

Abhandlung

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Causes and effects of diversified human impact in the Nida basin in the Roman period (Holy Cross Mts., Poland)

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Zusammenfassung: Die Autoren präsentieren Beispiele detaillierter Studien aus dem Nida-Tal vor dem Hintergrund der Klimaschwankungen in Europa. Sie dokumentieren einen sehr klaren, wenn auch nicht entscheidenden, multidirektionalen Einfluss der Klimaveränderungen in der Römerzeit auf die Siedlungen und die Aktivitäten der Gemeinschaft der Przeworsk Kultur. Auch lokale Faktoren spielten in diesem Bereich eine wichtige Rolle. Die Ökumene der Menschen der Przeworsk Kultur in Südpolen war nicht homogen, was zu regionalen Unterschieden im anthropogenen Druck führte, der in Formen und Sedimenten festgehalten wurde. Sie bestand aus „Zentren“ nichtlandwirtschaftlicher Produktionsgebiete. Eines davon war die metallurgische Region in den Bergen des Heiligen Kreuzes, das zweite war ein Töpferzentrum im Weichseltal östlich von Krakau – beide waren relativ dicht besiedelt und hatten erhebliche menschliche

Auswirkungen auf die Umwelt. Zwischen diesen Zentren (die relativ kleine Flächen einnahmen) gab es riesige landwirtschaftlich genutzte Gebiete – ein Mosaik aus Ackerland, Weiden und Wäldern, was zu Erosions- und Anhäufungsprozessen geringer Intensität führte. Die Heterogenität der Ökumene mit unterschiedlicher Attraktivität könnte zu Migrationsbewegungen führen, die nicht nur mit großen Migrationen der Bevölkerung der Przeworsk Kultur nach Süden zusammenhängen, sondern auch mit regionalen und lokalen Migrationen aus für die Landwirtschaft weniger günstigen Gebieten in Richtung beider Produktionszentren (analog zu modernen „Dorf-Stadt“-Migrationen). Dies könnte den Rückgang der Bevölkerungsdichte einiger landwirtschaftlicher Gebiete veranschaulichen, z. B. des Nida-Tals und seines linksseitigen, karstigen Einzugsgebiets nach dem römischen Klimaoptimum (nach 150 n. Chr.).

Schlüsselworte: Klimaschwankungen, Südpolen, Przeworsk Kultur, Römerzeit, Mensch-Umwelt-Interaktion

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Abstract: The authors present examples of detailed studies from the Nida River valley, against the background of climatic fluctuations in Europe. They document a very clear, although not determining, multidirectional impact of climate changes in the Roman period on the settlements and the activity of the Przeworsk culture community. Local factors were also playing an important role in this field. The ecumene of the Przeworsk culture people in southern Poland was not homogeneous, which resulted in regional differences in human impact recorded in forms and sediments. It consisted of ‘centres’ of non-agricultural production area. One was the metallurgical region in the Holy Cross Mts., the second was pottery centre in the Vistula River valley, east of Kraków – both relatively densely populated and with significant human impact on the environment. Between these centres (occupying relatively small areas) there were vast areas used for agriculture – a mosaic of arable land, pastures, and forests, which resulted in low-intensity erosion and accumulation processes. The heterogeneity of the ecumene with varying attractiveness could

result in migration movements related not only to great migrations of the Przeworsk culture population southward but also to regional and local migrations towards both production centres from areas less favourable to agriculture (analogical modern ‘village→town’ migrations). This migration could have led to the decline in the population density of some agricultural areas, e. g. the Nida River valley and its left-bank, karst part of the catchment, after the Roman Climate Optimum (after 150 AD).

Keywords: climatic fluctuations, southern Poland, Przeworsk culture, Roman period, man-environment interaction

Streszczenie: Na tle wahań klimatycznych w Europie przedstawiono przykłady szczegółowych studiów z doliny Nidy, które dokumentują bardzo wyraźny, aczkolwiek nie determinujący, wielokierunkowy wpływ zmian klimatycznych w okresie rzymskim na osadnictwo i charakter aktywności społeczności kultury przeworskiej. Istotną rolę odgrywały też uwarunkowania lokalne. Ekumena ludności tej kultury na południu Polski nie była jednolita, co powodowało regionalne zróżnicowanie antropopresji zapisane w formach i osadach. Składały się na nią „centra” produkcji pozarolniczej, metalurgiczne w regionie świętokrzyskim i garncarskie w dolinie Wisły na wschód od Krakowa, relatywnie gęsto zaludnione i znaczną antropopresją na środowisko przyrodnicze. Pomiędzy tymi centrami, zajmującymi stosunkowo niewielkie obszary, rozciągały się rozległe tereny wykorzystywane rolniczo, stanowiące mozaikę gruntów ornych, pastwisk, obszarów leśnych, co powodowało niewielką intensywność procesów erozyjno-akumulacyjnych. Heterogeniczność ekumeny o zróżnicowanej atrakcyjności mogła powodować ruchy migracyjne związane nie tylko z wielkimi przemieszczeniami ludności kultury przeworskiej na południe, ale również z lokalnymi migracjami do obu centrów produkcyjnych z obszarów mniej sprzyjających rolnictwu (odpowiednik współczesnych migracji „wieś→miasto”), co może ilustrować spadek gęstości zaludnienia niektórych obszarów rolniczych, np. doliny Nidy i jej lewobrzeżnej, krasowej części zlewni po rzymskim optimum klimatycznym (po 150 r. n.e.).

Słowa kluczowe: wahania klimatyczne, Polska południowa, kultura przeworska, okres rzymski, relacja człowiek-środowisko

1 Introduction and the state of research

The area of the Lesser Poland Upland with fertile soils developed on loess and carbonate rocks was inhabited by people of agricultural and breeding cultures since the Neolithic¹. In the second half of the Atlantic, the areas with the most fertile soils were settled by the cultures of the Danubian cycle². The Neolithic population settled on the slopes of valleys, e. g. the Nida and Nidzica rivers, while in the valley floors they used gypsum domes located above the floodplains^{3, 4} or erosion remnants of the Vistulian terrace⁵. The scale of changes in the upland environment depended on the type of economy, which resulted in the varied activation of morphogenetic processes and their recording in various sedimentary environments⁶. The appearance of the Mierzanowice culture (3950–3400 BP; cal 2350–1600 BC), Trzciniec culture (3400–3000 BP; cal 1700–1200 BC) and then Lusatian culture (1200–300 BC) in the upland areas in the Bronze Age did not cause a change in the type of sedimentation in the valley bottoms⁷, and the settlement of these cultures was located in analogous places as in the Neolithic in the regions of the greatest biogeodiversity⁸. In the Subatlantic, anthropogenic environmental changes were taking place, related to the settlement appearance of the Lusatian culture in these areas, the Celtic culture in the La Tène period, and later the Przeworsk culture. The population of the latter culture developed a large metallurgical center in the Holy Cross Mts. region.

Ancient metallurgy has been attracting great scientific and social interest for years. While its spread is widely recognized⁹, knowledge of its impact on environment changes is very poor¹⁰. The exceptions are Klatka’s works (1958) from the Świślina basin. He presented findings from above-flood level (11–9 m above river level; a.r.l.). At a depth of 1–5 m – numerous charcoals, macroslags, and lumps of pure iron were found *in situ*, which evidenced the

1 Tunia 1997; Czerniak/Kalicki 2024.

2 Czerniak 1994; Kaczanowski/Kozłowski 1998; Czekaj-Zastawny 2008; Balcer 2012.

3 Małęga *et al.* 2016; Korczyńska-Cappenberg *et al.* 2023; Kalicki/Biesaga 2024.

4 Małęga/Biesaga/Kalicki 2016; Korczyńska-Cappenberg *et al.* 2023; Kalicki/Biesaga 2024.

5 Czerniak/Kalicki 2024.

6 *Ibid.*; Kalicki/Biesaga 2024.

7 Michno 2004; Kalicki/Biesaga 2024.

8 Czerniak/Kalicki 2024.

9 Bielenin 1992; Przychodni 2002; 2006; Orzechowski 2007; 2013.

10 Kalicki *et al.* 2019; 2020.

Prehistoric metallurgical activity in this region¹¹ as well as subsequent aggradation. Redeposited microslags and iron spherules were also found in the overbank sediments of the floodplain (5.5–4.5 m a.r.l.)¹². Detailed research in the Czarna Nida valley¹³, where the Nida bloomery center was located¹⁴, did not produce unequivocal results indicating a significant impact of the Prehistorical metallurgy on fluvial processes and the evolution of the valley in the Subatlantic period.

2 Aim of the study and methods

The article is an attempt to synthesize previously published results of interdisciplinary studies of the Nida catchment environment and their correlation and integration with the results of archaeological research. The aim of the study was to characterize the regional differences in human impact – with respect to changing climate conditions during the Roman period and migration movements – in the environment of the Przeworsk culture community in the Nida River catchment area, as recorded by fluvial processes and sedimentation dynamics.

Interdisciplinary research covered the Nida floodplain in several study areas¹⁵. As part of the field research, geomorphological mapping, geological drilling, and facies and sequence-stratigraphic analysis of outcrops were carried out. Laboratory analyses of the collected samples were performed in the laboratory of the Department of Geomorphology and Geoarchaeology of the Institute of Geography and Environmental Sciences of Jan Kochanowski University in Kielce. The sediment grain size was analyzed by laser diffraction (particle size analyzer “Mastersizer 3000” from Malvern Instruments Ltd) for fine sediments, and by sieve method (set of DIN ISO 3310/1 sieves and “Retsch-Rahmen” screeners) for sands. Folk & Ward’s¹⁶ grain size distribution parameters were calculated. The sediments were also analyzed for microslag and iron spherules¹⁷ detection based on a modified magnetic spherule separation (MSS) method using a special magnetic gripper and 200–63 µm sieves¹⁸. The results of the analyses were presented using the graphic programs GRANULOM, Inkscape, and Corel.

Calibrations of radiocarbon dating, both new ones made at the Absolute Dating Laboratory in Skała, and older ones from the literature, were made using the OxCal v.4.4.4 program (last actualization: 25.06.2024)¹⁹ according to the calibration curve IntCal20²⁰ about calibration accuracy 95.4 % (Tab. 1). The Holocene division according to Starkel *et al.* (1996)²¹ is used in this work.

Using published and unpublished materials, updated thematic maps of the catchment area were prepared, in addition to digital elevation models (DEM), based on data obtained from CODGIK MGPP Aero, No. GI-FOTO.703.44.2014 Archaeological data from the latest publications²² and the data base of Archaeological Map of Poland (AZP) sheet AZP 87-61, AZP 88-61, AZP 88-62, AZP 91-91, AZP 91-92 and AZP 92-62 have been also processed²³.

3 Location and environment of the study area

The Nida River is a second-order watercourse whose catchment includes the Nida Basin and the Mesozoic margin of the Palaeozoic core of the Holy Cross Mts. (Figs. 1, 2). The river crosses an area that is highly diverse in terms of its geology and geomorphology, which had a strong impact on the Late Glacial and Holocene evolution of the valley on a local scale. Upstream from the gorge at Kopernia, the river course is characterized by depressions filled mainly with sand, which are surrounded by plateaus of Mesozoic rocks, mostly carbonate. Downstream, the river flows through the tectonic fault of the Solec graben – between the Wodzisław horst to the SW and the Pińczów horst to the NE –, on the border between the Cretaceous rocks of the Nida Basin and Miocene clays with the gypsum series of the Sandomierz Basin²⁴. On the right-bank of the river there is Wodzisław Hump, covered with loess, while on the left-bank part – an inversion karst relief, developed on folded gypsum²⁵.

