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Evolution of the hydrographic network in the middle Wieprz River Basin (E Poland)

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The Wieprz River Valley (Polesie Plain, east Poland) has evolved with regard to its dimensions, position and course since the end of the Neogene, its geological record showing how the Wieprz channel migrated and modified its character. Changes have also been observed in the water balance of the entire middle river basin, related to climate changes in the Pleistocene and Holocene. We provide new maps of the sub-Quaternary surface and trace topographical changes during the Pleistocene. Two separate rivers, the Pre-Bystrzyca and Pre-Wieprz, existed in Preglacial time. During the Narevian Glaciation, a network of subglacial troughs evolved in the area, largely disturbing and overprinting the earlier hydrographic system. Some of the troughs developed in older river valleys. The trough in which the present-day Wieprz gorge near Łęczna is located was most probably formed at that time. During subsequent glaciations and cold periods, sedimentary changes took place in the troughs and valleys – from erosion and removal of the accumulated material to their complete burial by sediments. During the Mazovian Interglacial (MIS 11c), several lakes formed in the study area, recorded by their infills of organic and mineral-organic deposits. During subsequent advances of the Scandinavian ice-sheet, water flow was dammed in towards the north, resulting in the formation of backwaters. Ice-sheet retreat resulted in the flow of proglacial waters towards the south-east, fluvioglacial sediment transport, and then unblocking of flow and subsequent reversal of flow directions to the north and west. During the Odranian Glaciation (MIS 6), catastrophic flow unblocked and shaped the present-day Wieprz gorge.

Key words: middle Wieprz River Basin, Wieprz gorge, Polesie Plain, Pleistocene changes, palynological analysis.

INTRODUCTION

The hydrographic network of the middle Wieprz River Basin (in the vicinity of Łęczna; Fig. 1) underwent numerous modifications between the Neogene and Holocene, with the most significant changes in the Pleistocene. Many authors have discussed the course changes of Wieprz and Bystrzyca rivers, as well as the formation of erosional forms and the resulting erosional and sedimentary record, as influenced by successive glacial and interglacial phases (Staszic, 1815; Zaborski, 1927; Jahn, 1956; Maruszczak, 1974; Harasimiuk and Henkiel, 1981; Brzezińska-Wójcik and Kociuba, 2001). It is generally agreed that, initially, the Wieprz in its middle basin did not flow along a valley from Łęczna through Spiczyn to Lubartów, and neither was it connected with the Bystrzyca. The stretch between Łęczna and Spiczyn is inferred as a gorge that developed after the separate evolution of the Wieprz and Bystrzyca river valleys. Already Staszic (1815) noted that there is evidence that the Tyśmienica and Wieprz rivers initially flowed into the Bug, and later in their evolution began to flow into the Vistula. Zaborski (1927) considered that Wieprz and Tyśmienica rivers in the study area flowed more or less parallel to one another, and later the Wieprz transferred its flow into the Tyśmienica Valley near Rozkopaczew, and then into the Bystrzyca Valley. According to Zaborski (1927), during the recession of the maximal stadial of the Middle-Polish ice-sheet, retrograde erosion in the Bystrzyca Valley resulted in the connection of both rivers and the formation of the Wieprz gorge.

Jahn (1956) presented a different concept for the formation of Wieprz gorge based on studies of the Wieprz Valley and the terraces near Łęczna. According to him, until the Vistulian there was a watershed between Bystrzyca and Wieprz valleys. At that time, the Wieprz flowed towards the north (approximately along the Tyśmienica Valley to the east of Łęczna). He inferred that during water level rise in the Vistulian, the waters of the Wieprz began to overflow into the Bystrzyca Valley. The overflowing took place at a place where the watershed was at its lowest: within a small valley, the tributary of Bystrzyca. The gorge developed when a very deep and narrow valley was carved in soft Cretaceous rocks. Traces of overflowing include the remains of a fan built of sands and gravels with large blocks of Cretaceous gaizes and crystalline rock. The fan formed at the gorge mouth which thus comprises Cretaceous rocks overlain by glacial deposits. Jahn (1956) emphasized the clearly different character

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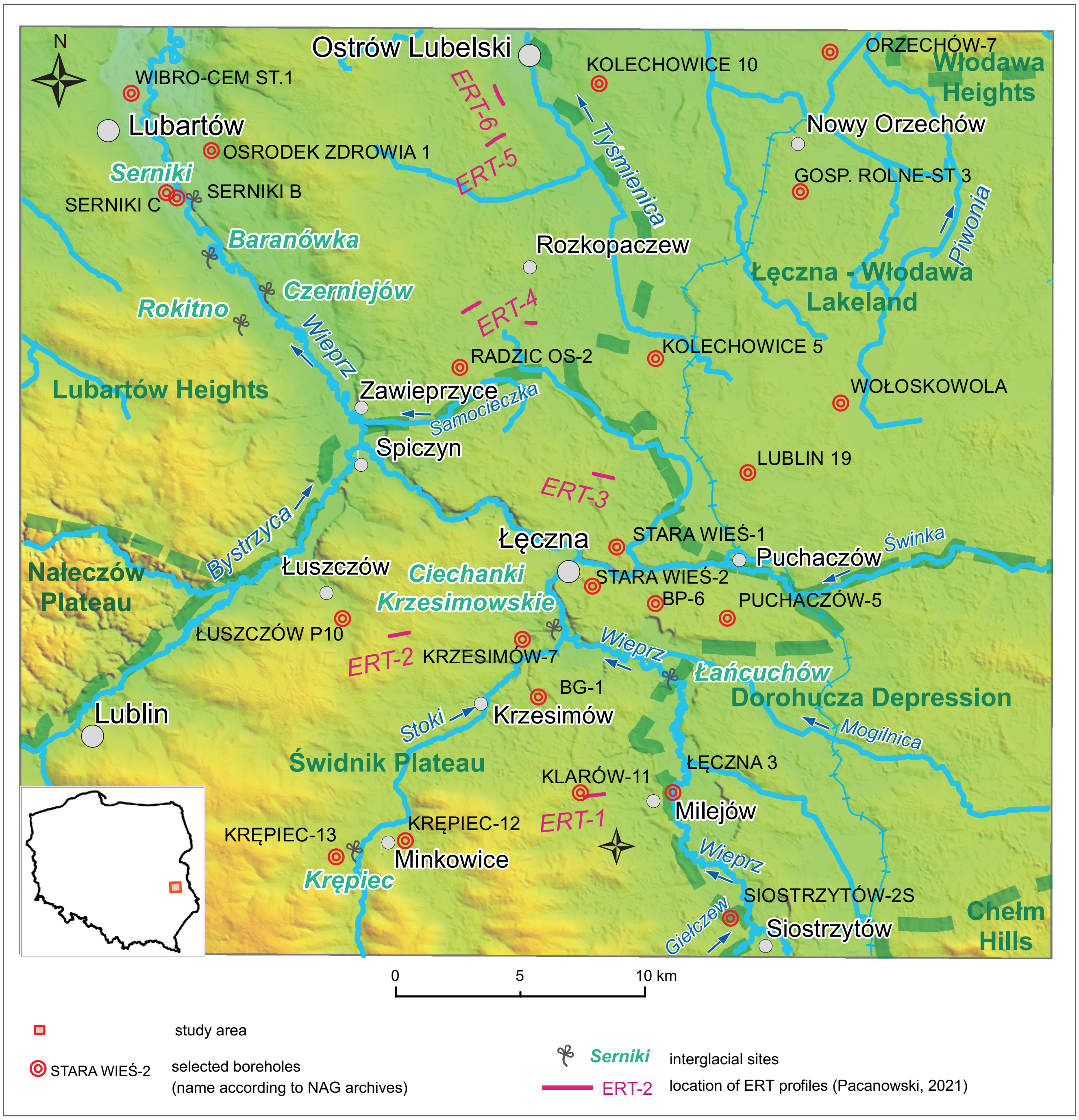

Fig. 1. Study area with respect to the digital elevation model and mesoregion boundaries according to Solon et al. (2018)

of the valley located to the south of Łęczna and Puchaczów, which is wide and relatively shallow, compared to the valley located in the gorge stretch, which is several times narrower and much deeper.

A much earlier age of the Wieprz gorge was postulated also by Maruszczak (1974), who inferred that a large ice-dammed lake existed in the study area during the maximal stadial of the Middle-Polish Glaciations (MIS 6; Table 1). Rivers flowing from the Lublin Plateau carved totally new channels, leaving embankments after the lake waters melted. Maruszczak (1974) connected the embankment pattern with the shift of Wieprz channel to the west of the Bystrzyca Valley. According to him, during high water levels, the waters flowed in several new channels towards the north-west, as shown by the erosional incision of the elevation built of Upper Cretaceous rocks between Łęczna and Spiczyn, and the shifting of the Wieprz waters to the Bystrzyca Valley.

Liszkowski (1979) located the change of the fluvial pattern in the vicinity of Łęczna in the Eemian Interglacial (MIS 5e; Table 1). According to him, connection of the Pre-Wieprz with the Pre-Bystrzyca took place due to blockage of water flow towards the north by the Middle-Polish ice-sheets. The ice-sheet front of the maximal stadial (Odranian Glaciation, MIS 6) broke up into a series of dead-ice blocks which were later buried within fluvio-

Table 1

Chronostratigraphic correlation in the Early, Middle and Late Pleistocene to Holocene in Poland (Mojski, 2005; Ber et al., 2007; Lindner and Marks, 2008; Marks et al., 2018; Marks, 2023), Western Europe (Ber et al., 2007; Lindner and Marks, 2008), Alps (Lindner, 1991; Mojski, 1993), Eastern Europe – Belarus and Ukraine (Lindner et al., 2006; Lindner and Marks, 2012) with the Marine Isotope Stages (MIS, Paepe et al., 1996; Nitychoruk et al., 2006)

