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LATE GLACIAL AND HOLOCENE EVOLUTION OF THE ESTUARINE SECTION OF THE NIDA RIVER

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A b s t r a c t. Based on the results of detailed geological-geomorphological studies, old maps from the past 200 years, and historical data, the paper is the first to present the structure of the valley floor in the estuary of the Nida River, an upland tributary of the Vistula, and discuss changes in the development and course of their channels. The aim of the study was to grasp the importance of local factors, both natural (palaeogeographical, lithological and tectonic) and anthropogenic, in the morphogenesis of this section, where a relatively small upland stream crossed in the medieval and modern periods by important overland and water routes of the Polish-Lithuanian Commonwealth flows into the Vistula River, which is ten times larger. The discussed section is not deltaic in character. The branching of the Nida into several simultaneously functioning outlet arms may have been caused by the blocking of outflow from the valley during floods and the drainage of the flood waters at the valley mouth in several directions, via channels both permanent and periodic. Changes in the numbers and locations of the Nida estuaries in recent centuries have both natural and anthropogenic causes. The interaction between the main stream and its many-times smaller tributary in the studied section has resulted in a complex mosaic of forms and cut-and-fills of both streams, but with the Vistula playing the dominant role. The cut-and-fills of the Vistula "enclose" the Nida alluvium inside its valley on the Winiary-Nowy Korczyn line, while the cut-and-fills of the Nida only occur in a very narrow strip under the edge of the terrace. The Nida followed abandoned channels of the Vistula on Holocene cut-and-fill IIA, flowing parallel to the Vistula for 9 km. The floor of the Nida Valley lacks Holocene mineral-organic and mineral sediments, characteristic of other upland tributaries from loess areas. The regulation of the Vistula in the mid-19th century and the Nida in the first half of the 20th century fixed the courses of the rivers, completely changing the sedimentation regime in the estuarine section of the Nida, where backflow and associated sedimentation of fine-grained deposits occurred.

K e y w o r d s: Estuary changes, Vistula river, Nida river, evolution river, cartographic changes, geological changes

INTRODUCTION

The Late-glacial and Holocene evolution of river valleys has attracted scholarly interest since the mid-20th century. It became the subject of national research programmes (MRI-25, CPBP) and international projects (IGCP-158A) and commissions (GLOCOPH, FLAG). This has allowed the development of, among other things, a methodology for the study of river valleys (Starkel, Thornes 1981), and a number of concepts and hypotheses (Kalicki 2006 with literature there). In Poland, the most comprehensive study of this type concerns the evolution of the valley of the Vistula River from its sources to its mouth, presented in the six-volume *Evolution of the Vistula River Valley during 15 000 years* and summarised in a monograph by Starkel (2001). The structure and evolution of the fans of almost all the Carpathian tributaries of the Vistula have been investigated as well (e.g. Alexandrowicz et al. 1981; Szumański 1982; Sokołowski 1987; Gębica 1995, 2004), and the same holds true with respect to selected watercourses in the piedmont zone (e.g. Kalicki 1997). In contrast, no such comprehensive studies are available for the second-order upland tributaries of the upper Vistula, and the research is relatively limited and patchy (e.g. Kosmowska-Suffczyńska 1983; Śnieszko 1987; Alexandrowicz, Sanko 1997; Michno 2004, 2013). The available studies rarely cover the lowest parts of the valleys, and none of them analyse the structure of the estuary sections where there is direct contact between the alluvia of a tributary and the Vistula River.

Although it clearly stands out geomorphologically in the Ponidzie region, the Nida River valley is likewise poorly understood (cf. Łajczak 2013). Despite 30 years of interdisciplinary research by Warsaw-based scholars in the Pińczów area (Richling 2013), the evolution of the Nida Valley floor is yet to be addressed. Geomorphological research has so far covered only small sections of the Nida Valley (e.g. Hakenberg, Lindner 1971, 1973; Mityk 1989; Tsemergas et al. 2000; Sołtysik 2002; Szwarczewski 2009, 2021; Kalicki et al. 2016; Biesaga 2016; Biesaga, Kalicki 2021; Frączek et al. 2021) and its subbasins or areas immediately adjacent to the basin (e.g. Sołtysik 2002; Krupa 2013; Chrabąszcz et al. 2017; Kalicki et al. 2022; Pabian et al. 2022). More recent studies have analysed in detail the factors shaping particular fragments of the Nida Valley floor (e.g. Kalicki, Biesaga 2022; Korczyńska-Cappenberg et al. 2023), as well as environmental changes caused by prehistoric settlement in the valley and on nearby uplands (e.g. Przychodni 2002, 2006; Szwarczewski 2009, 2021; Czernek 2015; Malęga et al. 2016, 2019; Malęga, Biesaga 2016; Moskal-del Hoyo et al. 2018; Kalicki, Biesaga 2022; Korczyńska-Cappenberg et al. 2023).

The first attempt at a comprehensive account of the Late-glacial and Holocene evolution of the middle and lower Nida Valley, which crosses a highly geologically and geomorphologically diverse area, succeeded in identifying the importance of various factors of valley morphogenesis on the local scale (Biesaga 2023). The results of the detailed geological and geomorphological research have also demonstrated the clear distinctiveness of the estuarine section, which will be presented in this paper. This paper is the first to analyse the valley floor structure in an area where an upland watercourse feeds into the Vistula, since, as mentioned above, there have been no such studies in the literature to date (cf. e.g. Michno 2004, 2013).

OBJECTIVE

The aim of the study was to grasp the importance of local factors, both natural (palaeogeographical, lithological and tectonic) and anthropogenic, in the morphogenesis of the section of the Nida Valley where this relatively small upland watercourse flows into the ten-times-larger Vistula. At the same time, in the Middle Ages and in modern times this area was part of very important communication routes of the Polish-Lithuanian Commonwealth, both overland (the Sandomierz route) and by water (the Vistula River) (cf. Chwalba 2023). The subsequent stages of the study established the structure of the valley floor (including the amount, structure and age of cuts and fills), the formation and facial variation of different-aged alluvia, and it traced the changes in the course and development of the Nida and Vistula channels, as well as the phases of erosion and accumulation.

METHODS

The study used interdisciplinary research methods. Geomorphological (Klimaszewski 1982; Starkel 2008) and geological mapping of Quaternary sediments were carried out during fieldwork. The studies made use of a hypsometric base map and digital terrain model (Table 1).

Hand drillings were carried out with a windowed hand auger from Eijkelkamp, and samples were taken from the cores for sedimentological analyses. These were performed at the Geomorphology and Hydrology Laboratory of the Department of Geomorphology and Geoarchaeology at Jan Kochanowski University in Kielce. The prepared sediment samples were subjected to granulometric analysis using a Mastersizer 3000 laser diffraction particle-size analyser from Malvern Instruments Ltd. (for the fine fractions with a grain size below 1 mm) and a set of sieves (DIN ISO 3310/1) and "Retsch – Rahmen" screens (for the fractions from 1 mm to 2.8 mm). Each pre-prepared sample was sieved for 10 minutes. The laser analyser was operated in manual mode using "Mastersizer

Table 1. List of DTM sheets used

Details	Sheet	Source
Digital Terrain Model	M-34-66-A-b-2-2, M-34-66-A-b-2-3, M-34-66-A-b-4-2, M-34-66-B-a-1-1, M-34-66-B-a-1-2, M-34-66-B-a-1-3, M-34-66-B-a-1-4, M-34-66-B-a-2-1, M-34-66-B-a-2-2, M-34-66-B-a-2-4, M-34-66-B-a-3-1, M-34-66-B-a-3-2, M-34-66-B-a-4-1, M-34-66-B-a-4-2	geoportal.gov.pl

