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HISTORICAL WATER-POWERED FERROUS METALLURGY RECONSTRUCTED FROM TREE-RINGS AND LACUSTRINE DEPOSITS (MAŁA PANEW BASIN, SOUTHERN POLAND)

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Abstract: According to historical sources in the basin of Mała Panew River there were at least 56 water-powered iron smelters from 14th–19th century. Now only two metallurgy plants work in the area. Many of the former smelting settlements ceased to exist. Historical data on the smelting industry in the area are often scarce. The aim of the study was to reconstruct the history of ferrous metallurgy from (1) the remains of wooden historical buildings, (2) remains of charcoal kilns and (3) deposits from former smelter pond. Results show that Regolowiec smelting settlement existed already in the 17th century (at least several decades earlier than historical written sources suggest) and was later repaired after destruction caused probably by floods. Charcoal used for iron smelting in the ironworks in Brusiek on the Mała Panew River was burnt at the turn of the 18th century. This is in accordance with historical sources indicating particular prosperity of the metallurgy in that period. Upstream of the ironworks in Brusiek in the first half of the 17th century a large pond existed flooding the floor of the Mała Panew valley. Study has shown that the pond was at least 100 years older than historical sources have indicated.

Keywords: historical bloomery, iron smelting, charcoal kiln, smelter pond, dendrochronology, lacustrine deposits.

1. INTRODUCTION

It is generally acknowledged that the Iron Age began around 2000 BC in Asia Minor (Tylecote, 1992). Between 1500 BC and 1000 BC iron was smelted in the Anatolia-Iran region (Yalçin, 1999). The skills connected with manufacturing iron objects later spread across Europe, Asia and northern Africa (Muhly *et al.,* 1985). Iron production increased significantly during the Roman period from kilograms up to hundreds of kilograms in particular areas of production. Iron was smelted without the support of water energy during that time. Bowl furnaces and shaft furnaces were used (Wilson, 2002).

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In medieval Europe, there are records of the use of water wheels in the milling industry, e.g. in Britain, there were 5000 watermills operating in the 11th century (Tylecote, 1992). Gradually water wheels started to be used in ferrous metallurgy as well. The first records of the iron bloomery process with the use of water power come from France (beginning of the 12th century), Sweden and Hungary (beginning of the 13th century) (Lucas, 2005). Ferrous metallurgy powered by water wheels started in England in the 15th century (Schubert, 1957). A few historical sources suggest that in Poland water-powered ferrous metallurgy started in the 14th century or even earlier (Szczech, 2001). Medieval ironworks were described in the so-called poem written by Roździeński in 1612 (Mańczyk, 2007). Yet, data on past ironworks have not, until now, been confirmed through environmental studies or dating results. Ironworks described by Roździeński existed in the basin of the Mała Panew River in the Silesian Upland and Lowland in southern Poland (**Fig. 1A**). At least 56 ironworks existed here in the past and are mentioned in historical documents and marked on archival maps of different ages (Goszyk, 2001; 2004; Juros, 2012) (**Fig. 1B**). The oldest maps date back to the 13th century, however it is possible that the ironworks were founded earlier (Juros, 2012). The area of the Mała Panew basin is characterized by good conditions for the development of the iron industry. The industry was based on the exploitation and smelting of bog iron ores which are abundant in the bedrock of the area. The development of the iron industry was also supported by the high degree of afforestation guaranteeing easy production of charcoal. The colonisation of the forested Mała Panew basin was mainly associated with iron smelting (Tyrol, 2006). Settlements developed in the bottoms of river valleys where water energy was used to drive water wheels which powered smelting machines. Hydraulic structures and technical constructions were accompanied by water dams/weirs providing water for smithies. Numerous smelter ponds were created (Wesołowska, 1963). In the mid-18th century 3–4 thousand tons/year of iron were produced in smelters working in the Mała Panew basin which indicates a relatively large level of industrialisation by the standards of the time (Juros, 2012). After the technical revolution which occurred due to the application of coke (product of the destructive coal distillation) in smelting, there was a decline of water-powered metallurgy based on charcoal. Water-powered ironworks, including those in the area of the study, were gradually closed and riverside smelting settlements depopulated fast. Some of them completely ceased to exist (Bednarek, 1992). The traces of such ironworks sometimes now remain in the places where they existed e.g. parts of weirs damming channels (Ciszewski *et al.*, 2005). Sometimes river erosion reveals wooden piles in places where past ironworks were located, these being the core of weirs or remains of smelting buildings. Charcoal kilns, where charcoal was produced for the needs of iron industry, are sometimes exposed during forest works and road construction or reconstruction (**Fig. 2A**, **2B**). Due to fluvial erosion deposits accumulated in former smelter ponds are also exposed (**Fig. 2C**). Studies undertaken in places where traces of iron smelting occur can possibly allow us to reconstruct the history of ferrous metallurgy, taking into account how incomplete are the archival documents which describe the history of particular ironworks. No attempts to date charcoal from charcoal kilns along with the wooden remains of smelter buildings have previously been undertaken. However, through the use of radioisotopic methods, deposits of former mill/smelting ponds were dated e.g. in the valley of the Ruda River in the upper Vistula River basin (Klimek *et al.,* 2003) and in the valley of the San River in the Bieszczady Mts (Kukulak, 2000, 2004).