Stratigraphy				Poland		W Europe Germany		Alps		E Europe: Belarus	E Europe: Ukraine	MIS
Quaternary	Holocene											1
Quaternary	Pleistocene	Late	North Polish Complex		Vistulian		Weichselian		Würm	Poozerian	Valdy	2-5d
Quaternary	Pleistocene	Late	North Polish Complex		Eemian		Eemian		Riss/Würm	Muravinian	Pryluky (Horokhiv)	5e
Quaternary	Pleistocene	Middle	Middle Polish Complex	Odranian	Odranian *s.s.* with Wartanian stadial	Saalian	Drenthe+ Warthe	Riss	Riss II	Dnieperian II (Pripyatian)	Dnieper 2 (Tysmyn)	6
Quaternary	Pleistocene	Middle	Middle Polish Complex	Odranian	Lublinian (Lubavian)	Saalian	Schöningen	Riss	R I/R II	Shklovian	Kaydaky	7
Quaternary	Pleistocene	Middle	Middle Polish Complex	Odranian	Krznanian	Saalian	?	Riss	Riss I	?	Dnieper 1	8
Quaternary	Pleistocene	Middle	Middle Polish Complex	Odranian	Zbójnian	Saalian	Reinsdorf	Riss	Pre-R/R I	Smolenskian	Potagaylivka	9
Quaternary	Pleistocene	Middle	Middle Polish Complex	Odranian	Liviecian	Saalian	Fuhne	Riss	Pre-Riss	Cooling	Orel	10
Quaternary	Pleistocene	Middle	Middle Polish Complex		Mazovian		Holsteinian		Mindel/ Riss	Alexandrian	Zavadivka (Likhvin)	11c
Quaternary	Pleistocene	Middle	South Polish Complex		Sanian 2		Elsterian		Mindel	Berezinian	Tiligul (Krukienice)	12
Quaternary	Pleistocene	Middle	South Polish Complex		Ferdynandovian		Cromerian		Günz/ Mindel	Belovezhian	Lubny	13-15
Quaternary	Pleistocene	Middle	South Polish Complex		Sanian 1		Cromerian		Günz	Servetskian	Sula	16
Quaternary	Pleistocene	Middle	South Polish Complex		Małopolanian		Cromerian		Günz	Korchevian	Martonosha	17-19 (21)
Quaternary	Pleistocene	Early	South Polish Complex		Nidanian		Cromerian		Günz	Narevian	Pryazowsk	20 (22)
Quaternary	Pleistocene	Early	Augustovian (Podlasian)		Augustovian (Podlasian)		Bavelian		Donau/Günz	Rogachevian	Shirikino	21-25 (27)
Quaternary	Pleistocene	Early	Oldest Glaciation		Narevian		Menapian		Donau	Gomelian	Ilyichivsk	26-28 (30)

glacial and proglacial fluvial deposits. The blocks did not melt completely during the following interstadial. In the Wartanian Stadial (MIS 6; Table 1), the area was also covered by fluvio-periglacial (backwater) sediments, i.e. the Spiczyn silts. This hampered flow of water along the old Wieprz channel between the Odranian Glaciation (MIS 6) and the Eemian Interglacial (MIS 5e; Table 1). At the beginning of the Eemian, the waters, not able to flow towards the north, formed a gorge in the vicinity of Łęczna (Liszkowski, 1979).

A detailed analysis of changes in the fluvial pattern of the area and formation of the Wieprz gorge near Łęczna was conducted by Harasimiuk and Henkiel (1980b, 1981). They constructed a hypsometric map of sub-Quaternary rocks and traced fossil valley forms near Łęczna. Harasimiuk and Henkiel (1981) postulated a tectonic origin for the Wieprz Valley. This was shown by analysis of deposits from the left valley slope, in which slickensides and open joint fractures were noted in cores. Furthermore, micropalaeontological studies of upper Maastrichtian rocks have indicated their much lower height in the western part of the valley compared to the eastern part. The fossil Wieprz Valley in this stretch, according to Harasimiuk and Henkiel (1981), used a tectonic dislocation located in the western margin of the valley, as shown by its straight course. These authors linked changes of the fluvial pattern with a series of intense neotectonic movements between the Sanian 2 Glaciation (MIS 12) and the Mazovian Interglacial (MIS 11c; Table 1). According to these authors, the fluvial pattern was modified after the uplift of the southern margin of Roztocze and shrinking of the Wieprz River Basin. Moreover, neotectonic (related to glacioisostasy) activity near Łęczna resulted in shifting of the Wieprz waters at first into the subglacial Łęczna-Milejów trough, and farther to the north, parallel to the old valley towards Ostrów Lubelski. Further neotectonic activity resulted in directing the waters of the Wieprz towards the Łańcuchów and Spiczyn trough, to the present-day Łęczyny gorge. Harasimiuk and Henkiel (1981) inferred also that neotectonic processes caused modification of the Giełczew course, directed towards Wieprz near Siostrzytów, which resulted in the formation of a lake in the Stawek Valley (Harasimiuk and Henkiel, 1981). Additional evidence that the valley of the present-day Wieprz in the Milejów stretch has no connection with the valley near Lubartów includes the entirely different character of the deposits in these fossil valleys. Those in the Milejów-Puchaczów stretch are referred to as the "Krasnystaw" facies and those in the Lubartów stretch as the "Ferdynandów" facies (Harasimiuk and Henkiel, 1981). In the gorge stretch both facies are lacking.

Lisicki (2003) re-analysed the petrography of glacial deposits from selected boreholes in the Vistula River Basin and determined the age. Data from the study area indicate that the valley bottoms near Łęczna include deposits from the Narevian Glaciation (Table 1), helping constrain the age of valley formation. The age of the deposits was determined palynologically.

Palynological data form the basis for establishing many of the chronostratigraphic units. The oldest known lake deposits found in the northeastern part of the study area, at the Sosnowica site (Janczyk-Kopikowa, 1991), represent the Ferdynandovian Interglacial (MIS 13–15; Table 1). Most common are deposits documenting the Mazovian Interglacial (MIS 11c; Table 1): at the Krępiec (Janczyk-Kopikowa, 1981), Nowiny Żukowskie (Dyakowska, 1952; Hrynowiecka-Czmielewska, 2010), Ciechanki Krzesimowskie (Brem, 1953), Serniki (Sobolewska, 1956), Czerniejów (Jahn, 1956) and Rokitno sites (Janczyk-Kopikowa, 1983). The last four sites are located in the Wieprz Valley. The youngest interglacial deposits, representing the

Eemian (MIS 5e; Table 1), were observed in the northwestern margin of the study area, at the Karczunek site (Krupiński et al., 1982).

Fieldwork performed in 2018–2021 by the authors, focused on updating the Detailed Geological Map of Poland (Ostrów Lubelski, Orzechów Nowy, Łęczna and Lubartów sheets), has allowed revision of the geological setting of the study area.

This study describes the development of fossil erosional valleys near Łęczna – from the vicinity of Milejów to the south to Lubartów in the north – and their influence on the present-day hydrographic pattern in the area. Erosional features formed due to the action of glacial waters, referred to as subglacial troughs, are distinguished here from fossil river valleys which were the effect of fluvial activity. An attempt was made to determine the age when particular forms evolved, the influence of the ice-sheets on the evolution of these forms, particularly the Wieprz gorge near Łęczna, and the palaeogeographic changes in the study area.

STUDY AREA

The study area covers a part of the middle Wieprz River Basin to the north-east of Lublin, near the towns of Milejów, Łęczna and Lubartów (Fig. 1). It is located within four meso-regions. Its northwestern part belongs to the Lubartów Heights, the northeastern part to the Łęczna-Włodawa Lakeland, the southwestern part to the Świdnik Plateau, and the southeastern part to the Dorohucza Depression Basin (Solon et al., 2018; Fig. 1).

MATERIALS AND METHODS

The studies were based on: archival borehole logs, geophysical surveys, DEM analysis (from data acquired through aerial laser scanning in the frame of the ISOK project), OSL absolute age determinations and field studies performed by the authors during updating of the Detailed Geological Map of Poland at the scale of 1:50,000 Lubartów, Łęczna, Ostrów Lubelski, Orzechów Nowy sheets, and the archival sheet Lublin (Butrym et al., 1982). Dating by optically stimulated luminescence (OSL) was performed at the Lumidatis laboratory in Toruń.

Studies conducted by the authors in the area in 2018–2021, coupled with new data, e.g. borehole logs and geophysical surveys (Pacanowski, 2021), have allowed construction of a hypsometric map of the sub-Quaternary surface (Fig. 2), informing interpretation of the development of the river valleys analysed. The stratigraphy of the Quaternary strata was based on studies that excluded the presence of Middle-Polish ice-sheets in the area (Lisicki, 2003; Czubla et al., 2013, 2019; Terpiłowski et al., 2013; Marks et al., 2018; Hrynowiecka et al., 2019; Żarski and Kucharska, 2020). The studies of Lisicki (2003) were used to determine the age of deposits noted in the bottoms of troughs and valleys, which further constrained the evolution of particular erosive forms in the study area.

Only selected boreholes, documenting erosional valleys, are described herein (Fig. 3). In all boreholes, upper Maastrichtian rocks were drilled in the trough bedrock, which significantly improves the age determination.

Palynological analysis was conducted for the Baranówka site located in the Wieprz Valley. The analysis was performed on 5 samples of organic deposits with a small admixture of mineral matter (samples from depths of 600, 620, 640, 660 and 680 cm). The material was subject to standard laboratory procedures for Pleistocene deposits. A 1 cm^3 sample from each sample was subject to acetholysis according to Erdtman (1960) with application of HF and addition of 1 pill of *Lycopodium* to determine pollen abundance. Two microscope slides (20 × 20 mm) were analysed from each depth. The abundance and preservation state of sporomorphs in the Baranówka samples was very good. Over 500 pollen grains and all spores of lower plants were counted. The samples from Baranówka yielded 43 sporomorph taxa, including 19 trees, bushes and shrubs, 13 herbaceous plants, 5 aqueous and reed plants, and 6 lower plants.

RESULTS AND DISCUSSION

EVOLUTION OF THE WIEPRZ VALLEY

PERIOD BEFORE THE GLACIATIONS

Erosion of upper Maastrichtian limestones outcropping in the area and evolution of the river valleys began already in the Paleocene. This was possible after a sea regression caused by tectonic uplift during the Laramian phase of the Alpine Orogeny (Piwocki et al., 2004). The last marine transgression took place in the late Eocene and marine sedimentation lasted until the beginning of the Oligocene (Słodkowska and Kasiński, 2016). From that time the area was constantly terrestrial. The present-day fluvial network began to evolve following the last marine regression. The Wieprz was initially a huge river, whose river basin was much larger than presently. Water discharge in its entire river basin took place from the present-day Sandomierz Basin, Roztocze and Lublin Upland (Brzezińska-Wójcik and Kociuba, 2001). Morphological analysis and studies of the sub-Quaternary basement indicate that Wieprz then (referred to as Pre-Wieprz) flowed in the stretch analysed differently than today (Fig. 2). To the north of Łęczna it used the present-day Tyśmienica Valley. The Bystrzyca (referred to as Pre-Bystrzyca) was a larger river than presently and in the study area did not flow into the Wieprz. It used its own channel, which changed flow direction from northeastwards near Lublin to northwestwards near Lubartów (Fig. 2).

