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LITHOLOGY AND CHEMICAL COMPOSITION OF A NEOHOLOCENE PALAEOCHANNEL INFILL WITHIN THE BIAŁKA RIVER VALLEY, KRAKÓW-CZĘSTOCHOWA UPLAND

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Abstract. Mires are common in the landscape of the Kraków-Częstochowa Upland, but they are rarely explored by Earth scientists. In addition to numerous morphological depressions filled with biogenic sediments, mires also occur within river valley, usually upstream from gaps. The intensification of marsh formation within the Białka River valley (left-side tributary of Krztynia, upper Pilica catchment) may have been influenced by the occurrence of poorly permeable, fluvial silty sands in the bedrock. Infilling of the studied depression at Młyny was accomplished via fluvial sedimentation characterised by local aggradation interrupted by carbonate precipitation, and sedentation of autochthonous organic matter. The former sediment type is represented mostly by mineral-organic aggraded silt with a dominant fine fraction, occurring mostly in the basal part of the studied core, and sand fraction in the top interval of the core, superjacent to calcareous-clay gyttja. Ash content reaches up to 87% and Fe concentrations are periodically elevated (30–48 mg/g). Calcium carbonate ($CaCO_3$) also occurs in the studied oxbow mire deposit, exceeding 40% in some intervals, which indicates that a more important part was played by groundwaters in the water balance of the Białka valley. This periods were periodically interrupted due to higher flooding activity and recorded by mineral sediments characterised by specific granulometric composition, and an elevated percentage of organic matter deposited as rhythmists. Elevated concentrations of trace elements noted in a horizon dated at 1885±105 BP by means of radiocarbon dating may point to human impact on the environment due to the adaptation of economy to local conditions. The geochemical record of human activity is corroborated by archaeological data from various parts of the Białka valley catchment. The reason for the concentration of trace elements being highest in the top interval of the studied core is the intense economic development of Silesia-Kraków region, and the associated deforestation, mining and metallurgy.

Key words: valley evolution, flood phases, trace elements, Neoholocene, southern Poland

Introduction

The current knowledge of river valley environment evolution in southern Poland indicates a diverse character and high dynamics of Holocene geomorphological processes. Previous studies focused mostly on the Nida Depression (Hakenberg, Lindner 1973), Kraków Gate (Godłowska *et al*. 1987), Wieluń Upland (Krzemiński 1989), Roztocze (Kociuba, Brzezińska-Wójcik 1999), Sandomierz Basin (Gębica 2011), Miechów Upland (Michno 2013), and the junction of the Silesian Upland and Racibórz Basin (Wójcicki 1999; Wójcicki *et al.* 2020). The above papers emphasizes, among other issues, the considerable lithological diversity of Holocene valley sediments, which are dependent on the respective river discharge and human activity.

An important trend in geoarchaeology is identifying the environmental context of resources, the sites where they were acquired, and how they were obtained. These make it possible to determine the mode of life and organisation of local communities in river valleys, which – as geomorphological features – are considered to react rapidly to climatic changes taking place in the catchment (Kalicki 2006). The results of numerous studies show that the record of the human–environment relationship can be reconstructed from surface geology (slope sediment accumulation), terrain relief (changes in valley floor range), plant cover (strong deforestation, an increase in synanthropic plant frequency) and sediment chemical composition, mostly via trace element enrichment (Ciszewski 1994; Szwarczewski 2003; Twardy 2013). Lake and mire sediments are especially important in this respect. Although these sediment types are rather rare in the lithosphere, they are especially well-suited as archives of the geographic environment in the past

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(Wasylikowa *et al.* 1985; Tobolski 2000). Geochemistry plays a major part in studies that attempt to reconstruct sedimentary conditions of aquatic sediments. Geochemical data are used mostly to reconstruct the types and intensity of denudation processes in river catchments, river hydrological regimes, and the degree of anthropogenic geochemical environment transformation (Bojakowska, Sokołowska 1998; Szwarczewski, Korabiewski 2003; Wójcicki, Marynowski 2011; Kittel *et al.* 2020).

As no organic sediments have been documented thus far in the tributaries of the upper Warta and Pilica rivers, few lithofacial, geochemical, or detailed stratigraphic studies have been performed based on sections located within the Kraków-Częstochowa Upland. On the other hand, however, the varying contribution of individual relief types in the subregions distinguished within the discussed zone determines both the number and the area of mires more than anywhere else in Poland (Dembek *et al.* 2000; Pulina 2001; Sołtysik 2002; Okupny, Jucha 2020). The diversity with respect to the origin and thickness of unconsolidated Quaternary sediment cover is responsible for the conditions for water infiltration, which is associated with the potential for the development of the individual ecological types of mires. Studies performed within the Polish Uplands have most frequently focused on the development of fens and the infilling of forms resulting from karst processes with organic, organic-mineral, and calcareous sediment (Nowak 1971; Wicik 2000; Kobojek, Nalej 2008; Brzozowicz, Forysiak 2016; Okupny *et al.* 2016). The infilling of forms associated with fluvial processes has been studied to a lesser extent (Ludwikowska-Kędzia 2000; Panek 2008).

The main aim of the present study was therefore to reconstruct the environmental conditions in the upper reaches of the Białka valley during the Neoholocene, based on the chemical composition and particle size of sediments infilling an oxbow-mire. The completion of this goal was preceded by a hydroclimatic, geological and geomorphological analysis, as well as an analysis of anthropogenic impact on the character and dynamics of the processes shaping the studied valley segment. The Młyny mire is the first site in the Krztynia River system to be analysed with a geochemical proxy. We assumed that the palaeohydrological changes were important in the upper part of the Białka River valley, where climatic, geomorphology changes and human impact and their consequences on the abiotic realm will be especially visible. In many places, the river channel in the lower part of the Białka valley has been straightened; these are fragments of a former millrace.

Study area

The Białka River valley has a latitudinal course, tectonic conditions (in relation to the Białka Zdowska tectonic ditch) and is located in the east of the Kraków-Częstochowa Upland (Fig. 1). The catchment area varies considerably in hypsometry and morphology. The highest elevations of the Kraków-Częstochowa Upland exceed 448 m a.s.l., and in the vicinity of Szczekociny, i.e., close to the confluence of the Białka and the Krztynia, elevations reach 262 m a.s.l. (Fig. 1C). The Białka River valley is marshy, making it one of few exceptions in the upland landscape, which has relatively few peatlands (Fig. 1A). Fluviogenous wetlands prevail on the valley floor, their total area being equal to 150 ha. Despite that, the 1:50 000 Detailed Geological Map of Poland distinguishes only fluvial sand and gravel within the flat valley floor, but no peat. The quantitative description of peat deposits compiled for the vicinity of Częstochowa by Żurek (1981) indicates the presence of mires within the Białka valley, with an average thickness of sedge peat of the order of 1.5–2 m. Between Bobolice and the confluence of the Białka and the Krztynia close to Szczekociny, a supra-flood terrace is composed of Late Glacial fluvial sand and gravel (Bednarek *et al.* 1983).

