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Iron, Humans and Landscape – Insights from a Micro-Region in the Widawa Catchment Area, Silesia

The Widawa catchment area is located in Northeastern Silesia, Poland, and belonged to the southwestern distribution area of the Przeworsk culture from the younger pre-Roman period until the younger Roman period. It is estimated that iron smelting was introduced to this area with the emergence of the Przeworsk culture, circa the 2nd century BCE. Certain cultural and environmental requirements must have been met in order for this technology to spread to this area. Within the framework of interdisciplinary research, the archaeological context of an archaeological site as well as the natural archives were investigated to explore the preconditions and to describe the beginning of early iron smelting in this region.

Bog iron ore; early iron smelting; formation; human-environmental interactions; landscape archaeology; pre-Roman Iron Age; Przeworsk culture.

1 Introduction

The implementation of interdisciplinary research between the sciences and the humanities in the context of a landscape archaeological project results in challenges for the researchers involved as well in mutual benefits. Combining the methodological and scientific strengths of prehistoric archaeology and physical geography is the key to the success of the implementation or adaptation of an approach integrating those disciplines. But the exciting question is how to build a bridge that can enable an active exchange and fruitful collaboration and how to keep it stable.

Our interdisciplinary approach examines the spread of iron smelting technologies, which started in the territory of the advanced civilization of the Hittite in the 2nd millennium BCE and arrived in the cultures of the northern Central European lowlands by at least the 5th century BCE.[1] The main evidence testifying to the rise of this new epoch in the Near East consists of written sources preserved on cuneiform clay tables, while

This study was supported by the Excellence Cluster Topoi and the collaboration of our Topoi Research Group A-5 Iron as a Raw Material. Our fieldwork would not have been possible without the help and support we received in the study area. Therefore, we would like to thank our cooperation partners from the Archaeological Institute of the University of Wrocław, Prof. Dr. Artur Błażejewski, and the Museum of Archaeology Wrocław, Dr. Paweł Madera. We would also like to thank Dr. Philipp Hoelzmann, M.A. Markolf Brumlich, Dipl.-Geogr. Johanna Seidel and the students of the 2013 and 2014 field campaigns of the Institute of Geographical Sciences and the Institute of Prehistoric Archaeology of the Freie Universität Berlin. Thanks also to Elke Heyde from the Institute of Geological Sciences of the Freie Universität Berlin for support in the geochemical laboratory. We would like to express our special thanks to the Department of Cultural Heritage Opole, Poland. Finally we also would like to address our special thanks to the reviewers of this paper for their helpful comments and advice.

1 Pleiner 2000, 8–9; Yalçin 2000, 309.

iron objects dating to this period are rare.[2] Early evidence for iron smelting in Central Europe has been documented for the La Tène culture in the region of the Black Forest (5th century BCE). Archaeological evidence of smelting slag deposits and furnaces from Brandenburg (Germany)[3] and Central Jutland (Denmark)[4] also date to this period. Thus the iron smelting technology was distributed within the region north of the Alps during the early La Tène period, from the 5th century BCE onwards. Compiling a spatial database on the "spread of iron smelting in Europe is currently quite difficult, as the state of research varies greatly from region to region".[5] It is widely accepted, however, that the introduction of iron is related to complex processes involving socio-economic and cultural aspects as well as the natural environment. For instance, within a short time of the discovery of this new metal, which is attributed to experienced copper smelters,[6] iron had become a very precious good, and its ownership was restricted to the religious or political elite of the Hittite culture.[7] Furthermore, the exploitation of natural resources, above all iron ores and wood for charcoal production, could trigger changes in the natural system.[8] Later on, the availability of iron tools (sickles, etc.) allows the development of new land use strategies, which also have the potential to affect the landscape budget.[9] In summary, the topic of iron as a new raw material comprises a multi-faceted research field, one that is predestined for interdisciplinary research.[10]

Following up on investigations of Przeworsk settlement sites in the southern forelands of the Harz Mountains (Fig. 1A),[11] this paper presents an interdisciplinary approach applied in a case study region in Silesia, southwestern Poland. According to the Archaeological Record of Poland (AZP),[12] numerous prehistoric iron slag sites have been detected in the floodplains of the Oder River and its tributaries, which were inhabited by the Przeworsk culture during the Early Iron Age. A distinct cluster of such sites lies to the north of the modern town of Namysłów in the catchment area of the Widawa River (Fig. 1B). Three neighboring archaeological sites at Pielgrzymowice, situated 10 km west of Namysłów, were chosen as a microregion in consultation with Artur Błażejewski from the Archaeological Institute of the University of Wrocław and Paweł Madera from the Wrocław Museum of Archaeology (Fig. 1B).[13]

By providing the results from archaeological surveys, sedimentological data and an analysis of the resource potential of the hinterland of these sites, this paper aims to present

2 Lychatz 2012, 13; Pleiner 1996, 285; Pleiner 2000, 8–9; Yalçin 2000, 309.
3 Brumlich, Meyer, and Lychatz 2012.
4 Matthissen 2011, 119; Olesen 2010.
5 A short overview of the state of the art will be given in the forthcoming publication Wiebke Bebermeier, Markolf Brumlich, Violetta Cordani, Salvatore de Vincenzo, Heidemarie Eilbracht, Angelika Hofmann, Jörg Klinger, Daniel Knitter, Enrico Lehnhardt, Michael Meyer, Stephan G. Schmid, Brigitta Schütt, Michael Thelemann, Burkart Ullrich, Matthias Wemhoff (accepted): "The coming of iron in a comparative perspective. Topoi Research Group A-5: Iron as a raw material", in *eTopoi. Journal for Ancient Studies*.
6 Lychatz 2012, 13; Pleiner 1996, 285; Pleiner 2000, 11–13.
7 Pleiner 1996, 284–285; Pleiner 2000, 7–8.
8 Killick and Fenn 2012; Mighall et al. 2006, 425–426.
9 Kalis, Merkt, and Wunderlich 2003.
10 A short overview of the state of the art will be given in the forthcoming publication Wiebke Bebermeier, Markolf Brumlich, Violetta Cordani, Salvatore de Vincenzo, Heidemarie Eilbracht, Angelika Hofmann, Jörg Klinger, Daniel Knitter, Enrico Lehnhardt, Michael Meyer, Stephan G. Schmid, Brigitta Schütt, Michael Thelemann, Burkart Ullrich, Matthias Wemhoff (accepted): "The coming of iron in a comparative perspective. Topoi Research Group A-5: Iron as a raw material", in *eTopoi. Journal for Ancient Studies*.
11 Meyer 2013, 290–292; Meyer and Rauchfuß 2014b; Meyer and Rauchfuß 2014a; Kaufmann, Ullrich, and Hoelzmann 2015; Hoelzmann et al. 2012; Ullrich et al. 2011.
12 AZP, since 1978: Archeologiczne Zdjęcie Polski, extensive archaeological survey of the entire country, begun 1978.
13 Barsch and Richter 1983, 7–8; Popova et al. 2013, 298.

one of the research group's case study sites and in that context to show how an interdisciplinary approach can be used to investigate early iron smelting.