The aim of the study was to reconstruct the age of iron foundries in Regolowiec and Brusiek through: (a) the dendrochronological dating of wooden piles which record the location of former smelting buildings (an example of the Regolowiec settlement), (b) dating charcoal from charcoal kilns near the foundry in Brusiek and (c) the analysis of deposits occurring directly upstream of the

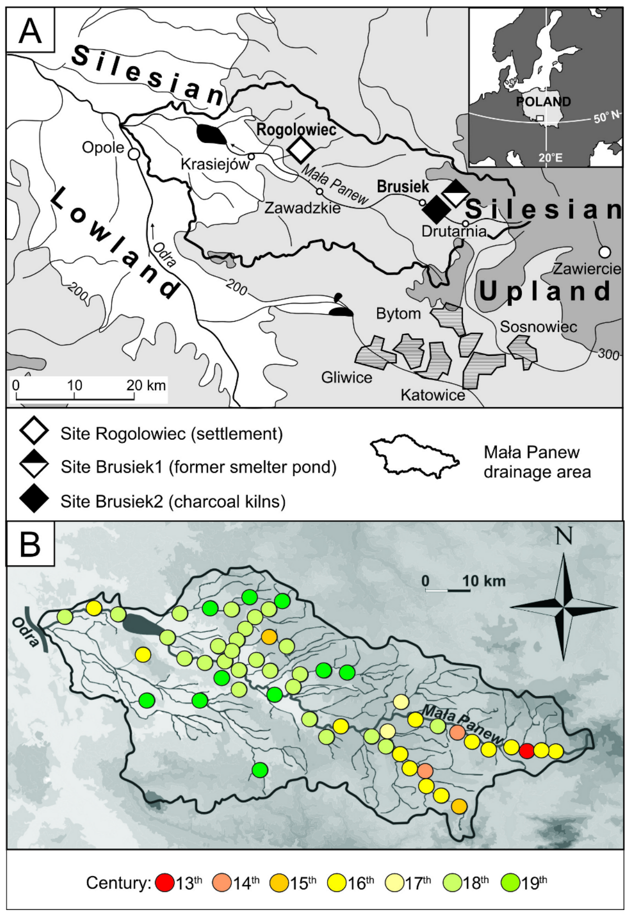

Fig. 1. *A – Location of study sites in the basin of Mała Panew River, B – Location of ironworks known from historical sources:*

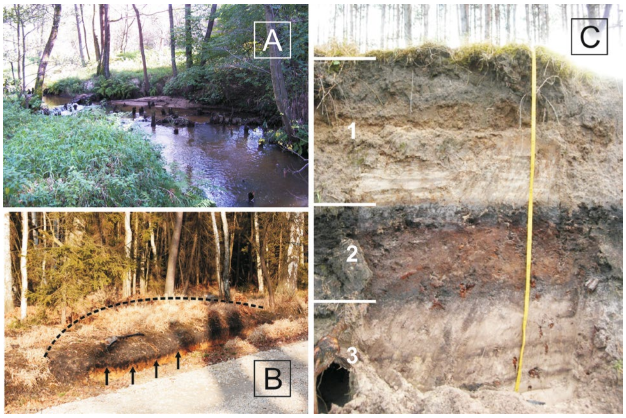

Fig. 2. *Remains of the historical iron industry in the basin of the Mała Panew River: A – wooden piles in the Bziniczka channel where a former smelting settlement was located (Bziniczka study site), B – layer of charcoal and ash in the location of a former charcoal kiln where charcoal was produced (Brusiek2 study site), C – fine-grained deposits of the smelter pond located upstream of a weir in Brusiek village (Brusiek1 study site).*

foundry and weir in Brusiek which are probably the remains of a former smelter pond (**Fig. 2A–C**).

2. AREA OF STUDY

The bedrock of the study basin of the Mała Panew River is composed of Pleistocene fluvioglacial sands. Keuper clays only occur in the valley bottoms downstream of Krasiejów (Malik, 2006) (**Fig. 1A**). The area is heavily afforested. Pine-oak forests are typical natural plant communities on the infertile sandy podzol soils of the study area. However the forests no longer have a natural character due to long and intensive forest management. They are formed of planted monocultures of Scots Pine (*Pinus sylvestris*) with small areas of riparian forest dominated by black alder and grey alder in the bottoms of the river valleys.

The rivers flowing through the forested parts of the basin usually have meandering channels while in open areas their courses are rather straight. The courses of the rivers are uneven and changes of channel gradient are clear in those places where mills and ironworks existed in the past (Ciszewski *et al.,* 2004; Ciszewski and Malik, 2004; Ciszewski *et al.,* 2006). Studies were carried out at three study sites (**Fig. 1A**):

a) The Regolowiec study site with remains of historic wooden buildings located in a former smelting settlement named Regolowiec in the valley of the Bziniczka River (right-bank tributary of the Mała Panew River), (site 1),
b) The Brusiek1 study site where deposits of the former smelter pond can be found. This is located near Brusiek village, a former smelting settlement situated in the Mała Panew valley, (site 2),
c) The Brusiek2 study site where charcoal kilns were found, located in the valley of the Leśnica River (right-bank tributary of Mała Panew River), 6 km NE of the former ironworks in Brusiek, (site 3).

