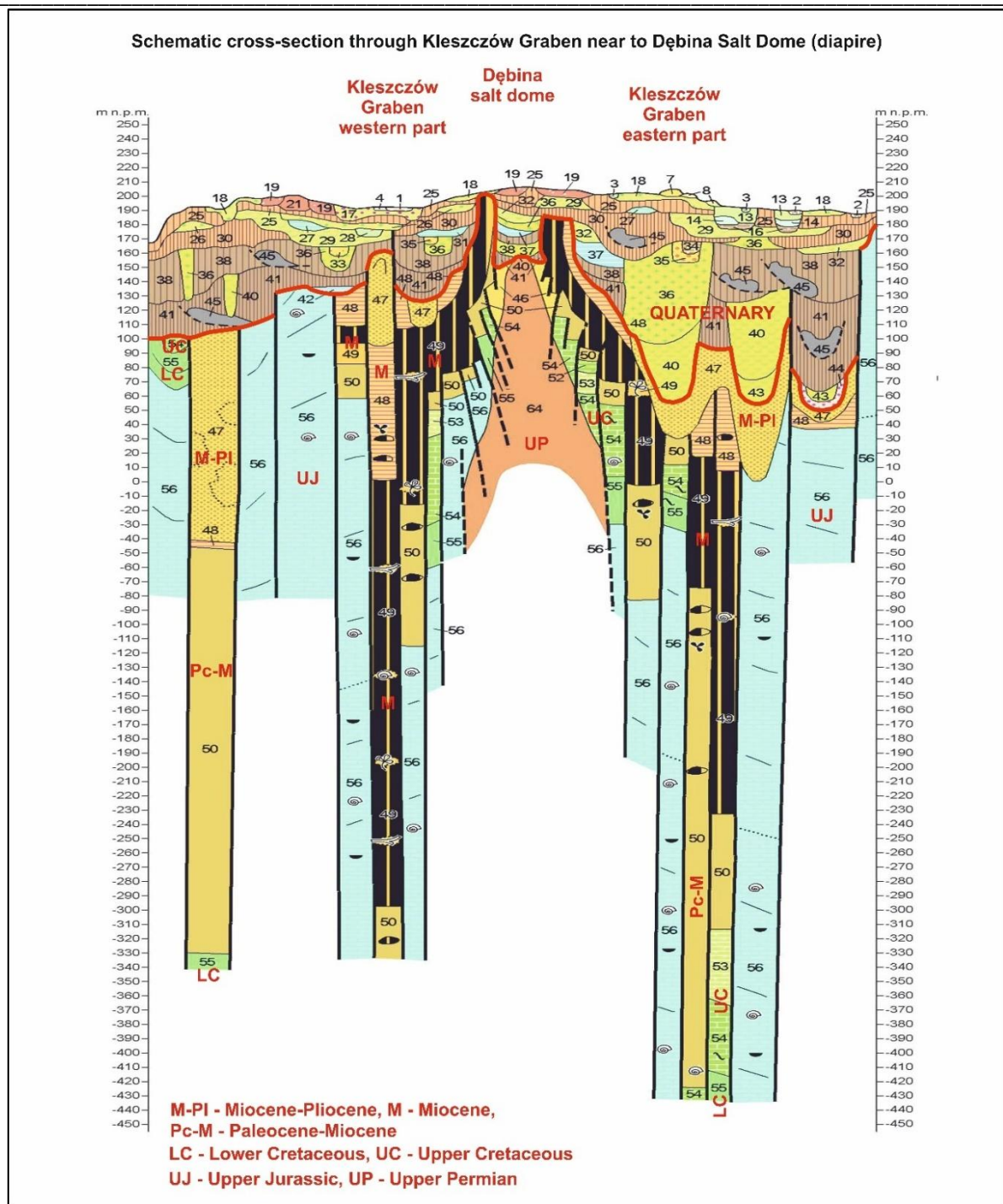


Fig. 2. Schematic cross-section trough the central part of the Kleszczów Graben near to Dębina salt dome (acc. to Wieczorek and Stoiński, 2019)

Explanations: 64 – Upper Permian – Zechstein salt; 56 – Upper Jurassic – limestone; 55 – Lower Cretaceous – sandstone; 54-52 – Upper Cretaceous – limestone, marl; 50 – Paleocene-Miocene – sand, clay; 49-48 – Miocene – lignite, clay; 47 – Miocene-Pliocene – sand; 46 – Miocene-Pliocene – breccias; 45 – Paleogene-Neogene – as a xenolith; 44 – Lower Pleistocene – sand; 43-40 – Nidanian Glaciation: 43 and 40 – fluvio-glacial, 42 – glaciolacustrine, 41 – glacial till; 39-36 – Sanian 1 Glaciation: 39 and 36 – fluvio-glacial, 38 – glacial till, 37 – glaciolacustrine; 35-34 – Mazovian Interglacial: fluvial and boggy; 33 – Zbójno Interglacial – fluvial; 32-29 – Odranian Glaciation: 32 and 29 – fluvio-glacial, 31 – glaciolacustrine, 30 – glacial till; 28 – Lubavian Interglacial – fluvial; 27-17 – Wartanian Glaciation: 27 – glaciolacustrine, 26, 24, 18 and 17 – fluvio-glacial and glacial, 25 – glacial till; 21 and 19 – kame; 16-15 – Eemian Interglacial – fluvial and boggy; 14-11 – Vistulian Glaciation: 14 – lake, 13-11 – fluvial; 8-7 – Late Vistulian – aeolian; 4-1 – Holocene – fluvial and boggy



Palaeobotanical analysis – pollen study (Features of documented interglacial successions)

The Szczerców Basin is rich in interglacial palaeoreservoirs. More than a dozen sediment profiles have been documented so far, representing various types of palaeolakes of meltwater and channel origin from several interglacial periods (Ferdynandovian, Masovian, Eemian) of the Middle and Upper Pleistocene (e.g. Marciniak, 1990; Balwierz, 2003; Wachecka-Kotkowska et al., 2018; Fig. 1). Most of them contain lacustrine sediments documenting a more or less complete sequence from the Eemian Interglacial, through the Early Vistulian (MIS 5d–5a), to the Plenivistulian (MIS 4 and MIS 3). Recent research also indicates the presence of relatively rarely described successions of the late glacial of the Odranian Glaciation (Majecka et al., 2022). Current research is focused primarily on the Parchliny site, where pollen analyses were conducted for the Parchliny 2012, 2014, and 2016 profiles (e.g., Wachecka-Kotkowska et al., 2018; Majecka et al., 2022; Wachecka-Kotkowska et al., 2026).

The pollen record for the Parchliny 2016 profile reflects climatic changes associated with the final phase of the Warta Stadial of the Odranian Glaciation (MIS 6a). Slight climatic oscillations in the late glacial correspond to the Zeifen Interstadial and the Kattegat Stadial identified in western Europe. The recorded herbaceous vegetation primarily reflects cool steppe vegetation (Majecka et al., 2022; Wachecka-Kotkowska et al., 2026).

The early Eemian Interglacial and the beginning of its middle phase (climatic optimum) were identified in the clay-silt sediments of the Parchliny 2012 profile (Kuszell and Iwanuś, 2012; Wachecka-Kotkowska et al., 2018). The Eemian succession in this profile corresponds to the levels from R PAZ E1 to the beginning of E4 according to Mamakowa (1989). Vegetation development is characterized by the initial dominance of birch and birch-pine communities (L PAZ P1 *Betula–Pinus–Ulmus*; L PAZ P2 *Pinus–Betula–Ulmus*), then mixed forests (L PAZ P3 *Quercus–Fraxinus–Ulmus*), and later oak forests (L PAZ P4 *Quercus–Corylus*), which is associated with the beginning of the climatic optimum. The uppermost part of the profile represents the beginning of the hazel phase (L PAZ P5 *Corylus–Tilia*).

The Parchliny 2014 profile encompasses the Middle and Late Eemian Interglacial and an overlying series of sediments over 2.5 m thick, correlated with the Early and Plenivistulian (Wachecka-Kotkowska et al., 2018). It is one of the few profiles in Poland documenting such a long and continuous Eemian and Vistulian succession. In the Middle and Late Eemian (R PAZ E3–E7), oak vegetation dominates, with an increasing importance of hazel and minimal participation of birch and pine (L PAZ PA-1 *Quercus–Corylus*). Subsequently, a dynamic expansion of hazel is observed (L PAZ PA-2 *Corylus–Tilia*), followed by the development of linden and hornbeam (L PAZ PA-3 *Carpinus–Alnus*). During this time, dense, multi-species forests occurred. In subsequent phases, the importance of fir and spruce (L PAZ PA-4 *Abies–Picea*) increases, followed by pine (L PAZ PA-5 *Pinus*). In pollen zones L PAZ PA-6 and PA-9, a clear decline in the share of dense forests and an increase in the importance of herbaceous vegetation is observed, primarily grasses, sedges (Cyperaceae), and mugwort (*Artemisia*), as well as shrubs such as juniper (*Juniperus communis*), dwarf birch (*Betula nana*), willow (*Salix*), and heather (Ericaceae). These changes correspond to the cool stages of the Early Vistulian – Herning and Redestall. In turn, the pollen record of L PAZ zones PA-7–PA-8 and PA-10–PA-11 indicates improved climatic conditions and the development of interstadial communities, with the dominance first of birch forests and then of pine forests. This pattern corresponds to the Brørup and Odderade interstadials. The highest local pollen zones (PA-12–PA-17), above the Odderade Interstadial, indicate the dominance of herbaceous vegetation. Grass communities were the most common, but the persistent presence of mugwort pollen suggests the development of a steppe-tundra-type community. The low proportion of tree pollen and the relatively high proportion of shrubs indicate the presence of shrub tundra with juniper, dwarf birch, and willows. Assuming continuous and undisturbed sedimentation, the L-zones PAZ PA-12–PA-17 can be considered to correspond to the Plenivistulian.

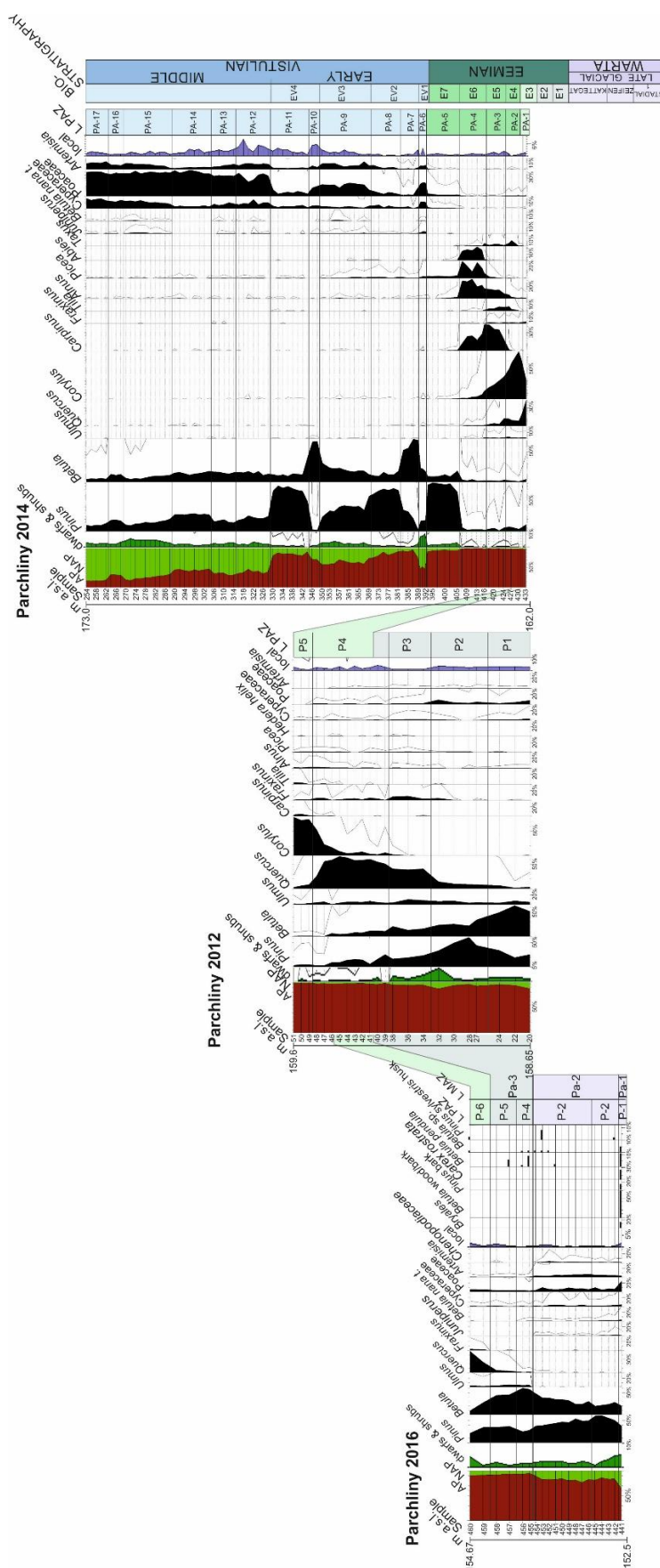


Complementary pollen analyses, supported by other macroremain analyses, geochemical and isotope analyses, resulted in three complementary profiles: Parchliny 2012 (Kuszell and Iwanus, 2012), Parchliny 2014 (Wachecka-Kotkowska et al., 2018), and Parchliny 2016 (Majecka et al., 2022; Płóciennik et al., 2023) which provide a complete picture of the sedimentary succession of a single palaeolake, encompassing the late glacial of the Odranian Glaciation, Eemian Interglacial, and Early Vistulian and Plenivistulian. In Central Poland, they constitute important reference levels for the late glacial (Late Saalian) in Parchliny 2016 and Plenivistulian in Parchliny 2014, the exploration of which in the region is still insufficient. These profiles significantly expand our knowledge of landscape changes in the Late Pleistocene and contribute to a better understanding of past climate changes (Fig. 3). Currently, sediment profiles from the area around the village of Kuźnica are being studied, i.e., the Kuźnica 2017 profile, where the Middle Pleistocene fossil reservoir was found.

Pollen analysis revealed an incomplete interglacial succession characteristic of the Ferdynandovian Interglacial. The local K-1 NAP-Jupnieres pollen level is characterized by a predominance of herbaceous plants (Poaceae, Cyperaceae, *Artemisia*, Chenopodiaceae, *Helianthemum*) and the presence of juniper, sea buckthorn, and willow. This pollen pattern may indicate the end of the San 1 Glaciation (MIS 16). The remaining pollen horizons from K-2 to K-5 are characterized by a predominance of trees over herbaceous plants and correspond to the lower optimum of the Ferdynandovian succession (MIS 15), i.e. the entire I pollen period and the beginning of the II pollen period (Malkiewicz et al., 2025). Nevertheless, currently conducted pollen analyses of the Kuźnica 2018 profile located in close proximity undoubtedly indicate the Eemian interglacial succession (cf. Majecka, unpublished data).

Palaeozoological analysis – Chironomidae study (Middle Pleistocene climate and lake ecology in Central Poland inferred from palaeobotanical and Chironomidae evidence)

Palaeolake deposits were uncovered in the Kuźnica 2017 and 2019 profiles, collected from the Szczerców outcrop. The palaeolake basins, situated within glaciofluvial sands and tills, are filled with silt-gyttja sediments. The Kuźnica 2017 (Ku2017) profile comprises 36 samples, whereas the Kuźnica 2019 (Ku2019) profile includes 13 samples from the gyttja layer. The pollen record in the lower layers of Ku2017 is characterised by the dominance of tundra communities from the Sanian 1 Glaciation (MIS 16). In contrast, the upper part of the profile is dominated by arboreal pollen (>80%), corresponding to the lower optimum of the Ferdynandovian Interglacial (MIS 15). The presence of *Pinus*, *Betula*, *Ulmus*, *Quercus*, *Fraxinus*, and *Corylus* indicates the development of dense deciduous and mixed forests in temperate climate conditions. Palaeobotanical analyses for Ku2019 are underway. The Chironomidae assemblages in Ku2017 are composed mainly of cold-stenothermic taxa, among which *Corynocera ambigua* and *Chironomus anthracinus*-type are the most frequent. The lake was relatively deep, as suggested by the presence of several taxa associated with the profundal zone (e.g., *Monodiamesa*, *Sergentia coracina*-type, and *Heterotrissocladius maeeri*-type). Only four warm-stenothermic taxa were identified; of these, the *Chironomus plumosus*-type is frequent, although this species also tolerates oxygen depletion in deeper waters. Phytophilous taxa are almost absent in Ku2017, indicating a narrow littoral zone. The Ku2019 chironomid assemblages developed in a warmer climate within a shallower, eutrophic lake. Cold-adapted taxa are rare, while seven warm-stenotherms and two phytophilous taxa are present, with *Ablabesmyia* being quite abundant. The lake was likely fed by a small stream, as evidenced by a few rheophilic morphotypes. *Zalutschia* type B indicates lower pH and dystrophic conditions in certain parts of the water body. The age of Ku2019 remains unknown, though the sediments probably date to MIS 11 or MIS 15. The Kuźnica 2018 profile, which documents a later stage of the Ku2017 palaeolake history, is planned for the next stage of research.



STOP 5.B. BEŁCHATÓW OUTCROP – ŻŁOBNICA

From the viewpoint in Żłobnica (approx. 210 m a.s.l.), there is a panoramic view of the Bełchatów Open-Cast Mine, formed as a result of lignite extraction from the Bełchatów outcrop (Fig. 4). This excavation is visible from space. It is currently about 5.5 km long, and at its widest point reaches 3.25 km. The depth of the pit is 310 m. In recent years, a significant part of the Bełchatów outcrop has been used as an internal waste dump.

"Góra Kamieński" (*Kamieński Hill*) was created as an external dump for the Bełchatów outcrop. Its relative height is about 205 m, and its absolute elevation reaches 395 m a.s.l. (Fig. 4), making it the highest anthropogenic hill in Poland. Its construction took nearly 20 years. Over an area of about 16 km², approximately 1.35 billion m³ of overburden material has been deposited. After reclamation and development, the area now hosts a recreation and sports center, including a ski slope, a playground, and a wind farm.

This area has provided and continues to provide valuable data on the tectonics, geology, and palaeogeography of Central Poland over the last one million years. Between 1980 and 2018, as overburden covering the Miocene lignite was removed in the Bełchatów Open-Cast Mine, Quaternary sediment profiles up to 200 m thick were exposed in the Bełchatów field (Fig. 4). As a result, many Polish and international Earth science researchers conducted important litho- and chronostratigraphic studies, as well as investigations into the tectonics of the Kleszczów Graben.

Currently, lignite is no longer being mined in the Bełchatów outcrop. A water reservoir is planned to be created in its place, with a depth of up to 186 m. The planned completion date for flooding the excavation is 2058.

