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Natural and anthropogenic indicators of fluvial system changes, the Bobrza Valley (Holy Cross Mts) as an example.

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Abstract
Transformations of a fluvial system are caused both by natural factors and human pressure. These factors model the system independently at different times and with different intensities or they affect it simultaneously. The aim of this study is to identify the transformation of the Bobrza river valley system occurring under natural conditions and that occurring under the influence of human activity. The identification was based on specific indicators The study was conducted in the valley mouth of the Bobrza River (Holy Cross Mountains), where three research sites were located. The investigation concerned the relief of the valley and the mineral and organic deposits. A wide range of research methods were used during the study e.g. analysis of LiDAR data, macronutrient analysis, and radioactive dating. The analyses enabled the natural and anthropogenic transformations of the Bobrza river system to be distinguished using the following indicators: morphometric and sedimentological characteristics of the palaeomeander (natural transformation), the sequence of mineral and organic deposits in exposures on the contemporary floodplain (natural and anthropogenic transformation) and transformation associated with the operation of a water mill (anthropogenic transformation). In addition, it is worth mentioning that the Bobrza channel is the location which has provided the only fossils of *Juncus subnodulosus* in south-east Poland.

Key words: meandering river, fluvial relief, sediments, human impact, *Juncus subnodulosus*

Introduction

The transformation of river valleys is a widespread and natural phenomenon. Elements of the fluvial system are very sensitive to environmental change (Korpak et al. 2008). The dynamics of the changes occurring in river valleys are dependent on a variety of environmental factors with varying intensity over time (Brocard et al. 2003; Korpak et al. 2008; Grimaud et al. 2014; Steward, Desloges 2014). Initially, geomorphological change in river valleys was only associated with natural processes. In the period 30-10 000 years BP there were significant changes in the evolution of riverbeds under the influence of climate change which reorganised river valleys through a system of braided-channels in a large-meandering to small-meandering system. The whole cycle consisted of changing trends of river erosion and accumulation, indicating a clear phase of erosion and the incision of rivers in the Holocene period (Gębica, Starkel 1987; Petera-Zganiacz, Forysiak 2012; Krupa 2013). Their accumulation and erosion were closely associated with fluctuations in climate (Kalicki 2006). In the Holocene, with time, human impact was increasingly evident in its role as the new factor affecting changes in relief (Majewski 2008; Kalicki, Tyniec 2009; Luc, Szmańda 2009). With the development of human cultures, it played an increasingly active role in the transformation of river valleys (Czebreszuk 2009; Kittel et al. 2008). Traces of human pressure are also stored in relief and valley sediment in a similar manner to traces of natural processes (Twardy et al. 2008). Populations engaged in cultivating the land, farming and shepherding in intensively logged and burned forests, changing the species composition of the vegetation cover, and modifying the slope profiles and intensifying erosion (Reder et al. 2010). Later, advanced forms of human activity such as ferrous metallurgy appeared in the river valleys causing changes in the longitudinal profile of the valley and the processes of deposition (Król et al., 2010; Krupa 2013; Malik et al. 2015). The aim of this study was to identify, on the basis of separate indicators, changes in the way the Bobrza river valley functions under natural conditions and under the influence of human activities. Due to the lack of such studies of the Bobrza valley, which is particularly important in regional terms, studies have been undertaken which may make a contribution to comprehensive palaeogeographic research on the region.

Study area

The Bobrza is the longest right bank affluent of the Czarna Nida river. It is a meandering, partially regulated, river with a sand and sand-gravel bed. The length of the main watercourse is 48.9 km. The area of its basin is 375 km². The part of the valley studied in detail is located in the Chęcińskie Hills (Holy Cross Mountains), approx. 15 km south-west of the city of Kielce (Fig.1). The research sites in this section of the river are located about 2.5 km from the river mouth (Fig.1). Hills consisting of limestone and Middle Devonian dolomites with an abasement on the Lower Carboniferous schist dominate in this part of the catchment (Czarnocki 1957, Filonowicz 1971, Gilewska 1972, Dylikowa 1973). During the San I and San II glaciations the valley was buried by glacial material. During the Warta and Odra glaciations, the Bobrza valley was filled with river sands and gravels mixed with solifluction material. During the Vistulian, the valley was under the influence of a periglacial climate. At that time, a loess cover arose. During the interglacial periods deposits were gradually washed out (Burchard 1978).