The valley network (Fig. 1B) in the study area is characterised by: numerous rapid drops in valley floor inclination; frequent disproportions between valley width and river discharge (e.g., very wide valley, low discharge); the occurrence of abandoned valleys, young river gaps, relatively long spans of watersheds located elsewhere than along the highest terrain elevations, but instead traversing old valleys and depressions; and a lack of congruence between the fossil valley arrangement and contemporary drainage directions (Kleczkowski 1972). Denudation valleys occur on the northern slopes of the Białka valley. Such valleys are a common geomorphological element also in other parts of the junction between the Polish Uplands and Polish Lowlands (Rodzik *et al.* 2008). Importantly, these terrain forms in central Poland have evolved through recent millennia under intense human impact (Twardy 2013). Studies by Kleczkowski (1972) indicate that within the catchments of the Krztynia and the Białka, there are springs characterised by discharge values exceeding 100 dm^3/s, which is unusual for non-mountainous areas. Total mineral content of

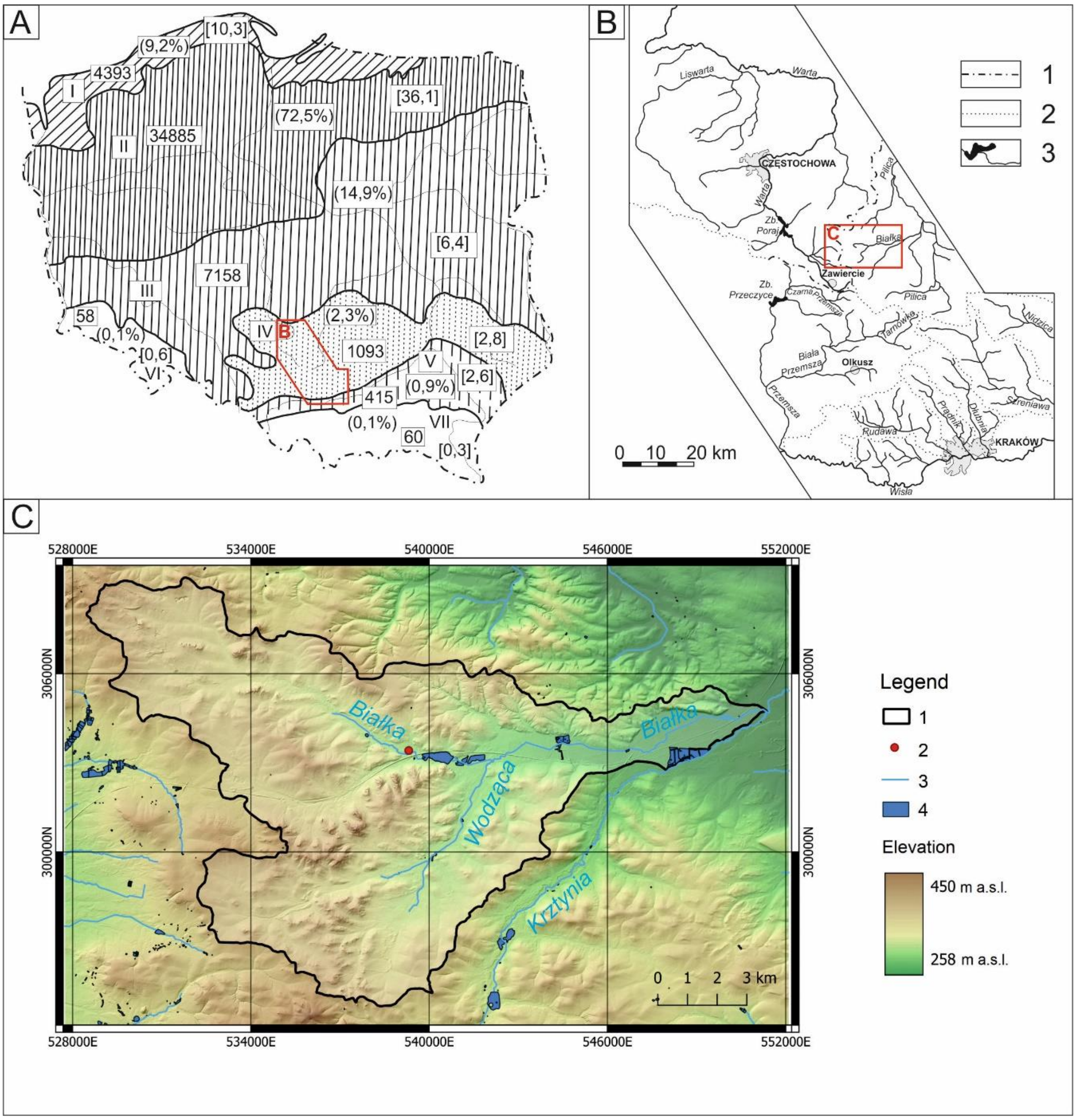

Fig. 1. Białka River valley

A. Location of study area against number of mires in various landscapes in Poland (acc. to Żurek 1987)

I – young glacial seashore, II – young glacial lake district, III – old glacial plains, IV – uplands, V – Carpathian basins, VI – Sudetes, VII – Carpathians, 4 393 – number of mires, (9.2%) – percentage of general number of mires, [10.3] – number of mires per 100 km^2

B. Location of study areas against river network in Kraków-Częstochowa Upland

1 – 1st-order watershed, 2 – 2nd-order watershed, 3 – rivers and water bodies

C. Białka River catchment and research oxbow mire against LiDAR model

1 – Białka River catchment, 2 – location of M-II core, 3 – rivers, 4 – water bodies

spring waters measured for six springs in the upper course of the Białka valley ranged from 180 to 493 mg/dm^3, with a considerably higher Ca ion content relative to the remaining part of the upper Pilica catchment (Chełmicki 2001).