The history and location of the Regolowiec smelting settlement in the valley of the Bziniczka River

According to written historical records the Regolowiec settlement was founded in the middle of the 18th century (document dating back to 1761) (Globisch, 2004). Historical manuscripts indicate that the foundation of the smelting centre started with the damming of the Bziniczka River with a weir and the creating of a pond with an area of 32 morgen (17.89 ha) (**Fig. 3A**) (Triest, 1864). The river powered one or two water wheels which powered a forge hammer and smelter blower. Seven dwellings were built for employees of the ironworks. In 1804 28 tons of iron bars were produced here by 6 employees and 23 people earned their living working in Regolowiec. The population of the settlement was 44 in 1818, 45 in 1840 and 63 in 1850. The greatest number of inhabitants was recorded in 1861: 81 people. The area of arable land also increased gradually and reached 123 morgen (68.78 ha) in the middle of the 19th century (Mańczyk, 2007). A grange existed here breeding sheep and fish in nearby ponds, including the smelter pond. In the same year, 1861, the ironworks closed. In the following years the settlement gradually depopulated. It was finally destroyed by fire in 1929 when the last inhabitant left Regolowiec (Mańczyk, 2007). Wooden piles in the bottom of the valley of the Bziniczka River and the remains of the weir are traces of former smelting settlement (**Fig. 1A**).

The weir damming the Bziniczka River was constructed at a natural narrowing of the valley limited by sand dunes to the north and connected with the edge of the high terrace to the south. The smelter pond was located south of the contemporary channel of the Bziniczka on a wide floodplain (**Fig. 4**). The location of smelting settlements depended strongly on the limitation of possible damage caused by floods. The settlement in Regolowiec had a particularly convenient location from this point of view. It was protected by a broad dunefield and high terrace.

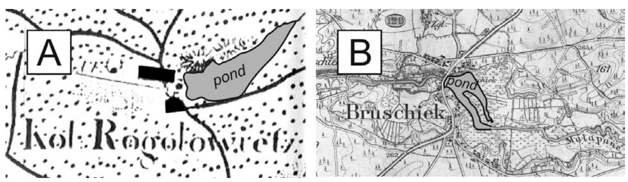

Fig. 3. *Smelter ponds on archival maps: A – smelter pond in Regolowiec on a map published in 1827, B – smelter pond in Brusiek on a map published in 1883.*

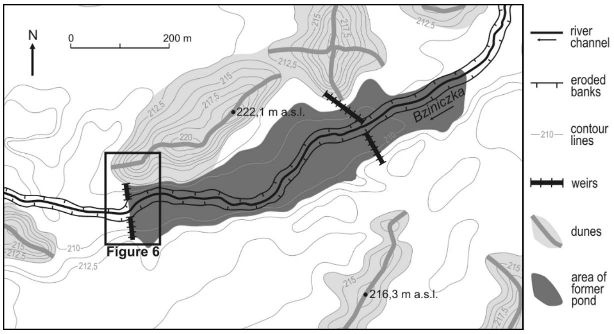

Fig. 4. *Area around the smelter in Regolowiec.*

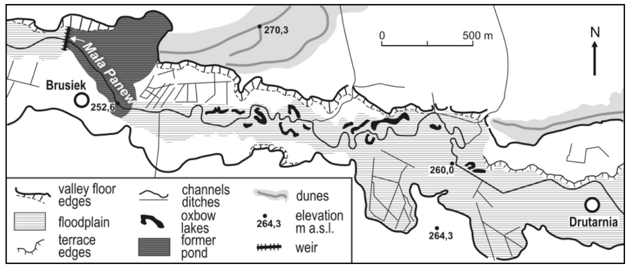

Fig. 5. *Area around the smelter in Brusiek.*

Several dozen wooden piles were found exposed by fluvial erosion in the channel of the Bziniczka in the area of the former Regolowiec settlement and excavated during the construction of a new artificial dam retaining a lake in 2013. These are the foundations of an old weir, and a smithy or other ironworks buildings.

The history and location of the Brusiek smelter settlement in the valley of the Mała Panew River

Roździeński's poem states that the oldest smelter on the Mała Panew River existed in Brusiek. It is stated that the smelter had even been founded in the 14th century (Roździeński, 1612). According to Szczech (2001) it is possible that Roździeński may have meant other factories founded in the area. Currently the smelter allegedly founded in Kuczów in the 13th century is considered the oldest on the Mała Panew River (**Fig. 1B**: smelter no. 3). There is no doubt that the smelter existed in Brusiek in the 15th century. In 1489 there was an inn near the smelter. Some documents have been preserved which suggest that the smelter from the 15th century was rebuilt on the site where an older smelter had previously existed (Szczech, 2001). Following the foundation of the smelter the Brusiek settlement grew and by the end of the 18th century had 600 permanent inhabitants, mainly dependent on blacksmithery. In 1848 164 pupils attended the school in Brusiek, in 1857 there were 101 pupils (Goszyk, 2001). By the end of the 19th century the smelter had closed and Brusiek started to depopulate. The village now has 50 inhabitants.

The weir damming the Mała Panew River in Brusiek was constructed in a narrowing of the valley bottom enclosed on both sides by the edges of high terraces (**Fig. 5**). The smelter pond was occupied a wide floodplain upstream of the weir (**Fig. 3B**). On a map from the end of the 19th century there is a 500 m long smelter pond in Brusiek, however, archival documents suggest that the weir in Brusiek was very high. At the end of the 18th century the weir was extended and made higher with the backwater part of the pond reaching Drutarnia village 4 km upstream from Brusiek (Goszyk, 2001). In the Brusiek1 study site, 1.5 km upstream of the weir and ironworks, lacustrine deposits of the smelter pond are exposed in the banks of the Mała Panew River.