Table 2. List of old maps used

Year	Name	Scale
1797	Szczegółowa Mapa województwa Sandomierskiego	1:225 000
1808	Heldensfeld-Benedicti: Carte von West-Gallizien	1:288 000
1864	Topograficzna karta Królestwa Polskiego, arkusz Nowe Miasto Korczyn	1:126 000
1915	West. Osteuropa in 1915 – Niemieckie mapy zaboru rosyjskiego, I wojna światowa	1:25 000
1936	WIG, Mapa Szczegółowa Polski, arkusz Nowy Korczyn	1:25 000
1942	Karte des Deutschen Reiches, Großblatt Einheitsblatt, arkusz Staszów	1:100 000

- v3.00" software. The instrument was coupled with a Hydro EV unit, designed to work with a material suspended in deionised water. Samples were analysed five times in 10-second measurements, and the results were then averaged (Racinowski 1973; Syvitski 1991; Racińowski et al. 2001; Schmidt et al. 2003). The results were processed in the GRANULOM program, which allowed them to be visualised, and the statistical grain size indices (Folk, Ward 1957) could be calculated: mean grain diameter (Mz), standard deviation (δ_I), skewness (Sk_I) and kurtosis (K_G).

Based on drilling and laboratory data, two general geological cross-sections (Łęka, Winiary) and two detailed ones were made through two palaeomeanders of the Vistula River: Kanna and Samocice (Fig. 1).

The analysis of riverbed changes in previous centuries was based on cartographic data (Table 2).

The study also used data and conventional radiocarbon dates from Sokołowski (1987), which have been calibrated using OxCal ver. 3.10.

The illustrations and text were processed using Microsoft Office 2007 and the PAINT, INKSCAPE, QGIS programs.

LOCATION OF THE STUDY AREA AND THE STATE OF RESEARCH

The Nida Valley is located in the Polish Uplands, between the Miechów and Kielce Uplands (Kondracki 2002). Below its gorge at Kopernia, the river flows through the Solec tectonic depression between two horsts: the Wodzisław horst to the SW and the Pińczów horst to the NE (Krysiak 2000; Urban 2019), on the boundary between the Cretaceous rocks of the Nida Basin and the Miocene silts with gypsum series of the Sandomierz Basin (Mądry 1997, 2002).

The estuary section of the Nida, about 7 km long, covers a fragment of the Sandomierz Basin at the confluence of the Nida and the Vistula. The floodplain in this area is common for both rivers, and it is bounded to the north by a poorly pronounced erosional edge of the Solec Basin, to which the Vistulian terrace adjoins. The morphological boundaries between all these forms are not very clear (Fig. 1), which led Gilewska (1972) and Łyczewska (1972) to assume subsidence movements for this region.

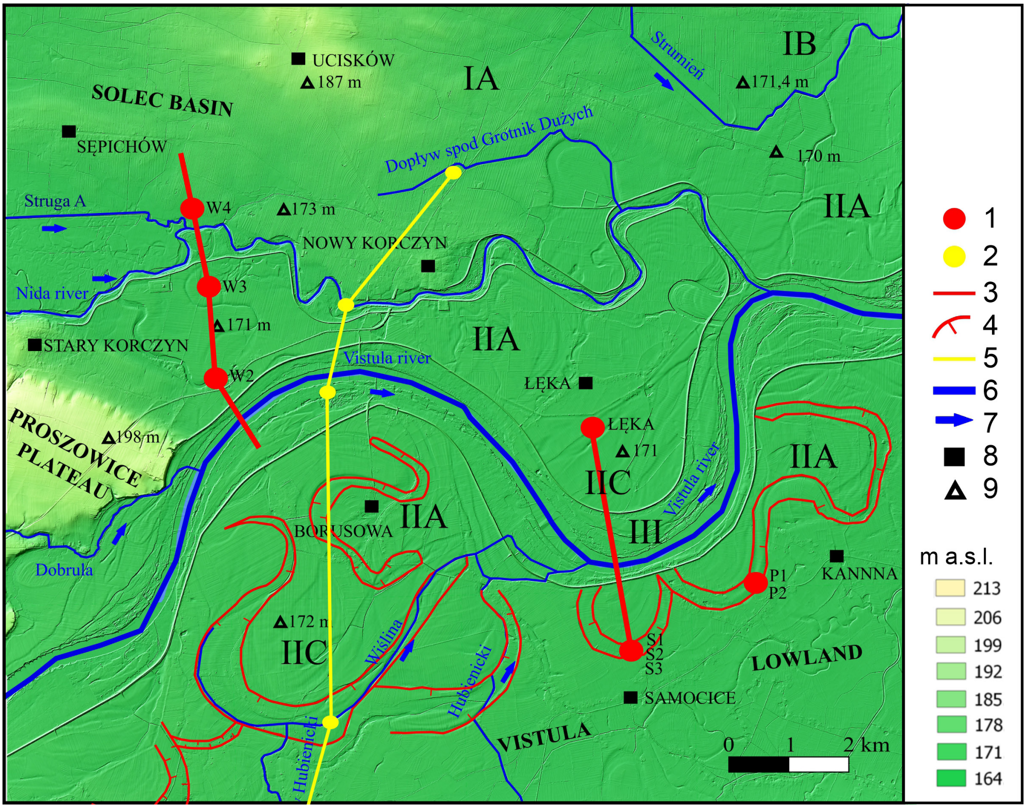

Fig. 1. Location of boreholes and geological cross-sections on the DTM at the confluence of the Nida and Vistula Rivers (data from geoportal.gov.pl). 1 – boreholes, 2 – old boreholes (Sokołowski 1987), 3 – geological cross-sections, 4 – oxbow lakes of the Vistula River, 5 – geological cross-section (Sokołowski 1987), 6 – streams, 7 – direction of flow, 8 – localities, 9 – spot heights; cut-and-fills (Sokołowski 1987 altered): IA – middle terrace, Vistulian, IB – Strumień depression, Late Glacial, IIA – Holocene cut-and--fill, IIC – cut-and-fill of the 15th–17th c., III – cut-and-fill of the 18th–21st c.

According to Sokołowski (1987), the oldest cut-and-fill in the Vistula Valley floor is the "middle terrace (I)" (Fig. 1). It covers both the Vistulian terrace as identified on the geological map (Mądry 1997, 2002) (Fig. 2) and a depression separated from it by a poorly marked bank up to 1 m high, stretching from Grotniki Małe and Wójtowe Łąki to Połaniec and today drained by the Strumień River (Fig. 1). In Sokołowski's opinion, this depression may have been used by the Nida River in the Late Glacial period when the Vistula flowed through the analogous Breń depression south of Garb Szczuciński. The sediments of this level are sand-and-gravel channel alluvia with clasts of Carpathian and upland rocks. However, linking these two forms (the terrace and the marginal depression) seems erroneous, especially in light of the results of more recent studies of the structure of the Vistula floodplain downstream of Kraków (Kalicki 1991, 2006), where such depressions in the marginal parts of the floodplain are relics of sand-and-gravel alluvial plains of the braided river from the end of the Younger