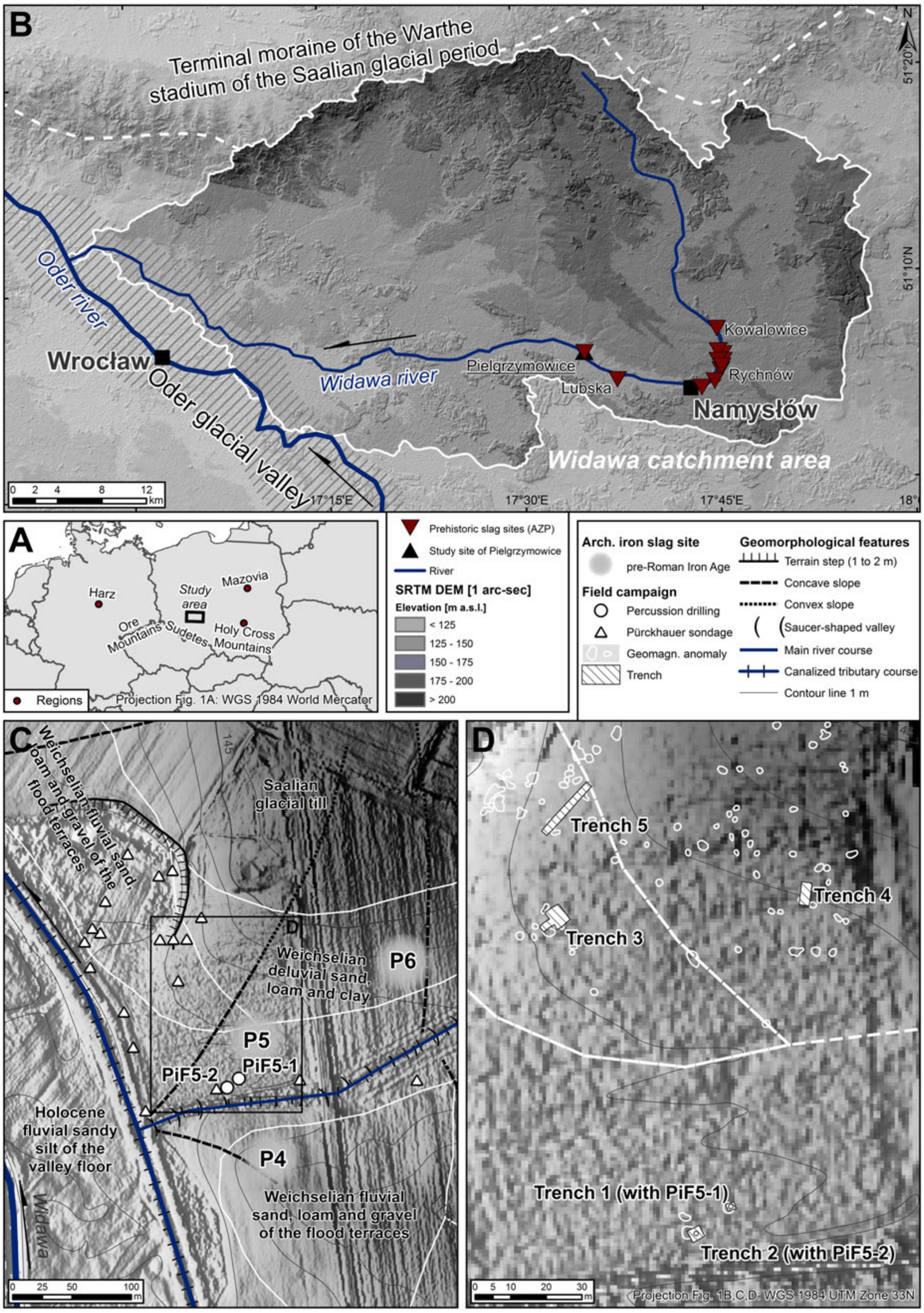

Fig. 1 | A: Overview map; B: Widawa catchment area; C: Study site Pielgrzymowice with the sub-sites P4–P6; D: Excavation trenches and geomagnetic results at Pielgrzymowice 5. – Sources: A: Natural Earth Data 2014; B: Digital elevation model and Widawa catchment area derivate SRTM-data: Reuter, Nelson, and Jarvis 2007; rivers: Natural Earth Data 2014; terminal moraine, Oder glacial valley: Liedtke 1981; settlement data: AZP, since 1978; C and D: Digital elevation model and hillshade: CODGiK 2013; settlement data: AZP, since 1978; geological data: Bartczak 1997, map sheet 0766, 1:50.000.

2 Cultural and technical setting

2.1 A brief history of the Przeworsk culture and iron smelting in Silesia

The Przeworsk culture (c. late 3rd century BCE to 5th century CE) is a European Iron Age culture that gets its name from an early Roman period cemetery in south-eastern Poland.[14] The transformation from the older Pomeranian culture to the Przeworsk culture in the 2nd century BCE took place in Silesia during a period of strong cultural and economic expansion of the La Tène culture (the Celts). There were La Tène culture settlements in Upper and Lower Silesia as well as Lesser Poland, in the area around Kraków.[15] In the younger pre-Roman period, people of the Przeworsk culture settled in Central and Lower Silesia as well as parts of Upper Silesia, Greater Poland, Kuyavia, Mazovia, Podlachia, Polesia and Lesser Poland.[16] The people of the Przeworsk culture lived in small settlements featuring predominantly pit houses and in proximity to small streams and rivers. Evidence of the spatial separation of dwellings and workshops has been detected in some of the settlement areas.[17]

Even in its early period, the Przeworsk culture has been associated with a wide spectrum of iron artefacts, such as iron weapons, fibulae, tools and small items in La Tène style, which were mostly imitations or imports. Their appearance marks the first occurrence of iron smelting in the area of present day Poland. This is interpreted as the result of a technology transfer from the La Tène culture.[18] Characteristic for the Przeworsk culture is also the introduced weapon burial rite in the cremation pit graves.[19] Influences from and on the Jastorf culture can also be detected[20]: several groups of the Przeworsk culture migrated westwards during the younger pre-Roman period to regions that were inhabited by groups of the La Tène culture or were associated with the so called "contact zone"[21] between the Jastorf culture and the La Tène culture.[22]

During the Roman period, the largest known iron smelting centers of *Barbaricum* developed within the settlement area of the Przeworsk culture. Mazovia, in mid north-eastern Poland was the first of these two large-scale production regions.[23] The second, slightly younger center, with a much bigger production outcome on a larger scale, developed in the Holy Cross Mountains (Fig. 1A).[24]

2.2 Technical steps and natural resources for early iron smelting

The production of malleable iron through iron smelting required the application of complex knowledge relating to different technical steps. These include the construction of the furnace, production of charcoal as fuel, the selection, mining, cleaning, preprocessing, e.g. roasting, of iron ore and the manufacture of bellows and tuyeres to stimulate com-

14 Dąbrowska 2003, 541.
15 Cf. Woźniak 1970; Bochnak 2011.
16 Andrzejowski 2010, 3.
17 Juściński 2003, 305–310; Michałowski 2003.
18 Dąbrowska 2003, 543.
19 For burial rites of the Przeworsk culture from pre-Roman period to the Migration Period in Silesia cf. Błażejewski 1998.
20 Cf. Woźniak 2013.
21 Cf. Brandt 2001, 26–27; 154–155.
22 Meyer 2008, 150–193.
23 Woyda 1977; Woyda 2002.
24 Pleiner 2000, 46; Orzechowski and Suliga 2007; Orzechowski 2013, 187–211.

bustion.[25] The right mixture of charcoal and iron ore, a reducing atmosphere and temperatures of at least 1150 °C are basic preconditions in the furnace for a successful smelting process.[26] Several natural resources were therefore needed for early iron smelting: clay for the construction of bloomery furnaces, wood for charcoal supplies, water for use in preprocessing ores and post-processing of the bloom and, above all, iron ores, preferably with high iron contents.[27] Clay for the construction of bloomery furnaces[28] was ubiquitously available in most areas of Central Europe in the form of (reworked) loess loam, fluvial loam or glacial loam deposits.[29] For greater stability of the constructed furnace, wheat chaff was added to temper the clay.[30] In addition, certain quantities of wood were needed for the charcoal used in the iron smelting process. According to Pleiner, a field experiment with a bloomery furnace determined that ratio, by weight, of charcoal to crude iron produced is 18:1.[31] Since the quantities of wood required were considerably greater than the required quantities of iron ore, one would expect bloomery sites would often be located in more densely forested areas, which corresponds with the situation described by Küster for Central Europe during this period.[32] For the small-scale attempts during the beginnings of iron smelting, large amounts of charcoal were probably not needed, and local forested areas would have been more than sufficient.[33] Due to the high firing temperatures of beeches[34] and the pine oil contents of pines, these tree species were preferred for use in iron smelting.[35]

In prehistory, early metallurgists exploited and processed predominantly ores containing no less than 55–60 mass% of iron.[36] Thus, early iron smelting entailed demands on the quality of the ore used, as well as its quantity. Since the occurrence of iron gangue minerals in Central Europe is limited to rock formations in the high and low mountain ranges, like the Alps, the Harz, the Holy Cross Mountains, the Ore Mountains and the Sudetes (Fig. 1A), and since exploitation of those minerals requires specific technologies, the utilisation of bog iron ore, as a resource for the iron production, was very widely spread.[37] Bog iron ores are iron-rich, hardened, compact, terrestrial accumulations in the form of concretions or layers formed gradually in hydromorphic, structureless, mostly fine and medium sandy, but also silty fluvial soils.[38] The iron was first mobilized from deeper horizons or upper catchment areas in Pleistocene landscapes (often glacial till plateaus) under reduced conditions by slightly acidified capillary water or rainwater.[39] The iron was then transported with the groundwater flux in the form of dissolved Fe^{2+} ions.[40] Under oxic conditions iron precipitated in the zone of groundwater oscillation.[41] Under stable ferrous groundwater fluxes with a significant amount of dissolved Fe^{2+} in the groundwater, iron-rich bog iron ore formations were able to develop within centuries