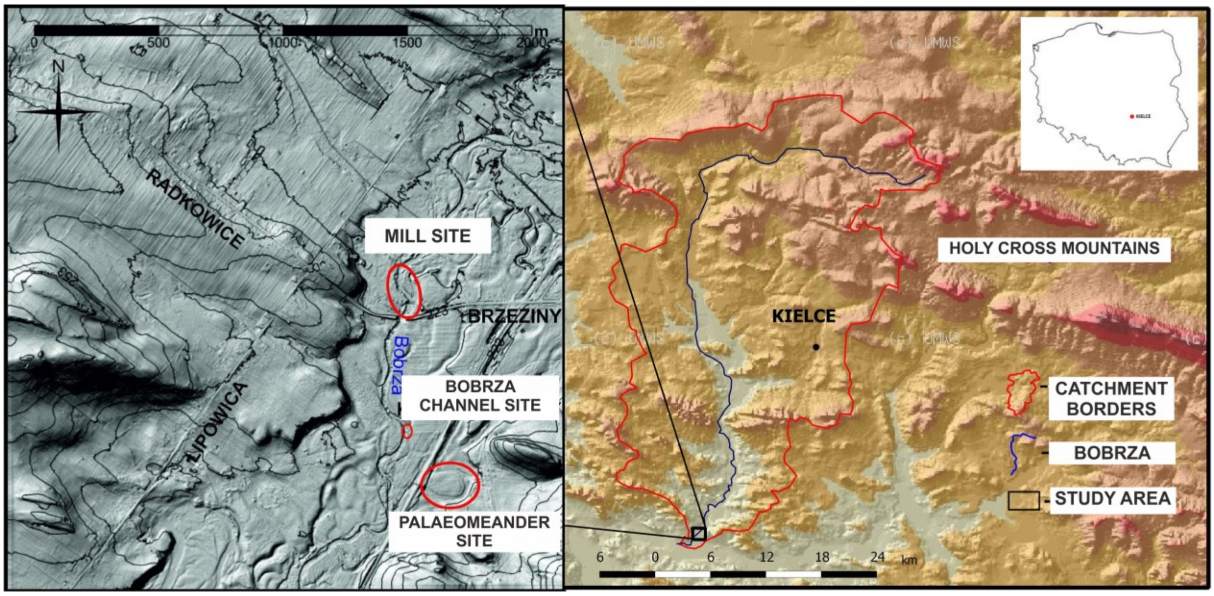


Fig.1. Location of research area and detailed location of research sites

In the Holocene, the period of time known as the Middle Ages is considered of vital concern in understanding the Bobrza valley. There was extensive human use for economic purposes at this time. Until the beginning of the twentieth century iron ore, copper, lead and barite mines were in operation there, sandstone, limestone and dolomite quarries were being worked and in addition lime kilns, steel works, iron works and weapons factories were in production. The river supplied as much as approx. 10-18 hp (horsepower) of energy to the water wheels of the blast furnaces (Król et al. 2010).

For the purposes of this study three research sites were identified:

- the "Mill" site, including part of the Bobrza channel with the mill remains
- the "Bobrza channel" site - located approx. 450 m below the previous site, covers a small part of the Bobrza channel, the left exposed part of the bank
- the "Palaeomeander" site - located approx. 200 m below and to the east of the “Bobrza channel” site in the distal part of the floodplain. It is a inactive river bed dissected in the late Vistulian sediments (Filonowicz 1971)

Materials and methods

The "Palaeomeander" site

A thorough analysis of the terrain was conducted by comparing topographic maps of different ages. The morphometric parameters of the palaeomeander were measured and compared with other meander generations and the contemporary river bed. The results were obtained from LiDAR data. On this site three bores were made in a line transverse to the axis of the palaeomeander. To collect the fill material, an Instorf drill was used in peat to extract 50 cm of sediment until the sand bed was reached. One of the samples (the clay fraction) from the "Palaeomeander" position (containing green grains) was subjected to a detailed petrographic analysis. This sample was washed in sieves with 1.0; 0.5; 0.25; and 0.125 mm mesh diameters, and was then subjected to drying without the reduction process in order to avoid damaging the grains. Then, 300 grains were selected for analysis aimed at identifying the origin of the grains.

The "Bobrza channel" site

To describe the deposits from the exposure at the “Bobrza Channel” site, the lithofacies code as modified by Zieliński (1995) was used. A total of 18 samples were collected for the analysis of sediments. Deposits were collected at every 10 cm vertical interval in the exposure. Samples were analysed by grain-size analysis (mesh diameter in mm: 1.0; 0.5; 0.25; 0.125; 0.1; 0.063). Separately, large white and brown fragments of rock and associated organic matter were collected. The rock fragments collected were subjected to macroscopic analysis, which aimed at identifying and determining the origin of the rocks. A sample of biogenic deposit from the "Bobrza channel" site was analysed for its macronutrient content and the presence of plants indicating human activity. The remainder of the organic sample was transferred to radioactive dating in the Laboratory of Absolute Dating in Skała.

