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EXAMPLES OF LANDSCAPE RECONSTRUCTIONS NEAR THE EASTERN RANGE OF THE MAGDALENIAN OCCUPATION (SE POLAND) BASED ON GIS ANALYSIS

ABSTRACT: SE Poland – the Carpathian foreland and the northern part of the Carpathian Mountains – is a marginal, easternmost part of the area settled by Magdalenian people. Several sites of this culture were investigated in this area by archaeologists and naturalists during the last decades. Based on the results of those studies, landscape of the surroundings of three Magdalenian camps (within direct penetration range) was reconstructed in detail.

GIS spatial analysis was used for 2D and 3D visualization of topographic surface features, both primary (slope and aspect) and secondary ones. The latter (viewshed and insolation) were calculated applying algorithms, based on DEMs (Digital elevation model) and other variables. On the relief maps of the sites' surroundings there were schematically presented the extent of the main types of plant communities (tundra, steppe, meadow, mixed forest, aquatic and peatland vegetation) at the time of settlement. All mentioned communities occurred near each of the investigated sites but in different proportions depending on the site age and altitude.

Attractiveness of the studied sites for Magdalenian hunters resulted among others from: good topoclimatic location resulting in favourable insolation of the sites, location in the leeward sides of high relief elements protecting them from the westerly winds. Moreover, a vast view over the surrounding areas enabled hunters to observe migrating animal herds and set traps, especially in the widenings of the valleys closed at both ends by narrowings. Rich dwarf or meadow steppe and patches of dwarf tundra occurring in the valleys, were good pasturage for herbivorous animals hunted by Magdalenian people.

KEY WORDS: Magdalenian – Geoarcheology – DEM – Palaeolandscape – Carpathian region

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INTRODUCTION

Magdalenian culture or Magdalenian technocomplex – one of the best known taxonomic units distinguished in the prehistory of Europe – has been studied by archaeologists since the second half of the 19th century (Kozłowski, Kozłowski 1996, Połtowicz-Bobak 2013, Svoboda 2000). Since the second half of the 20th century the extensive archaeological excavations in the sites of this culture have been accompanied by the research conducted by naturalists. Geoarchaeological, archaeozoological, botanical and other investigations provide more detailed information about the location of campsites and way of life of the Magdalenian people against a background of environmental conditions (e.g. Schild Ed. 2014).

The oldest traces of the Magdalenian culture have been found in its cradle – South-Western Europe – and date from the end of the Vistulian pleniglacial corresponding to the younger part of MIS 2 (21,000–20,000 cal BP). In archaeological literature (cited below), concerning the Magdalenian culture in the main area of its development, the contemporary environmental conditions, and especially vegetation cover, are considered to a small degree. Information about vegetation usually derives from palaeobotanical data obtained for the areas adjacent to archaeological sites, and is supplemented with numerous results of radiocarbon dating as it is for example in the studies of several centres of the Magdalenian settlement in the Iberian Peninsula. In the interior of peninsula the Magdalenian settlement developed continuously from 21,440 to 12,570 cal BP, both in warmer and colder periods, and all the time trees co-occurred with herbaceous plants, and around the mountain sites also with typical mountain vegetation (Cacho *et al.* 2012). In the zone of the Atlantic coast in Portugal the occurrence of evergreen trees together with other trees and herbaceous vegetation during the whole period of the Magdalenian settlement after the Last Glacial Maximum is found out (Bicho, Haws 2012). The sources of information about the environment in the surroundings of larger Magdalenian cave sites in Western Europe are indirect. These are palaeo-zoological data indicating ecological requirements of animals, the remains of which have been discovered in cave deposits. Such example is the El Mirón Cave in the Cantabrian region, where rich remains of small and big mammals are preserved in the whole deposit profile containing the traces of Magdalenian settlement (Straus, González Morales 2012, Cuenca-Bescós *et al.* 2012). The analysis of those remains indicates the continuous occurrence of various forest and meadow communities in the site surroundings, with the predominance of forests in colder periods. Sometimes only total faunal composition for the whole thickness of cave deposits is given in the literature (e.g. for the sites in SW France – Langlais *et al.* 2012), and then the obtained information about vegetation is more general and averaged. Open, woodless landscaped predominated in loess areas located much further to the north, where the remnants of short-term camps, associated probably with raw material exploitation, are found (Street *et al.* 2012, Rensink 2012).

During the peak development of the Magdalenian settlement in Western Europe, the Polish Lowland was covered by the Vistulian (LGM) ice sheet during the successive Leszno and Poznań Phases (*Figure 1A*). The area between the ice-sheet front and mountain ranges (Carpathians and Sudetes) was arctic desert (250 km wide zone) with aeolian activity, and further to the south a mosaic of poor tundra and tundra-steppe vegetation occurred, with patches of trees preserved in sheltered basins of the Carpathian foothills (Starkel 1988a, 1988b, 1994, Schild Ed. 2014, Łanczont, Madeyska Eds. 2015). The earliest, pioneer penetration of the Magdalenian people into the eastern part of Central Europe, recorded in the Maszycka Cave (Kraków-Częstochowa Upland), occurred in the phase of ice-sheet retreat after the Pomeranian stage, and is dated to the period from 16,350 to 16,100 cal BC (Kozłowski *et al.* 2012), which corresponds to GS-2c in the Greenland Scale (Rasmussen *et al.* 2006, Svensson *et al.* 2006).

The main stage of recolonization occurred in this area where the ice sheet retreated to the zone of southern coast and then to the place of present-day Baltic Sea basin (*Figure 1A*) at the end of Upper Pleniglacial and the beginning of Late Glacial (GS-2a – GL-1e in the Greenland scale; Björck *at al.* 1998). The twilight of Magdalenian expansion in Poland is dated to the Allerød interphase of Late Glacial (warmer period GI-1c-1a in the Greenland scale) (Połtowicz-Bobak 2012). Distribution of almost 40 Magdalenian sites discovered and examined in Poland indicates that population of this culture penetrated terrains as far as the right-bank part of the Vistula River basin in eastern Poland (Kozłowski *et al.* 2012, Ginter *et al.* 2002, Połtowicz 2006, Wiśniewski *et al.* 2012, Miller 2012, Otte 2012, Połtowicz-Bobak 2012, 2013). The newly-settled territories stretched between the Middle Polish lowlands and the northern slopes of the Sudetes and

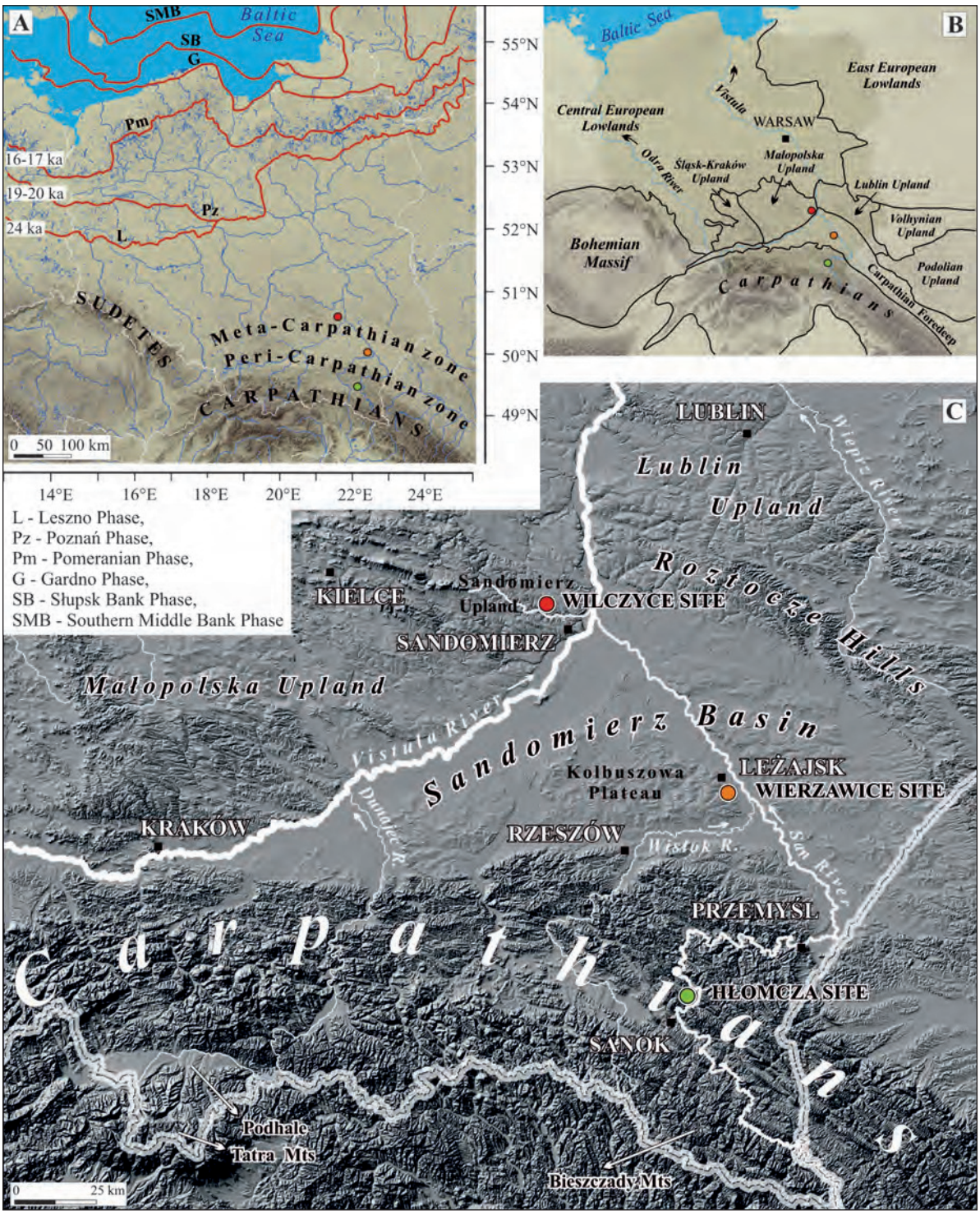


FIGURE 1. Location of the the Hłomcza, Wierzawice and Wilczyce sites in relation to: A, limits and ages of the major glacial phases during Late Vistulian in Poland and neighbouring areas: L, Leszno Phase; Pz, Poznań Phase; Pm, Pomeranian Phase; G, Gardno Phase; SB, Słupsk Bank Phase; SMB, Southern Middle Bank Phase (according to Marks 2012). B, main geographical regions of Central Europe; C, relief (source: SRTM data) and geographical regions of SE Poland, according to Kondracki (1998).

Carpathians (*Figure 1B, C*). The eastern area of the settlement concentration, named by Połtowicz-Bobak (2013) as "the Małopolska Centre", was connected with the valleys of the Vistula and San rivers and with the southern part of the Kraków-Częstochowa Upland. Few sites are located in the Carpathian region.