25 Pleiner 2000, 88–136.
26 Pleiner 2000, 132–136.
27 Koschke 2002, 7.
28 Koschke 2002, 7; Brumlich 2006, 79.
29 Haase et al. 2007, 1302–1304; Liedtke 1981.
30 Brumlich 2005, 46–47.
31 Pleiner 2000, 126.
32 Küster 1999, 125.
33 Pleiner 2000, 126–127.
34 Küster 1999, 126.
35 Brumlich 2005, 46–47.
36 Pleiner 2000, 87.
37 Küster 1999, 125; Kleemann 1988, 20.
38 Landuydt 1990, 289; Oberrascher 1939, 40; Banning 2008, 641.
39 Banning 2008, 641; Kaczorek, Brümmer, and Sommer 2005, 1111–1112; Shotyk 1988, 145; Landuydt 1990, 289–290.
40 Banning 2008, 641.
41 Banning 2008, 641; Graupner 1982, 165; Oberrascher 1939, 37.

or millennia.[42] Considerable manganese and phosphorus content are also characteristic for bog iron ores. The presence of manganese favors the slag formation in case of lower iron contents,[43] whereas phosphorus results in an embrittlement of the bloom.[44] Grain size, topography and geochemical conditions in the subsurface, such as oxic conditions or the occurrence of metal reducing bacteria, also play an important role in the formation of bog iron ores.[45] The areas favorable for the distribution of bog iron ore formations are the sandy margins of bogs in flat glaciofluvially shaped river valleys and lowlands with a shallow groundwater table.[46]

3 Study area

The study area is situated in the catchment area of the Widawa River, a tributary of the Oder River in the southeastern part of Lower Silesia (Fig. 1A). To the north the study area is bound by the Trzebnica Ridge (Wał Trzebnicki), which represents the terminal moraine of the Warthe stadial of the Saalian glacial period (Fig. 1B).[47] The Oder glacial valley forms the southern boundary. The source of the Widawa is a spring in the north of the catchment area close to the Trzebnica Ridge. From there the river runs in southern direction until it turns to the west at the town of Namysłów (Fig. 1B). The courses of the Widawa and its tributaries were canalized and redirected during the 19th and 20th centuries as part of melioration measures.[48] In 2001 the Michalice reservoir was dammed, leading to an impoundment of the Widawa course north of Namysłów (Fig. 1B).[49]

Two adjacent archaeological sites, Pielgrzymowice 5 and 6, which date to the younger pre-Roman period according to the AZP, are situated to the south of the village Pielgrzymowice. The archaeological record for these sites includes iron slag finds. Additionally, the adjacent site Pielgrzymowice 4 (with no slag finds according to the AZP) was also included into our study (Fig. 1C).

3.1 Geology and pedology

Geologically the study area belongs to the Old Drift landscape of the Saalian glacial period and is covered by Quaternary deposits reaching a thickness of up to 90 m.[50] Glacial till deposits of the Elsterian glaciation, which are located at several sites along the Widawa floodplain in the north, east and south of the study area, represent the oldest surface deposits in the study area and reach a thickness of up to 30 m in the subsurface of the plateaus in the northwest of the study area (Fig. 2).[51] The orientation of the sand and gravel eskers

42 Banning 2008, 641; Kaczorek, Brümmer, and Sommer 2005, 1111–1112; Shotyk 1988, 145; Landuydt 1990, 289–290.
43 Graupner 1982, 85.
44 Sperling 2003, 17.
45 Sperling 2003, 17; Sitschick et al. 2005, 120; Banning 2008, 642; Kaczorek, Brümmer, and Sommer 2005, 1110; Shotyk 1988, 145.
46 Wünsche 2007, 15; Oberrascher 1939, 40; Banning 2008, 641; Kaczorek and Sommer 2003, 394; Küster 1999, 125.
47 Rössner 1998, 14.
48 Reconstruction of canalization und redirection of river courses based on analysis of the following topographic maps: Topographical map 1899; Topographical map 1912; Topographical map 1938; Topographical map 1992.
49 Wiatkowski, Rosik-Dulewska, and Tyminski 2010, 1506.
50 Bartczak 1997, geological detailed map, map sheet 0766; Cincio 1997, geological detailed map, map sheet 0767.
51 Bartczak 1997, geological detailed map, map sheet 0766; Cincio 1997, geological detailed map, map sheet 0767.

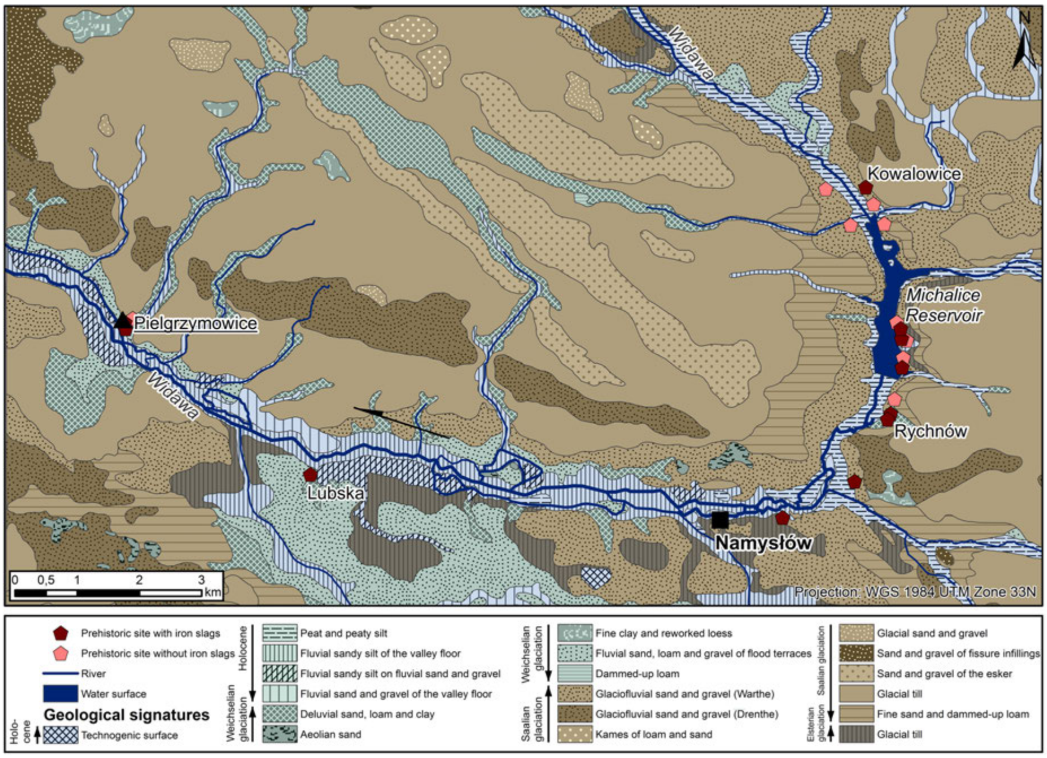

Fig. 2 | Quaternary deposits. – Sources: Geological data (generalized): Bartczak 1997, map sheet 0766, 1:50.000, Cincio 1997, map sheet 0767, 1:50.000; rivers and water surfaces: TK25, map sheets 4871 (1899), 4971 (1912) and 4972 (1938) and TK50, map sheet 453.4 1992; settlement data: AZP, since 1978.