In the southern part of the study area, between the vicinity of Siostrzytów through Milejów to Puchaczów, the Pre-Wieprz channel was much wider than presently. Its valley is very distinct and ~1.5–2 km wide (Fig. 2). It incised to a depth of ~110 m a.s.l. A 20 m high asymmetrical terrace is clearly visible in the morphology of the sub-Quaternary surface at ~130 m a.s.l.; to the west it is very narrow, in places disappearing completely, while to the east its width may reach 6 km (Fig. 2). South of Puchaczów the valley may reach 60–70 m deep. Analogously, the valley is also asymmetrical, with the western margin steep and deep, and the eastern one more gentle and shallower. In this part of the valley, in the southern part of the study area, the present-day Wieprz Valley overlies the fossil Pre-Wieprz Valley.

To the north of Puchaczów, the fossil Wieprz Valley was slightly narrower (usually not exceeding 2 km) and ran in two parallel channels with narrow terraces (Fig. 2). Between these fossil channels occurs an area with Maastrichtian rocks at elevations of up to 140 m a.s.l. (and locally to >160 m a.s.l.), whose lower parts, flattened at ~130 m a.s.l., are equivalents of the eastern terrace in the southern stretch. It is not clear whether both valleys functioned at the same time as a braided river, or whether they represent valleys of different ages, with the Pre-Wieprz changing its channel due to more intense modifications

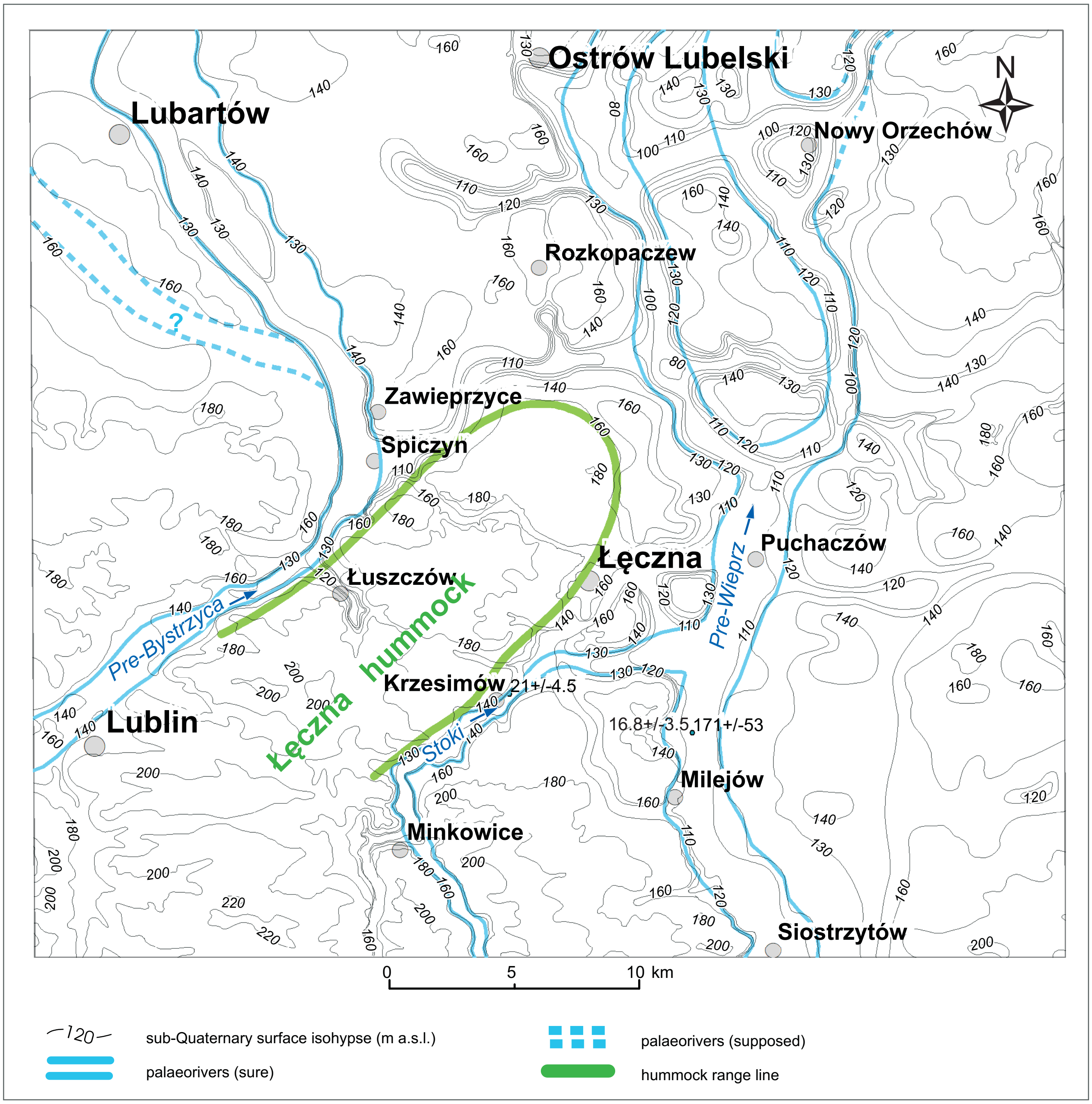

Fig. 2. The pattern of the largest rivers in the study area before the glaciations, with reference to the relief of the sub-Quaternary surface

Based on our research and also after Harasimiuk and Henkiel (1981)

of the river pattern. In the next stage, a change of watersheds took place and the Vistula River took over much of the discharge. The Wieprz shifted to the western valley where it created a wide channel flowing through Ostrów Lubelski (the present-day Tyśmienica Valley) towards the Vistula.

The northern stretch of the present-day Wieprz (near Lubartów) belonged to the Pre-Bystrzyca Valley. It was 1.5–2.0 km wide and its bottom was at 120 m a.s.l. A distinct fossil valley can be observed in the morphology of the sub-Quaternary surface; its incision in the Paleogene was to the depth of ~140 m a.s.l, diverting to the north-west at the level of Zawieprzyce (Fig. 2). Its continuation may be recognized to the west of Lubartów. This fossil channel contains deposits of younger intervals (warm deposits of the Ferdynandovian Interglacial and cool fluvial-periglacial deposits of the Odranian Glaciation).

PERIOD FROM THE OLDEST GLACIATIONS (NAREVIAN) TO THE END OF THE SANIAN 2 GLACIATION (MIS 12)

The glaciations caused changes to the river pattern and the relief of the study area (Fig. 3). Advances and retreats of successive ice-sheets and the associated climate changes determined the geological evolution. An important factor also influencing the

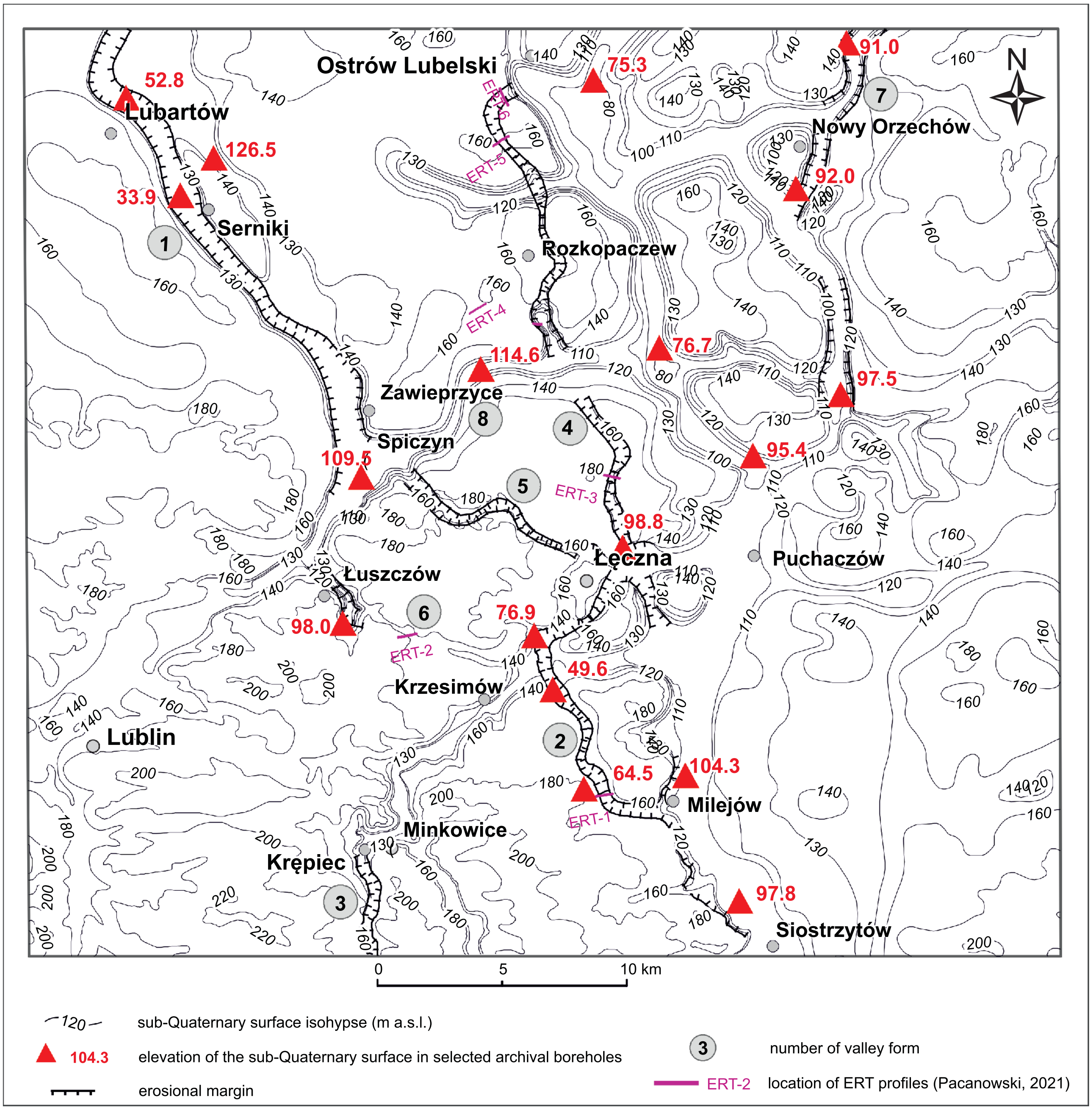

Fig. 3. Study area after the South-Polish Glaciations with reference to contour lines of the present-day sub-Quaternary surface, with the location of fossil erosional incisions of various types: 1 – Serniki Trough, 2 – Milejów Trough, 3 – Krępiec Valley, 4 – Ostrów Lubelski-Łęczna Valley, 5 – Spiczyn-Łęczna Valley, 6 – Łuszczów Valley, 7 – Orzechów Valley, 8 – Samocieczka Valley; based on our research and also after Harasimiuk and Henkiel (1981)

landscape was neotectonic activity (Liszkowski, 1975; Harasimiuk and Henkiel, 1976, 1981; Dobrowolski, 1995).