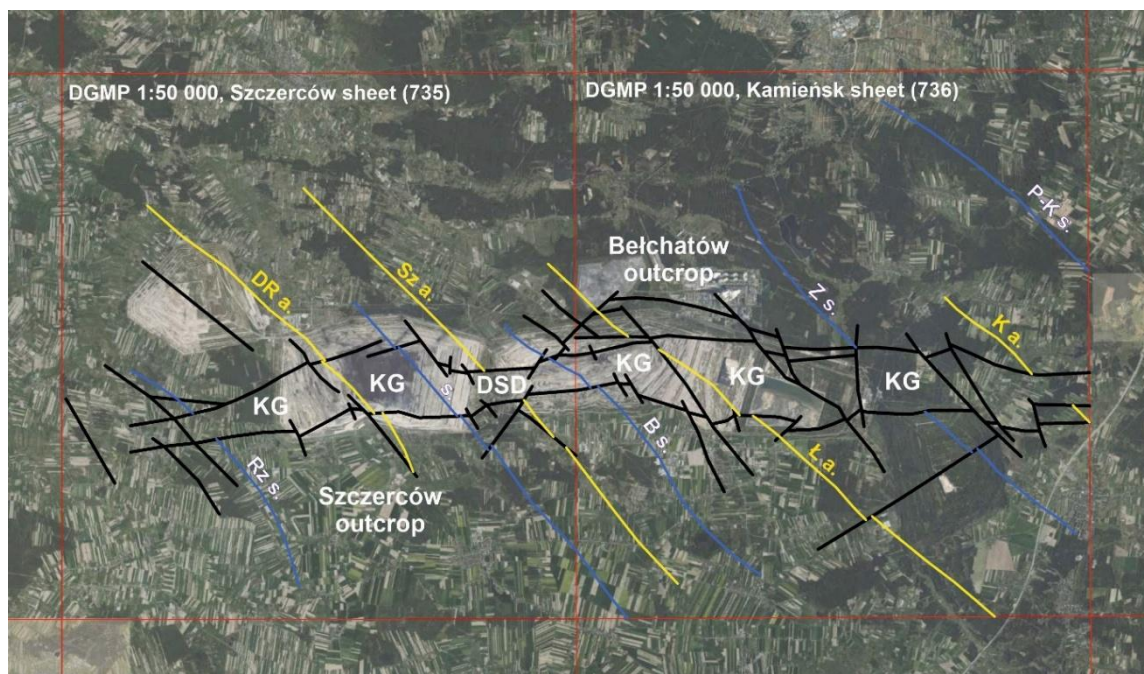


Fig. 4. Bełchatów and Szczerców outcrops in the background of the Kleszczów Graben and its surrounding folding structures (acc. to Pożaryski (1971) and Olchowy et al. (2019) – modified)

KG – Kleszczów Graben, **DSD** – Dębina Salt Dome; black lines – faults; yellow lines – anticlines, blue lines – synclines (Rz s. – Rząśnia syncline; B s. – Brudnice syncline; Z s. – Zapolice syncline; P-K s. – Parzno-Kraszewice syncline; DR a. – Dąbrowa Rusiecka anticline; Sz a. – Szczerców anticline; Ł a. – Łękińsko anticline; K a. – Kamieński anticline);

DGMP 1:50 000 – Detailed Geological Map of Poland in the scale 1:50,000



This research is part of the IDUB project entitled: “Eemian palaeolake ecosystems (Szczerców field, Bełchatów Lignite Mine) in the face of rapid climatic and hydrological changes” (No. 12/IGB/2025).

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STOP 6 – LUDWIKÓW

Middle Pleistocene – Vistulian sedimentary succession at the Ludwików site

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The Ludwików site comprises a ridge-type aeolian dune with a crest oriented NW–SE. In cross-section, the landform is asymmetrical. The southwestern slope is more gentle, with an inclination of 6–10°, whereas the northeastern slope is steeper, ranging from 12 to 20°. The dune is located on the watershed between the Widawka and Stawka River valleys, within the Bełchatów Heights, in close proximity to the Szczerców Basin (Fig. 1). The area was shaped by the Widawka ice lobe during the Saalian Glaciation. The substratum consists of Pleistocene deposits reaching up to approximately 30 m in thickness, including fluvial sands of Holsteinian age, glaciofluvial sands and gravels, and glacial tills related to the Saalian Glaciation. These deposits are overlain by a Late Pleistocene fluvio-aeolian succession, which constitutes the main subject of investigation (Moska et al., 2022).

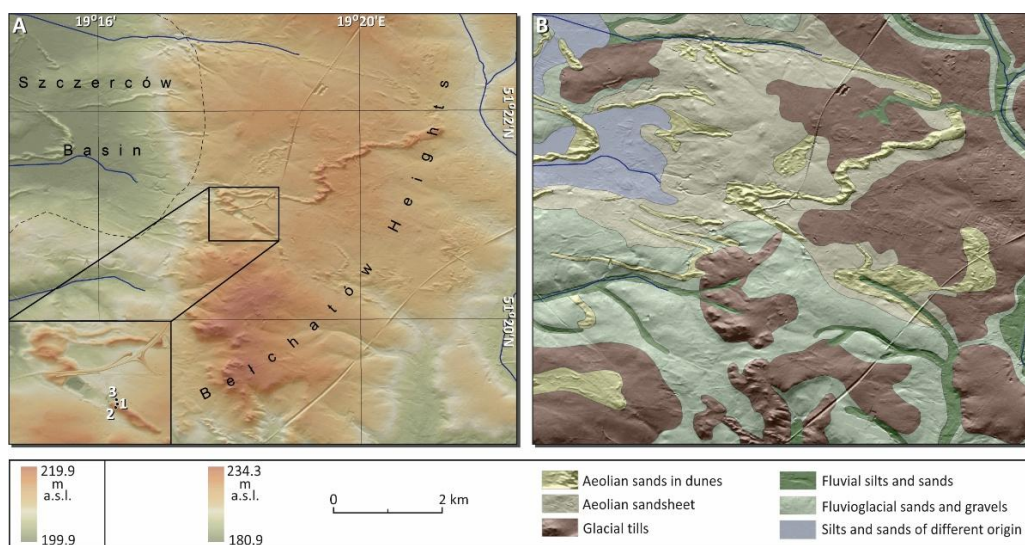


Fig. 1. Location of the Ludwików site
 (A) relief based on the DEM and (B) Cover deposits based on the Detailed Geological Map of Poland 1:50,000, Bełchatów sheet (Ziomek, 1989)

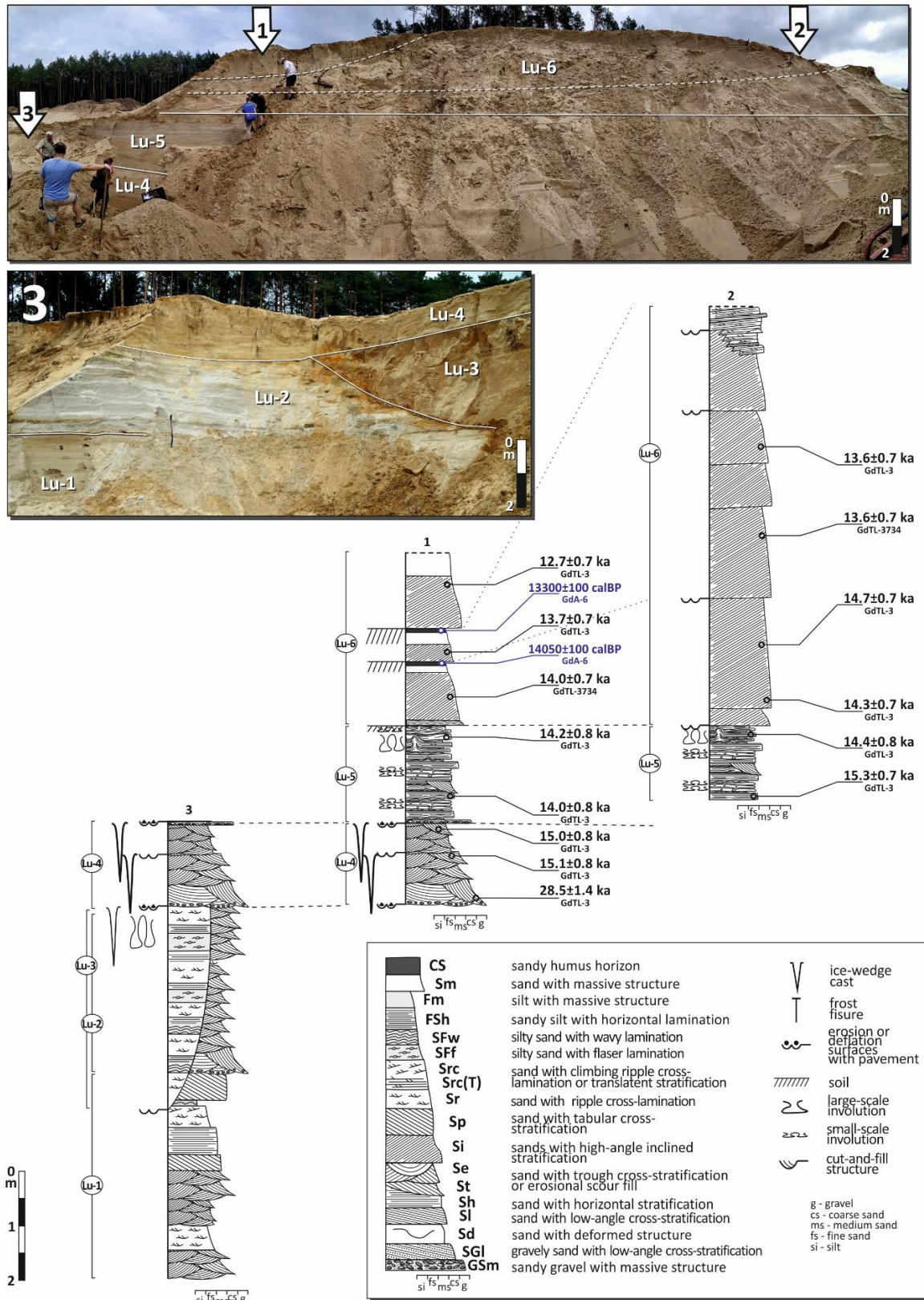


Fig 2. General view of the outcrop with the detailed location of the investigated profiles and sedimentological logs with optically stimulated luminescence and ^{14}C dating results



The sedimentary profile consists of six sedimentary units (Fig. 2). The lowest, Lu-1, is composed of sets of fine and medium sand with medium- and small-scale trough cross-stratification (St), passing upward into sand with ripple cross-lamination (Sr) or tabular cross-stratification (Sp) and horizontal stratification (Sh). The boundary with the overlying unit (Lu-2) is erosional.

Unit Lu-2 is composed of sand with trough cross-stratification (St, SGt), dissected by an erosional channel approximately 4 m deep. Its infill is formed by fine-grained deposits of unit Lu-3. These consist of cyclic alternations of sand, silty sand and silts with ripple cross-lamination (Sr, SFr), passing into flaser (SFf), wavy (Fw) and horizontal lamination (Fh, SFh). Within the Lu-3 unit occur large-scale load casts.

Unit Lu-4 comprises sand with trough cross-stratification (St, SGt). Its lower and upper boundaries are erosional and highlighted by deflation pavements composed of ventifacts. Within the unit occur clasts with vertically oriented long axes, as well as syngenetic ice-wedge cast structures.

Unit Lu-5 is composed of sand with horizontal (Sh) and translent stratification (Src(T)), interbedded with silty sand or silt showing horizontal (SFh, Fh) and wavy lamination (Fw), as well as cut-and-fill structures. An initial fossil soil approximately 25 cm thick is present at the top of the unit. It is characterized by the rusty colour of the enrichment horizon and greyish colouring in the upper part associated with the admixture of organic matter. The boundary between the soil and the underlying sand is diffuse.

Unit Lu-6 occurs only within the dune. Its lower part is composed of sand interbedded with horizontally laminated silts, passing upward into sand with tabular cross-stratification and large-scale inclined stratification. In the crest part, the uppermost part of the succession also contains sand with low-angle cross-stratification or translent stratification. Within the northwestern slope of the form, fossil horizons with organic matter are preserved, locally completely transformed by pedogenic processes. In one of the profiles, the paleosol horizon disappears and is replaced by a deflation surface. The upper part of the unit has been transformed by Holocene soil-forming processes.

Units Lu-1 and Lu-2 represent channel deposits related to the migration of bedforms within an active river channel. The predominance of sand with trough cross-stratification (St) indicates sediment transport under lower flow regime conditions and migration of three-dimensional bedforms. Upward, within individual cycles, St structures pass into ripple cross-lamination (Sr), locally also into wavy lamination (Fw), which may be associated with a decrease in flow energy during the falling stage of flood events. Locally documented sand with tabular cross-stratification (Sp) indicates the development of transverse bars or bedforms with a more two-dimensional geometry, whereas horizontally stratified sand (Sh) may reflect episodes of shallow and relatively rapid flow within a progressively shallowing channel.

Unit Lu-3 fills an erosional channel incised into the deposits of unit Lu-2. Its fine-grained character, with a predominance of silty sand and silt, together with the occurrence of ripple, flaser, wavy and horizontal lamination, indicates sedimentation in a depositional basin environment with a limited contribution of weak flows. The unit may be interpreted as a record of infilling of an abandoned or cut-off channel form, most likely an oxbow-type feature, where, following the erosional phase, fine-grained material accumulated in standing water conditions with periodic low-energy inflows (Toonen et al., 2012). Alternatively, this succession may reflect a change in the hydrological regime at the ice-sheet forefield, leading to reduced flow energy and transition from active channel sedimentation to depositional basin or quasi-lacustrine conditions.

Unit Lu-4 represents channel deposits of a sand-bed braided river functioning under periglacial conditions. The predominance of sand with trough cross-stratification (St) indicates migration of three-dimensional bedforms within the main flow zone (Miall, 2006). The erosional character of the lower



and upper boundaries of the unit, together with the presence of deflation pavements with ventifacts, reflects episodes of intense deflation under dry and cold environmental conditions (Christiansen and Svensson, 1998). Up-freezing stones (Goździk and French, 2004) and syngenetic ice-wedge casts document the presence of permafrost and active periglacial processes during sediment accumulation (Moska et al., 2022).

Unit Lu-5 represents deposits formed under variable contributions of fluvial and aeolian processes. Horizontally stratified sand indicate episodes of shallow flow, followed by deposition of aeolian material on a moist surface, represented by Fw and SFh structures. In turn, Src(T) structures indicate migration of aeolian ripples on a dry surface, whereas the resulting deposits were subsequently redeposited by concentrated flow, represented by cut-and-fill structures. The initial paleosol occurring at the top of the unit reflects temporary surface stabilization, reduced sediment supply and development of pedogenic processes. The entire succession indicates a fluvio-aeolian environment functioning under conditions of variable substrate moisture (Kasse, 2002; Moska et al., 2022).

Unit Lu-6 represents aeolian deposits related to the development of an inland dune. Sand with tabular cross-stratification and large-scale inclined stratification document the migration of the dune lee slope under conditions of intensive aeolian transport. In the crest part, the occurrence of sand with low-angle cross-stratification and translational stratification indicates ripple migration and accumulation within the crest and gentle slopes of the form (Lea, 1990). Fossil horizons with organic matter preserved on the northwestern slope indicate periodic phases of surface stabilization and development of pedogenic processes. The disappearance of the paleosol horizon and its replacement by a deflation surface indicate renewed activation of aeolian processes and erosion of the previously developed soil cover. The upper part of the unit was transformed by Holocene soil-forming processes (Moska et al., 2022).

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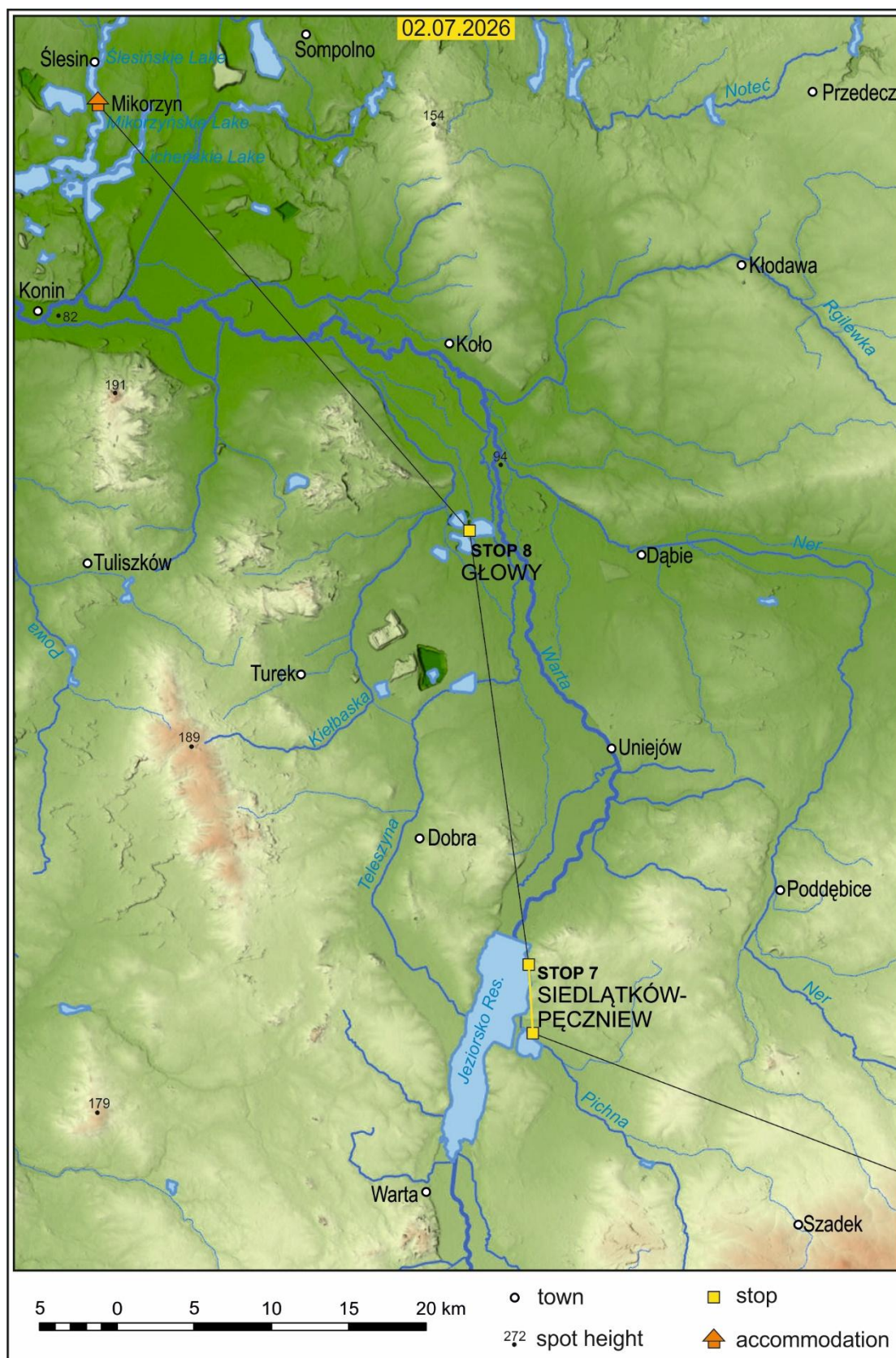


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STOP 7 – SIEDŁĄTKÓW-PĘCZNIEW

Sedimentary record of a glacial flood during the Saalian ice-sheet recession

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The Siedlątków and Pęczniew sites, located in the middle Warta River valley, represent a key area for studying the dynamics of the Late Saalian (Wartanian) ice sheet and associated meltwater processes. The sites are situated at the boundary between the Łask Upland Plain and the Sieradz Basin, within the former ice-marginal zone (Fig. 1).