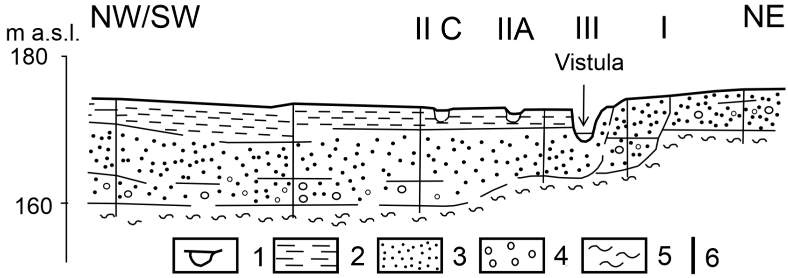

Fig. 2. Geological cross-section (see Fig. 1) through the valleys of the Vistula and Nida Rivers; (SOKOŁOWSKI 1987, supplemented). 1 – oxbow lake deposits, 2 – overbank deposits, 3 – sands, 4 – sands with gravels, 5 – Miocene silts, 6 – boreholes; I, IIA, IIC – cut-and-fills (explanations in the text)

Pleniglacial and Late Glacial. Like the Strumień depression, they are contemporarily drained by tributaries of the Vistula (Drwień, Drwinia), which for many kilometres flow parallel to the main channel and are separated from it by only slightly higher, broad natural levees. Therefore, it would be appropriate to divide this cut-and-fill into the actual terrace (IA) and the marginal depression of the Strumień (IB).

Semicircular erosional cuts in this terrace downstream of Nowy Korczyn and in Grotniki Małe mark the location of palaeomeanders. The palaeomeanders are contemporarily followed by the Nida and the Dopływ spod Grotnik Dużych, respectively. However, an unambiguous decision as to whether these were meanders of the Nida or the Vistula is difficult, as the parameters of the meanders of both rivers (cut-and-fills IIA and IIB according to SOKOŁOWSKI 1987) are similar.

On the broad floodplain of the Vistula below the mouth of the Dunajec River, SOKOŁOWSKI (1987) distinguishes three cut-and-fills of different ages, although the parameters of palaeomanders within them do not differ as much as in other sections of the Vistula Valley in the Sandomierz Basin (e.g. KALICKI 1991) or in the valleys of its Carpathian tributaries (e.g. ALEXANDROWICZ et al. 1981; SZUMAŃSKI 1982). Their alluvia show facial variation typical of a meandering river.

The IIA cut-and-fill (Figs 1, 2) covers the largest area, and the palaeomanders have regular shapes (slow migration), with radii within a range of 150–630 m (330 m on average) and widths of between 40 and 160 m. It formed in the Holocene, as evidenced by radiocarbon dates from the bottoms of palaeomeander fills (3–4 m thick) in the Szczucin area (about 10–15 km downstream of the Nida estuary): under the edge of the Vistulian terrace (6040±140 BP cal. 4400–3800 BC and 3970±80 BP cal. 2190–1860 BC), on the right bank close to the riverbed (Szczucin: 3270±200 BP cal. 1750–900 BC), and in an analogous position but closer to the mouth of the Nida River (5 km downstream) near Mędrzechów (4920±220 BP cal. 3450–2500 BC). A black oak trunk from the turn of the Atlantic and subboreal (4920±100 BP cal. 3180–2770 BC) was found in the alluvia of this terrace near Słupiec.

Cut-and-fill IIB (Figs 1, 2) is preserved in the form of isolated fragments near the Vistula riverbed and is lower than IIA by 1.0–1.5 m. The palaeomanders have a slightly larger average radius (370 m) and are not as regular in shape as in IIA, indicating faster migration. The cutting and formation of this cut-and-fill took place in the 10^{th}–15^{th} centuries, with very significant changes in the land use pattern occurring in the 13^{th}–14^{th} centuries (Dembińska 1972). Villages were founded on this cut-and-fill in the 16^{th}–18^{th} centuries, 200–400 years later than on IIA (Mateszew 1974).

Cut-and-fill IIC occurs inside palaeomanders with radii of up to 700 m and channel widths of 300 m. They are irregularly shaped, and the slip-off slopes indicate lateral migration. One of these palaeomeanders (Wiślina) south of Nowy Korczyn was still active in the 17^{th} century, as indicated by Michałowski's map (1678). This is confirmed by the fact that Borusowa (now a village on the right bank of the Vistula) belonged to the parish of Stary Korczyn (now the left bank) until 1772 (www.borusowa-wiz.diecezja.tarnów.pl). Likewise, the village of Winiary (left bank) and its hamlet Chałupy do Winiar (now on the right bank) probably both lay on the same (left) bank of the Vistula until the 18^{th} century.

Today, both the Vistula and the Nida are embanked. Cut-and-fill III, the modern floodplain between the Vistula embankments, began to form at the turn of the 17^{th} and 18^{th} centuries, when the frequency of floods and the stream load increased due to human activity. It forms narrow strips of channel deposits on both banks of the present Vistula riverbed. There are no abandoned palaeomanders here, and the fluvial relief is related to the functioning of the straight river (Sokołowski 1987).

GEOLOGICAL AND GEOMORPHOLOGICAL DATA

Samocice-Kanna palaeomeander system

The verification studies were first carried out on the IIA cut-and-fill (Fig. 1), which according to Sokołowski (1987) is located to the SE from Nowy Korczyn. Between Samocice and Kanna a system of Vistula palaeomanders is preserved, consisting of three bends with small radii (approx. 100–150 m) and widths of 30–40 m. A cross-section has been made through the westernmost one.

The approximately 35 m-wide palaeomeander is filled by silty sands and sandy silts (Fig. 3). We can distinguish three members corresponding to variable flow dynamics. In the lower part (I), sandy silts (Mz=3.8–5.2Φ) occur, which are poorly sorted (δI=1.5–2.0). In the middle (II) part, the sediments are coarser (Mz=3.2–3.9Φ) and also poorly sorted (δI=1.4–1.8), which may indicate an increase in flow dynamics. In the upper part (III) the sediments are again finer (Mz=4.3–5.5Φ) but still poorly sorted (δI=1.8–2.0).

The small number of samples and the lack of dates make a more detailed analysis of changes in fluvial dynamics impossible.

Samocice palaeomeander

The Samocice-Kanna palaeomeander system undercuts a single palaeomeander at Samocice. The latter has similar parameters, but the relative chronology indicates that