Period of Magdalenian recolonization was characterized by several, rapid and considerable climate changes, which resulted in transformations of bio-geosystems in the regions of southern Poland. Great changes occurred in river valleys where braided river channels changed into large meanders. The beginning of Late Glacial (Oldest Dryas) on the areas penetrated by the Magdalenian people was characterized by the occurrence of tundra in upland zone, and tundra with single trees – in mountain foothills and low mountains. Later, during the next period of cold climate (Older Dryas), it was park tundra with birch and heliophyta, and park tundra with birch and conifers, respectively. During the climate warming of Bølling the mentioned areas were covered by loose birch forests with aspen and heliophyta, and by loose mixed forests with heliophyta and tundra patches, and then, during the second warming (Allerød) – by a mosaic of forest, tundra and steppe, and loose mixed forest. Generally, in Late Vistulian the described areas were characterized by gradual development of soil cover, continuous tendency towards increasing species richness of plant communities (some species expanded from Carpathian refugia), and increasing amount of steppe elements eastwards (Komar *et al.* 2015, Madeyska 1998).

The aim of our study was to present the examples of detailed reconstruction of the environmental conditions near three Magdalenian camps. GIS spatial analysis was used for the reconstruction and graphic presentation of the surrounding landscape together with vegetation cover. The available palaeobotanical data, as well as geological and geomorphological field survey were used.

MATERIAL AND SELECTION OF SITES

In SE Poland, from the Moravian Gate to the east, archaeologists have discovered 9 Magdalenian cave sites in the Kraków-Częstochowa Upland and 19 open-air sites in the Carpathians and their northern foreland (Połtowicz-Bobak 2013). In recent years several sites from the latter group were studied by mulitidisciplinary teams, and the authors of this paper participated in some of these investigations.

For the analysis there were selected three Magdalenian open-air sites, i.e. Hłomcza 1, Wierzawice 31 and Wilczyce 10, occurring on the eastern periphery of this culture in Poland. The selected sites differ in age. In the Hłomcza and Wierzawice sites the archaeological finds occurred in original positions. The Wilczyce site was located in a depression formed in place of a degraded ice wedge cast, and the artefacts were slightly displaced during degradation of this periglacial structure. All three sites are located in river valleys as such location is a quite typical feature of the Magdalenian settlement (Połtowicz-Bobak 2009, 2012). River valleys were important communication routes and ecological corridors so they influenced both the spread of settlement and the size of exploited area (e.g. Otte 2012, Połtowicz-Bobak 2012, 2013). We selected the sites located in river valleys in order to analyse the advantages of such location and to point out these features of the sites, which were important for occupants.

Hłomcza and Wierzawice sites are located in the San River valley (medium-size river in the Central European scale; 457.76 km long), in the Carpathians and their foreland, respectively. Third site, the Wilczyce site, is located in the valley of small Opatówka River (55.88 km long) (*Figure 1C*). Both mentioned rivers are tributaries of the Vistula River, and they are rivers of trans-regional nature, which connect ecologically different regions. Taking into account the geological criterion, all studied sites are located in the areas covered by loess or loess-like deposits.

In the investigated sites the Magdalenian artefacts were found just below the ground surface (Bobak *et al.* 2010, Łanczont *et al.* 2014b, Valde-Nowak, Muzyczuk 2000) so the main problem is to estimate the degree to which the present-day relief corresponds to the relief of the Magdalenian settlement time. There is uncertainty as to the amount of mineral deposits accumulated in a site area after settlement episode and the degree of later denudation. The analysis of Holocene soils developed on loess in the surroundings of the studied sites indicates that these soils have been affected by denudation to varying degrees, even to mineral substratum, due to deforestation and long-lasting agricultural use of these areas (Bałaga *et al.* 2008, Łanczont *et al.* 2000, 2002, Bobak *et al.* 2010, Dobrzański, Malicki 1949, Turski, Witkowska-Walczak 2004). The denudation products were deposited in the slope troughs and small erosion-denudation valleys, at the foots of slopes and in the bottoms of river valleys. Based on the typical thickness of soil profile and the

depth to which loess is decalcified, there is approximately estimated that the primary surface of denuded slopes and hilltops was lowered by about 1.5–2 m. At the same time the concave elements of slopes became more gentle. Then, the main changes of the primary relief in Polish loess areas consisted in planation of undulating microrelief of aeolian origin (Rejman *et al.* 2005, Rodzik *et al.* 2014). Generally, relief changes in the immediate surroundings of selected sites were not great, except the valley bottoms and young gully systems. Therefore, we think that the reconstructions of Magdalenian landscapes can be reliably based on GIS analysis of the morphological features of the present-day relief.

The selected three sites were investigated using the same methods. The gathered observations – geological and sedimentological (analyses of deposit profiles in borings and exposures), geomorphological (mapping), palaeobotanical, and in one case also palaeozoological – were the source of information about relief, vegetation cover and landscapes in the time of Magdalenian settlement. GIS spatial analysis was used for visualization of topographic surface features and diversity of vegetation cover in the sites' surroundings.

Geological and geomorphological settings of sites and their characteristic

Carpathian site – Hłomcza. *Situation.* Hłomcza (precisely Hłomcza 1 site after Valde-Nowak, Muzyczuk 2000) is situated in the mountain section of the San River valley (*Figure 1C*). Several geomorphological units converge in this area (Klimaszewski, Starkel 1972): from the north and west – the ranges of Strzyżów, Dynów and Przemyśl Foothills, from the east – Słonne Mountains, and from the south – Bieszczady Niskie Mountains). The San River is the axis of the examined area, the river basically takes the meridional direction: downstream and upstream of this section the San River flows to the NW. The widening of the San River valley at Hłomcza forms a distinct and isolated local basin situated near the Mrzygłód and Łodzina villages (*Figure 2A*). In a larger geographical context the Hłomcza site is located in a very interesting place. It is the beginning of the gorge section of the San River valley, which connects the foothill, wide section of this river valley (the section ending in the Przemyśl Gate where the San River leaves the Carpathians, and where a Magdalenian artefact was discovered – see S. K. Kozłowski 1977) with the intra-Carpathian basins with gentle relief, which are named Jasło-Sanok Depression (*Figure 1C* and *2A*).

Geological setting. The area is located on the southern edge of the Skole Nappe – tectonic-facial unit of the Outer Carpathians. This zone is characterised by steeply inclined scale folds. Particular elements and tectonic lines mainly trend NW-SE. Among flysch rocks the dominant are thin- and medium-bedded calcareous sandstones and shales. Pleistocene alluvial and loess-like deposits occur on the sides of valleys, whereas the Holocene alluvia and swampy-organic deposits constitute the bottoms of valleys.

Relief and palaeorelief. The scale-like thrust tectonic structure resulted in the formation of a characteristic, related to the rocks' resistance, style of ridge-valley relief. This relief is reflected in the trellised drainage pattern, which is composed of narrow longitudinal segments and shorter transversal segments. The ridges are long, regular and narrow, and are characterized by steep slopes with relative height of 130–150 m (*Figure 2B*). The altitudes of remnant hills range from 460 to 500 m a.s.l. Relics of the partial planation surfaces are of little importance in the landscape of the examined area. The San valley is a lateral and insequent valley: meander sections are connected with epigenesis (Starkel 1969, Zuchiewicz 2009). Regarding the relief of this area, quite a peculiarity is a 67 m high, epigenetic, meander mountain (Diabla Góra) (*Figure 2A*). Three Pleistocene terraces occur in the analysed part of the San River valley. The lowest Pleistocene terrace, 10–15 m high, dated to the Vistulian glaciation, is found on both sides of the river in the form of irregularly spread narrow patches. The system of Holocene accumulation terraces occurs in the wide bottom of the San River valley.

The site occurs at 283.6 m a.s.l. on the Vistulian-age terrace, which forms a promontory protruding eastwards to the river and separated from the Holocene bottom of the valley by a very distinct, 5 m high erosion edge. To the NW the area gently slopes towards the valley of a small, nameless stream. From the W the terrace adjoins the slope of the Przysnop remnant mountain reaching 445 m a.s.l. The morphological situation in the Magdalenian time was different from the above-described present-day relief in that the braided channels of the contemporary San River could have still functioned on the valley bottom occurring probably at higher altitude at that time. Then, besides the change of river channel pattern, the relief was slightly modified by the deposition of slope deposits (younger than the archaeological site), which formed a thin layer on the surface of the Young Pleistocene terrace. Then, this layer was partially denuded as

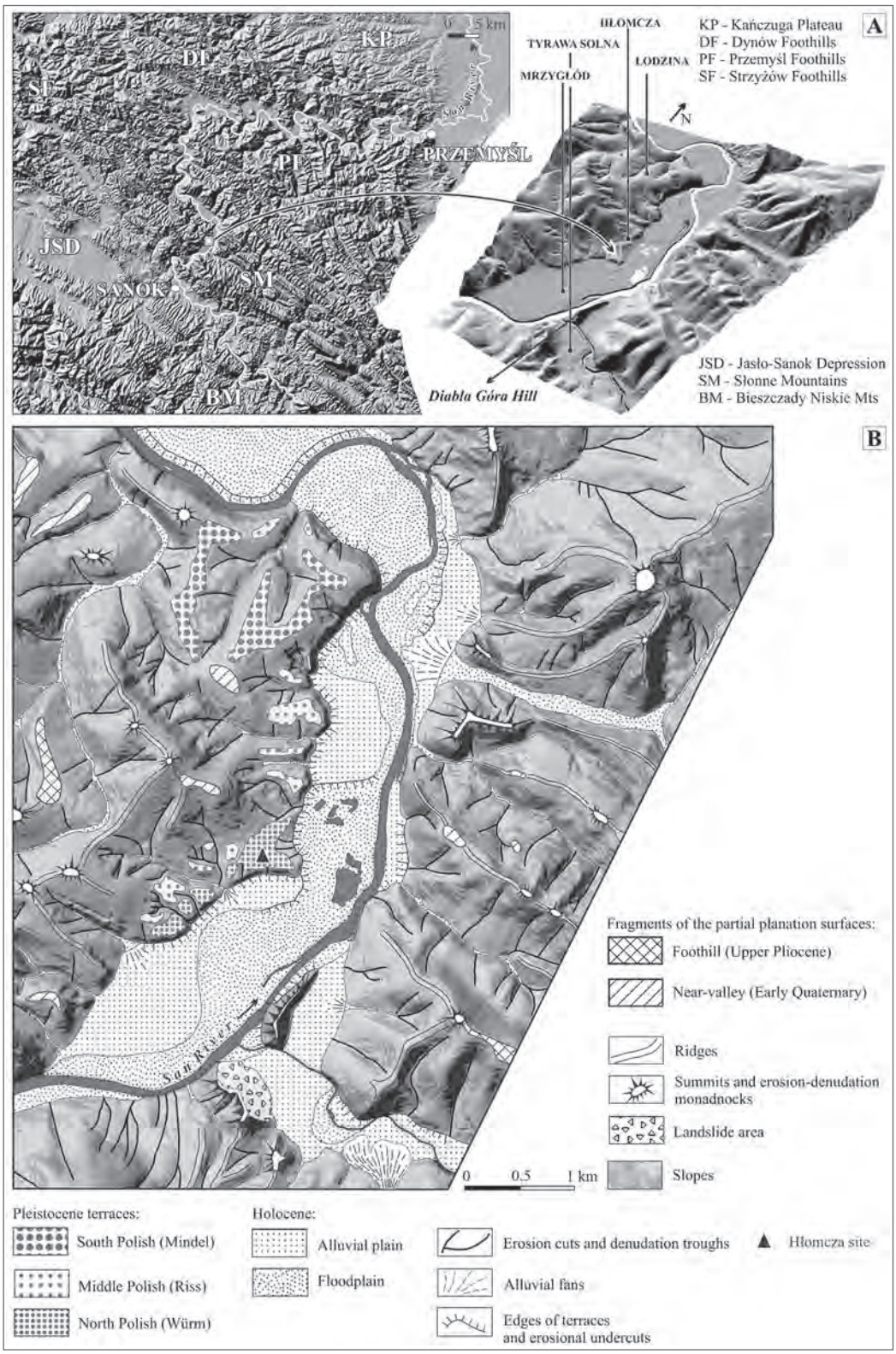


FIGURE 2. Landform model (A) and geomorphological sketch (B) of the Hłomcza area.

indicated by truncation of Holocene soil developed on the colluvia.

