PALEOGEOGRAPHY, STRATIGRAPHY, CHRONOLOGY, AND PALEOENVIRONMENT

REGIONAL PALEOGEOGRAPHIC ANALYSIS OF SITE WILCZYCE 10 IN THE OPATÓWKA VALLEY AND THE STRATIGRAPHIC CONTEXT OF THE ICE WEDGE CAST

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INTRODUCTION

A team of geographers from the Department of Geoecology and Paleogeography, Faculty of Earth Sciences and Spatial Management, Maria Curie-Skłodowska University in Lublin, went to work on the archaeological site Wilczyce 10 in 2007. The job of the scientists, invited to explore the site by Professor Romuald Schild, was to reconstruct the natural environment in the area as in the Late Plenivistulian and the Late Glacial and its subsequent evolution by determining the lithogenesis and age of sediments, characterizing land relief and documenting the parameters of the relevant paleoecosystems. The team focused their attention on the loess hill containing the archaeological site and the system of dry valleys next to it, and also on the section of the Opatówka River valley bounded by the gorges in Dacharzów and Wysiadłów. The field work involved detailed topographical, geomorphological, and soil mapping, as well as geological, geochemical and paleobotanical studies, supported by thermoluminescence and radiocarbon (^{14}C) dating. All this work was possible thanks to funding from a grant awarded to Professor Maria Łanczont by the Vice-Rector for Science of the Maria Curie-Skłodowska University in Lublin. This 2007/2008 project, titled The *Paleogeographical Context of the Magdalenian Site in Wilczyce on the Opatówka River (Sandomierz Plateau)* and headed by Professor Maria Łanczont, was completed with the involvement of Dr. Krystyna Bałaga, Beata Hołub, MS, Dr. Piotr Kulesza, Dr. Jarosław Kusiak, Dr. Przemysław Mroczek, and Dr. Paweł Zieliński as well as Dr. Maryna Komar, and Dr. Bożena Łącka (Łanczont, 2008). The first results of these studies were published by Bałaga *et al.*, (2008) and Komar *et al.*, (2008a, b, 2010). The same team of scholars, now joined also by geophysicists, continued their explorations of the region in 2010 and 2011, this time as part of the international project *Palaeolithic Oecumene of the Peri- and Metacarpathian Zone – A Study of Environment Changes of Western Ukraine and South-Eastern Poland in Pleistocene and their Influence on Primeval Settlement and Migration Routes (Based on Loess and Cave Sites)*" financed exclusively by Poland's Ministry of Science and Higher Education and headed by Professor Maria Łanczont (Grant No. 691–N/2010/0 Ukraine). The detailed geology of the loess hill and the floor of the Opatówka River valley was studied using geophysical prospecting methods by Dr. Bogdan Żogała and Maciej Mendecki, MS (Faculty of Earth Science, University of Silesia). More samples were collected in 2010 directly from the floor and walls of archaeological Cut 1D to determine the TL age of sediments forming and surrounding the ice wedge cast in which the archeological artifacts were deposited. The study of the Wilczyce Area was also assisted by students of the Maria Curie-Skłodowska University in Lublin working on their MA projects in physical geography.

THE STUDIED AREA

LOCATION

Site 10 of Wilczyce is located in the central part of the loess belt in the Middle Polish Uplands (Fig. 2.1.). The paleogeographic studies were confined to an area of some 45 square kilometers in the Opatówka River valley and the adjacent plateaus (Fig. 2.2). This area is part of the Opatów Upland (rising to a maximum of 260–300 m above m.s.l.), also known as the Sandomierz Upland, itself comprising a part of the eastern foothills of the Holy Cross Mountains (Gilewska, 1972), alternatively referred to by Kondracki (1998) as the eastern part of the Kielce Upland. The Sandomierz Upland is bordered in the north-east by the middle course of the Kamienna River valley and by the Czyżówka River valley, and in the north by the Świślina River valley. The southern and south-eastern extremities of this upland coincide with the distinct erosional edge (scarp) of the Vistula River valley, rising to around 60 meters, which separates it from the north-western outlet of the Sandomierz Basin.

GEOLOGY

The studied area lies in the contact zone of the Opatów anticlinorium, forming the eastern extension of the Holy Cross Mountains anticlinorium, and the northern syncline. The sublatitudinally oriented folds are transversely cut by disjunctive tectonic dislocations, including the Sienno-Ożarów-Zawada dislocation in the area of interest to us here. This structural pattern emerged in its present form during the Hercynian orogeny (Bielecka, 1968b; Samsonowicz, 1960; Tomczyk, 1974) and is overlain by a Middle Miocene zone of strata bends, probably tectonic in origin, extending also over the Opatówka Area, which formed during the development of the northern Carpathian foredeep (Bielecka, 1968b). The studied structural units are composed of Cambrian, Silurian and Devonian rocks (Fig. 2.3.).

The rocks of Middle Cambrian, exposed in places on the southern slope of the Opatówka Valley, are composed of steeply dipping (at angles of up to 80°) gray-yellow mudstones and sandstones as well as brown argillaceous slate grading eastward into mudstones, slates and gray sandy argillaceous slate with sandstone inserts (Bielecka, 1968b; Samsonowicz, 1934a, b).

Silurian rocks occur in two facies: graywackes were cored in the plateau area, directly beneath the Quaternary deposits; while a series of alternating beds of claystones with mudstones and clay slate with mudstone bands was identified in the Opatówka Valley depression, beneath the Miocene sediments. This series was subjected to severe tectonic disturbance and often forms breccias, its dip varying frequently in the 8–45° range. The northern side of the valley is made up of Devonian rocks visible in small quarries, namely light-gray sandstones of various grain size, thin-bedded, argillaceous or shaley in places (Bielecka, 1968b).

The Opatówka structural depression zone became filled with Upper Miocene deposits when the region became part of the mountain foredeep flooded on several occasions by the oscillating sea bays. These

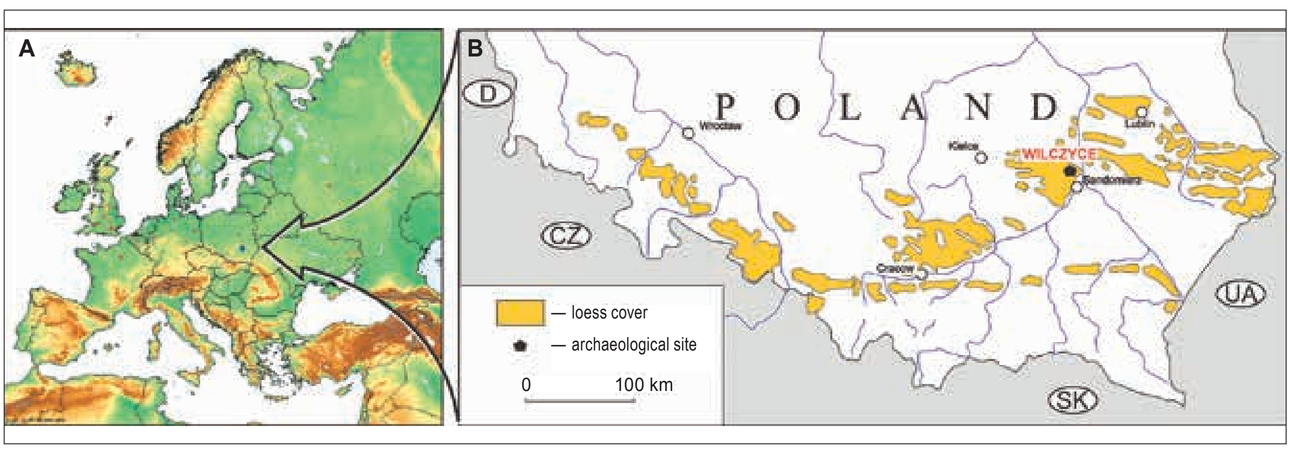


Figure 2.1. Location of the site in relation to: geographic map of Europe (A) and distribution of loess cover in southern Poland (B).

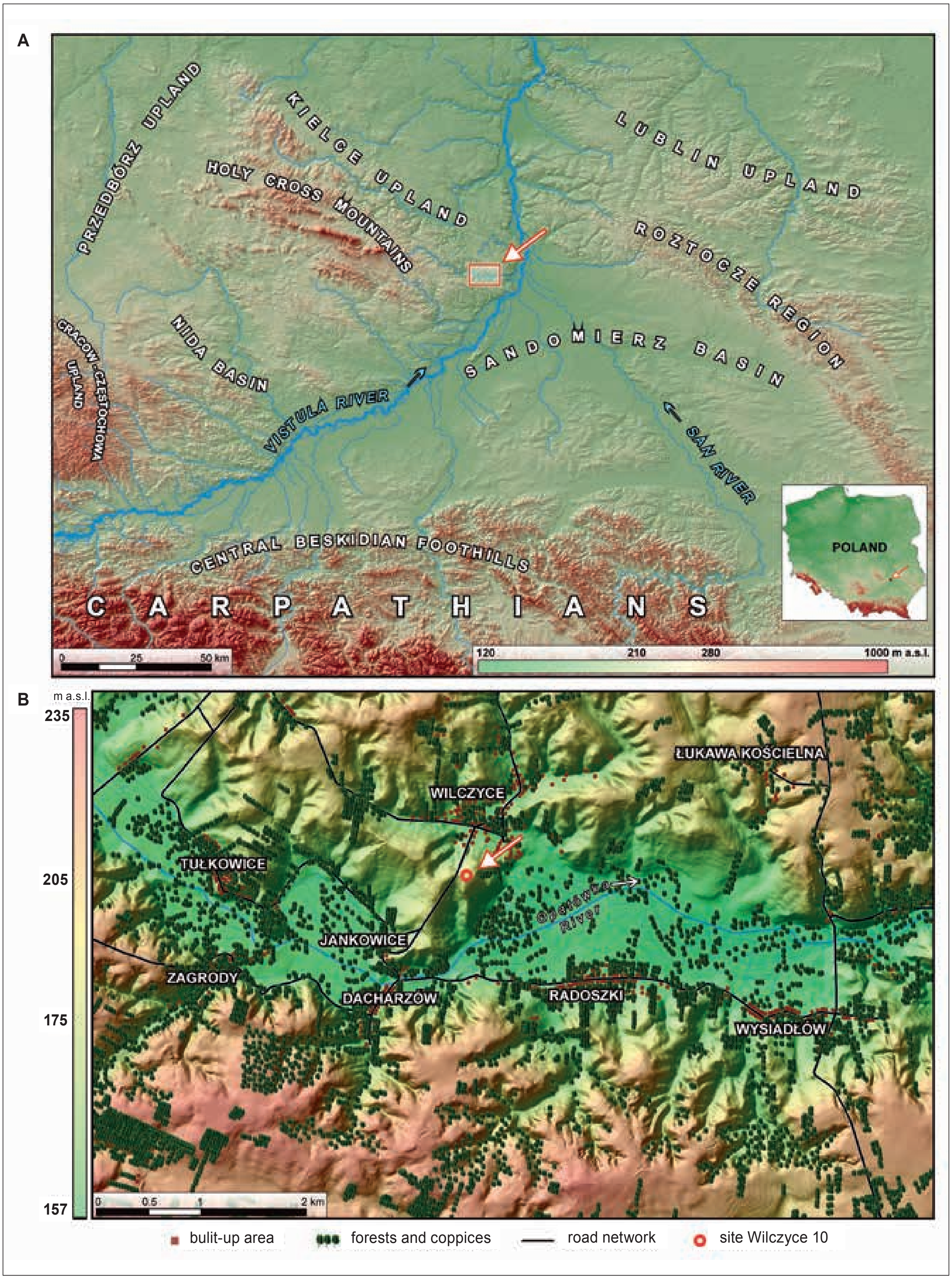


Figure 2.2. Location of the Wilczyce research area in relation to physical geographic regions of southeastern Poland (A) and the immediate surroundings of Site 10 in Wilczyce (B).

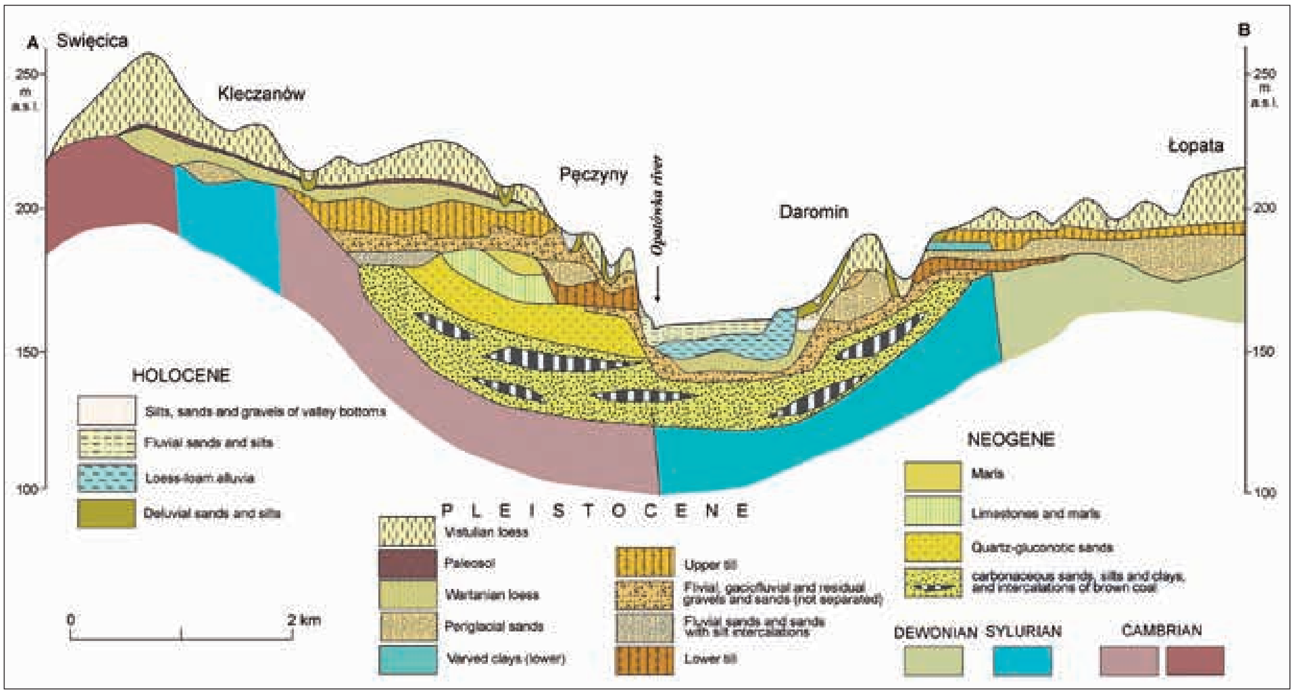


Figure 2.3. Geological cross-section of the Opatówka River Valley after Bielecka (1986a with later changes). The cross-section is located 2 km to the west of the research area.

sediments are represented at the base of the formation by sands and clayey silts with coal clay and brown coal inserts. On top of this formation is a discontinuous series of glauconitic sands, limestone and shale interbedded with coquinoid limestone (Bielecka, 1968a). These Miocene sediments (quartz conglomerate with limestone and sand) were observed during field work in exposures in the Dacharzów–Zagrody area on the southern slope of the Opatówka Valley (Fig. 2.4.).

Czarnecki (2005) interprets the Opatówka Valley as a Pliocene feature that underwent substantial remodeling during the Pleistocene. It cuts into the aforementioned deposits of a Miocene sea bay along almost its entire length, and its bottom is covered by Pleistocene (proglacial?, alluvial, glaciofluvial) undifferentiated gravel-sand series (Bielecka, 1968a) overlain by Warta Glaciation loess (?) (Fig. 2.5.).

The most complete sequence of Quaternary deposits is in evidence in the plateaus and valley sides. It is represented, most importantly, by two suits of glacigenic deposits separated by an interglacial fluvial series (Fig. 2.3.). The older of these suits, dating to the South Polish Glaciation (Elster), is comprised of glacial till underlain by a series of glaciofluvial sand. Evidence of the younger Middle Polish Glaciation (Saale) are argillaceous varves and silts deposited in proglacial lakes overlain and/or underlain by glacial tills, as well as large loess patches covered by glacial till (Czarnecki, 2005). Natural exposures of these sediments can be seen in places on the sides of dry erosion/denudation valleys merging into the Opatówka Valley. Czarnecki (2005) believes that as the Middle Polish Glaciation ice sheet receded, the Opatówka Valley was for a brief period a glacial stream valley.

The most recent Pleistocene sediments are loesses forming a continuous and thick mantle overlapping the earlier deposits and concealing the uneven surface of the older beds. According to Makowski (1976), the maximum thickness of the Opatów-Sandomierz loess cover, of up to 25 m, is recorded in the highest-lying regions — this being the highest figure in all of the Sandomierz Upland (Fig. 2.6.) — decreasing to 5–10 m in the basal parts of the slopes. Several loess profiles were thoroughly analysed in the vicinity of Sandomierz — in Gołębice, Żurawica and Złota/Polanów Samborzecki (Maruszczak [ed.], 1991, 2001), with the Polanów Samborzecki profile, studied over many years, having being especially well documented during the past decade (Dolecki *et al.*, 2006 [with the older literature listed there]; Jary, 2007; Kusiak, 2008; Kusiak, Łanczont, 2000; Łanczont, Komar, 2005; Mroczek, 2008). The loesses in the eastern part of the Opatów-Sandomierz mantle are part of the dry loess formation (Jersak *et al.*, 1992) consisting

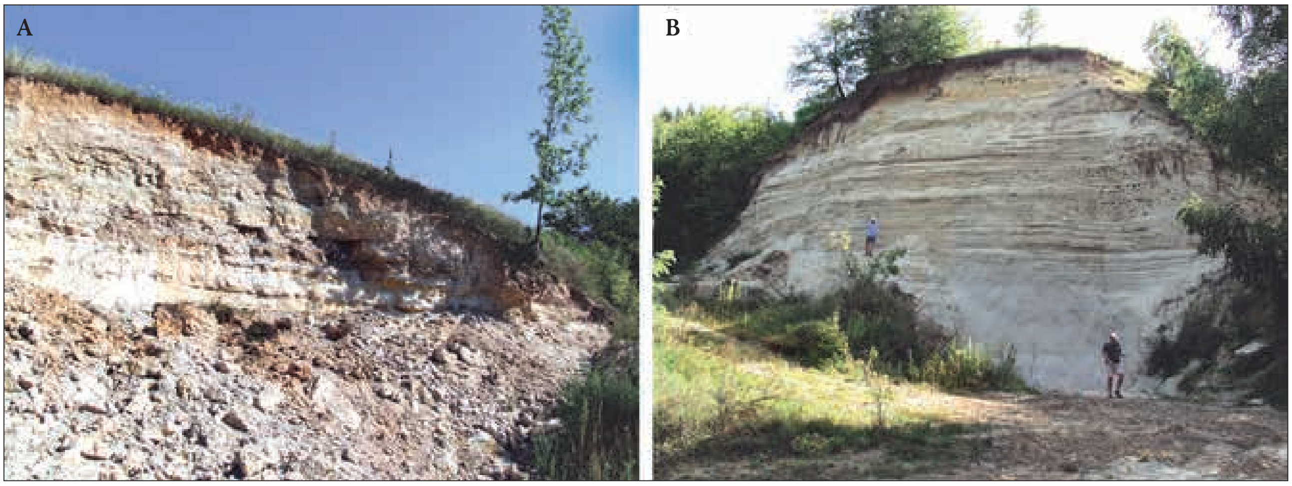


Figure 2.4. Miocene limestone-quartz conglomerates (A) and marine sand (B) in exposures in the area of Dacharzów — Zagrody. Photograph by M. Łanczont.

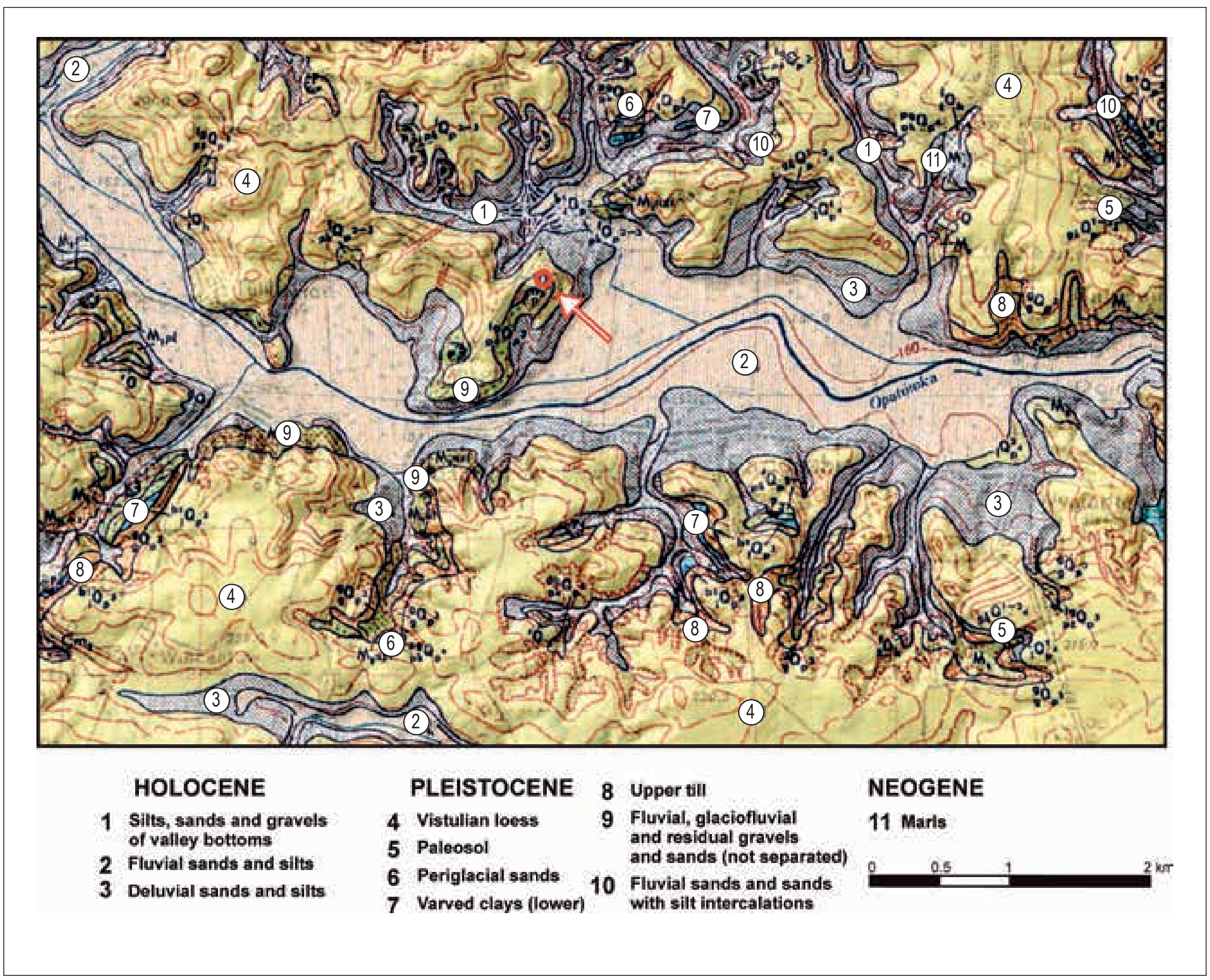


Figure 2.5. Surficial deposits in the middle Opatówka River Valley in the vicinity of Site Wilczyce 10. After Bielecka (1986a).