The "Mill" site

At this site topographic maps of different ages were also used for the purpose of analysing the terrain relief and the location of the mill buildings. Lateral and longitudinal profiles were created as part of the "Surfer" program in addition to graphics depicting terrain relief. All the digital models were developed using LiDAR data.

Results

The "Palaeomeander" site

The Palaeomeander in the eastern part of the valley undercuts a high terrace of middle Pleistocene age, and has a radius of approx. 80 m, an amplitude of approx. 100 m, and a channel width of approx. 15 m. On the opposite side of the palaeomeander there is a meander hummock. All the relief forms are clearly visible in the landscape. After comparing several generations of meanders, it can be concluded that the parameters of the study palaeomeander are larger than contemporary channel parameters and those of channels of other generations (Fig.2). The age of the forms was determined, on the basis of a geological map, to be a inactive river-channel dissected in late Vistulian sediments.

In the deepest location drilled, the palaeomeander is filled with material 123 cm thick composed of dark silts mixed with organic matter. Green mineral grains of vivianite were found at a depth of 122 cm in the layer where the silt is in contact with sands.

The "Bobrza channel" site

There are both mineral and organic deposits in the exposure on the contemporary bank of the Bobrza. The mineral layers are mainly composed of sand, and in addition there is a considerable amount of material of silty grain-size. In the profile analysed (Fig. 3) we can mainly distinguish lithofacies of sand with a massive (Sm) or deformed structure (Sd). There is also local cross-bedding (Sx) stratification of the sand. In the central part of the profile there is a distinct layer of massive sand with fines (SFm). In the bottom layer, beneath the solid profile of the massive coarse-textured sand (Sm), there is a lens of organic material (C), and rock debris (B) (diameter of 10 to 40 cm). In the bottom of the profile tree logs (C) were also deposited. The whole profile is characterised by the discontinuity of layers and distorted structures.

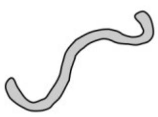
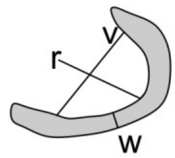
DISTANCE FROM COTEMPORARY CHANNEL	CONTEMPORARY CHANNEL	IN CONTACT WITH CONTEMPORARY CHANNEL	50 METERS	200 METERS (PALAEO MEANDER POSITION)
CHANNEL				
PARAMETERS OF CHANNEL [average wide (w) / radi (r) / amplitude (v)]	w=11 r=25 v=32	w=7 r=16 v=56	w=13 r=55 v=45	w=15 r=80 v=100

Fig.2. Comparison of the meanders of different generations with the contemporary river-bed, on the basis of selected parameters. w-the average width of the meander; r- radius of meander curvature; v- meander amplitude