Local concentrations of large amounts of charcoal and ash were exposed in the pale sands of the podzol soils in the forest on the Brusiek2 study site (6 km from the former foundry) due to tree felling and ploughing for new plantations. These are charcoal kilns — places where charcoal was burnt to supply the ferrous metallurgy industry. Historical sources provide information on very strong forest thinning near foundries in the Mała Panew basin which was the result of the large demands for charcoal in smelters and smithies (Tyrol, 2006). Foresters often discover the remains of charcoal kilns during ploughing with a density even reaching 5–6 per hectare (forester Czesław Tyrol — oral statement).

3. MATERIALS AND METHODS

Sampling and preparation of wooden piles and charcoal samples

Samples were taken from piles exposed by fluvial erosion in the area of the former Regolowiec settlement (4 piles in total, no. A1–A4) and piles excavated during the construction of a new artificial dam to retain a lake in 2013 (11 piles in total, no. 1–11) (**Fig. 6**). Using a chainsaw we sampled 15 discs from exposed piles. Discs were polished using sandpaper to reveal the wood structure and tree rings.

Five charcoal kilns (M1–M5) were sampled on the Brusiek2 study site. We have sampled the 90 biggest (2–9 cm long) charcoal fragments from individual kilns for analysis. The charcoal fragments sampled were cut using knives and scalpels to reveal their wood structure and tree rings.

Analysis of the species composition of the wooden piles and charcoal samples

We have determined the tree species composition of the wooden piles sampled and of the charcoal produced from wood. It was done to reconstruct the selection of tree species used for building construction and charcoal production. Identification of species was done through the observation of the cross sections, longitudinal sections and tangential sections of the wood under an optical

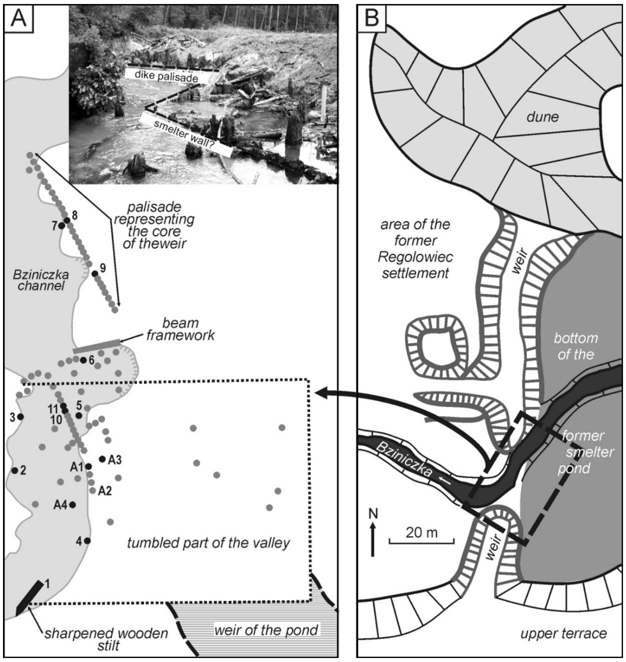

Fig. 6. *A – Remains of the smelting settlement in the Regolowiec study site (1–11, and A1–A4 – location of wooden samples dated using tree-rings), B – main relief features in the bottom of the Bziniczka River valley.*

microscope. Features of the wood anatomy observed on wood sections formed the basis of the species determination. Using the pattern of tree rings we have also determined the curvature of the rings, and thus the radius and size of trunks/branches used for charcoal production.

Dendrochronological dating of wooden piles and charcoal fragments

Measurements and analysis of tree-ring widths were conducted using standard methods (Ważny, 1993; 2001; Stokes and Smiley, 1996; Zielski and Krąpiec, 2004; Baillie, 2005; Speer, 2010). Annual rings in samples were measured using a RINNTECH Lintab 6 measuring station with TSAPWin Professional 4.65 software (Rinn, 2010). In Scots pine (*Pinus sylvestris*) it is established that a minimum of 50 rings is necessary for dating (Ważny 2001; Zielski and Krąpiec, 2004); a minimum of 30 rings is accepted when a large number of samples are available from a site/object (Backmeroff and Di Pasquale, 2001; Bilamboz, 2008). However due to the specificity of dendrochronological studies on charcoal we have analysed sequences that are >25 rings in length. The rather small number of rings in the samples demanded that the statistical criteria of dating confidence be outlined (**Table 1**). In dating we have analysed the values of the following parameters used in dendrochronology: coefficient of convergence (Gleichläufigkeit, GLK), Pearson correlation coefficient (r), t-values, and also the Cross-Date Index (CDI) which is a comprehensive indicator including values of t and GLK (Rinn, 2010). We have used Student's t-test to assess the statistical significance of the coefficients thus calculated. Critical values for different levels of significance (at 0.05, 0.01 and 0.001) were considered (**Table 2**, **3**). The value of the assumed level of significance was compared with the statistical test as calculated. In general, if the p-value was <0.05, then the sample has been considered as dated. To allow a better interpretation, the results of GLK were presented along with their statistical significance level. The verification of dating accuracy was conducted using COFECHA software (Holmes, 1983). Dating was conducted using a chronology of *Pinus sylvestris* including the period 1565–2010 AD. It was developed from tree-ring series from living trees growing in nature reserves and from construction wood from historic wooden buildings located in the Opole province (Opała, 2012, 2015), the region where three study sites are located. The dating was performed to determine the age of the smelting settlement in Regolowiec and to determine the time when charcoal kilns were used.