Some characteristics of the Magdalenian site at Hłomcza. It was extremely small hunters' camp, which was settled for a short time, probably only once. The traces of a structure, interpreted as hut or yurt, were discovered in the site at a depth of 0.8 m (Łanczont *et al.* 2000, 2002). The site was located 12 km from the local bed of flint at Bircza (Valde-Nowak, Muzyczuk 2000). The occurrence of numerous brine springs near the Hłomcza site (Szajnocha 1891) was important because they undoubtedly attracted animals and humans.

The time of settlement was determined based on the stratigraphy of the profile (the archaeological object is covered by weakly developed palaeosol of Bølling-Allerød age, and sandy deluvial deposits), as well as the TL dating results obtained for the material infilling the object (13.5±2 ka) and for the layer being the topographic surface before the Palaeolithic settlement (14.6±2.3 ka). They indicate that a cold period, according to the traditional system named the younger stage of the Oldest Dryas (it means the episode preceding the interstadial G1-1e in the Greenland scale), was probably the time of Magdalenian settlement episode in the San River valley near Hłomcza (Valde-Nowak, Muzyczuk 2000).

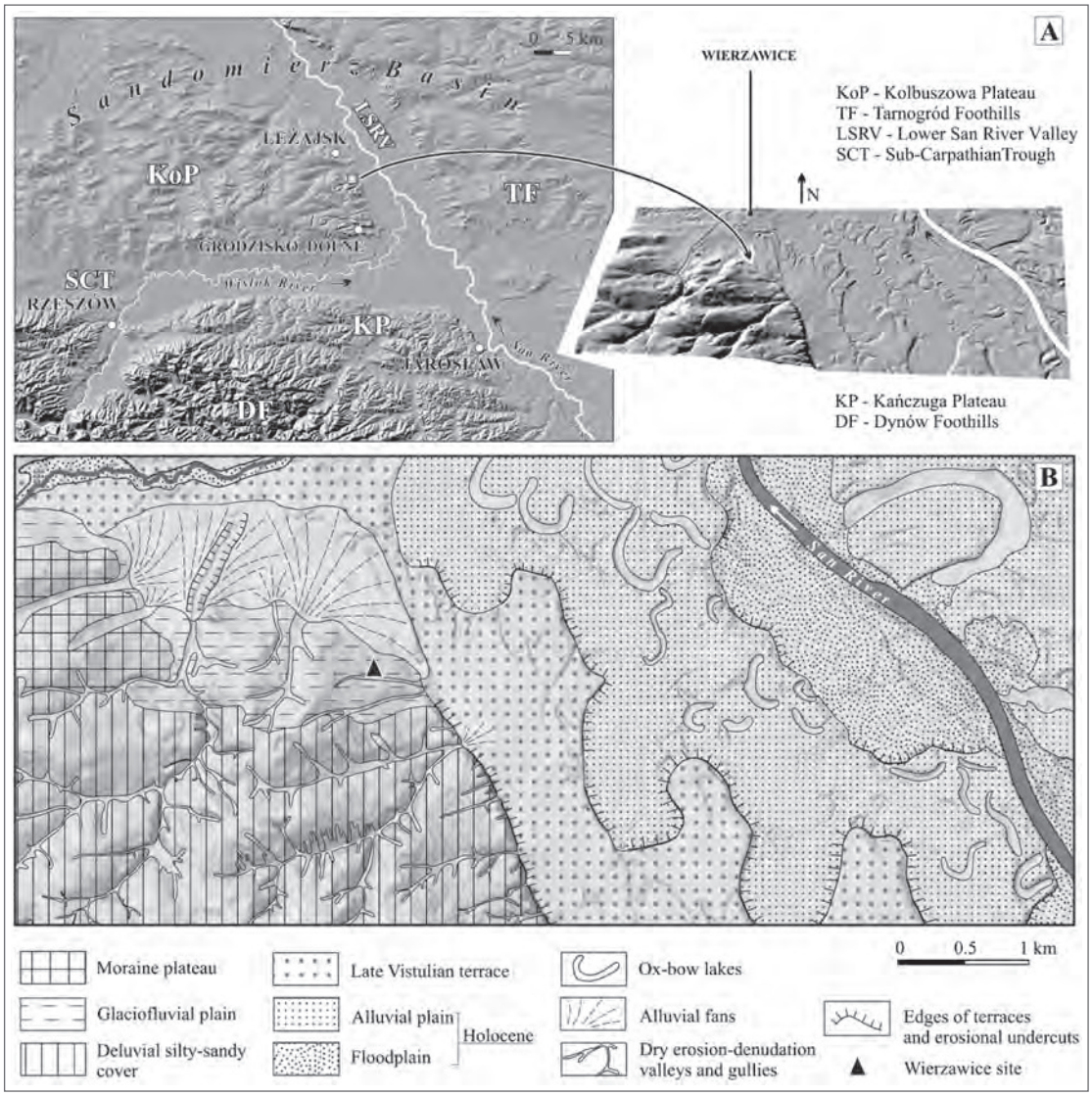


FIGURE 3. Landform model (A) and geomorphological sketch (B) of the Wierzawice area.

Peri-Carpathian site – Wierzawice. *Situation.* The Wierzawice (precisely Wierzawice 31 archaeological site after Bobak *et al.* 2010) is located in the San River valley in its lowland section in the central-eastern part of the foremountain Sandomierz Basin *(Figure 3A)*, in the eastern margin of the Kolbuszowa Plateau mesoregion adjoining the Lower San River valley (Starkel 2005).

Geological setting. The Kolbuszowa Plateau is an inter-valley "bump" cut in the marine (middle Miocene) clayey-sandy deposits. The Quaternary cover is discontinuous and of varying thickness, which locally reaches several dozen metres. The oldest deposits are strips of preglacial gravels. Glacial deposits, formed during the South Polish glaciations, are the most important. The overlying cover of silty-sandy and silty deposits, from several to even 10 m thick, was formed at the close of the Pleistocene by different processes – weathering, aeolian and slope wash (Wieczorek 2001, Wojtanowicz 1997). Younger Pleistocene sands occur on the terraces as discontinuous patches along the San River valley. The valley bottom is covered by the Holocene alluvia and boggy-organic deposits.

Relief and palaeorelief. The Kolbuszowa Plateau rises 40–70 m above the bottoms of surrounding river valleys. The plateau boundaries are distinct scarps, except for the northern boundary. The relief forms of the plateau are of different origin. The old glacial elements are a moraine plateau, and a kame terrace occurring near Leżajsk (Wieczorek 2001). These forms are strongly denuded and transformed under periglacial conditions. The relief is diversified by a regular system of asymmetric denudation valleys, and in the areas covered by thick loess deposits – by a quite dense system of gullies. The San River valley has typically developed elements with a system of Pleistocene terraces. On the Vistulian sandy terrace (8–13 m high) there are traces of braided channels (Szumański 1986, Starkel 2001). This terrace is undercut by the systems of the Late Vistulian large meanders (*Figure 3B*) occurring on the 5–9 m high terrace. The largest ones were formed in the Bølling interphase and cut off in the Older Dryas, while in the Allerød interphase slightly smaller meanders developed, which were abandoned in the Younger Dryas (Starkel 2001, Szumański 1982, 1986). The main part of the Holocene alluvial plain, about 3 km wide, is cut by several generations of small palaeochannels. Traces of braided channels are found on the lower floodplain, which occurs 3–4 m above the river level and is 1–1.5 km wide.

The site is located at 188 m a.s.l., in the lower part of the long, gentle, east-facing slope of the remnant hill rising 221.4 m a.s.l. This coniform summit is the highest point of the region and occurs at a distance of only 700 m from the site; from the top there is a vast view to the N and E, over the valleys. In the time of the Magdalenian settlement the relief of slopes was probably similar to the present-day one because anthropogenic denudation balanced earlier post-Magdalenian deposition. Denudation products overlie fragments of slopes and a near-slope part of the Late Vistulian terrace.

Some characteristics of the Magdalenian site at Wierzawice. This site can be classified as a short-term camp settled by a small group of people. Raw materials, i.e. glacial erratic flint, was accessible in a very short distance from the site (Bobak *et al.* 2010, 2014). The Magdalenian site remnants, among other things the traces of fire inside a circle of stone slabs (Bobak *et al.* 2010, Połtowicz-Bobak 2012), were discovered under 0.5–0.7 m thick cover of slope deposits. The primary thickness of these deposits was probably greater from the present-day one. It is indicated by the fact that the Holocene soil cover, which in non-eroded places is up to 1 m thick (Dobrzański, Malicki 1949, Turski, Witkowska-Walczak 2004), has been completely removed.

Stratigraphy of the Wierzawice profile, investigated in the archaeological trench, and the results of C-14 AMS dating (age between 13,539 and 13,275 cal BP) indicate that the Magdalenian settlement episode in the San River valley near Wierzawice may be correlated with the Allerød interphase (i.e. GI-1c in the Greenland scale) (Bobak *et al.* 2010, 2013, Połtowicz-Bobak 2013).

Meta-Carpathian site – Wilczyce. *Situation.* The Wilczyce (precisely Wilczyce 10 archaeological site after Fiedorczuk, Schild 2002) is located in the Opatówka River valley, about 10 km from its confluence with the Vistula river, in the loess Sandomierz Upland also known as the Opatów Upland (maximum height 260–300 m a.s.l.), which is a part of the eastern foreland of the Holy Cross Mountains (Gilewska 1972, Kondracki 1998; *Figure 4A*).