During the Pleistocene, when various processes were active, two significant events had the largest influence on the hydrographic network of the area. The first was the advance of the Narevian ice-sheet (Table 1). Migration of glacial waters caused a relatively simple pattern of two large river valleys (the Pre-Wieprz and Pre-Bystrzyca) with a more or less parallel watershed along the Ostrów Lubelski-Łęczna line, to be overprinted by a system of deeply incised subglacial troughs, later forming a complex hydrographic system (Fig. 3).

During the Narevian Glaciation (Table 1), ice masses covered the entire area. Triggering of rapid erosional processes caused deep incision into the Cretaceous basement. Erosion by subglacial waters resulted in the formation of a series of deeply incised subglacial troughs, up to 100 m deep. These can be clearly distinguished from the pre-existing fossil fluvial valleys. The deepest incisions reach levels of 30–60 m a.s.l. (Fig.

3). Their age is corroborated by glacial till representing the oldest glaciation drilled in the trough bottoms (Lisicki, 2003; Fig. 3). It cannot be excluded that some of the fossil rivers formed during the following glaciations (of the South-Polish complex). This refers particularly to troughs in which deposits of the oldest glaciation have not been documented.

The second fundamental event was related to retreat of the last ice-sheet from the area (i.e. the Main Stadial of the South-Polish Glaciations; MIS 12), which earlier had covered the entire area. The beginning of deglaciation of the area occupied by the Sanian 2 ice-sheet triggered neotectonic processes, which re-activated old fault zones (Liszkowski, 1979; Harasimiuk and Henkiel, 1981) and again disturbed the existing hydrographic system.

Characteristics of the erosional forms

The erosional forms analysed represent relatively narrow and very deep incisions filled with Quaternary deposits. Their characteristics, i.e. large depth reaching far below the erosional base of the contemporary and present-day rivers, small width, symmetrical and almost parallel slopes and their spatial arrangement, allow their classification as subglacial troughs. Their alignment shows two distinct systems (Fig. 3). The first is NW–SE-oriented and runs from Lubartów through Spiczyn and Łęczna to Milejów. The second is NNW–SSE-oriented and continues from Ostrów Lubelski through Rozkopaczew to Łęczna, and farther with the first system to Milejów. Some troughs, e.g. the incision near Serniki (Serniki Trough) were formed in the sites of existing river valleys and partly modified them. Most incisions developed in the Cretaceous bedrock. These include the Łęczna-Milejów Trough (Milejów Trough) and a system of troughs between Ostrów Lubelski and Łęczna. These troughs were filled with Pleistocene sediments and are documented only by a few boreholes and geophysical surveys. An additional clue to their existence may be the presence of sinuous ridges in the present-day relief. The origin of these strange forms was discussed by e.g., Maruszczak (1974), Liszkowski (1979), Harasimiuk and Henkiel (1981) (Fig. 3).

Part of the erosional landscape analysed was documented by research boreholes (Prószyński and Karaszewski, 1952; Karaszewski, 1954; Mojski and Morawski, 1956; Sobolewska, 1956; Mojski, 1963; Janczyk-Kopikowa, 1983; Harasimiuk and Henkiel, 1980b, 1981; Lisicki, 2003). This includes the Serniki Trough in the Pre-Bystrzyca Valley, referred to as the Sernickie Lake (Łozińska-Stępień et al., 1985a), Łęczna-Milejów Trough (Milejów Trough) and Krępiec Valley. The remaining less closely investigated erosional troughs have been interpreted via different analyses, boreholes and geophysical surveys (Pawłowska and Tracz, 1975; Pacanowski, 2021), based on which a map of the sub-Quaternary surface was constructed.

The **Serniki Trough** (1 in Fig. 3) is NW–SE-oriented and runs from the north of Lubartów to Spiczyn (present-day flow of the Bystrzyca into the Wieprz) in the study area (Fig. 3). Between Lubartów and Spiczyn it conforms with the present-day Wieprz Valley. Most probably it has its beginning to the north far beyond the study area, as indicated by a deep erosional incision near Luszawa (Łozińska-Stępień et al., 1985b), which resembles the Serniki Trough. Tills of the Narevian Glaciation documented in the trough bottom (Lisicki, 2003; Table 1 and Fig. 4) indicate its formation during the early stadial of this glaciation.

In the study area the trough reaches a length of almost 21.5 km. Its width varies from ~500 m in the vicinity of Serniki to over 1400 m near Spiczyn, with an average width of ~800 m. Its depth and course are documented by a number of boreholes, e.g., Wibro-Cem ST.1, Serniki B and Serniki C (Fig. 1). The trough is best documented near Serniki, where it reaches a depth of ~30 m a.s.l., i.e. over 120 m below the present-day Wieprz Valley bottom (Fig. 3).

The **Łęczna-Milejów Trough (Milejów Trough)** (2 in Fig. 3) was documented between the vicinity of Łęczna to its mouth to the Wieprz Valley near Milejów (Fig. 3) (in boreholes Stara Wieś-1, Krzesimów-7, BG-1, and Klarów-11, Fig. 1) (Harasimiuk and Henkiel, 1980a, b). The Milejów Trough generally has a NNW–SSE orientation, except in the vicinity of Łęczna, where it attains a NE–SW orientation, and the vicinity of Milejów in its terminal stretch, where it is almost parallel. The trough length is close to 14 km and its width is even, varying ~400–500 m. The trough bottom occurs at various depths: near Łęczna it is ~100 m a.s.l. (borehole Stara Wieś-1), farther to the south it is at 76.9 m a.s.l. (borehole Krzesimów-7), 49.6 m a.s.l. (borehole BG-1) and 64.5 m a.s.l. (borehole Klarów-11) (Figs. 1 and 3). The greatest depth was noted in borehole BG-1, indicating an incision of 127 m below the present-day surface. This level is almost 50 m lower than the documented bottom of the Pre-Wieprz Valley. The Łęczna-Milejów Trough is presently only an fossil valley.

The trough bottom contains a ~15 m thick layer of fluvioglacial sands and gravels, below which occur glacial deposits assigned by Lisicki (2003) to the Narevian Glaciation, and thus dating the trough formation (Fig. 4C).

The **Krępiec Valley** (3 in Fig. 3) has a N–S course and is located to the south of Minkowice. Its documented length in the study area is ~5 km. It is not as deep as the Serniki and Milejów troughs, reaching 60 m and incising to a depth of 120 m a.s.l. It is presently used by Stoki River. Preglacial deposits occur in its bottom (Fig. 4B; Harasimiuk and Henkiel, 1980a, b), dating its formation to the period before the glaciations; we interpret it as a river valley subsequently used by subglacial waters.

Ostrów Lubelski-Łęczna Trough (4 in Fig. 3) is composed of two stretches with a N–S orientation: a northern one running from Ostrów Lubelski to the Samocieczka Valley (to the south of Rozkopaczew) and a southern one located to the north and east of Łęczna (Fig. 3). The width of both stretches is ~500 m. They are separated by the Samocieczka river valley, deeply incised into the Cretaceous basement. Beside analysis of the bedrock map, the northern stretch was documented by two geophysical profiles (ERT-5 and ERT-6; Fig. 1) near Kolechowice, which have demonstrated the existence of a depression incised in the Cretaceous substratum to the depth of ~80 m a.s.l., i.e. ~80 m below the present-day surface. The southern stretch was documented by one geophysical profile (ERT-4, Fig. 1), which has corroborated the existence of a 55 m deep depression in the Cretaceous bedrock, i.e. to a depth of ~100 m a.s.l. A well-documented segment of this trough is the stretch located to the south-east of Łęczna. It represents a connection with the Wieprz Valley to the north of Milejów and is documented by the Stara Wieś-2 borehole (Fig. 4E). The trough has steep walls and is incised below the depth of 120 m a.s.l., i.e. 60 m below the present-day surface. It is almost completely filled with lake deposits from the Mazovian Interglacial (MIS 11c; Harasimiuk and Henkiel, 1980a, b). Glacial till assigned by Lisicki (2003) to the Narevian Glaciation occurs in the bottom of the trough (Table 1).

The subglacial troughs and valleys described above are filled with deposits showing a very similar geological succession. However, they differ in the basal part of the infilling. The bottoms of the subglacial troughs are overlain by glacial tills of the Narevian Glaciation (Table 1; Lisicki, 2003), linking their for-