indicates that the last ice advance during the Drenthe stadial came from the northwest. Along with glacial till and eskers, built-up loam, sands and gravels (of fissure infillings) and loamy and sandy kames were also deposited during this period. Since the ice retreat at the end of the Drenthe stadial the study area has stayed free of active glaciations.[52] Preliminary to the beginning of the subsequent Seyda interstadial,[53] the meltwaters of the Drenthe stadial induced an incision into the Saalian glacial till, and the Widawa valley began to develop, first flowing southwards from and then eastwards along the ice marginal position of the Warthe stadial.[54] Subsequently, being located in the periglacial zone of the Saalian Warthe stadial, the Widawa River aggraded glaciofluvial sands and gravels along the Widawa floodplain. The Eemian interglacial and Weichselian glaciation which followed were again characterized by at least one phase of incision followed by several accumulation phases of built-up loam, flood terraces and aeolian deposits.[55] Especially the lateral valleys of the Widawa are characterized by deluvial sands, loams and clays.[56] Also during the Holocene, the Widawa floodplain is characterized by at least one incision and several accumulation phases depositing fluvial sands and gravels and sandy silts in the west of Namysłów and peats and peaty silts in the north of Namysłów (Fig. 2).[57]

52 Liedtke 1981.
53 Litt et al. 2007, 42.
54 Liedtke 1981.
55 Bartczak 1997, geological detailed map, map sheet 0766; Cincio 1997, geological detailed map, map sheet 0767.
56 Bartczak 1997, geological detailed map, map sheet 0766; Cincio 1997, geological detailed map, map sheet 0767.
57 Bartczak 1997, geological detailed map, map sheet 0766; Cincio 1997, geological detailed map, map sheet 0767.

Pedologically the study area is characterized by rich chernozems on the western plateaus and acidic cambisols on the eastern plateaus, podzoluvisols on the slopes and alluvial soils along the floodplain.[58]

3.2 Climate and vegetation

According to Köppen, today the Silesian climate is classified as a humid continental Dfb climate (Fig. 3).[59] Due to the maritime and continental influences[60] with rather warm summers and cold winters the climate can be described as a continental transitional climate[61] with weak oceanic impacts.[62] Therefore the potential natural vegetation of the study area is comprised of a mixed-forest-vegetation with ashes, alders and elms in the valleys and oaks and hornbeams on the plateaus.[63] The present-day vegetation of the study area is strongly dominated by extensive agricultural land-use in the form of tillage farming and grassland cultivation. Wider forested areas occur in the south and north of the study area.[64]

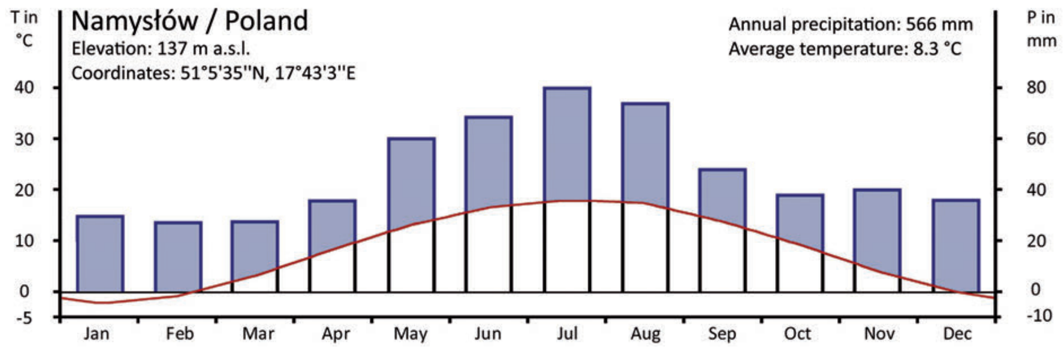

Fig. 3 | Climate of the study area. – Source: Climate-Data 1982–2012.

Information on local climate and vegetation during the Holocene is scarce: from what is known from studies conducted by Pawłowski et al. and by Starkel concerning adjacent areas, 100 km northeast and 200 km southeast of the study area, environmental conditions correspond to the Blytt-Sernander scheme:[65] with (i) a rapid and continuous temperature increase accompanied by a decreasing discharge activity[66] and changing vegetation from an initial boreal vegetation to mixed forests in the Preboreal (11.2–10.7 ka BP),[67] (ii) an increased humidity during the Boreal (10.0–9.2 ka BP),[68] (iii) the Atlantic period (8.6–5.8 ka BP)[69] with wetter and warmer climatic conditions and higher fluvial activity

58 Conrads 1994, 15; Pawlak 1997, map sheet 28.
59 Köppen 1931 quoted from Kuttler 2009, 161–164. – In the abbreviation Dfb, *D* refers to the main group *cold (continental)*, *f* refers to the climate type *without dry season*, *b* refers to the subtype with *warm summers*.
60 Ralska-Jasiewiczowa 1983, 135.
61 Conrads 1994, 14.
62 Pelzer 1991, 48.
63 Pawlak 1997, map sheet 52.
64 Pawlak 1997, map sheet 7.
65 D. Pawłowski et al. 2015; Starkel 1995, 34.
66 Starkel 2002, 160.
67 Starkel 1995, 34; Starkel, Roman, and Michczynska 2006, 30.
68 Starkel, Roman, and Michczynska 2006, 31.
69 Starkel, Roman, and Michczynska 2006, 31.

with higher water levels,[70] (iv) the Subboreal period (5.0–3.5 ka BP)[71] with slightly cooler temperatures[72] and dryer conditions in the mid-Subboreal (3.5–2.9 ka BP)[73] and (v) the Subatlantic period (2.2–1.7 ka BP),[74] characterized by another temperature decrease.[75]

Before settlement activity increased during medieval times, the vegetation in Lower Silesia was characterized by extensive woodlands.[76] Contemporaneously, the Widawa floodplain consisted of flood-prone wetlands and swamps.[77] As palynological data is only available for the interstadial periods of the Weichselian glacial period,[78] more detailed knowledge on the vegetation history is a desideratum.

4 Material and methods

Prehistorical sites dating to the younger pre-Roman period, identified on the basis of the AZP, were catalogued, and archaeological finds held by the Department of Cultural Heritage in Opole were re-examined. Micro-scale archaeological surveys were conducted on selected settlement sites of the Przeworsk culture at Rychnów, Kowalowice and Pielgrzymowice (Fig. 1B). Based on the survey results, the site of Pielgrzymowice, including the sub-sites Pielgrzymowice 4–6 (Fig. 1C), was chosen for further investigations:

Geomagnetic measurements[79] represented the basis for the selection of locations of five small-scale excavation trenches at Pielgrzymowice 5 (Fig. 1D). A mobile array was used for the on-site measurements with ten Foerster FEREX CON650 gradiometer probes and a vertical sensor spacing of 0.65 m. The magnetometers used measure variations of the magnetic field with an accuracy of 0.1 nanotesla. Data registration was performed using the 10-channel digitizer LEA D2, which was coupled with a GPS receiver. In order to examine two geomagnetic anomalies in the subsurface south of Pielgrzymowice 5 (Fig. 1C), two percussion drillings, PiF5-1 and PiF5-2, were also conducted and macroscopically described, applying the standards of the German Pedological Mapping Guide (KA5).[80] Five charcoal samples were dated at the Poznan Radiocarbon Laboratory. The ages are calibrated with Calib Rev 7.0.1., applying the calibration curve IntCal13.[81] Additionally, 19 Pürckhauer drillings were conducted at Pielgrzymowice 5 (Fig. 1C) in order to locate in-situ bog iron ore deposits. Furthermore, percussion drillings and Pürckhauer sondages were conducted throughout the study area to locate bog iron ore deposits.

The natural resource potential is descriptively assessed by discussing the natural conditions of the study area and the natural resources needed for iron production. Additionally, in order to evaluate an order of magnitude on variations in the present-day formation conditions of bog iron ores and to derive an idea of its spatial variability, water samples were taken from the Widawa River and its groundwater-fed receiving streams, and iron and manganese contents were determined for these samples. Geochemical data on the iron and manganese contents of the groundwater itself is not available for the study area. These watersamples, collected during the field campaigns in 2013 and 2014, were deposited in closed specimen containers at different locations of the study area and

70 D. Pawłowski et al. 2015, 14.
71 Starkel, Roman, and Michczynska 2006, 31.
72 Starkel 1995, 39.
73 Starkel 1995, 38; Starkel, Roman, and Michczynska 2006, 31.
74 Starkel, Roman, and Michczynska 2006, 31.
75 D. Pawłowski et al. 2015, 14.
76 Conrads 1994, 14.
77 Conrads 1994, 14.
78 Kuszell, Chmal, and Slychan 2007, 324.
79 Conducted by the company Eastern Atlas GmbH.
80 Ad-Hoc-AG Boden 2005.
81 Copyright 1986–2013 M. Stuiver and P.J. Reimer; Stuiver and Reimer 1993.

cooled. Subsequently, the iron and manganese contents were determined through ICP-OES analysis using an ICP-OES Spectrometer Optima 2100 DV from Perkin Elmer. The results were statistically correlated.