The location of the study area at the junction of the highest elevations of the Kraków-Częstochowa Upland and the extensive Włoszczowa Basin is manifested in a high variability of weather conditions, under the dominant influence of humid, polar marine and polar continental air masses (Dubaniewicz 1979). With respect to the development and intensity of individual geomorphological processes, the most significant climatic factors include: relatively uniform frequency of wind directions modified by the alignment of the major terrain forms (N–S trending elevations, and upper Pilica valley hydrographic hub), low average annual wind velocity value of the order of 2.7 m/s, significantly varied monthly precipitation sums (the lowest values are noted for January–March; monthly precipitation totals are twice as high in the summer half-year), and a clear increase in average monthly number of days with rainfall >1 mm and >10 mm between May and August.

Due to the low density of river network in the Kraków-Częstochowa Upland, groundwater outflows were an important factor in choice of locality for prehistoric settlements (Jędrysik 2018). Importantly, the numerous caves in the Kraków-Częstochowa Upland were also used as temporary shelters. Maps of prehistoric settlement show that numerous traces of human presence were found in caves (Jędrysik, Wagner 2015; Sudoł, Cyrek 2015). The majority of archaeological sites associated with the hydrographic hub of the upper Pilica valley were located on terraces, and on sandy capes slightly raised above periodically flooded meadows (Gedl 1973). The remaining features of the natural environment, such as: local occurrence of initial soils developed on calcareous substratum undergoing intense erosion, and podzols formed on sands, along with high permeability and significant groundwater level fluctuations would be expected to hinder the development of a stable settlement (Godłowski 1984).

Material and Methods

Detailed fieldwork in the Białka valley was preceded by a reconnaissance focusing on morphometric parameters and selected aspects of the geographic environment, including the locations of bronze age and iron age archaeological sites. Spatial data developed by the Polish geodetic and cartographic survey were used to elaborate the cartographic part of the paper. An orthophotomap of the study area was used as source data, as well as an Airborne Laser Scanner (ALS) point cloud made by Light Detection And Ranging (LiDAR) technology. Based on the ALS, a high-resolution Digital Elevation Model was made. Additionally, to develop the elevation data for the wider area, an open-source DEM from Shuttle Radar Topographic Mission (SRTM) was used.

The M-II sediment core was collected for geochemical studies from a site located in Młyny (50°35’47”N, 19°33’17”E), where the thickest organic deposits were found. The core was taken from an oxbow mire in the north-western part of the Białka floodplain (Fig. 1C). The sediment core was taken using a manual Instorf corer with a diameter of 5 cm and length of 50 cm. Furthermore, geological drillings (to depths varying from 50 to 200 cm, at distances ranging from 10 to 20 m between drilling sites) were performed at Młyny, and in other parts of the Białka River valley.

The organic, mineral-organic and carbonate series from the M-II core were described in accordance with the non-genetic classification by Troels-Smith (1955; for a discussion on the benefits of this classification see Tobolski 2000). Radiocarbon datings were performed at Radiocarbon Laboratory – GADAM Centre in Gliwice. Samples for geochemical studies were collected at 2-cm resolution. Organic matter content was determined via combustion in a muffle oven at 550 °C for 6 h. $CaCO_3$ content was measured using Scheibler apparatus. Non-calcareous mineral matter was determined as the content of residuum remaining following the dissolution of ash in HCl, H_2O_2 and KOH (Tobolski 2005). It is assumed that the difference between total sample weight and the residuum weight for each sample reflects the stratigraphic trends in terrigenous silica supply. Following these chemical procedures, gyttja kind and species was determined, following the classification of Markowski (1980). Peat was classified following Okruszko (1976) according to silt content. Thirty-nine samples taken at 5-cm resolution from all the lithological units recognised in the core were collected for detailed geochemical analyses, including the determinations of Fe, Cu, Zn and Pb concentrations. Chemical determinations were performed on sediments after mineralisation in 25–38% HCl and 65% HNO_3, following the Atomic Absorption Spectrometry method (AAS) (Borówka 1992).

Granulometric composition was determined for some samples, using a Mastersizer 3000 laser diffraction particle-size analyser. For particle-size analysis, the sample selection criterion was associated with the content of individual geochemical components. Thus, laser analysis was performed for 19 samples in which the mineral matter content exceeded 50%, and enough material was available to reach an appropriate obscurance level. For these samples, Folk and Ward’s statistical indices of grain-size distribution were calculated, as well as the frequency of occurrence of individual modal values according to sediment lithology and SPAN index (a dimensionless sorting index; Foster *et al.* 2008). Fluvial sedimentary environment dynamics in the upper course of the Białka valley was reconstructed using the C-M diagram according to Passega, Byramjee (1969), and M_z and δ relationship diagram according to Sly *et al.* (1983). The area of the former was divided into nine fields (I–IX) that characterise material transported and deposited in distinct dynamic conditions. In the latter, four sediment groups were marked (A–D), considering two current states (H – high, L – low).

Results and Discussion

Catchment morphometric diversity versus geology

The catchment of the studied river is clearly diverse in its hypsometry (Fig. 1C), as reflected in the values of relative elevations and slopes (Fig. 2). The western and northern parts are characterised by relative elevations of the order of 100–150 m, in contrast to the eastern part, which is hypsometrically less varied (20–50 m). With respect to the type and intensity of denudation processes it is notable that S, SE and N slope exposures prevail in the catchment (Fig. 3). Humid air masses inflow over the catchment mostly from the west and south-west (Dubaniewicz 1979). The dominant slope exposures are therefore not favourable for more intense denudation processes.

The hypsometric diversity (Fig. 1C) of the Białka catchment described above results from the bedrock geology. The catchment area includes part of the Silesian-Kraków monocline. For this reason, ranges of elevations commonly display a cuesta geometry. Cuestas are typical examples of structural relief, with dips of strata often exceeding 2°. The prevalent lithology within the catchment bedrock is of Jurassic rocks, represented mostly by massive limestone, and locally occurring chalky limestone and silty limestone. The remaining sedimentary complexes making up the catchment of the lower reaches of the valley include Quaternary loess, and sand and gravel (Fig. 4). Thus, the Białka catchment is characterised by a high diversity of water infiltration conditions. High- and medium-permeability areas occupy *ca* 45% of the catchment. Due to high slope angles, and a high degree of plant cover, infiltration may be hindered locally, e.g. between Bobolice and Kostkowice. Especially poor infiltration conditions occur in the northern part of the catchment, where surface water erosion intensification has led to the development of denudation valleys infilled by deluvial loess. Alluvial fans have arisen at the mouths of those valleys.