Analysis of lacustrine deposits

In the Brusiek1 study site we conducted a sedimentological analysis of the deposits exposed in the banks of Mała Panew River. We analysed two profiles (Profile 1, Profile 2) located 100 m away from one another. Profiles were analysed and described using the lithofacial code by Miall, modified by Zieliński (1995). In these profiles we have analysed the grain-size composition of particular sedimentary layers that were distinguished with the naked eye. The lower section of organic deposits in Profile 1 was dated using the radiocarbon method. Analyses of the sediments were conducted in order to determine the conditions of deposition of particular sedimentary layers. The aim was to date the deposits and to resolve whether they developed in flowing water in a river or in a stagnant water body — perhaps a smelter pond.

Table 1. *Established criteria of dating quality (based on: Rinn 2010; Kraler* et al.*, 2012 – modified), calculated for n = 50.*

Parameter	Abbrev.	Dating confidence level		
		1 (α = 0.001)	2 (α = 0.01)	3 (α = 0.05)
Gleichläufigkeit – coefficient of convergence	GLK	73.2	66.4	61.1
Pearson correlation coefficient	r	0.443	0.358	0.278
t-value (Bailie-Pichler) – value of t test according to Bailie and Pichler	TVBP	>3.5	3.5–2.0	<2
t-value (Hollstein) – value of t test according to Hollstein	TVH	>3.5	3.5–2.0	<2
Cross-Date Index – index of cross dating	CDI	>20	20–10	<10

Table 2. *Results of dendrochronological dating of wooden stilts.*

No	Lab code	No of tree rings	Parameter					Time period
			r	Glk	TVBP	TVH	CDI	
1	phut_08	77	0.435	85***	3.9	4.2	28	1527–1603
2	phut_09	51	0.353	73***	2.9	3.1	22	1589–1639
3	phut_02	73	0.465	59*	1.5	1.8	11	1653–1725
4	phut_01	45	0.703	60	3.4	2.9	19	1694–1738
5	phut_05	61	0.495	61*	3.1	3.6	20	1680–1740
6	phut_03	90	0.400	60*	3.2	3.6	21	1684–1773
7	phut_07	43	0.305	62*	2.4	2.1	14	1796–1838
8	phut_10	52	0.366	67**	2.8	2.2	17	1794–1845

Explanations for the table:
Significance of Gleichläufigkeit is divided into four categories:
**** – confidence level 99.9%; ** – confidence level 99%;* – confidence level 95%; lack of asterisks indicate confidence level 90%*

Table 3. *Results of dendrochronological dating of charcoals.*

No	Lab code	No of tree rings	Parameter					Time period
			r	Glk	TVBP	TVH	CDI	
Kiln 1								
1	M1.13	22	0.425	65	2.1	2.1	14	1646–1667
2	M1.46	49	0.506	71**	3.6	3.5	25	1649–1697
3	M1.4	30	0.545	79**	2.1	2.9	20	1658–1687
4	M1.3	24	0.557	59	0.5	1.1	5	1675–1698
5	M1.32	27	0.710	64	3.6	2.9	21	1675–1701
6	M1.36	26	0.662	50	1.8	1.4	8	1683–1708
7	M1.5	27	0.769	60	1.6	1.9	11	1685–1711
8	M1.1	43	0.521	63*	2.3	2.4	15	1671–1713
9	M1.17	43	0.521	64*	2.3	2.4	15	1671–1713
10	M1.10	23	0.617	67	0.4	1.4	6	1692–1714
11	M1.21	33	0.703	56	1.4	2.3	10	1683–1715
12	M1.51	28	0.511	46	1.9	1.4	7	1688–1715
13	M1.18	26	0.687	58	1.0	1.5	7	1691–1716
14	M1.20	24	0.804	50	0.7	0.8	4	1695–1718
15	M1.24	23	0.774	48	2.3	1.7	10	1700–1722
16	M1.31	34	0.642	52	1.0	1.0	5	1690–1723
17	M1.53	33	0.569	58	1.9	1.5	10	1699–1731
18	M1.22	33	0.451	65*	2.3	1.9	14	1821–1853
19	M1.30	46	0.415	67**	2.5	3.8	21	1857–1902
20	M1.45	45	0.538	70**	2.6	3.2	20	1876–1920
Kiln 2								
21	M2.05	27	0.486	67*	3.0	3.1	23	1616–1642
Kiln 3								
22	M3.15	22	0.500	85	4.6	2.1	29	1624–1645
23	M3.04	30	0.573	60	2.2	2.8	18	1621–1650
24	M3.05	30	0.716	71**	3.0	3.8	24	1621–1650
25	M3.16	24	0.528	24	0.9	1.8	11	1658–1681

Explanations for the table:
Data for samples with insufficient amount of tree rings (<25) is presented in grey (listed in the table for comparison purposes).
Significance of Gleichläufigkeit is divided into four categories:
**** – confidence level 99.9%; ** – confidence level 99%;* – confidence level 95%; lack of asterisks indicate confidence level 90%*

4. RESULTS

Wooden piles from the valley of the Bziniczka River, Regolowiec study site

Piles found in the bottom of the valley of the Bziniczka River, both exposed by fluvial erosion and excavated by man, can be divided into two groups. One of them includes piles that are regularly and geometrically distributed in the valley bottom (**Fig. 5**). The location of the piles probably reflects the former position of a building of the smithy. The second group is distributed in lines crosswise to the valley axis and river channel and reflects the shape and location of a weir partially destroyed due to fluvial erosion. The piles of the second group are probably a foundation of the earth embankment of the weir.