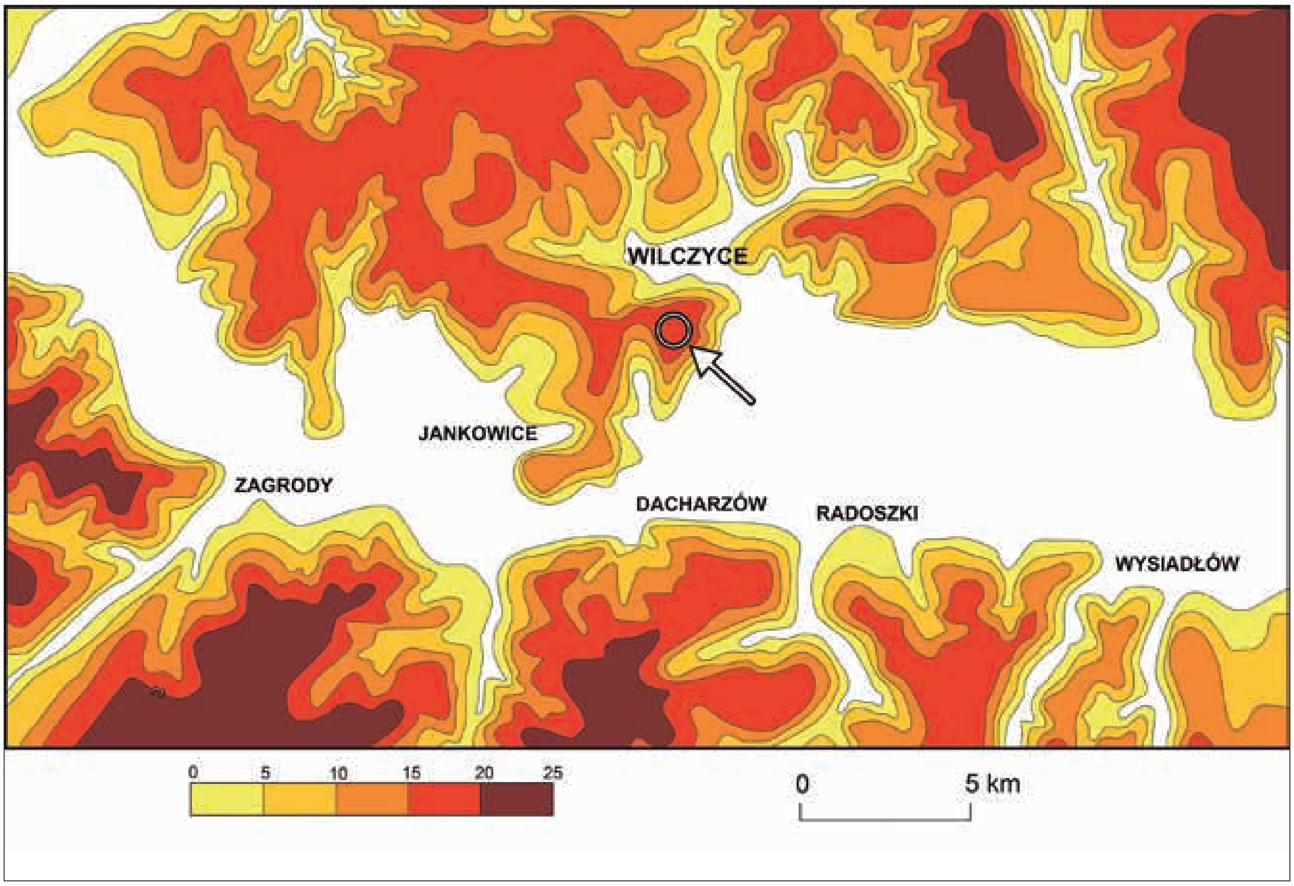


Figure 2.6. Thickness of loess cover in the vicinity of Site Wilczyce 10. After Makowski (1976) with later changes.

of three series of loesses separated by two interglacial soils. The Vistulian loess cover consists of two distinct units. The Younger Loess IIa, light ochre-colored, calcareous (5–10%) and porous, in which the Komorniki-type soil developed, assumes a depth of 5–7 m and is cut by large wedge structures with secondary infilling. The Younger Loess IIb, straw-colored and with a higher carbonate content (10–15%), was deposited during the Last Glacial Maximum, in the period extending up to the Late Glacial. This latter loess can be up to 13 m thick in places and the wedges with younger infill that cut into it are larger than those in the older loess (Jersak, 1973; Jersak *et al.*, 1992). The topmost portion of this more recent loess failed to survive, having been for the most part destroyed by powerful soil erosion processes.

The Holocene is represented by fluvial deposits infilling the Opatówka Valley: sands, clayey silts, and organic rich clayey and silty sediments deposited in layers up to a dozen or so meters thick. The dry valleys are filled by sands and fine particle washes, deposited also in the gully mouths on the river valley bottom (Figs 2.3., 2.5.).

RELIEF

In terms of geological structure, the studied area is made up of two major types of features — valleys and loess ridges. The orientation of the valleys (generally running WNW-ESE and NNE-SSW) coincides with the structural make-up of the region, with the valley of the middle course of the Opatówka River forming its latitudinal axis. The valley is 1.0–1.5 km wide, on average, and its gradient is less than 1‰. Its maximum present-day depth of incision is ca. 40 m and its absolute elevations decrease going north. Maximum elevations of the plateau north of the Opatówka Valley reach 210–217 m a.s.l., whereas the figure for the southern plateau is in excess of 230 m a.s.l. (Fig. 2.7.).

The left and right sides of the Opatówka Valley differ distinctly as to relief. The left (northern) valley side slope is longer than the one facing it (300–700 m), not very steep (2 to 10°), forming a highly erratic and uneven line. On the other hand, the opposite (right) side of the Opatówka Valley and the sides of the dry valleys display the highest average slope

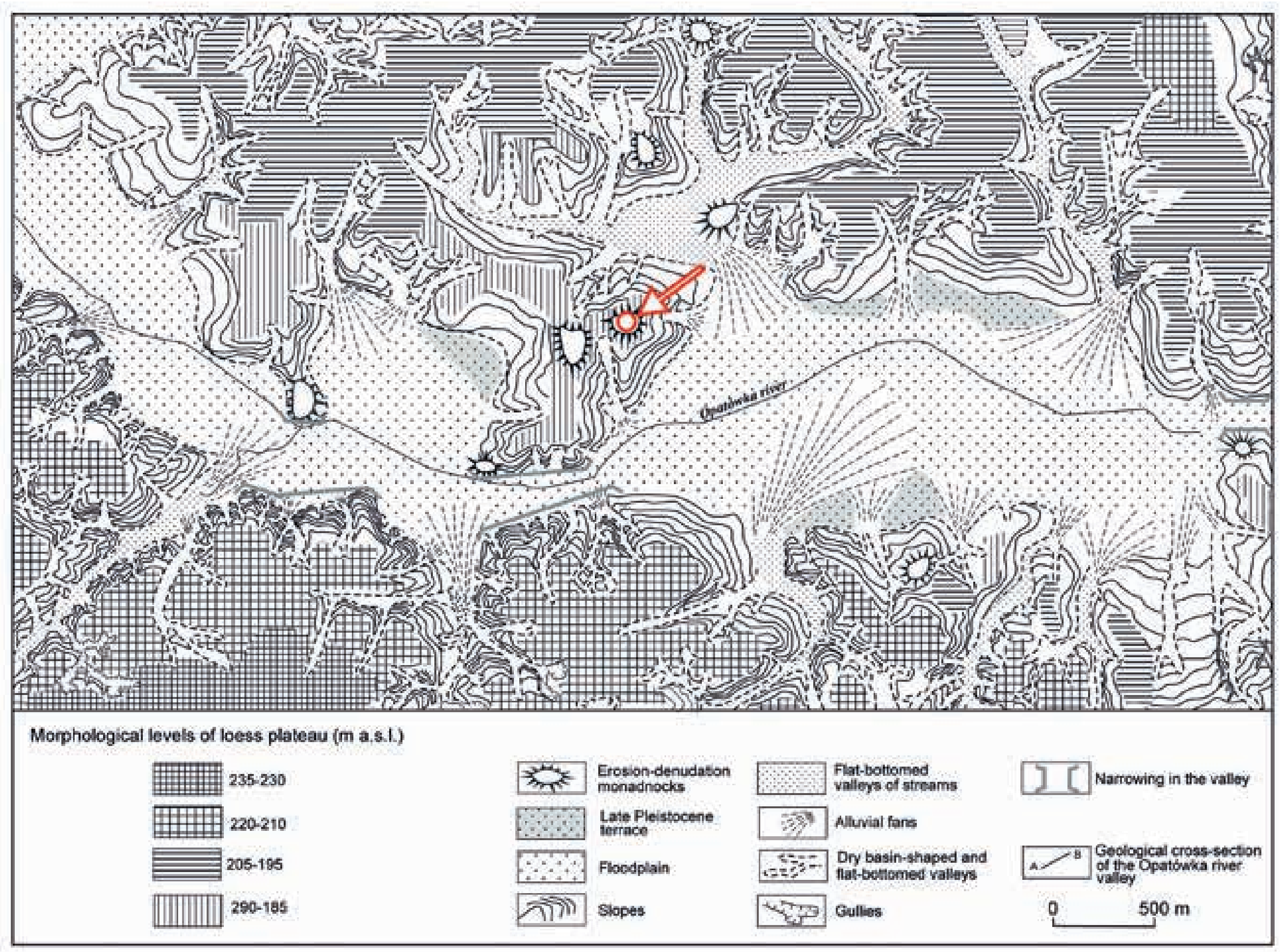


Figure 2.7. A sketch of the geomorphology of the Opatówka Valley in the vicinity of Wilczyce 10.

decline angles (8–22°), making for a more diversified relief in the southern part of the studied area. The southern valley slope is shorter (200–500 m) and steeper (upwards of 20°), with greater height differences (20–45 m) (Fig. 2.8.A, B, C). The foot of this slope is very regular, forming an almost straight line.

The latitudinal orientation of the valley translates into a predictable slopes exposure pattern (Fig. 2.8.D). The right-hand-side slope for the most part faces north, with just some stretches facing NW and NE. The left side of the valley, with its much more irregular course, presents a more diverse picture: while the southern and SW exposures prevail, considerable portions of the slope face E and SE (Fig. 2.9.). The promontories discernible along the valley edge have sides exposed in all directions.

A characteristic feature of the valley's relief are three gorge-type narrows, framed by steep slopes, separating two cauldron-shaped wider sections of the valley formed by river bends undercutting the left/northern slope. (Figs. 2.7. and 2.8.). The valley widens considerably to the east of Wilczyce, along a distance of 3.6 km, featuring two 100 m wide constrictions at either end of this stretch: the one in the west being next to the village of Dacharzów-Jankowice, and the other one to the east of Wysiadłów. The terrain relief in the zones of the narrows is distinct in that its loess surface is relatively smooth, which may be due to the presence of more resistant rocks in the bedrock underneath the loess mantle. According to Czarnecki (2005), the cauldron-shaped forms emerged as elements of subaerial deglaciation relief when the Odra ice sheet disintegrated, with the convex relief forms of kame type separating the widened sections of the valley which formed in the areas of stagnant *dead* ice blocks occurrence. Given that the cauldron-shaped sections of the Opatówka Valley are situated opposite the mouths of large tributary valleys cutting into the right-hand side of the main valley whose orientation, as already mentioned, is tectonically determined, we cannot rule out that they were also to some extent modeled by fluvial erosion processes.

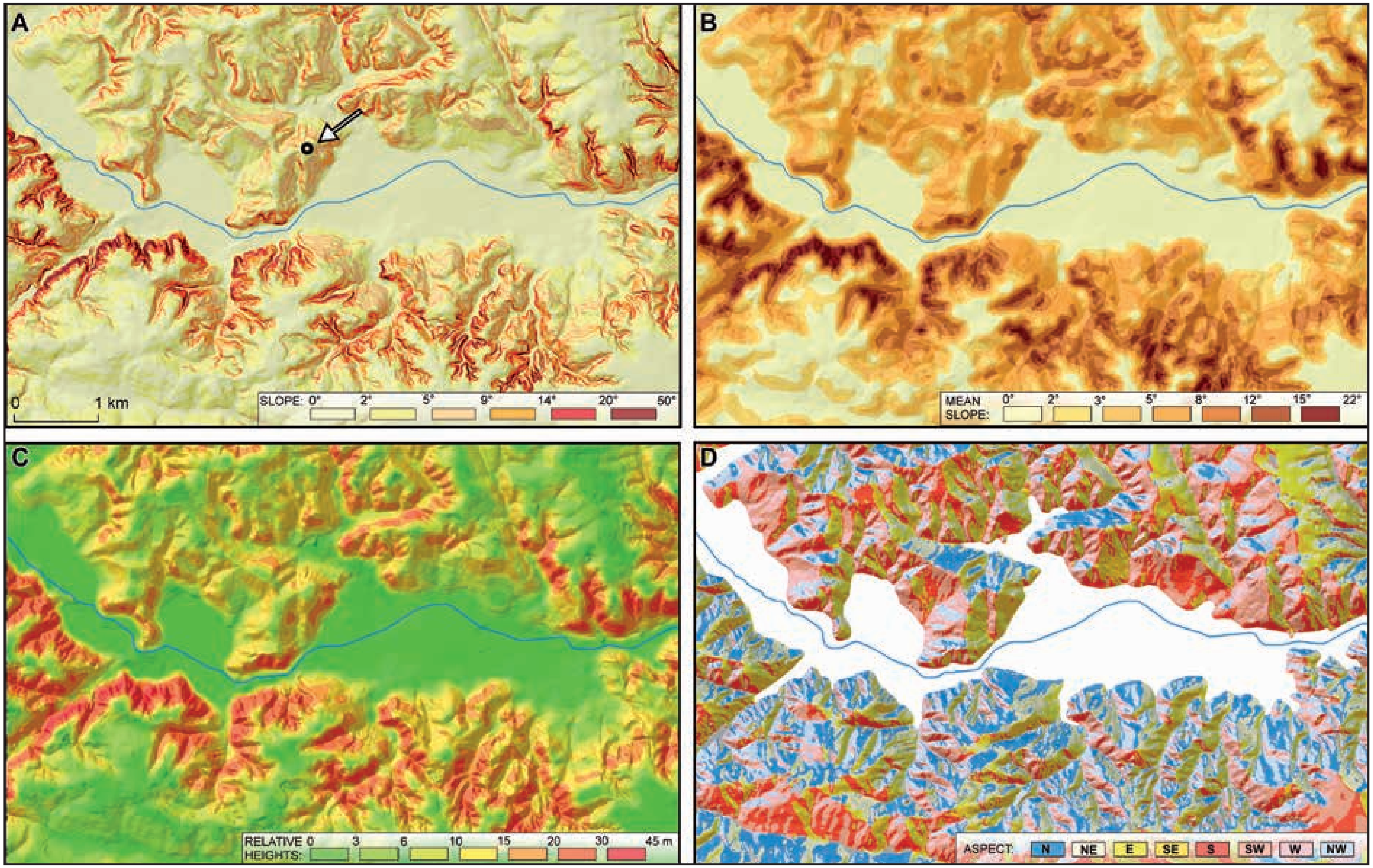


Figure 2.8. Morphometric characteristics of the Opatówka Valley in the vicinity of Wilczyce 10. Key: (A) Angles of slope inclination; (B) Average slope angles; (C) Relative relief; (D) Directions of slope exposures (for methodology of the study see section *Methods*, this chapter).

Most of the valley floor is taken up by a floodplain terrace rising to no more than 2 m above the river channel. Its relief is monotonous, with the older fluvial relief forms being concealed beneath large quantities of Holocene sediments (Czarnecki, 1996, 2005). Alluvial fans — rather indistinct fan-shaped rises, 200–900 m long and with a maximum width of anywhere between 100 and 1,000 m — are discernible on the valley floor. The first terrace above the floodplain in the studied section of the valley is in the form of a handful of narrow, discontinuous benches, each 200 to 500 m long and 5 to 100 m wide, rising up to 10 m above the river bed. In many places the terrace is covered by slope deposits. Czarnecki (1996) tentatively distinguished up to three terraces in the Opatówka Valley, with a similar interpretation being also arrived at by Bielecka (1968b).

The most extensive feature in the studied area is the loess plateau with the related loess forms. The plateau surface is rolling or flat, highly dissected, with three discernible ground levels of ca. 230–235, 210–220 and 195–205 m a.s.l. (Fig. 2.7), an observation confirmed by Czarnecki (1996). Fairly frequent remnant loess buttes can be seen in the northern side of the valley, most of them confined to the 185–190 m a.s.l. elevation range and characterized by steep (>20°) and short (up to 50 m) slopes (Fig. 2.8.A).

The plateau features a system of dry valleys incised by erosion and denudation, in variable stages of development, visible to the north and to the south of the Opatówka Valley. Czarnecki (1996) sees this situation as due to different groundwater levels, depending on the geologic structure of the strata underneath the loess mantle. The forms north of the valley are visibly longer, irregular in shape, with frequently changing orientation, forming complex dendritic systems. The largest of these, known as the Wilczyce Valley, is to be seen near the eponymic village. It is comprised of the principal valley, inverted S-shaped, up to 5 km in length and 100–500 m wide, with a mostly flat floor. Two similar tributary dry valleys join it in the mouth section, each ca. 1.5 km long, one latitudinally and the other longitudinally oriented. Disembouging into these are, in turn, numerous basin-shaped valleys, many of them further branching out, with lengths ranging from 100 to 1000 m and widths in the 20–100 m range.

The plateau south of the Opatówka Valley is cut by much narrower (up to 100 m wide) tributary valleys, clearly tending to run in straight lines (Fig. 2.7.). Most of them join the Opatówka Valley at right angles, comprising the axis of a system of sub-recent and recent dissections cutting into the bottoms of dry valleys. The majority of these dissections are gills — small V-shaped valleys with erosional bottoms and sides covered with slope deposits, no more than 100 m long and up to 30 m wide. In their lower courses the gills become gullies, forms with gradual floor-to-side transition. These are mature forms, up to 50 m wide and as many meters deep. Sub-recent and recent dissections are also often discerned in the southern side of the Opatówka Valley, serving as road gullies.

CLIMATE

In the geographic literature the Opatówka river basin is being included in radically diverse climatic zones, classified either as a lowland area (Sandomierz Basin margin) or viewed as part of upland or old mountain areas (Kielce Sandomierz Upland and the margin of the Holy Cross Mountains). For example, Okołowicz and Martyn (1979) describe the Opatówka Valley as lying in the north-western part of the Sandomierz climatic region, while Woś (2010) assigns it to the easternmost part of the northern Małopolska Region. Such diverse interpretations underscore the transitional, inter-regional nature of the climate in this area.

The weather station closest to the Wilczyce Area is in Sandomierz and that is where the basic climatic parameters for the 1971–2010 period come from. Generally speaking, in terms of temperature, the eastern part of the Sandomierz Upland is privileged when compared to the Kielce Upland as a whole (Czarnecki, 1996), with a mean annual temperature of 7.9°C. The hottest month is July (18.0°C) and the coldest is January (−2.9°C), the annual temperature amplitude being 20.9°C (Lorenc, 2005). Relative air humidity is fairly constant throughout the year, being lowest in May (72%) and peaking in December (89%), the mean annual figure being around 80%. The precipitation distribution is uneven, with rainfall levels in spring and summer exceeding the precipitation in the autumn and winter months. The mean annual precipitation stands at 570.1 mm, the mean precipitation figure for February being 22.2 mm and for August nearly four times that (84.2 mm). Wind velocities and intensity are moderate. Average monthly wind velocities range from 3.2 m/s (August) to 4.5 m/s (December), the average annual figure being 3.9 m/s. Winds usually blow from the western sector (Lorenc, 2005).

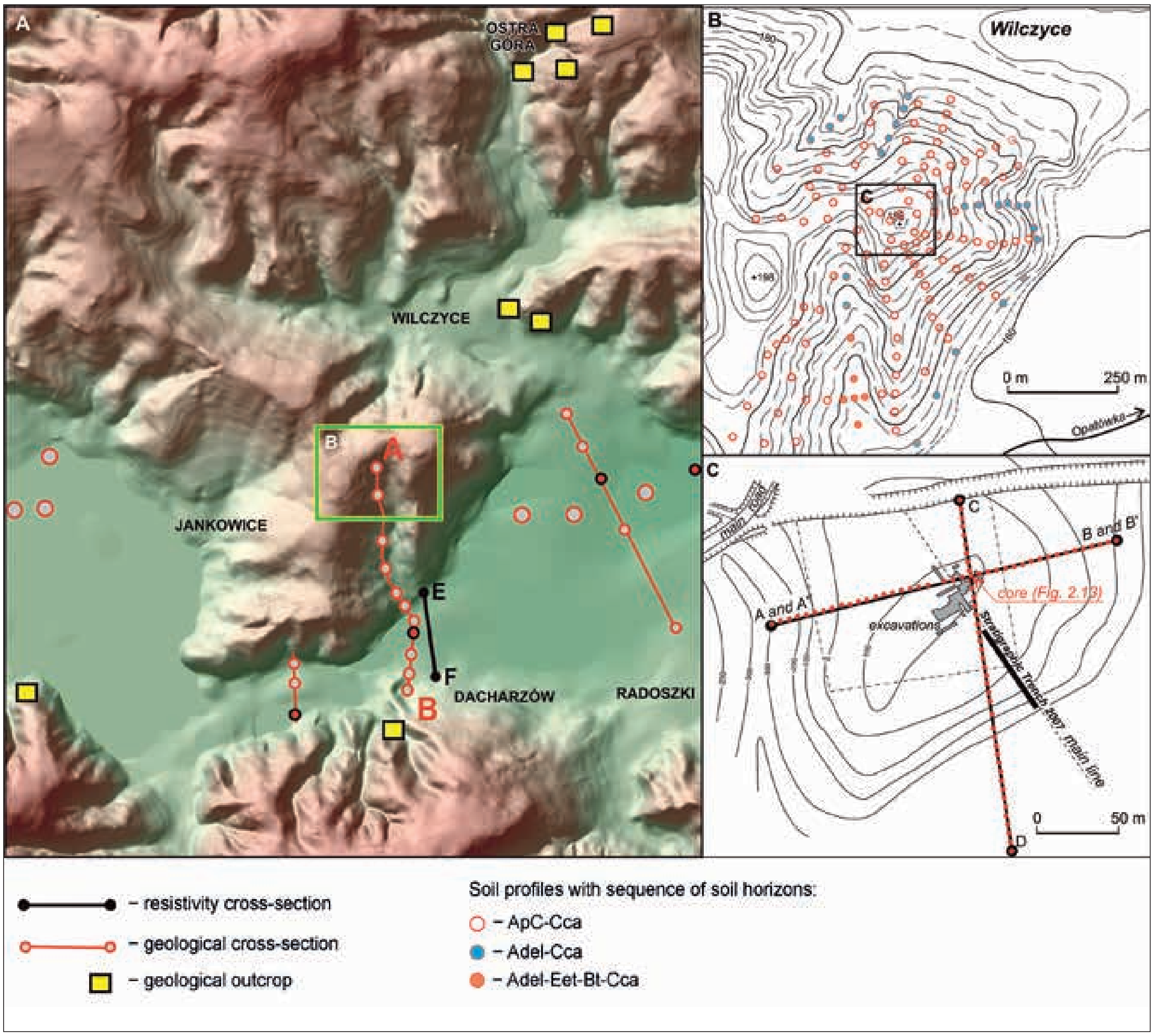


Figure 2.11. Location of main research points and cross-sections in the area of study and the landform model of the Opatówka Valley (A); contour map of Wilczyce Hill (B) and a map of Site 10 (C).