11 Radwan 1963; Bielenin 1992; Orzechowski 2007.

12 Przepióra/Kalicki 2024.

13 Krupa 2013; 2015.

14 Przychodni 2002; 2006.

15 Kalicki/Biesaga 2024.

16 Folk/Ward 1957.

17 Dungworth/Wilkes 2007.

18 Richeudeau 1977; Houbrechts *et al.* 2020.

19 Bronk Ramsey 2021.

20 Reimer *et al.* 2020.

21 Starkel *et al.* 1996.

22 Dobrzańska 1997; Przychodni 2002; 2006; Dobrzańska/Kalicki 2003; 2004; 2024.

23 Zabytek.pl

24 Urban *ed.* 2019.

25 Kondracki 1977; Kupczyk *et al.* 1994; Urban 2019; Richling *et al.* 2021.

Tab. 1: Summary of radiocarbon dates used in the work.

Catchment	Site	Archival radiocarbon dates	OxCal 4.4.4 calibration (95.4% accuracy)	Sources
Nida	Młodzawy Duże	11050±200 BP	11387-10740 BC	Szwarczewski 2009
Biała Nida	Mosty G7	8100±90 BP	7443-6699 BC	Lab no. MKL-6536
Biała Nida	M8 (M8/2024)	7700±100 BP	6901-6272 BC	Kalicki et al. 2025
Nida	Mozgawa MOZ 4/2015	6000±40 BP	4997-4791 BC	Moskal del-Hoyo 2018
Nida	Mozgawa	5890±100 BP	5004-4501 BC	Szwarczewski 2009
Biała Nida	Mosty G7	5720±80 BP	4774-4363 BC	Lab no. MKL-6537
Nida	Mozgawa (dry valley)	5720±80 BP	4774-4363 BC	Szwarczewski 2009
Nida	Mozgawa 2	5190±70 BP	4235-3801 BC	Biesaga 2023
Nida	Mozgawa 1	5040±80 BP	3976-3651 BC	Biesaga 2023
Biała Nida	M8 (M8/2025)	4590±80 BP	3620-3029 BC	Lab no. MKL-7102
Nida	Mozgawa 3	4560±110 BP	3618-2927 BC	Biesaga 2023
Czarna Nida	Łaziska 2	4490±90BP	3491-2914 BC	Krupa 2013; 2015
Nida	Mozgawa	4420±100 BP	3366-2887 BC	Szwarczewski 2021
Biała Nida	M3	4230±70 BP	3011-2581 BC	Maturlak 2024/Przepióra et al. 2024
Czarna Nida	Łaziska 2	4150±90 BP	2907-2476 BC	Krupa 2013; 2015
Mozgawka	Kozubów	3395±140 BP	2129-1403 BC	Szwarczewski 2021
Lubrzanka	Cedzyna	2810±50 BP	970-760 BC	Kowalski 2002
Bobrza	Słowik-Zalesie	2700±75 BP	910-600 BC	Sołtysik 2002
Czarna Nida	Kuby Młyny 4	2530±80 BP	750-420 BC	Krupa 2013; 2015
Belnianka	Bieliny A-II-1	2460±90 BP	789-399 BC	Ludwikowska-Kędzia 2000
Nida	Mozgawa 4	2240±90 BP	539-44 BC	Biesaga 2023
Czarna Nida	Borki	2200±200 BP	700 BC-150 AD	Śnieszko 1978
Nida	Mozgawa	2150±120 BP	478 BC-153 AD	Szwarczewski 2021
Czarna Nida	Brzegi	2145±70 BP	384 BC-5 AD	Przychodni 2002
Czarna Nida	Bilcza	2120±70 BP	366 BC-21 AD	Przychodni 2002
Belnianka	Napęków 20/8	2100±90 BP	376 BC-110 AD	Ludwikowska-Kędzia 2000
Belnianka	Napęków 14	2030±120 BP	361 BC-235 AD	Ludwikowska-Kędzia 2000
Czarna Nida	Bilcza	1960±70 BP	107 BC-236 AD	Przychodni 2002
Nida	Mozgawa 1	1950±100 BP	197 BC-331 AD	Biesaga 2023
Czarna Nida	Borki	1930±190 BP	400 BC-400 AD	Śnieszko 1978
Czarna Nida	Bilcza	1915±70 BP	49 BC-316 AD	Przychodni 2002
Lubrzanka	Cedzyna II	1800±50 BP	125-380 AD	Kowalski/Swałdek 1991
Nida	Mozgawa	1780±90 BP	30-531 AD	Szwarczewski 2021
Nida	Stawy 2/22	1760±110 BP	28-545 AD	Biesaga 2023
Czarna Nida	Ostrów 7	1740±40 BP	241-407 AD	Krupa 2013; 2015
Belnianka	Czapłów 16	1660±110 BP	133-637 AD	Ludwikowska-Kędzia 2000

Tab. 1 (continued)

Catchment	Site	Archival radiocarbon dates	OxCal 4.4.4 calibration (95.4% accuracy)	Sources
Lubrzanka	Cedzyna I	1650±50 BP	256-546 AD	Kowalski/Swałdek 1991
Czarna Nida	Bilcza	1590±70 BP	261–634 AD	Przychodni 2002
Biała Nida	Mosty G5	1590±110 BP	245-650 AD	Lab no. MKL 6538
Czarna Nida	Kuby Młyny 4	1530±70 BP	414-649 AD	Krupa 2013; 2015
Nida	Stawy 2/22	1520±70 BP	418-649 AD	Biesaga 2023
Czarna Nida	Bilcza	1510±70 BP	421–651 AD	Przychodni 2002
Lubrzanka	Cedzyna I	1510±50 BP	340-550 AD	Kowalski 2002
Nida	Mozgawa (alluvial fan of dry valley)	1440±100 BP	410-821 AD	Szwarczewski 2021
Mozgawka	Kozubów	1420±60 BP	538-774 AD	Szwarczewski 2021
Czarna Nida	Ostrów 10	1415±70 BP	440–775 AD	Krupa 2013; 2015
Lubrzanka	Lubrzanka gorge	1360±60 BP	574-819 AD	Kowalski 1990
Belnianka	Niwy Daleszyckie 35	1300±150 BP	433-1025 AD	Ludwikowska-Kędzia 2000
Czarna Nida	Zbrza I	1230±70 BP	660-975 AD	Krupa 2013; 2015
Czarna Nida	Łaziska 2	1190±35 BP	706–972 AD	Kalicki i in. 2016
Nida	Stawy 1/22	1140±70 BP	692-1027 AD	Biesaga 2023
Nida	Mozgawa	1050±80 BP	773-1169 AD	Szwarczewski 2009
Nida	Mozgawa	780±80 BP	1045-1391 AD	Szwarczewski 2009
Nida	Mozgawa 4	650±80 BP	1129 -1427 AD	Biesaga 2023
Czarna Nida	Ostrów 3	600±50 BP	1293–1421 AD	Krupa 2013; 2015

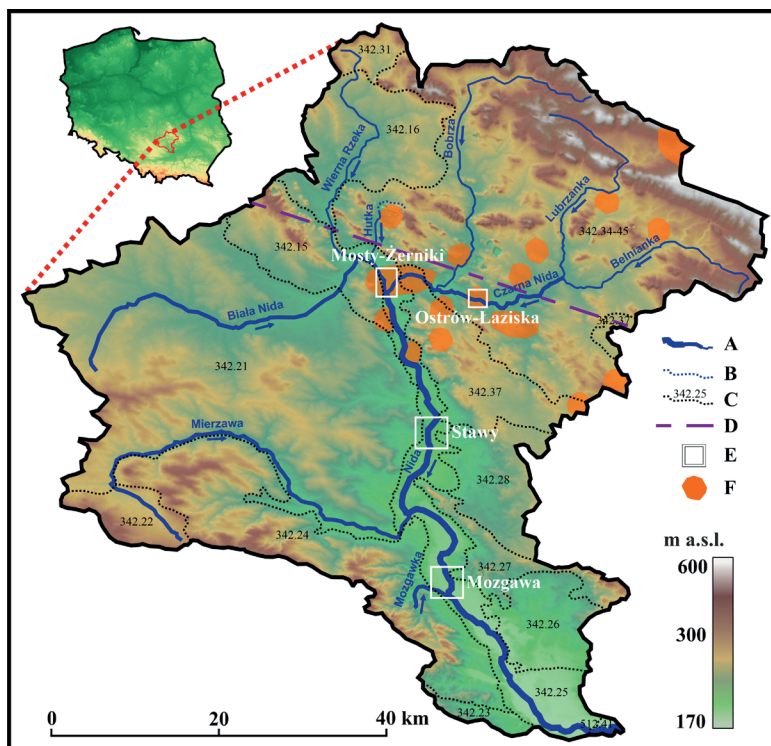


Fig. 1: Digital Elevation Model (DEM) of the Nida River basin with location of study areas (Geoportal.gov.pl.). A – rivers, B – periodic and episodic rivers, C – physico-geographical mesoregions (Solon *et al.* 2018), D – Old-Polish Industrial District range (Bielenin 1992), E – study areas, F – bloomerie activity sites (Przychodni 2002; 2006).

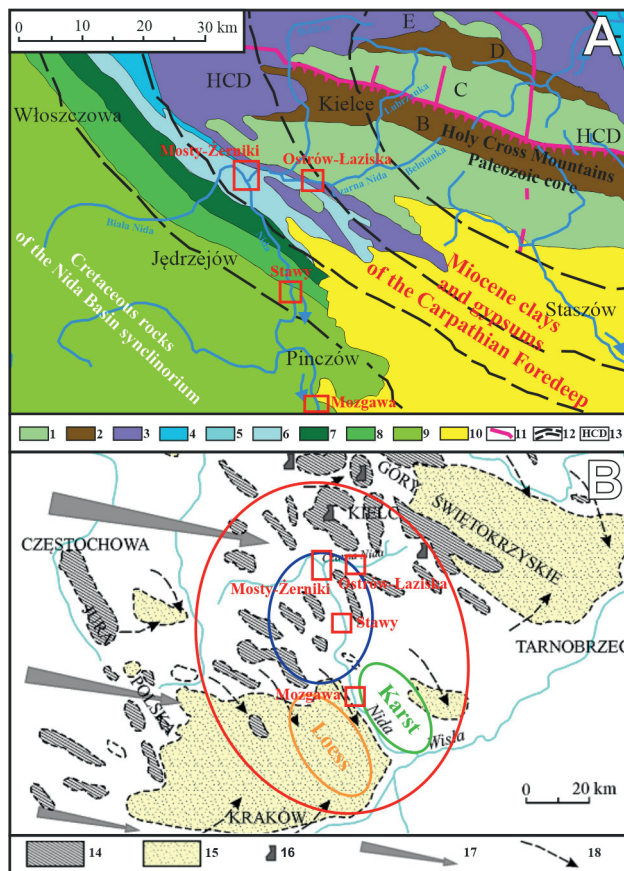


Fig. 2: Reconstruction of the Laramide morphostructure of the Holy Cross Mts. (Świętokrzyskie) section (Szydłowiec segment) of the Mid-Polish anticlinorium and Miechów segment of Szczecin-Miechów synclinorium on the pre-Quaternary geological basement (A) (Kowalski 2002; changed and supplemented.) and palaeogeographical reconstruction of the Nida River basin (red circle) during the Pleistocene periglacial conditions (B) (Lindner 1972; supplemented) with three part of Nida Basin: the upland relief with limestone elevation and sands in the depressions (blue circle), loess upland (orange circle) and gypsum karst area (green circle). A: 1 – Paleozoic structural units, neotectonic uplifted: A – Chęciny-Klimontów anticlinorium, C – Łysogóry fold zone, E – Bronkowice-Wydryszów anticline, 2 – Paleozoic structural units, neotectonic subsidence: B – Kielce fold zone, D – Bodzentyn syncline, 3 – Triassic, 4 – Lower Jurassic, 5 – Middle Jurassic, 6 – Upper Jurassic, 7 – Lower Cretaceous, 8 – Middle Cretaceous, 9 – Upper Cretaceous, 10 – Miocene sea sediments of Carpathian Foredeep, 11 – faults, 12 – isobases of reconstructed the Laramide tectonic morphostructure, 13 – Holy Cross fault. B: 14 – larger outcrops of the pre-Quaternary solid rocks covered by the Pleistocene frost weathering, 15 – larger loess cover, 16 – corrosive-deflation rocky tors, 17 – main directions of loess-forming winds, 18 – local directions of loess-forming winds.