Wood anatomy analysis of the 15 discs sampled from the piles has revealed that all of them are made from Scots pine (*Pinus sylvestris*). Dendrochronological analysis of the 15 discs from the piles from the Bziniczka valley allowed us to obtain 12 absolute dates. In dated samples the values of the Cross-Date Index CDI have ranged from 6 up to 28, values of the t test ranged from 1 up to 4.2, values of the coefficient of convergence GLK varied between 52 and 88, and the correlation coefficient r varied between 0.268 and 0.495 which indicated that the dates obtained are reliable (dates with a probability of error of < 5%); (**Table 2**).

Among the 12 dated piles those of the oldest group of 6 piles (no. 8, 9, A1,A2, A3, A4) date back to the end of 17th century (the age of the youngest ring in each pile) which means that the trees were cut down and used for construction in that period (**Fig. 7**). The piles are part of a palisade on which the weir was constructed. The palisade is probably the oldest part of the construction. One of the piles has a terminal ring (last ring under bark) preserved which was dated to 1692 AD. The next group of 4 piles was made from trees cut down between the middle and the end of the 18th century (discs from piles no. 1, 2, 3, 5). They record the construction of a building directly downstream of the weir which may have been a smithy. The last 2 piles (no. 7, 10) come from the middle of the 19th century.

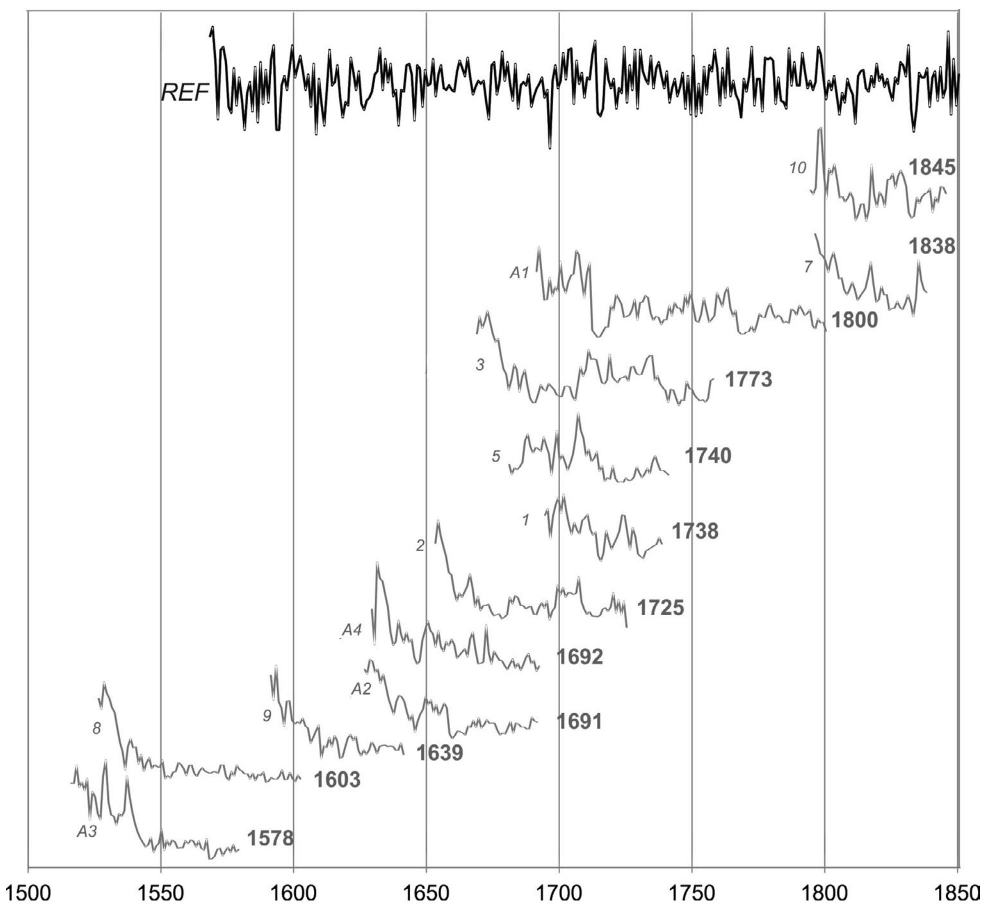

Fig. 7. *Dated tree-ring series from wooden piles collected from the valley floor of the Bziniczka River, REF — local chronology for Opole province (Regolowiec study site).*