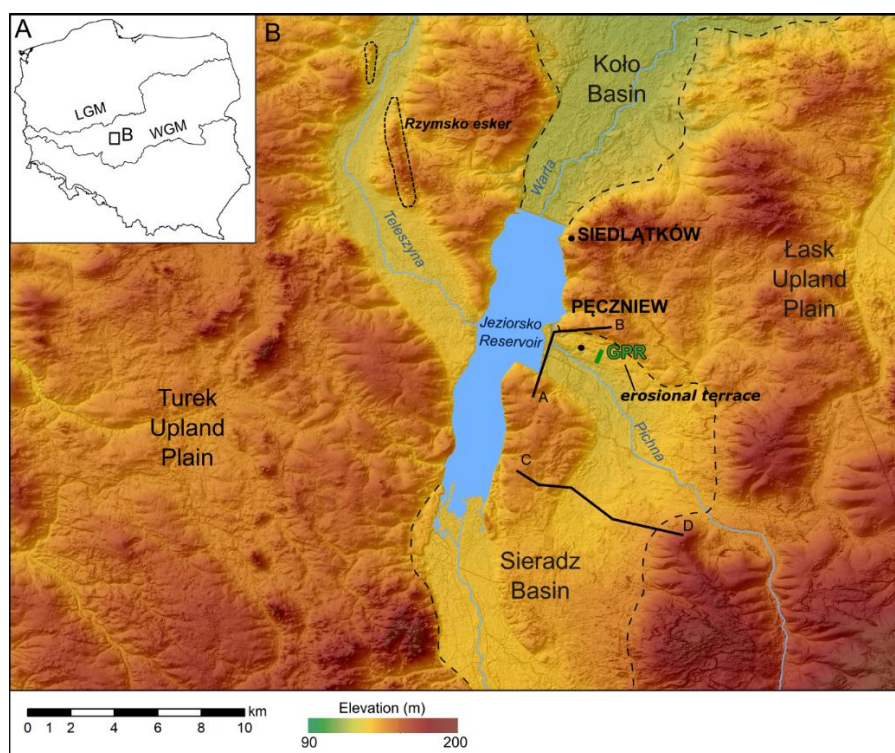


Fig. 1. Location and topography of the study area

(A) location of the study area in relation to the maximum ice-sheet extents in Poland: LGM – Last Glacial Maximum (Weichselian), WGM – maximum extent of the younger Saalian Stage (Wartanian); (B) DEM-based topography of the study area with presented sites Siedlątków and Pęczniew; geological cross-sections – black lines; GPR profile – green line

The geological substratum is composed of Maastrichtian marls and limestones, overlain by Quaternary deposits, including tills, glaciofluvial sands and gravels, glaciolacustrine sediments, and younger fluvial and aeolian sands. The present-day morphology reflects repeated ice advance and retreat, as well as strong meltwater activity during deglaciation.

The studied sites are exposed mainly in the cliffs of the Jeziorsko Reservoir, where a continuous sedimentary succession allows reconstruction of interactions between glacial accumulation, proglacial erosion and deposition, glaciotectonic deformation processes, and glaciolacustrine sedimentation during the final stage of deglaciation.

STOP 7.A. PĘCZNIEW

The Jeziorsko Reservoir area is characterised by a complex record of meltwater drainage associated with the recession of the Wartanian (Saalian) ice sheet. The present-day Warta River valley, near Pęczniew, intersects with the valleys of the Teleszyna (west of the reservoir) and the Pichna (east of the reservoir) (Fig. 1). These valleys are markedly oversized relative to the modern rivers occurring in them. The Teleszyna valley ranges from 1.2 to 3.4 km in width, while the Pichna valley reaches a minimum of 2 km near its confluence with the Warta and widens southeastwards to over 5 km. The valley floors of both the Teleszyna and Pichna are elevated by several metres above the contemporary Warta valley floor. Both valleys are filled in their lower parts with glaciofluvial deposits, overlain by younger fluvial sediments. The incision of the Pichna valley into the upland surface reaches up to 35 m (Fig. 2). It cuts glacial deposits of the Saalian Glaciation and older Elsterian Glaciation, as well as Neogene sediments and the Mesozoic bedrock.

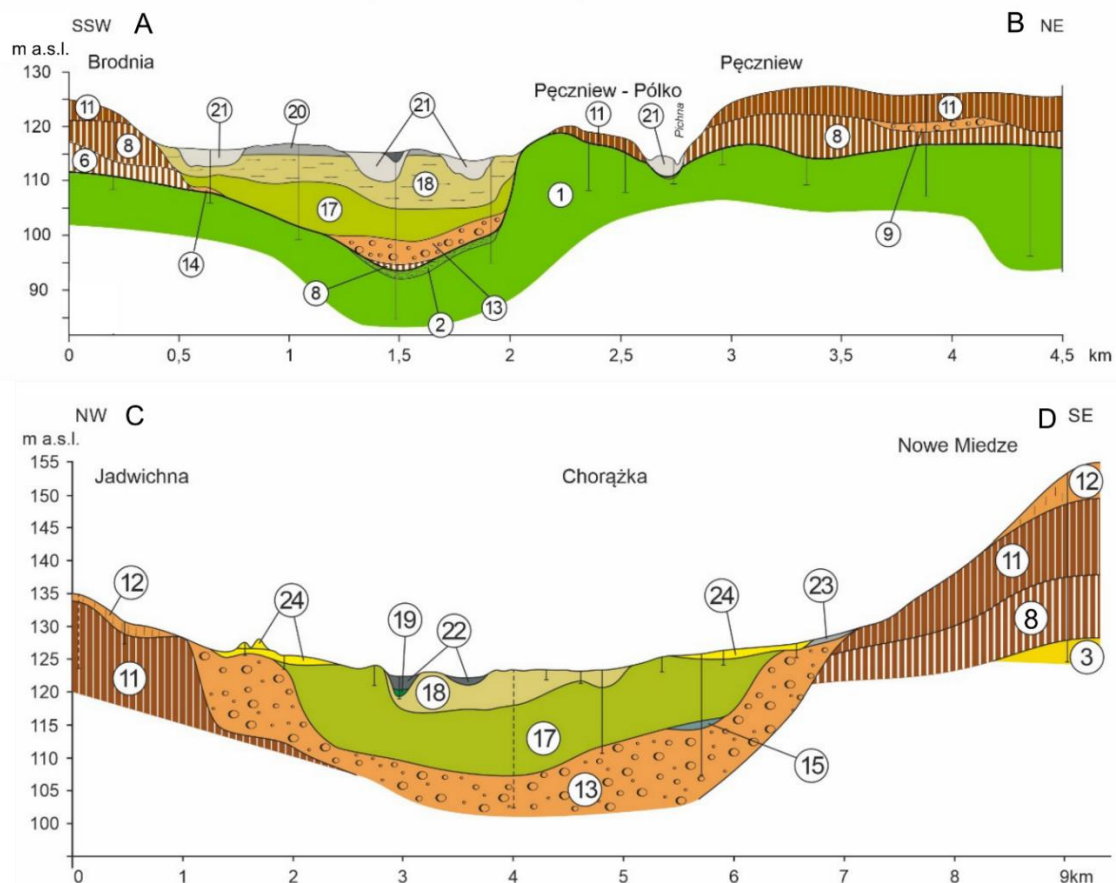


Fig. 2. Geological cross-sections of the Warta River valley (Rdzany et al., 2024)

Cretaceous: 1 – gaize, marl, limestone, 2 – limestone rubble; Neogene: 3 – mud; Quaternary, Elsterian Glaciations: 6 – till; Saalian Glaciations: 8 – till (Odranian), 9 – glaciofluvial gravel and sand, 11 – till (Wartanian), 12 – sandy till, 13 – glaciofluvial sand and gravel, 14 – glaciofluvial sand, 15 – silt; Vistulian: 17 – medium- and fine-grained fluvial sand, 18 – medium- and fine-grained sands with organic silt inserts, fluvial; 19 – gyttja; Holocene: 20 – sandy mud, 21 – fluvial sands with mud, 22 – peat, 23 – deluvial silt and sand, 24 – aeolian sand

The Teleszyna-Pichna valley may have functioned as a subglacial drainage pathway. In its immediate vicinity lies the Rzymisko esker, a landform of complex origin. Its formation began in a subglacial tunnel and continued within an ice-walled tunnel. Meltwater erosion of the Mesozoic bedrock is evidenced by a high proportion of local clasts within the esker sediments: 30–76% in the 8–64 mm fraction and up to 87% in the >64 mm fraction (Frydrych, 2016). Following the formation of the esker and the retreat of the ice margin, high-energy proglacial meltwater flows continued to operate, shaping the depressions of the present-day Teleszyna and Pichna valleys. In northern part of Picha valley, an erosional terrace extends for 5.5 km, with a maximum width of 1.3 km. The terrace surface lies 4 m above the present valley floor, while the adjacent upland edge rises 10 m above the terrace. The terrace is composed mainly of till, locally covered by aeolian sands and small dunes. Its surface is dissected by channels filled with sandy and sandy-gravel deposits (Fig. 3). At the boundary between till and better-sorted sediments, an erosional pavement occurs, formed by the washing out of finer material from glacial deposits. The surface of the terrace and the surrounding upland was extensively modified by periglacial processes, as evidenced by a dense network of ice-wedge polygons, which are visible in aerial imagery and are also expressed in radar profiles and outcrop exposures. The activity of aeolian processes is indicated by the presence of small dunes and aeolian covers, as well as a high proportion of aeolian, well-rounded grains in the near-surface terrace deposits.

According to Klatkova and Załoba (1991), the Teleszyna valley functioned as a proglacial meltwater drainage route towards the south, whereas both valleys were later reused by the palaeo-Warta after a reversal of flow direction to the north. The morphological characteristics of the valley and its infill of glaciofluvial sediments suggest that the principal elements of the landform developed at the earliest during the presence of the Warta Stage ice sheet. However, it cannot be excluded that this drainage system also functioned during deglaciation in the maximum phase of the Odra Glaciation.

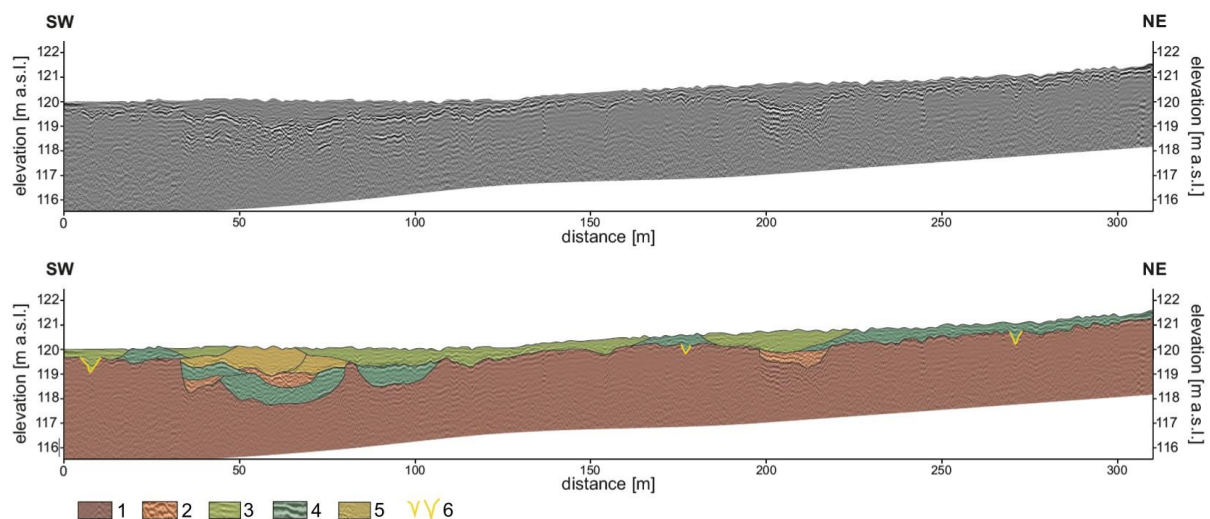


Fig. 3. Ground-penetrating radar (GPR) profile across the erosional terrace with identified radar facies

- 1 – radar facies RF1: low amplitude, sparse, chaotic and incoherent reflections, locally noisy;
- 2 – radar facies RF2: moderate amplitude, wavy and continuous reflections, locally finely dense undulated; 3 – radar facies RF3: low amplitude wavy or planar reflections, locally poorly observable; 4 – radar facies RF4: strong and continuous wavy and planar reflections; 5 – radar facies RF5: low amplitude and finely dense undulated reflections, locally poorly observable;
- 6 – probable deformational structures (ice wedge pseudomorphs)

STOP 7.B. SIEDŁĄTKÓW

The Siedlątków sites (S1–S4) expose a coherent sedimentary system developed within erosional channels (Fig. 4A, B) and boulder covers (Fig. 4C, D, E), formed by high-energy meltwater flows during the late stage of the Warta ice-sheet recession. The channels reach up to 10 m in depth and occur within a narrow elevation range of ca. 120–130 m a.s.l., suggesting their formation during a single or closely related flood events. The fills of palaeochannels and boulder covers extend laterally over distances of ca. 24 to 122 m. They are composed of massive, very poorly sorted boulder and gravel sediments (Fig. 4, 5). Locally, both normal and inverse grading can be observed. Some boulders show clear imbrication (Fig. 4C). The erosional surface at the base of the coarse-grained succession is irregular, with local scours interpreted as potholes, reaching up to 1 m in depth and 3 m in diameter (Fig. 4B). These features are filled with massive boulder and gravel material, with clasts up to 60 cm in size. Within the lower parts of the succession, numerous rip-up clasts and packages of stratified glaciofluvial sediments occur, ranging from a few centimetres to 60–80 cm. The largest boulders exceed 1 m in diameter.

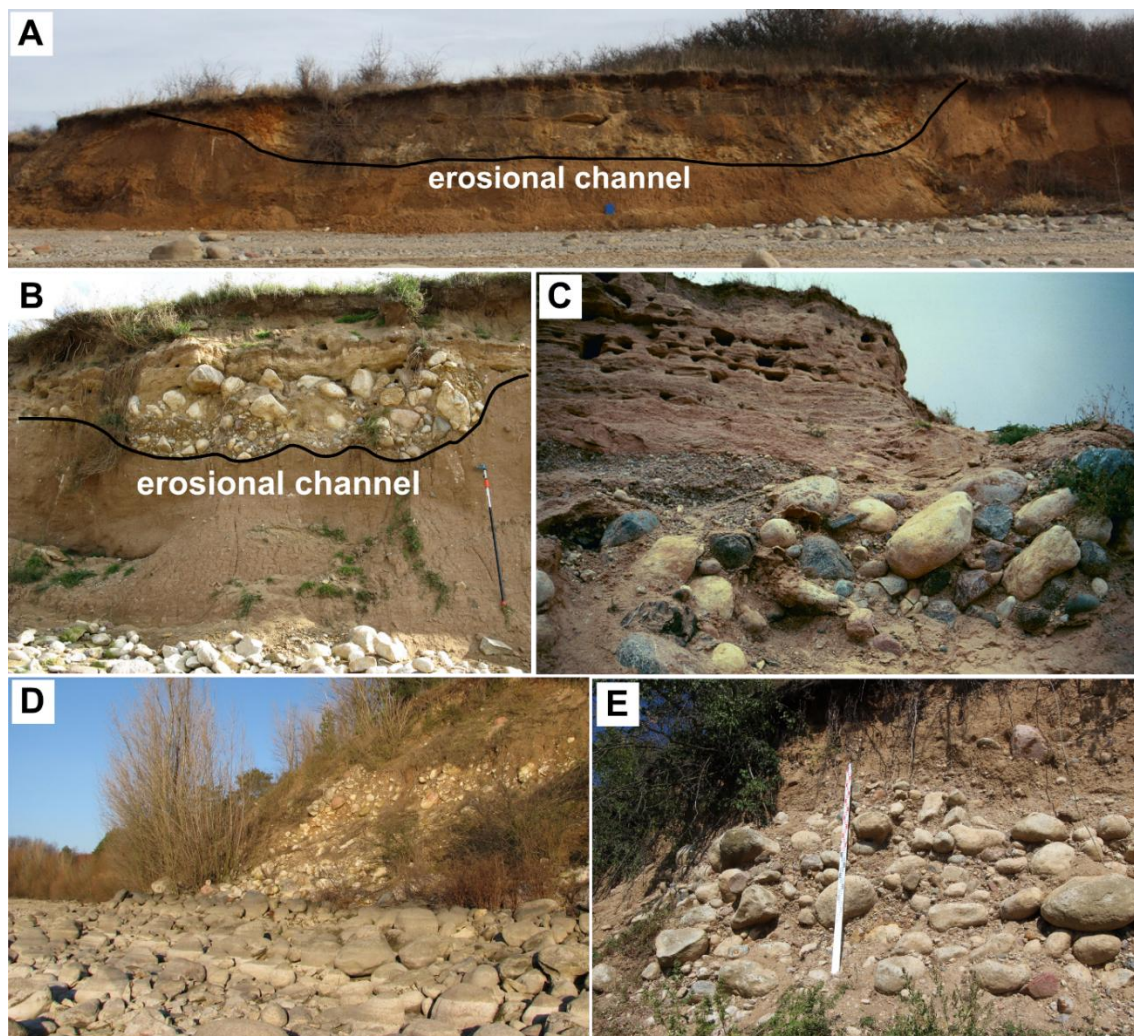


Fig. 4. Record of erosional and accumulation activity of proglacial waters
 (A) erosional channel in site S1; (B) part of the erosional channel in site S2; (C) imbricated gravel with boulders;
 (D) cliff of reservoir composed of gravelly boulders and boulders accumulated at the bottom of the cliff;
 (E) lenticular accumulation of clast-supported massive boulders and gravel



The morphoscopic composition of quartz grains in glacial flood sediments shows a relatively consistent trend across all analysed samples, with clear dominance of subrounded grains formed under mixed-transport conditions. In all cases, the matt partially-rounded (EM/RM) quartz grain fraction constitutes the largest proportion (39–47%), indicating a strong contribution from aeolian reworking, although not reaching full maturity. Since aeolian grains are known of minimal contribution in the glacial flood sediments (Martewicz et al., 2025), they may have been delivered from adjacent areas, whereby they underwent repeated recycling and alternating transport mechanisms. Cracked grains (C), interpreted as indicators of mechanical stress and high-energy events, show a clear decreasing trend from flood sediments (up to 23%) to diamicton cover (9%). In gravel sediments, intensive transport and grain-to-grain collisions promote grain breakage. In contrast, the lower proportion of cracked grains in the reference diamicton sample suggests reduced shear-stress, thus more stable depositional conditions. Quartz grains of glaciofluvial flood deposits from Siedlętków, within the 0.5–0.8 mm fraction, analysed using the automated particle analyser (Camsizer 1), are also characterised by distinctly lower values of sphericity, convexity, symmetry, and roundness compared to grains present in the glacial till, which can be partly explained by the different mineralogical composition of the samples.