Three climatic periods are distinguished²⁶ between 200 BC and 700 AD (archaeological periods: La Tène, Roman and Migration Periods, Early Middle Ages):

- **the Roman Climatic Optimum (c. 200 BC–150 AD)**, with a warm, humid and stable climate, when there was high insolation²⁷ and weak volcanic activity²⁸. The highest temperatures, higher than modern temperatures, occurred in the middle of the 1st century AD, and then began a very slow and uneven decline,
- **the Roman Transitional Period (c. 150–450 AD)**, which followed the gradual and staggered disappearance of the Roman climate optimum. Climate deterioration, disruption and global cooling was associated with a decline in solar activity²⁹, especially in the 40s of the 3rd century, although activity was quite high (maximum around 300 AD) and stable in the 4th and 5th centuries. These changes could have been deepened by volcanic activity, a volcanic eruption in 169 AD and another, larger one in 266 AD³⁰. The Roman Transitional Period is divided into an early (150–300 AD) and a later (300–450 AD), warmer period, dominated by the positive phase of the North Atlantic Oscillation (NAO),
- **the Late Antique Little Ice Age (c. 450–700 AD)**, which began at the end of the 5th century³¹, when several climate-forming factors overlapped with a general astronomical trend towards cooling. Its coldest phase occurred in the years 530–680 AD.

4 Settlement in the Nida River basin

In the Roman period, the entire Nida River basin was occupied by the community of the Przeworsk culture. During this period, there were changes in population density in the Nida River catchment area (Fig. 3)³². During the period of the Roman Climatic Optimum 0–150 AD (Early Roman Period: B1, B2), both the right-bank (loess) and left-bank (karst) parts of the catchment were densely populated. Migration movements occurred in the first decades (150–200 AD) of the Roman Transitional Period (Younger Roman Period: C1a). Archaeological sources indicate that the community of the Przeworsk culture left the part of Mazovia and Podlasie (located on the right bank of the Vistula River), moving to the areas of eastern Slovakia, Transcarpathian Ukraine, north-eastern Hungary, and north-western Romania, and in

26 Harper 2021, there literature.

27 Steinhilber/Beer/Fröhlich 2009; 2012.

28 Sigl *et al.* 2015.

29 Steinhilber/Beer/Fröhlich 2009; 2012.

30 Sigl *et al.* 2015.

31 Hirschfeld 2006.

32 Kaczanowski/Kozłowski 1998.

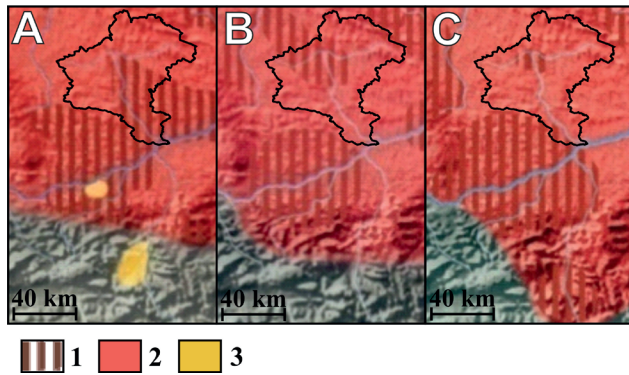


Fig. 3: Changes in settlement density in Nida basin and surrounding areas as early (B1, B2) 0–150 AD (A), younger (C1a) 150–200 AD (B) and younger and late (C1b–C3) 200–350 AD (C): 1 – densely populated area, 2 – Przeworsk culture, 3 – Púchov culture (Kaczanowski/Kozłowski 1998; changed).

their place the people of the Wielbark culture appeared³³. In the same period, the Nida River valley was depopulated, merely along its entire length, so was the left bank – karst part of its catchment area³⁴. Settlement was concentrated only in the area where Biała Nida and Czarna Nida Rivers connect, where the Nida bloomery center operated³⁵, and on the loess areas of the Wodzisław Hump and the Proszowice Plateau with agriculture activity.

The reason for this may have been an emigration from areas less favourable to agriculture (Nida valley wetlands, less fertile soils on gypsum, karst hydrography). People migrated to nearby regions³⁶, to the foothills of the Holy Cross Mts., where metallurgical production developed – primarily in the Kamienna River basin and in the Czarna Nida River, although already on a smaller scale³⁷ and to the Vistula's loess terrace eastward of Kraków with developing pottery and bronze production sites and on the Raba alluvial fan with ceramic workshops³⁸. A similar trend continued in the following centuries (200–350 AD; Younger-Late Roman Period: C1a–C3)³⁹, although the humid climate in the 3rd century until the mid-4th century had a favourable effect on settlement and agricultural conditions in the western Lesser Poland uplands. A greater number of permanent watercourses and an increase karst spring outflows and discharges facilitated (locally even enabled) the agricultural use of these areas and the location of settlements, which

is why traces of human penetration are found not only in river valleys, but also in watershed areas, and settlements near contemporary dry valleys⁴⁰.

5 Study areas

5.1 Czarna Nida River: Ostrów-Łaziska study area

In the 650 m wide valley floor, cut-and-fills of different ages have been identified; the right-bank part of the floodplain is composed of the meandering river alluvium, while the left-bank part is composed of the anastomosing river alluvium (Fig. 4A). To obtain additional data of the studied section of the river in a similar position to the previous cross-section (Fig. 4B)⁴¹, another geological cross-section was made (Fig. 4C)⁴². The Subboreal palaeomeander (Łaziska 2: profiles N1–N3), which is located under the edge of the Vistulian terrace, was cut off about 4500 years ago (4490±90 BP cal. 3491–2914 BC; 4150±90 BP cal. 2907–2476 BC). The peat bog in abandoned channel was covered with silty sands after 1190±35 BP cal. 706–972 AD⁴³(Fig. 4C). The northern part of the floodplain (profiles N6, N7, N8 and CN11 with palaeomeanders N4 and CN10) is composed of sands, while the youngest alluvia near the modern riverbed (CN9) are coarser and consist mainly of sands with single gravels and silty sands with gravels (Fig. 4C). The anastomosing system in the left-bank part of the floodplain functioned in the Roman Period and the Middle Ages, as evidenced by the dates of detritus from sandy alluvium (1415±70 BP cal. 440–775 AD) and peaty silts intercalation in the sandy-silty fills of palaeochannels (1740±40 BP cal. 241–407 AD; 600±50 BP cal. 1293–1421 AD)⁴⁴(Fig. 4B: profiles CN1–CN5). Nearer the Czarna Nida riverbed, sandy and sandy-gravel layers appear in the alluvia and in the abandoned channel fills (CN6–CN8, N5)⁴⁵.

A small amount of ferromagnetic microspherules was found in the floodplain alluvium. Single 200–63 µm iron spherules were found only in profiles CN3 (depth 52–60 cm), CN4 (depth 40–47 cm), N5 (depth 0–10 cm), CN8 (depth 0–20 cm) and CN9 (depth 22–43, 63–65 and 74–90 cm) and their number was estimated at 4–10 pieces per 10 g of mate-

³³ *Ibid.*

³⁴ *Ibid.*

³⁵ Przychodni 2002; 2006.

³⁶ Kalicki *et al.* 2024a; b.

³⁷ Bielenin 1992; Orzechowski 2007.

³⁸ Dobrzańska/Kalicki 2015; 2018.

³⁹ Kaczanowski/Kozłowski 1998.

⁴⁰ Dobrzańska/Kalicki 2003; 2004.

⁴¹ Krupa 2013; 2015.

⁴² Przepióra *et al.* 2024.

⁴³ Kalicki *et al.* 2016.

⁴⁴ Krupa 2013; 2015.

⁴⁵ Przepióra *et al.* 2024.

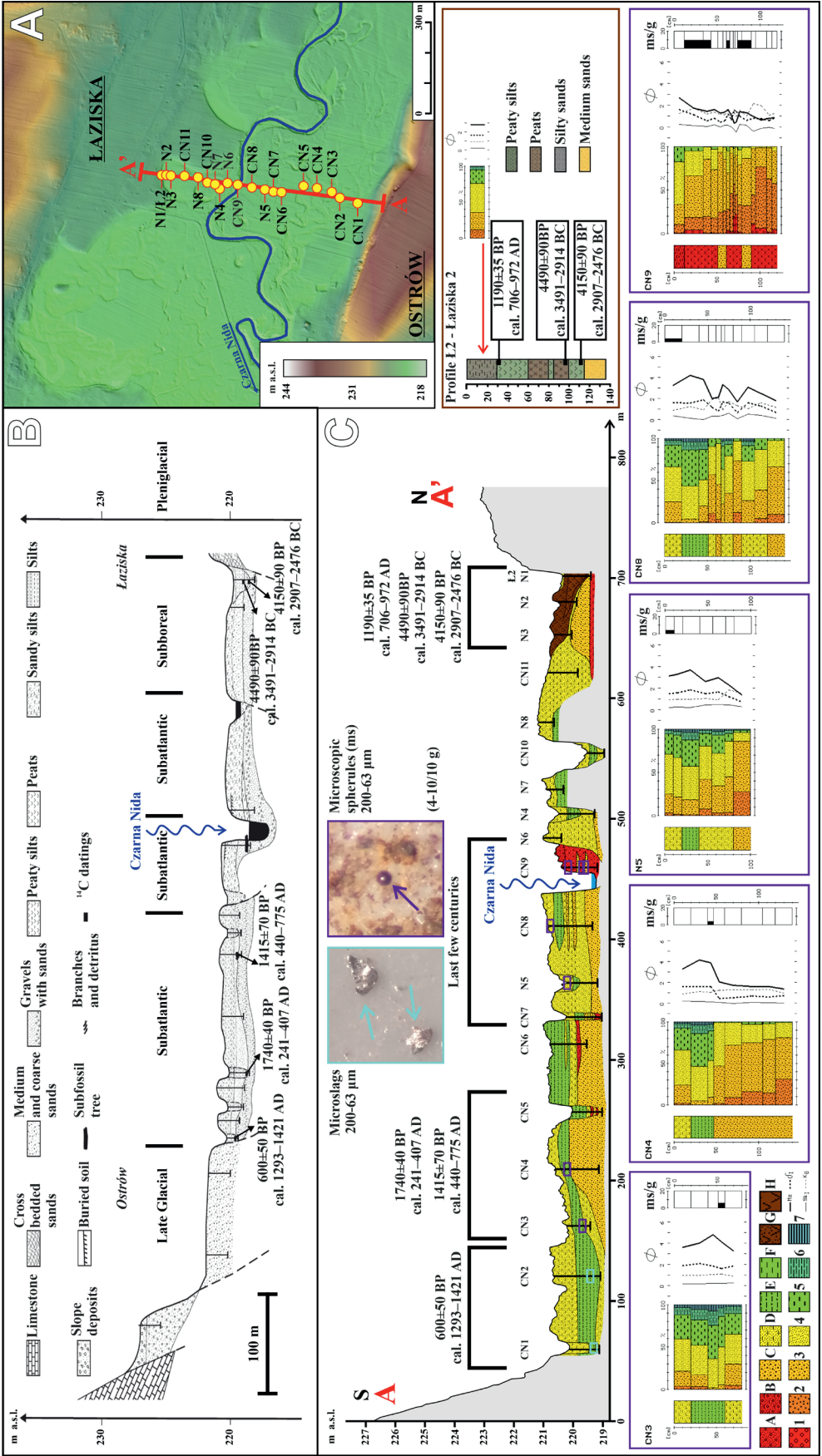


Fig. 4: DEM of study area (A) (Geoportal.gov.pl), geological Ostrów-Laziska section across the Czarna Nida floodplain with cut and fill of various ages (B) (Krupa 2013; 2015; Kalicki *et al.* 2016), lithology, grain size of sediments and distribution of microspherules (light blue box) and iron microspherules (purple box) in the profiles (C) (Przepióra *et al.* 2024) (photo by P. Przepióra 2022). Lithology: A – sands with single gravels, B – silty sands with gravels, C – medium sands, D – silty sands, E – sandy silts, F – silts, G – sandy peats, H – clayey peats; Fraction: 1 – gravel (below –1Φ), 2 – coarse sand (–1–1Φ), 3 – medium sand (1–2Φ), 4 – fine sand (2–4Φ), 5 – coarse and medium silt (4–6Φ), 6 – fine silt (6–8Φ), 7 – clay (above 8Φ); Grain size distribution parameters⁴⁶: Mz – mean size, δ_1 – standard deviation, Sk – skewness, K_g – kurtosis.