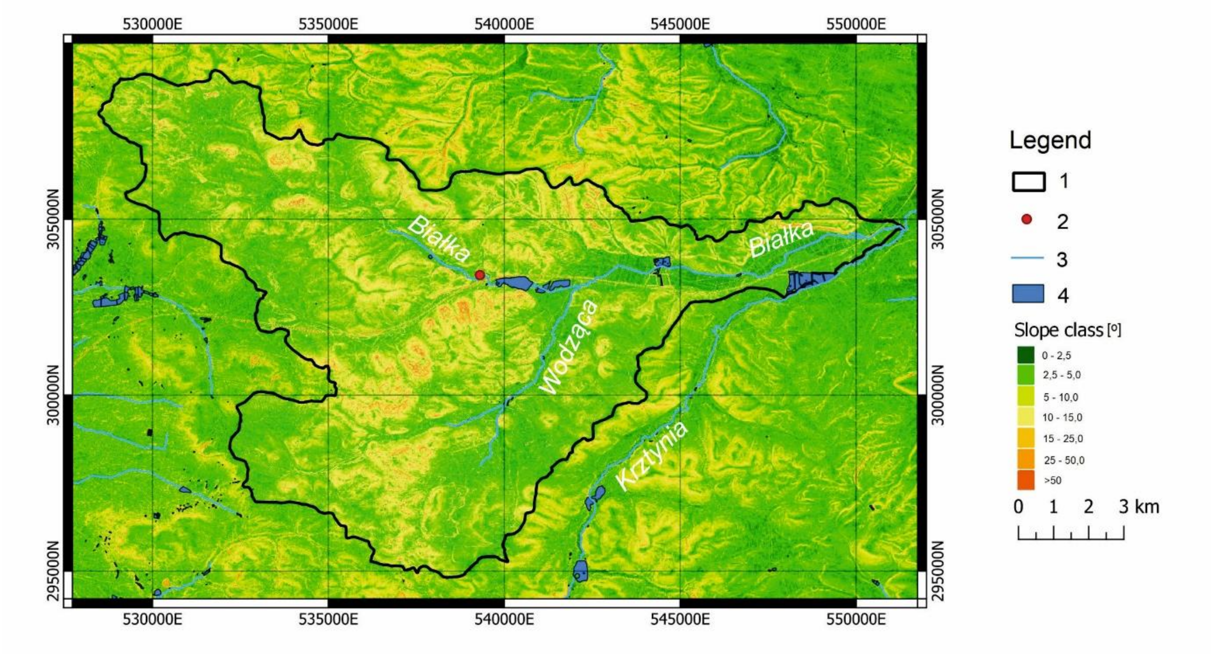

Fig. 2. Slope map of Białka River catchment (based on LiDAR model)

1 – Białka River catchment, 2 – location of M-II core, 3 – rivers, 4 – water bodies

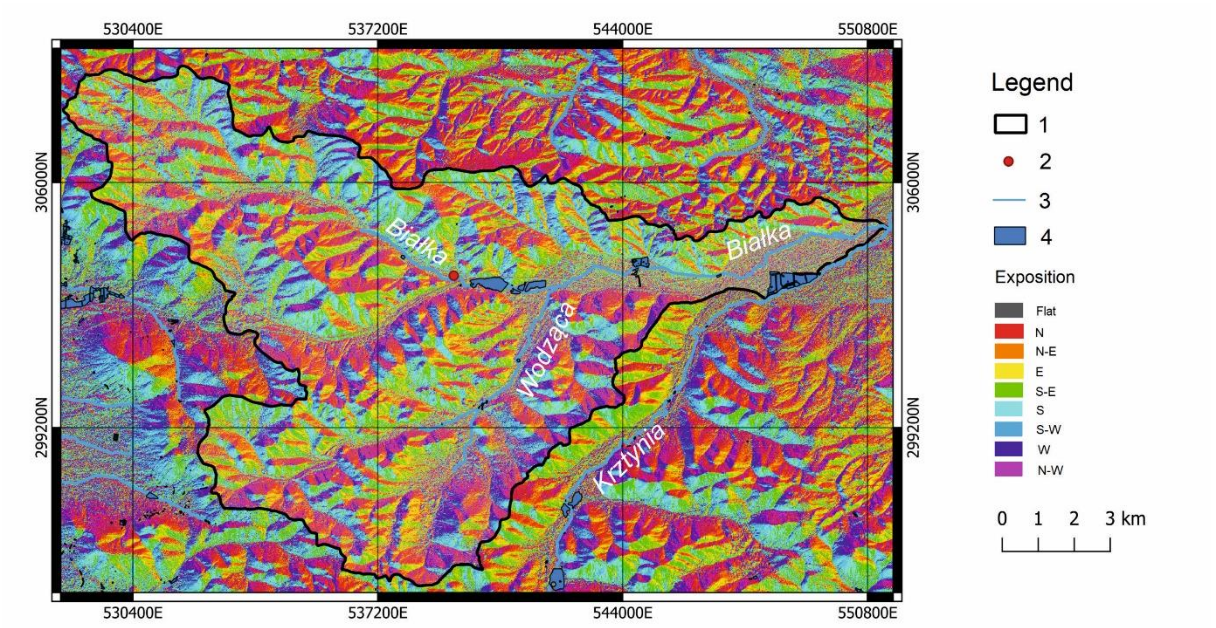

Fig. 3. Slope exposure map of Białka River catchment (based on LiDAR model)

1 – Białka River catchment, 2 – location of M-II core, 3 – rivers, 4 – water bodies