Geological setting. The site is located in the tectonic depression of the Opatówka River, which was filled in by the Upper Miocene marine deposits. The Quaternary profile consists of two complexes of glacigenic deposits separated by interglacial fluvial series. The youngest Pleistocene unit is loess, which forms a continuous and thick cover. Holocene is

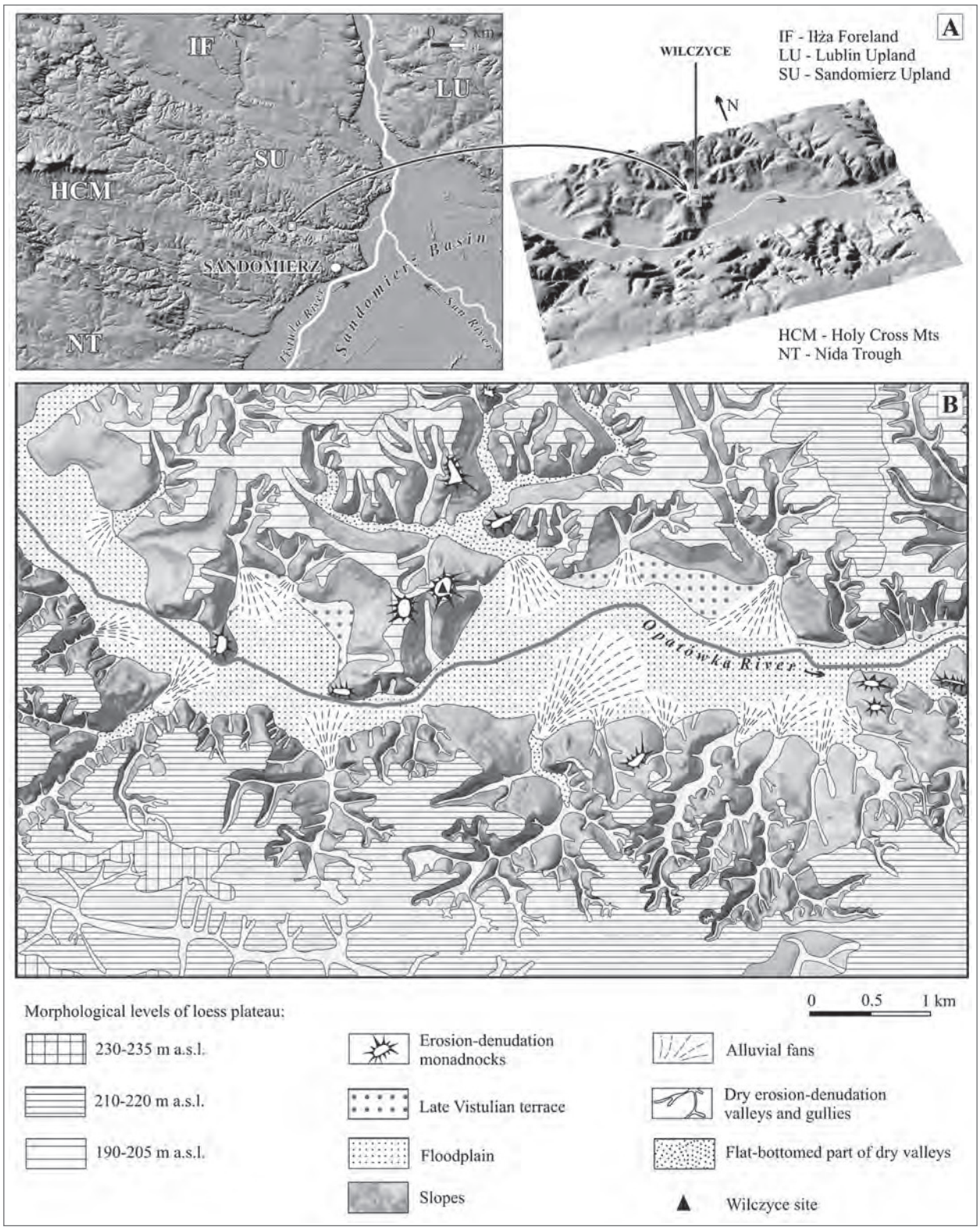


FIGURE 4. Landform model (A) and geomorphological sketch (B) of the Wilczyce area.

represented by fluvial deposits filling the Opatówka River valley – sand, silt, muds, and peaty muds up to a dozen or so metres thick.

Relief and palaeorelief. The main relief elements are river valleys and loess hills (*Figure 4B*). The surface of loess upland is undulating or flat, dissected by a system of dry erosion-denudation valleys. The middle Opatówka River valley is latitudinal axis of the area. To the N of the Opatówka River valley the maximum heights of the upland reach 210–220 m a.s.l., and to the S – about 230–235 m a.s.l. The valley bottom is mostly occupied by floodplain occurring up to 2 m over the river channel (Bałaga *et al.* 2008).

Hill with the Wilczyce archaeological site is exposed as a high promontory in the shape of truncated pyramid (195.0–197.4 m a.s.l.), protruding far into the Opatówka River valley and isolated by steep slopes almost all around, except the narrow land-bridge, which connects the hill with the main part of the loess plateau. The hill is the eastern part of a loess branched ridge, which separates two basin-shaped widenings of the Opatówka River valley.

In the time of the Magdalenian settlement the relief of slopes and hilltop, outside young gullies, was similar to the present-day one because denudation balanced the earlier accumulation of loess. Denudation products were transported mainly to the valley bottom but then they were removed from the catchment. It is indicated by the lack of deposits of that age in the bottom of the Opatówka River valley, which is filled with very young alluvia (Łanczont *et al.* 2014b).

Some characteristics of the Magdalenian site at Wilczyce. The Wilczyce site belongs to rare in Polish territory, large, rich and repeatedly occupied base camp sites (Fiedorczuk, Schild 2002, Schild Ed. 2014). It was located in a large ice wedge cast on the hilltop, which was covered by loess, and then lowered by denudation. The upper part of the layer with artefacts was also denuded. Poligonal cast system was formed in the loess upland during the occurrence of permafrost in LGM.

The site was located several km from the outcrops of Turonian flint and Upper Jurassic chocolate flint (Schild Ed. 2014). It has been estimated that the campsite dates back to the very end of the Upper Pleniglacial (Fiedorczuk *et al.* 2007). Based on the calibrated results of radiocarbon dating, oscillating in a wide range but distinctly concentrated around 15,500 cal BP (Irish *et al.* 2008), this settlement period may be correlated with the older phase of the last cold episode GS-2a (Bobak *et al.* 2013, Połtowicz-Bobak 2012, Nadachowski *et al.* 2014).

GIS-BASED SPATIAL ANALYSIS

Generally, GIS spatial analysis has been more and more commonly used in the investigations of the conditions of archaeological sites' location in relation to relief in the selected European regions. Most papers concern the sites of Holocene age (with Neolithic and younger settlements; e.g. Roughley 2001, Alexakis *et al.* 2007, Ballesteros, Burjachs 2010), more rarely of Pleistocene age (open and cave Palaeolithic campsites; e.g. White 1985, Kamermans, Rensink 1999, Duke, Steele 2010, Garcia 2013, Sahu *et al.* 2014, Neruda 2013, Blinková, Neruda 2013, 2015). Reconstructions of landscape in the surroundings of single sites are also made in local scale (Wiśniewski *et al.* 2012). However, to date there are no publications containing the reconstructions of past landscape together with spatial diversity of vegetation cover in the surroundings of a site. This situation has resulted from several reasons such as the decreasing amount and reliability of environmental materials as we go back into the past, as well as the scarce and fragmentary data, which would enable us to reconstruct palaeorelief determining the features of habitats. For some time the GIS software has been used in spatial archaeology (Kozłowski, Neustupný Eds. 2001) in order to characterize in detail the environmental determinants of sites' location.

GIS tools enable spatial statistical analyses carried out with the aim of finding correlations and relations between the variables. Such analyses require large data sets. In case of archaeological sites, such analyses can be carried out for the Holocene settlement pattern (e.g. Jasiewicz, Hildebrand-Radke 2009). Palaeolithic sites are less numerous and usually far apart so the finding of statistical correlations is very difficult and even impossible. However, statistical analysis was successfully used for the Magdalenian sites (exceptionally numerous and located relatively close to each other) in the Northern Iberian Peninsula in order to describe settlement location preferences (Garcia 2013).

Methods

We used GIS spatial analyses for 2D and 3D visualization of topographic surface features, both primary (such as slope and aspect) and secondary ones. The latter (viewshed and insolation) were calculated applying more complex algorithms, based on DEMs and other variables. The spatial analyses of topographic surface were carried out applying tools and algorithms of Esri's ArcGIS software. At first the detailed Digital

Elevation Models of land surface (DEMs) were created. Then the main topographic features (such as terrain slope and aspect) were calculated, based on the DEMs. These data were used in the further spatial analysis in order to calculate viewshed from each site and insolation of the adjacent areas.

DEM. DEM layer (cell size 2 × 2 m) was generated using the interpolation method Topo to Raster, which is used for creating a model of hydrologically correct surface. Altitudinal data were obtained by manual digitization of hypsometric features from the 1 : 10,000-scale topographic maps (original Coordinate Reference System: code *EPSG 3120* Hłomcza *[Mrzygłód, Witryłów, Tyrawa Solna sheets]* and Wilczyce *[Wilczyce, Garbów, Radoszki, Dwikozy sheets]*; and *EPSG 2180* Wierzawice *[Wierzawice, Piskorowice, Dębno, Miasto sheets]*).

Slope. Terrain slope layer is a derivative of DEM layer. The slope values were classified in order to facilitate the interpretation of calculated slope map. Taking into account local conditions, the slope categories were generalized as follows: 0–2° flat surfaces; 2–10° moderately inclined surfaces; 10–15° strongly inclined surfaces; >15° steep surfaces. These categories of slope values describe the relief forms in the areas where the sites occur, as well as those in the surrounding areas.

Aspect. Raster layer of aspect consists of cells, the values of which represent the directions measured with the use of compass according to the rule of azimuth determination. Therefore, the aspect values range from 0 to 360°. Aspect is a derivative of DEM and slope layers. That is why a perfectly flat surface, which is not inclined in any direction, has no aspect and its value (-1) is outside the scale of values.

Insolation. Insolation of an area is strongly influenced by its topography. The amount of sunlight received by an area depends on local factors (terrain slope and aspect) and topographic shading, which is of global function nature. This function is defined by hemisphere visibility algorithm (Rich *et al.* 1994, Fu, Rich 2002). Total solar radiation reaching the Earth's surface is the sum of direct radiation (calculated from the astronomical position of the Sun relative to the Earth) and diffuse radiation (calculated for each sky sector).