rial (after calculating by the sample weight) (Fig. 4B). Additionally, 200–63 µm ferromagnetic particles were separated from the sediments in profiles CN1 (depth 77–87 cm) and CN2 (depth 120–140 cm)⁴⁷. There are numerous irregular, flat iron scales with visibly jagged, sharp edges (Fig. 4B). Microscope analysis of these artifacts indicates that they may be microslags related to metallurgical activity in the Nida bloomery center during the La Tène and Roman Periods, because the following dates were obtained from charcoals originated from bloomeries at Bilcza, approximately 6 km upstream: 2120±70 BP cal. 366 BC–21 AD, 1960±70 BP cal. 107 BC–236 AD, 1915±70 BP cal. 49 BC–316 AD, 1590±70 BP cal. 261–634 AD, 1510±70 BP cal. 421–651 AD and the comparative dating was charcoal from the bottom of burial in a pit of the Przeworsk culture from Brzegi: 2145±70 BP cal. 384 BC–5 AD⁴⁸. The spherules may come from the closest production sites 17 and 31 known from the sheet 88-62 of Archaeological Map of Poland⁴⁹. Dating of charcoals from Bilcza and palaeochannel fills near Łaziska (Ostrów 7), where iron spherules were detected, confirm their probable source of origin in the alluvium of Czarna Nida from nearby bloomery sites⁵⁰. Spherules found in younger sediments near the modern riverbed could have been redeposited from the upstream section of the river valley, where bloomery sites were also located⁵¹. The small number of iron spherules in alluvium may result from the short or seasonal activity of the Prehistoric bloomeries, as well as the lower production intensity of the Nida centre, compared to the main bloomery centre in the Holy Cross Mts⁵².

5.2 Biała Nida and Czarna Nida Rivers: Mosty-Żerniki study area

In the study area at the confluence of the Czarna Nida and Biała Nida, remnants of terraces are preserved in the valley bottom and several Holocene cut-and-fills (related to the lateral migration of both riverbeds) were found (Figs. 5, 6 and 7). Three of them were dated and come from the Eo-, Meso- and Neoholocene, therefore, the age of the floodplain cut-and-fill units suggested in older publications⁵³ had to be revised⁵⁴.

The lateral migration of the Czarna Nida riverbed during the La Tène period and the Roman Climatic Optimum period is documented by a subfossil tree (*Quercus*) from its alluvium, felled around 2200±200 BP⁵⁵, cal. 700 BC–150 AD (Fig. 7A).

The period of maximum development of ancient metallurgy⁵⁶, including the Nida bloomery center⁵⁷, appeared during the Roman Climate Optimum period. Its traces, not only as bloomery sites but also macro-, microslags, and iron spherules (profile S1, M9; Fig. 8) occur in alluvium from this period⁵⁸. Microspherules found in the overbank deposits of the Czarna Nida River (profile S1) were probably redeposited from the metallurgical region in the upper course of the Czarna Nida River. While the ones in the sediments of the Biała Nida River near the torrential fan of dry fluvial-denudational valley (episodically and periodically drained) are deposited *in situ* and come from two production sites (58 and 59⁵⁹) located in this area (Fig. 8). Wood demand for bloomeries resulted in deforestation of the area and the initiation of aeolian processes in the sandy interfluvial area of both rivers⁶⁰, as evidenced by buried soil dated to 1930±190 BP⁶¹ cal. 400 BC–400 AD (Fig. 7). At the turn of the Roman Transitional Period and the Late Ancient Little Ice Age or later, the Biała Nida River cut-and-fill were formed in undercutting the Eoholocene cut-and-fill. They are dated at 1590±110 BP (MKL 6538) cal. 245–650 AD (Fig. 6).

5.3 Nida River: Stawy study area

In the Stawy section, located approximately 17 km downstream, the Holocene bottom of the Nida River valley is characterized by tectonic horsts, river incisions and fluvial deposits created by the river with an anastomosing (anabranching) and meandering pattern (near the contemporary riverbed). Radiocarbon dating of the palaeochannels of the anabranching system does not confirm their simultaneous functioning but indicates that a multichannel pattern existed in this section in the Atlantic and Roman periods (Fig. 9). The left-bank (eastern) part of the valley floor, probably Late Glacial (as indicated by the age of the abandoned channel preserved here), as well as the right-

⁴⁷ *Ibid.*

⁴⁸ Przychodni 2002.

⁴⁹ Zabytek.pl

⁵⁰ Przychodni 2002; 2006; Krupa 2015.

⁵¹ Przychodni 2002; 2006; Krupa 2013; 2015.

⁵² Przychodni 2006; Orzechowski 2007.

⁵³ Hakenberg/Lindner 1973.

⁵⁴ Kalicki/Biesaga 2024.

⁵⁵ Śnieszko 1978.

⁵⁶ Orzechowski 2007; 2013.

⁵⁷ Przychodni 2002; 2006.

⁵⁸ Przepióra *et al.* 2023.

⁵⁹ Przychodni 2006.

⁶⁰ Kalicki *et al.* 2024a; b.

⁶¹ Śnieszko 1978.

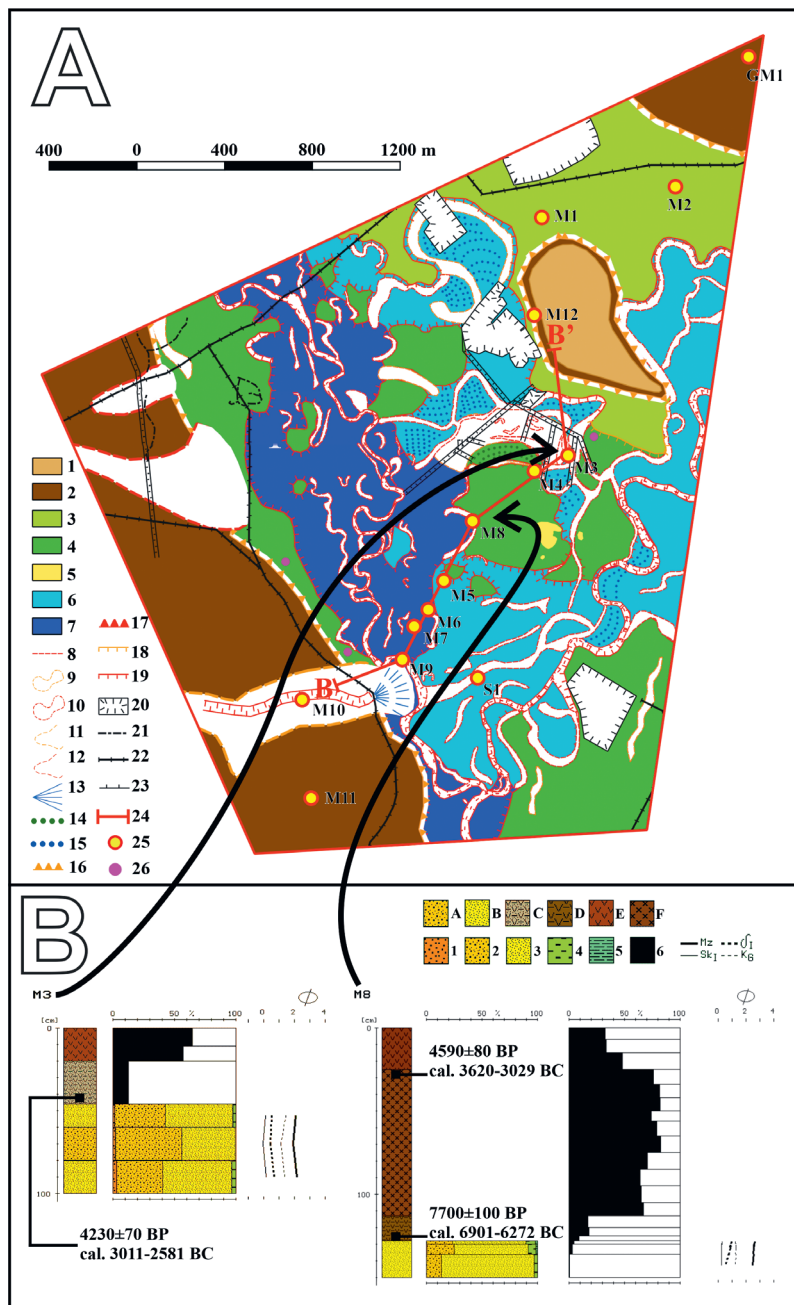


Fig. 5: Geomorphological map of the interfluvial area between the Biała Nida and Czarna Nida rivers (A) and the M3 and M8 profiles (B) (Maturlak 2024, changed and supplemented). A: 1 – watershed area (plateau), 2 – slope, 3 – Pleistocene upper terrace, 4 – Pleistocene lower terrace, 5 – dune, 6 – Holocene upper floodplain, 7 – Holocene lower floodplain, 8 – alluvial riverbed, 9 – Pleistocene palaeomeander, 10 – Holocene palaeomeander, 11 – Pleistocene dry fluvio-denudational valley, 12 – Holocene dry fluvio-denudational valley, 13 – Holocene alluvial or torrential fan, 14 – Pleistocene point bar, 15 – Holocene point bar, 16 – Pleistocene steep edge, 17 – Holocene steep edge, 18 – Pleistocene non-steep edge, 19 – Holocene non-steep edge, 20 – anthropogenic pit, 21 – war trenches, 22 – road embankment, 23 – anthropogenic edge, 24 – cross section line, 25 – geological profile, 26 – Roman archaeological bloomery site. B: Lithology: A – medium sands, B – fine sands, C – peaty silts with sands, D – peaty silts, E – clayey peats, F – peats; Fraction: 1 – coarse sand (-1Φ), 2 – medium sand ($1-2\Phi$), 3 – fine sand ($2-4\Phi$), 4 – coarse and medium silt ($4-6\Phi$), 5 – fine silt ($6-8\Phi$), 6 – organic matter; Grain size distribution parameters (Folk/Ward 1957): Mz – mean size, δI – standard deviation, Sk_k – skewness, K_G – kurtosis.