5 Results

5.1 Field survey and percussion drillings

At the archaeological sites Pielgrzymowice 4 (size: 2 ha) and 5 (size: 5 ha), approximately 0.75 kg (0.38 kg/ha) and 26 kg (5.25 kg/ha) of iron smelting slag deposits were found scattered at the surface during the survey. Additionally two small pieces of bog iron ore were collected at Pielgrzymowice 5, while it was not possible to detect in-situ bog iron ore deposits. At Pielgrzymowice 6 no slag was found (Fig. 4A).

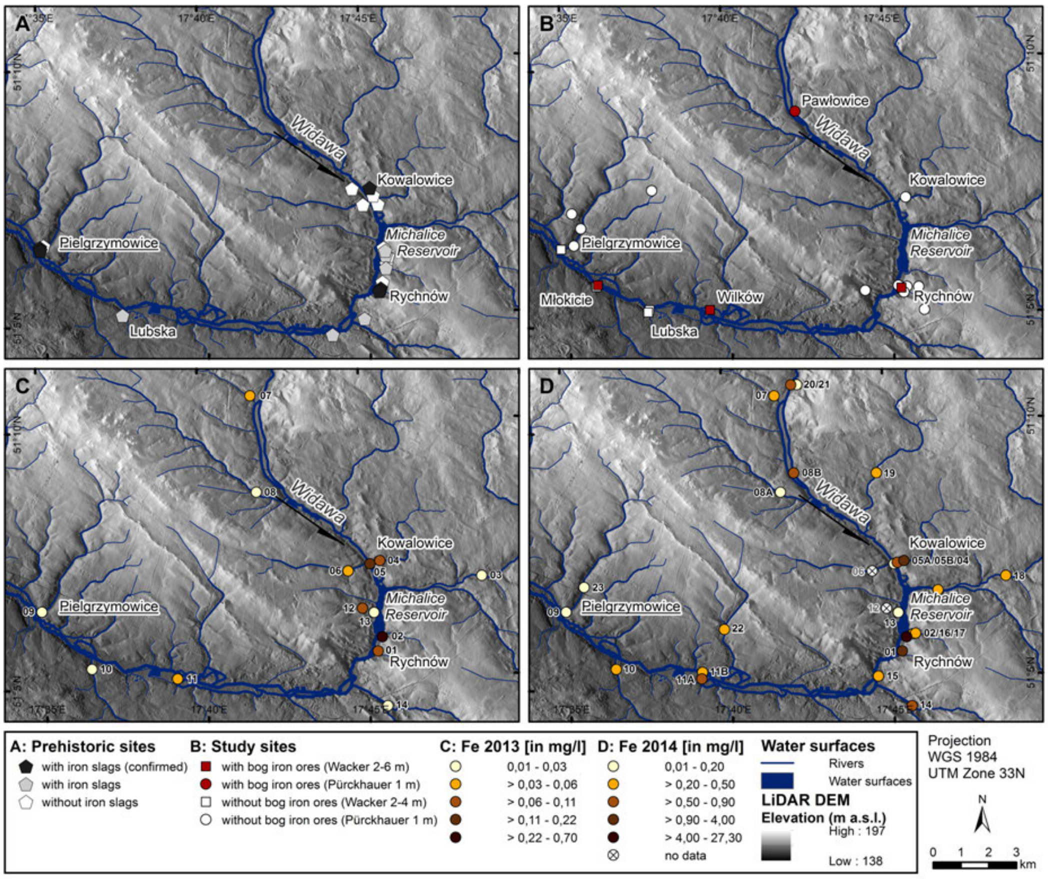

Fig. 4 | A: Prehistoric AZP sites with and without iron slag finds; B: Study sites with and without bog iron ore finds; C: Iron contents in water samples of rivers and receiving waters in 2013; D: Iron contents in water samples of rivers and receiving waters in 2014. – Sources: A and B: Digital elevation model and hillshade: CODGiK 2013; rivers and water surfaces: TK25, map sheets 4871 (1899), 4971 (1912) and 4972 (1938) and TK50, map sheet 453.4 (1992); prehistoric sites: AZP, since 1978. C and D: Digital elevation model and hillshade: CODGiK 2013; rivers and water surfaces: TK25, map sheets 4871 (1899), 4971 (1912) and 4972 (1938) and TK50, map sheet 453.4 (1992); water samples classed: Jenks-Caspall-algorithm.

The geomagnetic survey at all three sites revealed several anomalies, most of them at Pielgrzymowice 5 (Fig. 1D). The percussion drillings PiF5-1 and PiF5-2 were conducted at two of these anomalies in the southern part of Pielgrzymowice 5. Drilling PiF5-1 is situated on a slope close to a small tributary of the Widawa River, while drilling PiF5-2 was conducted closer to the floor of the valley of this tributary (Fig. 1C). Both drillings reached a depth of 2 m, showing three depositional units (I, II, III, Fig. 5).

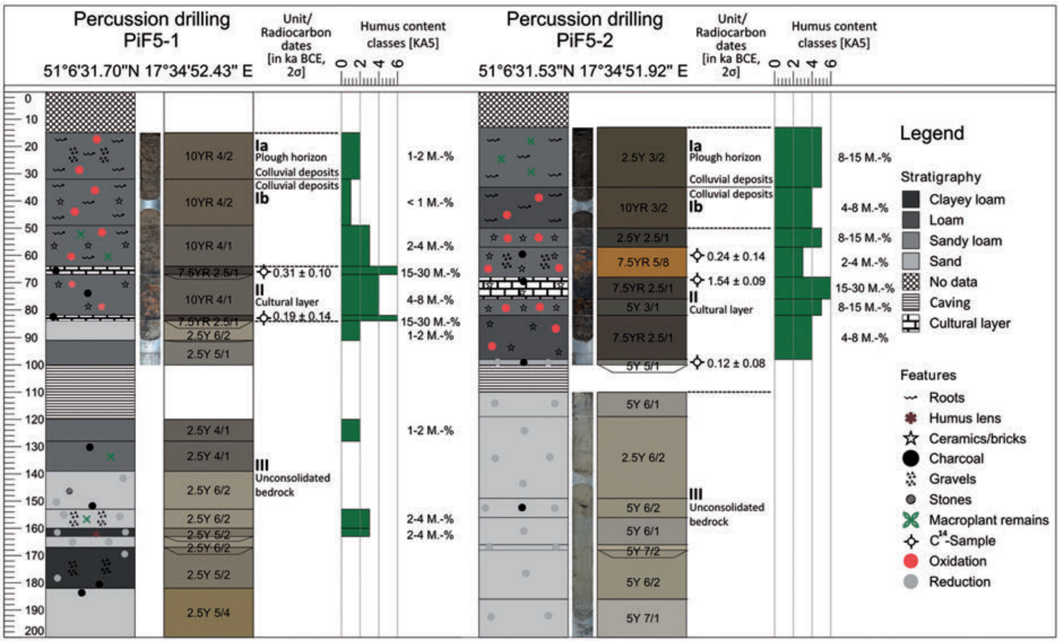

Fig. 5 | Percussion drillings PiF5-1 and PiF5-2 in the south of Pielgrzymowice 5 at trench 1 and 2. – Sources: Radiocarbon ages dated at the Poznan Radiocarbon Laboratory, calibration with Calib Rev 7.0.1., calibration curve IntCal13 after Stuiver and Reimer 1986–2013, Stuiver and Reimer 1993; Sedimentological description: Ad-Hoc-AG Boden 2005.

The bottom of drilling PiF5-1 (unit III), between 84 and 200 cm below surface (b.s.), is characterized by alternating layers made up of (i) sandy deposits and (ii) clayey loamy deposits, with distinct coarse-gravel contents, reduction features and small fragments of charcoal. In accordance to the geological map,[82] these layers are older Holocene deposits accumulated by the local tributary. The deposits between 64 and 84 cm b.s. (unit II) show two layers with particularly high humus, charcoal and ceramic contents as well as oxidation features. Above these layers, between 34 and 64 cm b.s. (unit Ib), the humus and ceramic contents, as well as the oxidation features, decrease. The topsoil is characterized by a 34 cm thick plough horizon (unit Ia, Fig. 5).