The sediments are typical of hyperconcentrated-flow deposits, indicating deposition under extreme flow conditions, including jökulhlaup-type events. In some places, they are associated with sandy lithofacies and glaciolacustrine sediments (locally varved – Fig. 4A), reflecting rapid transitions from high-energy channelized flow to low-energy conditions. A key feature of all sites is the strong glaciotectionic overprint. The deposits are intensively deformed as a result of pushing and compression by the advancing ice sheet during its oscillatory behaviour in the final phase of glaciation. Overall, the S1–S4 succession records a complex interplay of processes: (i) erosion by high-discharge meltwater, (ii) rapid infilling by coarse glaciofluvial flood deposits, (iii) episodes of glaciolacustrine sedimentation, and (iv) subsequent glaciotectionic deformation. This allows reconstruction of short-lived but extreme hydrological events superimposed on dynamic ice-margin oscillations during deglaciation (Frydrych and Rdzany, 2018).

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STOP 8 – GŁOWY

Anthropogenic landscape changes and its social perception (the post-mining area in the Warta River valley)

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A clear example of strong transformations of relief under the influence of anthropogenic factors is the area of the inactive Adamów Lignite Mine, located in the middle section of the Warta River valley. Lignite exploitation using the open-pit method was carried out between 1959 and 2021 (Orlikowski and Szwed, 2011). During the operation of the mine, the land relief underwent systematic and profound transformation, involving both the destruction of natural landforms and the creation of new, anthropogenic elements of the landscape. Long-term geological and geomorphological documentation, as well as direct observation of the course of mining and reclamation works, make it possible to assess the scale and nature of these transformations. This case fits into the discussion on the significance of intensified interactions between humans and the natural environment as a marker of the Anthropocene, during which anthropogenic pressure became the dominant factor of change. In this context, studies of anthropogenic geomorphological transformations gain particular importance, as they document the scale and rate of changes in relief and the modification of the functioning of morphogenetic environments under the influence of human economic activity, as well as the social implications of these phenomena.

Geologically, the study area is situated on the Palaeozoic Platform, where the Permo-Mesozoic platform cover forms the Szczecin-Miechów Synclinatorium and, more precisely, within the central part of the Mogilno-Łódź Segment. In this section of the synclinatorium, the Konin Elevation developed, where, among others, the Adamów Graben is located. The graben is filled with Neogene deposits containing Miocene lignite seams (Fig. 1) (Widera et al., 2022). The overburden consists of diversified Quaternary deposits, representing glacial, periglacial, fluvial, and aeolian environments. Prior to the onset of exploitation, the relief was characterized by small relative height differences and was dominated by morainic uplands, marginal valley levels, and the extensive Warta River valley with a system of terraces.

The beginning of overburden removal and the formation of external dumps at the end of the 1950s initiated high-intensity anthropogeomorphological processes. In the subsequent decades, mining activity encompassed successive open pits, leading to the elimination or significant reduction of numerous natural landforms, including marginal valley levels, river terraces, peatlands, and aeolian forms. Particularly strong transformations occurred in areas with the longest duration of exploitation and in zones of overburden deposition.

In the post-mining landscape, a fundamental change in hypsometric conditions has taken place. The highest and lowest-lying areas now have an anthropogenic origin, and the difference in relative heights has increased significantly from a few metres to approximately 80 metres. In place of the destroyed natural forms, both convex landforms associated with external and internal dumps and concave forms

– final excavation basins transformed into water reservoirs – have been created (Peters-Zganiacz and Dzieduszyńska, 2024).

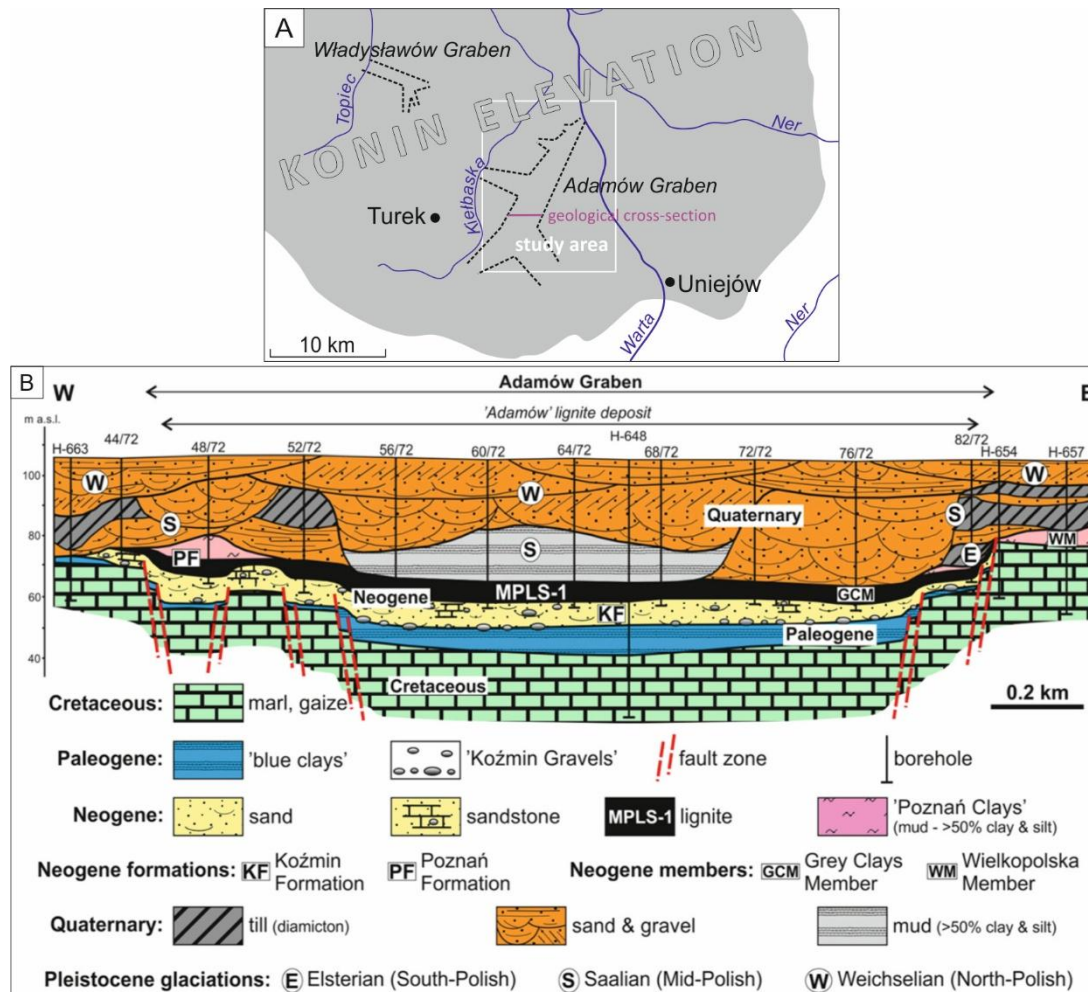


Fig. 1. Location of the study area relative to the Adamów Graben (A) and representative geological cross-section through the Adamów Graben (B) after Widera et al. (2022)

An important element of reclamation was the shaping of extensive anthropogenic planation surfaces, intended to refer to the original alluvial plains; however, the newly formed surfaces lack the geomorphological diversity characteristic of the natural landscape (Fig. 2). At the same time, the shaping of anthropogenic landforms reactivated natural secondary processes, such as mass movements and shoreline processes, which modify dump slopes and reservoir shores, influencing their further evolution (Karwacki, 2022).

The landscape transformation also resulted in significant changes in the land cover structure. Corine Land Cover data indicate that between 1990 and 2018, the development of open-pit mining led to a gradual increase in the surface area of mining areas at the expense of agricultural land and other natural landscape elements (Copernicus Land Monitoring Service, 2026). Since 2012, a reduction in the surface area of excavations and dumps has been observed, associated with the ongoing reclamation of post-mining areas. Simultaneously, throughout the analyzed period, there was a gradual decrease in the surface area of arable land and an increase in the area covered by grassland and semi-natural vegetation. The land cover transformation process was gradual and encompassed a transition from an

agricultural-forest landscape, through a phase of intensive open-pit mining and the formation of excavations and dumps to a phase of reclamation and the development of new land cover forms. In the final phase of mining activity and after its completion, there was a gradual development of grass vegetation, water reservoirs and bushes, related to both reclamation activities and plant succession processes.

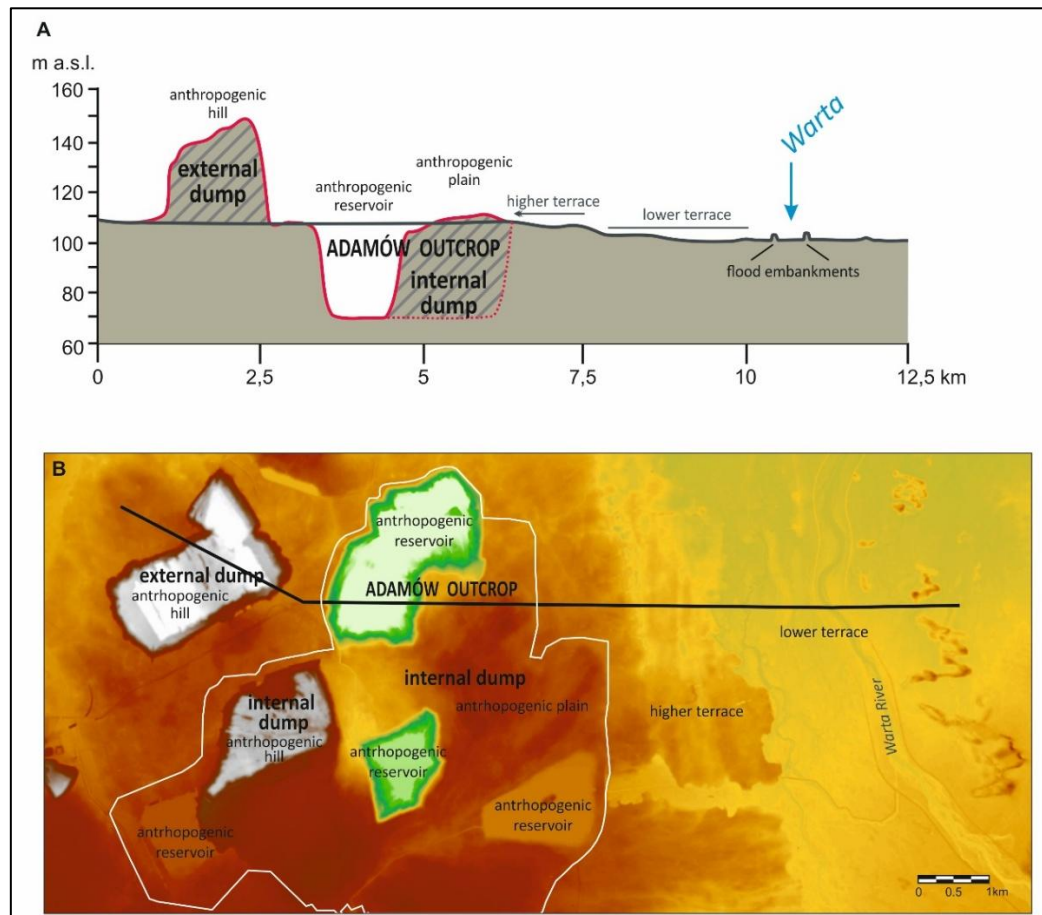


Fig. 2. Adamów outcrop post-mining area
 (A) topographic profile, (B) natural and anthropogenic relief

A more detailed picture of changes after 2015 is presented by data from the Database of Topographic Objects (BDOT10k), which documents land cover transformations in the final phase of mining operations and after the end of mining operations (GUGiK, 2026). During the analyzed period, arable land remained the dominant form of land cover, but its area decreased by approximately 17%. At the same time, forest decreased by nearly 9%. The reduction in the share of arable land and forest was related to spatial transformations resulting from mining operations and the subsequent formation of new land cover types.

At the same time, there was a significant increase in the area covered by grassland, approximately 26%. This phenomenon was associated with the development of secondary vegetation cover in reclaimed areas, particularly on dumps and areas of anthropogenic leveling. A significant increase was also noted in copses, as well as in shrubs and woodlots, indicating ongoing plant succession processes.

Significant changes also affected water surfaces. The area of water reservoirs nearly tripled as a result of the flooding of final excavations and the formation of anthropogenic water bodies. The area of flowing water also increased slightly.

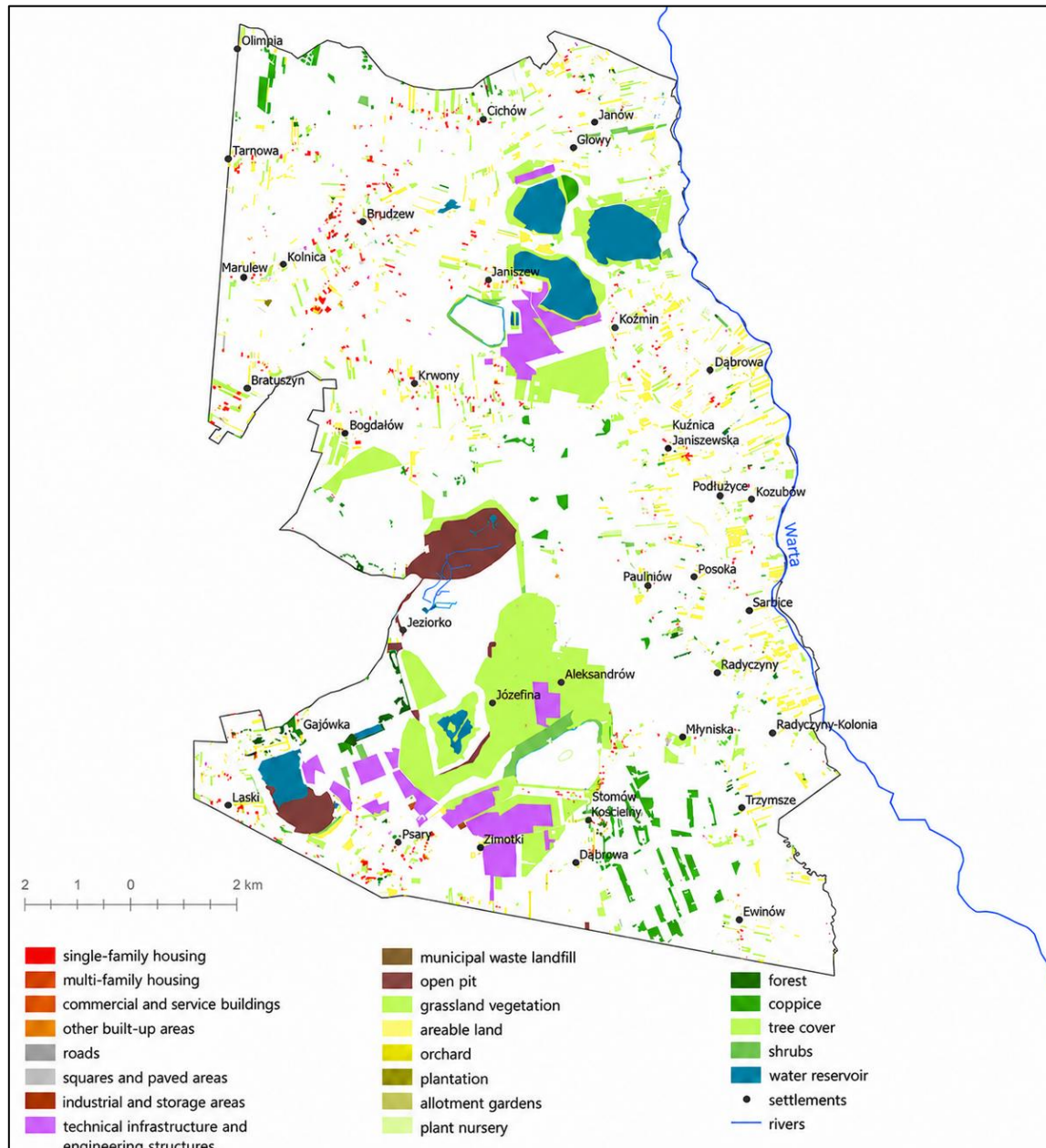


Fig. 3. Areas of land cover changes in the years 2015–2025 in the post-mining area of the “Adamów” Lignite Mine with the current land cover from 2025

At the same time, the area of excavations decreased by approximately 25%, while the dumps disappeared due to their transformation into biologically active areas or incorporation into new forms of use. Changes also affected infrastructure and build up areas. The area under technical equipment and structures has increased almost fourfold, which may indicate the development of infrastructure related to the reclamation and secondary development of post-mining areas, such as photovoltaic farms. Growth has also been noted in single-family and commercial/service buildup areas. Over the last 10 years, 22% of the area has undergone a change in land cover (Fig. 3).



Environmental transformations are also evident in changes in the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) values. The analysis was based on average NDVI and NDMI values calculated for the study area based on Sentinel-2 satellite imagery from late July and early August of each year (Copernicus Data Space Ecosystem, 2026). The NDVI is used to assess the condition, density, and health of vegetation and ranges from -1 to 1 . The higher the index value, the greater the biomass content and the better the condition of the vegetation cover. A general upward trend in NDVI values is visible for the study area. The average NDVI value increased from approximately 0.27 in 2015 to approximately 0.35 in 2017 and 2024–2025. This may indicate a gradual improvement in the condition of vegetation in reclaimed areas and the ongoing succession of vegetation on waste heaps and around water bodies (Shi et al., 2025). The NDMI is primarily used to assess environmental humidity conditions and monitor vegetation water stress. Changes in its value reflect the degree of moisture in the plant cover and subsoil, making it useful both in drought analyses and in assessing habitat transformations related to changes in water conditions. After 2019, a significant increase in the index value was observed, which can be attributed to the ongoing water reclamation of post-mining areas, the creation of anthropogenic water bodies, and the increasing share of wet habitats in post-mining areas. Fluctuations in the index values between years were related to differences in meteorological conditions, particularly temperature and precipitation patterns during the growing season (Nasiłowska and Kubiak, 2016).

The mining activities resulted not only in permanent landscape transformations, but also in profound functional and socioeconomic changes influencing the living conditions of the local community.

To answer the question of how local inhabitants perceive these transformations, social research was conducted in localities situated within the mine's zone of social impact. This zone was determined using an expert method. The research was conducted in summer and autumn 2025 among a representative sample of 120 residents of the study area. Respondents were selected using quota sampling based on place of residence. Empirical data were collected using a survey method with the CAPI technique (Computer-Assisted Personal Interview). The study had a retrospective character and captures perceptions referring to three temporal phases: the period before the mine was built, during its operation, and the current post-closure time period.

The research showed, that the period before the mine began operating is perceived through the prism of difficult living conditions resulting from poor conditions for agriculture (low-quality soils), which constituted the main source of income for local inhabitants. When asked about the landscape and environmental values of the area at that time, respondents who remembered this period emphasized the large number of forests, meadows, rivers and canals, as well as the marshy character of the terrain. Peace and quiet were also frequently highlighted. The aesthetic value of the landscape was not rated highly; most respondents described it as ordinary. In the context of living conditions, however, the abundance of rivers and canals was appreciated because it created opportunities for fishing.

Environmental changes caused by the opening of successive open-pit mines were perceived mainly in terms of the deterioration of conditions for agriculture, resulting from the lowering of groundwater levels, the drying up of rivers and canals, and experiences related to the necessity of relocating. Respondents also emphasized the transformation of the landscape from agricultural to industrial, as well as increased noise levels and air pollution. These changes were viewed as moderately negative because the mine, which became the main employer in the region, brought about a significant improvement in living conditions. It provided not only stable and relatively high wages, but also substantial compensation payments that enabled residents to purchase and furnish new homes. Moreover, the mine ensured social welfare support and contributed to infrastructure development, including the construction of a water supply system.