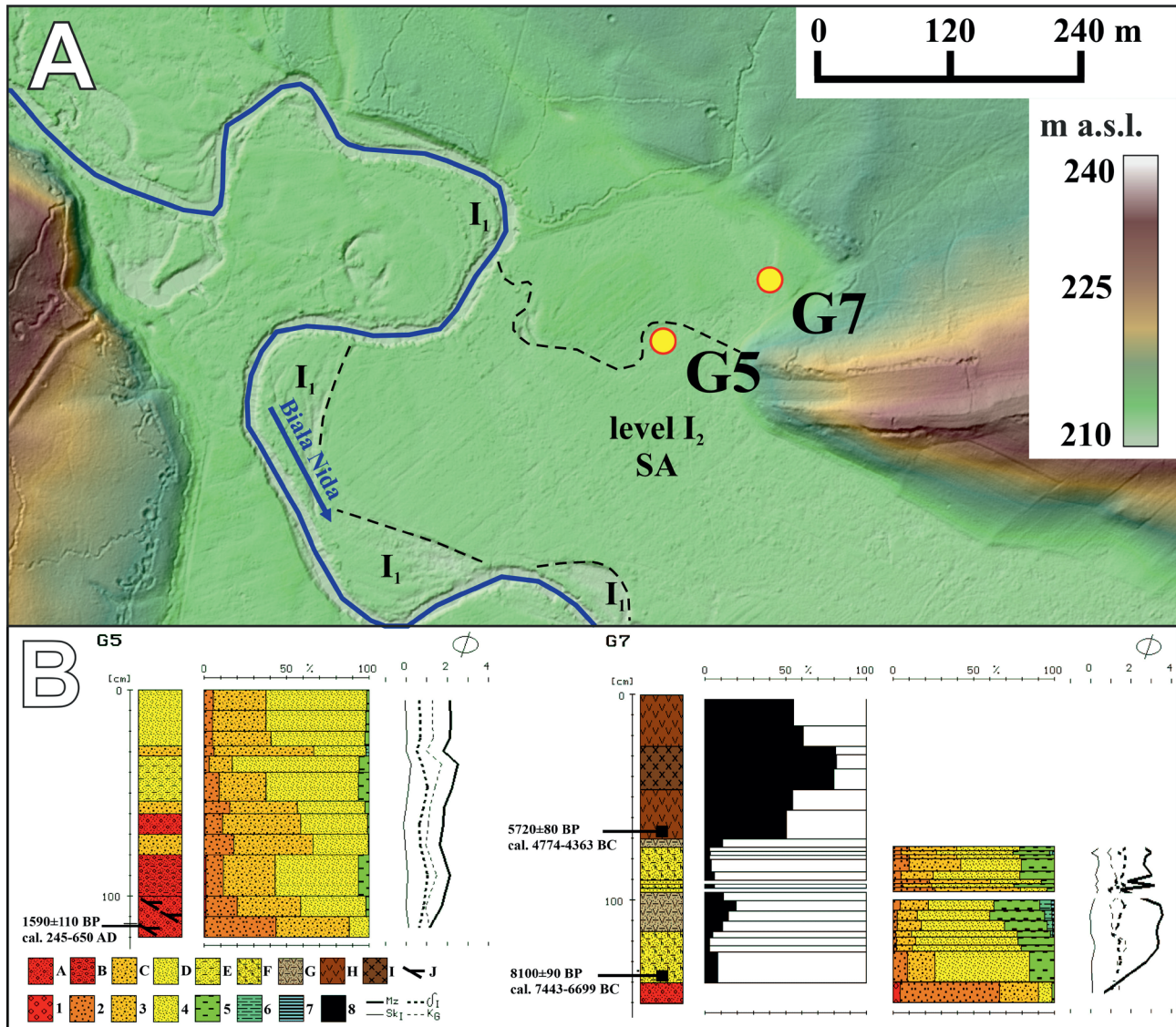


Fig. 6: DEM of Biała Nida River valley (A) (Geoportal.gov.pl.) and the Eoholocene (G7) and Roman (G5) cut and fill (Kalicki/Biesaga 2024), changed previously as the Subatlantic levels of floodplain (I_1 and I_2) (Hakenberg/Lindner 1973) and the detail study profiles (B). Lithology: A – sands with single gravels, B – silty sands with gravels, C – medium sands, D – fine sands, E – silty sands, F – organic silty sands, G – peaty silts with sand, H – clayey peats, I – peats, J – detritus; Fraction: 1 – gravel (below -1Φ), 2 – coarse sand ($-1-1\Phi$), 3 – medium sand ($1-2\Phi$), 4 – fine sand ($2-4\Phi$), 5 – coarse and medium silt ($4-6\Phi$), 6 – fine silt ($6-8\Phi$), 7 – clay (above 8Φ), 8 – content of organic matter; Grain size distribution parameters (Folk/Ward 1957): Mz – mean size, δ_1 – standard deviation, Sk₁ – skewness, K_g – kurtosis.

bank, most western part of the bottom (which is formed by the plain of the Mesoholocene anastomosing river) are slightly higher (0.5–0.7 m) than the cut-and-fill from the Roman period. The river had an anastomosing pattern, and the channel change and the creation of an oxbow lake occurred in the Roman Transitional Period around 1760 ± 110 BP cal. 28–545 AD. In the following centuries, sandy intercalations in organic palaeochannel fill were formed probably by single extreme flood events of the Late Ancient Little Ice Age. They are in the Atlantic palaeochan-

nel dated before 1140 ± 70 BP cal. 692–1027 AD and in the Roman ones dated after 1520 ± 70 BP cal. 418–649 AD⁶². In both profiles, single events rather than flood phases, are indicated by the type of the contact between layers in superposition.

Flood flows occurred only in the lower part of the floodplain in the Roman anastomosing system of palaeochannels. The magnitude of these events most likely in-

⁶² Biesaga 2023; Kalicki *et al.* 2024a; b.

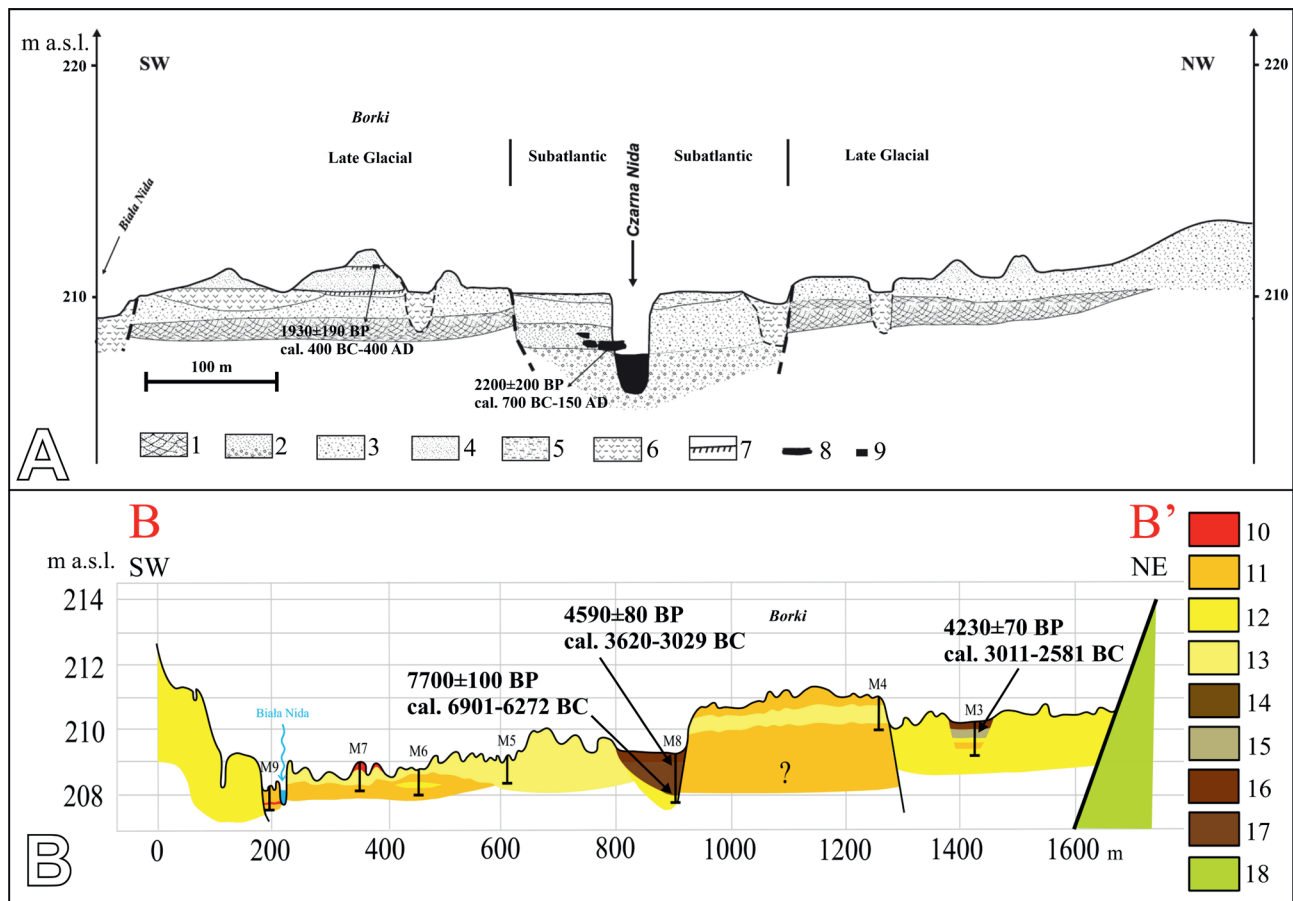


Fig. 7: Schematic section across floodplain interfluvial area between of the Czarna Nida (A) (Krupa 2013) and Biała Nida (B) (Maturlak 2024, changed and supplemented) (see Fig. 4). A: 1 – cross bedding sands, 2 – sands with gravels, 3 – middle and coarse sands, 4 – aeolian fine sands, 5 – sandy silts, 6 – peaty silts, 7 – buried soil, 8 – subfossil tree trunk, 9 – ^{14}C dating; B: 10 – sands with single gravels, 11 – medium sands, 12 – fine sands, 13 – silty sands, 14 – peaty silts, 15 – peaty silts with sands, 16 – clayey peats, 17 – peats, 18 – limestones.

creased in the 5th–7th century AD, and the 8th century, they could be also observed in the Atlantic anastomosing system of palaeochannels, which were situated at a higher elevation, and further away from the main/active channel of the Nida River. All in all, the record of these phenomena in the abandoned channels was determined not by the distance from the Nida riverbed (the distal and proximal parts of the floodplain) but by the relative height of the plain, and even tiny differences (0.5–0.7 m) could have prevented flood flows in the palaeochannels in these ‘elevated’ areas (Fig. 9).

5.4 Nida River: Mozgawa study area

Downstream from the Kopernia gorge, the Nida River valley runs between loess uplands (on the right bank) and areas of gypsum karst (on the left bank). The arrival of Neolithic agricultural communities in the Wodzisław Hump trig-

gered the erosion of soils (predominantly loess) in this area. Szwarczewski⁶³ suggests that the organic layers found near Kozubów in the Mozgawka valley (Fig. 10, 11) (the right tributary of the Nida that drains the Wodzisław Hump covered by loess) at a depth of 11–12 m were covered with washed-away loess during this period, but there is no evidence of this. However, in the bottom of the Nida River valley north of the Middle Neolithic settlement at Mozgawa located on its valley slope, a thick colluvium was formed, because the organic layers dated at 5720 ± 80 BP cal. 4774–4363 BC and at 4420 ± 100 BP cal. 3366–2887 BC lie under 8 m and 4.3 m thick sediments, respectively⁶⁴. At the mouth of the Mozgawka River, from 5890 ± 100 BP cal. 5004–4501 BC (depth 5.2 m), the lowest alluvial fan began its forming⁶⁵. The Neolithic

⁶³ Szwarczewski 2009; 2021.

⁶⁴ Szwarczewski 2009; 2021; Moskal-del Hoyo *et al.* 2018; Korczyńska-Cappenberg *et al.* 2023.