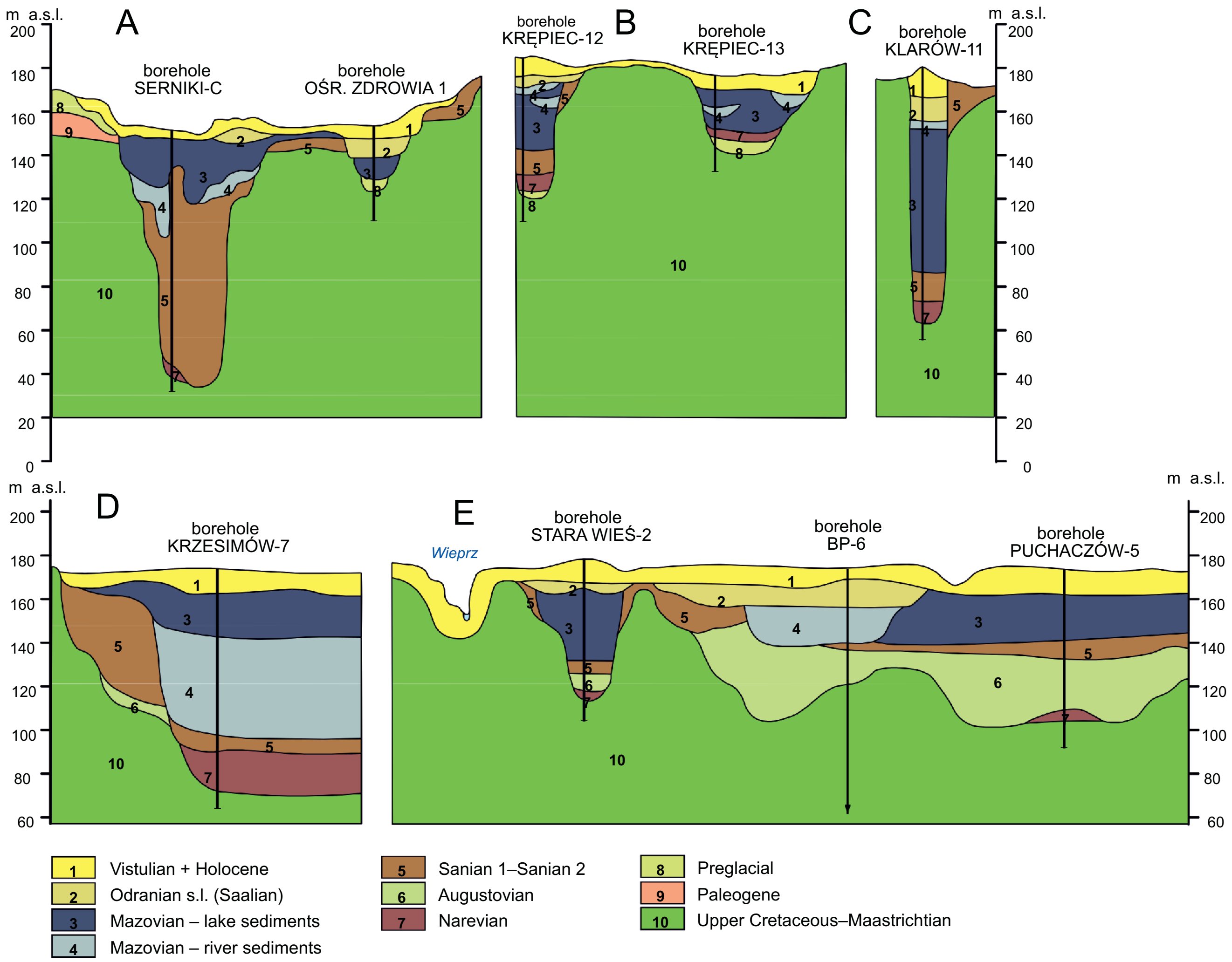

Fig. 4. Occurrence of Mazovian Interglacial deposits in the subglacial troughs and river valleys

Sites of cross-sections depicted by letters A to E are shown in Figure 5

mation to this glacial phase. The sparse occurrence of these tills and of the overlying deposits from the South-Polish Glaciations indicate that these troughs were subject to the same processes during subsequent glaciations. They were filled with glacial sediments during the glacial periods, while during deglaciation the glacial material was generally eroded, the depressions then being filled with fluvioglacial and lake-glacial sediments. During interstadials the depressions functioned as fluvial and fluvio-periglacial valleys (Fig. 4B). Valleys formed due to the action of fluvial waters (e.g., the Krępiec Valley) differ from subglacial troughs in the presence of preglacial deposits in their bottom (Fig. 4B; Harasimiuk and Henkiel, 1980a, b).

There are a number of other fossil erosional incisions in the study area, of which some are completely filled and masked by Quaternary deposits, while others are used by the present-day fluvial system. They have been interpreted following analysis of the sub-Quaternary map, and at some localities confirmed by boreholes and geophysical surveys (Pawłowska and Tracz, 1975; Pacanowski, 2021). They include:

The **Spiczyn-Łęczna Trough** (5 in Fig. 3) is a stretch of the present-day Wieprz Valley between Łęczna and Spiczyn, referred to as the Łęczna gorge of the Wieprz River. It has been much discussed, particularly as regards its origin and age of formation, which so far have not been unequivocally explained, though they are of crucial importance to the development of the present-day fluvial network (Zaborski, 1927; Jahn, 1956; Maruszczak, 1974; Liszkowski, 1979; Harasimiuk and Henkiel, 1980a, 1981). The valley is incised here in the Cretaceous substrate at ~35 m, and its width is only 150–200 m. Steep slopes built of Cretaceous rocks form the valley margins. The bottom is filled with sand and gravel up to 10 m thick, overlain by Holocene muds (Harasimiuk and Henkiel, 1981). The character, shape, valley morphology, and its position and location with regard to the remaining troughs, shows it as a subglacial trough.

The Wieprz gorge stretch connects the subglacial Serniki Trough with the Łęczna-Milejów Trough and is part of the subglacial system. Most probably the trough with the Wieprz gorge was formed at the same time as the troughs in Serniki and Łęczna-Milejów. It was thus part of a very long subglacial trough running from the north from the vicinity of Lubartów through Spiczyn and Łęczna to Milejów, essentially representing flow relating to one ice-sheet.

The valley in the vicinity of **Łuszczów Valley** (6 in Fig. 3) is almost parallel (latitudinal direction). Harasimiuk and Henkiel

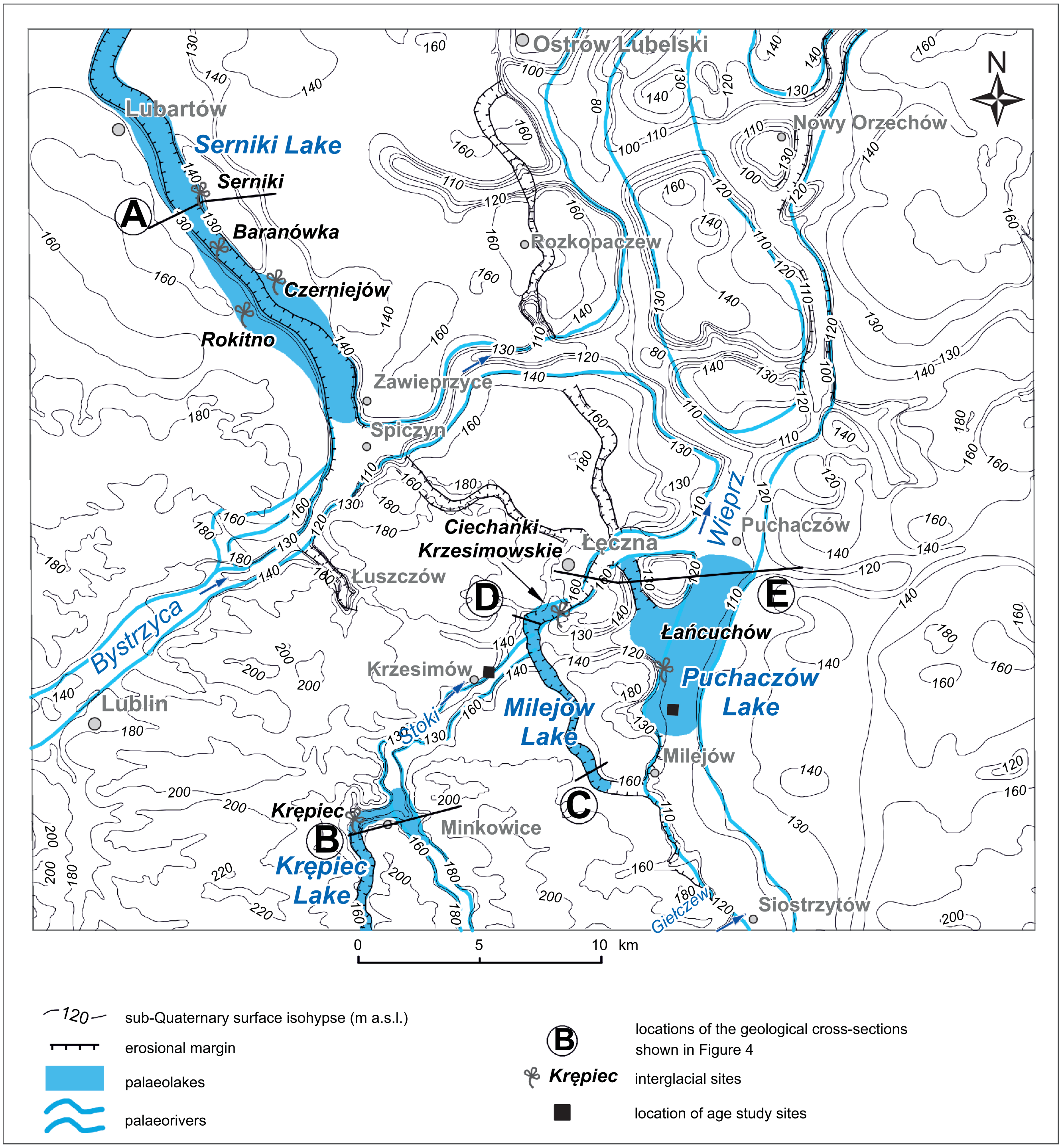

Fig. 5. Pattern of hydrographic network in the Mazovian Interglacial with reference to the relief of the sub-Quaternary surface

(1981) classified it as a probable fossil "Ciechanki-Łuszczów" trough. The valley is documented by borehole Łuszczów P10. Cretaceous pebbles occur at the depth of 42 m, with Scandinavian material to 57 m. Cretaceous deposits were noted at the depth of 71 m, at the altitude of 11.5 m a.s.l., i.e. close to the level of the Pre-Bystrzyca Valley bottom near Spiczyn (109.5 m a.s.l.). The continuation of this incised valley towards the east was not confirmed by geophysical surveys (ERT-2, Fig. 1) performed ~2.5 km to the ESE of borehole Łuszczów P10. They have shown the existence of a moderately shallow depression located ~10 m below the present-day surface and attaining a width of 100 m. This was a valley used rather by flow (or an erosional ravine) discharging from the Cretaceous plateau and with a mouth in the Bystrzyca Valley. The connection of this valley with corroborated the Stoki Valley, suggested by Harasimiuk and Henkiel (1981), has not been confirmed.

The **Orzechów Valley** (7 in Fig. 3) is located in the north-eastern part of the study area. Its course is approximately parallel to the fossil Pre-Wieprz Valley and may probably represent its primary course. Before the glaciations and at the beginning of the South-Polish Glaciations, the waters of the Pre-Wieprz most probably flowed into the Bug (which at that time belonged to the Pripyat River Basin). The Orzechów Valley has a width of ~900 m and a depth of >70 m. Its deepest occurrences were noted at 91.0 m a.s.l. in borehole Orzechów-7 and at 92.0 m a.s.l. in borehole Gosp. Rolne-St. 3 (Figs. 1 and 3). It has also been corroborated by geophysical surveys (Pawłowska and Tracz, 1975). The valley can be considered a subglacial trough, as suggested by the incision depth, and the presence of deposits from the Sanian 1 Glaciation (MIS 16; Table 1) and probably also the Augustovian Interglacial at its bottom (Table 1).