Local climate diversity is due to the variegated relief and the considerable terrain denivelations of the area. One of the most important and characteristic phenomena is thermal inversion, occurring especially during spells of clear skies and no wind. Temperatures in the narrow Opatówka Valley differ from those on the plateau by 0.5 to 4.6°C, and higher relative air humidity is recorded on the bottom of depressions, often producing radiation fog. Another feature of the local climate are the differences (albeit small) in temperature and humidity on the slopes, depending on the direction the various valley sides are facing. Higher temperatures are recorded, in general, on the plateau, near the slope edges and on the south-exposed slopes (Czarnecki, 1996).

HYDROGRAPHY

Wilczyce lies in the central part of the Opatówka basin. The Opatówka River, classified as a second-order water-course, issues into the Vistula downstream from Dwikozy, to the east of Słupcza. The basin fragment of interest to us here, extending from Tułkowice through Wilczyce to Wysiadłów (6 km; ~161–156 m a.s.l.) is of an upland character, differing from the mountain environment in its upper course (the Jeleniów Mountain Range with the river source at 330 m a.s.l.) and the lowland environment in its lower course (the Sandomierz Basin with the river mouth at 138 m a.s.l.).

The hydrographic network in the Wilczyce Area is distinctly diversified. We have here a single

Figure 2.12. Wilczyce Hill. Electroresistivity survey, looking north. Photograph by M. Łanczont.

Figure 2.13. Geological coring in the vicinity of Site 10. For the location of core compare Fig. 2.11.C.
Photograph by M. Łanczont.

Figure 2.14. Site Wilczyce 10, Stratigraphic Trench/2007, looking northwest (center) and southeast (left and right).
Photograph by M. Łanczont.

regulated river bed in the narrows of the Opatówka Valley (Fig. 2.7.) while in the cauldron-shaped widenings the entire natural waterlogged valley floor was dissected with systems of artificial drainage ditches. Today, the Opatówka River bed is a straight-line, artificial channel fitted with a system of weirs, with incision in excess of 2 meters. Nevertheless, the older, natural channel of the Opatówka is still discernible, meandering along the valley floor, currently cut off from the river and partly filled with alluvial sediments.

The land was also drained on the floors of the larger valleys formed by erosion and denudation (the Wilczyce Valley) and at the mouths of the gully systems (the Dacharzów-Radoszki area).

No water springs were discovered in the studied area, and there is just one subterranean water reservoir in the lithologically differentiated rocks. Shallow water horizons were documented in Quaternary deposits beneath the valley floors, hydraulically related to their water source (precipitation → river water). The groundwater reservoirs go down deeper further away from the Opatówka River channel and the type of the main aquiferous horizon changes. Crevice water is encountered in Neogene limestones and marls, and a few horizons of water may occur in sands. The greatest depths at which these waters are found (as much as 20 m in places) are in the watershed zones. In places these are accompanied by perched waters blocked by impermeable shields. The principal percolation barriers include Pleistocene glacial tills and fluvioglacial sediments (Bielecka, 1968b).

Soil cover

The soil cover in the Wilczyce Area comprises several types and kinds of soils, the present form of which is due in the main part to soil erosion processes (*Zmiana studium*, 2006; Rybicki, 2010).

The valley floor is covered by alluvial soil (Fluvisols) but elsewhere we have developed in the loess, typical Luvisols and various types of other eroded Luvisols, with infrequent enclaves of degraded chernozems (Czarnecki, 1996).

The primary soils of the loess culmination containing Site 10 and the slopes of this hill were transformed by prolonged land tillage to such an extent that today we have there nothing but heavily altered, eroded soils. The present-day tilled horizon usually coincides with its illuvial horizon (ApBt). Denudation is so severe in places, that the calcareous loess bedrock (ApCca) is now exposed on the surface. The primary soils are likewise poorly preserved in concave middle sized elements of the relief (gullies and slope depressions) where they are buried beneath a bed of agriculture triggered colluvium comprised of soil horizons redeposited from higher sections of slopes. Similar series of brown colluvial soils are observed at the foot of the hillslopes (Fig. 2.10.).

The soil cover of the valley floor is also anthropogenic, consisting of bio-mineral hydrogenic soils developed in biogenic sediments (peat and organic rich fluvial silts) and in loess colluvium. Much of the surface of the primary valley floor is covered with a layer of mineral sediments, dumped there in the course of digging — and later deepening — the drainage ditches system.

Methods

A variety of research methods were required to reconstruct the paleogeographic conditions prevailing at and around the Magdalenian site, including field and laboratory studies and the processing of the obtained results.

Field studies

Field studies were confined to the immediate vicinity of the Magdalenian campsite and the adjacent section of the Opatówka Valley, and included the following.

Detailed geomorphologial mapping serving to identify the various relief elements and compare them with the situation as depicted in the available geomorphological maps drawn to various scales. This work made it possible to single out areas and points requiring further detailed studies.

Geophysical surveying, carried out on the summit of the loess remnant hill in Wilczyce and on the floor of the Opatówka River valley. The inverted resistivity imaging method (Loke, 1999; Marcak *et al.*, 2011) was used and the measurement results were processed using the Res2D software (*Instrukcja obsługi Res2Dinv*, 2001). Measurements were made along two 200 m long traverses (A–B and C–D) staked out at right angles to each other, with electrodes spaced

Figure 2.15. Coring in the floor of the Opatówka Valley (A) and core samples obtained in 2007. Photograph by M. Łanczont.

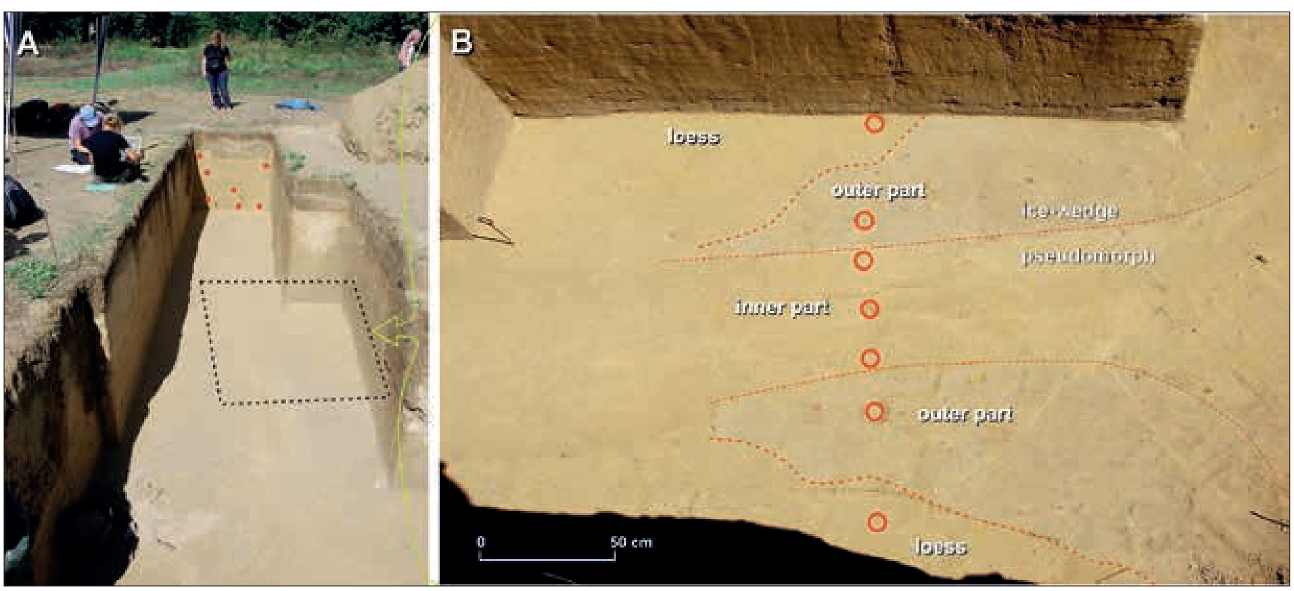


Figure 2.16. Location of samples in archaeological cutting (2010), compare Fig. 2.23. Photograph by M. Łanczont.

2.5 m apart (Fig. 2.11., 2.12.). The depth of imaging reached ca. 20 m. The measurements were repeated alongside traverse A–B (traverse A'–B'), this time with the electrodes spaced 5.0 m apart, which made it possible to achieve a depth of imaging of around 40 m. The traverses intersected at a point where a 9-m borehole was drilled to explore the geological structure. A third traverse (E–F), 400 m in length, was staked out on the Opatówka Valley bottom, in the Wilczyce–Dacharzów Area, at right angles to the valley axis. In this case the measurements were carried out with electrodes spaced 5.0 m apart, with the depth of imaging reaching ca. 40 m.

Lithologic and pedologic recording. The lithological makeup of sediments and soil horizons was determined by sounding with an Eikelkamp chamber probe (30 mm in diameter). Cores with undisturbed structure reaching down to the parent rock (calcareous loess, horizon C) were taken from the Wilczyce hill to establish the extent of denudation and reduction of the Holocene soil profile and thus get a picture of transformations of the original topographic surface. In 2011 a hole was sunk to a depth of 9 m on the archeological site[1], using an Eikelkamp percussion coring tube, to determine the thickness and stratigraphy of the loesses forming the hill and provide a geological basis for geoelectric studies (Fig. 2.13.).

In 2007 a long stratigraphic trench, measuring 50 × 3 × 2.5 m, was dug along the edge of the site using a backhoe with the view to producing a detailed characteristic of the periglacial structures Fig. 2.14.)).

Also in 2007 coring was performed in the Opatówka Valley, with the holes going down to a depth of around 6 m before hitting the impermeable waterlogged sand horizon (2.15.). Cores were taken in three representative points in the valley using a 60-mm chamber probe to explore the sediments filling the valley bottom, the assumption being that there could be sediment horizons coeval with the Magdalenian campsite. The determination of the age of these sediments could also be useful in establishing their relationship, if any, with the sediments redeposited from the slopes.

Collection of samples for laboratory analyses. Samples for laboratory assays and dating were collected from four sources: the drill core taken from the archaeological site (Fig. 2.13.)), the site cut (Cut 1D) excavated in 2010 (cf. Figs 2.16. and 2.23.), a representative profile in the eastern face of Stratigraphic Trench (Fig. 2.14.), and the Opatówka Valley — from complete cores (Figs 2.11. and 2.15.). Loess samples for micromorphological, geochemical and palynological studies were collected from the eastern face of Stratigraphic Trench.

LABORATORY STUDIES

1. The basic physico-chemical analyses were performed using standard pedologic methodologies (Oleksynowa *et al.*, 1993). The following determinations were made:
   a) particle size distribution was determined by areometer, with additional data for the 2.0–0.05 mm size class obtained by sieving (samples from the trench), and by laser diffraction (borehole samples) using a Mastersizer 2000HydroG analyzer[2]. This data was then used to calculate granulometric indices according to Folk and Ward (1957, quoted by Racinowski *et al.*, 2001); the grain size terminology adopted is consistent with the Polish Norm PN-R-04033:1998;
   b) soil color of wet samples was determined in the laboratory according to Munsell's color scale (*Revised Standard Soil Color Charts*, 1999);
   c) organic carbon content was analyzed by Tiurin's method, carbonates content by Scheibler's method, and Fe_2O_3 by the colorimetric method with ammonium rhodanate;
2. Soil micromorphology was determined by analyzing thin sections of intact loess samples using the methodology proposed by Mroczek (2008).
3. Pollen analyses were twofold in nature: the material recovered from mineral (loess) sediments were analyzed using the laboratory method described by Komar (2002) while that originating from organogenic (biogenic) sediments was studied with the standard methodology applicable to this type of sediments (Wasylikowa, 1973).

[1] Our heartfelt thanks to Professor Radosław Dobrowolski, Department of Geoecology and Palaeogeography, Maria Curie-Skłodowska University, for his assistance in this work.

[2] The particle size analyzer was purchased under the Operational Programme entitled „Development of Eastern Poland" for the period 2007–13. Priority Axis 1: Modern Economy. Measure I.3. Supporting Innovativeness. „Increasing the R&D Potential of the Departments of Chemistry, Biology and Earth Sciences of the Maria Curie-Składowska University in Lublin."

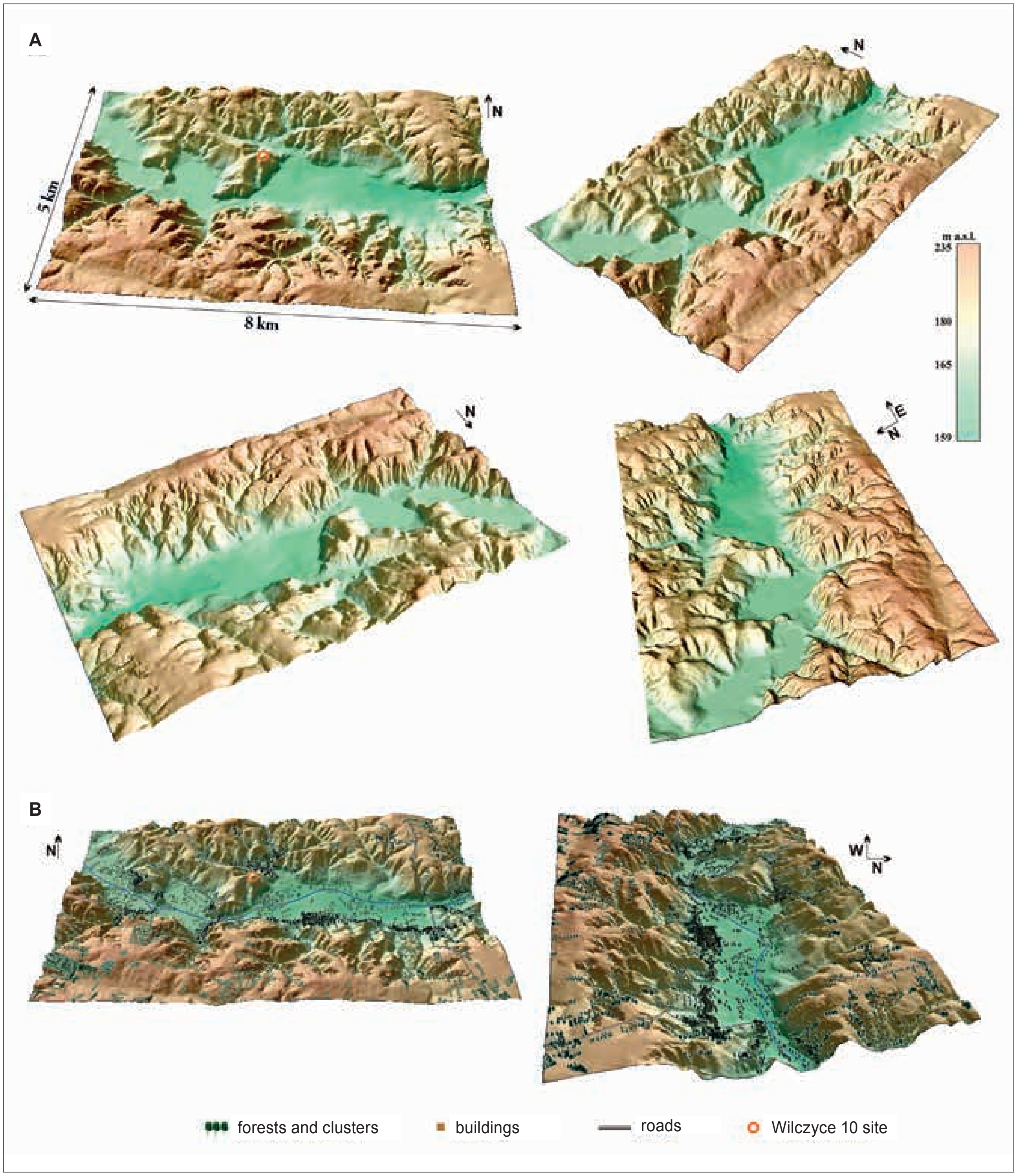


Figure 2.17. Landform models in the vicinity of Site 10 without (A) and with selected elements of geographic environments (B).

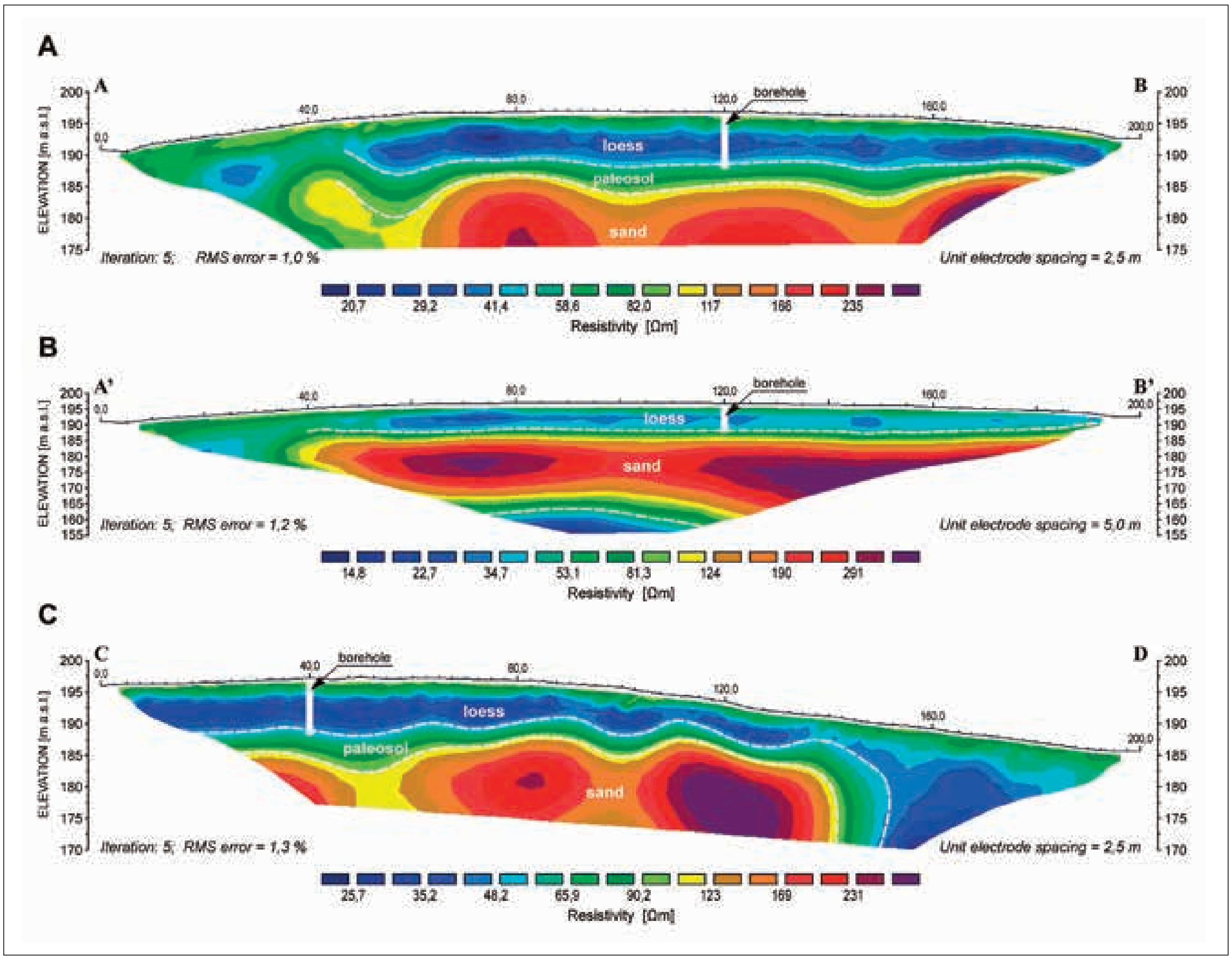


Figure 2.18. Electrical resistivity profiles (A, B and C) in the vicinity of Site 10. Location of profiles in Fig. 2.11.

4. Stable isotopes of carbon and oxygen were determined with the method described by Łącka *et al.* (2008). Paleotemperatures were estimated based on the oxygen isotope composition in calcite cement using the formula quoted by Dworkin *et al.* (2005).
5. Geochronology was determined by dating sediments with the thermoluminescence method used by Kusiak (e.g., Kusiak *et al.*, 2007; Kusiak, 2008).
6. Radiocarbon (^{14}C) dating was performed by the Department of Radioisotopes, Institute of Physics, University of Technology, Gliwice, Poland and the Institute of Geological Sciences of the Ukrainian National Academy of Sciences in Kiev (Ukraine).

PROCESSING OF ELECTRORESISTIVITY AND CARTOMETRIC DATA

The next stage of studies involved statistical analyses of laboratory results and graphic presentation of field, laboratory and morphometric/statistical data.

The results of electroresistivity survey were interpreted by resistivity imaging software (Loke, 1999; Marcak *et al.*, 2011) using the Res2D inversion software (Res2Dinv software manual).

Cartometric work involved numeric modeling of terrain relief using on-screen digitization of hypsometric data (1:10,000-scale topographic maps plotted in 1965: Dwikozy, Radoszki, Wilczyce and Garbów sheets). The Digital Elevation Model (DEM) was the starting point for further topographic analyses, such as determinations of basic terrain features, i.e., slope and aspect (exposure to sunshine) and drawing long profiles of the area. This model was also used to analyze visibility *(Viewshade)*, calculated for the Wilczyce 10 site at 197.4 m above m.s.l. *(SPOT)* (OffsetA) within the full 360° range and maximum vertical angle of 180°. Relative elevations and mean slope angles were calculated with the Spline interpolation method.

Pollen analysis. All the prepared pollen material was used in microscopic analyses of the mineral samples (loess and sediments from the floor of the archaeological cuttings). The frequency of sporomorphs ranged from 112 to 217 pollen grains of trees, herbaceous plants and spores, and their state of preservation is fairly good. The percentage figures for the various taxa were calculated in relation to the basic pollen sum (AP + NAP + P), with tree and shrub pollen being included in the AP category, pollen of dwarf shrubs and terrestrial herbaceous plants in the NAP group, and spores designated with P. Pollen grains of aquatic plants, *varia* and redeposited pollen were left out of the basic sum, but the percentage figures for them were calculated in relation to it.

A reconstruction of the summer and winter paleotemperatures (MTC, MTW) was attempted based on the pollen spectrum in two selected samples, assuming that the temperature tolerance of the various plant species was the same in the Quaternary as it is today. All the identified taxa were plotted on a climatogram with its horizontal axis displaying the average temperature in the coldest month (January) and the vertical axis showing the average temperature in the warmest month (July). The climatogram shows the temperature range for the fossil plants whose present-day counterparts are well researched as to their precise thermal requirements (Grichuk, 1969, 1985).

The pollen and spores in organogenic samples were counted in the entire surface of the slide, at 400× magnification. Pollen frequency in the samples was relatively low, with anywhere between 400 to 600 AP + NAP grains being observed. Statistical calculations were carried out based on the sum of AP and NAP, leaving out the pollen of marsh-dwelling plants and spores. Histograms of the obtained results were generated using POLPAL software (Walanus, Nalepka, 2003).