⁶⁵ Szwarczewski 2009.

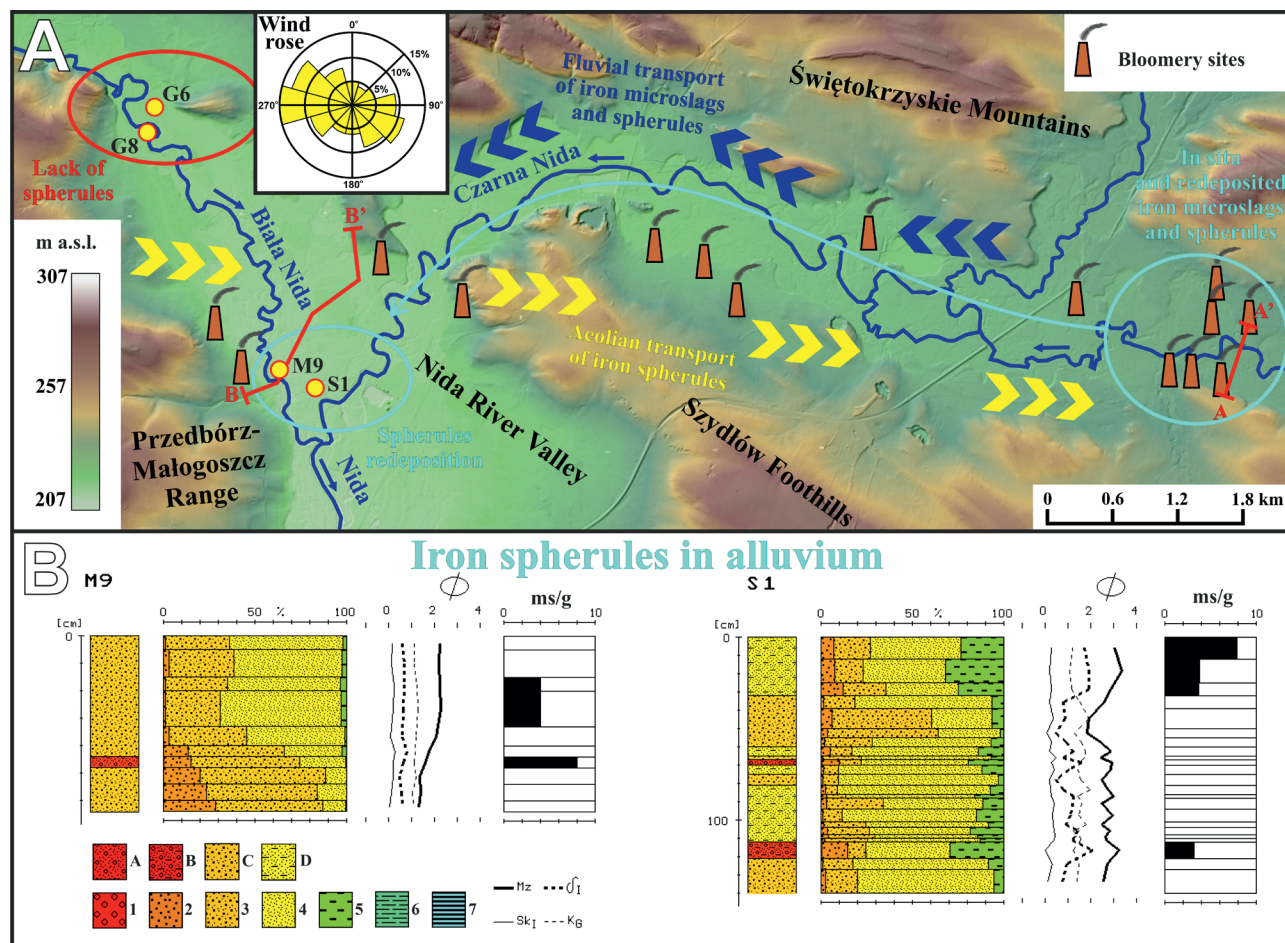


Fig. 8: DEM of Biała Nida and Czarna Nida confluence section (Geoportal.gov.pl.) with location of bloomery sites based on Archaeological Map of Poland (Przychodni 2006; Zabytek.pl.), selected profiles and cross-sections (see Fig. 4 and 7B) location with interpretation of the iron microspherules redeposition (Kalicki/Biesaga 2024; Przepióra *et al.* 2025, changed and supplemented) including wind frequency rose (Globalwindatlas.info) (A), M9 and S1 profiles with iron microspherules distribution (ms/g) (B); Lithology: A – sands with single gravels, B – silty sands with gravels, C – medium sands, D – silty sands; Fraction: 1 – gravel (below -1Φ), 2 – coarse sand ($-1-1\Phi$), 3 – medium sand ($1-2\Phi$), 4 – fine sand ($2-4\Phi$), 5 – coarse and medium silt ($4-6\Phi$), 6 – fine silt ($6-8\Phi$), 7 – clay (above 8Φ); Grain size distribution parameters (Folk/Ward 1957): Mz – mean size, δ_1 – standard deviation, Sk₁ – skewness, K₆ – kurtosis.

alluvial fan of the Mozgawka River was up to 3 m thick and horizontally reached approximately 800 m into the Nida River floodplain⁶⁶.

Near Kozubów in the Mozgawka River valley bottom from the Subboreal 3395±140 BP cal. 2129–1403 BC to 1420±60 BP cal. 538–774 AD⁶⁷ the organic layer was accumulated (Fig. 11). The lack of intensive vertical accretion of clastic sediments in the La Tène period, both on the floodplain and on the alluvial fan of this stream, is indicated by the layer of peaty silts that covered the sediments of the Neolithic alluvial fan at Mozgawa. In profile M3, the bottom of peaty silts was dated to 2240±90 BP cal. 539–44 BC, while closer to

the mouth of the Mozgawka River (Fig. 12 – M1 profile) on a thin layer of peaty silts dating 1950±100 BP cal. 197 BC–331 AD another clastic unit was deposited during the Roman Climate Optimum, when loess areas were densely populated and used for agriculture⁶⁸. It begins with silty sands, very poorly sorted, above which there is a thick layer (2 m) of sandy silts thickening coarsening upward, poorly sorted (Fig. 12). These sediments form the smallest of the three alluvial fans, the Roman one.

Geochemical analyzes of sediments from this period conducted by Szwarczewski⁶⁹ do not show an increase in heavy metals in the profile, although the author thinks otherwise

⁶⁶ Kalicki/Biesaga 2022; 2024.

⁶⁷ Szwarczewski 2021.

⁶⁸ Biesaga 2023; Kalicki *et al.* 2024a; b; Kalicki/Biesaga 2024.

⁶⁹ Szwarczewski 2009.

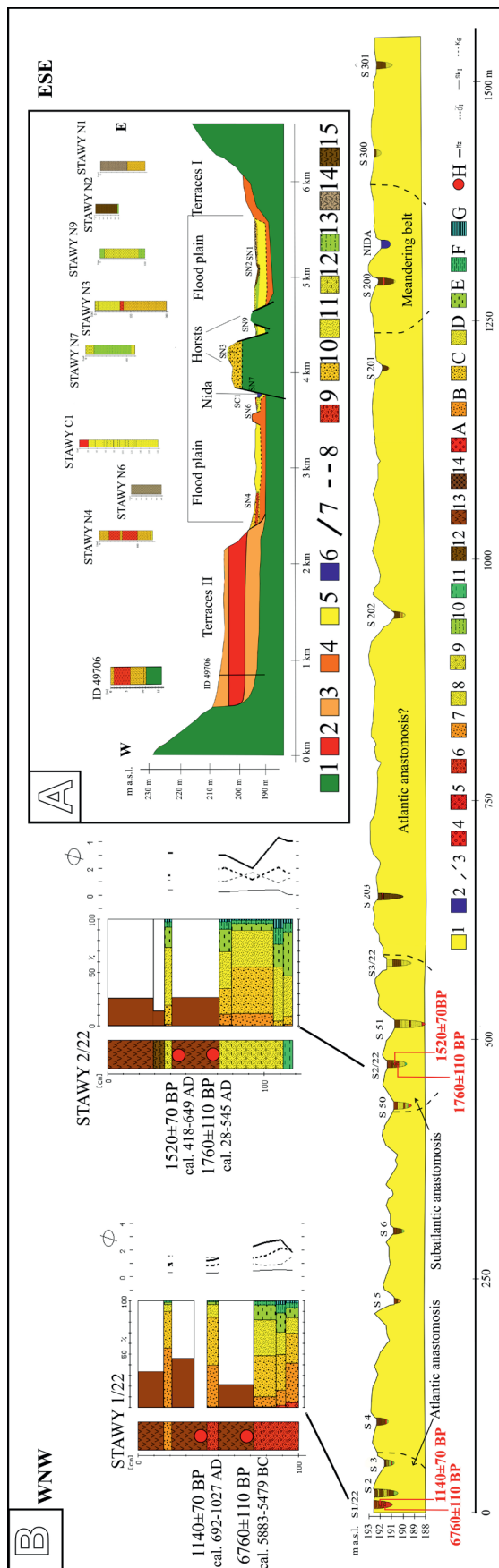


Fig. 9: Geological section across the Nida River valley near Stawy (A) and across western part of floodplain (B) (Kalicki/Biesaga 2024). A: 1 – gaizes, marls and limestones Cretaceous (Maastrichtian), 2 – sands with gravels (Holocene), 6 – Nida riverbed, 7 – fault, 8 – supposed limit of layers: Lithology: 9 – fluvial-periglacial sands of the braided river (Middle Polish glaciation), 4 – fluvial-periglacial sands of the braided river (Vistulian), 5 – various-grained sands (Holocene), 10 – peaty silts, 11 – silts, 12 – peaty silts, 13 – clayey-silty sands, 14 – sandy silts, 15 – sandy silts; B: 1 – sands, 2 – Nida riverbed, 3 – border of cut and fill, 4 – gravels, 5 – sands with single gravels, 6 – clay sands with single gravels, 7 – medium sands, 8 – fine sands, 9 – silty sands, 10 – sandy silts, 11 – silts, 12 – peaty silts, 13 – clayey peats, 14 – peats; Fraction: A – gravel (below -1ϕ), B – coarse sand ($-1-2\phi$), C – medium sand ($2-4\phi$), D – fine sand ($4-6\phi$), E – coarse and medium silt ($6-8\phi$), F – fine silt ($8-10\phi$), G – clay (above 8ϕ); H – ^{14}C dating; Grain size distribution parameters (Folk/Ward 1957): Mz – mean size, δ_1 – standard deviation, Sk_1 – skewness, K_g – kurtosis.