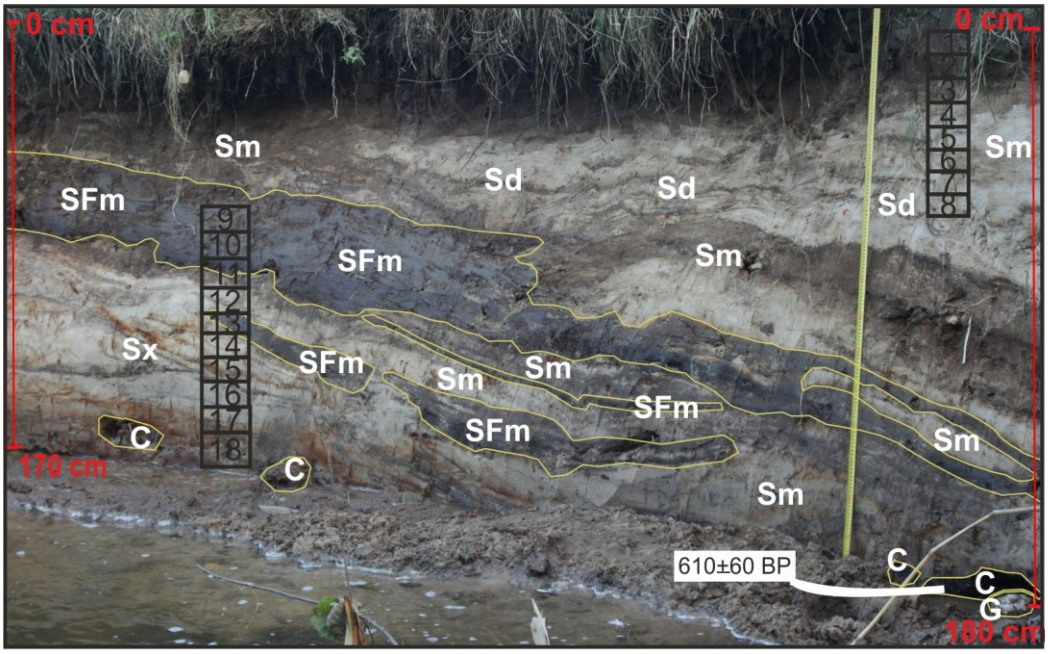


Fig.3. Exposure of deposits from the "Bobrza channel" site described using the lithofacies code. The black rectangles marked are sampling locations. Structural symbols of sediments: G-gravel/ conglomerate; S-sand/ sandstone; F- fines, silt / mud or siltstone / mudstone; C- organic deposits; SF-sandstone with fines. Textural symbols of sediments: m- massive structure; x-cross-stratification (in general); d-deformed structure

Starting from the lowest layer of the profile, bigger, beige rock fragments were classified as micrite limestone on the basis of macroscopic diagnosis. The fragments of limestone do not bear any traces of fluvial transport. However, they were, to a large extent, weathered (soft to slimy surface layers). Smaller fragments of brown rock were identified as flint.

The residual solids of organic material lying above the micrite limestone were dated using radiocarbon as having an age of 610 ± 60 BP (1421cal AD). Wood was found to be dominant in the organic sample (more than 80% of the surviving phytoclasts). The first material identified was the wood of broadleaves belonging to different species of poplar, willow, grey alder and black alder. The wood of Scots pine is also present with a high frequency. In addition to the wood, periderm is listed in a sample which indicates the presence of the remains of other trees. Tracheids of *Polypodiales* (Fig. 4) are also present. The epidermis (*Cyperaceae* and *Poaceae*) has been found in the sample, as well as the roots of rush type plants, among them the common reed and very rarely sedges (*Carex*). From the carpological findings the seed husks of *Juncus subnodulosus,* now rare, were identified.

Moving on to the next layers above the limestone, the value of the grain size composition index should be taken into account when considering them as mineral deposits. This part of the exposure can be divided into three parts. At a depth of between 180 and 120 cm, the average grain size increases. The standard deviation takes values in the range from 0.5 to 1, which indicates an average sorting of the deposit. The value of skewness indicates a relatively symmetrical distribution of the grain size of the sediments resulting from a tendency to the thickening of grains. Also kurtosis confirms a more dynamic deposition environment. At a depth of 120 to 70 cm the value of the standard deviation increases to 1.49, indicating a weak sorting of the sediment and a changing deposition environment. Mean grain diameter decreases,

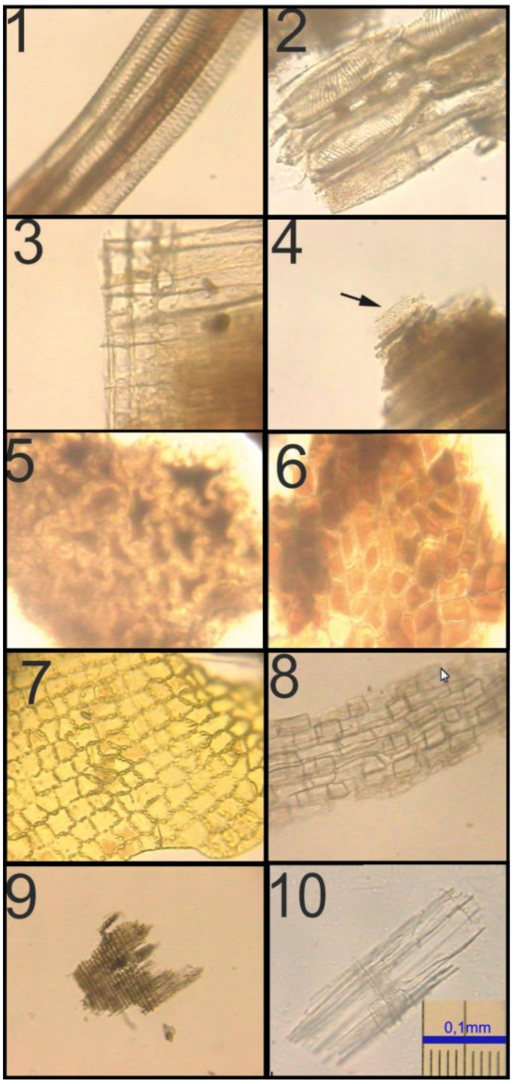


Fig.4. Pictures of macroscopic remains, taken with an optical microscope with transmitted light (magnification of 100 to 400X). 1. Coils of *Polypediales* x400; 2. *Alnus* wood x400; 3. *Pinus Silvestris* wood, x400; 4. *Corylus* wood, spiral bead x400; 5.*Pinus* peryderma x400; 6.Peryderma x400; 7. *Juncus subnodulosus* x400; 8. *Carex* root x400; 9. *Populus* wood, homogeneous rays x100; 10, *Populus* radial wood x 400 (Phot. K. Wójcicki)