The **Samocieczka Valley** (8 in Fig. 3) is situated to the north of the Łęczna Hummock, running north-eastwards from Spiczyn and linking the Pre-Bystrzyca and Pre-Wieprz valleys (Fig. 3). It has a different character to the earlier described erosional incisions representing subglacial troughs. Presently this depression is marked as a wide, flat valley used by the small Samocieczka Stream. Available rare borehole data and analysis of the sub-Quaternary basement map indicate that this depression represents a fluvial valley rather than a subglacial trough. The valley is ~13 km long. In its middle part its course is close to N–S, while both its final stretches occurring in the vicinity of the mouths of the Pre-Bystrzyca and Pre-Wieprz are parallel. The valley slopes are gentle, and the bottom is wide and flat, occurring at ~110 m a.s.l., and does not display a significant dip in any direction. This elevation corresponds to the level of the bottom of Pre-Bystrzyca and Pre-Wieprz at the connections with these valleys. The deposits in the valley bottom do not contain glacial facies typical of subglacial troughs, while clays with marl fragments, fine sands and marl pebbles occurring in the basal part of the infilling may point to the fluvial origin of the depression (borehole Radzic OS-2).

The development of the Samocieczka Valley is closely connected with the course change of Pre-Bystrzyca. The Pre-Bystrzyca outflow was directed to the east to the Samocieczka Valley and is connected with the Pre-Wieprz Valley to the south of Rozkopaczew (Fig. 3). This connection took place in the Mazovian Interglacial during the formation of a large lake in the fossil Serniki Trough, as indicated by sandy gravels from the Mazovian Interglacial (MIS 11c; Table 1) occurring in the fossil Samocieczka Valley, drilled in borehole Radzic OS-2 (Fig. 1), and developed similarly to the deposits in the Pre-Wieprz Valley near Ostrów Lubelski (Liszkowski, 1979). It cannot be excluded that the valley itself has a much older, pre-Pleistocene origin.

PERIOD OF THE MAZOVIAN INTERGLACIAL (MIS 11C)

Retreat of the last South-Polish ice-sheet (Sanian 2, MIS 12; Table 1) from the study area caused deep erosion in the valleys, reaching to a depth of ~140 m a.s.l. and in some troughs reaching 80 m a.s.l. (Fig. 4), and almost complete removal of glacial deposits. Neotectonic activity resulted in the reactivation of old fault zones (Liszkowski, 1979; Harasimiuk and Henkiel, 1980b). Uplift of the southern margin of Roztocze took place to the south of the study area (Laskowska-Wysoczańska, 1979; Brzezińska-Wójcik and Kociuba, 2001); which significantly modified the hydrographic pattern of the entire Lublin region. The Wieprz became a much smaller river, losing the Carpathian-Sandomirian part of its basin. During the Mazovian Interglacial (MIS 11c; Table 1) gradual increase in its fluvial erosional base took place. The Wieprz gradually transformed into a braided channel. Lakes started to form in the former wide Pre-Wieprz Valley (Fig. 5). Flows in the Bystrzyca and Wieprz Valleys decreased substantially. This is shown by the augmented fluvial and lacustrine sedimentation which resulted in filling of all the deeper depressions.

Thick lacustrine deposits occurring in river valleys and subglacial troughs have been documented by boreholes in the study area (Fig. 4).

Depressions representing fossil subglacial troughs and valleys, when filled with water, created vast lakes. The deposits of the Mazovian Interglacial point to the existence of several large and deep lakes in the study area: the Serniki and Milejów lakes, which are trough lakes, and the Puchaczów and Krępiec lakes, which formed in fossil river valleys (Fig. 5).

Characteristics of the lakes

Serniki Lake (Fig. 5) was formed in the Serniki subglacial trough (Fig. 4A). Multiple erosion and accumulation processes took place in the valley until the Mazovian Interglacial (MIS 11c; Table 1), and the narrowest part of the trough was filled with extremely diverse deposits. In the initial phase of the Mazovian Interglacial, the Pre-Bystrzyca Valley still existed with a subglacial trough below, filled with deposits of the South-Polish Glaciations (Fig. 4A). Fluvial sands and sands with gravel were deposited in the trough. Most probably further neotectonic activity and a continuous decrease of flow intensity caused change in the water flow. The Pre-Bystrzyca thalweg was directed to the east to the Samocieczka Valley connected with the Pre-Wieprz Valley to the south of Rozkopaczów, and a small part of the flow began to fill the Pre-Bystrzyca Valley with water to the north of Spiczyn, forming a vast lake with a constant flow. In Serniki, lacustrine deposits are documented in research boreholes drilled in the Wieprz Valley during preparation of the Detailed Geological Map of Poland, Lubartów sheet (Łozińska-Stępień et al., 1985a, c). A Mazovian Interglacial (MIS 11c; Table 1) succession was observed in Serniki Lake in the Serniki (Sobolewska, 1956), Czerniejów (Jahn, 1956), Rokitno (Janczyk-Kopikowa, 1983) and Baranówka sites; the results for the latter site are presented in this study.

Milejów Lake (Fig. 5) formed in the Milejów Trough and was the deepest water body in the area (Fig. 4C). Sedimentation of lacustrine deposits (muds and clays) took place in the deep depression (Harasimiuk and Henkiel, 1981); these were documented to the depth of ~86 m a.s.l. by boreholes BG-1 and Klarów-11. A full palynological record of the Mazovian Interglacial (MIS 11c; Table 1) succession was observed within the boundaries of Milejów Lake in a ~11 m sedimentary profile at the Ciechanki Krzesimowskie site (Fig. 5; Brem, 1953).

Krępiec Lake (Fig. 5) formed due to cut-off of the upper stretch of the Stoki River and its eastern tributary in the terminal part of the Sanian 2 Glaciation, caused by local block movements in the southern part of the area, which prevented flow in the valleys (Harasimiuk et al., 1988). Water supplying the Stoki River Valley were directed to the east of the Wieprz Valley near Siostrzytów, forming the present-day Giełczew River (Harasimiuk et al., 1988). A deep water body formed in the place of the Krępiec Valley (Harasimiuk and Henkiel, 1980b), i.e. Krępiec Lake (Fig. 4B), in which >40 m thick Mazovian Interglacial deposits occur, recording a full palynological succession of that interval (Janczyk-Kopikowa, 1981).

Puchaczów Lake (Fig. 5) formed in the wide Wieprz Valley between Milejów and Puchaczów (Harasimiuk and Henkiel, 1981). It was either one vast lake or comprised several smaller backwaters with diverse flows. Muds and sandy muds were deposited in them, an fluvial deposits in the flow zones (Fig. 4E). Pollen analysis from the Łańcuchów site within Puchaczów Lake (Fig. 5; Środoń, 1960) indicates the protocratic pine-birch phase and mesocratic phase of the first spruce-alder climate optimum of the Mazovian Interglacial.

Results of palynological analysis of the Baranówka site and description of deposits

Lacustrine sedimentation began in the Mazovian Interglacial in Serniki Lake, as in most lakes with a Mazovian succession, when the area was subject to the expansion of pioneer birch forests with the pine that gradually began to dominate in them (Sobolewska, 1956; Hrynowiecka-Czmielewska, 2010). Rapidly improving climate conditions and a complex fluvial network lead to the expansion of alder riparian forests with ash and spruce (first climatic optimum), the culmination of which was the exceptionally rich development of yew assemblages. The Older Holsteinian Oscillation (OHO) climatic oscillation (Koutsodendris et al., 2010), registered in the whole of Poland and Europe, led to climate breakdown, when thermophilous trees withdrew and the study area was recolonized by pioneer pine-birch forests with abundant herbaceous vegetation. Subsequent warming resulted in the development of mixed hornbeam-fir forests (second climatic optimum – Younger Holsteinian Oscillation – YHO; Koutsodendris et al., 2010) and riparian forests but without spruce and yew. In this warmest period of the Mazovian Interglacial (MIS 11c; Table 1) there appeared thermophilous taxa such as *Buxus*, *Pterocarya* and *Vitis*. Then, sedimentation of detrital or calcareous gyttia, or lake muds, usually took place in the lakes. The post-optimal gradual climate cooling was reflected in the withdrawal of deciduous forests and domination of coniferous assemblages with fir, pine and subsequently spruce. Further climate change resulted in fir withdrawal, followed by spruce, after which the last period of the interglacial was characterized by the domination of pine with a birch admixture (Janczyk-Kopikowa, 1983).

Gradual climate change caused slow decline of the lakes and sedimentation change to boggy conditions, as a result of which peats and mineral-organic sediments were deposited.

During update of the Detailed Geological Map of Poland, field studies in 2020 discovered and documented a new site of the Mazovian Interglacial in the Wieprz Valley in Baranówka (Łozińska-Stępień et al., 1985a).

The deposits analysed in Baranówka (Fig. 6) are characterized by a very similar pattern of pollen curves and taxonomic composition. Pollen of *Pinus* dominates, from 29 to 53%, and *Alnus* reaches 17–32%. Pollen of *Abies*, *Picea* and *Carpinus* appears equally frequently – at 9–13%, 3–8%, and 2–6%, respectively. Pollen of *Corylus*, *Quercus*, *Betula*, and *Ulmus* is infrequent. Pollen of the remaining trees appears as single grains, similarly as *Buxus*, *Pterocarya*, *Taxus baccata* and *Vitis*. Pollen of shrubs is equally rare. Among herbaceous plants, the most common are the Cyperaceae (max. 3%) and Poaceae. Other herbaceous plants, as well as reed (*Phragmites*, *Sparganium*, *Typha latifolia*) and aqueous plants (*Nuphar lutea*) appear rarely. There are numerous fern spores, from 6 to 40%, and moss spores (up to 9%). Taxa typical for Neogene flora have not been observed.

All 5 samples should be assigned to one zone: a *Pinus-Abies-Picea* LPAZ (Fig. 6). This was a time of pine forest domination with spruce and fir, with remnants of hornbeam forests. In humid and overflooded habitats, there grew riparian forests with alder, elm, ash and willow. A temperate climate prevailed at that time.

Results of pollen analysis in Baranówka (Lubartów sheet) point to a Mazovian age of the deposits (MIS 11c; Table 1). The zone analysed represents the terminal part of the interglacial characterized by the domination of pine, while numerous spruce, fir and hornbeam are remnants from the earlier warmer period.