Charcoal from charcoal kilns in the Brusiek2 study site

The sampled charcoal kilns are oval hummocks up to c 0.5 m high (e.g. **Fig. 2B**) and with a diameter of 7, 8, 8, 9 and 15 m. The hummocks are located at a distance of 100–150 m from one another. Among the 90 pieces of charcoal sampled for the dendrochronological study we have obtained absolute dendrochronological dating results from only 21 tree-ring series. This is an effect of the rejection of series shorter than 25 rings/years which predominated in the material studied (75% of charcoal fragments sampled). The statistical parameters of dating quality that were calculated were poorer than in case of the wooden piles from the Regolowiec site. In the case of charcoal fragments the Cross-Date Index CDI varied between 5 and 25, values of the t test varied between 1.0 and 3.8, values of the coefficient of convergence GLK ranged from 27 up to 79, the coefficient of convergence r ranged from 0.415 up to 0.716. The dating results obtained can be divided into two periods: 1642–1650 AD (charcoal kilns no. M2 and M3) and 1697–1731 AD (charcoal kiln no. M1), (**Fig. 7**). Despite the critically small number of tree rings in the charcoal fragments analysed it can be regarded as a reliable conclusion that their age dated to the start of the 18th century. This is due to the large number of dates covering a similar period (12 dates). We have also obtained relatively good statistical parameters of dating quality in the case of some samples (CDI>20, TV>3.5, p=99.9%): M1.46, M1.32, M3.05 (**Table 3**). Certain results that were obtained from the dating match well with the remainder of the dates obtained for other tree-ring series which fulfilled the criteria of the dendrochronological method. The results obtained suggest that the charcoal kilns originate from the 17th–18th century. In the M1 kiln (the biggest one, 15 m in diameter) we have identified charcoal pieces with the highest number of tree rings (the longest tree-ring series). A total of 16 pieces of charcoal were dated from the M1 kiln (**Fig. 8**). The youngest rings that were measured in particular fragments of charcoal from kiln M1 include the 1667–1722 AD period. However, the majority of charcoal pieces were dated to the turn of the 18th century (1697–1722 AD). It is significant that many of the dates match and cover the 1710–1722 AD period (as many as 11 charcoal fragments) (**Fig. 8**). From the M2 kiln only one piece of charcoal was dated to 1642 AD. In case of kiln M3 we were able to date 5 charcoal fragments. The ages of the youngest rings in these charcoal pieces are between 1642 and 1650 (4 samples) (**Fig. 8**). These charcoal fragments have relatively short 30-year-long ring series. We were not able to date any charcoal pieces collected from kilns M4 and M5.

All the pieces of charcoal sampled were produced from the wood of Scots pine (*Pinus sylvestris*). In most of the fragments of charcoal analysed we found low curvature of the rings. This suggests that the charcoal analysed was produced through burning relatively thick branches or stems. Fragments of small branches with a diameter of 0.5–2.0 cm are less frequent.

Deposits of the smelter pond in the Brusiek1 study site

Alluvial sands with cross-bedding can be found in the lower parts (170–250 cm and 130–180 cm below the ground surface) of both sediment profiles analysed (**Fig. 9**). Higher up in the profiles they turn into clays and muds (95–170 cm and 75–130 cm) with horizontal lamination. In the upper parts of profiles (60–95 cm and 35–75 cm below the ground surface) we have once again observed sands with cross-bedding, wavy, uncontinuous bedding or massive structure. In the surface parts of the sediment profile soils have developed (0–60 cm and 0–35 cm). The middle parts of profiles, composed of clays and muds, contain large amounts of poorly decomposed organic material. In these layers we found remains of wood, including burnt wood, pieces of bark and cones, needles and a few fragments of leaves. Charcoal from the lowermost part of the fine deposits of Profile 1 was dated using the radiocarbon method to 305 ± 50 years BP which allows one to estimate the date of the beginning of sediment deposition (**Fig. 9**) and implies that the clays and muds were deposited not earlier than 1600–1650 AD (Lab number: Ki 11881).

5. DISCUSSION

The dating results obtained for the wooden piles from the bottom of the valley of the Bziniczka River at the Regolowiec study site indicate that the smelting settlement of Regolowiec already existed at the end of the 17th century. This was proven by the dated age of the terminal ring in one of the piles (sample: disc A4 with 1692 terminal ring). Another sample (disc A2) has a very similar age to the youngest ring: 1691 AD. This suggests that the Regolowiec settlement is at least a few decades older than the middle of the 18th century as historical written sources indicate (Globisch, 2004; Mańczyk, 2007). It is interesting that there are also older datings of piles: 1578 AD, 1603 AD, 1639 AD. Although the piles do not have terminal rings and the tree-ring series obtained from these piles are not long (51–77 rings each), it is possible that the settlement existed earlier than 1692 AD. Historical sources often indicate the date when smelting settlements already existed which is why field and laboratory studies with the use of dendrochronological methods allow us to verify the real age of wooden buildings and through this also the foundation dates of settlements (Krąpiec *et al.*, 1996; Krąpiec, 1998; Poleski and Krąpiec, 2000). In the case of the Regolowiec settlement we cannot exclude the possibility that an older generation of piles/older settlement event in the valley of Bziniczka River is not necessarily related with ferrous metallurgy. Undoubtedly the oldest piles are a core of the weir, so in the Regolowiec area water was a source of power at an earlier time than is stated in historical sources. It could have been used for