and skewness presents negative values, giving a symmetrical or negatively skewed distribution, which in turn indicates a change in the pulse periods of increased growth in sedimentary environments. Pulsed changes also confirm the value of kurtosis. In this part of the profile we are faced with a dramatic change in the deposition environment in comparison with the deposits referred to above. From a depth of 80 cm to the ceiling of exposure, the standard deviation reaches values of 0.5 to slightly more than 1, which indicates an average sorting of sediment. Skewness closes in the range from +0.1 to +0.3 and has a positively skewed distribution, which indicates moderate dynamics of the sedimentary environment and uniform deposition conditions.

The "Mill" site

The mill building (now non-existent), connected to the mill wheel, was located right by the left edge of the river bank. Damming was achieved by abstracting from the main channel with a two-part structure (Fig. 5). At the upper level of the dam there was a weir through which water was directed to the mill wheel. Elements of the weir are visible today on the remains of the dam.

Fig.5. A – A photo from the 1950's showing the dam and the mill building. B- The interrupted dam, with the remains of the weir on the right hand side and the eroded bank of the left hand side of the river channel

On the basis of the Digital Terrain Model and field analysis of the contemporary morphology of the river channel, it was found that the range of the backwater is about 130 m. Thorough analysis of the river bottom based on the Digital Terrain Model enables one to state that bottom changes go much further, to approx. 500 m (Fig. 6). The profiles generated represent changes in the river Bobrza morphology caused by the dam. The changes were both in the transverse plan and longitudinal profile of the channel (Fig.6). When constructing profiles a large elevation was deliberately used so that the changes can be indicated.

Discussion and summary

The summary should commence with the oldest form in the study area, which is a palaeomeander in a distal part of the valley. It is a form which is a remnant of the functioning river channel with large flow parameters and larger than current metric parameters (Fig. 7 I).

The contemporary riverbed has less tortuosity, has smaller meander radii, and is also narrower. As we know from the geological map (Filonowicz 1971), the palaeomeander is located on a fluvial sand substrate of late Pleistocene age