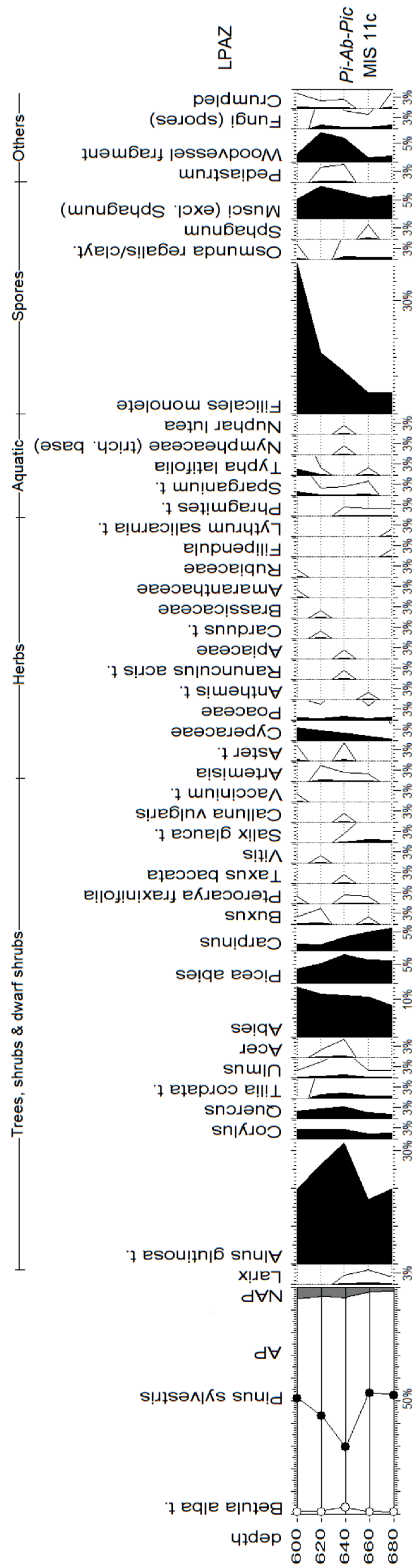

Fig. 6. Simplified pollen diagram for the Baranówka site

The pollen spectra from Baranówka are similar to spectra from eastern Poland (Hrynowiecka-Czmielewska, 2010; Hrynowiecka et al., 2014; Hrynowiecka and Pidek, 2017).

PERIOD AFTER THE MAZOVIAN INTERGLACIAL

During the Middle- and North-Polish Glaciations the study area was free of ice. During these glaciations, the encroaching ice-sheets caused damming of water flow towards the north. As a result, extensive backwaters accumulating sediment formed. The deposition level in the Wieprz Valley reached >160 m a.s.l. During ice-sheet recession, intense water flow from the ice front took place towards the south-east. New flow paths were formed, which largely used the former hydrographic system. During dewatering of the Wartanian ice-sheet (MIS; Table 1), according to Harasimiuk et al. (2004), several proglacial pathways of water flow existed in the study area: the Tyśmienica Valley, Piwonia Valley, Wieprz gorge, and Świnka Valley. It is possible that a meltwater pathway, as in the parallel Tyśmienica Valley, existed in the Bystrzyca Valley (Serniki Trough) during deglaciation periods, particularly during the last stadial (Wartanian) of the Odranian Glaciation (MIS 6; Table 1) (Harasimiuk et al., 2004).

Ice-sheet retreat caused freeing of water flow again to the north and west. In the first stage, these flows could locally be highly energetic, causing strong erosion. Evidence for such dynamic flow include the deposits documented in Baranówka (Fig. 7), where organic deposits from the Mazovian Interglacial (MIS 11c; Table 1) are overlain by a succession of sands and gravels. This observation sheds new light on the nature of the valley infilling, as well as on processes taking place in the area after the Mazovian Interglacial. In Baranówka, almost 3.5 m of sands and gravels were documented; they are overlain by a large accumulation of gravels and poorly rounded boulders up to 40 cm across (Figs. 7 and 8). OSL analysis points to the Lubavian Interstadial (=Lublinian; MIS 7; Table 1) of the Odranian Glaciation (*s.l.*). The age of this succession is 227 ±88 ka, and its facies points to very high flow energy and strong erosion. Grain dimensions and poor rounding indicate short sediment transport (Fig. 8). Their origin may be linked with washing out of older glacial covers and rapid redeposition. Above the sands and gravels there occur fine-grained deposits, which we link with the Vistulian, as shown by the OSL age of 19.1 ±3.6 ka (Fig. 7). Similar deposits, formed during the Last Glaciation, occur across extensive parts of the plateau surface.

OSL analyses performed on similarly developed floodplain sediments from the Wieprz Valley escarpment near Milejów corroborate cyclic processes taking place during the last two glacials. The upper part, 3 m thick (at ~165.0 m a.s.l.), represents the Vistulian and is dated at 16.8 ±3.5 ka. The lower part (occurring below 3 m at ~163.0 m a.s.l.) is from the Wartanian Stadial of the Odranian Glaciation (MIS 6; Table 1) and is dated at 171 ±53 ka BP.

Backwash deposits from the last two glacials have been documented across the entire study area as well as in neighbouring regions at elevations exceeding 170 m a.s.l. by Harasimiuk et al. (2017), and recently also in our fieldwork on the Detailed Geological Maps. The presence of these deposits confirms the very high water level and formation of backwashes and lakes in these intervals.

FORMATION OF THE WIEPRZ GORGE

We consider the gorge as an fossil subglacial trough, which was used, probably several times in the Pleistocene, as a pathway for waters. Following the most recent concepts regarding the lack of the Middle-Polish ice-sheets in the study area (Lisicki, 2003; Czubla et al., 2013, 2019; Terpiłowski et al., 2013; Marks et al., 2018; Hrynowiecka et al., 2019; Żarski and Kucharska 2020), the hypotheses of Liszkowski (1979) and Maruszczak (1974) should be supported. Liszkowski (1979) linked the gorge formation with the occurrence of dead-ice

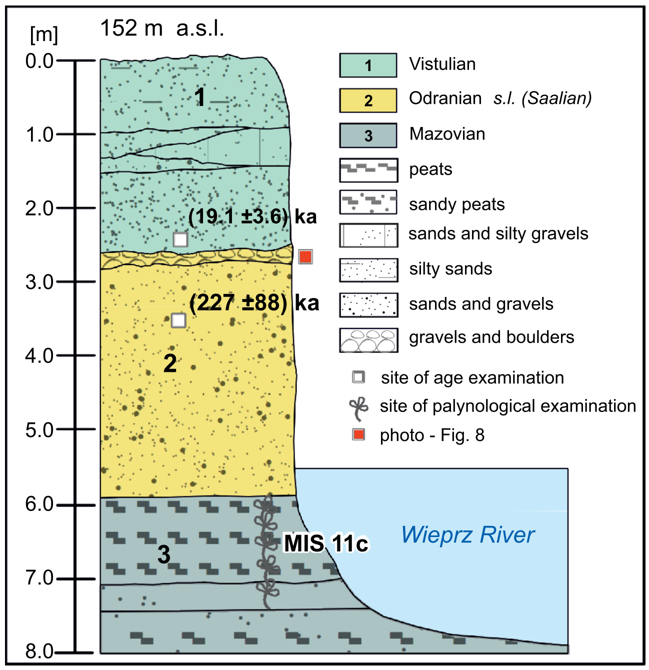

Fig. 7. Sedimentary log of the Baranówka site

Fig. 8. Boulders at the Baranówka site

blocks, which blocked the flow towards the north. We lean towards the ideas of Maruszczak (1974) of water flowing on frozen ice during the Odranian Glaciation. However, the ice was from frozen backwashes formed by rivers flowing from the south, after which the sinuous ridges characteristic of the area formed. It is also difficult to accept the concept that deep erosion of Cretaceous rocks (>30 m) could have taken place during the high water levels which formed the backwashes.

It is clear that, as suggested by Harasimiuk and Henkiel (1981), change of the hydrographic pattern was induced by neotectonic activity between the Sanian 2 Glaciation and the Mazovian Interglacial. According to these authors, the causal factor for the development of the Wieprz gorge was collapse of a tectonic zone cutting the Wieprz Valley to the south of Łęczna and Puchaczów. The Łęczna Hummock with an elevation exceeding 180 m a.s.l. was too large for the water to overspill. If so, the waters would again enter the older, lower-lying valley, flowing to the north to Ostrów Lubelski. Formation of the gorge as a result of tectonic activity would have been possible if uplift of the area around Łęczna is assumed (from the level of ~150–160 m a.s.l.) and an antecedent gorge would be formed; however, Harasimiuk and Henkiel (1981) suggested a continuously high position of the Łęczna Hummock. Furthermore, the young relief of the valley in the gorge stretch indicates that it could not have been preserved in this state from the end of the South-Polish Glaciations.

We do not concur with the views of Jahn (1956) that the waters overspilled in the place of the existing denudation valley through a pass at an altitude of 176 m a.s.l. with a regressive gorge form the during the Last Glacial. The waters could freely flow to the Bystrzyca Valley bypassing the Cretaceous ridge to the north of the gorge, or flow further using the old valley towards Ostrów Lubelski. Between Spiczyn and Rozkopaczew there are areas located much lower (~140 m a.s.l.) than the gorge.

We consider that the erosional incision of the present-day Wieprz gorge took place before the change of its course near Łęczna. Its characteristics, i.e. small width, very steep walls and a sinuous course, may point to its formation by subglacial waters. The age of this incision is not clear. A much shallower depth compared to the Serniki and Milejów troughs suggests a different time of its formation. The trough pattern, forming one series, may suggest their common ancestry and formation during the Narevian Glaciation (Table 1), a view that we agree with. From that time, the stretch between Łęczna and Spiczyn did not function as a continuous flow. The trough was partly buried and conserved by glacial deposits of subsequent glaciations. Remnants of this burial are most probably the coarse sands with clasts of Cretaceous and Scandinavian rocks building the terrace on the northern side of the Wieprz, as described by Jahn (1956). The trough was again eroded by waters of the Wieprz during the gorge formation, which caused change in the flow, connection with the Bystrzyca Valley and complete decline of the valley to the north of Puchaczów.

The most recent investigations performed in the area have supplied several clues allowing determination of the time of the Wieprz gorge development.