The bottom of drilling PiF5-2, between 98 and 200 cm b.s. (unit III), is characterized by relatively homogenous layers of reduced sandy deposits, which are characterized as younger Holocene sediments, also accumulated by the local tributary. Between 50 and 98 cm b.s. (unit II) the profile shows varying humus contents with charcoal fragments, ceramic fragments and oxidation features. In the upper meter of this profile the humus contents are relatively high in comparison to those in PiF5-1. From the depth of 50 cm to 37 cm b.s. (unit Ib) the profile exhibits a continuously high humus content with distinct traces of oxidation, but no evidence of ceramic fragments. These layers also show distinct traces of oxidation. The topsoil is characterized by a 37 cm thick plough horizon (unit Ia). All sediments in both drillings are carbonate-free (Fig. 5).

82 Bartczak 1997, geological detailed map, map sheet 0766.

For the period between 400 BCE and approximately the turn of the era, the calibration curve has only a slight inclination and several wiggles, which results in relatively high ranges for the calibrated radiocarbon ages (Table 1). Thus a precise ^{14}C-dating of the archaeological features is difficult. The radiocarbon samples from the geomagnetic anomaly at drilling PiF5-1 were dated to between 410 and 50 cal. BCE, taking the radiocarbon ages, Poz-58590 (depth: 66 cm) and Poz-58506 (depth: 83 cm) into account. For PiF5-2, the radiocarbon samples Poz-58507 (depth: 60 cm) and Poz-58509 (depth: 99 cm) dated the archaeological finds to between 380 and 40 cal. BCE (Table 1). The last sample in drilling PiF5-2, Poz-58508 (depth: 69 cm), does not reflect the stratigraphic order and dates to 1.540 ± 90 cal. BCE (Table 1).

Additionally, no in-situ bog iron ores were found anywhere in the percussion drillings and Pürckhauer sondages performed at Pielgrzymowice (Fig. 1C), unlike Pawłowice, Rychnów, Wilków and Młokicie (Fig. 4B), where bog iron ore was found.

No	Sample	Type	Drilling	Depth [in cm bs]	Uncalibrated age [in a BP]	Calibrated age[83] [in cal. a BCE, 2σ]
I	Poz-58590	Charcoal	PiF5-1	66	2.280 ± 40	315 ± 100
II	Poz-58506	Charcoal	PiF5-1	83	2.110 ± 30	145 ± 190
III	Poz-58507	Charcoal	PiF5-2	60	2.180 ± 50	240 ± 140
IV	Poz-58508	Charcoal	PiF5-2	69	3.270 ± 35	1.540 ± 85
V	Poz-58509	Charcoal	PiF5-2	99	2.090 ± 30	120 ± 75

Tab. 1 | Radiocarbon ages of percussion drillings PiF5-1 and PiF5-2 at study site Pielgrzymowice 5. – Sources: Calibration with Calib Rev 7.0.1., calibration curve IntCal13 after Stuiver and Reimer 1986–2013; Measurement at the Poznan Radiocarbon Laboratory, Poland.

5.2 Excavation

The trenches opened at Pielgrzymowice during an excavation in summer 2014 allowed the acquisition of a more detailed picture of the site. Trench 1 (depth 55 cm b.s.) and 2 (depth 45 cm b.s.), which were located at the same position as the radiocarbon dated drillings PiF5-1 and PiF5-2 (Fig. 5), in particular exposed big heterogenic structures (Fig. 6). The excavation confirmed that these structures are covered by colluvial material of at least 40 cm thickness. Trenches 3 (depth 30 cm b.s.) and 4 (depth 30 cm b.s.) exposed two furnaces, two fire places and two pits. The bloomery furnaces at trenches 3 and 4 had inner diameters of up to 1 m. The excavated furnace in trench 4 additionally had a big flat stone, 70 cm in diameter, at its bottom. Trench 5 (depth 30 cm b.s.) contained at least six rectangular stoves filled with stones (Fig. 1D). During our excavation at Pielgrzymowice 5, approximately 185 kg of iron slag and further fragments of coarse ware were collected.

5.3 Water samples from sub-catchment areas

The sample size of water samples was n = 14 in 2013 and n = 24 in 2014. The iron and manganese content in the selected sub-catchment areas varies. Results for 2013 samples came in at 0.01–0.70 ($\overline{x}$= 0.11) mg Fe/l and 0.002–0.400 ($\overline{x}$= 0.062) mg Mn/l. Those of 2014 at 0.10–27.30 ($\overline{x}$= 1.75) mg Fe/l and 0.020–1.500 ($\overline{x}$= 0.289) mg Mn/l. A linear correlation between iron and manganese contents shows a correlation coefficient of R=0.76 in 2013

83 Calibration with Calib Rev 7.0.1., calibration curve IntCal13 after Stuiver and Reimer 1986–2013.

Fig. 6 | House remains in in the south of Pielgrzymowice 5, trench 1.

and R=0.61 in 2014 (Table 2; Figs. 4C and 4D). Comparing the measurements sampled at the same sites in 2013 and 2014, the element contents show a positive correlation of R=0.96 for iron (Table 2; Figs. 4C and 4D) and R=0.76 (Table 2) for manganese. The field campaign in 2013 was conducted during a rather rainy period, with the last rainfall only two days before the measurements were taken, whereas the measurements in 2014 were taken in a rather dry period with the last rainfall four days before the measurements. Furthermore, the sub-catchment areas differ in size and average hillslope.

6 Discussion

6.1 Field survey and excavation

In contradiction to the AZP data, during the archaeological field campaign at Pielgrzymowice, iron slag sites were detected at Pielgrzymowice 4 and 5 – with most slag sites at Pielgrzymowice 5 – but none were found at Pielgrzymowice 6. These results are also confirmed by the geomagnetic prospection, which yielded clear geomagnetic structures only for sites 4 and 5 (Fig. 1C). Interpreting the amounts of slag collected through survey and excavation, the smelting site of Pielgrzymowice seems to represent rather a small-scale iron production site. Based on the results of the five radiocarbon dating, the excavated remains of the trenches 1 and 2 in the south of Pielgrzymowice 5 can be dated to the period 410–50 cal. BCE (PiF5-1) and 380–40 cal. BCE (PiF5-2) and therefore from the middle pre-Roman to the older Roman period. The third dating at PiF5-2, within the range between 1,450 and 1,630 cal. BCE, dates from the early to the middle Bronze Age (Table 1). Since this sample with a relatively old date originates from a layer between those of the other two samples, it may be possible to ascribe the early date to an old wood