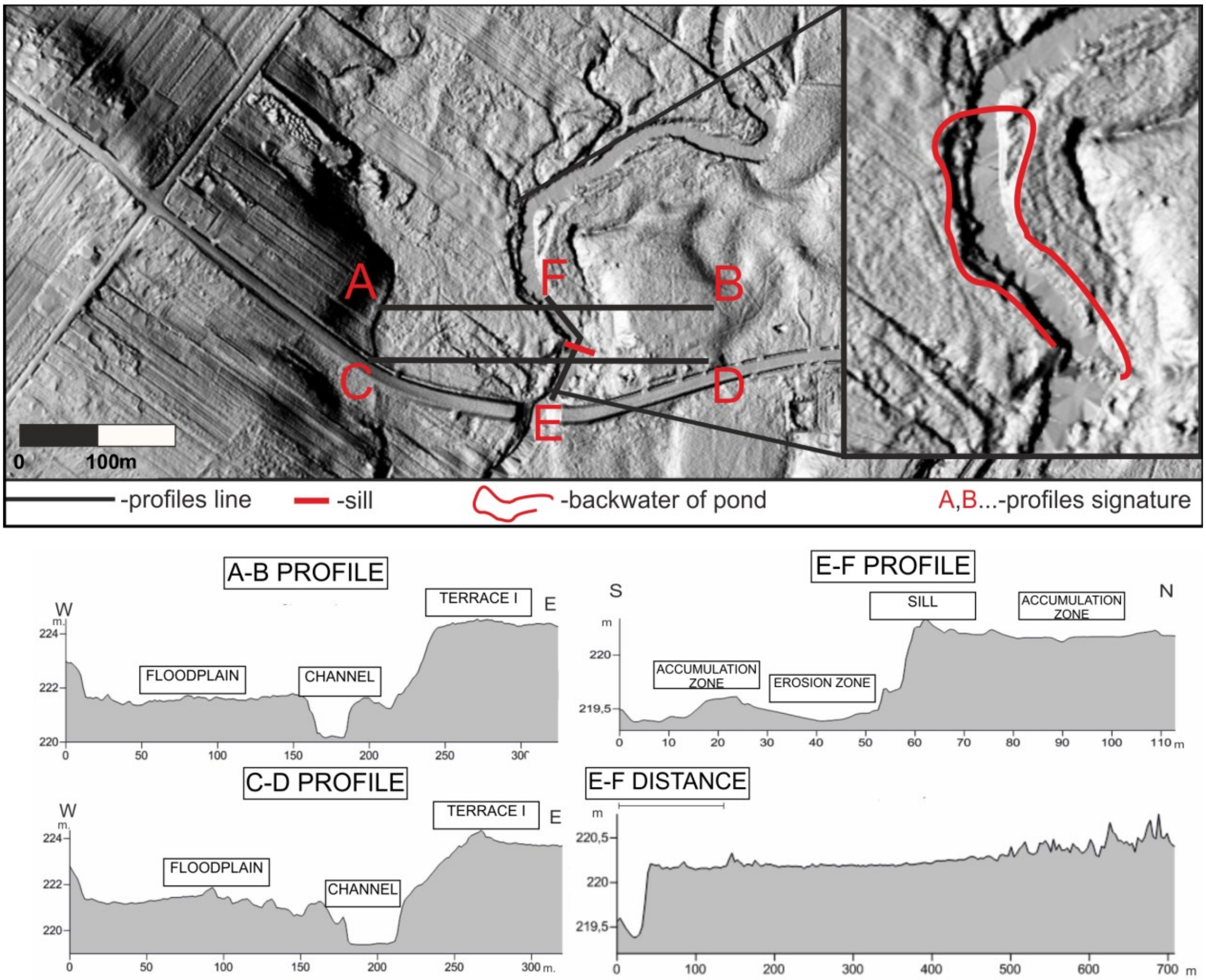


Fig.6. Location of the transverse and longitudinal profiles routed through the valley and the Bobrza channel on the "Mill" site. In the upper right hand corner there is an outline of the pond backwater visible in channel morphology

and undercuts a higher river terrace, built of river and periglacial sand and gravel, which derives from the Odra and Warta as well as Vistula glaciations.Only the bottom part of the valley was involved in the channel transformation from huge meanders to meanders with smaller parameters, as a result of which parts of the valley with remnants of huge meanders with large flow parameters were able to survive (Szwajgier 1999). Apart from the form examined, such fragments of meanders are rather scarce in the study area. The sediment filling oxbows usually consists of a mixture of biogenic and minerogenic components (Wójcicki 2013). The same is true in the case of the "Palaeomeander" site. The palaeomeander is filled with fine-textured mineral sediment with an admixture of organic components. This type of filling shows frequent episodes of flooding, depositing fine particulate material. We also gain information about the separation of the old oxbow from the active channel of the river which lasted for a considerable period of time. Green grains of vivianite, contained in the filling of the palaeomeander, are formed as a derivative mineral of many ores. It is found in clay sediments or as a component of lacustrine iron ore and is commonly found in peat, bog iron ore and brown iron-ore (Bolewski, Manecki 1993). When analysing the deposits, the possibility that the origin of these mineral grains was associated with industrial activities was excluded. The substrate age, a comparison of the parameters of the form, its fill material and the processes identified can be used as indicators of the natural origin and development of the palaeomeander.

At the next site – the “Bobrza channel” – the sediments of the contemporary floodplain are revealed. This area 'is an example of' a dynamic system in which there is almost constant erosion in some places and accumulation in others (Hupp, Bornette 2003). Trying to explain the presence of the rock fragments in the bottom part of the exposure in the Bobrza channel, one should take into account the fact that the supply of coarse mantle-rock fragments to riverbeds is affected both by fluvial and by slope processes. The upper part of the drainage basin is a zone of debris production and that is where there is a feedback system between the river bed and the slope (Owczarek 2004). In broad bottom valleys (as in the section examined) the valley bottom takes the supply role of the slopes (Kostrzewski et al. 1994).