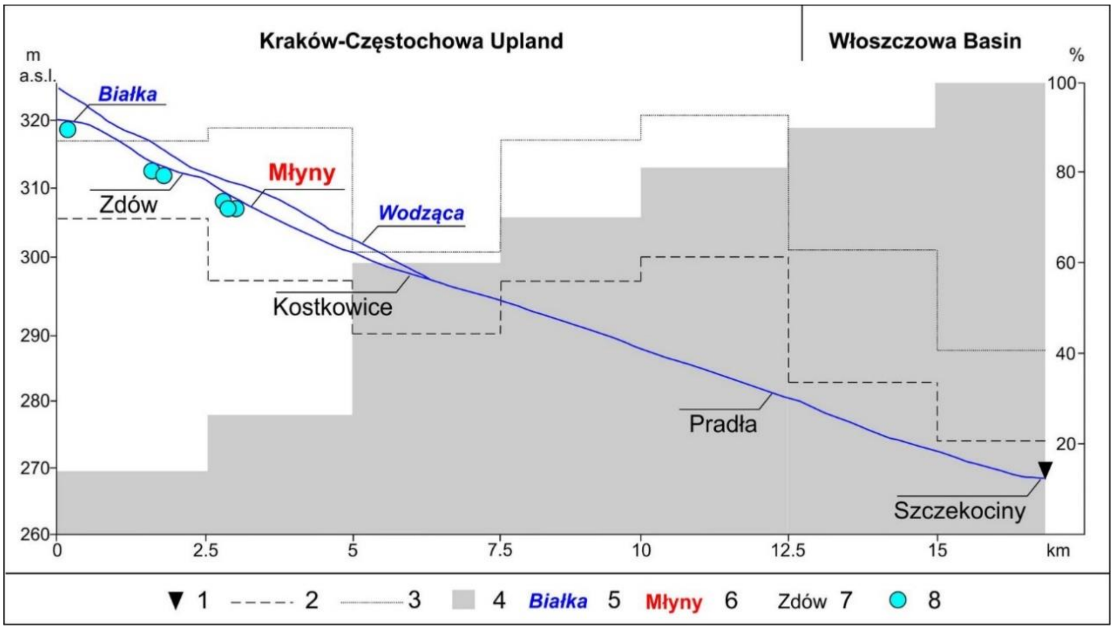

Fig. 4. Location of research oxbow mire indicated on river-long profiles of Białka system and results of division of surface geology to two groups (very permeable: limestones and chalky limestones and poorly permeable: silt and loess) based on Bednarek *et al.* (1983) and location of other peatland in Białka River valley (after Żurek 1981)

1 – water gauge to Krztynia River (Szczekociny) 2 – share of very permeable bedrocks in catchments (%), 3 – share of poorly permeable bedrocks in catchments (%), 4 – cumulative river catchment area (%), 5 – rivers, 6 – study site, 7 – other sites with peat deposits in Białka River valley, 8 – springs

The diversity of the longitudinal profile, and an assessment of hydrogeological conditions both suggest a twofold division of the studied valley (Fig. 4). This division is also consistent with the diversity of the catchment shape. The area restricted by the watershed for the upper course of the Białka valley is more isometric, in contrast to the lower course, which is more elongate. As a result, swells may have been higher and shorter-lasting over the first 4 km of the Białka valley. During swells exceeding channel level, waters flooded the entire floodplain, especially given that average specific runoff in the upper reaches of the Krztynia and the Białka is >10 $dm^3/s/km^2$, and is thus the highest in the entire Polish Uplands belt (Stachy, Biernat 1994). In the transitional zone between the Kraków-Częstochowa Upland and the Włoszczowa Basin (i.e., the distance from the confluence of the Wodząca and the Białka to the confluence of the Białka and the Krztynia), more than half of the valley area is occupied by a flat floor covered with sediments that are typical for periodically flooded habitats experiencing groundwater level fluctuations of the order of 2 m (Żurek 1981). Furthermore, within the discussed area, slope angles rarely exceed 10°, and the dominant slope exposure is toward the S and SW. Regardless of the spatial diversity of morphometric parameters in the partial catchments distinguished here, the entire Białka catchment area is located within an area characterised by spring swell occurrence. Swells occur especially in March and April, and the number of swells in a year ranges from 5 to 10 (Jokiel, Bartnik 2017).

Palaeochannel deposits and their usefulness for palaeoenvironmental reconstructions

Mineral-organic silt with a variable $CaCO_3$ content (usually 2–10%, but a maximum of 40% has been observed) is the dominant sediment group recognised within the Białka valley (Fig. 5). In addition, four intervals composed of peat with rather a high silt content (organic matter content exceeds 50% in only two samples) were documented in the M-II core. A calcareous-clay gyttja with an average $CaCO_3$ content reaches a similar thickness (about 70 cm in total). Thus, the above sedimentary sequence is a record of frequent swells, periods of stable hydrological conditions required for organic matter sedimentation, and shallow groundwater level and calcareous substrate leaching.

Due to the highly dynamic nature of fluvial processes in the Subatlantic period (Żurek *et al.* 2006), it was a challenge to provide a precise date for the Młyny oxbow cut-off, and its transformation into a biogenic accumulation basin. In any case, the onset of organic deposit sedimentation at 200 cm depth was dated at 1885 ±105 BP (GdS-3856). Meltwaters and rainfall played a key role in the water balance of the mire. However, the superjacent peat layer yielded a radiocarbon age of 1135±85 BP (GdS-3878) at 143 cm depth. Thus, it appears that relatively stable hydrological conditions were rapidly superseded by groundwater level rise (a rapid increase in $CaCO_3$ content from 0 to 40%), and frequent swells – a broad range of variations in SiO_{2ter} content and in percentage of individual fractions in each successive sample (Fig. 5).

Notably, the radiocarbon dating results place these events within the Neoholocene phase of lake basin and mire formation onset, during which bronze age or iron age human economic activity was responsible for local changes in terrain relief and water relations (Twardy 2013). The onset of wetland development has also been documented in numerous small river valleys of central Poland. The age of organic sediments from the basal parts of numerous profiles of various thicknesses ranges from 2700±75 BP in the Bobrza valley (Sołtysik 2002), through 2530±60 BP in an upper Tarnówka depression cut off by a dune (Woźniak, Żurek 2005), 2350±50 BP in the Rawka valley (Kittel 2013), 2250±50 BP in the Krasówka valley (Balwierz *et al.* 2005), 2215±80 in the Obręczówka valley (Gałka 2016), and 1920±100 BP in the Łagowica valley (Ludwikowska-Kędzia *et al.* 2009) to 1660±110 BP in the Belnianka valley (Ludwikowska-Kędzia 2000). The high dynamics of morphogenetic processes probably triggered by humans was documented also by Szczypek (1986), where charcoal sampled from soil horizons within aeolian sands yielded the following ages: 2840±100 BP, 2160±100 BP and 1590 ± 60 BP.