RESULS OF STUDIES IN THE WILCZYCE HILL AREA

MORPHOMETRY

Site 10 in Wilczyce is located at 50°44'32.53 N, 21°39'20.04 E, on the culmination of a truncated pyramid-shaped remnant loess hill. The site lies at an altitude of 195–197.4 m a.s.l., rising 37.4 m above the valley floor (Fig. 2.17.). The hill comprises the eastern part of a loess hump featuring finger-like arranged protrusions and separating two basin-shaped widenings of the Opatówka Valley near Wilczyce. The loess hump is inverse L-shaped, with its longer axis (2.4 km) running NW-SE, rising to the culmination at the axes junction. The shorter (1.9 km) axis runs SW-NE and cuts across the site at the 1.4 km point. The hump crest forms the water divide between the Opatówka Valley and the river valley of its left-bank tributary where the village of Wilczyce is situated, known as the Wilczyce Valley.

The 195 m a.s.l. isohypse bounds almost the entire flat hill culmination, with surface declines not exceeding 3° — an area of 1.14 ha containing the site. The decline angles become much more pronounced at the transition between the flat hill culmination and the hillslope, below which the downgrades are fairly steep and diversified, especially on the W-, NW- and NE-facing slopes. In this area the system of slopes is cut by a series of minor depressions and small gulleys, the largest of which — at the western edge of the culmination and at right angles to the Opatówka Valley — is 600 m long (Fig. 2.17.).

The Wilczyce Hill is exposed, in the main, in three directions: north (facing Wilczyce), east and west — with some NW and NE exposures as well. The average surface declines in the N, E and W slopes are under 12°, and relative heights do not exceed 15 m, except where the arroyo system cuts into the terrain. The 600-m eastern hill slope extends down to the Opatówka Valley floor, with considerable average declines (up to as much as 15°) and relative heights (in excess of 20 m) observed in its lower reaches. Only small fragments of the hillslopes face south, and this is where the steepest declines are observed (>20°), with relative heights attaining 40 m. This part of the slope forms the northern element of the Jankowice–Dacharzów narrowing (gorge) dividing the Opatówka Valley into the western and eastern basins. This gorge is ca. 1.5 km long and 120–230 m wide, and the hill containing our site overlooks the eastern basin (Fig. 2.17).

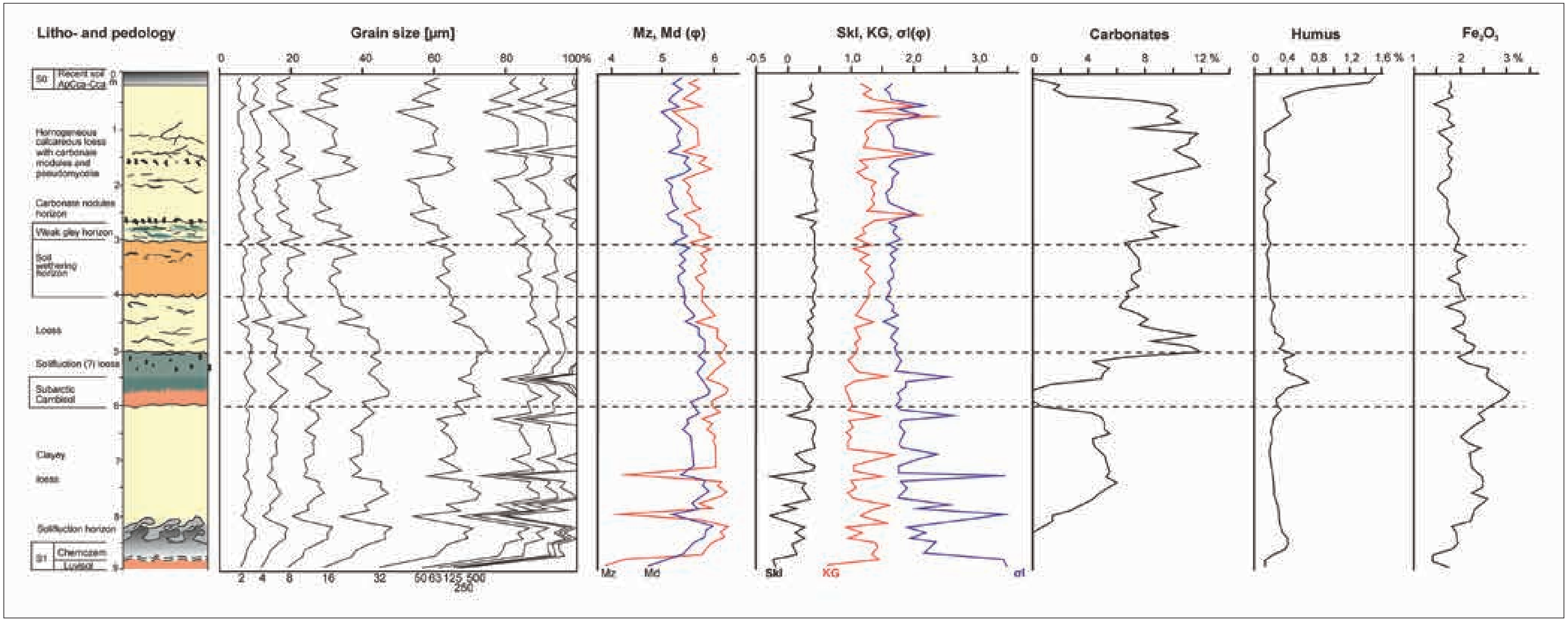


Figure 2.19. Loess cross-section and results of basic analyses of the core recorded in Site Wilczyce 10.

Results of the electrical resistivity survey on the hill

The geoelectrical traverses A–B and A'–B' (Fig. 2.18.A, B), both representing the same measurements, and the C–D traverse (Fig. 2.18.C), reveal a visibly layered structure with relatively low resistances. The topmost layer, with resistances ranging from 20 to 50 Ωm, is ca. 10 m thick at the intersection of the two traverses, which is in agreement with the findings from geological coring (Fig. 2.19.). The depth of the loess mantle is uniform over most of the studied area — up to 10 m — with a pronounced increase to 20 m in the northern extremity of the C–D traverse on the westernmost ends of traverses A–B and A'–B'. The slightly higher resistivity recorded in the near-surface layers (~90 Ωm) may be attributed to the gradually decreasing humidity of the sediments.

Beneath the loess mantle, visible as a uniforms feature in the geophysical image, is a ca. 2.5 m thick bed with higher resistivity (in the 50–110 Ωm range) which may be a fossil soil horizon. Soil horizons do not conduct electricity as well as loess sediments do because of their different texture and mineral composition. Mixtures of loess and soil as well as thin laminae of loess in the soil horizons are not discernible in electrical resistivity surveys but may increase the resistivity of the given suite of deposits as a whole. The soil horizon referred to here steeply dips towards the end of the C–D traverse (at ca. 152 m) and near the beginning of the A–B traverse (at ca. 40 m).

Underneath the fossil soil horizon is a suite of sediments with resistivity ranging from ca. 120 Ωm to over 300 Ωm. Figures of this magnitude are characteristic for waterlogged sand and gravelly sand forms. This suite dips steeply starting from ca. 142 m of the C–D traverse while in the deep A'–B' traverse it is discernible, starting from ca. 35 m, as a horizontal layer, ca. 20 m thick. Another anomaly with low resistivity figures characteristic for loess deposits, visible at a depth of ca. 35 m, may represent the next — older — horizon.

The above interpretation of the sequence of beds forming the hill contributes to our understanding of the topography of the paleosurface subjacent to the loess and of the geology of the Quaternary deposits of the area. The relief of the older bedrock on the lower hillslopes is diversified, with a distinct bench, more than 15 m high, running parallel to the valley axis. The origin of this bench is unclear, and it may be an erosion feature. The loess cover in the area of this bench is thicker (>20 m) than in the summit area, completely obliterating the differences in the bedrock relief beneath it. The bedrock in the area explored with geophysical methods is composed of a glaciofluvial series (?) underlain by the so-called sub-morainic loess (Odra Glaciation?).

Litho- and pedostratigraphy, the age of loess soils and periglacial structures

The field and laboratory studies show the loess soils in the area around the site to differ in terms of lithology, structure, physico-chemical properties and age. The boundary planes separating the particular beds unequivocally set apart fossil soils of varying stratigraphic significance as well as surfaces of unconformity.

Coring in 2011

The 8.9 m long core disclosed several loess layers interbedded with fossil soils which may be seen as coinciding with the oxygen isotope stages (MIS) 2–6 of deep ocean cores oxygen record (Figs 11, 12). The bulk of the profile (8.6 m) is taken up by a sequence of L1 loesses (Vistulian Glaciation) followed by just the topmost part of the S1 pedocomplex from the Last Interglacial (Eemian) and the Early Glacial. An old loess pit in Wilczyce and a handful of natural exposures in the area (including the one in Ostra Góra, for example) reveal the same kind of soil evolved on L2 loesses (MIS 6). In these exposures the paleosol was in most cases dislocated by periglacial processes and truncated, or considerably denudated, after its formation. Its thickness usually exceeds 1.5 m, and the surviving illuvial endopedon (Bt-argillic) serves as the diagnostic level.

The youngest lithostratigraphic unit in the profile is a loess bed 5.55 m thick, this being 1.5 to 2 m less than its original thickness, as indicated by primary calcareous loess just beneath the ground surface and the initial character of the recent soil (ApCca soil horizon). The particle (grain) structure of the loess shows small differentiation, with a heavy presence (>40%) of grains 16–52 μm in diameter in all the analyzed samples; mean grain size (Mz) decreases slightly with the increase of depth — by anywhere between

Table 1. Thermoluminiscence ages of loess samples from the core sunk in 2011 at Site Wilczyce 10 (compare Fig. 2.19). Dates by J. Kusiak.

Depth	Laboratory No. Lu-	Sample No.	Annual Dose DR (Gy)	Equivalent Dose ED (Gy)	TL Age (ka)
0,4–0,5	5364	TL 1	3,19 ± 0,10	60,0 ± 4,2	18,6 ± 1,3
0,6–0,7	5365	TL 2	3,18 ± 0,10	59,8 ± 4,1	18,8 ± 1,5
1,3–1,4	5366	TL 3	3,22 ± 0,10	66,0 ± 4,6	20,5 ± 1,8
1,7–1,8	5367	TL 4	3,20 ± 0,10	65,0 ± 3,9	20,3 ± 1,7
2,3–2,4	5368	TL 4A	3,17 ± 0,10	66,9 ± 4,0	21,2 ± 1,9
2,8–2,9	5369	TL 4B	3,17 ± 0,10	72,9 ± 4,4	23,0 ± 1,8
3,2–3,3	5370	TL 5	3,21 ± 0,10	72,2 ± 4,3	22,5 ± 2,0
3,8–3,9	5371	TL 6	3,11 ± 0,09	70,6 ± 4,2	22,7 ± 1,8
4,3–4,4	5272	TL 7	3,14 ± 0,09	76,6 ± 4,6	24,1 ± 1,4
5,2–5,3	5373	TL 8	3,19 ± 0,10	80,4 ± 4,8	25,2 ± 2,0
5,6–5,7	5374	TL 9	3,00 ± 0,09	90,9 ± 5,5	30,3 ± 2,4
5,8–5,9	5375	TL 10	2,90 ± 0,09	162 ± 11	55,9 ± 4,4
6,2–6,3	5376	TL 11	3,12 ± 0,09	185 ± 14	59,2 ± 5,3
6,6–6,7	5377	TL 12	3,12 ± 0,09	181 ± 13	58,1 ± 5,2
7,2–7,3	5378	TL 13	3,12 ± 0,09	187 ± 13	60,0 ± 5,7
7,7–7,8	5379	TL 14	3,16 ± 0,10	197 ± 13	62,3 ± 6,2
8,6–8,7	5380	TL 15	2,89 ± 0,09	278 ± 35	96 ± 12
8,7–8,8	5381	TL 16	2,89 ± 0,09	294 ± 31	102 ± 11
8,8–8,9	5382	TL 17	2,98 ± 0,09	395 ± 44	132 ± 15
8,9–9,0	5383	TL 18	3,05 ± 0,09	466 ± 62	153 ± 22

Table 2. Thermoluminiscence ages of loess samples from Section B of Stratigraphic Trench 2007 (compare Fig. 2.21.). Dates by J. Kusiak.

Depth	Laboratory No. Lub-	Sample No.	Annual Dose DR (Gy)	Equivalent Dose ED (Gy)	TL Age (ka)
0,65 m	4486	8	3,11 ± 0,10	57,2 ± 4,0	18,4 ± 1,7
0,85 m	4485	7	3,08 ± 0,09	60,4 ± 3,3	19,6 ± 1,9
2,00 m	4481	3	3,14 ± 0,09	68,1 ± 4,8	21,7 ± 2,0
2,25 m	4480	2	3,14 ± 0,09	69,1 ± 4,8	22,0 ± 2,1

ca. 5 to 5.3 φ — which is typical for this particular unit of loesses in the Sandomierz region (e.g., Jary, 2007). Carbonates occur in both their primary and secondary forms (depositions on fissure walls, carbonate veins of the pseudomycelium type, loess concretions and their vertical distribution changes with depth. Two horizons of enrichment (of up to 12%) are observed at depths of 0.5–1.5 m and 4.5–5 m. The base of this loess coincides with the decalcification limit.

A horizon with signs of weathering transformations is apparent at a depth of 2.7–3 m (Fig. 2.19.). These features include weak gleying of sediment, the presence of fine biogenic channels made more prominent by depositions of delicate ferricrusts, and visible dissolution of the carbonate component. One to three such gley horizons or pedogenic formations are to be found in Upper Pleniglacial loesses (Maruszczak, 1991, 2001) and are interpreted as inter-stage phases of increased pedogenesis (soil formation) intensity.

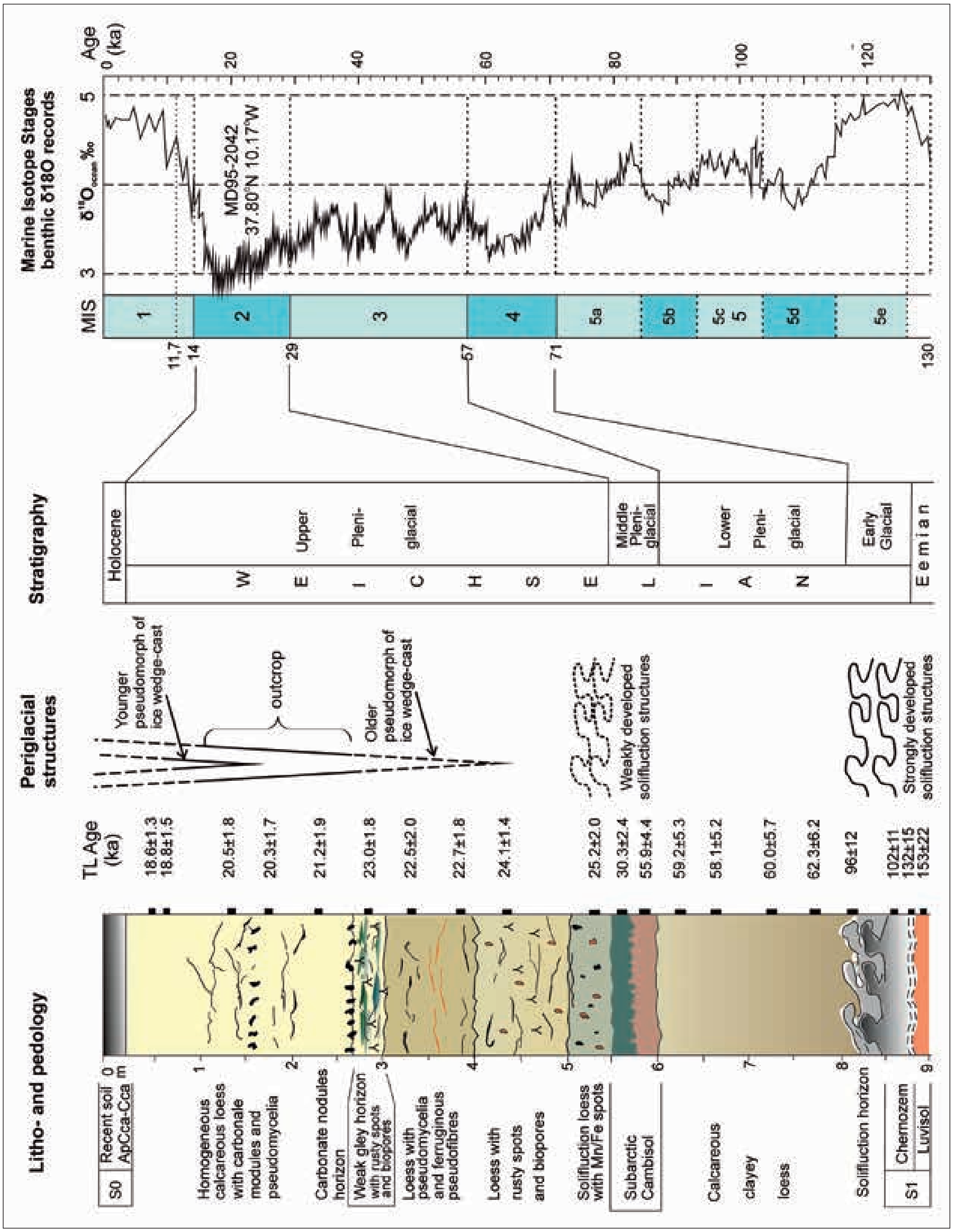


Figure 2.20. Lithologic and pedologic variability, periglacial structures and TL ages of the Wilczyce Site 10 core in relation to the chronostratigraphic sequence of the last glaciation and Marine Isotope Stages 5e-1. The bracket in the periglacial section of the diagram indicates fragments of ice wedges observed in Stratigraphic Trench 2007 (Fig. 1.13:SXIII).

The age of the loess described here, determined based on the TL-dating of samples 1–8 (Table 1), is in the 18.6–25.2 ka range (Fig. 2.10.), which places it in the MIS 2.

Worth noting in this context is that two loess horizons were distinguished in the similarly aged Volhynian and Podolian loesses, representing the same province the Sandomierz loesses are included in, deposited in a stratigraphic position similar to that of the distinguished weathering horizon (at depths of 2.7–3 m), namely the (younger) Krasyliv and (older) Rivne horizons (Bogucki, 1987).

The next lithostratigrahic unit distinguished in the Wilczyce profile — at 5.55–6.0 m — is subarctic fossil soil comprised of a bed of pseudogley soil with up to 0.8% of humus overlying a browning horizon of a subarctic soil containing up to 3% of ferric oxides — the highest figure for this compound in the entire studied profile. The twofold nature of this unit is clearly reflected in the TL dates (Table 1): the upper part of the soil profile is much younger, at 30.3 ka (Sample 9), compared to the lower part dated to 55.9 ka (Sample 10). This soil unit probably corresponds to Jersak's Komorniki soil unit (Jersak *et al.*, 1992). Relying on the most recent chronostratigraphical correlation table for the last glaciation in Europe (the Vistulian or Weichselian), it would appear that two warmings of the Middle Pleniglacial (MIS 3) are represented in the Wilczyce coring profile. According to the *Regional Chronostratigraphical Correlation Table*... (2011), MIS 3 lasted from 29 to 57 ka, with Mojski (1999) preferring the 25–58 ka range.

The loess underlying the Komorniki soil is quite thick (>2 m) and although it appears to be quite homogeneous, it in facts divides into two subunits differing as to grain size distribution. The boundary between the subunits is at 7.25 m, from which point coarser-grain loess becomes significantly more apparent. Four TL dates are available for this loess (Samples 11–14), ranging from 58.1 to 62.3 ka (Table 1). This loess represents the Lower Pleniglacial (MIS 4) which in Poland is dated to 58–75 ka (Mojski, 1999) and in Europe to 57–71 ka (*Regional Chronostratigraphical Correlation Table*... 2011).

Only fragments of the S1 pedocomplex, generally corresponding to the MIS 5 stage, are represented in the profile, but the beds that were distinguished are diagnostic for the key phases of its formation. The topmost layer (0.55 cm) is comprised of loess disturbed by solifluction phenomena and mixed with humus (Sample 15), dated to 96 ka, and a chernozem type soil (0.2 m) dated to 102 ka (Sample 16; cf. Table 1). One cannot rule out that these are remnants of Brørup Interstadial soil overlain by a solifluction horizon formed for the most part by redeposited sediments. Deeper down we have a thin Eet horizon (0.1 m) and we can also discern the topmost part of the Bt horizon of the interglacial (Eemian, sensu stricto) Luvisol SS1. This soil is developed on a sandy loess (Samples 17 and 18) of the penultimate glacial dated to 132 and 153 ka (Table 1), and — as already mentioned — its topmost part is also discernible at various depths in the geophysical sections, which means that the paleosurface of the terrain in the late Eemian Interglacial was variable and that the older loess beds were relatively thin.

The Stratigraphic Trench studied in 2007

While the stratigraphic differentiation of the L1 loesses was well discernible in the core profile, the loess forms and the nature of the periglacial structures deforming the soil in the youngest horizons — all of which are of crucial importance in the context of the location of Site 10 — could be examined along a 50-m stretch of the walls of the N–S Stratigraphic Trench sunk to the south of the site, at the junction between the nearly flat hilltop and the slanting hillslope. The difference in elevation between the two ends of the trench was about 3 m.

Lithology and TL age. The geological studies were restricted to two fragments of the trench walls: Section A selected because of its close proximity to non-continuous periglacial structures (in the top part of the trench, closer to the site), and Section B (chosen in order to explore loess undisturbed by periglacial processes).

Section A revealed that the properties (grain size and geochemical parameters) of the loess filling the ice-wedge pseudomorph (Samples B8–B13 collected in the horizontal plane, across the infill) and of the soil in the vicinity of this feature (Samples B1–B7 collected in the vertical plane) are very similar in every respect save for a negligibly smaller (by ca. 2–3%) presence of calcium carbonate in the structure infill (Fig. 2.21.).