Sample	Location		Campaign 2014		Campaign 2013	
	Geographic coordinates	Study site	[Aug 30^{th} 2014]		[Sep 17^{th} 2013]	
Name	WGS 1984	Name	Fe [mg/l]	Mn [mg/l]	Fe [mg/l]	Mn [mg/l]
WS01	51°05‘31“N, 17°45‘19“E	Rychnów	2.30	0.190	0.08	0.070
WS02	51°05‘48“N, 17°45‘28“E	Widawa Reservoir	27.30	1.400	0.70	0.400
WS03	51°06’55”N, 17°48’36”E	Baldwinowice	0.40	0.100	0.03	0.010
WS04	51°07’17”N, 17°45’28”E	Kowalowice	4.00	1.400	0.11	0.010
WS05A	51°07‘14“N, 17°45‘09“E	Objazda	0.20	0.050	0.22	0.005
WS05B	51°07‘16“N, 17°45‘16“E	Objazda	0.80	0.180		
WS06	51°07‘07“N, 17°44‘28“E	Objazda	*ran dry*	*ran dry*	0.04	0.004
WS07	51°10’35”N, 17°41’38”E	Golebice	0.34	0.160	0.04	0.003
WS08A	51°08’43”N, 17°41’43”E	Agroosiedle	0.20	0.100	0.03	0.003
WS08B	51°09‘05“N, 17°42‘09“E	Agroosiedle	0.60	0.170		
WS09	51°06’31”N, 17°34’57”E	Pielgrzymowice	0.15	0.040	0.02	0.004
WS10	51°05’22”N, 17°36’26”E	Lubska	0.30	0.200	0.02	0.080
WS11A	51°05‘07“N, 17°39‘05“E	Wildow	0.90	1.500	0.06	0.270
WS11B	51°05‘15“N, 17°39‘06“E	Wildow	0.40	0.100		
WS12	51°06‘22“N, 17°44‘53“E	Jozefkow	ran dry	ran dry	0.09	0.003
WS13	51°06‘17“N, 17°45‘14“E	Jozefkow	0.20	0.100	0.02	0.005
WS14	51°04‘27“N, 17°45‘33“E	Kamienna	0.70	0.200	0.01	0.002
WS15	51°05‘03“N, 17°44‘33“E	Namysłów	0.40	0.200		
WS16	51°05‘51“N, 17°45‘40“E	Widawa	0.40	0.150		
WS17	51°05‘52“N, 17°45‘45“E	Widawa Reservoir	0.50	0.100		
WS18	51°06‘42“N, 17°46‘29“E	Michalice	0.30	0.100		
WS19	51°09‘01“N, 17°44‘43“E	Smogorzow	0.40	0.100		
WS20	51°10‘47“N, 17°42‘09“E	Golebice	0.60	0.200		
WS21	51°10‘47“N, 17°42‘21“E	Wygoda	0.20	0.040		
WS22	51°06‘04“N, 17°39‘50“E	Wilków	0.30	0.140		
WS23	51°06‘59“N, 17°35‘32“E	Pielgrzymowice	0.10	0.020		
Ø	mean		1.75	0.289	0.11	0.062
R	linear correlation coefficient Fe/Mn		0.61		0.76	
R	linear correlation coefficient 2013/14 Fe			0.96		
R	linear correlation coefficient 2013/14 Mn			0.76		

Tab. 2 | Iron and manganese contents in water samples of rivers and receiving waters in 2013 and 2014.

effect.[84] Due to their size and shape, these structures are interpreted as parts of former prehistoric pit houses (Fig. 6) with fire pits identified in a depth of between 64 and 84 cm b.s. at PiF5-1 and 50 and 98 cm b.s. at PiF5-2 (Fig. 5). The sediments above each of these layers are interpreted as younger colluvial material (unit I) or pit fillings because they are non-stratified and unsorted and show high humus contents down to a depth of 50 and 64 cm b.s. (Fig. 5).[85] The upper part of each of these deposits is characterized by a 34 to 37 cm thick plough horizon, which represents the topsoil (unit Ia).

At the moment, it is not possible to say whether the furnaces at Pielgrzymowice 5 can also be assigned to the period from the middle pre-Roman until the younger pre-Roman period. The establishment of a relative chronology based on ceramics is difficult, as only one small ceramic fragment with a typical faceted rim was found in trench 4, which dates to the younger pre-Roman period. Although this fragment was found at the location of a trench containing one of the big furnaces, it was collected from the topsoil, not from one of the archaeological features or cultural layers. Additionally, one stove can be dated, on the basis of ceramics featuring a distinct foot rim, at least to the end of the older Roman period (phase B2: 50–170 CE). Therefore they yield a chronological range from the middle pre-Roman period to the middle Roman period. Further radiocarbon dating of samples from a smelting furnace and stoves are in progress.

Different types of furnaces were used in various regions and times during the pre-Roman Iron Age: bowl furnaces,[86] doomed furnaces[87] and shaft furnaces with greater variations in size and form.[88] The furnaces excavated at Pielgrzymowice are distinct in terms of size and construction – as in one case a big flat stone was used as a base for the slag pit of the furnace. The excavated furnaces belong to a group of iron smelting constructions that Madera (2008) described as bloomery furnaces with a "very big" hearth.[89] In total, including Pielgrzymowice, 20 different smelting sites with this type of furnace have been identified in Silesia.[90] Nearly all of them date to the Roman period, phases B2 to C2 (50–320 CE). The majority of them are located in settlements of the middle and late Roman period around the river Oder in Upper and Lower Silesia.[91] Apart from Pielgrzymowice 5, the use of a big stone under the slag pit or even of a number of smaller stones within the furnace wall is known only from one other site, Dobrzeń Mały.[92] The use of a big stone to function as a base of the furnace pit by the Przeworsk culture is unique in Europe. The rectangular structures of trench 5, which were identified as stoves, are in configuration and shape typical for the Przeworsk culture.[93]

6.2 Assessment of the natural resource potential

For a comprehensive analysis of the iron smelting site of Pielgrzymowice, the natural resource potential was as well assessed in the environs of this site. Although most of the vicinity of Pielgrzymowice is characterized by rather sandy deposits, excavation trench 1 revealed sufficient quantities of lateral fluvial slope-wash deposits made of clay, which are suitable for the construction of bloomery furnaces (Fig. 5: clayey loam in Unit III, PiF5-1).

84 Warner 1990, 159–160.
85 Leopold and Völkel 2007, 133.
86 Pleiner 2000, 145–149.
87 Garner 2010; Gassmann, Matthes, and Wieland 2011; Pleiner 2000, 163–172; Wallner 2013, 59–63.
88 For shaft furnaces with slag pit in the Przeworsk culture cf. Orzechowski 2013, 95–117; Pleiner 2000, 149–162.
89 Madera 2008.
90 Madera 2008.
91 Madera 2008, 173, Fig. 1.
92 A. Pawłowski 1979.
93 Madyda-Legutko, Pohorska-Kleja, and Rodzińska-Nowak 2006.

As the detailed geological map indicates, those clay deposits are widespread in the study area. This is also true for the natural resources water and wood, the latter relevant in terms of charcoal as fuel. As the climate of the study area is classified as a moderate continental climate, the potential natural vegetation consists of forest areas with oak, hornbeam, ash and pine trees[94] and the perennial discharge of the Widawa River yielded sufficient water throughout a year.

The weight of slag found during the survey and excavation at Pielgrzymowice 5 totals 211 kg, pointing to small-scale iron production. The amount of fuel needed for smelting the respective amount of charcoal can be approximated on the basis of empirical values measured in field experiments by Pleiner[95] (Table 3).

Ratio content	Ratio numbers
forest (ha) : wood (kg)	1 : 72.000[96], 1 : 250.000[97]
charcoal (kg) : wood (kg) ratio	1 : 5.7[98], 1 : 7.1[99]
iron ore (kg) : charcoal (kg)	1 : 1[100], 1 : 2.5[101]
crude iron (kg) : iron ore (kg)	1 : 5.6[102], 1 : 7.3[103], 1 : 9.8[104]
crude iron : iron slag	1 : 4[105], 1 : 5[106]

Tab. 3 | Ratios for the estimation of the natural resources fuel and iron ore. – Sources: Pleiner 2000, 86, 126–128; Dunikowski and Cabboi 1996 , 126, cited after Pleiner 2000, 127; Cleere 1976, 240–241, cited after Pleiner 2000, 127; Crew and Salter 1991, 16–17, cited after Pleiner 2000, 126; Bielenin 1874, 194–195, cited after Pleiner 2000, 127.

Taking the variance of the production ratios into account, the following quantities of natural resources were needed to produce 210 kg of iron slag as a by-product, in order to produce approximately 40 to 50 kg of sponge iron (bloom) (Table 3):

- approximately 300 to 700 kg of bog iron ore (depending on the iron content as a quality measure of the ore)
- approximately 300 to 1,700 kg charcoal, equivalent to between 1,700 and 12,000 kg of wood, which is equivalent to between 0.01 and 0.17 ha of forest (Table 3)

In summary, there is no question but that the vicinity of Pielgrzymowice 5 would have provided sufficient wood for charcoal production to sustain iron production on such a small-scale. Applying the production ratios introduced above, Pleiner even concludes that seasonal small-scale iron smelting would have "no significant effect on the tree cover in the vicinity of bloomery ironworks".[107]

94 Pawlak 1997, map sheet 52, 1:300.000, 1997.
95 Pleiner 2000.
96 Dunikowski and Cabboi 1996, 126, cited after Pleiner 2000, 127.
97 Cleere 1976, 240–241, cited after Pleiner 2000, 127.
98 Pleiner 2000, 126; Crew and Salter 1991, 16–17, cited after Pleiner 2000, 126.
99 Cleere 1976, 240–241, cited after Pleiner 2000, 127.
100 Crew and Salter 1991, 16–17, cited after Pleiner 2000, 126–127; Bielenin 1874, 194–195, cited after Pleiner 2000, 127.
101 Pleiner 2000, 126.
102 Crew and Salter 1991, 16–17, cited after Pleiner 2000, 126–127.
103 Pleiner 2000, 126.
104 Bielenin 1874, 194–19, cited after Pleiner 2000, 127.
105 Crew and Salter 1991, 16–17, cited after Pleiner 2000, 126–127.
106 Pleiner 2000, 86.
107 Pleiner 2000, 126.