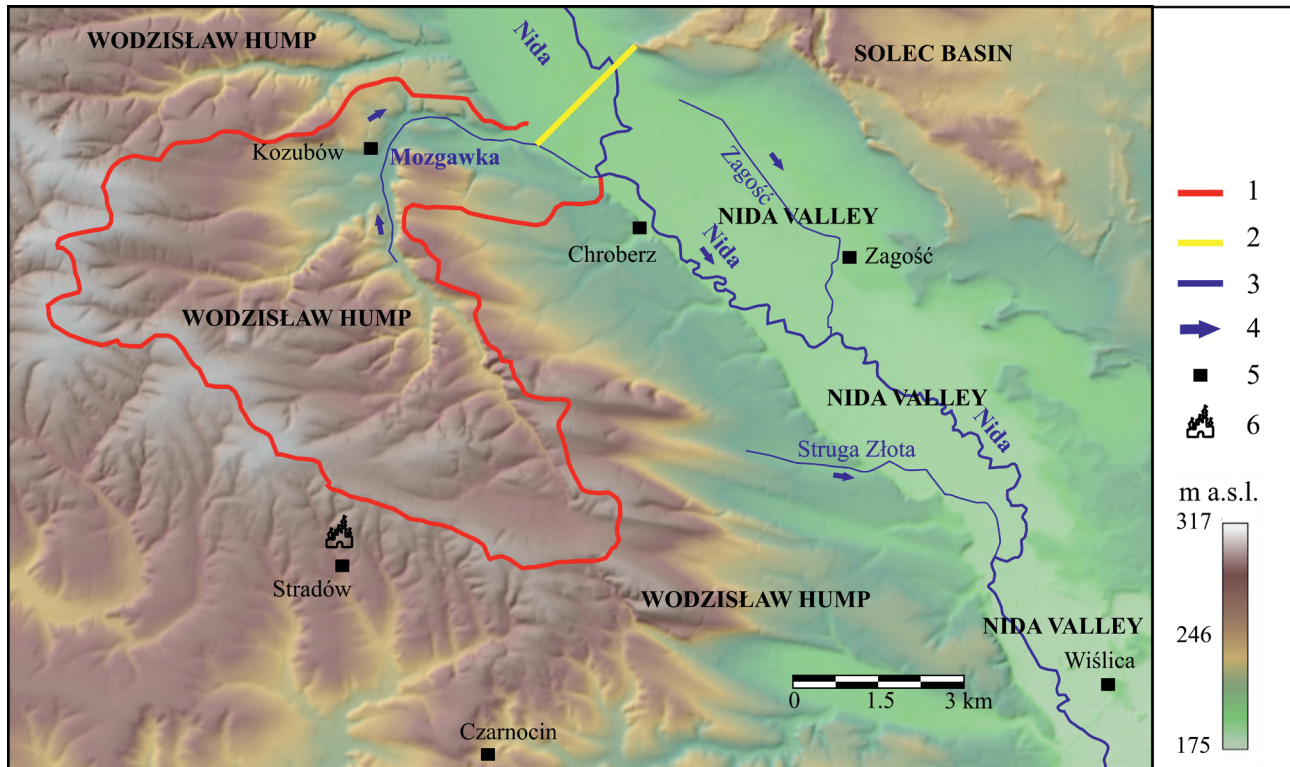


Fig. 10: DEM of Mozgawka River basin and Nida River valley (Geoportal.gov.pl.). 1 – limit of Mozgawka River basin, 2 – Mozgawka cross-section (see Fig. 12), 3 – rivers, 4 – direction of river flow, 5 – villages and towns, 6 – Early Medieval Stradów stronghold.

and associates small peaks of Pb, Zn at a depth of 3–1 m with metallurgical activity from the Bronze Age and the Roman period. Three alluvial fans in superposition, Neolithic, Roman and Medieval, whose sizes and thicknesses differ significantly, caused the Nida riverbed to shift to the east.

6 Discussion and conclusions

In the Holocene, many sections of the Nida River and its tributaries were multichannel rivers of ‘anabranching’ type⁷⁰ because anastomosis developed also in sandy, not fine sediments. Therefore, individual riverbeds, especially the main ones but also the secondary ones, could migrate laterally. This type of development was not the result of anthropopressure, as multi-channel systems already existed in the Holy Cross Mts. region in the Eoholocene⁷¹. In the Roman period, this type of river pattern occurred in the Czarna Nida valley near Ostrów, where it persisted until the Middle Ages⁷² (Fig. 4), and in the Nida valley near Stawy (Fig. 9).

At the turn of the Subboreal and the Subatlantic, the incision phase of the Czarna Nida River began and reached its maximum around 2500 BP⁷³. A short-term increase in fluvial activity, synchronous with events in the Czarna Konecka River valley⁷⁴, occurred during the 2.7–2.6 ka BP phase⁷⁵, although some datings go beyond its time frame. It is preceded by an increase in the rate of lateral migration of the Lubrzanka River (2810±50 BP cal. 970–760 BC)⁷⁶. Later, there was a change in the sedimentation type in the Bobrza River floodplain (2700±75 BP cal. 910–600 BC)⁷⁷ and changes in the Czarna Nida riverbed (2530±80 BP cal. 750–420 BC)⁷⁸.

The La Tène period was a phase of fluvial processes stabilization, although individual data indicate changes in the sedimentation type in the Belnianka River floodplain (Bieliny: 2460±90 BP cal. 789–399 BC)⁷⁹ or the lateral migration of the Czarna Nida riverbed (2200±200 BP cal. 700

⁷⁰ Wang/Li/Yin 2000; Kalicki/Szmańda 2008.

⁷¹ cf. Krupa 2013; 2015.

⁷² *Ibid.*

⁷³ *Ibid.*

⁷⁴ Kusztal 2022.

⁷⁵ Kalicki 2006.

⁷⁶ Kowalski 2002.

⁷⁷ Sołtysik 2002.

⁷⁸ Krupa 2013; 2015.

⁷⁹ Ludwikowska-Kędzia 2000.

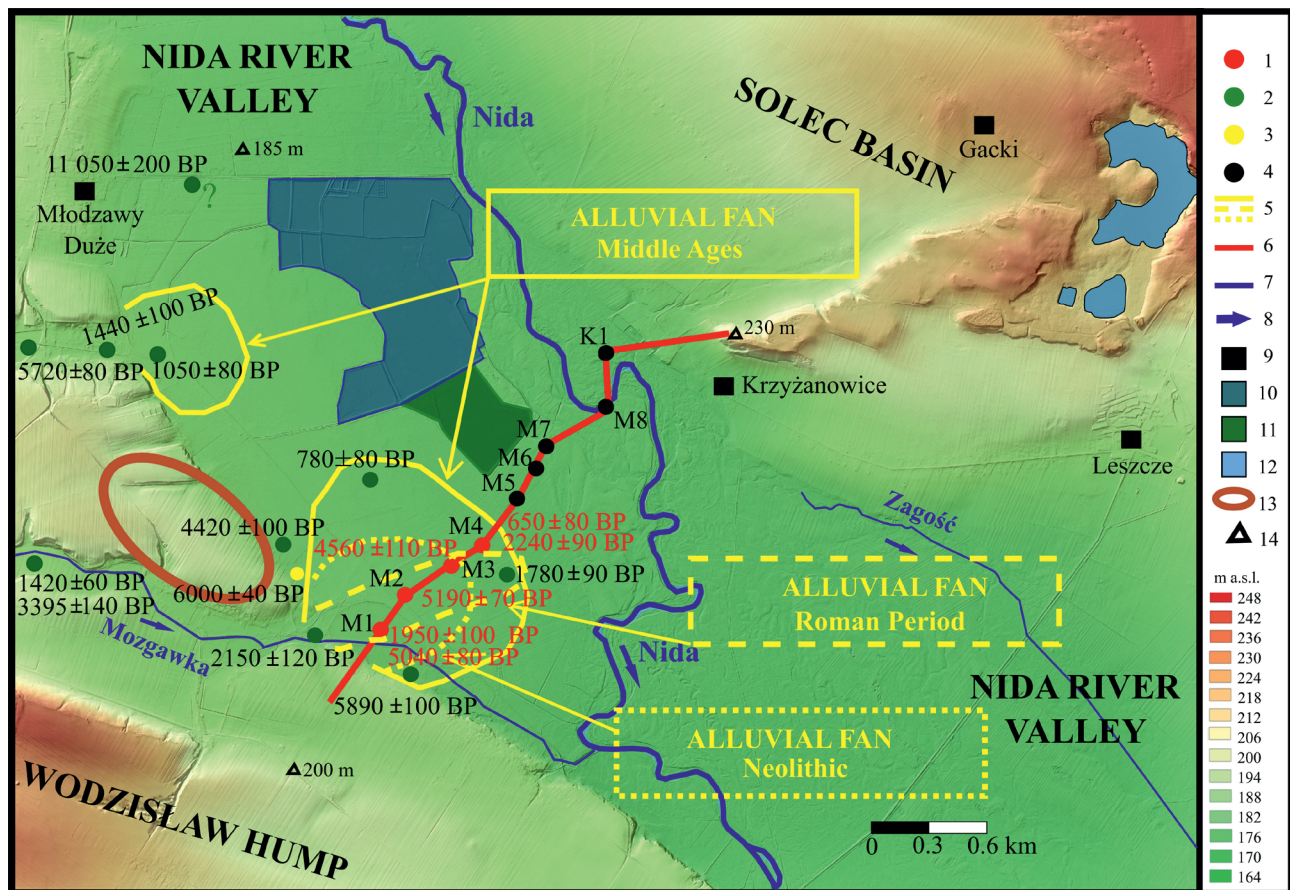


Fig. 11: DEM (Geoportal.gov.pl.) with alluvial fans of different age of Mozgawka River and torrential fan in the Nida River valley near Mozgawa (Biesaga 2023, Kalicki/Biesaga 2024; changed and supplemented). Radiocarbon dating: 1 – new, 2 – according to Szwarczewski (Szwarczewski 2009), 3 – according to Moskal del Hoyo *et al.* (Moskal del Hoyo *et al.* 2018); 4 – drilling and geological outcrops, 5 – alluvial fans, 6 – cross-section line (see Fig. 12), 7 – rivers, 8 – direction of rivers, 9 – towns and villages, 10 – ponds, 11 – remains of ponds, 12 – recreational reservoirs, 13 – archaeological site, 14 – height point (m a.s.l.).

BC–150 AD)⁸⁰. The lack of intensive accumulation of clastic sediments at that time, both on the floodplain of the Nida River and in the valley of its tributary, the Mozgawka River, and at its outlet, is indicated by peat accumulation at the valley bottom (Kozubów) and a layer of peaty silts (2240±90 BP cal. 539–44 BC), which covered sediments of the Neolithic alluvial fan at Mozgawa.

In the Roman period, there was an increase in the fluvial activity of Central European rivers, as indicated also by a series of catastrophic events in slope and valley geosystems of rivers of various orders in the upper Vistula River basin⁸¹, as well as in the valleys in the Holy Cross Mts. region, e. g. Czarna Konecka⁸². A concentration of this type of events also occurs in the Nida River catchment. During

the Roman Climate Optimum, the accumulation of peats in the bottom of the Mozgawka valley near Kozubów did not end despite the dense settlement of the Przeworsk culture community in the loess areas of the Wodzisław Hump; only a small alluvial fan was formed at the outlet of this valley after 1950±100 BP cal. 197 BC–331 AD. However, in the upper segment of the Nida River catchment, where the Nida Bloomery Region developed⁸³, we note higher activity of morphogenetic processes. Deforestation activated aeolian processes (1930±190 BP cal. 400 BC–400 AD) on the terrace in the interfluvium of Biała Nida and Czarna Nida Rivers⁸⁴, lateral erosion of the Lubrzanka River caused the accumulation of tree trunks in alluvium dating at 1800±50 BP cal. 125–380 AD, 1650±50 BP cal. 256–546 AD, 1510±50 BP cal. 340–

⁸⁰ Śnieżko 1978.

⁸¹ Kalicki 2006.

⁸² Kusztal 2022.

⁸³ Przychoński 2002; 2006.

⁸⁴ Śnieżko 1978.