Section B was studied to determine sediment texture, the basic chemical features and stable isotopes

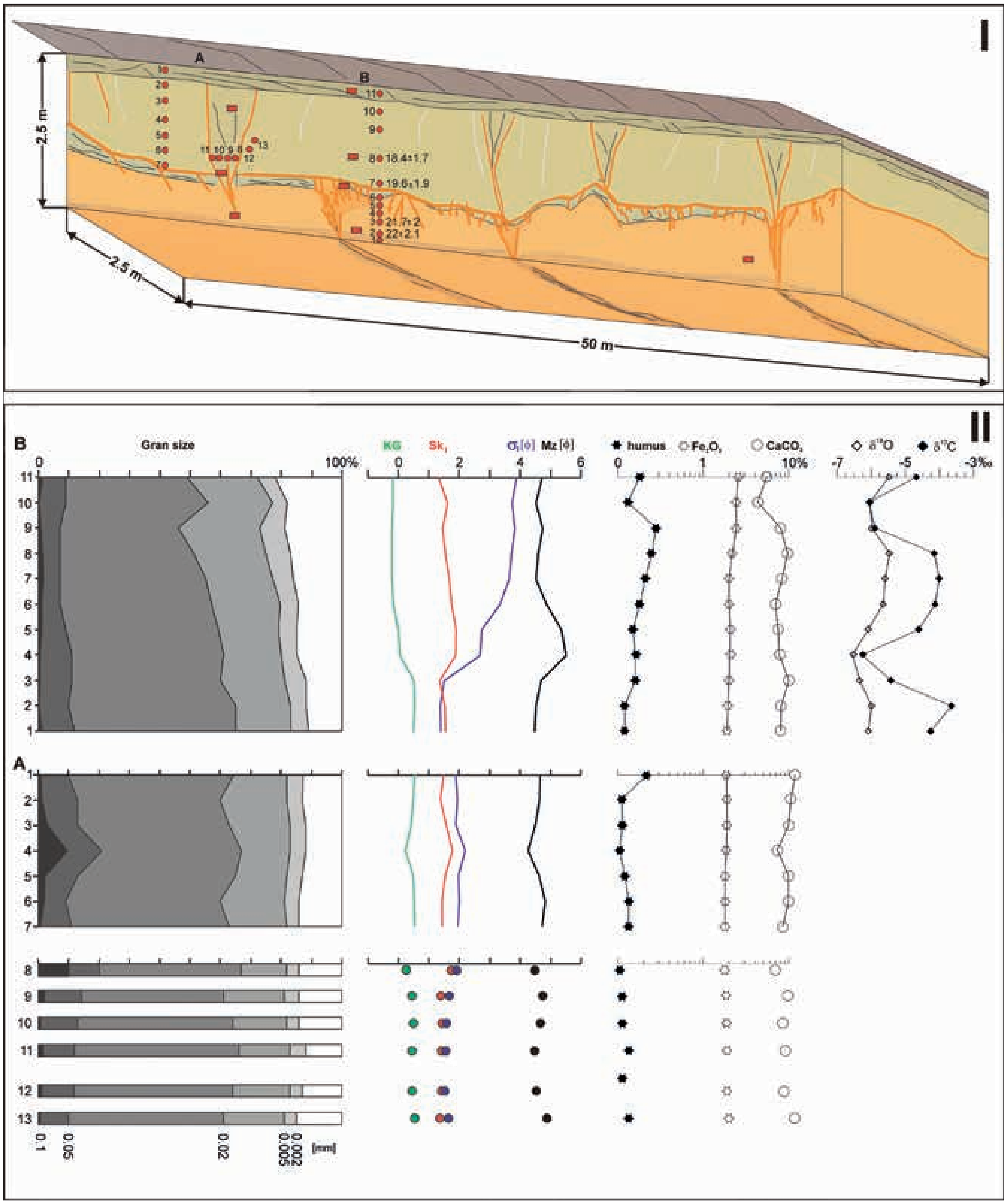


Figure 2.21. Loess characteristics in Stratigraphic Trench 2007. Key: I. Structural features of loess cover and placement of samples (lithology and TL samples — red circle, micromorphology — red rectangle, palynology — red triangle); II. Results of physicochemical, isotopic and micromorphological analyses in Sections A and B. Location of the trench indicated in Fig. 2.11.

content in the soil (Samples D11–D1). The TL age was determined for four samples (2, 3, 7, 8; cf., Table 2). Another nine samples for micromorphological analyses were collected in close proximity to this profile (Table 3).

Three lithostratigraphic units were distinguished in the profile. Starting from the top, down to a depth of 1.0 m (Samples D11–D7), we have gray-brown loess, with mean grain size Mz = 4.9 φ, poorly sorted (δ_{1} = 1.9 φ), with a positively skewed grain size distribution (Sk_{1} = 0.2). A characteristic feature of this loess is the high content of secondary infiltration of calcium carbonate in the form of fissure infills and concretions up to 7 cm in diameter. Its carbonate saturation increases with depth, from ca. 4% to almost 10%, while humic elements are present throughout the profile in trace proportions only (0.12–0.16%). Iron compounds are not plentiful (ca. 2%). There are two dates available for this loess: 18.4 ± 1.7 ka (Sample 8) and 19.6 ± 1.9 ka (Sample 7) (Table 2).

A distinct unconformity separates this loess from the middle unit, developed in the topmost part of the gray glaying horizon (sample D6), 0.25 m thick, with calcium carbonate content down to 7% and with manganese spots, 1–2 mm in diameter, forming concentrations and numerous ferruginous bands, conformable to the plane of unconformity of the topographic surface, and also subvertical or vertical. The lower unit (Samples D5–D1) is comprised of dark gray-brown loess, with carbonate saturation of up to 10% and carbonate concretions up to 5 cm in diameter. Closer to the base it becomes a layered, mottled loess, slightly less carbonates-rich (ca. 8%). This loess contains slightly higher concentrations of humic compounds, especially in places where gleying was more intense and in layered lithofacies (0.13–0.28). It also contains slightly more iron compounds (up to 2.6%). The grain size parameters (Mz = 4.6 φ, δ_{1} = 3 φ, Sk_{1} = –0.2) are evidence that this soil was deposited in conditions different from those affecting the topmost loess layer, with slope process also contributing to its formation (Racinowski *et al*.,. 2001). The age of the lower unit loess is indicated by two TL dates: 21.7 ± 2.0 ka (Sample 3) and 22.0 ± 2.1 ka (Sample 2) (Table 2).

Micromorphology. Samples for studies were collected in Section B from the top, middle and bottom units (4, 2 and 3 samples, respectively; Table 3). The loess in all these samples displays microfeatures typical for primary loesses *sensu* Mroczek (2008). For the main part, these sediments are indicative of synsedimentation processes in a periglacial environment, evidence of which are medium-grained silt carbonaceous deposits. The channel type of microstructure predominating in the thin sections is the result of biological activity of organisms and plants in the soil during soil accumulation. The biogenic voids are everywhere accompanied by calcitic coatings and infillings — results of leaching of carbonates during synsedimentation and their percolation in soil solutions. Another type of carbonates forming in voids there are the so-called root pseudomorphs left by buried roots which underwent mineralization. The period when the roots were mineralized must be seen as coinciding with the relatively rapid deposition of new loess layers which caused the roots to be buried and, consequently, led to their wilting. The diffused-boundary Fe and Mn-Fe microfeatures are evidence of the reduction and migration of Fe and Mn-Fe compounds in solutions and their subsequent precipitation in an oxidizing environment. These processes must have taken place mostly in the periglacial environment when the loesses were being deposited. The sharp-edged forms encountered in the tilled horizon Ap (w4) were redeposited.

Isotopic composition of carbon and oxygen in calcite. In all the 11 samples collected from Section B in the trench, calcite occurs almost exclusively as cement in rhizoliths (rhizoconcretions). Rhizoliths are formed when carbonates precipitate in root microecosystems in conditions of equilibrium with soil CO_2. Soil CO_2 is a mixture of carbon dioxide produced during mineralization of organic substances in the soil, by roots, and of CO_2 diffused from the atmosphere and from deeper soil strata (Nordt *et al*., 1996). When the proportions of the various kinds of carbon dioxide change, as when more atmospheric CO_2 or $CO_{2\text{ from}}$ decomposition of plants of the C-4 variety appears, the calcite precipitating in the soil becomes richer in the heavier carbon isotope. The ^{13}C enrichment of the analyzed carbonates may mean that there were more of the C-4-type plants in the ecosystem and/or be evidence of early calcium precipitation in the near-root soil zones close to where the loess was being deposited. Changes in $\delta^{18}O$ indices are directly conditional on the isotopic composition of meteoric water and on temperature. In the case of the rhizoconcretions, these changes may be an indirect indication of changes in above-ground

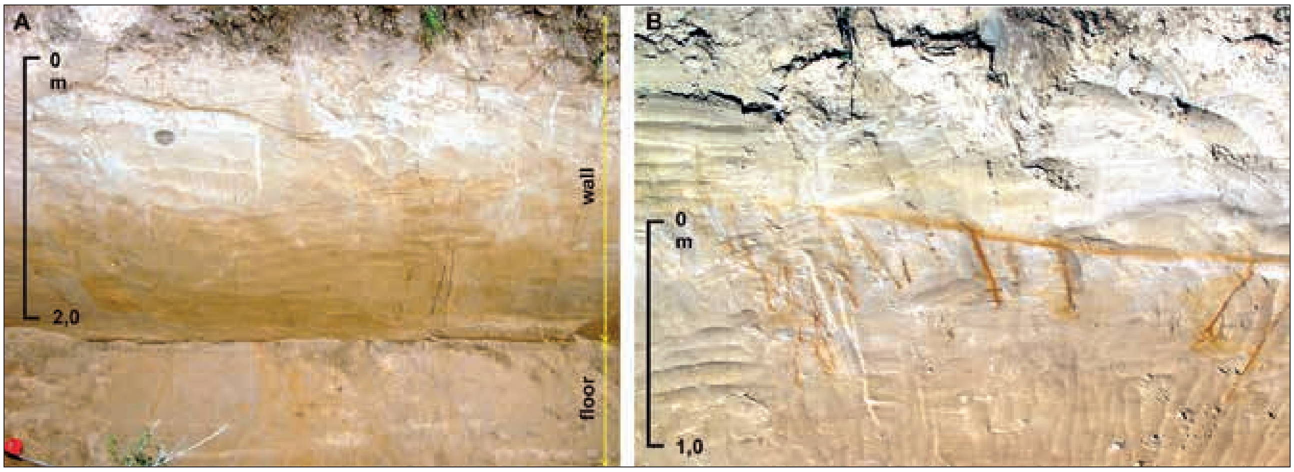


Figure 2.22. Frost fissures with gley and ferruginous precipitate seen on the floor of Stratigraphic Trench 2007 marking a paleotopographic surface separating two beds of loess (compare Fig. 2.21 and the description in the text). Photograph by M. Łanczont.

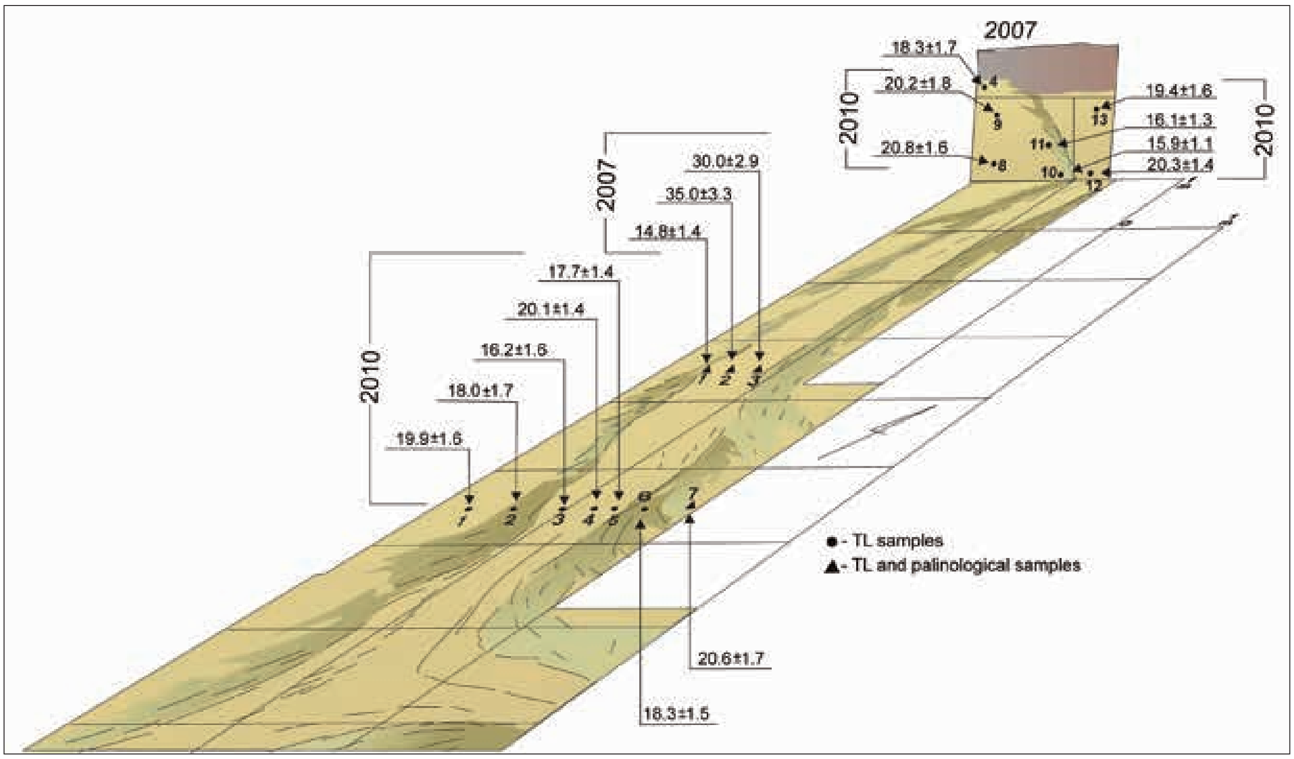


Figure 2.23. Wilczyce Site 10, Archaeological Cut, north-western section of the ice wedge cast. Location of TL assays measured in 2007 and 2010 (compare Tables 4 and 5). Placement of the Cut shown in Figs 2.11, 4.1–4.2 and 9.1.

temperatures during vegetation periods (Wang, Greenberg, 2007). Drops in the $\delta^{18}O$ indices — corresponding to increased contents of ^{16}O — are usually the result of periodic drops in temperature.

The variations in isotopic carbon composition in the studied profile are illustrated by changes in $\delta^{13}C$ indices (Fig. 2.21. IIB). The figures for this carbon range from −6.07 to −3.65‰ (mostly hovering around −4.2 ‰), with two distinct minima corresponding to Samples 4 and 9–10, due to higher contents of the lighter isotope ^{12}C in these samples (displaying $\delta^{13}C$ indices lower by about −2‰). Except for the topmost part of the studied profile (Sample 10), no clear correlation was found between the isotopic composition of the calcitic cement on the one hand and the respective contents of carbonates, humus and Fe_2O_3 or the particles structure in the loess on the other. The lower $\delta^{13}C$ and $\delta^{18}O$ indices in Sample 10

Table 3. Micromorphological record of loesses in the Stratigraphic Trench 2007.
The frequency of features is shown by the number of bold squares.

Key: 1. (■), single occurrence; 2. (■■■■), common occurrence; m, massive microstructures; f, fissures; ch, channel microstructures.

Sample no.	Litho- and podegenic characteristic	Microstructure	Carbonates					Fe microforms				Fe-Mn microforms		Organic matter			Loose faecal infillings
					coatings			nodules				nodules		plant tissue			
			micritic b-fabric	crystals	hypo-coatings	intra-channel	intra-channel infillings	with sharp boundries	diffuse	background	hypocoatings	with sharp boundries	diffuse	with internal structure	aporphic	aporphic charcoals	
W4	Ap soil horizon	ch-f	■■	■■■	■■	■■	■■■	■■		■■		■■		■■	■	■	■■
W9	Primary loess: lower-most part	ch-m	■■■■	■■	■■■	■■■	■■■		■■	■■■	■■■		■■				
W6	Primary loess: lower-most part	ch-m	■■■■	■	■■	■■■	■■■		■■	■■	■■■		■■				
W2	Primary loess	ch-m	■■■■	■■	■	■■■	■■■		■■	■■■	■■■		■■				
W8	Weathered horizon	ch-m	■■■■	■■	■■	■■■			■■	■■	■■		■■■				

Table 4. Thermoluminescence ages of loess samples from archaeological cuts excavated in 2007
(compare location of sample in Fig. 2.23.). Dates by J. Kusiak.

Provenance of Samples	Laboratory No. Lub-	Sample No.	Annual Dose DR (Gy)	Equivalent Dose ED (Gy)	TL Age (ka)
Layered loess, sterile, lateral part of wedge	4475	1	3, 15 ± 0,10	46,6 ± 3,3	14,8 ± 1,4
Loess, central part of wegde with artifacts	4476	2	3,06 ± 0,09	107,1 ± 7,8	35,0 ± 3,3
Loess, central part of wedge with artifacts	4477	3	3,08 ± 0,09	92,4 ± 6,3	30,0 ± 2,9
Undisturbed loess, outside the wedge	4478	4	3,21 ± 0,10	58,7 ± 4,1	18,3 ± 1,7

Provenance of Samples	Laboratory No. Lub-	Sample No.	Annual Dose DR (Gy)	Equivalent Dose ED (Gy)	TL Age (ka)
Layered loess, sterile, lateral part of wedge	4475	1	3, 15 ± 0,10	46,6 ± 3,3	14,8 ± 1,4
Loess, central part of wedge with artifacts	4476	2	3,06 ± 0,09	107,1 ± 7,8	35,0 ± 3,3
Loess, central part of wedge with artifacts	4477	3	3,08 ± 0,09	92,4 ± 6,3	30,0 ± 2,9
Undisturbed loess, outside the wedge	4478	4	3,21 ± 0,10	58,7 ± 4,1	18,3 ± 1,7

go together with less calcite and humus in the loess, which may be evidence of a temporary cooling of climate and a less abundant vegetation cover.

The distribution of $\delta^{18}O$ indices for calcitic cement is very similar to that of $\delta^{13}C$ indices, but with less pronounced minima (Fig. 2.21. IIB). The $\delta^{18}O$ indices are down by ca. −0.5‰. Throughout the profile, the $\delta^{18}O$ indices remain within the very narrow range from −6.55 to −5.46‰. The $\delta^{13}C$ and $\delta^{18}O$ distribution curves suggest that climatic conditions varied during loess sedimentation. The relatively lower negative values for $\delta^{13}C$ and $\delta^{18}O$ at depths of 0.25–0.45 m and 1.75–2.0 m, due to more advanced degradation of organic substances, may be indicative of a cooler and more humid climate, while the slightly higher content of the heavier isotopes of carbon and/or oxygen in the carbonates deposited at depths from 2 to 2.25 m signal brief and minor climatic changes involving e.g. less precipitation or more intense evaporation caused by higher temperatures, among other factors (cf. Łącka *et al.*, 2007).

Periglacial structures. The most prominent feature in the 2.5-m deep profile exposed on the eastern wall of the Stratigraphic Trench is a fossil surface, around 1 m below ground surface, in the form of an erosional, denuded surface altered by periglacial processes (Fig. 2.21.). This slightly inclined paleosurface stands out thanks to secondary accumulations of Fe compounds forming a horizon ca. 5 cm wide. The course of this horizon is uneven, suggestive of a dynamic microrelief of the fossil (primary) hillslope, consisting of several wide (5 to 7 m) basin-shaped depressions interspaced with narrower elements, either convex or flattish. This surface is accompanied by numerous cryogenic structures of various rank (Fig. 2.21.I). Two types of these structures were distinguished:

(1) Pseudomorphs of two generations of cryogenic polygonal wedge structures, superimposed one over the other, representing fissures with secondary infill (Jersak *et al.*, 1992). The identification of these structures is slightly hindered by the fact that the lithological features of the infill are similar to those of the sediment the infill is included in. Nevertheless, the outlines of these forms are legible thanks to accumulations of secondary Fe compounds or the gleying of their contours. The older-generation pseudomorphs did not survive intact, their topmost parts having been truncated by the erosional surface. Only the basal parts of the more recent pseudomorphs survive and these are the forms that gave rise to the discontinuous deformations separating these structures on the topographic paleosurface. Given that only fragments of these pseudomorphs can still be seen today, their height may only be roughly guessed to have been in the 3–3.5 m range.

(2) Small discontinuous deformations — small fissures made prominent by concentration of Fe compounds and gleying, 1–5 mm wide and 0.2–0.7 m deep (Fig. 2.22.), forming systems, most of which are aligned at an angle to the fossil surface, and comprising two sets of fissures at an angle (40–70°) to each other. In places, small faults have developed along the fissures, with displacements conformable to the fossil hillsope, 0.4 m in depth and 0.3 m wide.

TL Dating of Samples Collected Directly from Archaeological Cuttings (Field Seasons of 2007 and 2010)

The sediments associated with the younger-generation ice wedge cast were dated on the archaeological site itself on two occasions.

The sediment samples collected in 2007, from places ranging from the edges to the center of the ice wedge structure, yielded TL dates of 14.8 ± 1.4, 35.0 ± 3.3 i 30.0 ± 2.9 ka, with a further date of 18.3 ± 1.7 ka determined on the undisturbed loess outside the structure (Table 4).

TL dating was repeated during the 2010 field season on the samples collected from the floor of the cutting (1–7) and from its northern wall (8–13) (Table 5). The following elements of the wedge cast were exposed, looking west to east:

1. A gray-brown undisturbed, archaeologically sterile loess on outside of the cast;
2. An archaeologically sterile streaky loess, grayish and gleyey, with numerous rust-colored and brown spots and streaks of ferruginous and manganese precipitates, forming the lateral part of the cast;
3. Loess in the central part of the cast, gray-brown, structureless, containing archaeological artifacts;
4. A sterile, streaky loess identical to that forming the western lateral part of the wedge cast (Fig. 2.23.). A fairly dense orthogonal grid (with sides ≥20 cm) of narrow fissures filled with secondary calcareous precipitate extends over the entire explored area. These fissures are probably frost cracks developed in the level of active cryodiagenesis (Maruszczak, 1998).

Table 5. Thermoluminiscence ages of loess samples from archaeological cuts excavated in 2010 (compare location of samples in Fig. 2.23.). Dates by J. Kusiak.

Provenance of Samples	Laboratory No. Lub-	Sample No.	Annual Dose DR (Gy)	Equivalent Dose ED (Gy)	TL Age (ka)
Loess	5119	1	3,31 ± 0,10	66,0 ± 4,0	19,9 ± 1,6
Layered loess, western, sterile, lateral part of wedge	5120	2	3,08 ± 0,09	55,5 ± 3,3	18,0 ± 1,7
Loess, central part of wedge with artifacts	5121	3	3,14 ± 0,09	51,0 ± 3,6	16,2 ± 1,6
Loess, central part of wedge with artifacts	5122	4	2,84 ± 0,09	57,0 ± 4,0	20,1 ± 1,4
Loess, central part of wedge with artifacts	5123	5	3,22 ± 0,10	57,1 ± 3,7	17,7 ± 1,4
Layered loess, eastern, sterile, lateral part of wedge	5124	6	3,20 ± 0,10	58,5 ± 3,5	18,3 ± 1,5
Loess	5125	7	3,06 ± 0,09	63,0 ± 3,8	20,6 ± 1,7
Loess	5126	8	3,15 ± 0,09	65,5 ± 4,3	20,8 ± 1,6
Loess	5127	9	3,21 ± 0,10	64,8 ± 4,5	20,2 ± 1,8
Layered loess, western, sterile, lateral part of wedge	5128	10	3,16 ± 0,09	51,0 ± 3,6	16,1 ± 1,3
Layered loess, western sterile, lateral part of wedge	5129	11	3,18 ± 0,09	50,5 ± 3,5	15,9 ± 1,1
Loess, central part of wedge with artifacts	5130	12	3,14 ± 0,09	64,5 ± 4,5	20,5 ± 1,4
Loess, central part of wedge with artifacts	5131	13	3,24 ± 0,10	63,0 ± 4,4	19,4 ± 1,6

A look at all the TL dates from samples collected in 2007 and 2010 reveals the following:

1 The dates from the loess in which the wedge cast is embedded are similar, clustered in the ca. 18–20 ka range. They indicate the age of the loess in the profile of the archaeological trenches and are well correlated with the dates obtained for this same loess horizon in the Stratigraphic Trench and in the borehole.
2. The dates for the streaky loess representing the first phase of the wedge cast infilling, directly preceding the formation of its central part and the appearance of the Magdalenian settlement, are all in the ca. 16–18 ka range. The Magdalenian artifacts found their way to the wedge cast already in the initial stages of infilling of its central part and the dates for the streaky loess therefore coincide with or are just slightly older than the settlement; bearing in mind the standard deviations, which can be considerable in the case of TL dates, and the radiocarbon dates, the respective dates for the loess deposit in the central part of the cast and for the settlement are statistically very close to one another. In terms of deposition dynamics, we believe this loess may be the result of secondary seasonal infilling of frost fissures that formed during winter along the edges of the ice core in the near-surface zone (*sensu* Jersak *et al.*, 1992). The fissures were being filled in with gleyey loess formed in the active layer. It entered the fissures when the ground thawed in summer. Fossil beds, 0.5 to 1.0 m thick, of such gleyey loesses (Krasyliv horizon) are being distinguished by Bogucki (1987) in the Volhynian-Podolian loesses.
3. The dates for the inner/central infill of the wedge cast range more widely, from ca. 16 to ca. 35 ka, with most of the dates clustering in the 18–20 ka range. These dates would appear to indicate that it is loess of this age which comprises most of the sediments filling this part of the cast. The dynamics of the cast infilling would be in accordance with the hypothesis proposed by Kolstrup (this volume). However, the considerably older dates, in the 30–35 ka range, may perhaps be attributable to human activity:

artificial admixtures of quartz originating from disintegrating slabs made from a variety of local Miocene sandstones used to pave the floors of dwellings/huts (Fiedorczuk, Schild, 2002) may have ended up in the loess deposit. The sandstones are relatively soft, prone to crumbling and not resistant to wear (Kowalski, this volume). The dated deposit could have become contaminated with secondary quartz grains (of "non-loess" character) as the paving slabs cracked and crumbled, and the grains could also have been "transported" by people moving about the campsite.