The chemical composition of biogenic sediments in the Białka valley determined here depends on sediment lithology resulting from dynamics of water relation changes and especially from the activity of river waters (Fig. 5). A threefold increase in Fe concentrations (even to 40–50 mg/g) and relatively high content of organic matter (above 30%) indicate decreasing redox conditions in the river accumulation environment. Calcium carbonate precipitation in the studied basin should be associated with chemical denudation of the catchment, and with the valley being supplied by the first aquifer, at present occurring at a depth of about 5 m. That the $CaCO_3$ concentration is three times lower in the studied sediments compared to the Holocene infill of the Racławka valley (Rutkowski 1991) lends support to the importance of the catchment geology in supplying clastic material of particular chemical composition to river valleys, as postulated by numerous studies (e.g. Oświt *et al.* 1980; Klimek 1996).

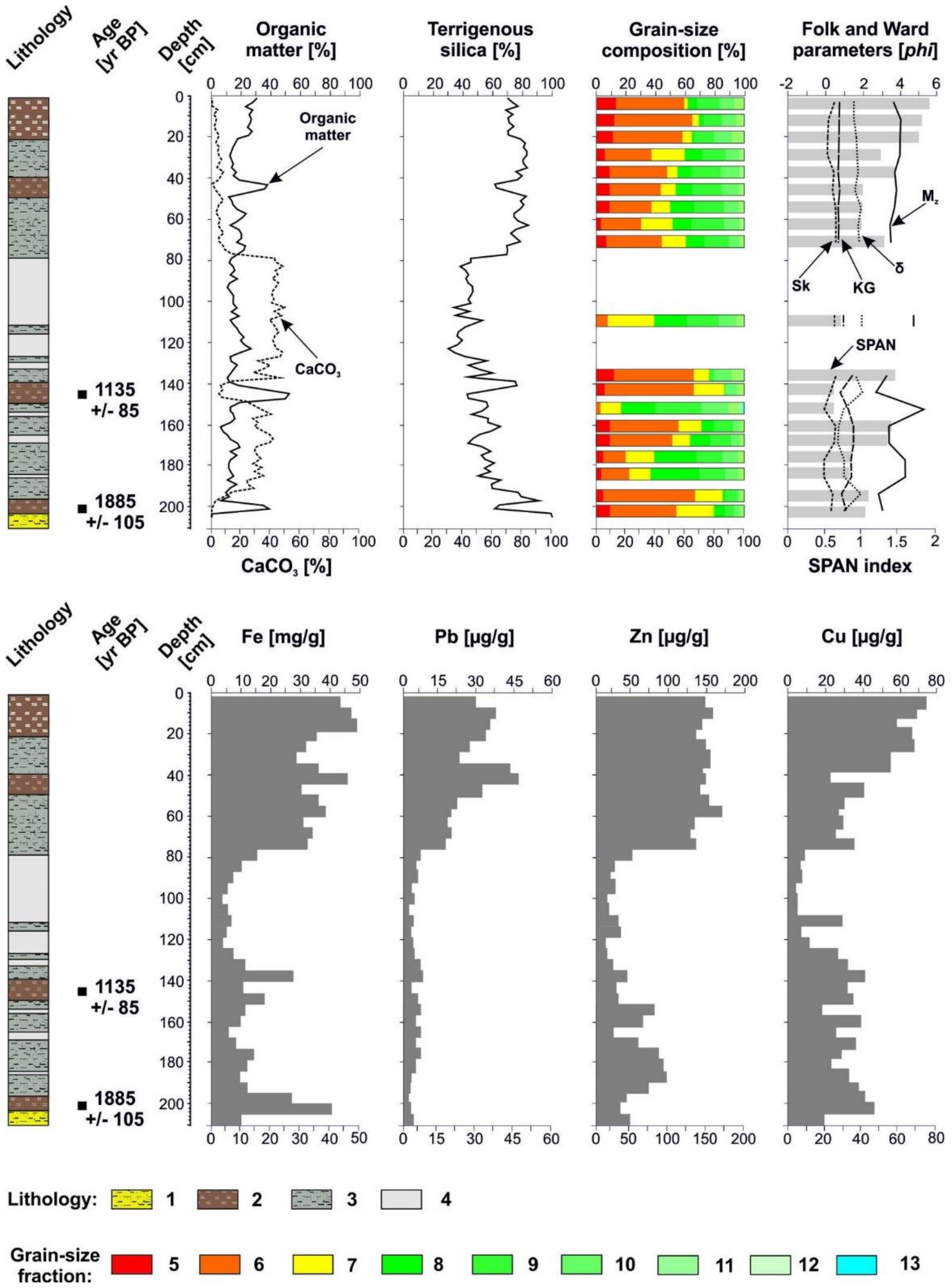

Fig. 5. Geochemical and grains-size results for deposits from M-II core in Białka River valley against lithology and age

lithology: 1 – fluvial sand, 2 – decomposed peat, 3 – mineral-organic silt, 4 – calcareous-clay gyttja; grain-size fraction: 5 – medium sand, 6 – fine sand, 7 – very fine sand, 8 – very coarse silt, 9 – coarse silt, 10 – medium silt, 11 – fine silt, 12 – very fine silt, 13 – clay

The mineral-organic graded silt that accumulated in an environment more or less intensely flooded by river waters contained up to ten times higher concentrations of metals than the sediments deposited in the absence of flooding (Fig. 5). Due to the occurrence of numerous archaeological sites in the Białka valley, especially upstream of the studied profile and along the whole of the Krztynia valley (Kopacz, Pelisiak 1986; Jędrysik 2018), deforestation is a likely cause of the increasing flooding activity. According to Rodzik *et al.* (2008), leaching and downwashing processes prevail in such conditions. An important part in the frequency and height of swells may be ascribed also to the entire western segment of the watershed lying within the Białka River catchment (about 25 km) within the 1st-order watershed separating the catchments of The Vistula and Odra rivers. According to Dubaniewicz (1979), in the vicinity of Częstochowa this zone controls the course of 550–575 and 575–600 mm isohyets, and mean annual rainfall sum values are 25–50 mm higher compared to the neighbouring areas. Snow cover lasts longer in this area, which in turn influences the snowmelt occurrence period.