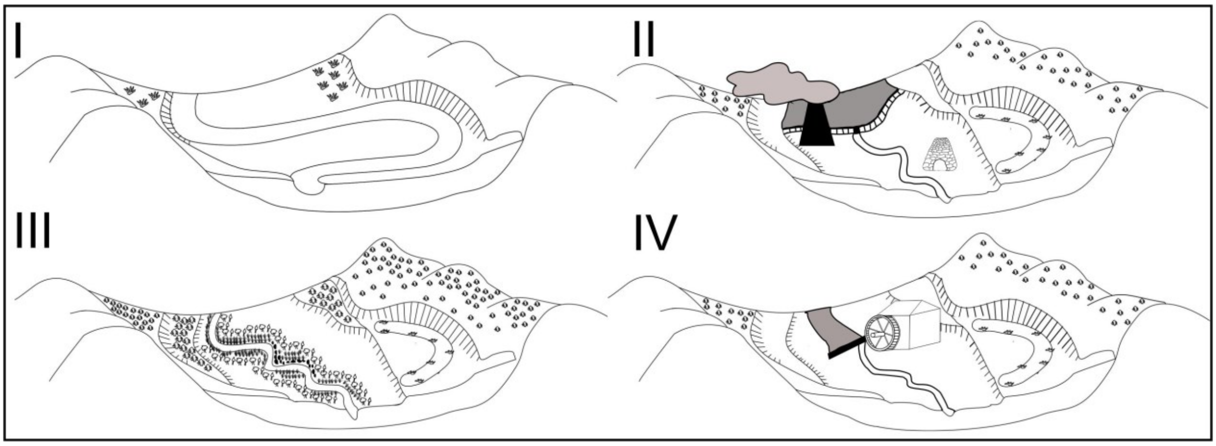


Fig.7. Diagram showing some stages of operation of the Bobrza channel at different times (hypothetical). I- period of huge meanders II- period of industrial activity; III- period of the occurrence of *Juncus subnodulosus* cover with the surrounding forest communities; IV- period of operation of the water mill

On the basis of these assumptions, it is likely that rock elements were deposited in the bottom of the valley during an episode of extreme flooding or intense human activity. However, given the remoteness and location of the limestone rock outcrop (coarse-bedded limestone, rocky and platy with flints) below the current site of deposition, the second scenario seems more likely. Also, the age of the organic material (1421 AD) on residual fragments of limestone, indicates a greater probability of its deposition in the bottom of the valley as a result of human activity. The moment of deposition that was established for the organic sample follows immediately after the start of increased human activity in river valleys in Poland and in Europe generally (Florek 2008, Kalicki 2006). We have information on the existence of an ironworks and steelworks a few hundred meters from the area investigated which dated from the XIII century (Kmieć 1998). According to the findings, it has been shown that the steel industry in the Mazowieckie metallurgy centre was closely associated with the production of burnt lime. The location of the lime is associated with the location of blast furnaces, and the results of chemical analyses of cinders clearly indicate the use of lime as a feature in metallurgical processes (Chomentowska 1982). This fact can be linked to the existence of a lime kiln in the area, the remains of which may be attributed to the fragments of limestone found (Fig. 7 II). Analysis of the macronutrients of organic matter from the bottom of the exposure indicates that the deposition took place in a forest environment containing a large variety of wood species (Fig. 7 III). Using a guide for classifying Polish plant communities (Matuszkiewicz 2006), the botanical composition indicated by the components can be classified as: riparian forests with willows and poplars and humid coniferous forest. The seed husks of the now rare *Juncus subnodulosus* identified in the sample may be another diagnostic element of environmental change. According to the ecological index numbers (Zarzycki et al., 2002), this is a subatlantic species which grows on alkaline, rich, moist and wet soils in warm temperate climates, and with full access to light. Currently, the occurrence of this species is limited to areas of north-western Poland, Pomerania and a single position in the Odra valley (Gałka 2009). To get a better overview of the situation relating to the development of *Juncus subnodulosus* stands on the "Bobrza channel" site, a description of one of the contemporary stands of this species in Poland needs to be provided. Such a description was made by Buliński (2005). The stand is located in Gdańsk Oliwa, in a side branch of the Valley of Joy. The area is inclined at an angle of 5 to 10° in the direction of flow, with a southern exposure. It is a damp area, with numerous seepages. The stand of *Juncus subnodulosus* is located in an open area 30 x 15 m in size and surrounded by black alder trees. There is a dense patch reaching a height of 1 m and which tends to lodge when growing in a dense clump. The species occurs in an area covered by a layer composed 100% of herbs with a significant share of bryophytes. Turning to the mineral deposit lying at a depth of 170 to 120 cm in the profile, the variations in average grain size, alternating between increasing and diminishing, and variable values of skewness periodically indicate a river transport of greater or lesser strength. This kind of change in pulse energy is characteristic of a sandy braided river (Ludwikowska-Kędzia 2000). At this level one can also see that gutter scour infill has also been inserted in the profile; this is fill of sandstone with fines facies, probably representing wash-out structures of erosion channels. According to the study by Kaczmarzyk et al. (2008) investigating sequences of deposits in the valley of the middle Wieprza, another fine-grained material in the 120-70 cm level should be identified with the inflow of large amounts of flood water carrying a large amount of homogeneous clayey suspension. The ferrous precipitation regularly occurring at this level is the result of post-sedimentation processes associated with the penetration of the plant root systems. This level of fine-grained sediment should be identified with the distal zone of the floodplain (Gradziński 1973). In the depth from 70 to 20 cm the average size of grains decreases upward, the sorting of sand improves and the skewness is positive indicating a stabilization of the river energy which makes the conditions favourable for deposition. The sequence characterised by a diminution of grain size towards to the top is considered as a diagnostic cyclothem of a meandering river. The lower part of this sequence is formed of lateral growth alluvial deposits by bottom flow transport while the upper part of the cyclothem is vertical growth alluvium deposited during floods (Szmańda 2011). The section from 20 cm depth to the land surface is a currently forming floodplain. The sequences of mineral deposits described should be regarded as an indicator of natural influences shaping this river system. An important indicator of the changes recorded in this exposure is the species composition of macronutrients with the rare species *Juncus Subnodulosus*, which provides evidence that the herbaceous layer could be also present in the study zone of the Bobrza valley (Fig. 7 III). The fragments of rock are an ambiguous indicator, which can be interpreted in two ways. However, the author inclines to the thesis that they are related to human activity.