Results of Pollen Analyses

Reconstructing the natural environment of open-air Paleolithic sites is no easy task given that few, if any, contemporaneous organogenic sediments are normally available for them. Pollen analysis of mineral deposits is helpful, but this method is rarely used in Poland. Samples for pollen analysis were collected on two occasions: in 2007 (Series I) and in 2010 (Series II). The first batch of samples came from two locations:

1. Loess Samples W4/2007 and W5/2007 were collected from the western and eastern sides of the Stratigraphic Trench;
2. Samples W1/2007, W2/2007, W3/2007 and W7/2007 come from the archaeological cuttings, with the first three representing the wedge cast infill and the last (W7/2007) being a loess sample from outside the cast (Fig. 2.23.). The pollen analysis of these samples was carried out in 2008.

Five more samples were collected in 2010 for the purposes of a repeat pollen analysis, together with the samples required for TL dating. Samples W3/2010, W4/2010 and W5/2010 represent the central wedge cast infill containing artifacts, Sample W2/2010 came from the streaky, lateral part of the cast along its western edge, and Sample W1/2010 from the loess adjacent to/outside the wedge cast (Fig. 2.23.; Table 5).

Loess Samples Collected in 2007

The pollen spectra of Samples W4/2007 and W5/2007 display low degrees of taxonomic differentiation and relatively low AP pollen indices (17% and 21%, respectively), with just *Pinus* and *Salix* pollen being in evidence. The bulk of pollen grains represent the *Pinus* genus (*P. cembra* and *P. sylvestris*), with *Salix* pollen being much less plentiful. NAP reveals the presence of Caryophyllaceae, Saxifragaceae and Cyperaceae taxa, as well as plants of the *Artemisia* and *Thalictrum* genera. Spores account for 10% and 5% of pollen in the two samples, respectively, with Bryales mosses prevailing in sample W4/2007 (Fig. 2.24.).

First batch of test samples collected from the archaeological cuttings (2007)

Total AP in the samples collected from the site (W1/2007, W 2/2007, W3/2007, W7/2007) ranges from 24% in Sample W1/2007 to 35% in Sample W7/2007. Relatively high proportions of pine (*Pinus sylvestris*) pollen can be seen in the spectra, the highest figure being recorded in Sample W7. Also relatively plentiful is *Pinus cembra* pollen. Small quantities of spruce pollen were discovered in Samples W3 and W7 which also contained fir pollen. Willow pollen was distinctly present in all the spectra, unlike that of sea-buckthorn which was to be seen only in Samples W1/2007 and W2/2007. This last sample also contained birch pollen. Pollen of herbaceous plants is less copious than in the loess Samples W4/2007 and W5/2007, ranging from 47 to 65%.

The most plentiful NAP in all the samples is that of Chenopodiaceae, Cyperaceae and Poaceae plants. Not all the samples contain pollen of heliophytes such as *Artemisia, Thalictrum* or *Heliantemum*. *Artemisia* was recorded in Samples W3/2007 and W7/2007, *Helianthemum* in Samples W1/2007 and W7/2007, and *Thalictrum* is not present in Sample W7/2007. This last-mentioned sample, although very similar to Samples W1/2007, W2/2007 and W3/2007, is distinct in lacking spores Bryales, Polypodiaceae, *Lycopodium* and *Sellaginella selaginoides,* among others. Sample W3/2007 is likewise unremarkable as regards variety of spores, which represent just the Polypodiaceae family (23%). In both the remaining samples — W1/2007 and W2/2007 — spores account for 13% of pollen, with Sample W2/2007 being the only one to contain spikemoss (*Selaginella selaginoides*) spores (Fig. 2.25.).

Second Batch of Test Samples Collected from the Archeological Cuttings (2010)

The pollen spectra for these samples resemble those for the samples collected in 2007 in that herba-

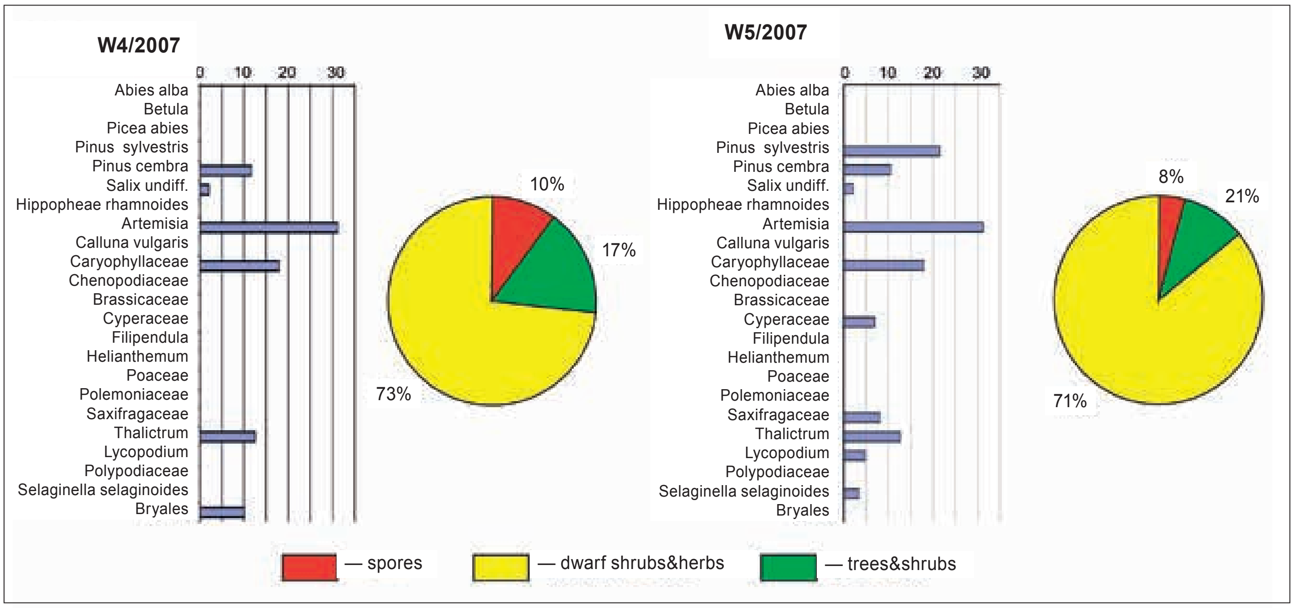


Figure 2.24. Bar and circular percentage graphs showing proportion of pollen types in loess samples from Stratigraphic Trench 2007. Location of samples shown in Fig. 2.21.

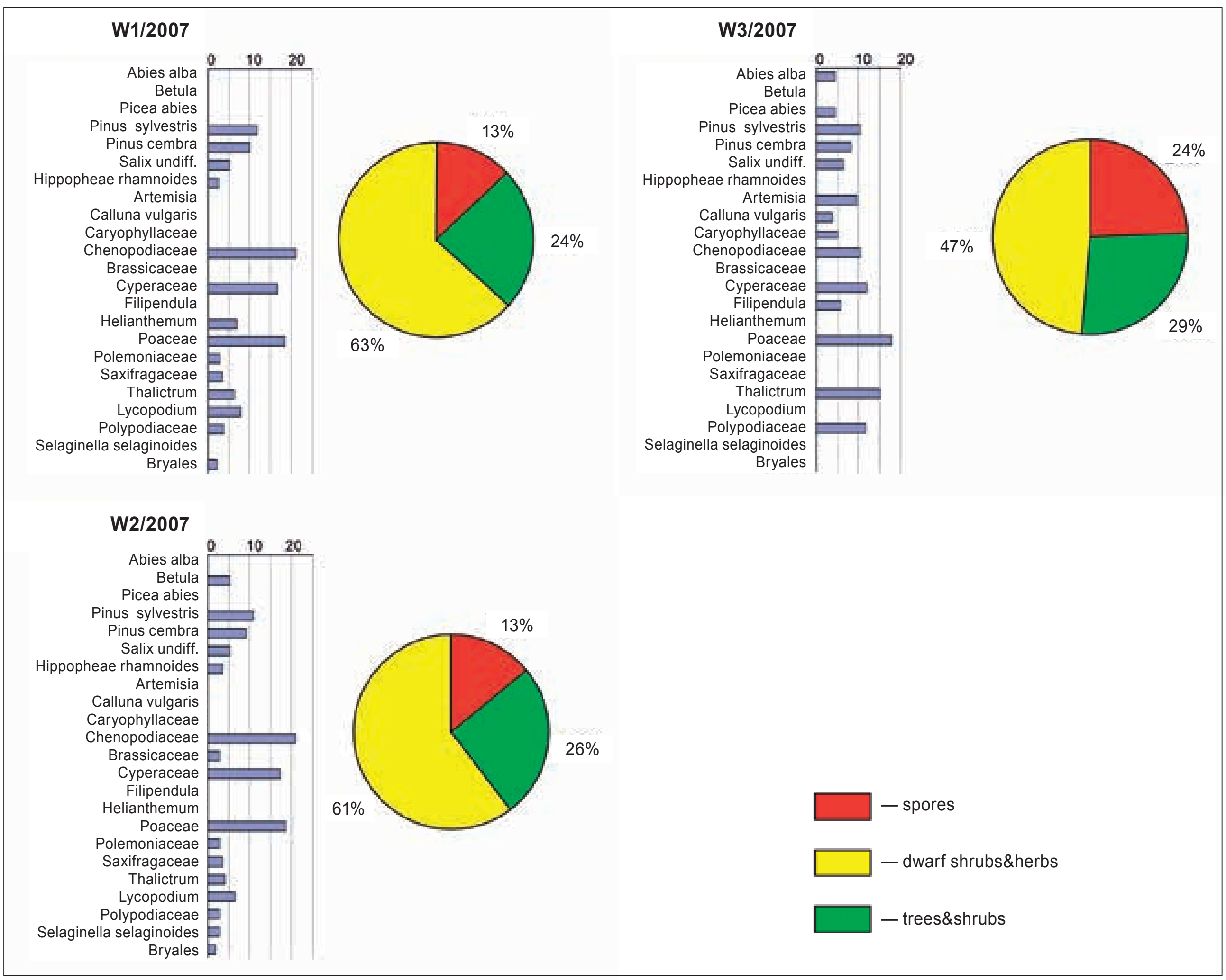
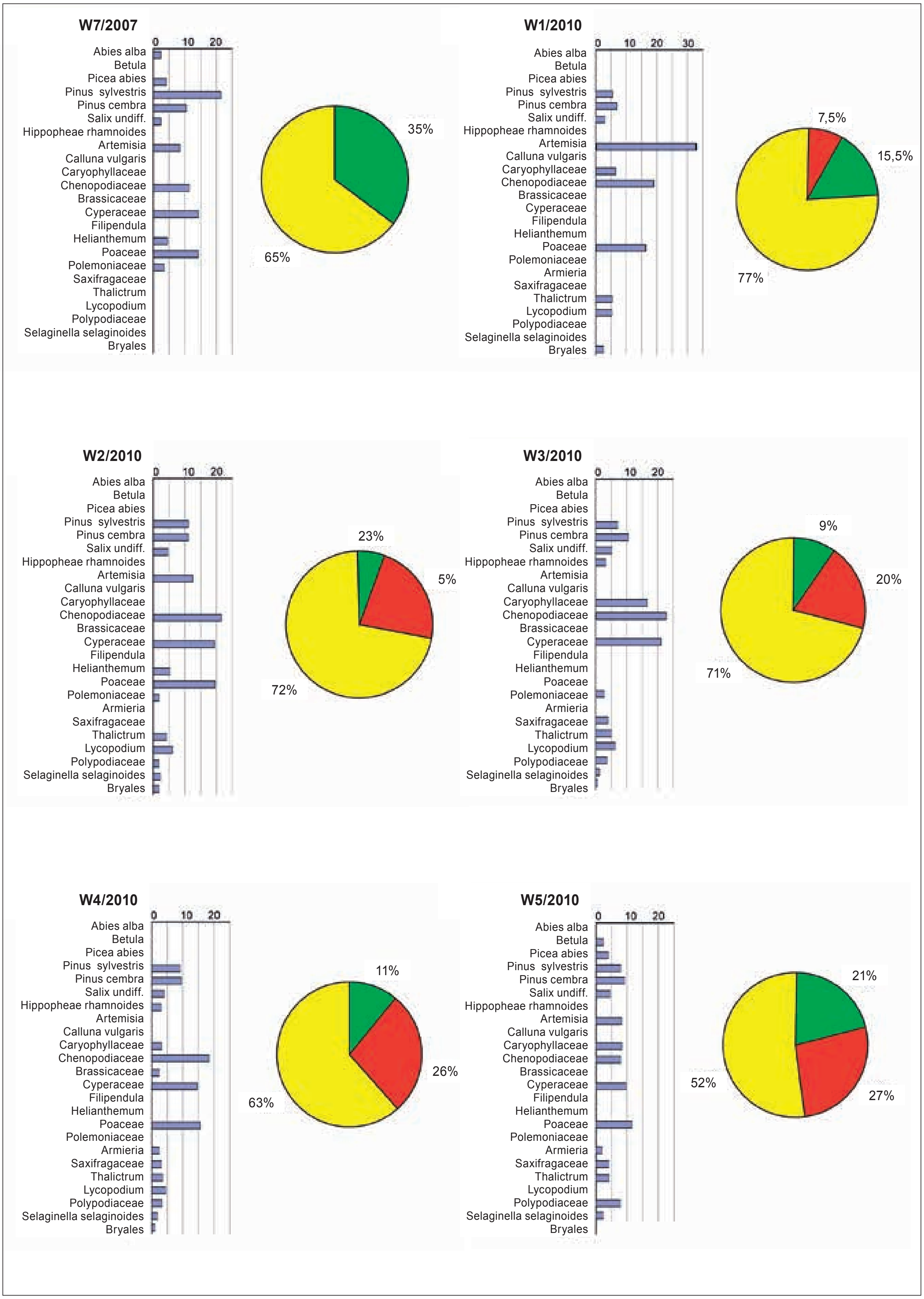


Figure 2.25. Bar and circular percentage graphs showing proportion of pollen types in loess samples from Archaeological Cut. Location of samples shown in Fig. 2.23. (cd. na stronie obok)


W7/2007
0 10 20
Abies alba
Betula
Picea abies
Pinus sylvestris
Pinus cembra
Salix undiff.
Hippopheae rhamnoides
Artemisia
Calluna vulgaris
Caryophyllaceae
Chenopodiaceae
Brassicaceae
Cyperaceae
Filipendula
Helianthemum
Poaceae
Polemoniaceae
Saxifragaceae
Thalictrum
Lycopodium
Polypodiaceae
Selaginella selaginoides
Bryales
35%
65%
W1/2010
0 10 20 30
Abies alba
Betula
Picea abies
Pinus sylvestris
Pinus cembra
Salix undiff.
Hippopheae rhamnoides
Artemisia
Calluna vulgaris
Caryophyllaceae
Chenopodiaceae
Brassicaceae
Cyperaceae
Filipendula
Helianthemum
Poaceae
Polemoniaceae
Armieria
Saxifragaceae
Thalictrum
Lycopodium
Polypodiaceae
Selaginella selaginoides
Bryales
7,5%
15,5%
77%
W2/2010
0 10 20
Abies alba
Betula
Picea abies
Pinus sylvestris
Pinus cembra
Salix undiff.
Hippopheae rhamnoides
Artemisia
Calluna vulgaris
Caryophyllaceae
Chenopodiaceae
Brassicaceae
Cyperaceae
Filipendula
Helianthemum
Poaceae
Polemoniaceae
Armieria
Saxifragaceae
Thalictrum
Lycopodium
Polypodiaceae
Selaginella selaginoides
Bryales
23%
5%
72%
W3/2010
0 10 20
Abies alba
Betula
Picea abies
Pinus sylvestris
Pinus cembra
Salix undiff.
Hippopheae rhamnoides
Artemisia
Calluna vulgaris
Caryophyllaceae
Chenopodiaceae
Brassicaceae
Cyperaceae
Filipendula
Helianthemum
Poaceae
Polemoniaceae
Armieria
Saxifragaceae
Thalictrum
Lycopodium
Polypodiaceae
Selaginella selaginoides
Bryales
9%
20%
71%
W4/2010
0 10 20
Abies alba
Betula
Picea abies
Pinus sylvestris
Pinus cembra
Salix undiff.
Hippopheae rhamnoides
Artemisia
Calluna vulgaris
Caryophyllaceae
Chenopodiaceae
Brassicaceae
Cyperaceae
Filipendula
Helianthemum
Poaceae
Polemoniaceae
Armieria
Saxifragaceae
Thalictrum
Lycopodium
Polypodiaceae
Selaginella selaginoides
Bryales
11%
26%
63%
W5/2010
0 10 20
Abies alba
Betula
Picea abies
Pinus sylvestris
Pinus cembra
Salix undiff.
Hippopheae rhamnoides
Artemisia
Calluna vulgaris
Caryophyllaceae
Chenopodiaceae
Brassicaceae
Cyperaceae
Filipendula
Helianthemum
Poaceae
Polemoniaceae
Armieria
Saxifragaceae
Thalictrum
Lycopodium
Polypodiaceae
Selaginella selaginoides
Bryales
21%
27%
52%

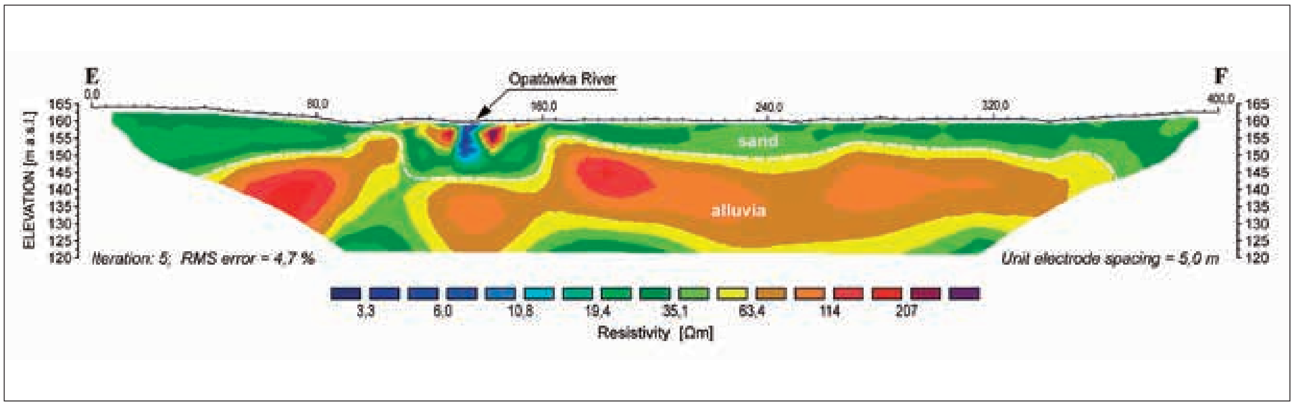


Figure 2.26. Electrical resistivity tomography cross-sections in the area of Dacharzów. Location of cross-sections in Fig. 2.11.

ceous plants (*Artemisia*, Chenopodiacae, Cyperaceae, Poaceae) definitely predominate in them as well. Tree pollen is slightly less plentiful (not exceeding 27.4%). Fir pollen is not to be found in the 2010 samples at all, while birch pollen was identified in Sample W5/2010 alone. Two of the samples (W3/2010 i W4/2010) contain sea-buckthorn pollen. Spores are present in all the samples, mostly representing Polypodiaceae, *Selaginella selaginoides* and Bryales mosses. Polypodiaceae spores are missing in loess Sample W1/2010 collected from the vicinity of the cuttings, the same being true of Sample W7/2007, which contains only spores of brown mosses.

Results of Paleogeographic Studies of the Opatówka Valley Floor

The area selected for detailed studies extends from the Dacharzów-Jankowice narrowing (gorge) to the mouth of the dry valley with the Wilczyce village (the Wilczyce dry valley). A 400-m long electrical resistivity traverse was staked out on the floor of the Opatówka valley, at right angles to its axis, immediately below the hill atop of which the archaeological site is located (Fig. 2.11.). A series of cores were drilled to collect samples for detailed analyses. The cores were drilled along three composite profiles cutting across the valley floor and its sides — in the narrowest section at the mouth of the dry valley in the vicinity of the archaeological site (Fig. 2.11.) and in its widest part, along an extension of the axis of the Wilczyce dry valley opening up into the Opatówka Valley. One of the cores (Dacharzów 1) was used for pollen analyse sampling, and five samples taken from three cores were radiocarbon dated.

Electrical Resistivity Survey

Measurements were performed using a Schlumberger-Wenner array with 5.0 m probe separation, achieving depths of imaging of up to ca. 40 m (Fig. 2.26.). The survey revealed a distinctly layered geological setting. The resistance measured in the near-surface electrical layer ranges from 15 to 50 Ωm; the layer is ca. 10 m thick on average, and is thicker at both ends of the profile. The very low resistance values may be due to the local waterlogged and probably silty sand and alluvial muds, dating to the Holocene and rich in organic materials. This level forms the modern floodplain, with the very distinct channel of the Opatówka River, ca. 40 m wide, incised into it. Also distinctly visible is the present-day drained channel of this river, ca. 5 m in width, with all its hydrotechnical installations.

The layer underlying the topmost one is ca. 20–25 m thick, with resistivity in the ca. 50–300 Ωm range. These parameters are also those of waterlogged sands which Bielecka (1968a) interprets as laminated alluvial deposits marked by variable grain sizes, featuring alternating coarse and fine-grained sand laminas, mineralogically diverse and containing detrital material. All these factors — and electrical anisotropy in particular — always drive up the electrical resistivity measured in the sediments.

Sediments with very low resistivity, much like that in the near-surface layer, reappear at the base of the cross-section, at depths of around 40 m, displaying features reminiscent of loesses and possibly being what is known as an alluvial loess. These sediments probably correspond to the older Pleistocene loesses in the geological cross-section published by Bielecka (1968b).