With regard to the environmental changes resulting from the closure of open pits, nearly all respondents pointed to the rise in groundwater levels, the refilling of drainage ditches with water, and improvements in vegetation cover, but also to the waterlogging of meadows. The return of water is perceived not only in terms of changes in the landscape, but also in relation to changes in the possibilities for economic activity, mainly agriculture, which has traditionally been characteristic of these areas. Respondents also strongly emphasized the presence of new anthropogenic landscape elements, including new water reservoirs created by flooding post-mining areas and large-scale photovoltaic farms. The latter are perceived in two ways: negatively, in the context of “spoiling the landscape” and, less frequently, due to concerns about potential negative impacts on health; but also positively, as a source of income for municipalities and private landowners, as well as environmentally friendly installations. The presence of water reservoirs, in contrast, is viewed very positively. According to the respondents, they diversify the landscape and create new recreational opportunities for local inhabitants.

Summing up, the results of the study indicate a predominantly positive assessment of the mine’s impact on the study area and on the local population. Well-paid employment, which reduced residents’ dependence on agriculture, together with the significant improvement in living conditions that took place at that time outweighed issues related to environmental degradation in the perceptions of local inhabitants.

Transformations of the environment, from the river valley to the formation of the anthropogenic lake area, show the extent to which humans are able to drive geomorphological processes and have an important social dimension, as they occurred during the lifetime of one generation and had far-reaching effects for the entire local community.

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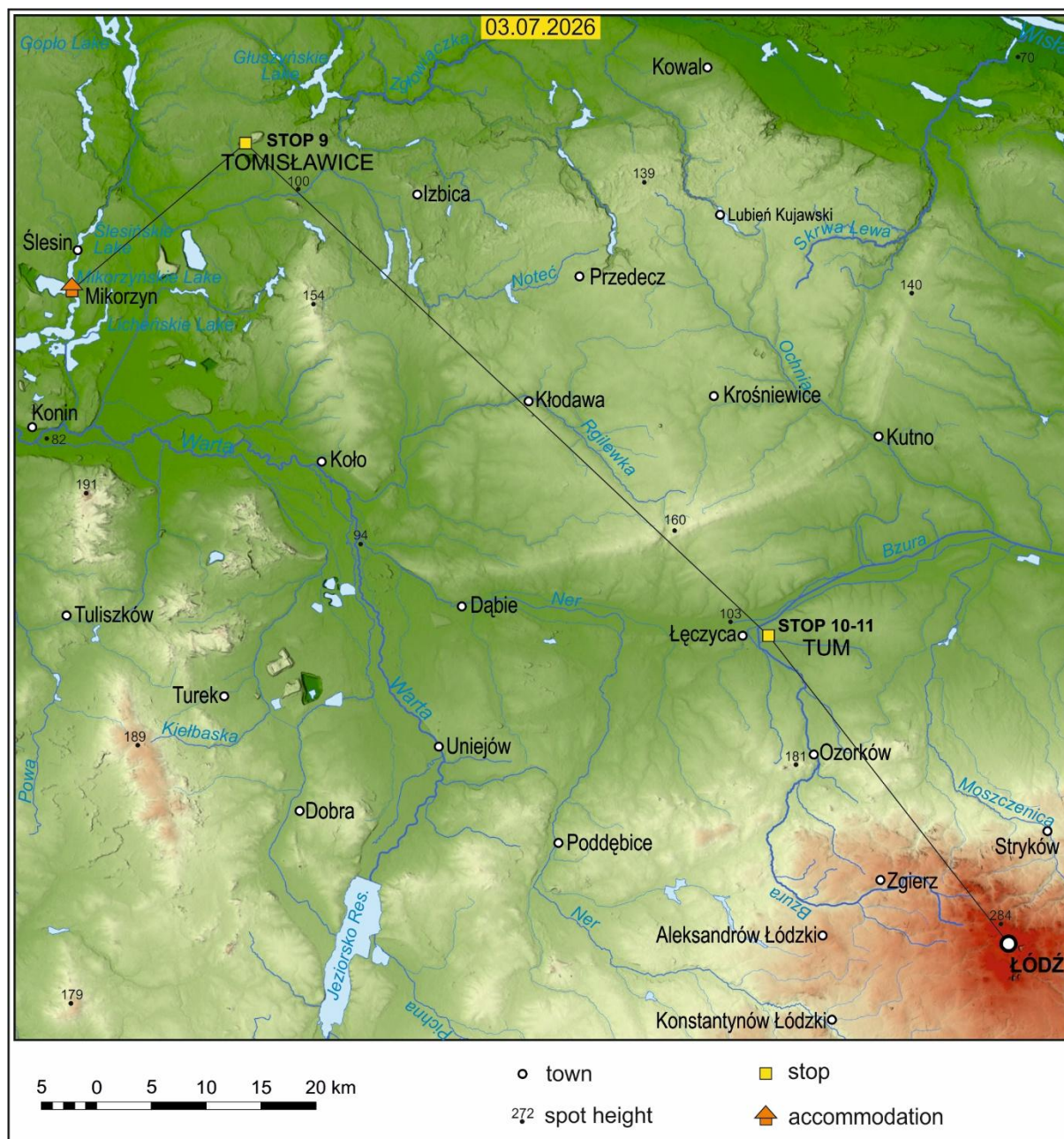


International Field Symposium

“Glacials and interglacials of the Middle and Upper Pleistocene in central Poland”

INQUA PeriBaltic Working Group Meeting, June 28 – July 3, 2026, Łódź, Poland





STOP 9 – TOMISŁAWICE

Lithostratigraphy and sedimentology of the Pleistocene succession in the Tomisławice site, Central Poland

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The Tomisławice opencast lignite mine is situated in Central Poland within the Wielkopolska Lake District (Fig. 1). The southern tip of Lake Gopło lies approximately 7 km to the west, whilst the Warta River valley is situated 27 km to the south. The entire Tomisławice opencast site lies within the range of the last glaciation, the maximum extent of which was approximately 30 km to the south. Prior to mining operations, the area was a moraine plateau used predominantly for agriculture. The mine began stripping the Quaternary overburden in 2010.

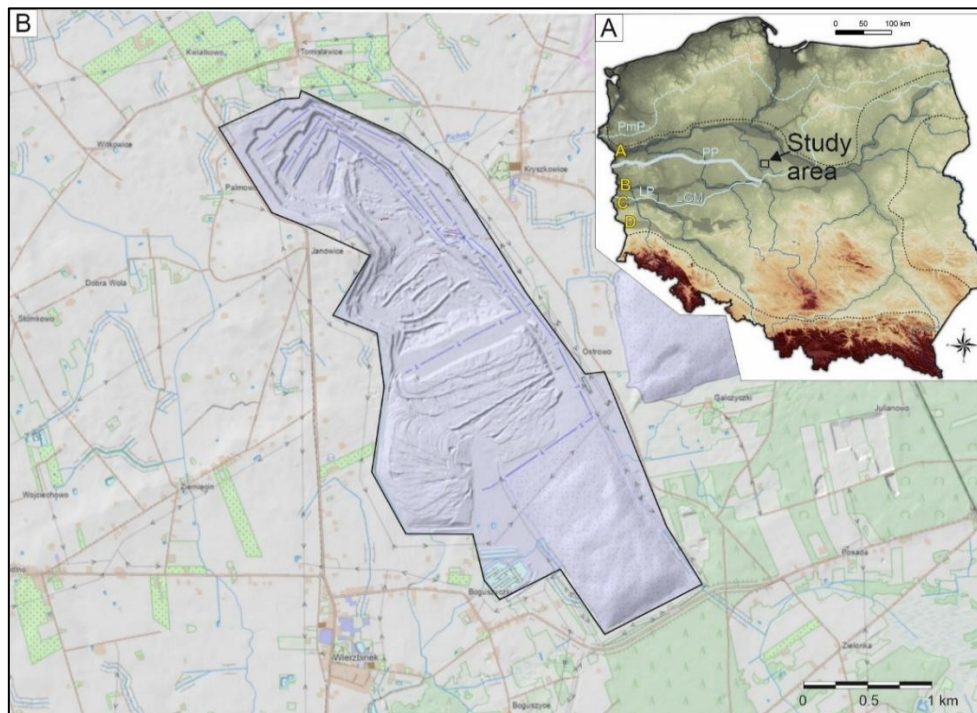


Fig. 1. Location map
 (A) location of the study area; (B) Tomisławice outcrop

The deposits being mined consist of Miocene-age lignite (Widera et al., 2024). They are covered by Quaternary sediments with a thickness ranging from 40 m to over 60 m. There are no major disturbances or glaciotectionic deformations in the opencast mine. In places, the glacial tills contained fragments of Miocene Poznań clays (Wachocki et al., 2024).

Quaternary deposits were studied in the southern part of the Tomisławice open-cast mine. The outcrops currently accessible are located in the northern part of the excavation, where new research has been conducted. The thickness of these deposits, as exposed, reached up to 40 m. Based on an analysis of sediments in both parts of the mine and on exploration drilling, nine lithostratigraphic units have been identified (Fig. 2).

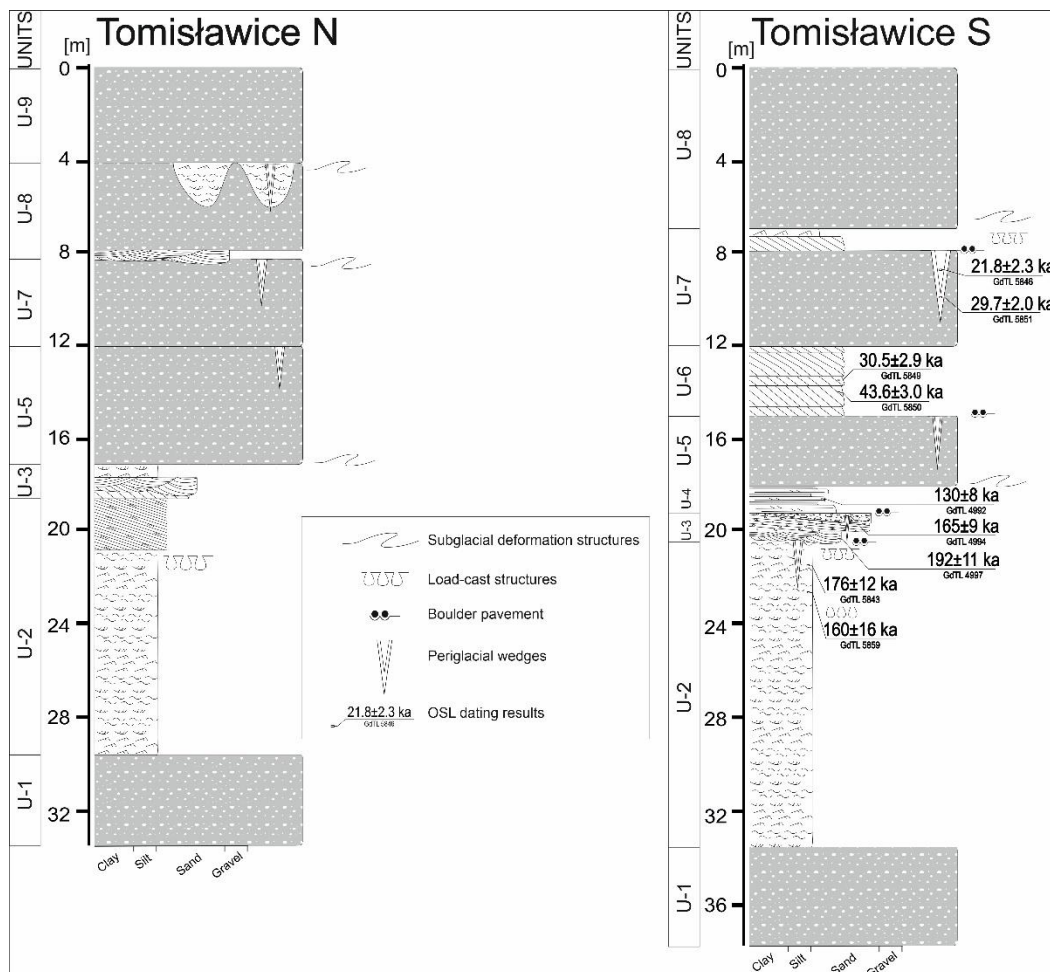


Fig. 2. Generalized lithological profiles from southern and northern part of the Tomisławice outcrop

The oldest glacial till (unit U-1) lies directly on top of the Miocene lignite. This is a sandy brown diamicton with a thickness from 2–4 m to 14 m. Above this lies the thicker (up to 14 m) and widely distributed Unit U-2. It consists of horizontally lying clays and silts that transition upwards into fine-grained sands. Numerous soft-sediment deformations occur within this unit, mainly in the form of load-cast structures (Fig 3A). In the upper part, coarsening-upward cycles with a thickness of 2–5 m are visible. The cycles exhibit a tripartite structure. The lower part is dominated by silts with horizontal and wavy lamination and climbing ripple marks. The middle part consists of fine sands with medium- and large-scale inclined bedding, containing layers of scattered plant detritus. The upper part consists of medium- and coarse-grained sands with trough-cross stratification. In the upper part of this unit



discontinuous layers of diamicton are visible, sometimes with a deformed load-cast structure. At their top, at the contact with unit U-3, there is a deflation boulder pavement and epigenetic ice wedge pseudomorphs and sand wedges (Fig. 3B).

Unit U-3 consists of gravels, boulders and discontinuous layer of grey sandy diamicton. Gravels have trough-cross stratification. Boulders have usually massive structure. In the upper part of this unit, traces of soil formation processes, deflation pavement and wedges with primary sandy fill are visible (Fig. 3C).

Unit U-4 lies directly on top of unit U-2 or U-3, where these are preserved. It consists of sands of varying grain sizes and silt, exhibiting horizontal, trough cross-bedding, and ripple-mark lamination (Fig. 3D). The thickness of these deposits does not usually exceed 1 m.

Unit U-5 consists of dark brown sandy diamicton with boulder pavement and deformation structures at the base (Fig. 3E). In the available outcrops, the thickness of this unit reaches from dozen of centimeters to 5-6 m. Boulder pavements and layers of poorly sorted gravel with a thickness of 20–40 cm are more common. Their top layer contains sandy wedges and deflationary pavement.

Unit U-6 occurs mainly in the southern part of the open-cast mine. It consists of mixed-grain sands with an admixture of gravel, exhibiting planar-cross stratification, ripple-cross lamination and, to a lesser extent, trough-cross stratification (Fig. 3F). The thickness of these sediments in outcrops does not exceed 3 m, whilst borehole analysis indicates that their thickness may reach 5–6 m.

Unit U-7 consists of sandy grey stratified diamicton, with a thickness of approximately 4 m (Fig. 3E). The top of this till layer features a polygon of wedges with primary-sand infill up to 2 m in length, as well as a deflation pavement (Fig. 3G). In the north-western part of the outcrop, the sandy wedge horizon is horizontally cut, and individual sections of the wedges are displaced by several metres (Fig. 3H). In the northern part of the outcrop, there is a layer of sand and gravel 20–30 cm thick. Its counterpart in the southern part consists of fine-grained and silty sands with lenses of fine gravel, 20–40 cm thick. The sediments are also deformed in places. There are two types of deformation: load-cast structures and subhorizontal shear structures (Fig. 3G).

Unit U-8 consists of grey sandy diamicton, 4 m thick in the northern part and up to 8 m thick in the southern part of the outcrop (fig. 3E). At the contact with the bedrock deposits, there is generally a zone of deformation up to 20 cm thick, and in places there are also rafts of older deposits in the lower part of the diamicton. In the northern part of the Tomisławice mine, pockets up to 2 m thick, filled with laminated sand and silt, occur in the upper part of the till. These contain water-escape structures and pseudomorphs after ice wedges.

Unit U-9 has been identified only in the northern part of the Tomisławice mine. It consists of a layer of brown diamicton up to 4 m thick. This diamicton tapers off towards the south and is replaced by sands and silts with horizontal lamination, containing diamicton interbeds several tens of centimetres thick.

INTERPRETATION

The Tomisławice site is located within the range of all main Scandinavian Ice Sheet (SIS) transgressions in the Pleistocene (Marks, 2023). Five glacial units have been identified, each representing a distinct SIS transgression within the study area. The absence of organic interglacial sediments means that the stratigraphy of Quaternary deposits in the Tomisławice open-cast mine is based on lithostratigraphy and optically stimulated luminescence (OSL) dating results from the southern part (Fig. 2). However,



due to the absence of glacetectonic disturbances, most units continue throughout virtually the entire length of the excavation.

An important lithostratigraphic unit at the Tomisławice site is U-2. It occurs continuously throughout the outcrop and separates the oldest glacial till (unit U-1) from the overlying glacial levels. The sediments of unit U-2 were deposited in the basin as a result of the gravitational flow of glacial sediments enriched in fine fractions. These underwent fractionation, with fine (silty-clayey) fractions accumulating in the central part, whilst flow diamictos accumulated at the basin margins and deltaic fans prograded. Intense sediment deposition, combined with low compaction and the inclination of the depositional slopes, led to the development of gravity flows and the resuspension of fine fractions, as well as the formation of soft-sediment deformations. Towards the end of the U-2 sedimentation phase, the basin became shallower and meltwater flows became dominant (U-3 unit). This allows the entire U-2 and U-3 succession to be characterised as coarsening-upward, and the depositional environment as glaciolimnic (Gruska, 2007). As a result, sandy-gravelly sediments were deposited. Following the completion of deposition of the U-2 and U-3 units, periglacial processes developed on its surface. Their remnants are sandy wedges developed in the top of the coarse-grained sediments and ice-wedge pseudomorphs in the top of the fine-grained sediments.

The OSL dating results obtained do not provide a definitive answer as to the age of Unit U-2 and U-3. They range from 246 ± 19 ka to 92.6 ± 8.9 ka. More information on this subject is provided by the dating results for the epigenetic fillings of the sandy wedges in their upper part (from 173.0 ± 9.6 ka to 164.7 ± 9.1 ka). It is likely that the age of these deposits exceeds the capabilities of the OSL method, and the results obtained should be treated with great caution. It can be tentatively assumed that these are deposits formed during the SIS recession following the deposition of till U-1, during one of the South Polish Glaciations or the first advance of the ice sheet during the Middle Polish Glaciations.

The sediments of Unit U-4 exhibit characteristics typical of fluvio-aeolian deposits, namely the erosion of aeolian cover by episodic low-flow events, resulting mainly from snowmelt (Good and Bryant, 1985; Kasse, 2002). It is assumed that during the Pleistocene, sediments of this type were deposited in the European Lowlands under dry and cold climatic conditions with well-developed permafrost (Kasse et al., 2007). Sediments of this type have so far been described only from the end of the last glaciation (Vandenberghe et al., 2013; Zieliński et al., 2015). In this case, we would be dealing with significantly older fluvio-aeolian sediments. Their OSL age (129.8 ± 7.7 ka) indicates that their deposition may have taken place at the end of the Warta/Saale Glaciation (Marine Isotope Stage 6) or after the Eemian interglacial. This issue requires further investigation due to the number of glacial units overlying them.