In this work the amount of insolation was calculated for the whole year in monthly interval (in two-hour intervals from sunrise to sunset for each day). The value of variable has modern dimension so not quantitative but qualitative (low – high) characteristics should be used for the interpretation of spatial distribution of insolation.

Insolation of an area was also an important factor conditioning vegetation development and settlement preferences. It had a considerable influence on the existence and functioning of a hunters' camp during season or year. As the contemporary topography near the studied sites was similar to the present-day one, the analysis of insolation, carried out for the sites and their surroundings, was based on the present-day morphological conditions.

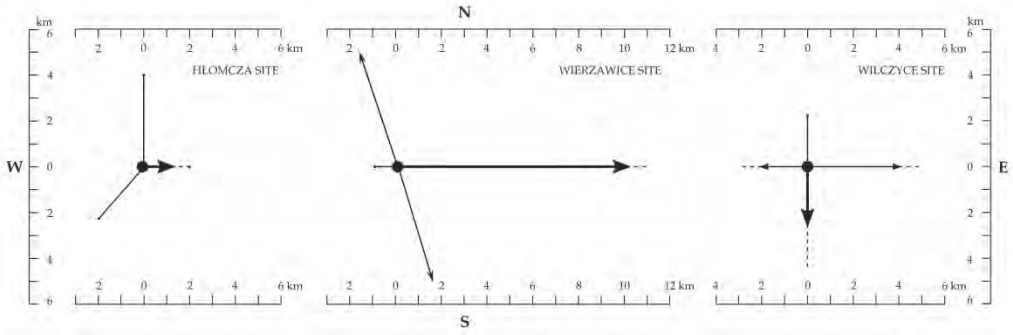
Viewshed. Viewshed analysis belongs to the most useful and most widespread applications of GIS tools in archaeology (Topouzi *et al.* 2000). In this work the viewshed analysis was used to determine the maximum extent of visible topographic surface from a site, calculated from several lookout points, which were located in a site and in its immediate surroundings.

It is evident that visibility depends on the site location. The altitude values were supplemented by offset A, which was here understood as the average height (2 m) of adult man (hunter) representing the Magdalenian Culture (Lieff 2003). The observed surface corresponded to topographic surface (offset B), without taking into consideration the vegetation cover because it was open enough and did not obscure visibility in those times. Viewshed was calculated for the whole azimuthal range (0–360°) and for horizontal plane between the maximum values of vertical angle: upper (0–90°) and lower (0–(-90°)). The calculations were made as one-stage analysis, without division into several vertical angles (Zamora 2011). As a result the binary viewshed was obtained, i.e. the simplified picture reflecting the visibility around a site (Fisher 1996).

Results of spatial analysis

All examined sites were excellent lookout points providing a vast view over the bottoms and sides of the valleys. In case of the Wierzawice site, located on the flat slope, at a distance of a few hundred metres from the valley edge, several meters above the bottom of very wide (about 8 km) valley of the San River (*Figure 6B*), very good viewshed reached 10 km (*Figure 6A*). In the Hłomcza (*Figure 5A*) and Wilczyce (*Figure 7A*) sites the viewshed radius was smaller. Though viewshed was limited due to topography, the geological-geomorphological conditions near these sites (natural narrowings of the valleys) were very favourable for the Magdalenian hunters. The Hłomcza site was located 10 m above the Late Pleniglacial bottom of the San River valley, just near the valley edge (*Figure 5B*). This location provided a view over the 7 km long and 1 km wide valley section with the 250 m and 850 m wide narrowings occurring at its S and

Table 1. Parameters describing location of the studied Magdalenian sites.

Parameters	HŁOMCZA SITE	WIERZAWICE SITE	WILCZYCE SITE
Absolute altitude (m a.s.l.)	282	189	197.5
Relative altitude (m)	15	14	37.5
Relief	Vistulian terrace	Slope	Loess hill
Landscape	Main valley, S-N orientation	Main valley, SE-NW orientation	Tributary valley, W-E orientation
Valley width (km)	0.6-1	8	0.17-1.1
Slope (°)	1-2.7 Flat surface	1.8-2.5 Moderately inclined surface	1.5-2.5 Moderately inclined surface
Aspect	NE and E	NE and E	E and SE
Insolation	High	High	High
Classification	Open-air	Open-air	Open-air
Visibility			

N ends, respectively. Similar situation was found in the Wilczyce site, which was located quite high (over 30 m) above the valley bottom (*Figure 7B*), on the third, lowest morphological level (190–205 m a.s.l.) of the loess plateau. From the site there was an excellent view over the 6 km long and 1 km wide section of the Opatówka River valley, with the 170 m wide narrowings at the W and E ends of the section. The camps in these two sites were located in strategic points in respect of observation, in the middle parts of the wide valleys' sections, the lengths of which were about 10 km, i.e. within the limits of human eye excellent perception. Therefore, the Magdalenian hunters could have observed migration of animals without the necessity of moving from the camp (*Table 1*).

The examined sites are located in three different geomorphological positions. However, in each case the location is characterized by a very low surface inclination angle: from the flat terrace surface at Hłomcza (1–2.5°) (*Figure 5C*), through the gentle slope at Wierzawice (1.8–2.5°) (*Figure 6C*), to the flat plateau at Wilczyce (1.5–2.4°) (*Figure 7C*). The highest slope values are measured on the erosional edges and valleys' sides. In the post-glacial period these valleys were dissected and deepened, and their sides (as well as the near-valley parts of plateau surfaces in the Carpathian foreland) were transformed by the systems of basin-shaped small valleys, sometimes of gully nature (*Table 1*).

The Hłomcza and Wierzawice sites are located on the NE and E facing sides of the valleys (*Figures 5D and 6D*). This fact results from the location of these sites on the left side of the San River valley, which runs along meridional and sub-meridional direction in the described sections. The Wilczyce site is located on the mostly E and SE facing promontory of the loess plateau (*Figure 7D*), on the north side of the Opatówka River valley, which runs latitudinally.

Insolation of an area depends on the altitude, terrain aspect and slope. For this reason the greatest contrast between the maximum and minimum values of annual insolation are observed in the Hłomcza surroundings (*Figures 5E, 6E and 7E*). Due to the

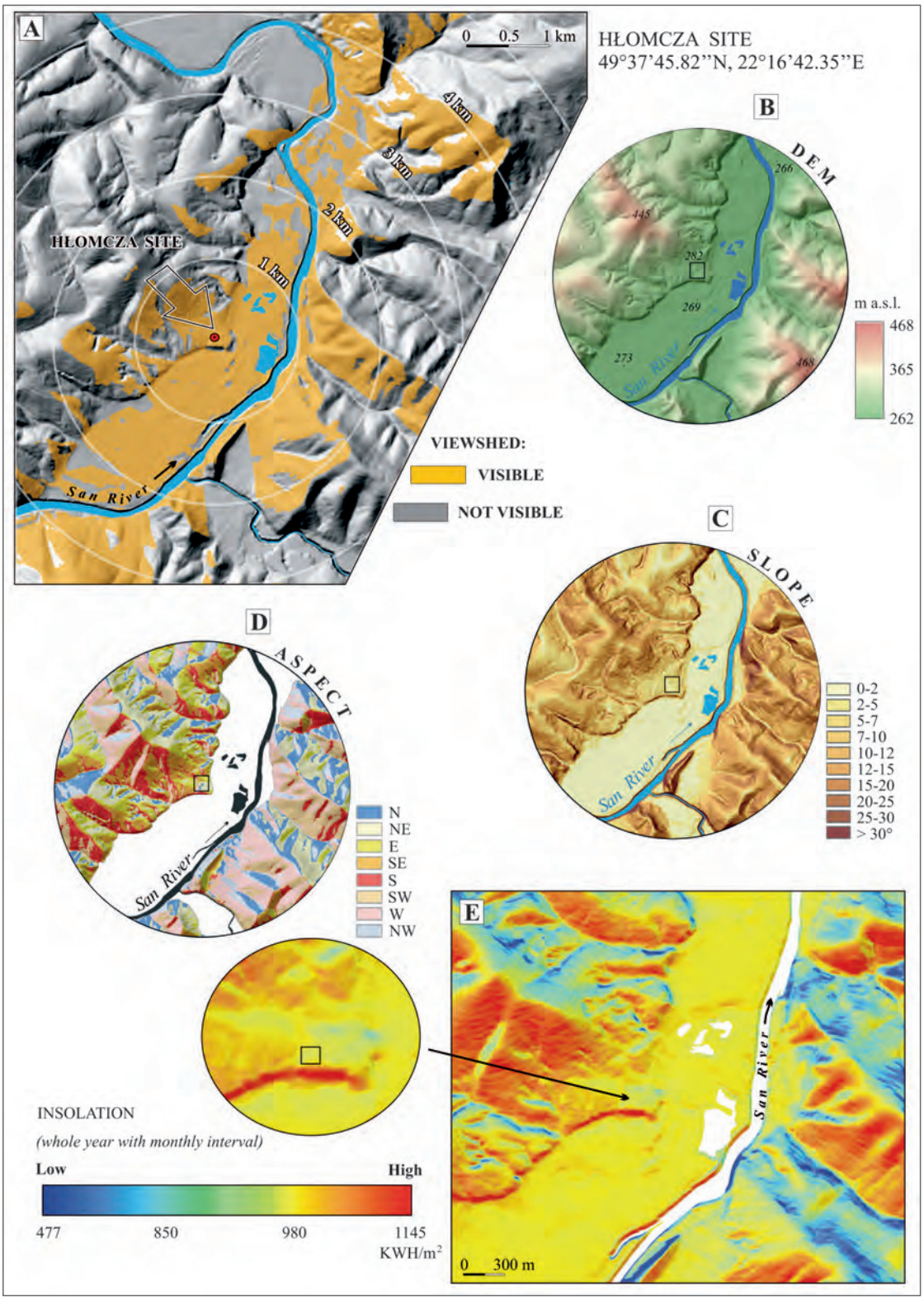


FIGURE 5. Spatial analysis of the Hłomcza site: A, viewshed; B, DEM; C, slope; D, aspect; E, insolation.