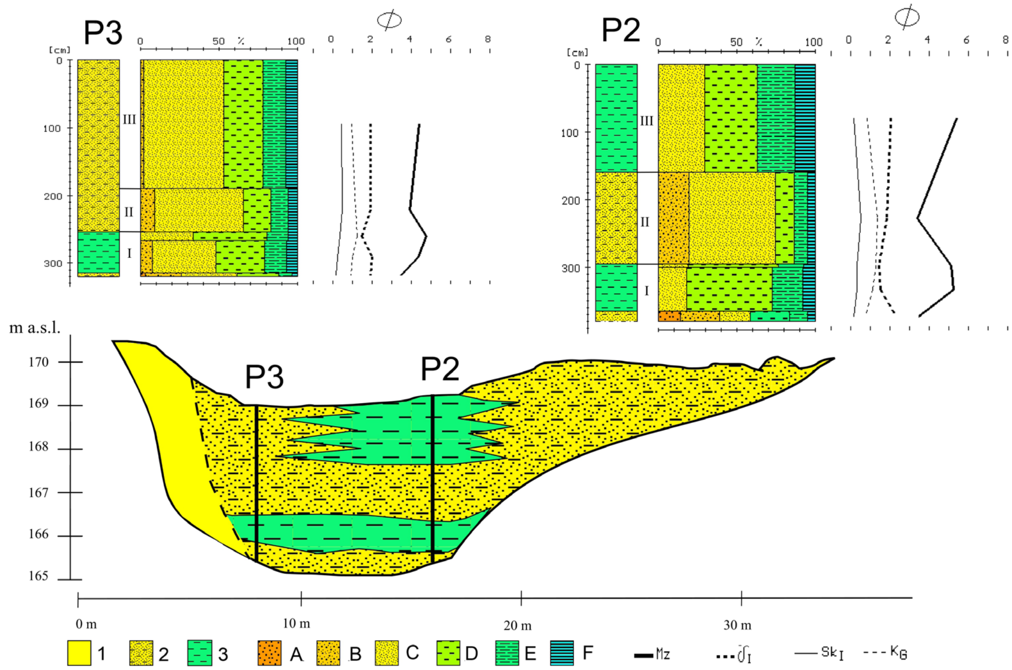

Fig. 3. Schematic cross-section through a palaeomeander of the Vistula River at Kanna. Lithology: 1 – sands, 2 – different-grained sands, 3 – silty-loamy sands; Fractions: A – coarse-grained sand (−1–1Φ), B – medium-grained sand (1–2Φ), C – fine-grained sand (2–4Φ), D – medium-grained silt (4–6Φ), E – fine-grained silt (6–8Φ), F – clay (over 8Φ); Folk-Ward (1957) grain size distribution parameters: Mz – mean diameter, δI – standard deviation, Skl – skewness, KG – kurtosis

it must be older than the system undercutting it. No organic sediments were found in the sand and silt filling it, which makes radiocarbon dating impossible.

Three members can be distinguished in the current zone (Fig. 4) (S1), differing in the proportions of finer and coarser sediments. The lower member (I) is formed by sands (Mz=2.2–3.5Φ), poorly and very poorly sorted (δI=1.2–2.2), whereas the middle one (II) is dominated by poorly sorted (δI=1.5–2.0) sandy silts (Mz=4.0–4.5Φ) with thin interbeds of poorly sorted (δI=1.0–1.8) silty sands (Mz=4, 0–4.1Φ). The upper member (III) is built of poorly and very poorly sorted (δI=1.8–2.2) silty sands (Mz=3.8–4.2Φ), with an interbed of poorly sorted (δI=2.0) silt (Mz=5.8Φ).

Again, the lack of dates does not allow us to establish a time frame for the changes in flow dynamics. However, the hypothetical age of these palaeomeanders can be established by comparing the heights (calculated above the water level of the Vistula River) of slip-off slopes and bottoms of the palaeomeander systems in Kanna and Borusowa and the palaeomeander in Samocice with analogous heights for the palaeomeander in Mędrzechów, dated to 4920±220 BP (cal. 3450–2500 BC). For the palaeomanders at Mędrzechów and Samocice, these heights are +2.0 m and 2.2 m (bottom) and +4.5 m and 5.0 m (slope), respectively, allowing them to be grouped into a single generation abandoned at the turn of the Atlantic and Subboreal periods. For the systems at

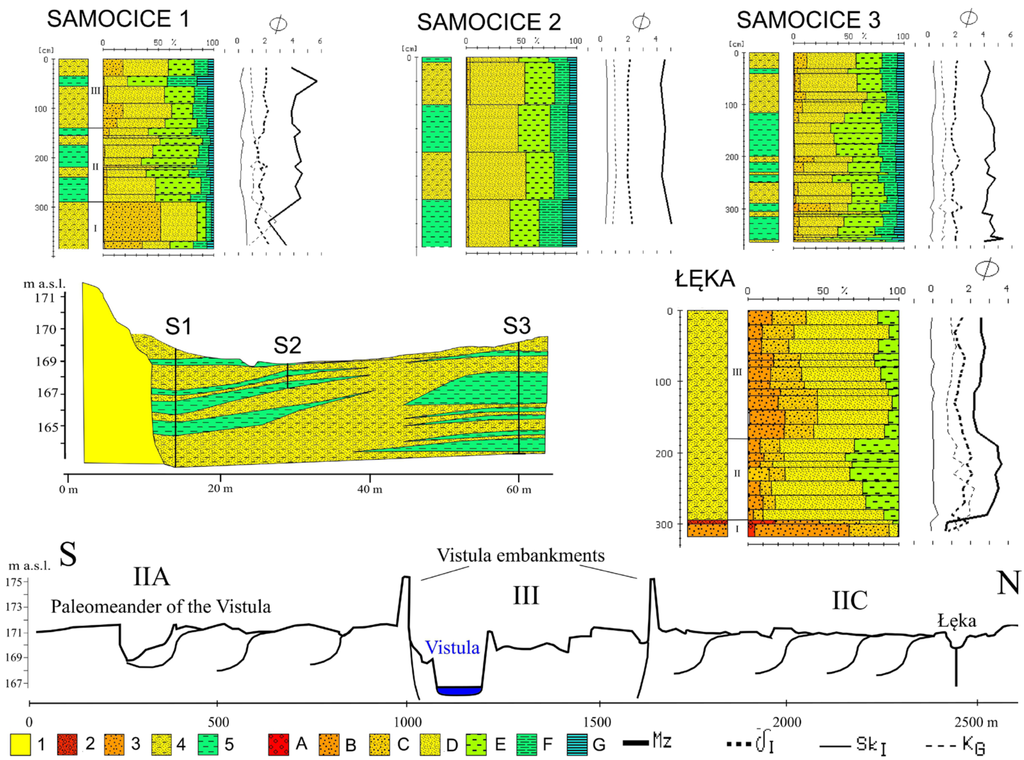

Fig. 4. Schematic Łęka cross-section through the Vistula River valley. Lithology: 1 – different-grained sands, 2 – sands with gravels, 3 – medium-grained sands, 4 – silty-dusty sands, 5 – dusty silts; Fractions: A – gravel (below −1Φ), B – coarse-grained sand (−1–1Φ), C – medium-grained sand (1–2Φ), D – fine-grained sand (2–4Φ), E – medium-grained silt (4–6Φ), F – fine-grained silt (6–8Φ), G – clay (above 8Φ); Folk-Ward (1957) grain size distribution parameters: Mz – mean diameter, δ_I – standard deviation, Sk_I – skewness, K_G – kurtosis

Borusowa and Kanna these values are slightly higher, at +2.7 m (bottom) and +5.0 m and 4.5 m (slope), suggesting that they represent a single system abandoned as a result of avulsion, which may have occurred shortly after the channel-straightening stage and the cutting off of individual meanders, probably in the Subboreal.

Łęka profile

The topographic profile starts at the Holocene cut-and-fill IIA (Fig. 1), with the Samocice palaeomeander, then crosses cut-and-fill III in the area between the embankments of this river and ends with a borehole within cut-and-fill IIC, which can be dated to the 16th–17th centuries and linked to a Vistula palaeomeander (known as the Wiślina) south of Korczyn, still active at the end of the 17th century. Later changes to parish boundaries in the area may confirm changes to the Vistula riverbed. In 1772, a new parish was erected, consisting of three villages which today are located on the right bank: Kozłów (originally part of the Gręboszów parish), Borusowa (originally part of the Stary Korczyn parish) and Hubienice (originally part of the Nowy Korczyn parish). The Vistula River formed the natural boundary of the parish, although in the case of Hubienice this is much in doubt, as the course of the Vistula in this area and the cutting off of the Wiślina did not cause the village to "move" from the left bank to the right. This unusual location of the village in relation to the church (on the opposite bank) may have been due to the existence of an important ferry crossing, operating here since at least since the 14th century (www.greboszow.pl/historia). A map from the late 18th century shows the name Przewóz (Polish for 'crossing') in this area (Fig. 6).