In the case of the U-5 unit, the till occurs as a continuous layer throughout the outcrop. It records another SIS transgression and the variability of subglacial deposition conditions. The interbedding of sandy-gravelly and silty layers indicates a significant contribution from subglacial waters and their flow. Despite the significant thickness and lithofacial variability, there are no clear indications that could point to a SIS recession and a subsequent transgression within the same glaciation. However, this issue requires further investigation.

The stratigraphic position of Unit U-5 is significant. This may be indirectly indicated by the dating results of the underlying sediments and the overlying sediments of Unit U-6. Their comparison gives us a range from 160 (or even 129) ka to 43–30 ka. With a degree of caution, it can therefore be assumed that this till was deposited at the end of MIS 6, i.e. during the Warta/Saale Glaciation. The OSL dating results for the epigenetic fillings of the sand wedges in the top of unit U-5, which are currently being carried out, may shed further light on this matter.

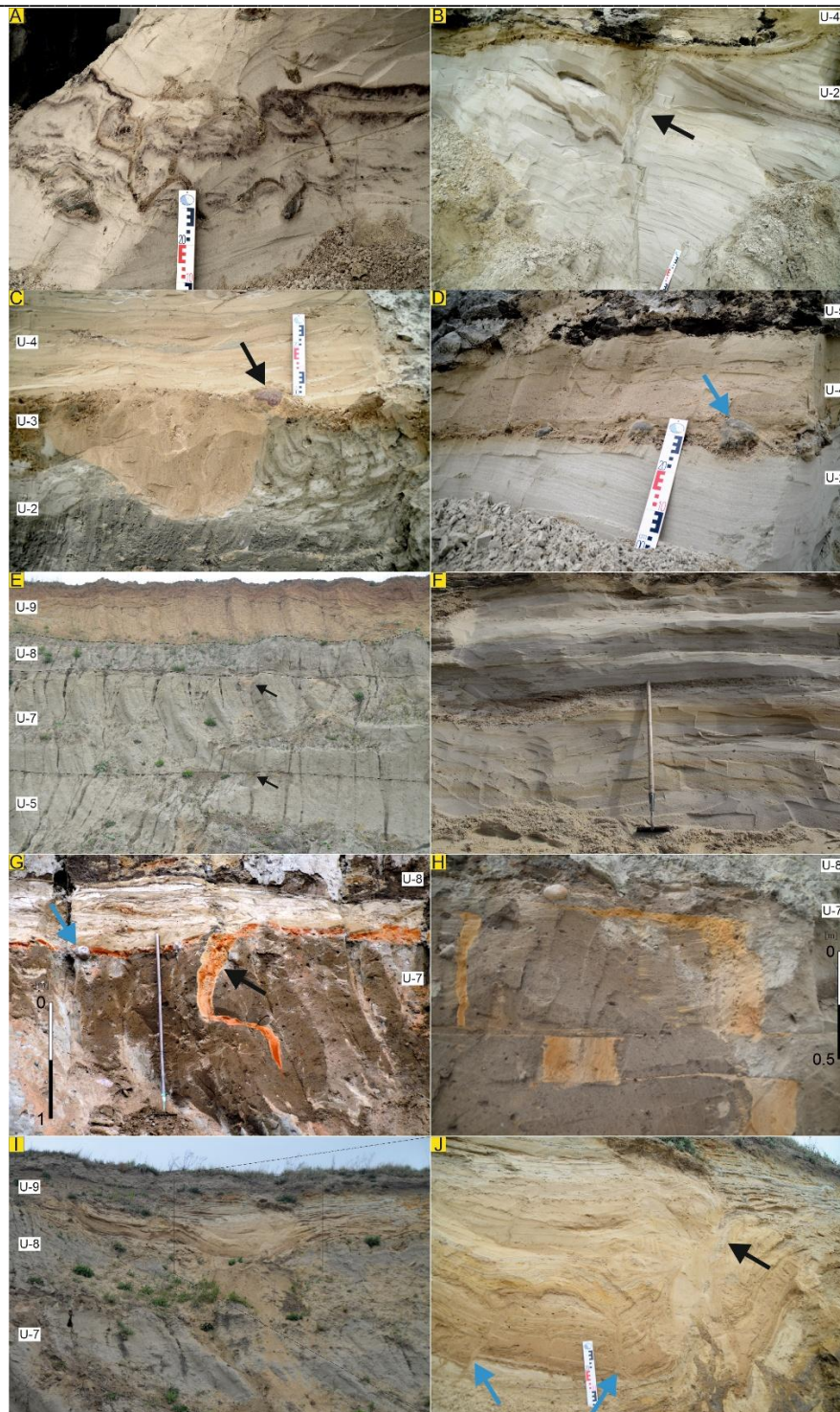


Fig. 3. Lithostratigraphic units

(A) fine-grained sediments of Unit U-2 with load-cast structures; (B) a section of the deltaic foreset in the upper part of Unit U-2 showing pseudomorphosis of an epigenetic ice wedge (black arrow); (C) Unit U-3 with a sandy wedge and deflationary cobbles on the upper surface (black arrow). Large load-cast structures visible in the U-2 sediments; (D) contact between units U-2 and U-4 with deflationary cobbles (blue arrow) and minor shear deformations at the contact with U-5 till; (E) four superimposed tills separated by sandy wedges (arrows), north-eastern part of the Tomisławice outcrop; (F) sandy sediments with gravel lenses in unit U-6; (G) epigenetic sandy wedge (arrow) in the top of unit U-7, covered by sands and silts with load-cast deformations; (H) epigenetic sandy wedges displaced along horizontal shear surfaces; (I) – glaciolimnic sands and silts (U-9) filling a depression in the roof top of unit U-8; (J) – pseudomorph after an ice wedge (black arrow) and water-escape structures in the sediments of unit U-9.



The lithofacial sequence of Unit U-6 suggests that its sediments were deposited in a relatively small sand-bed braided river, with a clear predominance of sediment accretion in the channel bed. Transport directions show some variation, but southward flow was dominant. It is presumed that this was a local river which drained the area towards the Warta River valley. OSL dating results suggest that the U-6 deposits were deposited during the Pleniglacial period prior to the next SIS advance. Their deposition lasted from 43 ka to 25 ka.

Unit U-7 was deposited subglacially during the subsequent SIS transgression in the study area. At its base, there is a zone of deformation and subhorizontal shears, typical of a basal sliding zone and fast ice flow (Piotrowski and Tulaczyk, 1999). The results of OSL dating of the sandy sediments of Unit U-6, as well as the epigenetic fillings of the sandy wedges occurring in large numbers in the top of the U-7 clay, allow the time of their deposition to be determined at approximately 25–21 ka, i.e. the first SIS transgression during the main stage of the last glaciation. This period was followed by a SIS recession and the development of periglacial processes and intense deflation, as indicated by the level of boulder pavement.

The subsequent SIS transgression caused, among other things, horizontal shearing and displacement along the surfaces of these sandy wedges in the top of the U-7 till. As a result of the ice sheet transgression, the U-8 till unit was deposited. The pockets filled with sandy-silty sediments occurring in its top are a record of the ice sheet recession and deposition in small local water bodies. Climatic conditions remained cool and favoured the re-aggradation of permafrost and the formation of ice wedges.

The last episode of deposition is documented by Unit U-9. Its occurrence solely in the northern part of the Tomisławice open-cast mine, as well as the replacement of glacial clay by glaciolimnic and glaci-fluvial sediments, indicates that deposition took place within the immediate vicinity of the ice sheet margin. The diamicton itself was presumably deposited during a glacial advance and is a remnant of a local ice-sheet advance. This indicates high dynamics of the SIS in the study area and its oscillatory retreat.

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STOP 10 – TUM

Geological setting and functioning of the Warsaw-Berlin ice-marginal spillway in Łęczyca area, Central Poland

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The area around the town of Łęczyca lies within the Middle-Polish Lowlands. The landscape is quite monotonous and dominated by flat surfaces, but consists of the Łowicz-Błonie Plain, the Kłodawa Heights and the Kutno Plain. These geomorphological regions encompass the areas occupied by the Saalian ice sheet and the LGM ice sheet limit is located 20-30 km north of Łęczyca. The section of the Warsaw-Berlin ice-marginal spillway between the Warsaw Basin and the Koło Basin predominates the area (Fig. 1).

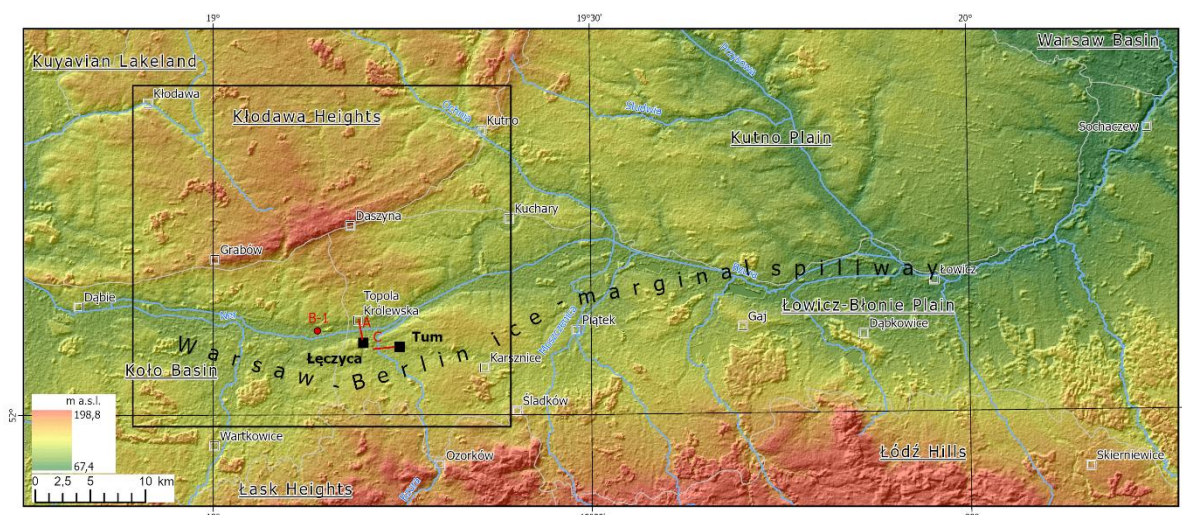


Fig. 1. Location map. A and C – geological cross-sections (Fig. 4 and 6), B-1 – Błonie profile of organic deposits (Fig. 5). The black rectangle indicates the range of Fig. 3.

The presented fragment of the Warsaw-Berlin ice-marginal spillway has a characteristic geomorphological configuration: altitude 101.0 m a.s.l. near Łęczyca the valley floor slopes eastwards and westwards. This spillway was used as a marginal outflow route during the Vistulian Glaciation

(Forysiak et al., 2024a, b), but meltwater activity was limited to the valley floor. It was also used by proglacial waters earlier, during the Saalian Glaciation (Forysiak et al., 2026).

BEDROCK, ITS GEOLOGY AND TECTONICS

The Quaternary bedrock occurs at depth from about 10 m to over 300 m. The study area is located at the junction of two large tectonic units – the Szczecin-Miechów Synclinorium and the Mid-Polish Anticlinorium, located within the Mid-Polish Trough that is a part of the Central European Basin System (CEBS) (Krzywiec, 2004; Maystrenko et al., 2008). The salt diapirs are the characteristic geological structures in this area. The Kłodawa salt diapir is the largest salt structure in the Kujawy segment of the Mid-Polish Trough. Its tectonic evolution was primarily affected by extension and normal faulting of the sub-Zechstein basement and salt withdrawal processes during the Triassic and Jurassic (Krzywiec, 2012). This is well evidenced by strong lateral change in thickness of the Triassic-Jurassic cover between NE and SW sides of the Kłodawa salt structure (Fig. 2a). The withdrawal processes influenced significantly a limited subsidence and thus the formation of a rim syncline (Fig. 2b). Although this syncline is located between the analyzed salt structure and the Wojszyce salt pillow to the NE, their development was more controlled by a salt flow into the growing Kłodawa structure: first into a salt pillow, then into a salt diapir (Krzywiec, 2004).

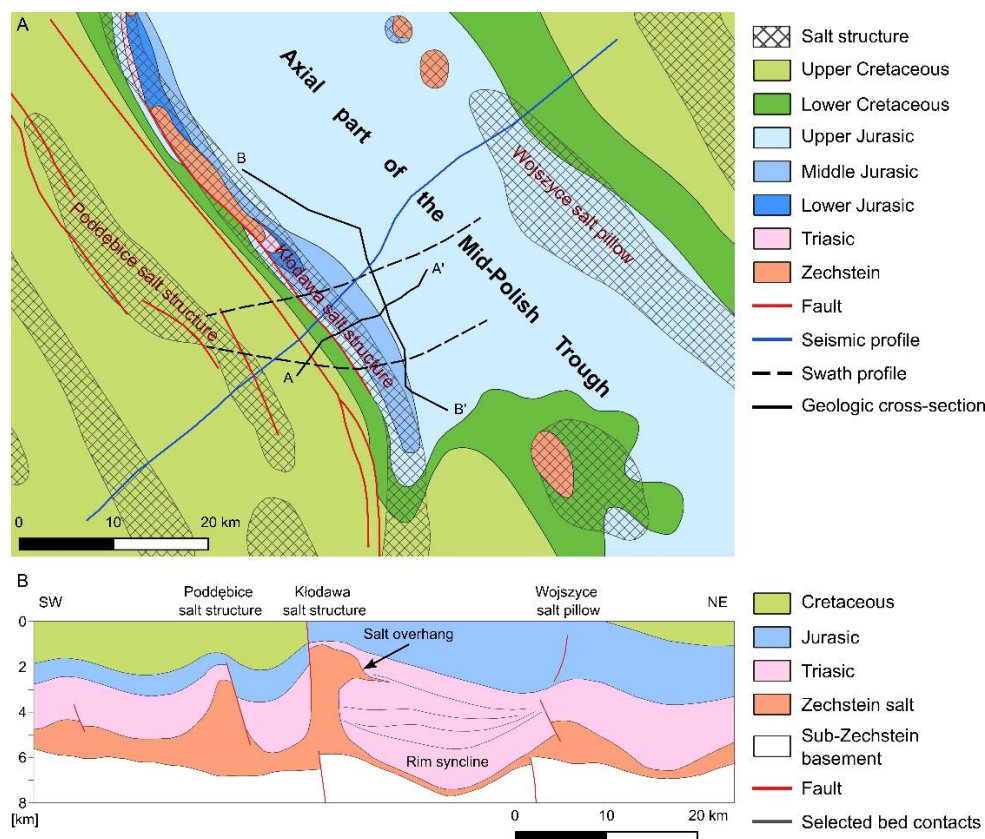


Fig. 2. Tectonics of the Kłodawa salt structure and related Kłodawa-Łęczyca anticline within the Kujawy segment of the Mid-Polish Trough

(A) simplified tectonic sketch based on the Geological Map of Poland without the Cenozoic cover (Dadlez et al., 2000) and the Tectonic Map of Poland. Note the location of the seismic profile (blue line), interpreted by Krzywiec (2004) and presented in the inset (B), the swath profiles illustrated in Fig. 3, and the geological cross-sections realised for the 3D GIS modelling

The Late Cretaceous compression and thus inversion of the Kujawy segment of the Mid-Polish Trough influenced significant uplift of the NE side of the Kłodawa salt structure (Krzywiec, 2012). This process was controlled by reverse reactivation of the normal fault, which was primarily developed within the sub-Zechstein basement and then propagated up into the Mesozoic cover on the SW side of the Kłodawa salt structure. Significant uplift of the northeastern side of the Kłodawa salt structure is well evidenced by erosion of the Cretaceous cover, across the gentle inclined northeastern limb of the anticline up to the fault cutting the hinge zone on the southwestern side of the analyzed salt structure.

The tectonic activity of the Kłodawa salt structure and the related Kłodawa- Łęczyca anticline during the Quaternary have been discussed previously (Poborski, 1957; Baraniecka, 1975; Molewski, 2014). This activity is manifested in terrain topography where elongated elevation trending NW-SE can be determined (Fig. 3). This elevation exhibiting gentle slopes with a height up to ca. 30 m is a dominant feature of the terrain topography, in relation to more local glacial and fluvial landforms within the Kutno end moraine and adjacent morainic plateaus (Fig. 3). A watershed on the extension of the analyzed elevation towards the south-east, is transverse to the axis of the Warsaw-Berlin ice-marginal spillway. The swath profile (Fig. 3) shows that the watershed is elevated up to ca. 4.5 m. Due to this watershed, a river flow from the east to the west is impossible at present and therefore the Bzura and Ner rivers that use the ice-marginal spillway display separate watercourses, namely into the Vistula and the Odra river basins. Moreover, occurrences of fluvial and ice-dammed glaciolacustrine deposits are limited extent due to a development of this transverse watershed (Molewski, 2014; Kucharska and Krawczyk, 2017, 2022).

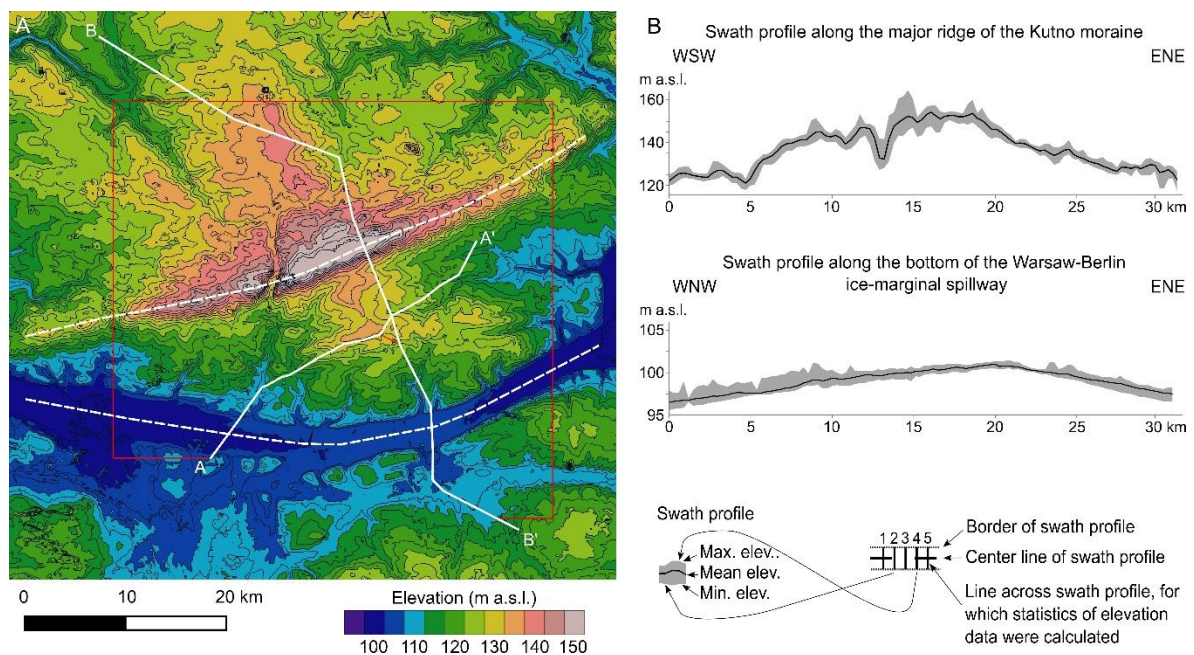


Fig. 3. Tectonically controlled terrain topography in the area between the Warsaw-Berlin ice-marginal spillway near Łęczyca and the Kutno moraine to the north

(A) Generalised contour map of the terrain topography. Contours are plotted every 2.5 m. White dashed lines mark the location of the swath profiles, which are shown in the inset B. Note the white thick solid lines corresponding to geological cross-sections and thin red lines, both of which border the 3D GIS model. (B) Swath profiles along the major ridge of the Kutno moraine and the bottom of the Warsaw-Berlin ice-marginal spillway. The location of these profiles is marked in the inset A and Fig. 2.