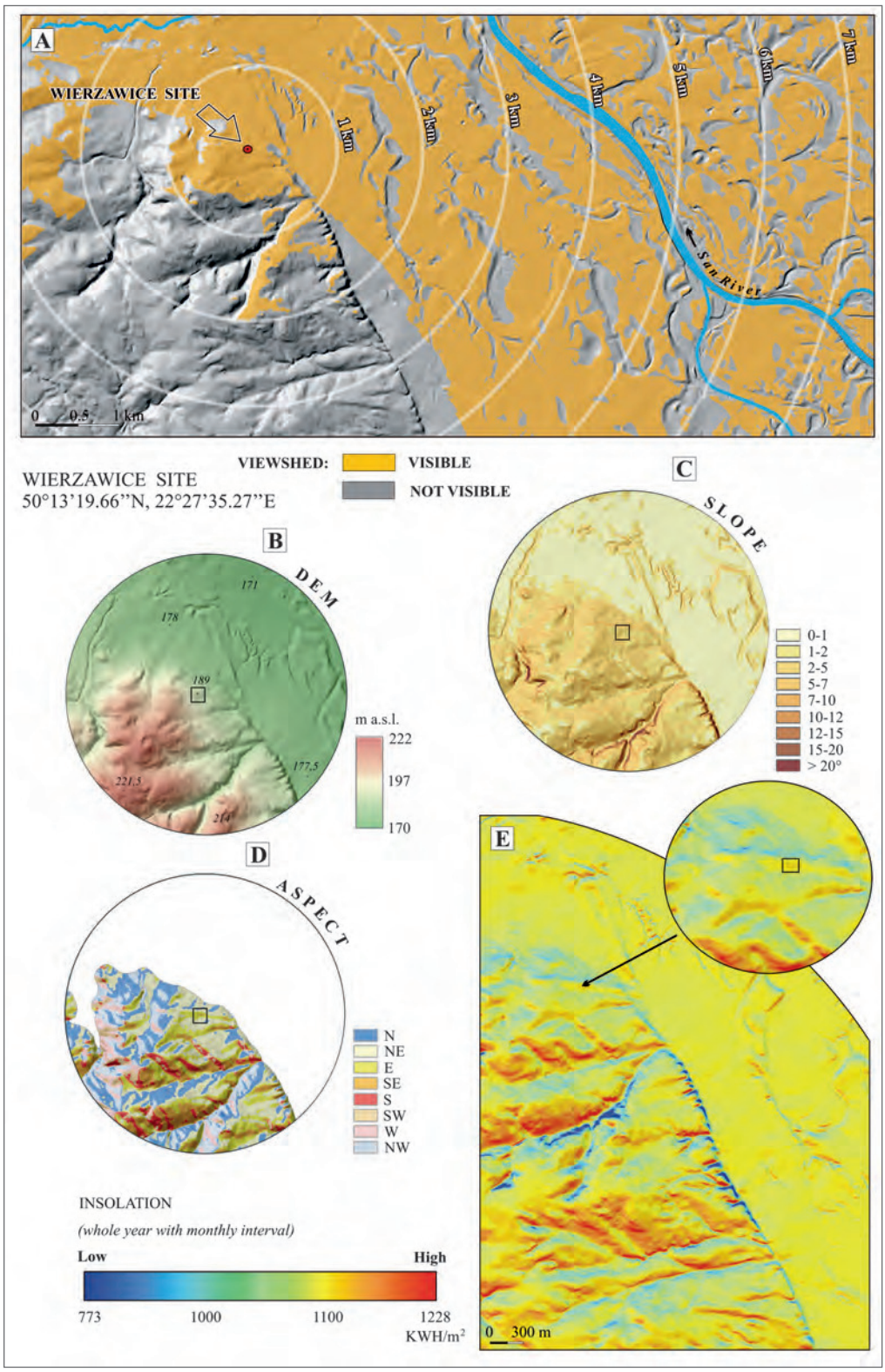


FIGURE 6. Spatial analysis of the Wierzawice site: A, viewshed; B, DEM; C, slope; D, aspect; E, insolation.

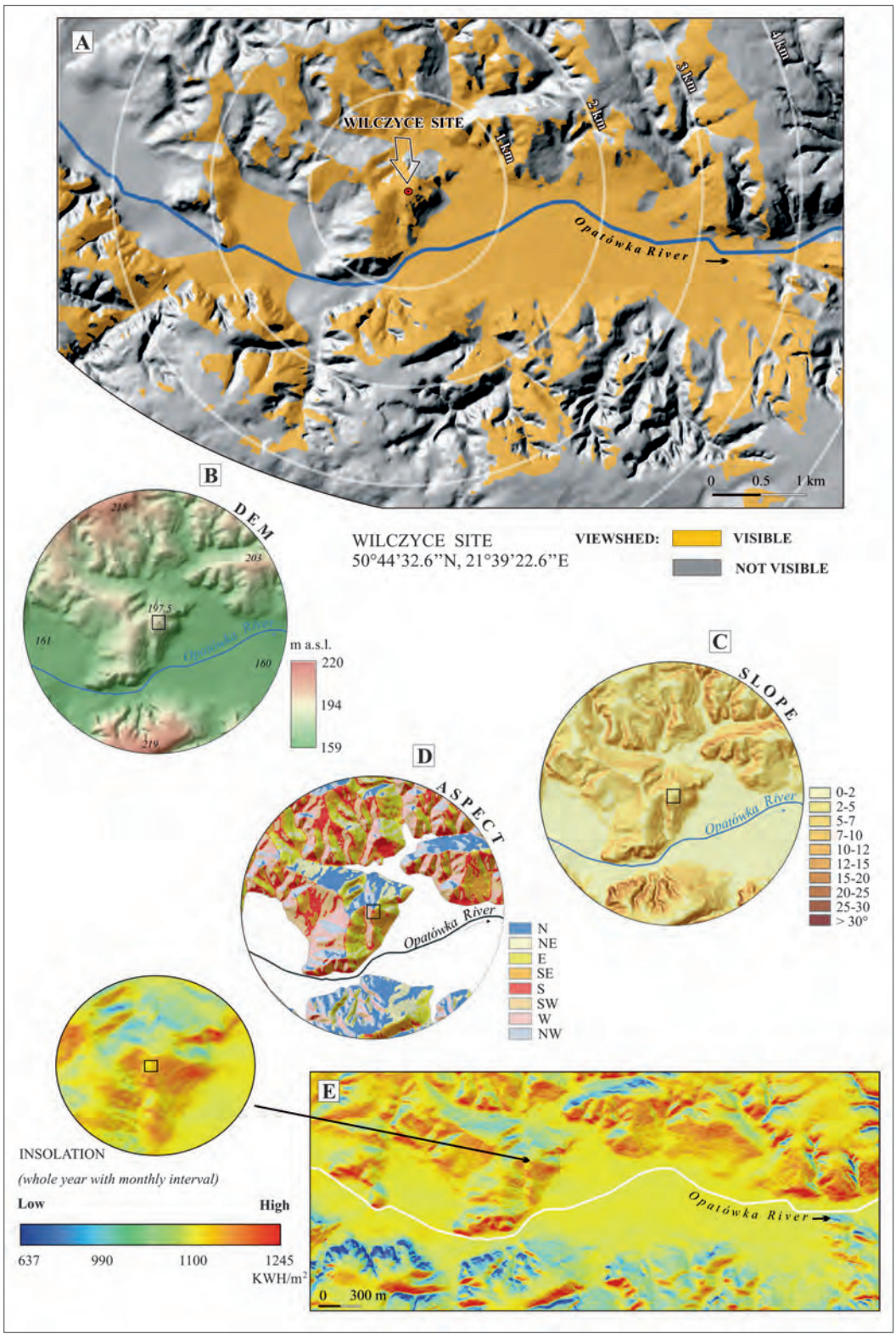


FIGURE 7. Spatial analysis of the Wilczyce site: A, viewshed; B, DEM; C, slope; D, aspect; E, insolation.

diversified loess relief the Wilczyce area is also characterized by larger differences in the amount of solar radiation received over the year than the Wierzawice area. However, due to geographical situation and surface aspects of the sites, the highest insolation occurs in the Wilczyce site, and the lowest – in the Hłomcza site. Generally, all examined sites are characterized by high annual insolation (*Table 1*). As relatively warm places, they were favourable to stays of the Magdalenian hunters.

RECONSTRUCTION OF VEGETATION COVER

Methods

Reconstruction of vegetation cover near the sites was based on the analysis of palynological data published by different authors. The used palynological data have been obtained by the following palaeobotanics: K. Bałaga, K. Harmata, P. Kołaczek, M. Komar, W. Koperowa, K. Mamakowa and M. Ralska-Jasiewiczowa. These were pollen analyses of organogenic deposits accumulated in lake or swamp basins situated at a distance of about several to tens of kilometres (exceptionally even farther) from the studied sites. In case of the Wilczyce site there were used the pollen analysis results obtained for mineral deposits occurring in this site. In the interpretation of these last data we took into account the methodological remarks published among others by N. Bolikhowskaya (1995), N. Gerasimenko (2006) and M. Komar (2011). These authors specialize in the investigations of loess-soil sequences in order to reconstruct vegetation cover in cold glacial periods.

Each pollen analysis provides information about the occurrence of particular plant species growing at different distance from the sampling place, depending on the ability of pollen grains to be transported over long or short distance. This information is approximate due to different pollen productivity of particular species as well as the way and extent of their spread (Latałowa 2004). The composition of pollen spectrum indicates approximate total species composition of all plant communities growing in a large region. We describe individual vegetation communities based on the interpretations of palynologists and data about the present-day extent of pollen dispersal (Pidek *et al.* 2010, Poska, Pidek 2010, Sugita *et al.* 2010). Habitats of main types of vegetation communities were distinguished taking into account the whole combination of environmental conditions such as basement lithology, relief and associated features (altitude, slope, aspect, water conditions, topoclimate diversity), and relating them to habitat requirements of particular species. Reconstruction presented in this paper is an estimate conducted in order to visualize the spatial distribution of plant communities near archaeological sites. Similar attempts to reconstruct plant cover were successfully made in the Seret River valley (Podolia) near the Middle Palaeolithic site at Pronyatyn (Łanczont *et al.* 2015c), in the plateau-slope-valley toposequences in the Gravettian site at Kraków-Spadzista (Łanczont *et al.* 2015a, 2015b) and Magdalenian site at Wilczyce (Łanczont *et al.* 2014b). Next similar studies were conducted in some sites between the Dniester and Dnieper rivers in order to show latitudinal diversity of vegetation cover during MIS 7 (Łanczont *et al.* 2014a).

Additional information about vegetation cover was provided by faunal composition of the remnants discovered in the Wilczyce site due to the occurrence of animal species with specific habitat requirements.

Results of vegetation cover

Hłomcza. Based on the results of palaeobotanical analyses of the sites situated in the adjacent regions, we deduced what environmental conditions prevailed in the Late Glacial in the environs of Hłomcza. Vegetation of the Oldest Dryas and Bølling was described only in one Carpathian site: Jasło 4, which is situated 60 km to the west of Hłomcza, in the Jasiołka River valley, at 250 m a.s.l. Loose park landscape was typical of the Jasło surroundings in the Oldest Dryas.

Vegetation of the Older Dryas and next periods was identified in the pollen diagrams obtained for the following nearby sites: Tarnawa Wyżna – situated in the San River valley in the Bieszczady Mts. at 670 m a.s.l. (Ralska-Jasiewiczowa 1980), 65 km to SSE of Hłomcza; Podbukowina – in the San River terrace, 230 m a.s.l., 20 km to NNE of Hłomcza (Mamakowa 1962); Besko – situated at 290 m a.s.l., 25 km to WNW of Hłomcza (Koperowa 1970); Roztoki and Tarnawce, 50 km to WNW Hłomcza (Harmata 1987, 1995).