The Łęka profile (Fig. 4) is located in the zone of the slip-off slopes of cut-and-fill IIC. They are an NE extension of the Vistula riverbed, associated with the Wiślina palaeomeander and the lateral migration of the channel in this section (to the S). Three members can be distinguished in the profile. In the lowest part are channel sediments (I). These are sands with gravels and medium-grained sands (Mz=0.6–0.7Φ), moderately and poorly sorted (δI=0.8–1.8). Higher up are two members of overbank sediments. The lower (member II) is formed by silty sands (Mz=3.0–3.7Φ), poorly sorted (δI=1.0–2.0), with a weakly marked tendency to finer grains with decreasing depth, typical for meandering rivers. The higher member (member III) is fine-grained sands, with minor admixtures of silt (Mz=2.1–2.8Φ), poorly sorted (δI=1.0–1.8).

Further to the N, the floodplain of the Vistula River continues up to the Nida, and to the W of the profile line there is another Vistula palaeomeander (Zawodzie). Its small size is indicative of its connection with the Holocene IIA cut-and-fill. Here, the Nida cut-and-fill is very narrow and "squeezed" under the edge of the terrace on which Nowy Korczyn lies. The slip-off slopes of this palaeomeander are undercut by a system of very small palaeomeanders of the Nida extending S towards the modern Vistula. This system surrounds from the E a square hill (100×100 m) on which the castle of Nowy Korczyn stood (built in the 14th century by Casimir the Great), and for which the Nida was the N moat. It is possible that the palaeomeander system preserved in the relief was at the time an active Nida riverbed serving as a barrier preventing access to the castle from the E side.

Winiary profile

The cross-section starts between the Vistula embankments (cut-and-fill III) (Fig. 1) and crosses the bottom of the Nida Valley, its old estuary channel (W2) (Fig. 5), and the floodplain with abandoned channels (W3). It ends in the marginal part of the floodplain at the confluence of the Struga A with the Nida (W4), between the flood bank to the S and the edge of the terrace to the N.

In the old estuarine channel of the Nida (profile W2), which still functioned in the mid-19th century and was not completely abandoned until the early 20th century, three members could be distinguished. The lowest one (member I) was built of channel sands (Mz=1.5–2.2Φ), well, moderately well, moderately and poorly sorted (δI=0.4–1.5), on which initially silty sands (Mz=2.5–4.0Φ), poorly and very poorly sorted (δI=1, 6–2.1) accumulated (member II), with interbeds of poorly sorted (δI=1.8–2.0) silts (Mz=4.2–5.2Φ).

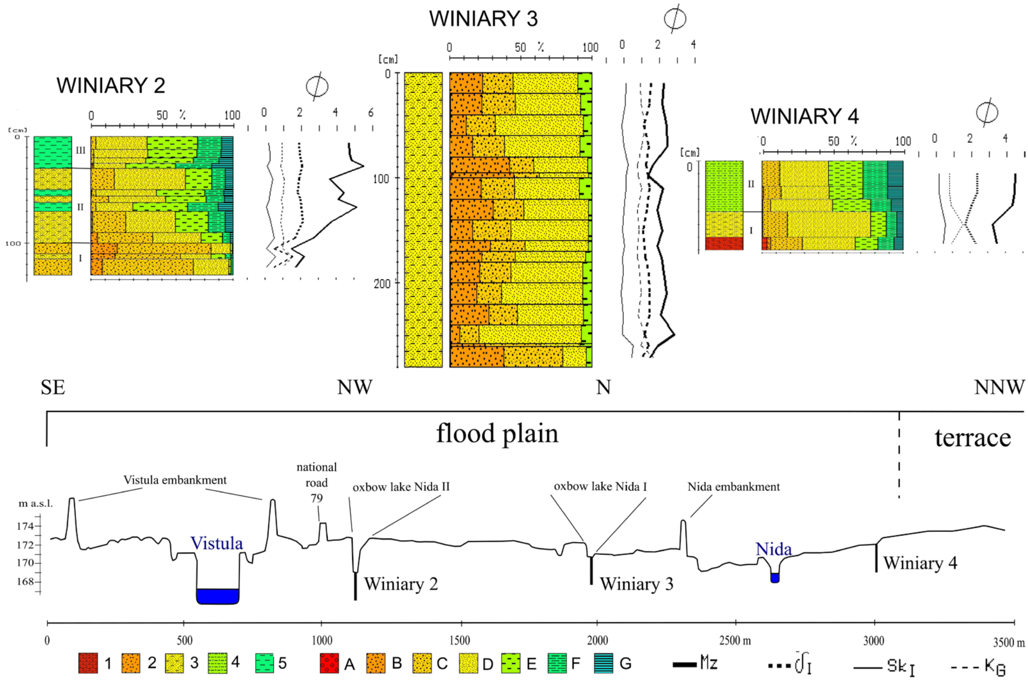

Fig. 5. Schematic Winiary cross-section through the Vistula and Nida Valleys. Lithology: 1 – silty sands with gravels, 2 – medium-grained sands, 3 – silty-dusty sands, 4 – sandy silts, 5 – dusty silts; Fractions: A – gravel (below −1Φ), B – coarse-grained sand (−1–1Φ), C – medium-grained sand (1–2Φ), D – fine-grained sand (2–4Φ), E – medium-grained silt (4–6Φ), F – fine-grained silt (6–8Φ), G – clay (above 8Φ); Folk-Ward (1957) grain size distribution parameters: Mz – mean diameter, δ_I – standard deviation, Sk_I – skewness, K_G – kurtosis

Later, probably after the complete abandonment of the channel, sandy silts (Mz=4.5–5.5Φ), poorly and very poorly sorted (δI=1.8–2.1) accumulated there (member III).

The abandoned channel (profile W3) is well visible in the relief, as it is essentially not filled by sediments. The channel sediments in its bed consist of sands, mainly fine-grained (Mz=1.4–2.9Φ), poorly sorted (δI=1.0–1.5).

In the zone flooded by the Nida River between the flood bank and the terrace (W4), the lower member (I) consists of silty sands with gravels and sands (Mz=3.2–3.5Φ), poorly and very poorly sorted (δI=1.8–2.2), and the higher one (member II) of sandy silts (Mz=4.2–4.5Φ), very poorly sorted (δI=2.0–2.5).

CARTOGRAPHIC DATA

The analysis of cartographic data over the last 250 years for the area where the Nida and the Vistula meet indicates that we are dealing with one of the most common arrangements in the Vistula basin, in which the mouth of a tributary shifted downstream when the tributary followed *wiśliska* (abandoned channels of the Vistula) or flowed

Fig. 6. Fragment of the 1979 map “Szczegółowa Mapa województwa Sandomierskiego”, on a scale of 1:225 000

in parallel separated by a natural levee. We are also considering the “delta” type, in which a tributary emptied into the Vistula via several branches, forming alluvial fans within its valley (Plit 2006).

On the oldest maps from the end of the 18th century, the Vistula already has an altered course, similar to the present one, and it forms the IIC cut-and-fill. In its meandering channel (wide with a large radius), numerous mid-channel bars are marked (Fig. 6), which may indicate a tendency towards braiding. At that time, the natural channel of the downstream Nida River was divided into several arms. The first bifurcation occurred near Stary Korczyn. One arm followed SE through Spichlerze and emptied into the Vistula vis-à-vis Borusowa, dividing just before the mouth into three “deltaic” branches, possibly on a small alluvial fan. The second main stream headed to the E and flowed parallel to the meandering Vistula for about 9 km. Over this distance it had several additional connections with the Vistula. At the height of Nowy Korczyn there was an anthropogenic ditch surrounding the castle to the W. It remains debatable whether this can be seen as another estuary of the Nida, or whether it was Vistula waters that were diverted into the moat and further fed the Nida. Further to the E the Nida flowed under the terrace edge taking advantage, like today, of abandoned channels. The next estuary of the Nida to the Vistula was located downstream of Podraje. However, part of its waters headed NNE towards the Strumień depression (a small stream), while the larger part turned E and eventually flowed into the Vistula near Pawłowo.