It is very important to note that both the elongated elevation (NW-SE) and the transverse watershed are not located directly above the hinge zone of the Kłodawa-Łęczyca anticline, but are shifted towards the NE limb. Thus, the location of these terrain topographic features seems to be spatially coincided with the rim syncline and the salt overhang which were recognized within the Mesozoic basement. However taking into account the width ca. 30 km of the analyzed topographic features, they better correspond with the size of the rim syncline.

FUNCTIONING OF THE ICE-MARGINAL SPILLWAY

The ice-marginal spillway floor is mainly filled with the Vistulian and Holocene deposits. There is no glacial till and the valley filling is composed of sand-silt and sand-gravel formations (Fig. 4; Forysiak et al., 2024a). However, the higher morphological levels of the ice-marginal valley were formed on glaciogenic deposits, covered with glaciofluvial sand and gravel.

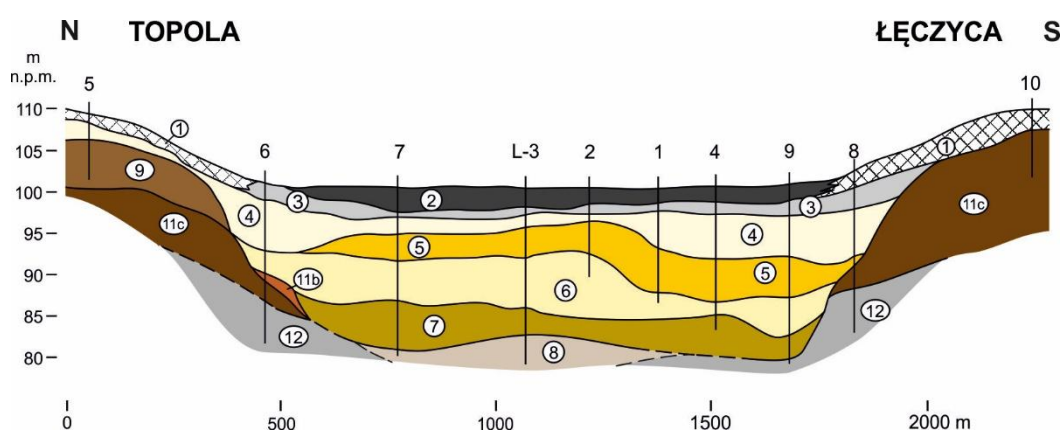


Fig. 4. Geological cross-section across the floor of the Warsaw-Berlin ice-marginal spillway, Łęczyca-Topola (location on Fig. 1)

- 1 – embankment, 2 – biogenic sediments: peat and gyttja, 3 – vari-grained sand with scattered organic matter or with peat and gyttja inserts, 4 – fine sand, 4a – aeolian fine sand, 5 – medium and fine sand, 6 – fine sand, 7 – sandy mud, 8 – clayey mud, 9 – sandy till, 10 – sand with admixture of gravel, 11 – till, in general, including: 11a – till, 11b – clayey sand, 11c – older till, 12 – mineral-organic silts

This ice-marginal valley functioned as a drainage spillway of proglacial and extraglacial meltwaters during the Saalian retreat phases. During the Kutno Phase, when the Kutno end-moraine was formed, it served as the foreground of the ice sheet, draining proglacial waters into the Koło Basin (Forysiak et al., 2026), then flowed westwards into the Baruth-Głogów ice-marginal valley system. A progressive ice sheet retreat during the late Saalian caused the exclusion of this outflow of proglacial waters, but fluvial processes could still have operated there during the Eemian Interglacial and the beginning of the Vistulian.

The renewed activity of proglacial outflow through the Warsaw-Berlin ice-marginal spillway between the Warsaw and the Koło Basins occurred during the maximum extent of the Vistulian Glaciation (LGM), as repeatedly emphasized in the literature (cf. Forysiak, 2014; Forysiak et al., 2024a). Sandy and sandy gravel deposits correlated with this valley activity are to 10-12 m thick (Fig. 4; Forysiak et al., 2024a). After the end of the meltwater flow, between the Poznań and the Pomeranian Phases, the streams in the Łęczyca area likely continued flowing westwards. Between Łęczyca and Topola, glaciofluvial sand layer is overlain by sand with admixture of organic material, and the analysis of quartz grains indicates a significant contribution of aeolian material (Forysiak et al., 2024a).

The impact of the salt structure, activated during the advance of the ice sheet in the northern zone of the Kłodawa salt structure, persisted after its retreat and influenced a hydrographic system of the described area. The river flow from east to west gradually ceased, and shallow lake basins were formed in the depressions of the valley floor since the late Vistulian. During the Holocene, the entire area was subjected to peat formation. This resulted in the formation of a several-kilometer-long belt of wetlands, occupying the Warsaw-Berlin ice-marginal spillway floor, ranging from 1.3 km to 3 km wide, largely fed by groundwater. Uplift of the geological bedrock between Łęczycza and Topola resulted in the creation of a watershed and the diversion of the Bzura River eastwards.

Another effect of the salt structure activity and the contact of the salt water with Cenozoic aquifer and water flowing within the edge and floor of the ice-marginal valley west of Łęczycza was expressed by a development of halophyte communities in the area of Błonie and Wilczkowice. The studied biogenic sediment profiles record the presence of highly saline waters as early as the Vistulian/Holocene transition (Janas and Forsyia, 2023; Forsyia et al., 2024a, b). They persisted throughout the Holocene (Fig. 5). Halophyte communities occurred until recently in the Błonie reserve, and halophyte vegetation continues to be observed in meadow communities in Wilczkowice.

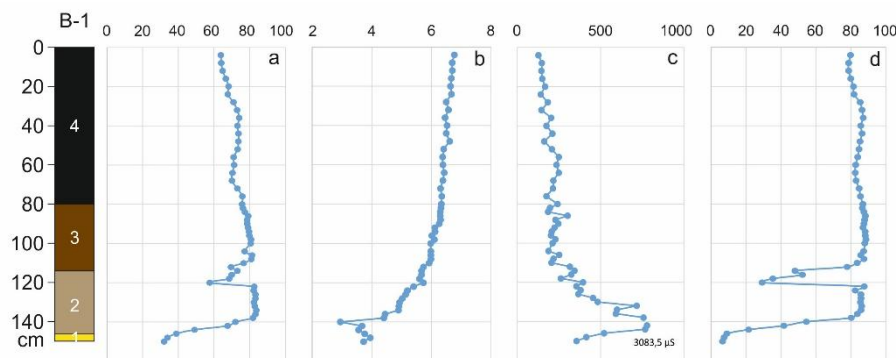


Fig. 5. Physicochemical parameters of sediments from the B-1 profile in Błonie
 Deposits profile: 1 – sand, 2 – detrital gyttja, 3 – herbaceous and moss peat; 4 – heavily decomposed peat and muck;
 a – water content [%], b – pH, c – electrolytic conductivity (PEW) [$\mu\text{S}/\text{cm}$], d – organic matter content [%].

The functioning of this wetland system was gradually disrupted, initially by maintaining the crossing system from Łęczycza and Tum northward, then by the construction of a road causeway in the early 19th century and a railway causeway (late 19th century), as well as by drainage canals for the wetland area, effectively lowering the groundwater level. This enabled peat exploitation and meadow management. Since the mid-20th century, the peat deposit has been degrading at a significant rate. Currently, the surface layer of 40 to 70 cm is muck, with a layer of sedge and sedge-reed peat below. The water level is so low (in summer and autumn, even below 150 cm) that the degradation – peat decay and mineralization progresses going deeper and deeper. Peat-forming vegetation persists only in the depressions left by peat exploitation.

TUM IN BZURA RIVER VALLEY

The Bzura river is one of several small rivers, flowing from the northern slopes of the Łódź Plateau into the Warsaw-Berlin ice-marginal spillway, running along the eastern margin of the salt anticline. This relatively narrow valley at the Ozorków town passes into a fluvial basin with erosional levels of the ice-marginal spillway and patches of the Vistulian terrace, dissected by poorly defined depressions, utilized by the river and peatlands during the Holocene. These converge occurs near the villages Leśmierz, Tum and Łęczycza, where the Holocene valley floor is more than 2 km wide, but exhibits minimal longitudinal gradient toward the axis of the ice-marginal spillway. This resulted in the formation of a multi-channel

system and significant marshy conditions. There are "hidden" elements of the older Vistulian levels and erosional outliers.

In this landscape, on one of the faintly defined mineral hillock, the stronghold settlement in Tum was founded. It was surrounded by numerous, shallow, river channels and marshes. However, the stronghold was built not on river deposits, but on a remnant of glacial sediments – till, covered by a thin layer of clayey sand (Fig. 6). Petrographic analysis revealed that this clay did not correspond to the Saalian till erratic spectrum, and therefore is likely the older – of the Elsterian age (after Czubla P. in Forysiak et al., 2015; Fig. 6 – 11a). This location not only ensured the stronghold's protection from external interference but also provided a good ground for the wooden-earthen construction.

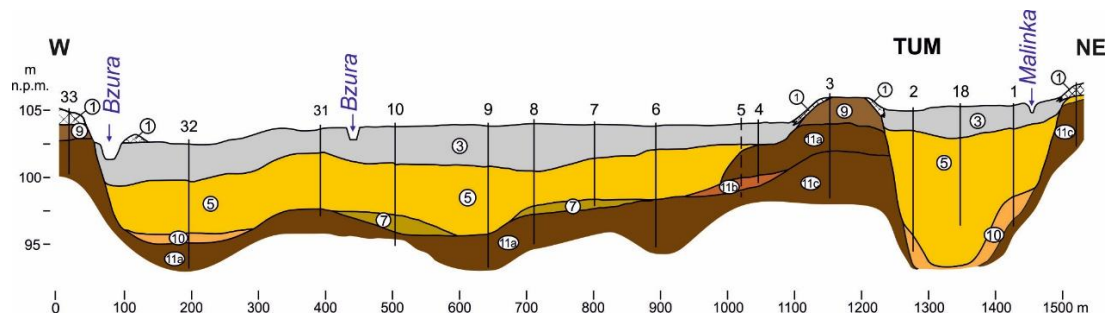


Fig. 6. Geological cross-section through the Bzura valley (location on Fig. 1)

1 – embankment; 2 – biogenic sediments: peat and gyttja; 3 – vari-grained sand with scattered organic matter or with peat and gyttja inserts; 4 – fine sand; 4a – fine aeolian sand; 5 – medium and fine sand; 6 – fine sand; 7 – sandy mud; 8 – clayey mud; 9 – sandy till; 10 – sand with an admixture of gravel; 11 – till, in general, including: 11a – till; 11b – clay sand; 11c – older till; 12 – mineral-organic silts

In the 12th century, the collegiate church in Tum was built, also within, till-based erosional fragment of the ice-marginal valley terrace. The town of Łęczyca, with several locations, was founded on the left bank of the Bzura River, also on a bed of glacial sediments. A 14th-century castle was built at one of the few, yet most convenient, crossings of the wetlands (Łęczyca-Topola). It may have consisted of embankment and a causeway, the remains of which are still visible east of the modern road crossing.

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International Field Symposium

“Glacials and interglacials of the Middle and Upper Pleistocene in central Poland”

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STOP 11 – TUM

The influence of the environment on human settlement in the Middle Ages and prehistory in Central Poland

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INTRODUCTION

Central Poland has been a classic area of Quaternary research for over a century. Thanks to the well-developed marginal zones of the last and previous glaciations, it is an area exceptionally rich in diverse erosional, deformational and accumulative features, which are a direct result of the influence of the Scandinavian ice sheet on this region. During the periods between successive advances of the Scandinavian ice sheet, fluvial and aeolian processes developed intensively, whilst lacustrine sedimentation took place in glacial depressions. The final, but equally important, morphogenetic factor was periglacial phenomena, for which the area of Central Poland is of great significance for the development of research into these processes.

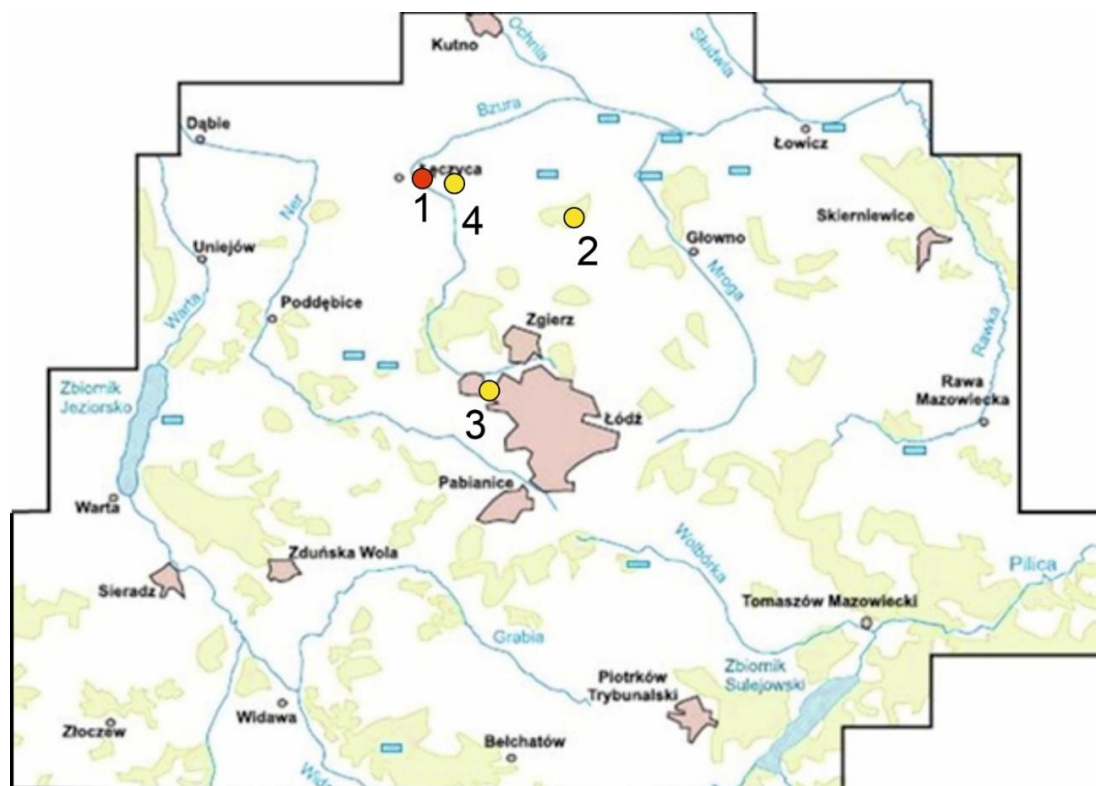


Fig. 1. Location of the sites under discussion

1 – Tum, Łęczyca county; 2 – Witów, Piątek county; 3 – Aleksandrów Łódzki - Rąbień peat-bog;
 4 – Góra Św. Małgorzaty, Łęczyca county

All the above factors contributed to this area being attractive for human settlement in prehistory, including the Middle Ages and Stone Age. Although there may not be as many sites associated, for example, with the Neolithic Period as in Kujawy or on the loess plains near Kraków and Sandomierz, over the last nearly 100 years many significant sites have been discovered, which were selected, among other reasons, due to the diversity and uniqueness of the geomorphological features.

In the Łódź region, the development of research combining geological and archaeological issues is linked to Jan Dylík and Konrad Jażdżewski, who developed the Łódź academic community at the University of Łódź (cf. Płaza and Buławka, 2026). Thanks to their collaboration, many sites have undergone multi-faceted analyses, and this multidisciplinary approach has been applied in the work of both archaeologists and Earth science specialists.

In this text, I would like to present selected archaeological sites as examples of research that has brought together archaeologists and geomorphologists. These will be the oldest part of Łęczyca at the early medieval settlement in Tum and Stone Age sites at Góra Św. Małgorzaty, Witów and Aleksandrów Łódzki (Rąbień) (Fig. 1).

TUM

Early middle age stronghold in Tum, Łęczyca district

Tum village is situated approximately 40 km north of Łódź, about 2 km east of the centre of town Łęczyca. It lies within the mesoregion known as the Łowicz-Błoński Plain, whose most significant morphological feature is the Warsaw-Berlin ice-marginal spillway (Fig. 2).

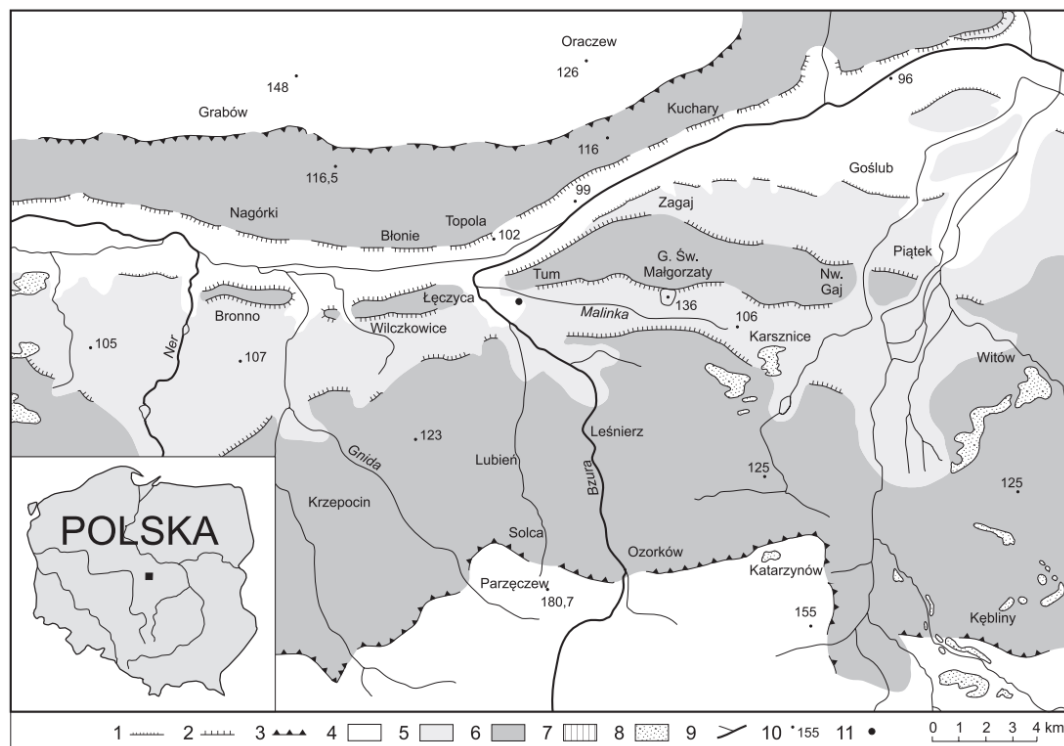


Fig. 2. Location of archaeological site in Tum on the geomorphological background

- 1 – middle terrace edge, 2 – high terrace edge, 3 – upland edges, 4 – Warsaw-Berlin ice-marginal spillway bottom level,
- 5 – middle terrace, 6 – high terrace, 7 – moraine uplands, 8 – selected dunes, 9 – rivers, 10 – benchmarks,
- 11 – situation of the stronghold (Forysiak et al., 2015)



From a geomorphological point of view, the Tum stronghold is situated in the widening of the Bzura River valley, where it joins the Malinka stream valley. Immediately to the north of Tum, the Bzura valley transitions into the bed of the Warsaw-Berlin ice-marginal spillway.