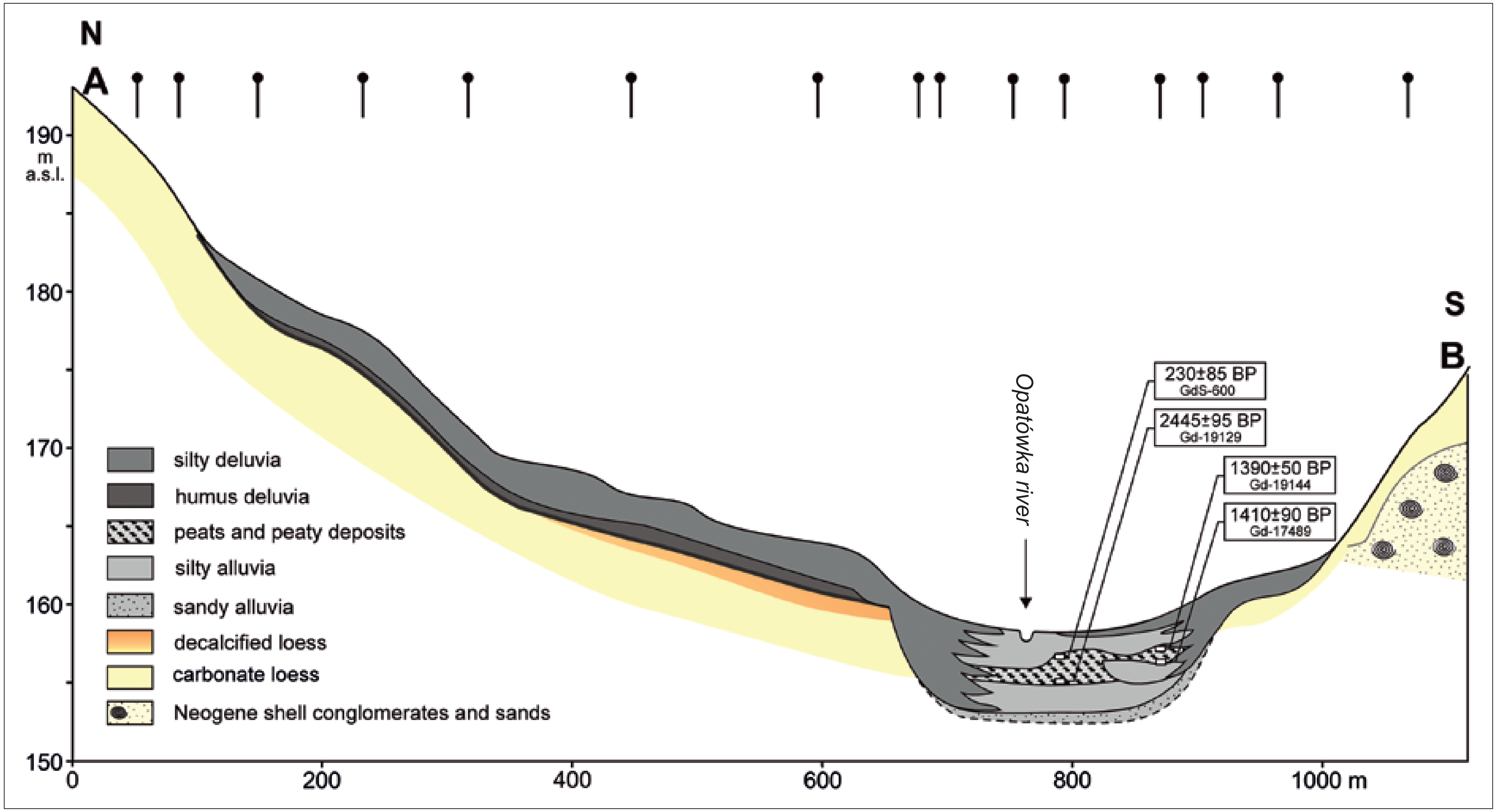


Figure 2.27. Geological cross-section of the Opatówka Valley in the area of Dacharzów. Location of the cross-section in Fig. 2.11.

Lithology, Origin and Age of Sediments in the Opatówka Valley

The cores serving to explore the lithogenesis of deposits infilling the Opatówka Valley were drilled down to a depth of no more than 6.5 m — to the level of the waterlogged sandy deposits identified in the electrical resistivity survey. These deposits blanket the entire valley and were also detected on the slopes (Czarnecki, 1996) and on the terrace benches buried beneath a 2–3 m thick layer of slope-wash sediments. They are in the form of fine- and medium-grained sand, gray in color, interbedded with gray silt, and may have been left behind by a river with a highly non-uniform flow regime. This fact, together with the presence of these deposits on the terrace benches, may be evidence of a braiding river channel, and this would suggest that they date to the Late Glacial rather than the Holocene (cf. Jersak *et al.*, 1992; Liedke, 1993). The distinct borderline separating their topmost part (underscored with a layer of medium-grained sand) and the overlying sediments may mean that what we have here is an erosional plane, which in turn may be evidence of intense incising processes taking place in the Late Glacial (Starkel, 2012). The formation of this plane may be dated to this period. It is overlain by a layer, up to 2 m thick, of gray, horizontally laminated muds and silty muds. The top of this layer is encountered at various elevations. The muds layer becomes thicker the closer it is to the valley sides/slopes and the muds grade into silt-sized deposits. In all likelihood they are alluvial sediments deposited in the river channel or meanders. They interfinger with slope-wash sediments caused by erosion and denudation processes destroying the loess mantle in the vicinity of the valley. The sediments are covered, in their turn, by a discontinuous horizon of peaty muds, interbedded with severely degraded peat, up to 2 m in thickness. The peat began accumulating in the Atlantic period, as suggested by the radiocarbon date of 6640 ± 80 BP (Ki-14360) obtained for a sample collected from the basal part of this horizon in the core drilled at the mouth of the Wilczyce Valley. The peaty interbeds visible in the Dacharzów 1 and Dacharzów 2 profiles are younger, dated in this basal and top parts to, respectively: 1390 ± 50 BP (Gd-19144) (at a depth of 420–425 cm) and 1410 ± 90 BP (Gd-17489) (depth of 385–390 cm), and to 2445 ± 95 BP (Gd-19129) and 230 ± 85 BP (GdS-600) (Fig. 2.27., Table 6). These sediments represent a later stage of development of the floodplain and flood basins in the valley floor. The areas suitable for peat formation were being gradually reduced by the expanding fine-grained alluvial fans forming at the mouths of the tributary valleys and next to the main valley sides.

The youngest soil horizon in the valley is a suite of gray/light brown/olive-colored fine-grained deposits which found their way to the Opatówka Valley bottom as a result of an intense denudation of the loess mantle. In terms of lithology, these deposits are very similar to loesses, and this is an indication of intense denudation of the loess cover, a phenomenon universally seen as a result of intense land tillage in the period from the 19th through the end of the 20th centuries (Maruszczak, 1973, 1986; Rodzik, 2006; Schmitt *et al.*, 2006).

Pollen Analysis

The pollen analysis results for the Dacharzów 1 cross-section are presented in Fig. 2.28. The pollen spectra for a 45-cm layer of deposits are pretty much the same, with relatively high concentrations of NAP (40–60%). The frequency of herbaceous plant pollen was low (ca. 20%) only in the sample from the basal part of the profile. Pine pollen was the most frequent, with lower quantities of pollen representing *Quercus, Betula* and *Alnus.* Also infrequent was *Tilia* and *Ulmus* pollen. The *Carpinus*, *Fagus* and *Abies* pollen discerned in the samples are an unequivocal indication of sediments deposition in the Younger Holocene, something that is also confirmed by anthropogenic markers such as *Triticum* type, *Secale cereale* and *Plantago lanceolata*.

The foremost herbaceous plants represented by the pollen are those of the Cyperaceae and Poaceae families. Cyperaceae pollen predominates in the older part of the profile, while Poaceae pollen comes to the fore in its more recent part. The increased frequency of Cyperaceae pollen coincides with the appearance of lesser bulrush (*Typha latifolia*) pollen, which may be an indication of more humid climatic conditions. The rise in Poaceae pollen frequency is accompanied by increased quantities of pollen representing anthropogenic markers, heliophytes and nitrophilic plants (such as *Artemisia*, Chenopodiaceae, *Melampyrum* and *Rumex*), all if which is evidence of an increasing intensity of human economic activity.

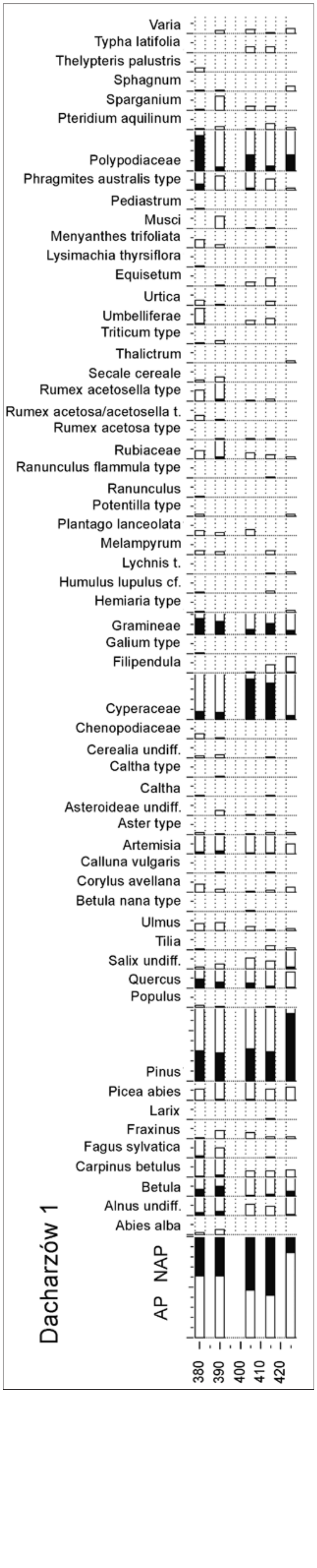


Figure 2.28. Dacharzów 1, pollen diagram.

Figure 2.29. Location of Site Wilczyce 10 in relation to: the maximal extent of Vistulian ice sheet (LGM) and distribution of loess covers (orange patches) in Europe (A); the Late Vistulian major glacial phases (Pz — Poznań, Pm — Pomerania, Ga — Gardno, Sb — Słupsk Bank, Sm — Southern Middle Bank) and distribution of loess cover (orange patches) in Poland (B).

LATE QUATERNARY PALEOLANDSCAPES IN THE WILCZYCE AREA

PALEOGEOGRAPHIC BACKGROUND

Glacial events of the main stadial are the foremost developments in the paleogeography of the Upper Pleniglacial of the Vistula Glaciation (Vistulian, Weichselian, LGM) in Poland. The first Vistulian advance of the Scandinavian ice sheet in the Polish Lowland (Leszno Phase/Stadial), extending over much of north-western and north-central Poland, took place 22–20 ka BP. The next advancement (Poznań Phase), reaching in places further than the first one, is dated to 19–18 ka BP (Mojski, 1999; Wysota, 2002). The Pomeranian Phase (16.5 ka BP) and Gardno Phase (16 ka BP) oscillations coincided with the recession of this ice sheet (Wysota, 2002). Mojski (1999) dates the Pomeranian Phase to 15.2 ka BP. The most recent aging of the glacial events in Poland reviewed by Marks (2012), relying on cosmogenic isotopes (^{36}Cl and ^{10}Be) suggest the following times of the main advancement phases: 24 ka BP (Leszno Phase), 20–19 ka BP (Poznań Phase), 17–16 ka BP (Pomeranian Phase).

The glacial events of the main stadial of the Vistula Glaciation coincide with phases of intense eolian processes in the periglacial environment. Loess deposition in Europe took place in two stages — 28–18 ka BP and 18-(14)13 ka BP — spanning the entire MIS2 period (Fedorowicz, Łanczont, 2007; Frechen *et al.*, 2001, 2003; Kusiak *et al.*, 2012), with the process stifled on two occasions — around 20 ka BP and around 15–16 ka BP. During those times, when permafrost persisted for years, diverse periglacial phenomena evolved, leaving two horizons of cryogenic structures which we can see today. These belong to the most recent (A) stage of development of periglacial processes in Central and Eastern Europe (Lindner, Bogucki, 2002) and represent two phases of development of diverse cryogenic structures which are best apparent in sites located in the Volhynian Upland. The older horizon there coincides in most instances with the gley horizon representing the Rivne unit and what we see here are solifluction structures and cryoturbations as well as epigenetic pseudomorphoses formed in polygonal ice veins (Bogucki, 1990). Various laboratories have dated this lithostratigraphic unit in various sites throughout Central Europe to pretty much the same period, from 17 to 23 ka BP, with most of the dates falling around 20 ka (Bokhorst *et al.*, 2011, Fedorowicz *et al.*, 2013; Fedorowicz, Łanczont 2004; Kusiak *et al.* 2012).

The younger horizon of periglacial structures is represented primarily by large structures known as final ice wedge casts, formed in conditions of continuous permafrost persisting for many years in the subsoil or bedrock. These structures range in depth from 4–5 m to 7 m in the northern areas of the Volhyn Upland, and from 2 to 3 in the Podolia Upland, and the polygons they formed were up to 25–30 m in width (Bogucki, 1990; Bogucki, Wołoszyn, 1992). For structures of this kind to develop, the mean annual air temperature (MAAT) must have dropped to ≤ –4°C (Vandenberghe, 2004) or even to ≤ –8°C (to –6°C) (Muton, 2007). According to Dolecki (2003), in the period when these structures were forming, the mean temperature in January ranged from –24 to –30°C, while in July it stood at 14–18°C.

The pseudomorphs left by the ice veins are overlain by a gleyed loess which is interpreted as the fossil active layer. In profiles exposed in the Ukraine this is the Krasyliv unit (Bogucki, 1987) — on the whole poorly researched and infrequently described in the literature, and this because it is overlain by just a thin layer of loess and, being close to the surface, it is either masked by later-day soil processes or else destroyed by erosion (Jersak *et al.*, 1992, Maruszczak, 1998). This is one reason why so few thermoluminescence dates are available for this horizon (Kusiak *et al.*, 2012). This unit was recently dated in the Boyanychi profile in Volhynia Upland to 14.2–14.6 ka (Kusiak *et al.*, 2012) while the age of the Volochysk profile in Podolia Upland was put at 14.5–15.7 ka (Muton, 2007). Spectacular profiles of variously intersected ice polygons dating to the Krasyliv horizon may be seen on walls of large open pits of brickyards and, conditions permitting, also in aerial photos thanks to the diverse properties of materials filling the wedges and of the sediments in which the frost fissure polygons were formed (Dąbski, 2011; Maruszczak, 1998).

It is believed that loess deposition ceased as a result of changes in the source areas which took place probably before the onset of the first warming period (Bølling, GI-1e). It is hard to say when exactly the loess deposition declined, both because of the metachronous character of this process and

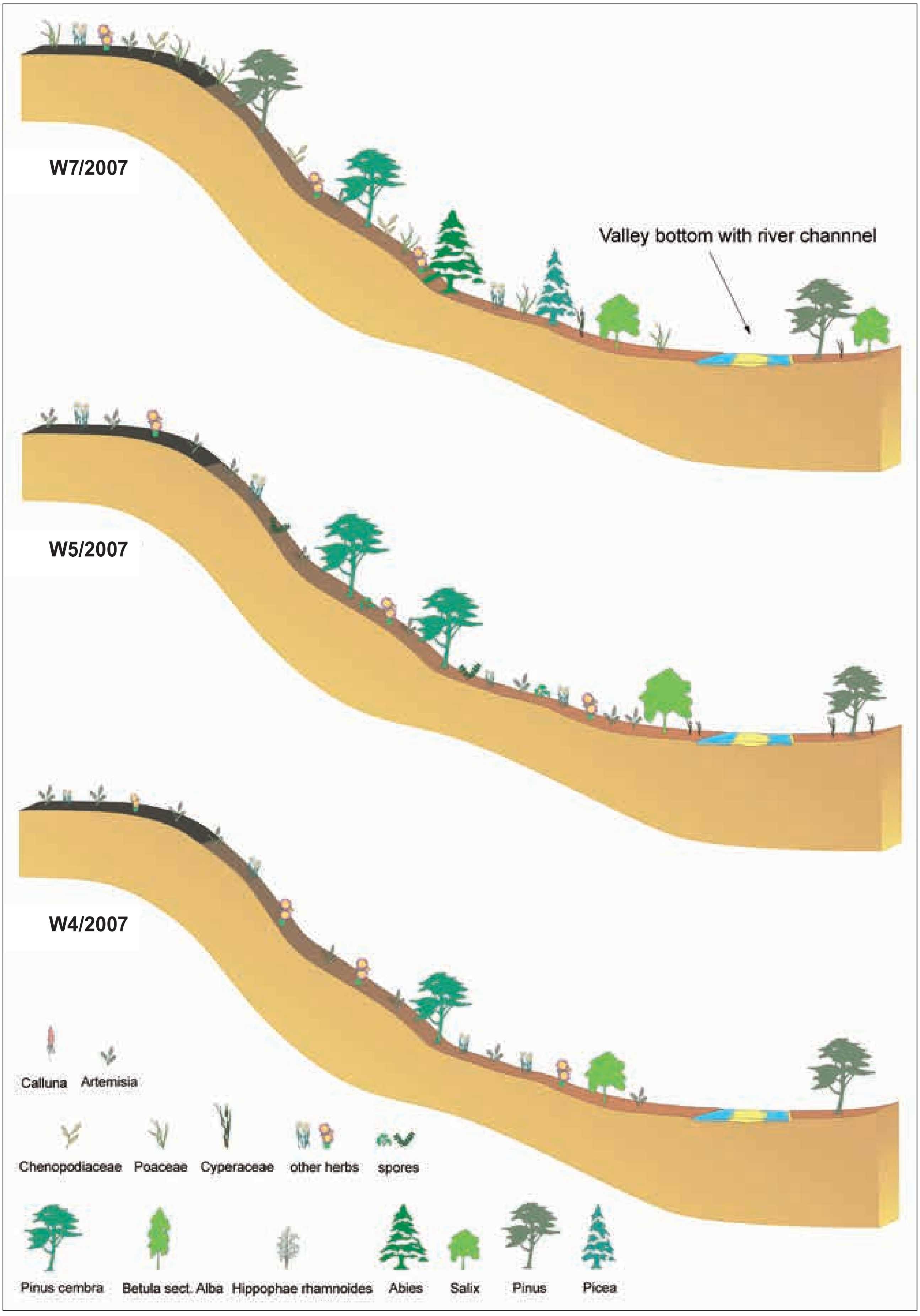


Figure 2.30. Reconstruction of plant cover during older (W4) and younger (W5 and W7) phases of loess deposition in the Upper Plenivistulian.

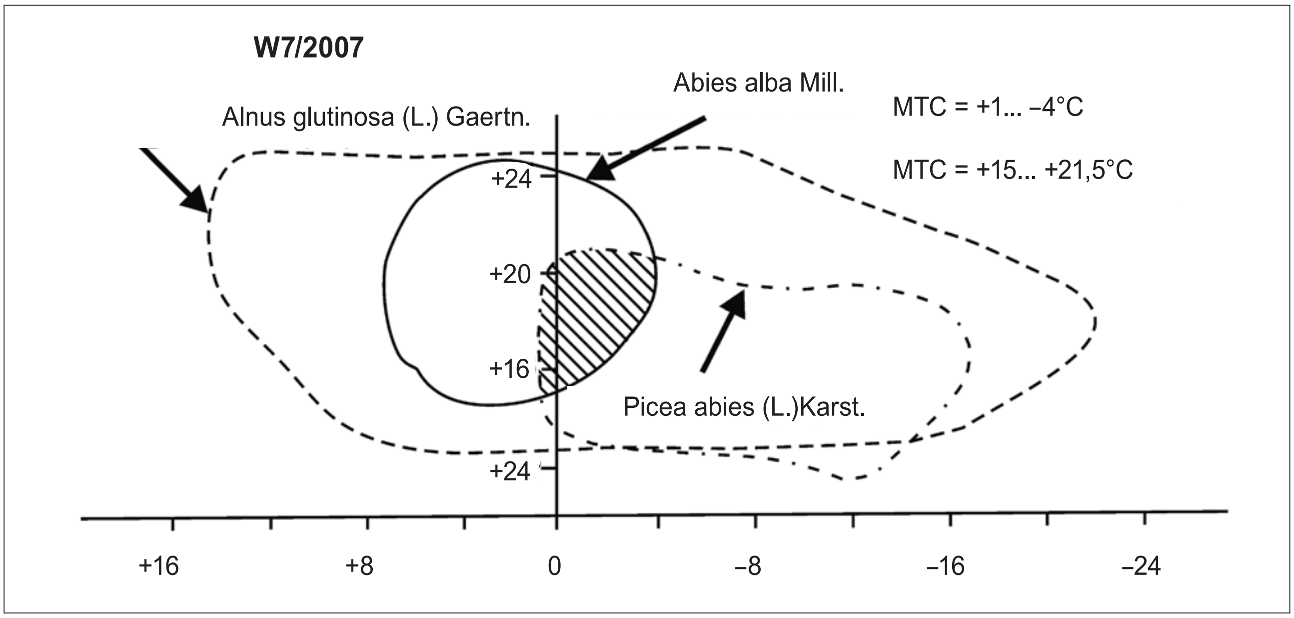


Figure 2.31. Reconstructed MTC and MTW paleotemperatures based on pollen data for the period of 18.3 ± 1.7 ka.

because the topmost section of the loess beds is missing (Jersak *et al.*, 1992).

The palynology of biogenic deposits in south--central Poland (Balwierz, 1995; Mamakowa, Środoń, 1977; Mamakowa, Starkel, 1977; Tobolski, 1991) reveals that as the Vistulian ice sheet was advancing and retreating, central Poland experienced a moderately arctic climate which became highly arctic as the ice sheet advanced, while in the south of the country, where the loess deposition was taking place (the South Poland Uplands), the climate was subarctic/boreal. The dry habitats were overgrown with patches of steppe vegetation, prominently represented by grasses and sagebrush, while in the wetter areas tundra developed, with dwarf birch and dwarf willow. There could also have survived ecological niches with parkland steppe-tundra overgrown with larch, stone pine, birch and pine. Data from the Smerek profile (Ralska-Jasiewiczowa, 1980), to mention but one example, show that an open stone-pine/larch forest with some Scotch pine, spruce and birch survived in the Bieszczady Mountains (ca. 16 ka BP). Once the ice sheet receded from Poland, the vegetation in the Late Glacial assumed a mosaic character, with both steppe and tundra elements in evidence, locally featuring also larch and probably birch as well. The Bølling warming (13 540–13 670 cal. years BP) brought with it the expansion of open birch forests with some aspen and occasional pine (Wasylikowa, 1964, Latałowa, 2003).

The Paleoenvironment around Wilczyce during Last Glacial Maximum (LGM)

The paleoclimate in the younger Upper Pleniglacial in and around Wilczyce was a consequence of glacial events taking place in Northern Poland — the Leszno and Poznań phase ice sheet transgressions. The southernmost reach of the Leszno advance in western Poland was just 140 km from the parallel of latitude of Wilczyce, with the distance to the ice-sheet margin measured along the meridian passing through Wilczyce being almost 280 km (Fig. 2.29).