By the turn of the 18th and 19th centuries, the meandering channel of the Vistula, with mid-channel bars, had not undergone any significant changes, whereas the changes to the Nida channel were very significant. The arm running to the SE from Stary Korczyn was “renewed”, and at its mouth the maps show a large mid-channel bar in the Vistula (Fig. 7), probably built up from sand material carried by the tributary (Nida delta). The second arm, flowing E as far as Podraje with a connection to the Vistula near Nowy Korczyn, did not change much. The Nida River became shorter by about 3 km, as the reach towards Pawłowo was abandoned and became an oxbow lake.

Fig. 7. Fragment of Heldensfeld-Benedicti’s map “Carte von West-Gallizien” from 1808, on a scale of 1:288 000

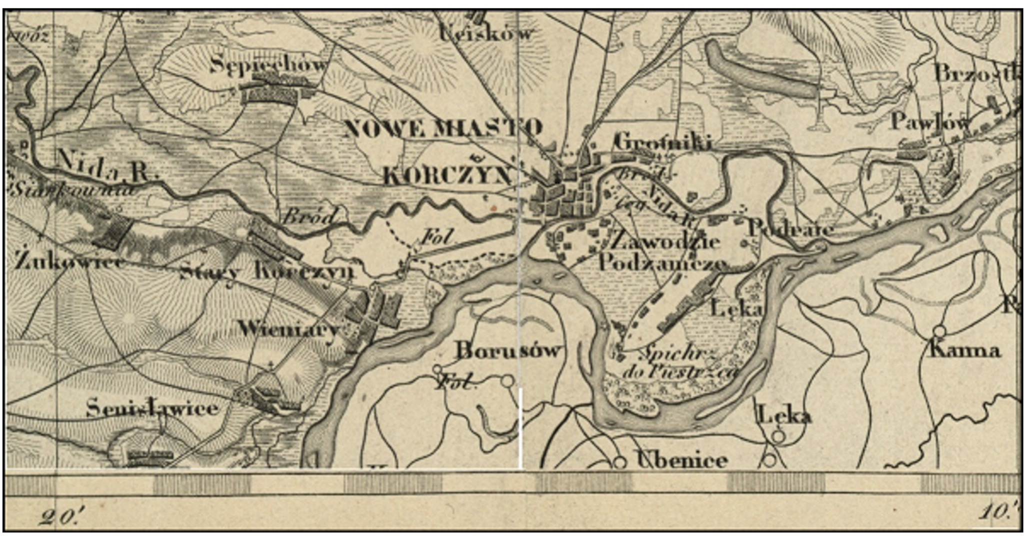

Fig. 8. Fragment of the 1864 map “Topograficzna karta Królestwa Polskiego”, sheet Nowe Miasto Korczyn, scale 1:126 000

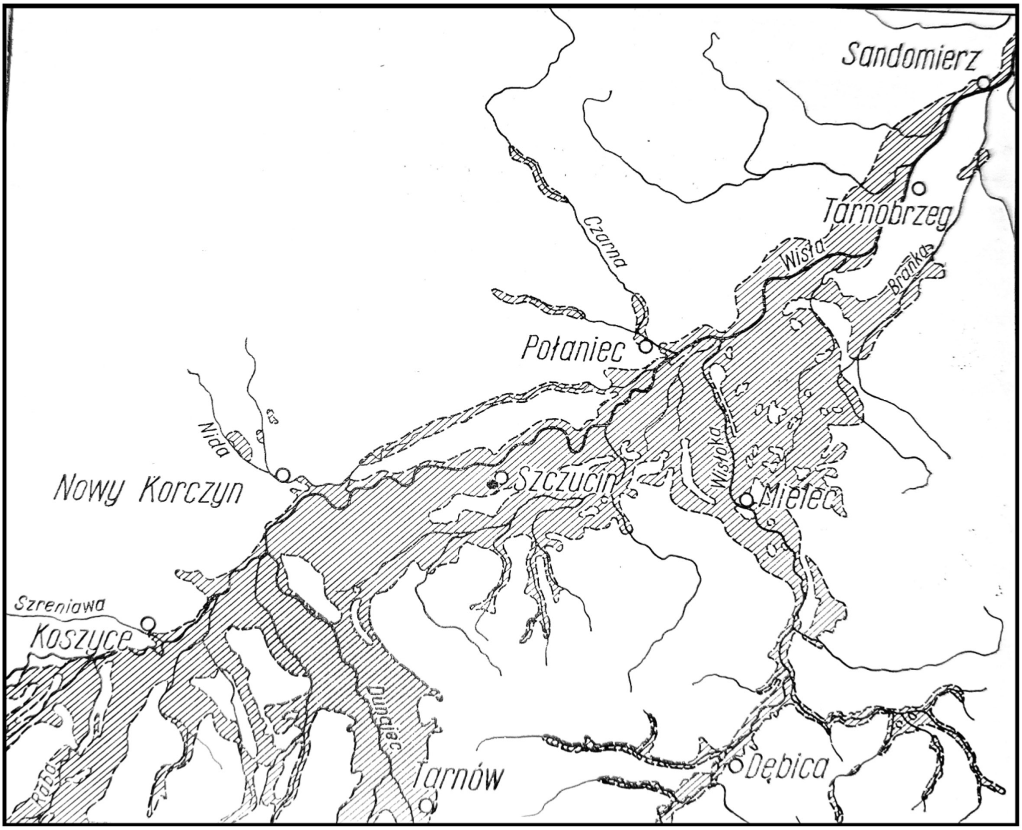

Fig. 9. The areas (hatched) inundated by the flood of July 1934 in the Sandomierz Basin (Głodek et al. 1967)

In the mid-19th century, the unregulated Vistula River with mid-channel bars shifted to the N in the Podraje area. The bars were narrower and less numerous (Fig. 8) but still located in similar places as on older maps. The arm of the Nida flowing to the E from Stary Korczyn to Podraje became the main one, while the one heading to the SE was clearly losing its importance.

The extent of the natural flood plain of the Vistula, inundated during floods, is shown in Fig. 9 (Głodek et al. 1967).

After the regulation and embankment of the Vistula River (Fig. 10) in the second half of the 19th century, mid-channel bars disappeared from its bed at the beginning of the 20th century. The Nida River was not yet embanked in 1915. The arm formerly flowing SE from Stary Korczyn was abandoned and became an oxbow lake (profile W2) (Fig. 1). To the NE of it, an oxbow lake system is clearly visible on the flood plain (profile W3) (Fig. 1), although it is difficult to relate it to the course of the river shown on earlier maps. The connection between the Nida and the Vistula at Nowy Korczyn also disappeared, probably during the regulation of the Vistula. Further east, the Nida was meandering, and just before the place where it joined the Vistula, a characteristic meander was formed (Fig. 1), which has survived in the relief to this day.