To sum up, the Late Vistulian vegetation in the whole area was changing to a small degree, and its nature depended mostly on the altitude. For example, open landscapes with slightly diversified herbaceous vegetation, juniper, sea buckthorn and willow predominated in the lower parts of the Bieszczady Mts. Trees (pine, Swiss stone pine and larch) probably occurred in groups. Park type vegetation with spruce occupied the depressions of wide Carpathian basins and valleys.

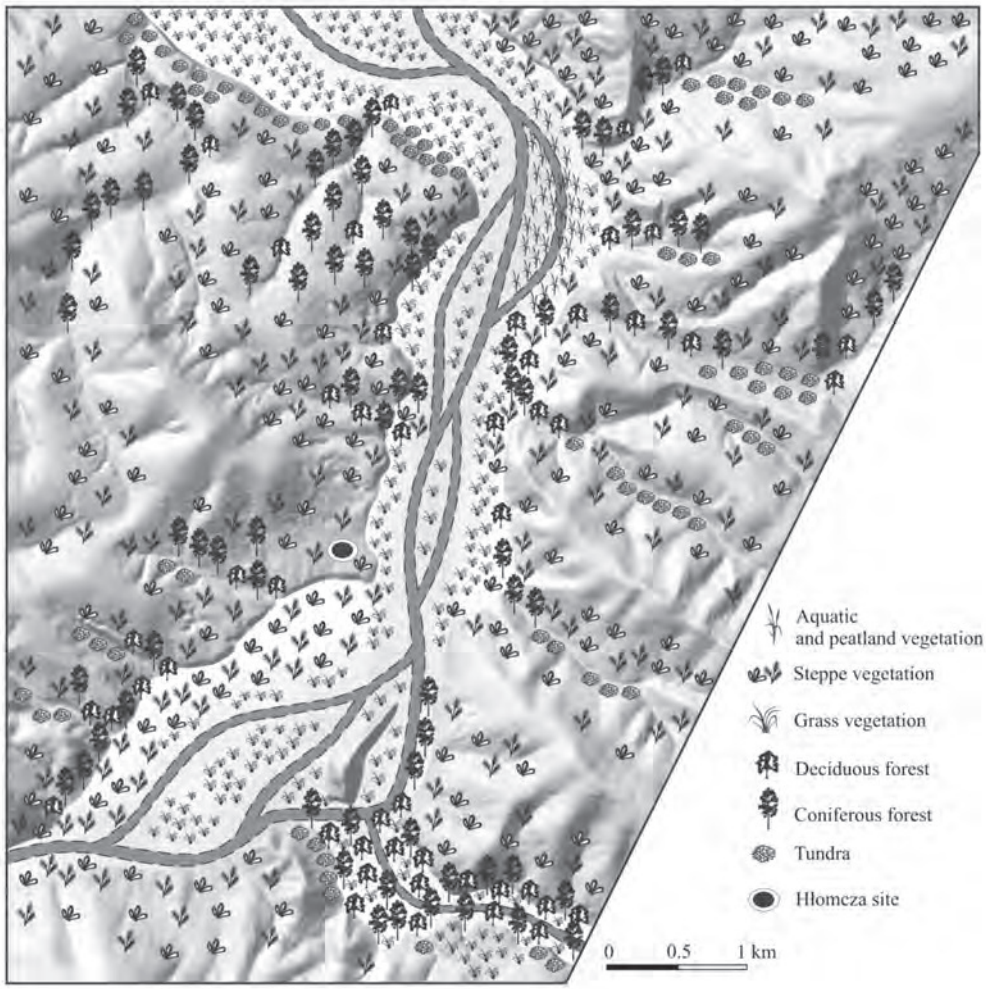


FIGURE 8. Visualization of the reconstructed vegetation cover in the Hłomcza region (channel pattern is presented in schematic form).

Based on the data from the above-mentioned palynological sites, we can suppose that loose park landscape also occurred in the environs of Hłomcza in the Oldest Dryas (*Figure 8*). Permafrost was probably preserved in places, and the San River had braided channels (Starkel 2001). Besides the places without vegetation, large areas were covered by steppe with typical of continental climate heliophyta (*Heliantemum, Artemisia*, Chenopodiaceae, *Filipendula, Ephedra, Hippophaë*), while dwarf tundra patches with *Betula nana, Selaginella selaginoides* and heather survived in humid shaded habitats with limited insolation. Forest patches with Swiss stone pine, larch, birch, pine, aspen, probably spruce, with willow in undergrowth and juniper in peripheries grew in warm and enough wet places. The widening of the San River valley near the site was a sheltered basin, which could have been one of those local refugia. *Typha angustifolia* and *Myriophyllum* grew in the San River valley, in oxbow lakes. Both rich steppe and dwarf tundra were good pasturage for herbivorous animals hunted by Magdalenian people who could have used the points overlooking the San River valley for observation.

Wierzawice. Well developed and large river meanders, which undercut the Vistulian terrace, were typical of the Allerød landscape in the San River valley near Wierzawice (*Figures 3 and 9*). We indirectly determined the vegetation cover composition during the Allerød interphase in this area, based on the results of palaeobotanical analyses of organogenic deposits from

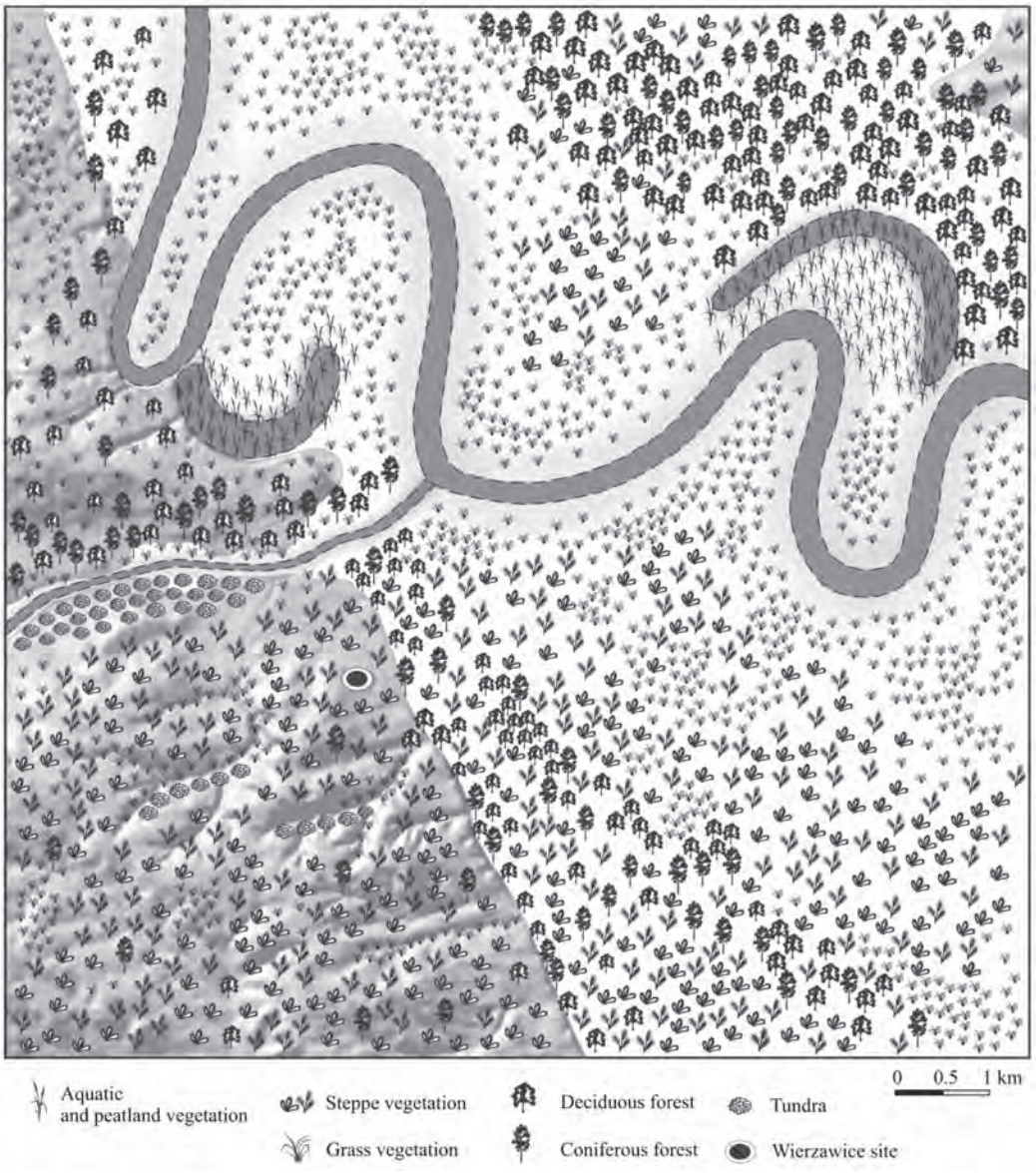


FIGURE 9. Visualization of the reconstructed vegetation cover in the Wierzawice region (channel pattern is presented in schematic form).

the following sites situated at a distance of 10–50 km to the south-east and south from Wierzawice: Stubno (Klimek *et al.* 1997), Świlcza, Podbukowina and Obary (Mamakowa 1962), Grodzisko Nowe (Kołaczek 2010). The nearest analogy is the Allerød optimum vegetation described by Mamakowa (1962), based on the pollen analysis results obtained for the Podbukowina, Świlcza and Obary sites. At that time mosaic vegetation dominated. Pine-birch-larch forests with clusters of willow shrubs and ferns, patches of rich steppe (with *Artemisia, Helianthemum, Gentiana, Chenopodiaceae, Compositae, Umbelliferae*) occurred (*Figure 9*). Heliophyta *(Hyppophaë rhamnoides and Ephedra distachya)* grew in very sunny places, while *Selaginella selaginoides* in wet places. The occurrence of thermophilous water species *(Typha latifolia, Schoenoplectus lacustris)* indicates cool temperate climate, while *Ephedra distachya* – periodically drier climate (topoclimate) conditions.