The shift from calcareous to mineral and mineral-organic sediments documented at 80 cm depth is correlative with an increase in Pb and Cu concentrations (Fig. 5). This likely represents a record of the development of mining and metallurgy along the Olkusz–Sławków–Częstochowa–Tarnowskie Góry region. The Cu:Pb:Zn concentration geochemical index by Weng *et al.* (2003) indicates that most samples from the studied profile should be classified as contaminated due to human activity. Only five calcareous-clay gyttja samples fall within natural limits of Cu:Pb:Zn concentration relationship (Fig. 6). Similar intervals with peak trace element concentrations in the top parts of the deposits have been documented in numerous peat deposits within central and southern Poland, and their values are even five times above the local geochemical background (Kosiński *et al.* 1994; Szwarczewski, Korabiewski 2003; Borówka *et al.* 2015; Pawełczyk *et al.* 2018; Foltyn *et al.* 2018). At present, estimating the degree of sediment enrichment in trace elements in the Białka valley is not fully possible, for two reasons. The first reason concerns difficulties in determining threshold values for the southern Poland geochemical background (Lis, Pasieczna 2001). Secondly, heavy metal concentrations and forms of bonding depend also on numerous other factors, including redox conditions existing in wetland habitats, or ash quantity and origin (Kwiatkowski 1971; Rydelek 2013).

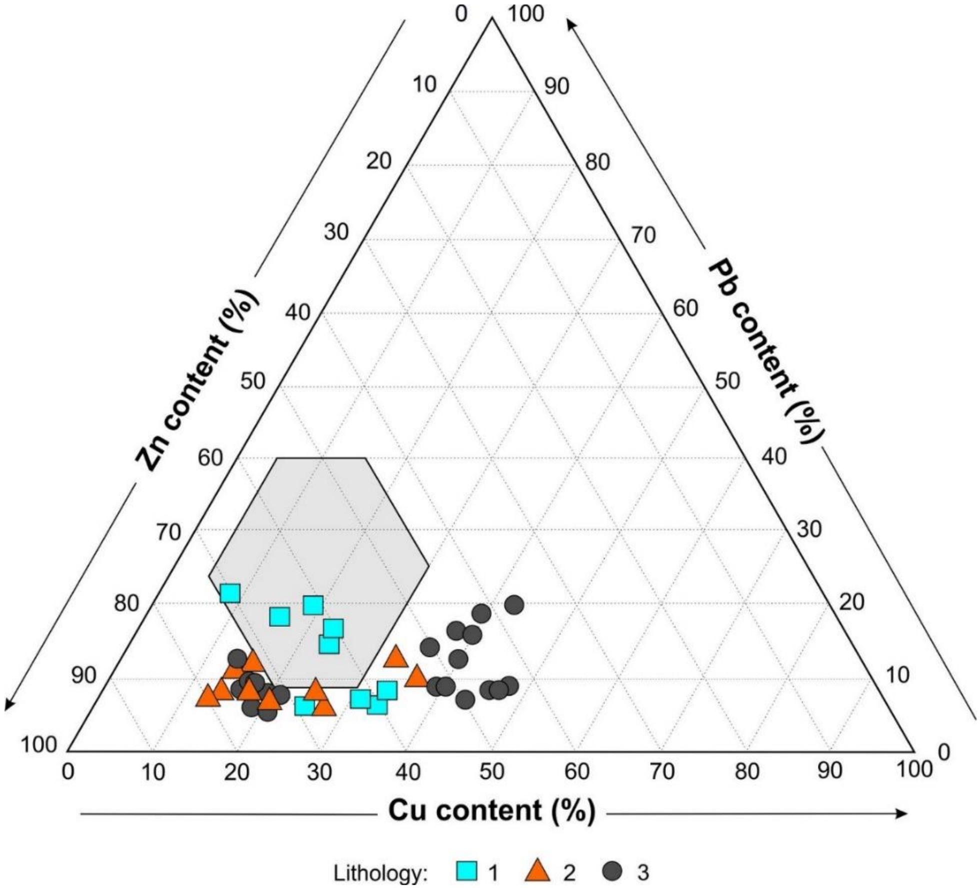

Fig. 6. Relationship between elements Cu, Pb and Zn for M-II core sediments. Inside grey area, values considered natural based on Weng *et al.* (2003)

1 – calcareous-clay gyttja, 2 – decomposed peat, 3 – mineral-organic silt

The lack of age control for the uppermost part of the deposit infilling the Młyny palaeochannel precludes a unanimous determination of the age and causes of organic-mineral silt sedimentation, characterised by the highest concentrations of trace elements. However, considering the changes in settlement intensity, and the directions and degree of landscape transformation in the vicinity of Kraków, as compiled by Rutkowski and Starkel (1989) for the past 1000 years, it is plausible that these graded silts correlate with the intense deforestation of loess covers. The study by Rutkowski (1991), performed in the valley of Racławka, reveals that the petrographic composition of medieval mineral fluvisols indicates erosion mostly of loess, calcareous sinter, and – to a lesser extent – calcareous sediments of Jurassic age. The increase in load transported by rivers at that time resulted not only from a regional-scale agricultural colonisation, but also from fires, the local character of which is evidenced by the presence of charcoal and sand supply from the neighbouring slopes. An elevated demand for lumber and charcoal during this period is reflected also in palynological diagrams derived from many mires in southern Poland, such as: Kroczyce (analysis by K. Korzeń following Jędrysik 2018), Wolbrom (Latałowa, Nalepka 1987), Jaworzno (Szczepanek, Stachowicz-Rybka 2004), Krzywopłoty (Żurek *et al.* 2011), Jezioro Lake (Nita, Szymczyk 2010; Fajer *et al.* 2012), valleys of the upper Odra River tributaries (Wójcicki, Nita 2016) and Bydlin (Okupny *et al.* 2016).

Despite the relatively low number of granulometric data for the M-II profile, and Szmańda's (2010) reservations regarding the plausibility of interpreting sediment distribution based on Passega's C-M diagram fields, we decided to utilise this method of particle-size data presentation, with a special emphasis on differences between the distinguished sedimentary lithological types. The results are grouped within three out of nine fields distinguished by Passega (1964), i.e., fields V, VI and VII (Fig. 7A). The highest density of empirical points is seen in fields V and VII. Field V is characteristic for sediments resulting from a gradational suspension in moderately active environment dynamics (mineral fraction for graded silt and peat). Field VII is characteristic for sediments laid down from a fine-grained, homogenous, pelagic suspension. Both groups include data points representing the mineral fraction of graded silts and peats. Two points associated with the mineral fraction extracted from the calcareous-clay gyttja fall within field VI, which characterises sediments deposited from a gradational suspension in low environment dynamics activity.