Fig.10. Fragment of the map “West. Osteuropa in 1915-German maps of the Russian partition, WWI” on a scale of 1:25 000

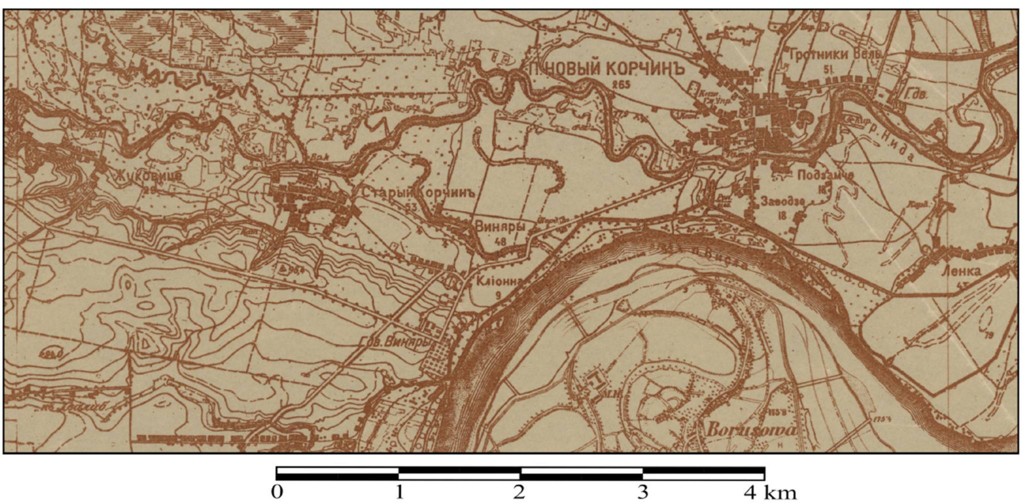

Fig. 11. Fragment of the WIG map “Mapa Szczegółowa Polski”, sheet Nowy Korczyn on a scale 1:25 000 from 1936

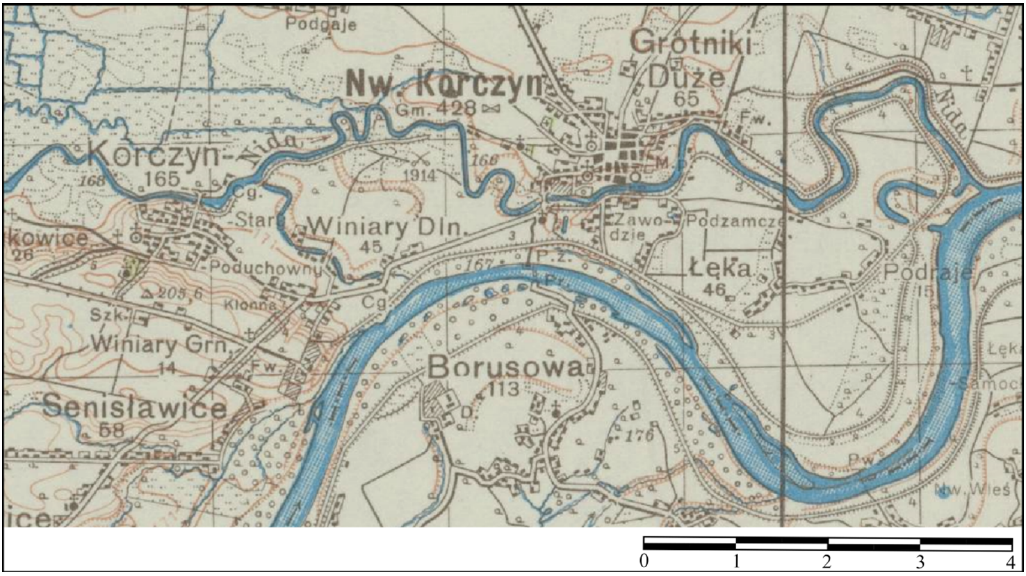

Fig. 12. Fragment of the map "Karte des Deutschen Reiches, Großblatt Einheitsblatt", sheet Staszów on a scale of 1:100 000 from 1942

Fig. 13. A still from Marek Sadowski's film "The Nida River – flight in the area of Stary Korczyn, Czarkowy" made on 4 May 2017 and uploaded to YouTube on 5 May 2017

The regulation and embankment of the Nida River took place between 1936 and 1942 (Figs 11, 12). The characteristic meander just before the river mouth was cut off and flood banks were constructed from the mouth to Grotniki Duże on the left bank, and on the right bank from the mouth to Stary Korczyn with a gap of about 2 km to the W from Nowy Korczyn. At the same time, a characteristic backflow phenomenon appeared in an area between the Nida levees during the Vistula floods (Fig. 13) reaching as far as Żukowice-Czarków (approx. 6–7 km upstream of the Nida).

DISCUSSION

In the Vistulian period, both braided rivers were depositing sediments (clasts of upland and Carpathian rocks) of the alluvial plain at the mouth of the Nida Valley. Today they adjoin the indistinct edge of the Solec Basin and form the strip of the terrace preserved here (IA).

Probably at the end of the Pleistocene (Late Glacial?), the Vistula shifted southwards and followed the Breń depression to the S of Garb Szczuciński. To the N from Garb Szczuciński, the Nida cut the hitherto common alluvial plain and flowed through the Strumień depression, which was formed at this time (IB: approx. 1 m below the surface of the terrace), only joining the Vistula near Połaniec, after approx. 30 km from the valley mouth.

The Vistula was gradually pushed to the N by the fan of the Dunajec River and, in the Late Glacial, it did not develop in the section below the Dunajec mouth a series of large meanders typical of this period, such as those preserved in its other sections and in the valleys of the Carpathian tributaries (Kalicki 2006 literature there). The Nida probably did not have such a development either, unless the semicircular undercuts in the terraces near Nowy Korczyn and Grotniki Małe are traces of great palaeomanders of the Nida and not small Holocene ones of the Vistula. Their parameters match the size of the Holocene palaeomeanders of the Vistula on cut-and-fill IIA.

In the Holocene, the concentration of the riverbed caused it to incise, and the meander belt of the Vistula ran to the N of the Szczucin Hump. At least from the Meso-Holocene onwards (Szczucin: 6040±140 BP cal. 4400–3800 BC) it flowed in small, slowly migrating meanders and shaped the flood plain of cut-and-fill IIA. In the subboreal (3970±80 BP cal. 2190–1860 BC) it widened the valley floor to the N of Szczucin by undercutting the Late Glacial Strumień depression (IB). It is possible that a similar situation also took place at the mouth of the Nida River (although it is not known in what period), where meander cuts are preserved near Nowy Korczyn and Grotniki Małe. Also unknown is the age of the palaeomeander systems preserved to the S and SE of Nowy Korczyn, at Borusowa and Kanna, which, judging by their form, were abandoned due to avulsion. The single palaeomeander at Samocice is older than the avulsion at Kanna, while determining the sequence and age, even relative, of the avulsions is impossible at this stage of the research. It is also possible that the two sections of the meandering channel may have constituted a single system, contemporarily separated by younger intrusions. This is supported by both the cut-and-fills having similar relative heights above the level of the Vistula. The avulsion was preceded by a stage of straightening of the channel and cutting off of individual meanders, which, given the similar height of the palaeomeander fills at Samocice and Mędrzechów, can be dated to 4920±220 BP (cal. 3450–2500 BC). In that case, the avulsion may have occurred at the beginning of the Subboreal. The avulsive changes to the channel may have been related to subsidence movements (already pointed out by Gilewska (1972) and Łyczewska (1972)), which may have triggered aggradation tendencies, as can be seen by comparing the heights of the cut-and-fills of single late Atlantic palaeomeanders (Samocice, Mędrzechów) with the Borusowa-Samocice-Kanna system.