At the "Mill" site, the known time frame for the initiation and application of human impact allows for a certain positioning of changes in time. In the case of the location in question, we are dealing with a specific structure, a two-part stone dam with a weir and a sluice gate supplying a mill. According to the study by Wyżga (2005) and Kościelniak (2005) it is just this type of structure that causes the greatest changes to riverbed morphology. As with all water mills constructed in the valleys of relatively small rivers, this was also a location where a pond was established in the bed of the watercourse (Kobojek 2009) (Fig. 7 IV). By analysing archival and contemporary photographs, we get a view of the situation in this part of channel during the operation of the mill dam and its facilities up to the present. On abandonment of the dam, it was mainly its higher parts that were preserved. Obstruction of the riverbed resulted in changes in morphology, dividing it into two zones above and below the dam, which is the typical result of the impact of this type of structure (Witek 2012; Witek, Białobrzeska 2012). The clearest changes caused by the construction of the dam are presented in a longitudinal profile along the main channel of the Bobrza river passing over the weir. Very clearly visible is the weir that separates the zone of accumulation of sediments above and the erosion zone and the secondary zone of accumulation below. These zones were mainly formed when the weir and mill sluice mechanism were in operation. According to research by Podgórski (2009), conducted in the Chełmińskie Lakeland, mill ponds were a local zone of sediment accumulation, while parts of the channel below obstructions were characterised by a significant deepening. The gradually degraded and deteriorating dam supplying the mill slowed down the process of the scouring of sludge from the accumulation zone, and the zone of erosion was partially buried and has lost its distinctive character. The channel has not yet returned to equilibrium. The process is confirmed by the results of Witek and Białobrzeska (2012) obtained during tests on larger structures of this type in the Kłodzko area. On this basis, you may well find that the changes caused by the operation of the mill buildings occurred in a very similar way, with both large and small scale buildings. The length of backwater retained in the pond after the dam broke and the degree of water lowering has highlighted the degree of undercutting of the shore and widening of the channel. The uneven bank, which used to be the bottom of the channel, creates a contemporary subterrace in the main channel. The main channel was wider during the period when it was dammed. However, as is apparent from the channel cross profile seen in the water flow above the dam, it is relatively deep restricting the upward expansion of the edges. Under natural conditions, the increase in depth of the channel is compensated for by a reduction in its width and a reduction in slope of the river profile (Wyżga et al. 2008). However the cross profile below the dam shows a channel with a regular plan, slightly wider with lower, almost vertical banks. The disorder in the correct sequence of relief-forming processes was caused by the interruption of the dam, the increase in the fall of the channel above the dam, and the consequent transformation of its plan from the period of operation of the mill and the dam. Currently, secondary erosion of the river above the dam restricts the possibility of accumulation of overbank deposits in the bottom of the valley and the retention of flood water on the flood plains.

Conclusions

In the selected study area natural and anthropogenic transformation of the Bobrza river system was found, based on the following indicators:

- the age of the substrate, a comparison of the palaeomeander parameters, its fill and the processes identified, should be regarded as indicators of the natural origin and development of the palaeomeander,
- the sequence of mineral deposits is an indicator of natural influences shaping the river system; the grain size composition index and lithofacial analyses of deposits fully allowed for unambiguous identification of depositional environments,
- the species composition of macronutrients, including the rare *Juncus subnodulosus,* gives rise to the assertion that such a herbaceous layer was also present in the study section of the Bobrza valley,
- most of the evidence related to the fragments of rock in the bank exposure indicates that they appeared there in connection with human activity,
- the operation of a water mill and the associated transformation of relief should be explicitly considered as an indicator of anthropogenic trigger factors transforming the system,
- in addition, it is worth mentioning that in the "Bobrza channel" site, the only subfossil stand of *Juncus subnodulosus* in the south-eastern part of Poland was discovered.

Acknowledgments

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