The presence of Mazovian fluvial deposits was noted in the Pre-Wieprz stretch to the north of Puchaczów (borehole BP-6; Fig. 4E), incising into the lacustrine deposits of the same interval (described earlier by Harasimiuk and Henkiel, 1980a, 1981). This testifies for the fact that the Wieprz flowed farther to the north at this locality during the Mazovian Interglacial (MIS 11c; Table 1). Near Puchaczów, the Mazovian deposits are overlain by a thin succession of fluvial-periglacial deposits of the Middle-Polish Glaciations probably belonging to an early phase of this period. This also points to the existence of a fluvial valley at that time and negates the creation of a gorge and change of river flow between the South-Polish Glaciations and the Mazovian Interglacial, as suggested by Harasimiuk and Henkiel (1981). Loesses occurring above fluvial-periglacial deposits (Fig. 4E; Harasimiuk and Henkiel, 1980a, b) indicate complete freezing of flow in the area during the Vistulian. The last stage of loess accumulation in the Last Glacial took place in the upper Pleniglacial, dated at 28 to 12 ka BP (Maruszczak, 2001; Frechen et al., 2003). This is corroborated by dating of fluvial deposits that occur above the loesses at the Krzesimów site at 21 ±4.5 ka BP. Uniform fluvial deposits, 11 m thick, infilling the Wieprz Valley in the gorge area and overlain by Holocene muds, are interpreted as having being formed during the Last Glacial (Maruszczak, 1974; Harasimiuk and Henkiel, 1981). This indicates that the gorge existed during the Vistulian.

To the south of the dead stretch of the Wieprz analysed, i.e. near Milejów, through the entire Pleistocene the valley functioned continuously, and the level of burial by sediment reached over 165 m a.s.l. In the escarpment of the Wieprz Valley near Milejów, the fluvial-periglacial deposits noted at 163 m a.s.l. have an age of 171 ±53 ka BP.

The Baranówka site has thrown new light on the processes taking place in the study area. The sand-gravel-boulder deposits dated at 227 ±88 ka BP (Figs. 7 and 8), indicate powerful flow in that interval. The level of peat incision from the Mazovian Interglacial is located at 146.0 m a.s.l., i.e. close to the base of Wieprz gorge near Łęczna. It is a level 10–15 m lower than for the Mazovian Interglacial deposits and early Odranian Glaciation fluvial-periglacial deposits occurring in the vicinity of Puchaczów (Fig. 4E). Unblocking of the Wieprz gorge probably took place in the middle phase of the Middle-Polish Glaciations, the Lubavian (Lublinian, MIS 7; Table 1). At that time the water level was above 170 m a.s.l. This is indicated by the common occurrence of fluvial-periglacial and backwash deposits of the Odranian Glaciation at levels exceeding 170 m a.s.l. Gradual fall of the water level caused removal of backwash deposits beyond the source area. This process led to erosion in the Spiczyn-Łęczna Trough. Flow was equalized in the gorge and in the Baranówka area at the level of ~146–150 m a.s.l.

The Wieprz never returned to its old channel after overflowing and taking over the Bystrzyca Valley below Spiczyn. Later, after the gorge stretch of the old Wieprz Valley was formed to the north of Puchaczów, it was filled with eolian sediments (loess) during the Vistulian (Table 1). The Samocieczka and Tyśmienica valleys became extensive areas with increased organic sedimentation and small flows dewatering the surrounding areas. A new watershed was formed between the Świnka Valley and the spring zones of Piwonia and Tyśmienica (Fig. 9). This pattern occurs to the present.

The distribution of the present-day lakes is linked with areas where Maastrichtian rocks occur close to the surface and fossil fluvial valleys are present in the subsurface (Fig. 9). Numerous lakes occur between parts of the rock massif cut by a latticed valley pattern, which may suggest their karst origin. The depressions and later the lakes began to evolve due to water drainage into deep rock masses during lowering of the base level in the fossil fluvial valleys.

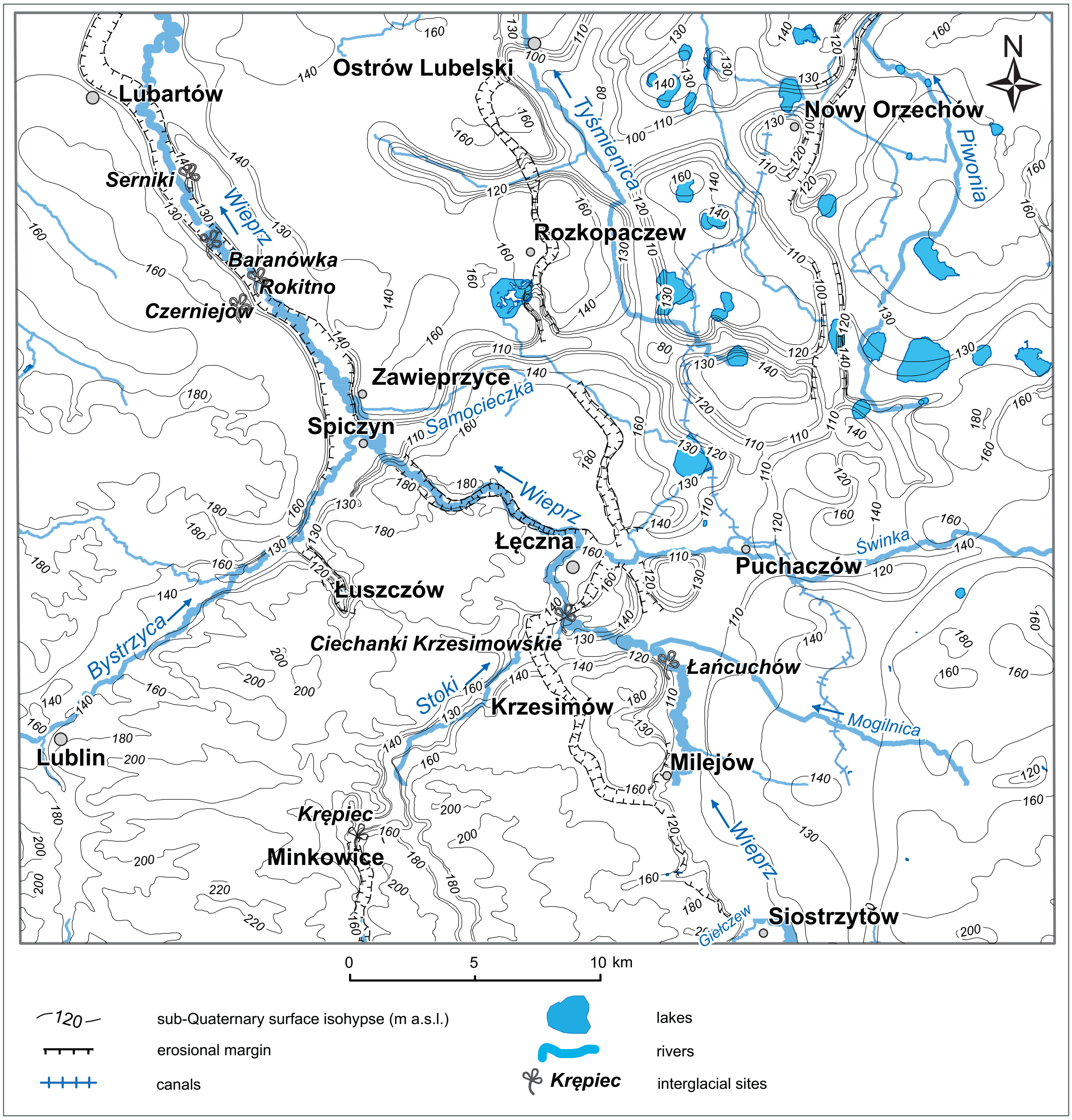

Fig. 9. Present-day river pattern with respect to the sub-Quaternary relief

SUMMARY AND CONCLUSIONS

Our new maps of the sub-Quaternary surface allow interpretation of the evolution of the hydrographic network and its erosional forms (Figs. 2, 3 and 5). Fossil erosional valleys have been characterized and described, and divided into fossil river valleys and subglacial troughs. A new perspective of the geological processes during the Pleistocene in the study area is provided, and a new site of the Mazovian Interglacial in Baranówka is documented which, together with other studies, allow a new interpretation of the genesis and age of the Wieprz gorge.

From the end of the Mesozoic until the present, the dimensions and position of the Wieprz Valley has evolved, influenced by a number of factors.The record of fossil valleys indicates migration of the Wieprz Valley and change of its characteristics, as well as of the water balance of the entire stretch of middle Wieprz basin, influenced by climate changes in the Pleistocene and Holocene. The valley system was also influenced by isostatic movements caused by ice sheets. The presence of two separate rivers already in the preglacial period, i.e., the Pre-Bystrzyca and Pre-Wieprz, has been corroborated. During the Narevian Glaciation a system of subglacial troughs developed in the study area; these troughs strongly disturbed the existing hydrographic system, partly overprinting it. Some of the troughs developed in fossil river valleys. Most probably at that time, the Spiczyn-Łęczna Trough also developed. During subsequent glaciations and cold periods, sedimentary changes took place in the troughs and valleys, from erosion and removal of material to their complete burial under sediments. During the Sanian 2 Glaciation (MIS 12) and the Mazovian Interglacial (MIS 11c), large changes in the entire hydrographic system took place. Several lakes were formed; these are recorded in a succession of organic and mineral-organic sediments. Our studies have not confirmed the existence of a trough in the vicinity of Łuszczów (6 in Fig. 3), which was supposed to connect the Bystrzyca and Stoki rivers.

The Middle-Polish and North-Polish glaciations represent a period with similar cycles of sedimentation and erosion. During successive ice-sheet advances, water flow towards the north was dammed. Extensive backwaters developed, reaching an elevation of 180 m a.s.l.; accumulative conditions prevailed in them. Ice-sheet retreats caused proglacial water flow towards the south-east, and transport of fluvioglacial sediments. In the Milejów stretch of the Wieprz Valley, the overfilling exceeded 160 m a.s.l. Further withdrawal of ice-sheets towards the north caused draining of flow routes and subsequent reversal of flow directions to the north and west. Sand-silt covers that had earlier accumulated on the plateau underwent partial degradation and transport beyond the depositional area.

During water flow to the north-west in the Odranian Glaciation (MIS 6), Spiczyn-Łęczna Trough was drained and the Wieprz gorge developed. The deposits documented in Baranówka suggest that this took place at 227 ±88 ka BP, i.e., most probably in the Lublinian Interglacial (MIS 7). The Wieprz flowed into the Bystrzyca Valley, taking over its channel. The Samocieczka Valley and the fossil Wieprz Valley to the north of its flow to Mogielnica disappeared. Loess sedimentation took place in the Vistulian in the Puchaczów stretch of the fossil valley. The valley stretch up to Ostrów Lubelski and the Samocieczka Valley were converted into wide plains including the small flows of the Samocieczka and Tyśmienica, which dewatered only the nearest area. Organic sedimentation began to dominate within these plains.

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