A change in the pattern from aggradation to bottom erosion took place in the Middle Ages (10^{th}–15^{th} c.), when the faster migrating Vistula River started to shape cut-and-fill IIB, 1.0–1.5 m lower than IIA. It is preserved to the S from the easternmost historical mouth of the Nida at Pawłowo (form the late 18^{th} century). This may have been caused by very significant changes in land use patterns in the 13^{th}–14^{th} centuries (Dembińska 1972).

Subsequent transformations of the riverbed, an increase in its parameters and an acceleration of lateral migration (IIC), as well as a tendency towards braiding manifested by very numerous mid-channel sandbars, continued in the following centuries until the regulation of the Vistula in the mid-19^{th} century. Unlike in earlier periods, this can be traced in detail through historical and cartographic data. As late as the second half of the 17^{th} century (1678), the Vistula still flowed south of Borusowa through a channel known today as the Wiślina, and the fast-migrating river was accumulating slip-off slopes in Łęka. It is difficult to determine the number and locations of the Nida outlets to the Vistula at this time. Heading S, the Nida in its lowest reaches (either the whole river or only one or more of its branches, e.g. W3) may have followed a system of older palaeomanders (IIA) at Borusowa, which had a connection with the Wiślina. It seems very likely that a second branch of the Nida, heading E, was also functioning at that time. It remains an open question whether the palaeomeander system of this river preserved in the morphology to the E of the former castle, which partially destroyed the slip-off slopes of the Holocene palaeomeander at Zawodzie (IIA), originates from this period, or whether the Nida flowed further east and followed, as it did later, the palaeomeanders under the terrace below Nowy Korczyn and on the IIA cut-and-fill.

In the second half of the 18^{th} century, the Wiślina meander was cut off, as indirectly indicated by changes in parish boundaries (the creation of a new parish in Borusowa in 1772), and directly by the oldest cartographic data from 1797. Maps from the last 250 years show that the number and location of the Nida outlets to the Vistula varied, which qualifies it into the most common group of downward-shifted and multi-branch ("deltaic") estuaries on tributary fans (Plit 2006). While one can agree with this attribution, as the Nida used the Vistula palaeomeanders of Holocene cut-and-fill IIA and flowed parallel to the Vistula for 9 km, the division into numerous arms was not "deltaic" in nature, as the Nida did not form a fan in the Holocene due to the large difference in size of the two rivers. The Vistula cut-and-fills "enclose" the alluvia of the Nida inside its valley on the Winiary-Nowy Korczyn line, while the Nida cut-and-fills occur only in a very narrow strip under the edge of the terrace on which Nowy Korczyn lies, and also occupy a small area to the E of the former castle in that town. The division into several arms may have been caused by the blocking of the outflow from the Nida Valley during floods and the drainage of the flood waters at the mouth of the valley in several directions, through both permanent channels and periodic ones, like W3 marked on maps from the early 20^{th} century onwards.

Changes in the numbers and locations of the Nida estuaries in the last two centuries appear to have had both natural and anthropogenic causes. The westernmost arm of the Nida, probably natural, was most likely shortened in the 18^{th} century following changes to the Vistula channel in the Borusowa area and the abandonment of the Wiślina. In the following decades its importance diminished. Until the beginning of the 19th century, it was the main estuary arm, transporting a considerable amount of material. At the end of the 18th century, at the confluence with the Vistula, it branched "delta-like" into three arms, possibly on a small fan at the mouth, and 10 years later material from the tributary and the main river formed an extensive channel bar in the Vistula. By the mid-19th century this arm had become a secondary, and by the early 20th century (1915) it turned into an oxbow lake cut off from the Nida and the Vistula.

The other arm of the Nida headed eastwards from Stary Korczyn. As late as the end of the 18th century, the river, taking advantage of old features (both the Holocene palaeomanders of the Vistula and the Late Glacial Strumień depression), flowed into the Vistula between 9 and even 30 km to the E of the valley mouth. However, this arm also connected with the Vistula earlier in two places. The first was a linear canal dug to the W from the former castle in Nowy Korczyn, and the second was an outlet near Podraje. At the beginning of the 19th century, this arm became much shorter as the river lost contact with the Strumień depression, and the section from the estuary in Podraje to Pawłów (approx. 3 km long) became an oxbow lake. From the mid-19th century, this arm became the main branch of the Nida, flowing into the Vistula near Podraje. The concentration of flows within it resulted in increased lateral mobility, which in turn led to the formation of a characteristic meander just before it joined the Vistula.

The embankment of the Vistula in the middle of the 19th century resulted in the formation by the straight river of the modern floodplain between the embankments (cut-and-fill III). It also broke the connection of the Nida with the Vistula through the anthropogenic channel to the W from the former castle in Nowy Korczyn, although it remains visible in the morphology today. The embankment and regulation of the Nida River occurred later, in the 1930-40s, leading to the western (W2) and periodic (W3) arms being completely cut off from flood waters. This also made it possible to locate the buildings of Winiary Dolne village by the former arm. At the same time, a characteristic backflow phenomenon started to occur between the Nida embankments during the Vistula floods, reaching as far as Żukowice-Czarków (approx. 6–7 km upstream of the Nida mouth). In less than 100 years, fine-grained sediments were deposited here (member II in profile W4 at the Winiary profile), consisting of very poorly sorted (δI=2.0–2.5) sandy silts (Mz=4.2–4.5Φ).

In the estuarine and lowest sections of the Nida Valley, sandy alluvia definitely dominate. Fine-grained sediments started to be deposited here only after the river was embanked and the backwater phenomenon activated. Characteristic Holocene mineral-organic overlain by mineral sediments ("agricultural, anthropogenic *mada*"), which have been found in the Rudawa (Rutkowski 1991) and Prądnik (Alexandrowicz, Sanko 1997) catchments and in the "estuary" (and in fact lower) sections of the Nida and Szreniawa valleys (Michno 2004, 2013), are absent here. This is all the more puzzling as the Nida, like these last two rivers, drains a loess area. Determining the reasons behind this dissimilarity requires further research.

CONCLUSIONS

The estuary section of the Nida stands out as being different from the rest of the valley. It does not have a delta character, even though the Nida had several outlets to the Vistula at the same time. The division into several arms may have been caused by the blocking of outflow from the Nida Valley during floods and the drainage of the flood waters at the mouth of the valley in several directions, both by permanent channels and periodic ones. Changes in the numbers and locations of the Nida estuaries in recent centuries seem to have had both natural and anthropogenic causes, as the area was located at very important communication routes of the Polish-Lithuanian Commonwealth, both overland (Sandomierz route) and by water (Vistula).

We are dealing here with a complex interaction between the main river and its ten-times-smaller tributary. The result is an intricate mosaic of forms and cut-and-fills of both streams, but with the Vistula playing a dominant role. The Vistula cut-and-fills "enclose" the alluvia of the Nida inside its valley on the Winiary-Nowy Korczyn line, while the Nida cut-and-fills occur only in a very narrow strip under the edge of the terrace. The Nida exploited the Vistula's Holocene IIA cut-and-fill and flowed parallel to the Vistula for 9 km.

The regulation of the Vistula in the mid-19th century and of the Nida in the first half of the 20th century fixed the courses of the rivers and completely changed the sedimentation regime in the estuarine section of the Nida, where backflow and associated deposition of fine-grained sediments occurred.

The Nida Valley floor lacks the Holocene mineral-organic sediments overlain by mineral sediments characteristic of other upland tributaries from loess areas, and further research is required to determine the reasons for this dissimilarity.

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