As indicated by TL dating, this distant ice-sheet foreland witnessed eolian deposition of loess in the period from 25 to 15 ka, and it is likely that this process continued into ca. 14–13 ka BP, although direct evidence of the latter is scarce since the youngest loess layers were denuded. An erosional surface separating loess units aged 20–25 ka and 20–15 ka is evidence that this deposit accumulated in two phases. A feature related to this surface is a horizon of older-generation periglacial fissure structures represented exclusively by their basal parts, the upper parts having been truncated by a distinct discontinuous fossil unconformity. The course of this unconformity suggests that the microrelief of the Wilczyce hilltop surface in the period of interest to us here was rather uneven, featuring gulley-shaped depressions which were probably remnants of a system of degraded

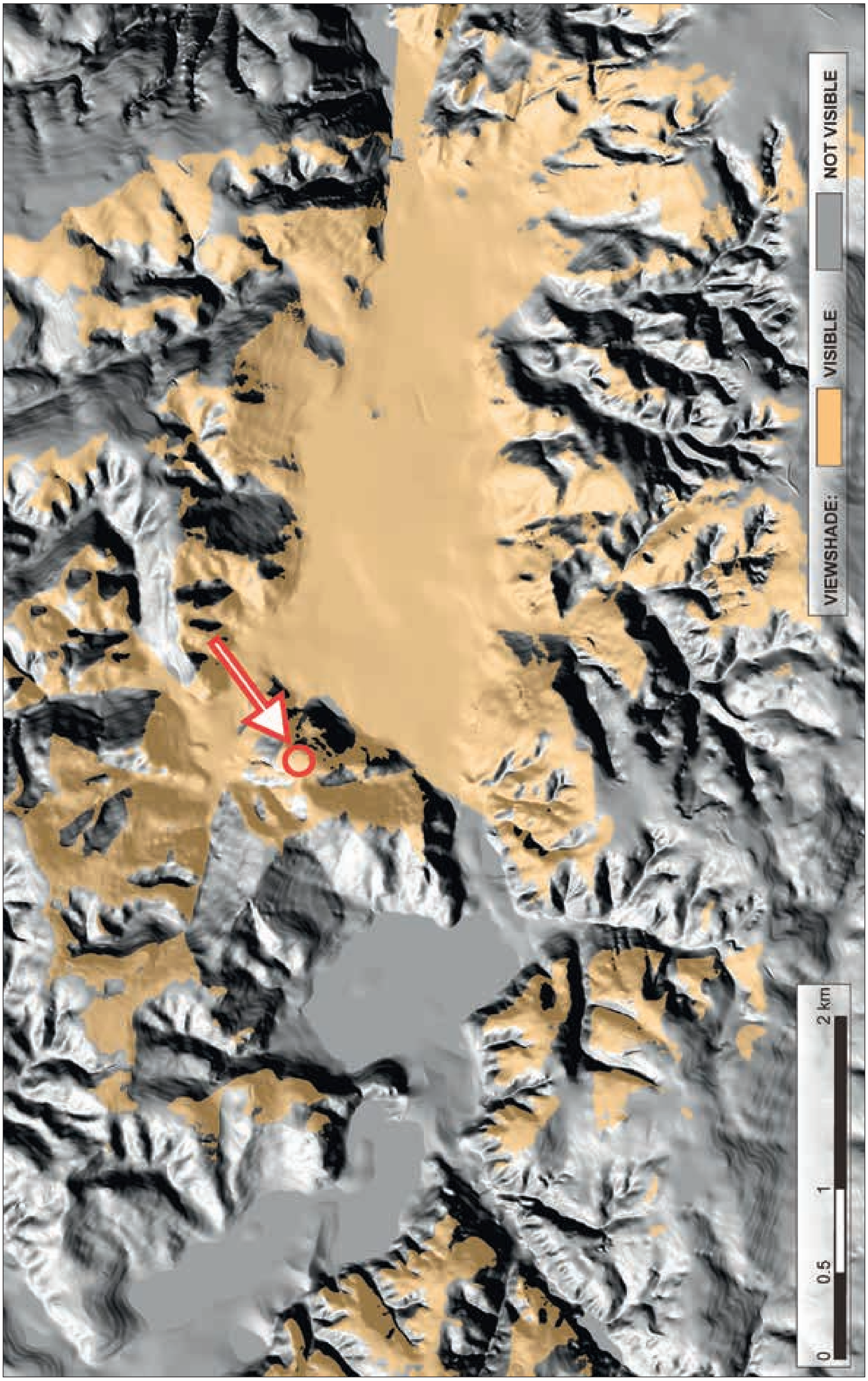


Figure 2.32. Visual ranges from the Magdalenian camp site projected onto a contemporaneous topographic relief imagery.

older-generation ice-wedge casts exposed to surface erosion processes.

Herbaceous and moss plant communities prevailed in the Wilczyce area in both the phases of loess deposition. Meager arboreal patches were probably also present in sheltered places and on valley sides closer to the valley bottoms, although it cannot be ruled out that tree pollen transported over long distances ended up deposited in open landscapes. The tree patches were probably made up of *Pinus cembra*, P. *sylvestris* and *Picea abies*. The herbaceous communities in dry biotopes were comprised of heliophytes (*Artemisia*, Caryopyllaceae, *Thalictrum*, *Saxifraga*) with diverse species of sagebrush predominating in patches of this vegetation. Plant communities characteristic for humid biotopes developed in ground depressions, featuring more cryptogamous plants. One of the plants present in these communities was the bird's nest moss *Selaginella selaginoides*, a species characteristic for moss tundra (Fig. 2.30.).

The paleotemperatures during the vegetation periods (assessed based on isotopic oxygen composition of calcitic cements) probably ranged from 12 to 13°C in the earlier phase and from 14 to 15°C in the more recent phase. Very similar results were obtained for this last phase (ca. 18.3 ± 1.7 ka) from pollen data. Paleotemperatures in the warmest month (MTW) could have ranged from +15 do +21.5°C, with those in the coldest months (MTC) ranging from +1 to –4° (Fig. 231.).

THE PALEOENVIRONMENT AROUND WILCZYCE IN THE TIMES OF MAGDALENIAN SETTLEMENT

The hill on which the archaeological site Wilczyce 10 was discovered is an elevation in the form of an isolated promontory, with exposed slopes on all sides save for the base, jutting out prominently into the Opatówka Valley. The relief of this area as we see it today differs slightly from that during the Vistulian Pleniglacial when the Opatówka Valley was being colonized by the Magdalenian hunters. As shown by the hypsometry of the paleorelief around the site, in those days the relative height differences were slightly bigger than today, and the slopes were not as dissected. The flat valley floor, rising 2–3 m higher than today, was dominated by a braiding river which froze over during winter.

The abiotic environmental features around Wilczyce are in line with the expectations of Magdalenian hunters. Examples of landscape utilization models preferred by Magdalenian hunters or representatives of other Upper and Late Palaeolithic traditions in Central and Eastern Europe are given, for example, by Lisá *et al.* (2012), Połtowicz-Bobak (2012), Synicyna (2012) and Wiśniewski *et al.* (2012). In their ecological strategies these hunters looked for proximity to wide river valleys, geomorphological narrowings and river confluences, and sought out natural groundwater sources.

Three important features of the geographic localization of the Wilczyce site are worth emphasizing:

(1) the proximity to the Opatówka Valley which served, most importantly, as a natural route of animal migrations along the east–west axis, while also linking the ecologically diverse regions of the Holy Cross Mountains and the nearby Vistula Valley (less than 20 km from Wilczyce). Wilczyce may thus be seen as situated right next to an intersection of two important ecological corridors;

(2) the extensive eastward view from the site across the entire valley, covering an area of more than 7 km^2, with vistas of up 4 km away (Fig. 2.32.). The site dwellers could observe all of the valley floor, the two gorges blocking it, and the southern and northern valley slopes. Also visible from the site were fragments of the Wilczyce Valley's catchment area and some of the valley sides overlooking the site (Jankowice-Dankowice-Zagrody). Thanks to the location of the site and the exceptionally favorable morphology of the valley, the Magdalenian hunters were certainly in a position to monitor everything that was going on in the valley floor (migrations of large game animals) which perhaps also gave them opportunities to immediately react to the observed developments, possibly by blocking both gorges with systems of artificial barriers;

(3) the site was shielded from the west with a loess hump which could have been beneficial for any Magdalenian hunters that may have been dwelling on the mostly elevated parts of the promontory. Westerly winds prevailed in the Upper Pleniglacial (Chlebowski, *et al.*, 2002, 2003; Nawrocki, *et al.*, 2006) which must have been unpleasant in the open hilltop landscape, especially in places where the terrain orography created tunnel effects.

The Magdalenian settlement in Wilczyce coincides closely with the younger generation of periglacial structures forming the system of polygonal structural grounds on the hilltop and extending at least over the topmost sections of the Wilczyce hill slopes. The system of ice wedge pseudomorphs was

Figure 2.33. Reconstruction of plant cover during the Late Magdalenian settlement at Wilczyce. For key compare Fig. 2.30.

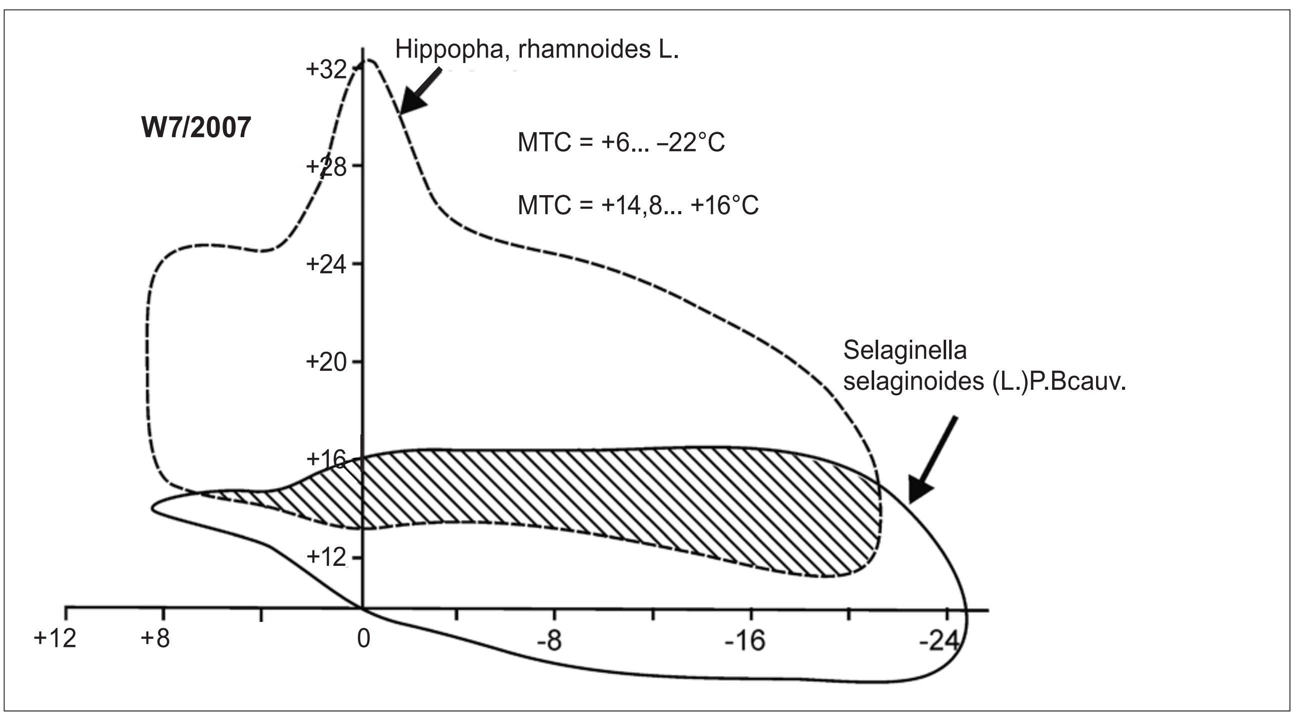


Figure 2.34. Reconstructed MTC and MTW paleotemperatures based on pollen data for the period of 14.8 ± 1.4 ka.

responsible for the specific relief of the then topographic surface. This micro-morphosystem featured concavities forming as in warmer seasons the ground thawed near the surface (active permafrost layer) above the intersection of the cracks, linked with a network of channels (furrows) developed above the lines of cracks. These concavities were bounded by small ridges (*ramparts*) of sediments pushed upwards by the expanding ice wedges (Maruszczak, 1998). The southern exposure of the site area probably caused the soil to thaw down to a greater depth, which in turn could have added to the dynamism of the mentioned processes.

The vegetation cover in the times of Magdalenian settlement in Wilczyce differed only slightly from that before the Magdalenian hunters arrived. Herbaceous plants were less prevalent, probably as a result of a greater spread of tree patches in the landscape, comprised mostly of conifers (pine, stone pine, spruce and less frequent fir) and most probably confined to relatively low-lying, more sheltered places. The undergrowth flora in these patches included mosses, ferns and club-mosses. Sea-buckthorn thickets were also to be found, with willow and sedge communities occurring in more humid biotopes. Likewise in evidence is birch. The herbaceous vegetation patches in dry biotopes were comprised primarily of *Chenopodium* species and grasses, with various admixtures of sagebrush, the latter sometimes accounting for more than 30% of the plants (Fig. 2.33.). The picture we have is thus one of a mosaic of plant communities in the vicinity of the site. The simultaneous presence of vegetation requiring diverse biotopes was possible thanks to the local diversity of ground relief which gave rise to a variety of topoclimatic conditions (temperature, humidity, length of the vegetation period) which can also be observed in our times. This kind of situation probably existed also in the periglacial climate. Studies of microclimate in the Spitsbergen Islands revealed considerable differentiation of thermal characteristics of periglacial valley sides (Jahn, 1967; Łanczont, Rodzik, 1989).

The highly dissected relief of the area around Wilczyce, with the contrasting southern and northern slopes being its dominant feature (Fig. 2.8.D), caused patches of tundra, steppe, forest-tundra vegetation and open forest groves to develop side by side. A similar picture emerges from the analysis of the many species of fossil fauna excavated in Wilczyce (Nadachowski *et al.*, this volume).

The temperature conditions as reflected in the pollen record for the period around 15 ka suggest that the climate was cold but not homogeneous. MTW figures in the days when the Magdalenian hunters inhabited the area around Wilczyce could have ranged from +14.8 to +16°C, with MTC being from +6°C to −22°C (Fig. 2.34.). The winter temperatures are slightly higher than those reconstructed for the main phase of formation of the fissure structures. This would suggest that the decay phase of these structures coincided with the period we are describing here.

The results of palynological studies may also be seen as providing indirect evidence that the hunters occupying the Wilczyce hill may have used mosses and ferns as insulating materials, if only by covering the stone-paved floors of their dwellings with them. That this could be so is suggested by the absence of spores in samples W7/2007 and W1/2010 which differ in this respect from all the other samples of the two studied series.

THE ENVIRONMENT AROUND WILCZYCE IN THE POST-MAGDALENIAN PERIOD — THE HOLOCENE

Precious little information is available on the Late Vistulian and Early Holocene in the Opatówka river valley. The reason for this is that the valley floor level coincides with the river base level in the Vistula Valley near Dwikozy. In the Late Vistulian, the river regimes evolved from braided river channels to meandering channels, in the process transforming from an intensely aggrading river into a river incising into its own older alluvial beds (Kozarski, Rotnicki, 1978; Kozarski *et al.*, 1988; Liedke, 1993; Starkel, 2001). Moreover, cataglacial phases like the Late Vistulian bring with them intensified erosion processes (Starkel, 2012) which is why there are no sediments to be found in the Opatówka Valley of an age correlating with that of the Magdalenian campsite.

Alluvia, peat and muds began accumulating in the valley towards the end of the Atlantic Period (as indicated by the 6644 ± 80 BP date) and the process gained momentum in the Subatlantic Period of the Younger Holocene — as shown by the accumulation of peaty muds taking place from 2445 ± 95BP to 230 ± 85 BP, i.e. in the period from 796–389 BC to 1483–1892 AD (Dacharzów 2 core). The mud layers overlying the biogenic sediments are quite thick (ca. 3–4 m), with this thickness differing depending

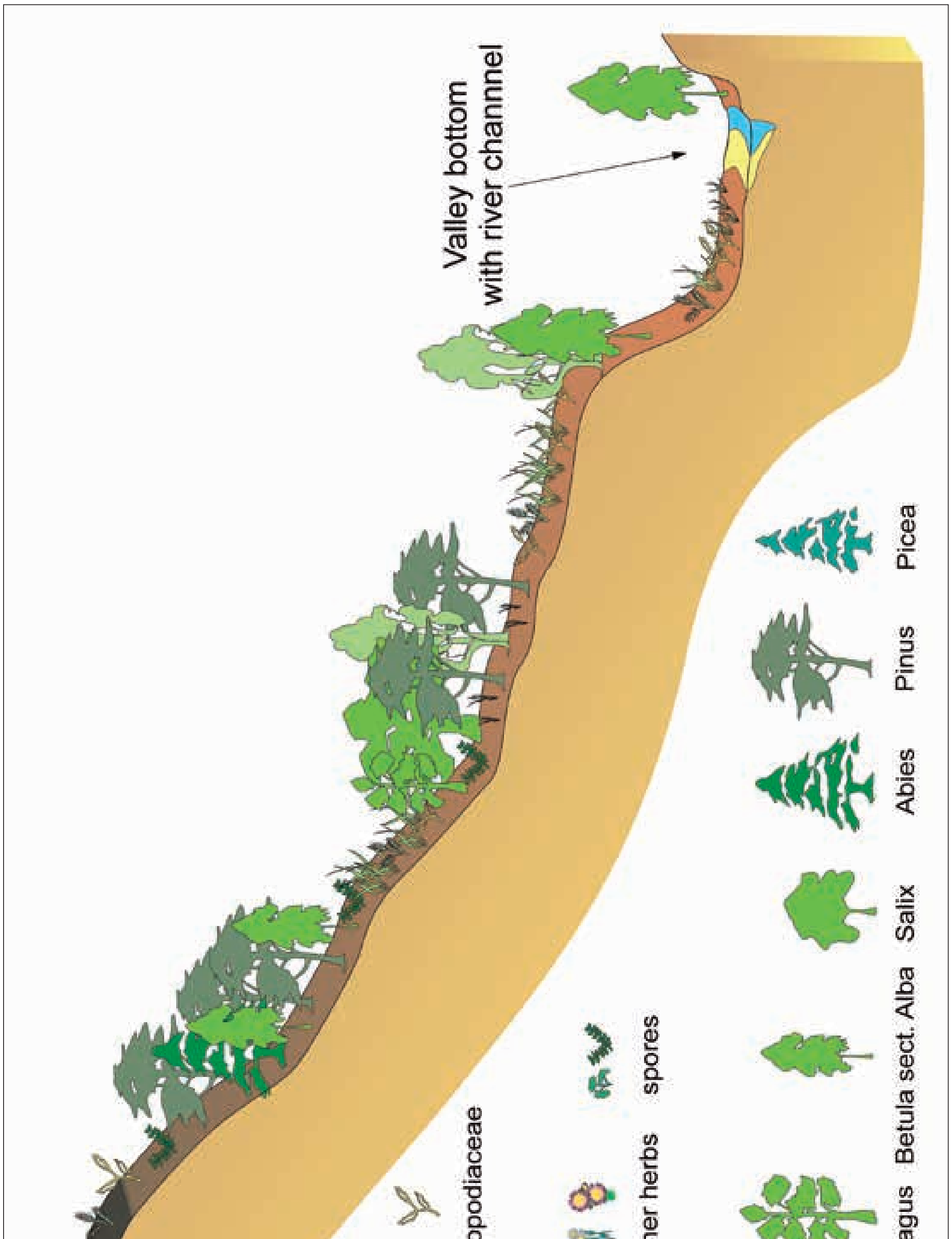


Figure 2.35. Reconstruction of plant cover during Roman influences (*eit*) period.

on where in the valley we look. The muds accumulated in conditions of intensifying deforestation and erosion processes, as evidenced by the high indices of ash content in the sediments —in the ca. 91–96% range (Czerwonka, 2009).

These processes are distinctly in line with developments in the Vistula Valley (Starkel, 2001). The intensified accumulation in the valley was favored by denudation processes taking place in the loess patches. The alluvial fans developing in the Opatówka Valley, especially in its wider sections, elevated the local base levels in places which triggered the aggradation of floodplain. These processes could also have led to fragments of the valley becoming cut off, creating flood basins with better conditions for peat formation and accumulation of muds.

The available pollen analysis results (for Dacharzów 1, Fig. 2.28.) make it possible to reconstruct the vegetation cover for just a brief period in the Younger Holocene (Fig. 2.35.). The analyzed peaty sediments are dated to this period by *Carpinus*, *Abies* and *Fagus* pollen, accompanied by pollen of *Tilia*, *Ulmus* and *Corylus*, by now already infrequent, as well as by anthropogenic markers including cereals and *Plantago lanceolata* pollen, the latter being an indicator of a stress on pastoral husbandry. *Triticum* type and *Secale cereale* pollen were discovered in two samples collected from the topmost beds, which also contain more plentiful pollen of meadow and nitrophilous plants. The presence of rye pollen in them may suggest that the samples could in fact date to the modern era since this cereal started to be grown on a larger scale only since the Roman influences period (*Keiserzeit*), and its pollen dating from earlier times is interpreted in terms of weed presence in fields of other cereals. The pollen analysis results are consistent with radiocarbon dating which places the sediments in the 1390 ± 50 BP and 1410 ± 90 BP periods (i.e., in the 560–710 AD and 423–780 AD periods, respectively, at two Σ), at the same time documenting the relatively brief episode of accumulation of the analyzed peaty muds which probably took place in the Roman Period.

Centuries of land tillage led in many places to substantial erosion of the mantle of mature Late Glacial/Holocene soils which developed on the loesses. Based on the typical thickness of this layer of Luvisols (lessivé soil) and knowing the depth at which the decalcification limit (separating the soil horizons from the non-weathered primary loess) can be found, we may safely assume that the original ground surface was lowered by about 2 m. As a result, what we have today within the summit of the Wilczyce hill accommodating the site and the adjacent slopes are mostly transformed and reduced soils of the ApBt-C-Cca profiles (according to *Klasyfikacja Gleb Polski* [Classification of Soils in Poland], 2011). The tilled horizon in this case is the illuvial level (ApBt), everywhere of relic character, displaying features of the argillic diagnostic horizon (decalcification and a colloidal fraction level exceeding that in the bedrock), documented micromorphologically with the finest-grained fraction of illuvial origin forming encrustations and intrachannel fillings. Denudation is so severe in places that the loess bedrock (Cca) became exposed. As the original surface of the summit wore off and became lowered, the relief of the hill slopes was smoothed out as the gray brown soils in the small gulleys and cupholes cutting into the slopes were gradually filled in with deluvial material redeposited from higher up the hill as the soil horizons became denuded in the course of agricultural activities (Apdel1–Adel2...). A similar situation is observed at the foot of the Wilczyce hill where it descends to the bottom of the Opatówka Valley. Here too we have sequence of Luvisol-deluvial soils, up to 2 m thick in places. Beds of the degraded loess and soil erosion products accumulated in fan-shaped, inerfingering alluvial fans forming at the mouths of all the tributary valleys and burying beneath them the biogenic layers.

The past few centuries witnessed also an intensification of gully-forming erosion processes which remodeled the original relief in the dry valleys in the slopes. The uppermost sections of the slopes in particular feature complex gully systems, cutting through the loess mantle down all the way to the older bedrock. Forms comprising these systems are also accompanied by road gullies which are still in use today, and both the former and the latter share pretty much the same origin. Many of the gullies — especially the N–S-oriented ones and those leading in the direction of Sandomierz in the vicinity of Dacharzów and Radoszki — are in fact abandoned road gullies. The hill summit with the site is also traversed by a 260-m long road gully linking the municipal road with the former manor. In its lower-lying section, this latter gully incises into the sediment to a depth of more than 1.5 m.

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