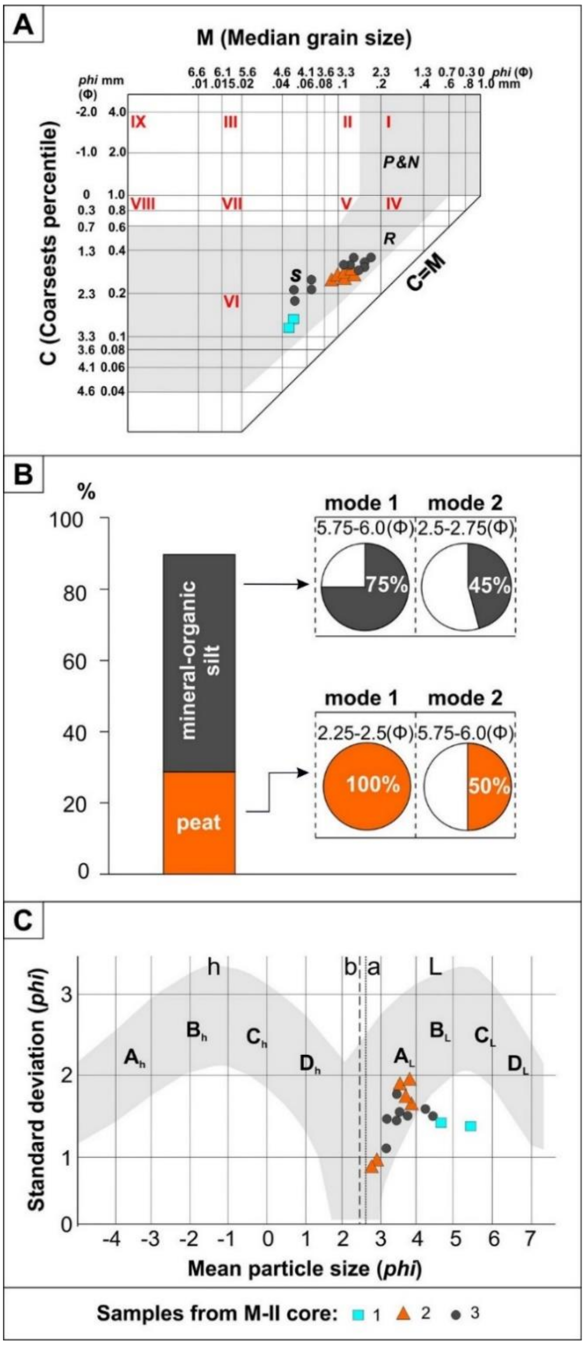

Fig. 7. Grain-size results for mineral fraction from M-II core deposits

lithology description: 1 – calcareous-clay gyttja, 2 – decomposed peat, 3 – mineral-organic silt

A. Distribution of research samples on C-M diagram after Passega (1964)

S – mainly homogenous suspension, R – mainly graded suspension, P&N – salting and rolling, I–IX – individual field numbers

B. Frequency of occurrence of modal values in different types of M-II core deposits

C. Relation between mean grain size (M_z) and sorting (δ) against flow regime after Sly *et al.* (1983) and tendency lines relative to sediment origin

h – high-energy regime, L – low-energy regime, A – deposition conditions, B and C – transport conditions, D – erosional conditions, a – maximum kurtosis values, b – divided based on skewness

A generally weak and stable fluvial environment dynamics of Białka in the Neoholocene is corroborated by the frequency of individual modal values (Fig. 7B). Due to the insufficient number of samples, this analysis does not include the calcareous-clay gyttja. In the case of mineral-organic silt and peat, the determined mineral grain size enables these to be classified as silty sand. Most analysed samples display a strongly expressed first mode within the sand fraction (72% of samples in the range 2.5–2.75 phi), and second mode within the silt fraction (45% of samples in the range 5.25–5.5 phi). In peat samples, however, the first mode within the sand fraction (2.25–2.5 phi) concerns all samples, i.e., with twice as high frequency compared to the second mode (5.75–6.0 phi) (Fig. 7B).

The mineral fraction from the M-II profile displays poor sorting. Most samples are clustered within the A_L field on the diagram of mean grain diameter versus sorting (Fig. 7C). Samples align with trend lines for B_L and C_L fields to a lower degree. As a result, the admixture and grain size in the studied sediments may record a lack of significant differentiation in the mineral matter source, with a synchronous overly short fluvial transport. This is especially evident in the case of small river valleys, in which a reaction to changes in hydroclimatic conditions is reflected in a high diversity of geomorphological processes dynamics, and in sediment chemical composition (Oświt *et al.* 1980; Zwoliński 1985; Pawłowski *et al.* 2014).

In the case of the Białka valley sediments, this is partly confirmed by changes in SPAN index (Fig. 5). The average value of this parameter is slightly higher for sediments with elevated mineral matter content, and the lowest values concern $CaCO_3$-rich sediments. Notably, however, the relatively low difference between the maximum and minimum values of the SPAN index likely results from low diversity in natural conditions (swell height and duration or alimentation area) in the upper reaches of the Białka valley. Moreover, the allochthonous mineral material that was supplied to the Młyny basin due to invigorated fluvial activity of the river was transported from a distance not exceeding 2 km. This question certainly requires further study, not least because of the high lithological diversity and volume of slope sediments supplied to the valleys of the Kraków-Częstochowa Upland (Kobojek, Kobojek 2003).

Conclusions

Spatial diversity in morphometric features and in bedrock geology of the catchment are responsible for the division of the Białka River valley into two zones of denudation and conditions for the accumulation of limnic and peat sediments. Moreover, the location of the studied valley at the junction of the Kraków-Częstochowa Upland and Włoszczowa Basin is reflected in strongly varied water infiltration conditions, and a variable potential for water and allochthonous material supply to the valley floor.

Sedimentological and geochemical data from the Białka valley, which point to high dynamics of denudation processes and human impact on environment are in broad agreement with the phases of settlement within the central part of the Kraków-Częstochowa Upland during the last two thousand years. During the Subatlantic period, two episodes of markedly increased trace element concentrations are noted. The first is associated with the onset of autochthonous organic matter sedentation during the bronze age. The second episode represents a longer period and, due to absolute metal concentrations and the relationships among these metals, probably corresponds to a period of functioning of numerous metallurgic facilities.

The geochemical profile for sediments infilling the oxbow in the Białka valley is characterised by the occurrence of both intervals displaying a natural concentration of heavy metals, consistent with an increased chemical denudation of the catchment, and intervals displaying a marked transformation of the original geochemical relations. The presented results are therefore yet another line of evidence for a high degree of southern Poland's geochemical environment transformation, and furthermore, confirm the utility of aquatic sediments as an archive of these transformations.

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