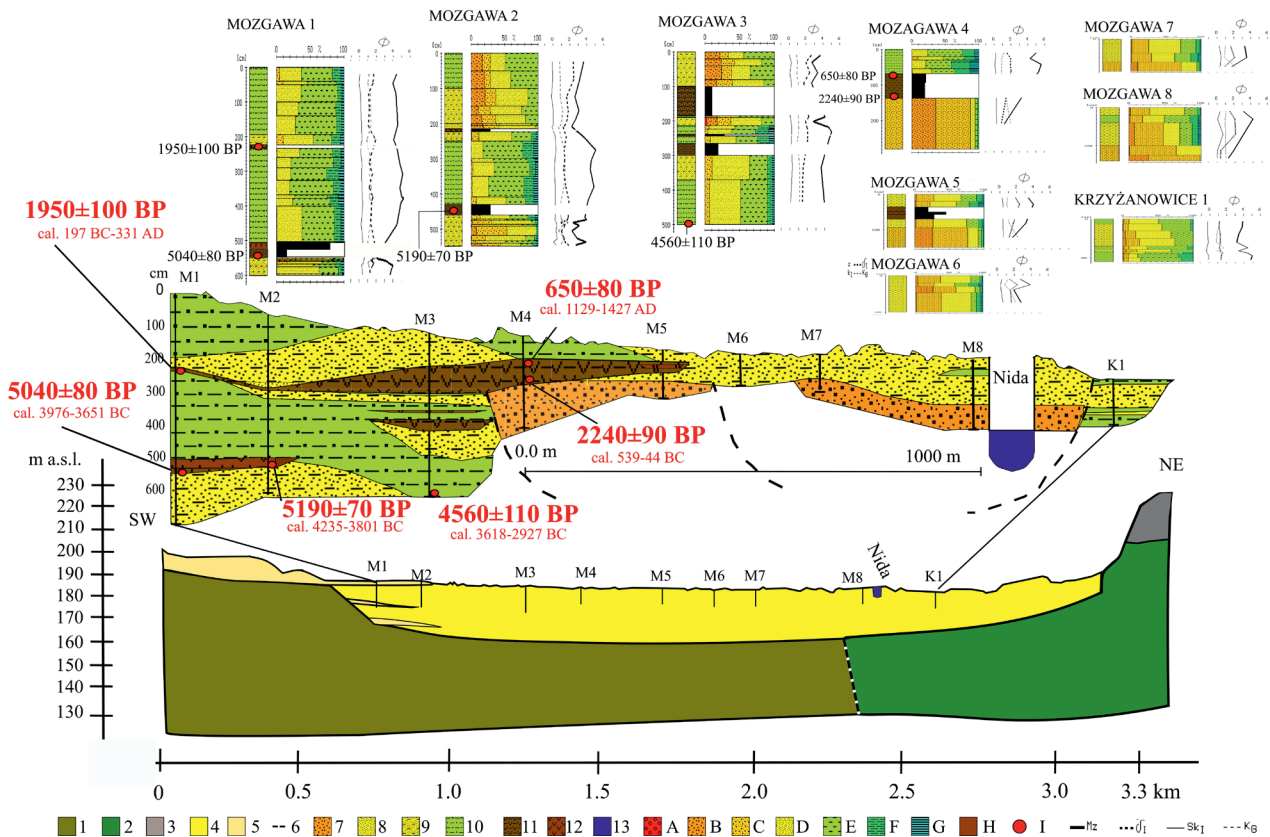


Fig. 12: Sections across Nida River valley at Mozgawa and alluvial fans of Mozgawka River (see Fig. 10, 11) (Kalicki/Biesaga 2024, changed). Lithology on cross-section: 1 – Cretaceous marls and gaizes (Lower Maastrichtian), 2 – Cretaceous gaizes, marls and limestones (Upper Campan), 3 – Miocene marls (Subliothaminous level), 4 – Pleistocene and Holocene sands, 5 – Pleistocene loess, 6 – fault; Lithology of profiles: 7 – medium sands, 8 – fine sands, 9 – silty sands, 10 – silts, 11 – peaty silts, 12 – clayey peats; 13 – Nida riverbed; Fraction: A – gravel (below -1Φ), B – coarse- sand ($-1-1 \Phi$), C – medium sand ($1-2 \Phi$), D – fine- sand ($2-4 \Phi$), E – coarse and medium silt ($4-6 \Phi$), F – fine silt ($6-8 \Phi$), G – clay (above 8Φ); H – ^{14}C dating; Grain size distribution parameters (Folk/Ward 1957): Mz – mean size, δ_1 – standard deviation, Sk_1 – skewness, K_6 – kurtosis.

550⁸⁵, while the intensive levee accumulation of the Belnianska River led to peat bog development in backswamps at Napęków 2100±90 BP cal. 376 BC-110 AD and 2030±120 BP cal. 361 BC-235 AD and at Czaplów 1660±110 BP cal. 133–637 AD⁸⁶.

Fluvial activity continued in this part of the Nida River catchment area also in the Roman Transitional Period, when the areas around the anastomosing riverbeds of the Nida River near Stawy (1760±110 BP cal. 28–545 AD)⁸⁷ and of the Czarna Nida River near Ostrów (1740±40 BP cal. 241–407 AD)⁸⁸ were abandoned; similarly, in the Late Antique Little Ice Age, when new incisions and fills were formed by the Biała Nida (1590±110 BP cal. 245–650 AD)(MKL 6538)(Fig. 5, 6) and Czarna Nida Rivers (1415±70 BP cal. 440–775 AD)⁸⁹.

This intensification of fluvial activity is also manifested by the addition of sandy layers into the anastomosis palaeochannel fill at Stawy, dating from the period after 1520±70 BP cal. 418–649 AD and before 1140±70 BP cal. 692–1027 AD. However, this could have been caused by one-time events, as indicated by the type of contact between layers in superposition. In the Czarna Nida River valley, an increase in the accumulation rate of overbank sediments was recorded in the palaeomeander fill (Kuby Młyny 4) after 1530±70 BP cal. 414–649 AD, as well as in the levee zone (Zbrza: soil fossilization at 1230±70 BP cal. 660–975 AD)⁹⁰. In the Belnianska River valley, overbank sediments interrupted the peat accumulation in the palaeochannel around 1300±150 BP cal. 433–1025 AD⁹¹. In the Lubrzanka River valley after 1360±60 BP cal. 574–819 AD, another dammed lake was created⁹².

⁸⁵ Kowalski/Swałdek 1991; Kowalski 2002.

⁸⁶ Ludwikowska-Kędzia 2000.

⁸⁷ Biesaga 2023.

⁸⁸ Krupa 2013; 2015.

⁸⁹ *Ibid.*

⁹⁰ *Ibid.*

⁹¹ Ludwikowska-Kędzia 2000.

⁹² Kowalski 2002.

In the Late Antique Little Ice Age, clastic layer began to accumulate on an organic layer after 1440±100 BP cal. 410–821 AD (depth 3.8 m) on the dry valley bottom at Mozgawa. Later (1050±80 BP cal. 773–1169 AD), the deposition of the torrential fan occurred at its outlet (depth 2.6 m)⁹³. Around the same time, approximately 1420±60 BP cal. 538–774 AD, there was a change in the sedimentation type – organic to clastic in the the Mozgawka River valley bottom (Kozubów)⁹⁴. However, this aggradation did not reach the mouth of the valley, because the Roman alluvial fan of the Mozgawka River is much smaller than the Neolithic and Medieval ones. Changes in the sedimentation type in both cases were probably caused by a greater frequency of flash floods and not by human activity, because at that time the population density and land use of the Wodzisław Hump were lower. This may also be related to the fact that in the lower Nidzica valley the mineral-organic overbank series continued to sediment until about 1000 years BP and only locally, e. g. near Cło, it changed into the mineral overbank series after 1950±70 BP cal. 103 BC–240 AD⁹⁵.

Geochemical changes in sediments (macro-, microslags and iron spherules) are observed only in the Nida bloomery center⁹⁶. In the Nida River valley near Mozgawa, there are no such changes and there is no increase in heavy metals in the sediments, although Szwarczewski⁹⁷ thinks otherwise and associates small peaks of Pb, Zn at a depth of 3–1 m with metallurgical activity from the Bronze and Roman periods. However, it must be clearly noted that the scale of the Prehistorical metallurgy in the Nida River catchment was small, as documented by the very scant number of slags and spherules in the alluvium, even in the vicinity of the production sites. Therefore, metallurgical activities could not have had a significant impact on geochemical changes in such faraway areas as Mozgawa.

The different sections of the Nida River and its tributaries were used for different purposes: on the one hand, the Nida bloomery center developed here, and on the other hand, agriculture dominated in the loess and karst areas.

The research results indicate regional differences of human impact in the Nida River catchment area during the Roman period. Two separate regions can be distinguished:

1. ‘industrial’ – the Nida bloomery center in the lower courses and interfluvial area of the Biała Nida and Czarna Nida rivers, where relatively intense environmental transformations resulted in the intensification

of fluvial processes, lateral migration of riverbeds (subfossil trees in alluvium) and the formation of alluvial cut-and-fills, geochemical changes in sediments (macro-, microslags and iron spherules), and deforestation related to the production of charcoal used in the bloomery process triggered aeolian processes (buried soil in dunes)

2. ‘agricultural’ – the Nida River valley downstream of the gorge at Kopernia, where the decline in the intensity of use of the loess areas of the Wodzisław Hump after the Roman Climatic Optimum can only be evidenced by small alluvial fans of the Nida River tributaries, much smaller than the Neolithic and Medieval ones (Fig. 11) and the lack of changes in the sedimentation type from organic to clastic in the valley bottoms of rivers of various orders (e. g. Mozgawka, Nidzica) draining the Wodzisław Hump.

Humid climate in the 3rd century until the mid-4th century had a positive impact on settlement and agricultural conditions in the upland areas of western Lesser Poland. The number of permanent streams and the efficiency of springs increased which facilitated agricultural land use and the settlement of watershed areas. However, migration movements and a decline in population density resulted in decreased anthropopressure in the ‘agricultural’ part of the Nida River basin after the Roman Climatic Optimum, as evidenced by the relatively small Mozgawka River alluvial fan and the lack of torrential fans and a colluvium series. However, the development of the Nida bloomery center in the lower reaches and the interfluvial area of the Biała Nida and Czarna Nida, relatively intense transformations of the environment of the “industrial” part of the basin resulted in the intensification of fluvial processes, lateral migration of riverbeds (subfossil trees in alluvium) and the formation of new series (cut and fill) of alluvium with remains of metallurgy and iron processing (macro-, microslags and iron spherules)(Fig. 4), and deforestation related to the production of charcoal used in the smelting process triggered aeolian processes and the formation of fossil soils.

7 Final remarks

The presented case studies from the Nida basin document a very clear, although not determining, multidirectional impact of climate changes in the Roman period on the settlement and the activity of the Przeworsk culture community.

In addition to climatic fluctuations related to pan-European trends, local factors also played a very important

⁹³ Szwarczewski 2009; 2021.

⁹⁴ *Ibid.*

⁹⁵ Michno 2004.

⁹⁶ Przepióra *et al.* 2024.

⁹⁷ Szwarczewski 2009.

role, which should be recognized through detailed interdisciplinary research and considered in paleogeographic and geoarchaeological interpretations.

The above discussed evidence illustrates that the ecumene of the Przeworsk culture community in southern Poland was not homogeneous. It consisted of non-agricultural production ‘centres’ – i. e. metallurgical centres in the Holy Cross Mts. region, and pottery production centres in the Vistula River valley, east of Kraków, which were relatively densely populated and characterized by significant human impact on the environment. This heterogeneity was reflected in the activation of fluvial processes in the river valleys and aeolian processes in deforested sandy terrains. Between these centres, occupying relatively small areas, there were vast areas used for agriculture. However, they must have had the character of a ‘park landscape’ and be a mosaic of arable land, pastures, groves, and forest areas, and therefore the intensity of erosion and accumulation processes on loess was low.

The heterogeneity of the ecumene could cause not only regional differences in anthropopressure recorded in forms and sediments but also migration movements related not only to large movements of the Przeworsk culture community to the south but also to regional and local migrations to both production centres from areas less favourable to agriculture (equivalent to modern village → city migrations), which may illustrate the decline in population density of some agricultural areas, e. g. the Nida River valley and its left-bank, karst part of the catchment after the Roman Climatic Optimum (after 150 AD).

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