The area surrounding the hillfort is relatively flat. It rises from 102.5 to 105.5 m above sea level within the aforementioned valleys, and to approximately 108 m above sea level on the clayey erosion surface adjacent to the north and east. The hillfort and the settlement surrounding it occupy the most prominent position within the valley floor. They are situated on an elevation of an erosional outlier.

The bedrock of Quaternary formations in the Tum and Łęczyca area consists of Jurassic rocks and patchy Neogene strata. The Middle and Upper Jurassic rocks, forming the roof of the solid Mesozoic bedrock in the described area, are represented mainly by various types of limestone, but also marl, dolomite and others rock types.

In the vicinity of the stronghold, Holocene and Late Vistulian river sediments are present on the surface, among which extra-channel sands with silt and mixed-grain channel sands predominate (Forysiak et al., 2015). Biogenic deposits in the form of peat, gyttja and organic silt have also been documented, filling primarily fossil river channels and oxbow lakes in the valley floor and low-lying areas. The total thickness of the river series reaches 4 meters.

The first fortified settlement in Tum was built at a time when the area of present-day Poland was inhabited by various tribes, such as the Polans and the Vistulans. Towards the end of the 8th century, one of these tribes erected the first circular rampart with a central open space (known as a ‘majdan’) inside. There were no permanent buildings there at the time, as the stronghold served as a refuge – a defensive site where people could take shelter in the event of danger. It is likely that at this time, on a small hill situated right next to the stronghold, on its eastern side, a defensive palisade was also erected, most likely enclosing a site of pagan worship.

Archaeologists have designated the history of the stronghold during the pre-Piast Period, also known as the tribal period, as Phase I. This lasted until the end of the 10th century. During this time, it was rebuilt three times, using various construction techniques: in the 60s of the 9th century (when the rampart was fitted with an impressive row of long, sharpened stakes pointing outwards), at the beginning of the 10th century, and in the 20s of the 10th century, following a great fire. Each time, the ramparts became higher and, at the same time, wider at the base. By the end of the 10th century, they were approximately 8 meters high and 15 meters wide at the base.

The first turning point in the history of early medieval Łęczyca came in the final decade of the 10th century. It was then, as established by recent archaeological research, that the stronghold was taken over by the Piasts, who were building the first Polish state. Phase II, the early Piast Period, began. The new authorities set about a thorough reconstruction of the entire complex. The old ramparts were partially levelled, and new fortifications with a distinctive, impressive stone facing were built on their foundations. In the northern section there was a wooden entrance gate, and within the stronghold, along the ramparts, permanent wooden structures were erected. Wells, built in the mid-90s of the 10th century, were situated in the centre. Artefacts from this period attest to the presence of an armed garrison in the stronghold, including mounted warriors. Some finds can even be linked to the stationing here of a Varangian band – warriors of Scandinavian origin, who were also strongly influenced by Rus’ Culture. Importantly, it is from the end of Phase II (the turn of the 11th and 12th centuries) that the most significant artefact dates – a unique polygonal silver ring bearing a Latin inscription. The settlement mound, meanwhile, was surrounded by a solid, double palisade, and at its highest point archaeologists discovered traces of mysterious, still-pagan cult practices.

It is also known that at that time the Łęczyca stronghold was the central hub of the Łęczyca region and served administrative and defensive functions. It was also the main feature of Łęczyca at the time, which did not have a uniform, compact settlement but was scattered and spread out on both sides of the Bzura valley, with the stronghold at its centre. To the northeast, on the site of today's collegiate church, stood a Benedictine abbey, founded in the 1060s. To the west, beyond the pre-town settlement on the so-called Kępa Dzierzbietów, there were buildings, including, most likely, the manors of representatives of the emerging knightly class. This was the so-called Old Town, i.e. the pre-town settlement located in the area of the now-defunct Church of the Holy Cross (this place was once known to the local population as Emaus).

The early 12th century

Thanks to written sources, we know that at the beginning of the 12th century, battles were fought over Łęczyca during the civil war between the sons of Władysław Herman – the elder Zbigniew and the younger Bolesław Krzywousty, the latter of whom, as the victor, was to have restored the old stronghold, as Anonim Gall writes in his Chronicle of the Kingdom. Interestingly, this account of the reconstruction has not been confirmed by archaeological research. In 1138, following the death of Prince Bolesław Krzywousty, the Łęczyca lands were set aside as a so-called widow's dower for Princess Salomea. Sources mention her court, which was said to have been located in Łęczyca. Archaeologists had expected to discover its remains within the stronghold. However, it was established that from the early 12th century until the mid-13th century, the stronghold's history saw a period of over 100 years marked by a significant decline in activity. During this time, the Łęczyca stronghold likely still served as a defensive site, but, much like in the pre-Piast Period, it was not permanently inhabited.



Fig. 3. The partly reconstructed stronghold in Tum near Łęczyca in the Bzura River valley

Following this transitional period, in the late 1250s, the third phase of the stronghold's development began, the so-called castellan period, which lasted until the mid-14th century. The timber-and-earth fortress was extensively rebuilt. An elaborate system of outer ramparts and moats was employed, over which a wooden bridge was constructed from the north to the new gate. Buildings returned to the

main square, including a completely new multi-storey tower. Monuments from this period indicate intensive use of the stronghold, including by a military garrison, and also attest to the operation of a chancellery and specialised craft workshops within the Łęczyca stronghold. The Łęczyca stronghold was a very important defensive strongpoint, as well as a ducal and castellany seat. The nearby settlement, in turn, served as the stronghold's immediate hinterland, where, among other things, iron metallurgy was developed. On the site of the Benedictine abbey, a magnificent collegiate church dedicated to the Blessed Virgin Mary and St. Alexius was erected, consecrated in 1161, whilst on the other side of the Bzura River, the old town of Łęczyca flourished.

From the mid-14th century, after more than 500 years of development, the disused Łęczyca stronghold quickly faded into obscurity, gradually taking on the form of today's stronghold (Fig. 3). Its role was taken over by a bricked castle, the construction of which began during the reign of King Casimir III the Great (Grygiel et al., 2014)

During the excavation work, a vast number of artefacts were discovered, including, above all, pottery, animal bones, metal objects, jewellery, weapons and coins. A discovery made during the 2009 excavation season at the Tum fortified settlement deserves special mention. It is a polygonal silver ring with a well-preserved inscription. The ring was discovered in a cultural layer lying just above the ground floor of a large building dating from the second half of the 11th to the early 12th century. It takes the form of a nine-sided band, the sides of which were shaped into a polygon with flat sides using a hammer. This unique ornament was made of high-purity silver, containing over 87% Ag. The sides of the ring are adorned with a Latin inscription in Roman capital letters. To improve the legibility of the inscription, the engraved letters were filled with a black silver sulphide paste. The dark letters certainly stood out strikingly against the bright silver (Fig. 4).



Fig. 4. Silver ring from Tum with inscription + TOT VIVAS FELIX QUOT VIVIT TEPORA FENIX: which means: May you live happily for as long as the phoenix lives.

However, the creator of the inscription employed a highly symbolic technique, using so-called ligatures (abbreviations) to achieve a specific effect. Once all the abbreviations are expanded, the sentence on the ring should read: *Tot vivas foelix, quot vivit tempora phoenix*. It has, however, been shortened. Why? Was it merely to fit within the available space?

The beginning of the sentence is marked by an equal-armed cross, whilst it ends with a colon. The presence of Christ in the inscription is emphasised both by the cross and by the mythical phoenix rising from its own ashes, symbolising in this case the risen Saviour of the World. The Latin sentence, including ligatures (abbreviations), comprises 33 letters, which correspond exactly to the earthly years of Christ's life (Fig. 4).

DUNE AND PEAT BOG IN WITÓW

The site in Witów is located on a dune adjacent to the north and northwest of a fairly large, now peat-covered water body known as "Silne Błoto". A stream called "Malina" flows out of it. It is located about 13 km from the Bzura River valley and the Warsaw-Berlin ice-marginal spillway.

The Witów dune is the highest and largest feature in the area. It stretches in an arc with a chord length of 4 km, running from the southwest towards the northeast. The terrain consists of a series of higher and lower hills and dune arcs, as well as larger sandy fields (Fig. 5). The site itself is located in the central part of the dune ridge, approximately 3.5 m above the former water level (Fig. 5). Currently, the area is mostly covered by forest.

In addition to significant archaeological findings, the geological and palynological studies conducted by Krystyna Wasylkowa (1964, 2001) were of great importance.



Fig. 5. Excavation works at the site Witów in the 1950s

Among the archaeological finds, a collection of artefacts and objects associated with the Allerød communities of the "Arch Backed Pieces" stands out (Sobkowiak-Tabaka, 2017). The dune in Witów was also used and inhabited by reindeer hunters of the so-called Świderian Culture, as well as by Mesolithic hunters and gatherers and in later chronological periods.

ALEKSANDRÓW ŁÓDZKI – A DUNE AND PEAT BOG IN RĄBIEŃ

The Rąbień peat bog is situated within the Łask Upland, approximately 11 km west of the centre of Łódź. Almost the entire area of the peat bog is protected as a nature reserve. The dune complex adjacent to the peat bog, where archaeological research was conducted (Fig. 6A), lies within the territory of the town Aleksandrów Łódzki. The peat bog is situated in an oval, bowl-shaped, drainless depression, bounded by the 190 m a.s.l. contour line. Along the crest of the post-glacial hills, situated to the north-east of the studied peat bog, runs a first-order watershed between the Vistula and Oder river basins. Small seasonal watercourses flowing out of the peat bog in its southern part belong to the Ner (Oder) river system. Archaeological sites are located within the dunes lying directly to the west of the peat bog.

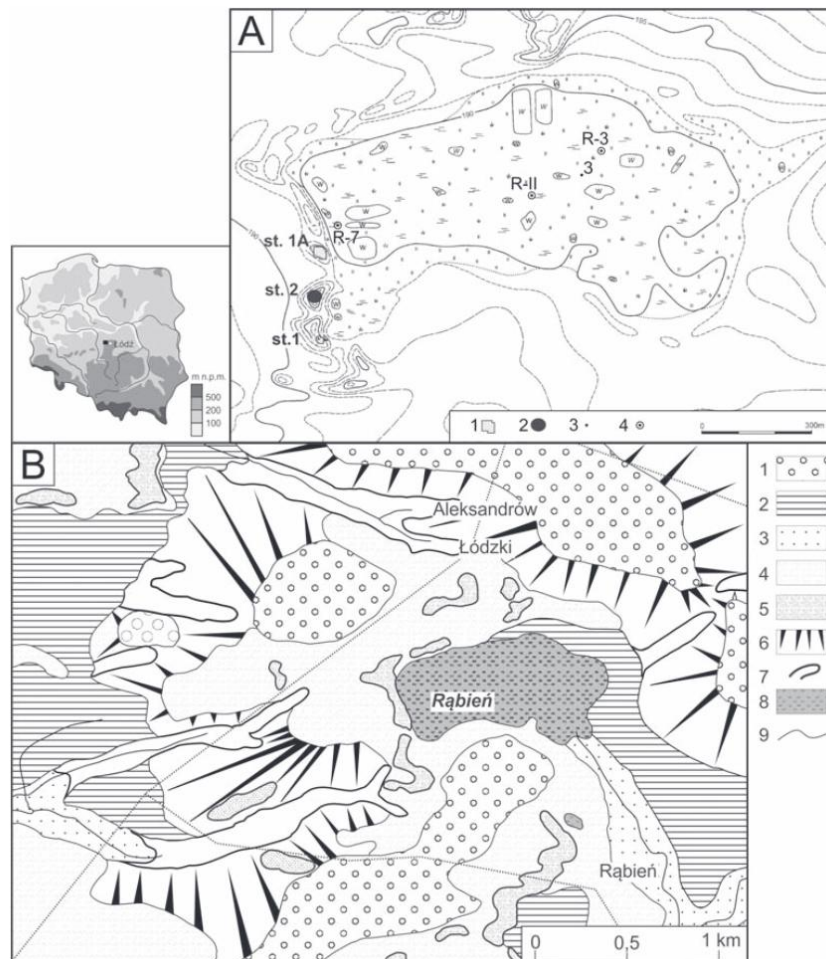


Fig. 6. Rąbień peat-bog and archaeological sites

(A) location of archaeological sites. Site 1 and 1A – excavated (Niesiołowska-Śreniowska et al., 2011) and location of the cross-sections of the explored biogenic sediments. Explanations: 1 – archaeological trenches, 2 – location of site 2, 3 – location of deposits profile analyzed by Balwierz (Niesiołowska-Śreniowska et al., 2011), 4 – location of studied profiles. (B) geomorphological sketch of the vicinity of the mire at Rąbień. Explanations: 1 – fluvioglacial hillocks; 2 – flu-vial-periglacial plains; 3 – valley bottoms; 4 – aeolian sand sheets; 5 – dunes; 6 – slopes; 7 – dry valleys; 8 – peatland; 9 – streams

Research in Aleksandrów Łódzki has enabled us to gain a better understanding of, amongst other things, the history of settlement in Central Poland from the end of the Ice Age, when the region was systematically penetrated by various migrating groups, including those mainly associated with the Świderian, Komornica and Janisławice Cultures (Płaza et al., 2013/2015). It appears that the areas of Central Poland, with their poor soils, mixed forests, and a large number of small watercourses and wetlands, served as a kind of refuge for mobile hunter-gatherer groups during the Early and Middle Stone Age.

It was important to combine archaeological (Fig. 6A) and environmental research, including palynological studies (Fig. 6B), which made it possible to determine when and with what intensity human groups were active on the dune near the overgrown and shallowing lake.

The Stone Age sites No. 1, 1A and 2 were investigated by Ewa Niesiołowska of the Archaeological and Ethnographic Museum in Łódź between 1991 and 2001. The camps were established in the southern part of the dune by the lake's bay, approximately 5 m above the water level. The total area of the archaeological excavations at these sites between 1991 and 2001 amounted to 940 m² (Fig. 7A), from which a total of several tens of thousands of flint artefacts and a large quantity of stone pebbles (Niesiołowska-Śreniowska et al., 2011) dating to the Late Palaeolithic associated with the Świderian Culture (Fig. 7B) and the Mesolithic (Fig. 7C) were recovered from the two excavations.

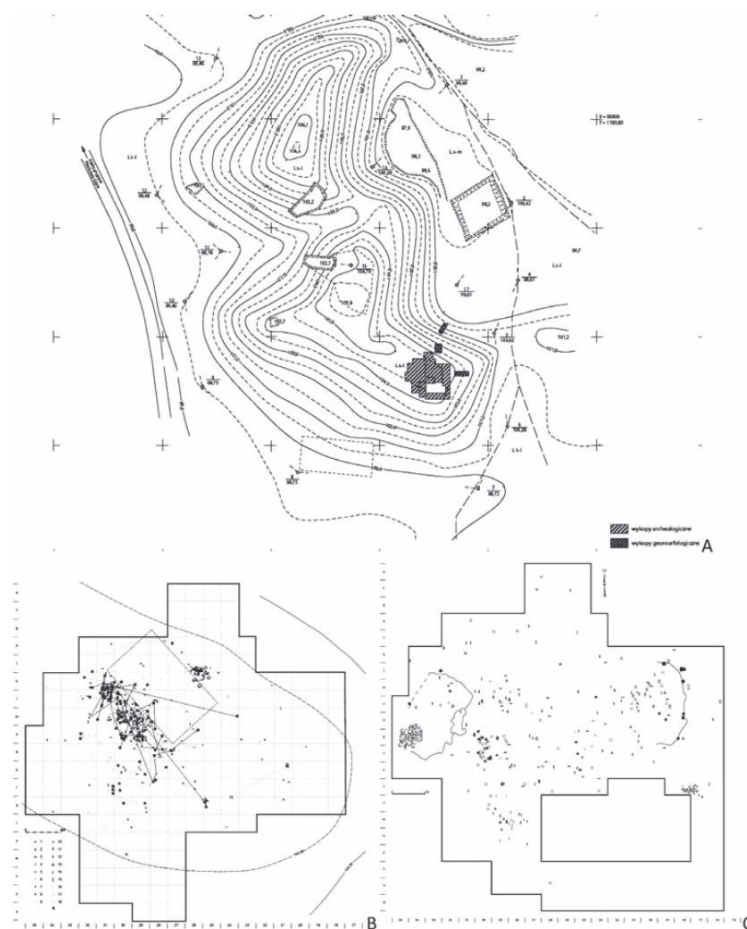


Fig. 7. (A) Land-survey and height map with marked archaeological trenches on the site 1. (B) Spatial analysis of flints of the Świderian Culture along with the network of composite tools. (C) Spatial analysis of flints from the Mesolithic (Niesiołowska-Śreniowska et al., 2011).

During the archaeological work, geomorphological and geological investigations of the dune and the adjacent peat bog were also carried out. Several test pits were dug within the peat bog, revealing a thickness of 3.25 m of biogenic sediments in the eastern part of the bog. Sediment cores were collected here for palynological analysis and for radiocarbon dating, as well as for other geochemical studies (Niesiołowska-Śreniowska et al., 2011).

Indeed, the analysed cores also clearly reflect Neolithic cultural horizons, the material traces of which are practically imperceptible in the archaeologically explored trenches. Interestingly, sites of this age are known from the slightly more distant surroundings of the dune, suggesting that this location was used quite specifically for economic purposes by farmers of the Atlantic and Sub-Boreal periods.

GÓRA ŚW. MAŁGORZATY

Góra Św. Małgorzaty is both a village located a few kilometers east of Łęczyca and a panoramic hill (136 m above sea level), reaching a relative height of 30 m, located on a flat plain of Warsaw-Berlin ice marginal spillway.



Fig. 8. A view of Góra Św. Małgorzaty with the church at the summit

The hill is of glacial origin; numerous rock outcrops on the slope offer a view of the area's geological structure (Jewtuchowicz, 1967). At the top of the hill stands a church, whose original Gothic structure was destroyed during a 19th-century reconstruction in the neoclassical style (Fig. 8). One flint artefact from this site has been published; it is recognised in the literature as an object made by a Neanderthal and discovered in the Early Vistulian layers. It is a single-sided scraper (Chmielewski, 1975).



SUMMARY

The sites listed above are of particular importance to the history of Central Poland. Each archaeological sites are situated on or within unique landforms, which have shaped the pattern of settlement or the nature of the location of flint artefacts – or those made from other materials, as in the case of the stronghold in Tum.

It is also significant that each of the research examples mentioned demonstrates how effectively and for how many years Earth science specialists – including geologists and geomorphologists from the University of Łódź and archaeologists from the Archaeological and Ethnographic Museum in Łódź – have been collaborating.

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Field trip routes