The results of investigations carried out in the Stubno site (fossil oxbow), situated in the lower San

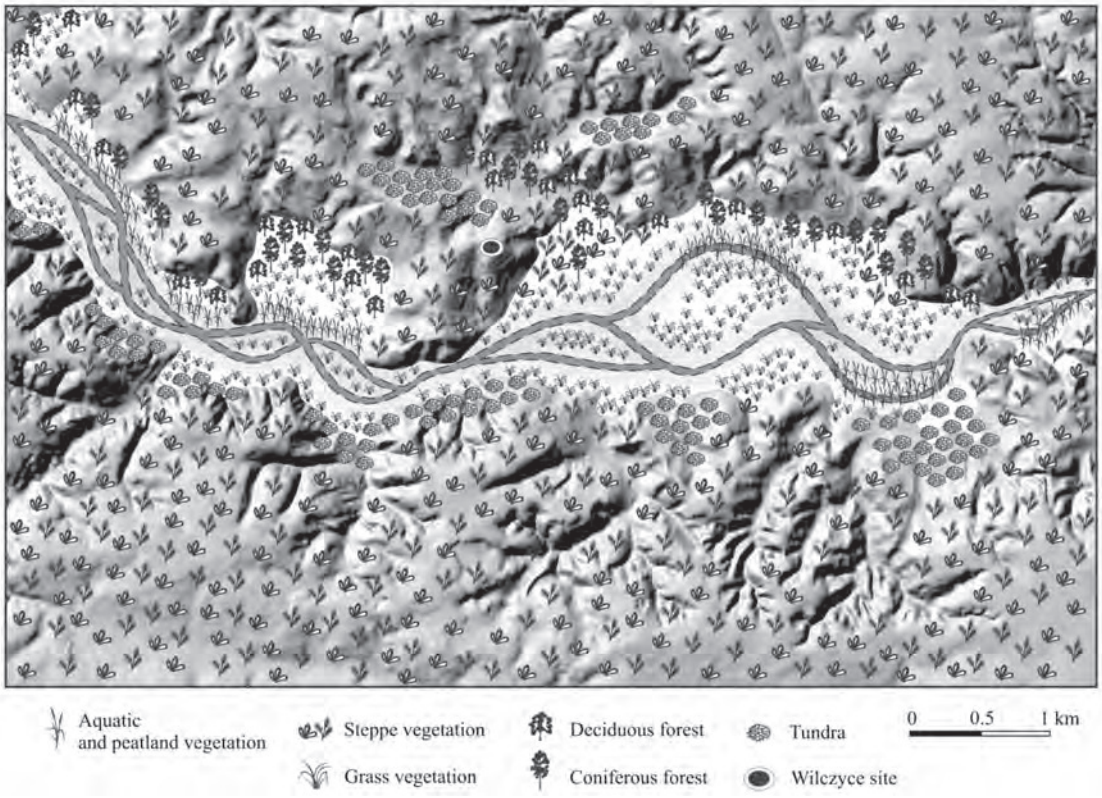


FIGURE 10. Visualization of the reconstructed vegetation cover in the Wilczyce region (channel pattern is presented in schematic form).

River valley, in immediate foreland of the Carpathians, 50 km to SE of Wierzawice, indicate the occurrence of open landscape in this area during the younger, so-called pine phase of Allerød. The plateaux and slopes were covered mainly by steppe with *Artemisia*, while patches of moss tundra grew in wet, shaded places. Open park birch-pine forests, with shrubs of sea buckthorn, juniper and *Ephedra* in the margins, occurred in sheltered places on the slopes and on the Pleistocene terraces. Willow shrubs grew in wet places near morphological edges. Sedge, horsetail, and ferns grew on peatlands. Plant indicators of cold climate, such as *Selaginella selaginoides* and *Betula nana*, appeared. The existence of tundra patches with dwarf birch at the close of Allerød was documented in the Grodzisko Nowe site (Kołaczek 2010). Climate was dry and continental.

Wilczyce. Permafrost occurred during the Magdalenian settlement. Traces of polygonal ice wedges were found on the top of the hill settled by Magdalenian hunters, who built their camp in the depression occurring in a polygon node (Fiedorczuk, Schild 2002, Schild Ed. 2014). Opatówka River had braided pattern of channels at that time.

Vegetation of the Magdalenian period was described based on the results of pollen analysis of loess deposits sampled in archaeological excavations (Komar *et al.* 2008). The vegetation cover near the site was a mosaic of plant communities with different habitat requirements (*Figure 10*). The patches of herbs, which dominated on dry habitats, were mainly composed of typical steppe heliophyta and xerophyta: Chenopodiaceae and grasses with *Artemisia*. The patches of trees, mainly of pine (indirectly confirmed by the occurrence of charcoals in the site) and Swiss stone-pine, with a small admixture of spruce, fir, willow and birch (*Betula* sect. *Alba*), with moss, fern and club-moss in undergrowth, and with sea buckthorn shrubs in the margins, grew in sheltered places on the slopes and in tributary valleys. The occurrence of trees may indicate that the isolated, sheltered from the north, basin-shaped fragments of the Opatówka River valley functioned as refugia during cold period of Upper Pleniglacial. Wetter habitats were covered by willow

and sedge communities. It is very probable that trees survived near the Carpathians even during temperature pessimum of the Upper Pleniglacial. The causes can be sought both in their affilation to genera with large temperature tolerance and location of the studied profiles near natural refugia for trees in mountains (Komar *et al.* 2009, Willis, van Andel 2004). Palaeotemperatures in the warmest month ranged from +14.8 to +16°C, and in the coldest month from +6°C to -22°C (Łanczont *et al.* 2014b).

Remnants of different animal species were found in the site. Species preferring open areas, mainly rich steppe and dwarf tundra, dominated among vertebrata (e.g. *Vulpes lagopus, Equus ferus, Coelodonta antiquitatis, Mammuthus primigenius, Rangifer tarandus, Ochotona pusilla*). Animals of habitats overgrown by shrubs or low trees were also found (e.g. *Vulpes vulpes, Ursus arctos, Tetrao tetrix*). Such faunal composition indicates that predominant biome during the settlement was steppe-tundra with relatively high primary production. The co-occurrence of plants with different habitat requirements was conditioned by local relief, soil type and moisture, and topoclimate (Bratlund 2002, Nadachowski *et al.* 2014).

CONCLUSIONS

As it was mentioned in the introduction, we decided to reconstruct, with the use of GIS methods, the palaeolandscape in the surroundings of three Magdalenian sites located near the eastern range of this culture. We selected these particular sites because a lot of information about their immediate surroundings and adjacent areas was available. The reconstruction gave a picture of the living conditions of the Magdalenian community. The obtained results encourage to using and developing similar methods in the studies of prehistory of other regions and age, and – we hope – may facilitate the selection of new promising areas for future geoarchaeological research (e.g. Łanczont, Madeyska Eds. 2015).

The choice of three Magdalenian sites located in river valleys in the SE Poland aimed at analysing the advantages of such location for specific examples. We applied GIS analysis in order to characterize in detail the palaeolandscapes of these sites, and then to indicate the common features of relief and its attractiveness for settlement. The calculated parameters and raster surfaces of the selected relief features (such as slope, aspect) and insolation, enabled us to reconstruct the vegetation cover in the surroundings of the Magdalenian sites during their functioning and to visualize its spatial diversity on the maps (*Figures 8–10*). Therefore, it was an attempt to present information obtained from pollen analysis (which gave a summary picture of vegetation including both plants growing in the surroundings of a studied site and those, mostly wind-pollinated trees, growing at a greater distance from it) in the form of spatial picture. To sum up, GIS analysis allowed the integration of detailed knowledge of geographical parameters of the sites with knowledge of habitat requirements of main vegetation communities and plant species identified by means of pollen analysis in the studied area.

The studied Magdalenian sites represent the settlement in the Late Pleniglacial, Oldest Dryas and Allerød periods. The Late Glacial was the time of climatic oscillations, at first small and then abrupt (Svensson *et al.* 2006), which favoured high diversity of vegetation, not only in time but also in space. However, these environmental changes were not such intensive in the whole area of the Carpathian, peri- and meta-Carpathian regions. They could have been less dynamic for example in intermontane basins or basin-shaped widenings of river valleys with specific mesoclimate. This fact could have been important for the Late Palaeolithic settlement.

Based on the above-described pollen data, we think that the surroundings of sites representing late Upper Pleniglacial (Wilczyce, Hłomcza) were overgrown by vegetation of open landscapes (xerothermic steppe plants, those preferring wet or boggy habitats, and even tundra plants) with trees growing singly or in small groups. Vegetation cover in the surroundings of the Wierzawice site, representing Allerød warming, was park forest. Patches of steppe and tundra vegetation with tree groups were characterized by high productivity and provided food for herbivorous animals. Grass communities covered large areas in the wide bottom of the San River valley.

The conducted analyses confirmed general regularities of location of many Upper Palaeolithic site. Morphological attractiveness of the studied sites could have resulted especially from the following conditions occurring in different spatial scales:

- considering the palaeorelief of the San River valley, the location of the Hłomcza and Wierzawice sites was quite close to the contemporary valley bottom, it means easy access to water and at the same time safe from floods of rivers, as the bottom was at least several meters below the camps (*Figures 2 and 3*);

- morphological isolation of the camps – terrace promontory (Hłomcza), hilltop (Wilczyce), and hill slope (Wierzawice) are exposed and protruding into the valleys – provided security because access to the camps was difficult;
- location of the sites near the wide fragments of the valleys, closed at both ends by the narrowings – these places enabled the Palaeolithic hunters to observe migrating animal herds, and were natural traps facilitating big-game hunting as exemplified by Wilczyce and Hłomcza;
- location of the Wierzawice site at the junction of two river valleys enabled simultaneous observation of two migration routes of animals;
- vast view over the surrounding areas (*Figures 5A, 6A and 7A*); scattered trees growing near the sites did not block view; in case of the Hłomcza and Wierzawice sites an additional value was close proximity of the easily accessible culminations providing a wider view over the valleys than from the camps;
- location of all sites in the leeward sides of high relief elements protecting them from the westerly winds, which are predominant in our times and were also frequent and strong in the younger part of the Last Glacial (Isarin *et al.* 1997, Nawrocki *et al.* 2006), as was reflected, among other things, by intensive development of aeolian processes in the European Lowlands and Uplands;
- occurrence in the valleys of rich dwarf or meadow steppe and patches of dwarf tundra, which were good pasturage for herbivorous animals hunted by Magdalenian people (*Figures 8-10*);
- diverse relief in the Wilczyce surroundings, and especially the occurrence of sheltered basins on the loess plateau cut by the Opatówka River valley, which was revealed by GIS analysis. These basins could have been refugia for trees during the cold period at the close of Upper Pleniglacial, and this possibility was confirmed by the results of pollen and palaeozoological analyses. By analogy, we think that similar conditions for occurrence of refugia could have occurred in the Hłomcza area.

Based on vegetation diversity recorded in pollen diagrams and interpreted in relation to relief, we concluded that the surroundings of the described Magdalenian sites were characterized by medium (in five-class scale) landform geodiversity (with medium or low landform energy and medium landform fragmentation; *see* Zwoliński 2008, 2009). Such landform geodiversity was especially favouring for the occurrence of mosaic pattern of vegetation and attractive for human groups.

ACKNOWLEDGEMENTS

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