Today bog iron ores can be described as a scarce resource in the floodplain of the Widawa River, as in-situ bog iron ore deposits were identified only at the four investigated sites of Pawłowice, Rychnów, Wilków and Młokicie (Fig. 4B). However these results do not permit conclusions to be drawn about the availability of bog iron ore deposits at Pielgrzymowice during prehistory. Instead, they are an indication of more recent distinct modification of the landscape in the vicinity of Pielgrzymowice resulting from deforestation, centuries of intensive agricultural usage, melioration measures and intensified drainage activity, in terms of construction of channels and artificial drainage systems, which, taken together, led to a deterioration of the landscape's formation conditions.[108] Colluvial deposits, which today cover wide areas at the margins of the Widawa floodplain – as it has been shown to be the case for Pielgrzymowice – also impede the creation of neo-formations of bog iron ores. These factors not only inhibit the formation of bog iron ores, but also lead to a degradation of previously formed deposits.[109] In addition, it can be assumed that the exploitation of such deposits began in the Pre-Roman Iron Age, and was continued in subsequent cultural epochs as well. A geochemical and mineralogical analysis of bog iron ores and slag from the study site are a subject for supplementary investigations.

Further considerations must take into account that the geogenic reserve of iron in the source areas of Quaternary deposits is not unlimited and is depleted over millennia of weathering and subsequent solution of iron and manganese. In this regard, one should note, as well, that the iron and manganese contents in the water samples from the Widawa River and its groundwater-fed receiving streams – with contents between 0.01 and 0.70 mg Fe/l in 2013 and between 0.10 and 27.30 mg Fe/l in 2014 (Table 2) – mostly show relatively low element contents. According to the WHO (1996), median iron concentrations in rivers are reported to be 0.7 mg Fe/l.[110] These iron contents in the Widawa samples are also of an order comparable to those for another study area in the Oder River catchment area – to which the Widawa River belongs – with iron contents between 0.01 and 1.04 mg Fe/l at Polecko and Krajnik Dolny (Poland) in 1992, 1996 and 2000.[111] In contrast, the local manganese contents – with values between 0.002 and 0.4 mg Mn/l in 2013 and between 0.04 and 1.5 mg Mn/l in 2014 – are relatively high. For manganese, the WHO cites a typical range of 0.001 to 0.2 mg Mn/l in rivers.[112] Nevertheless, a study of the Serby River, also situated in the Oder catchment area – with iron contents between 2.1 and 39.4 mg Fe/l and manganese contents between 0.28 and 1.50 mg Mn/l[113] – shows that iron and manganese contents in areas not known as centers for prehistoric iron production can also reach similarly heights or be even higher.

It is possible that the differences between the mean values for the two measurement series in the Widawa catchment area could be explained by the different weather conditions prevailing during the two field campaigns: in 2013 the four weeks prior to the field campaign were mainly characterized by rainy weather with partly strong rainfall events, while in 2014 the four weeks before the sampling were characterized by relatively dry weather conditions.[114] This suggests that the wetter conditions in 2013 lead to a dilution of the discharge, while the higher values in 2014 are a product of a concentration of iron

108 Ahmad 2005; Reconstruction of canalization und redirection of river courses based on analysis of the following topographic maps: Topographical map 1899; Topographical map 1912; Topographical map 1938; Topographical map 1992.

109 Leb 1983, 130; Koschke 2002, 9.

110 Sheffer 2003, 2.

111 Adriaanse et al. 2001, 96.

112 Sheffer 2011, 3.

113 Zapart 2008, 205.

114 Climateve.com 2013; Climateve.com 2014.

and manganese in the receiving waters. Therefore the measured values provide only a temporal impression of the absolute iron and manganese contents in the surface waters.

The positive correlation of the iron and manganese contents in the samples collected at the same sites in 2013 and 2014 (Table 2) indicates that – despite the distinct absolute differences – the results of the two years are fairly comparable. This points to a constant spatial pattern in the variability of the iron and manganese contents of the local receiving waters (Table 2; Figs. 4C and 4D). At Rychnów (sampling points WS01 and WS02) and Kowalowice (sampling point WS04) in the vicinity of the Michalice reservoir, the iron and manganese contents are relatively high. At Pielgrzymowice (sampling point WS09) and Lubska (sampling point WS10) in the lower reaches of the Widawa River, the iron and manganese contents are relatively low (Table 2). The higher iron contents in the receiving waters, in particular, seem to coincide with the concentration of iron slag sites in the study area (Fig. 4A).

As the elemental contents in the different sub-catchment areas represent only a small sample and higher iron (and manganese) contents only represent one indicator for characterizing favorable sub-catchment areas for bog iron ores, the spatial variability in the results can only be interpreted tentatively in terms of generally more and less favorable bog iron ore formation areas.

7 Conclusion

The introduction of iron smelting in the primary distribution area of the Przeworsk culture was investigated in a micro-region in Lower Silesia, Poland. An integrated landscape archaeological approach was followed: in interdisciplinary cooperation a mix of on-site and off-site investigations were performed, including archaeological surveys and excavations as well as geographical fieldwork, involving drillings and sondages as well as the analysis of sediments and water samples. The results obtained allow results from previous studies to be revised in some respects and supplemented in others. The survey and excavation at Pielgrzymowice 5 revealed a number of slag finds, pit houses, stoves or fire places and two bloomery furnaces with a very big hearth, which can be associated with the later Przeworsk period or the Roman period of phases B2 to C2 (50–320 CE). A big stone as a foundation of the slag pit is a remarkable feature of the excavated furnace type. In contrast, the house remains excavated in excavation trench 1 were dated to the middle pre-Roman to the younger pre-Roman period and thus seem to be of slightly older age. These structures are overlaid by colluvial deposits, which show typical age inversions.

The geographical investigations focus on the resource potential of the region for early iron smelters. They led to the conclusion that the natural resources of clay, water and fuel do not constitute scarce natural resources in the region. More challenging is the evaluation of the availability of high quality bog iron ore deposits and their former spatial distribution in the fluvial valleys of the study area, e.g. due to lower groundwater levels resulting from modern agriculture and melioration measures. An extended field campaign during which percussion drilling and Pürckhauer sondages were conducted in the vicinity of the slag site of Pielgrzymowice 5, was not able to detect bog iron ore deposits on the micro-scale. On the macro-scale spatial analyses of the elemental composition of water samples from the Widawa and receiving waters indicate that iron and manganese contents are higher in the vicinity of the Michalice reservoir, than in the wider vicinity of Pielgrzymowice. This observation matches with a local cluster of prehistoric slag sites in the study area, where bog iron ores were also found at the slag site of Rychnów. This result is the basis for the conclusion that the glacial till deposits of the study area are not completely depleted of iron and manganese and that the content of these elements in the Quaternary deposits would be sufficient to sustain bog iron ore formation in the Widawa valley.

The application of this interdisciplinary approach, involving close collaboration between prehistoric archaeologists and physical geographers, has proven to be very fruitful when working on the landscape archaeological topic of the introduction of iron smelting. Through the different perspectives and interests of these two scientific fields, and by drawing on necessary expertise of each field, it is possible to shed light on socio-cultural processes and applied prehistoric technologies, as well as the natural conditions such as the resource potential. Exemplary of the way in which this project is benefitting from its interdisciplinarity is the blending of the techniques of geomagnetic surveys, percussion drillings, Pürckhauer sondages and excavation trenches, which allowed an integration of sedimentological and archaeological evidence leading to: (i) a first tentative interpretation of the sedimentological conditions and (ii) a preliminary association of the cultural layers to the Przeworsk culture with the results of absolute and relative dating complementing each other. To allude to the title of this special issue and to summarize our experience with interdisciplinary research, the challenge at the crux of an integrated approach is rather being in the same boat, having everyone rowing in the same direction, than that of building a bridge.

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