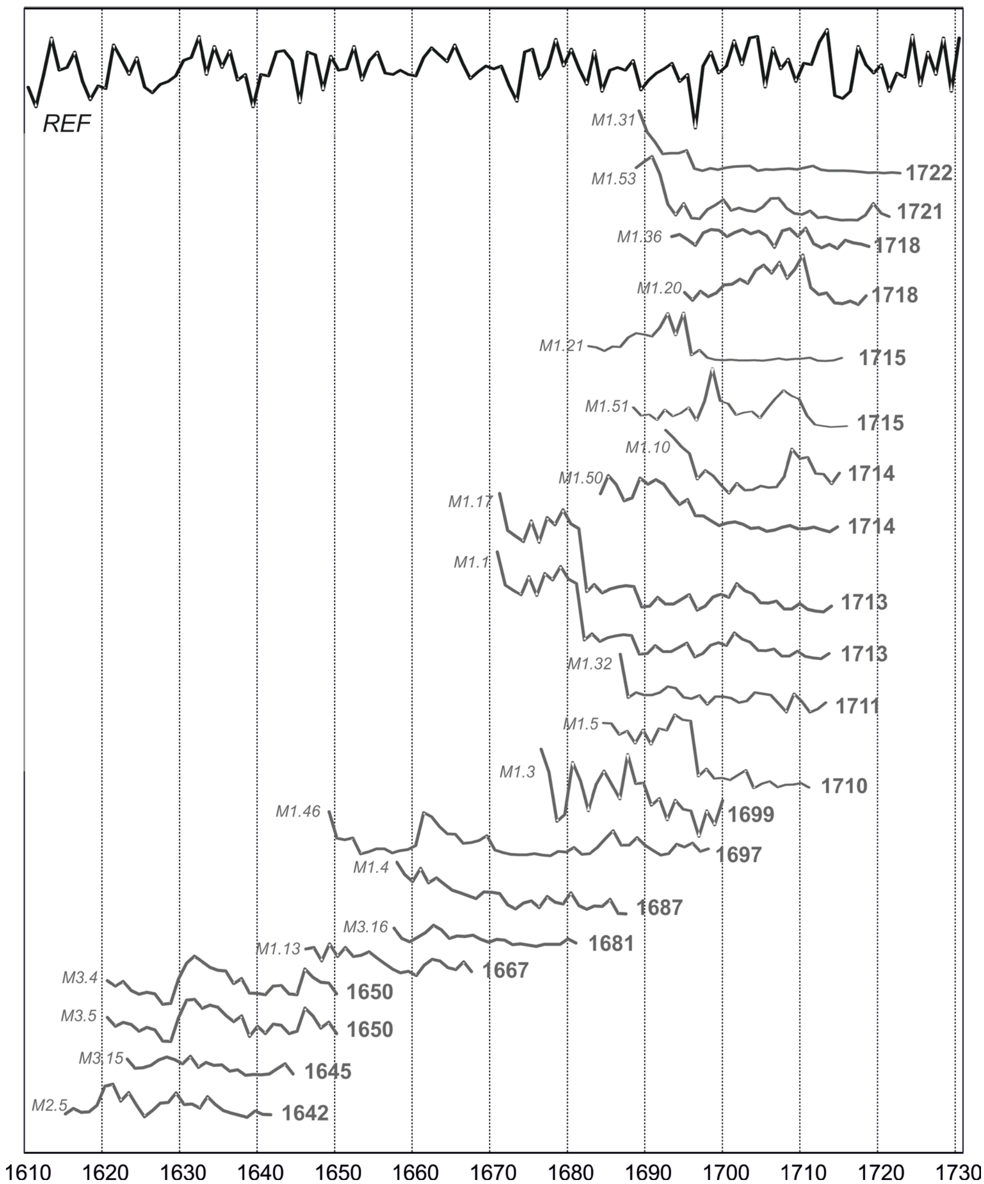

Fig. 8. *Dated tree-ring series from charcoal fragments collected in the kilns studied, REF — local chronology for Opole province (Brusiek2 study site).*

the needs of ironworks but also it could have been that a watermill existed in Regolowiec before the ironworks was founded. Yet, no information on a watermill has been found in historical sources until now. Yet, in medieval Europe ironworks were often founded in the same places that watermills had earlier existed (Tylecote, 1992).

Some wooden piles in the area where an ironworks existed in Regolowiec were also dated to the 19th century (discs from piles: 7, 10). These piles adjoin the palisade which is a core of the weir. The 19th century piles could have been incorporated into an older, existing weir during its repair e.g. after it was partially destroyed or broken. There are numerous references in historical documents to the destruction of hydraulic constructions and weirs during floods which occurred in the basin of Mała Panew River (Goszyk, 2001; 2004).

The dating results obtained indicate that in the charcoal kilns studied on the Brusiek2 study site (near the ironworks in Brusiek village), charcoal was produced at the turn of the 17–18th centuries. A few charcoal fragments provided older dates which suggests that kilns could have been used earlier — maybe they had already been operating since the middle of the 17th century (samples M2.5, M3.4, M3.5, M3.15). It was a period of fast development of ferrous metallurgy in the study area and on the whole Opole Plain where the basin of the Mała Panew River is located (Juros, 2012). There are, however, some limitations connected with dating charcoal fragments. We have dated relatively short series of tree-rings.

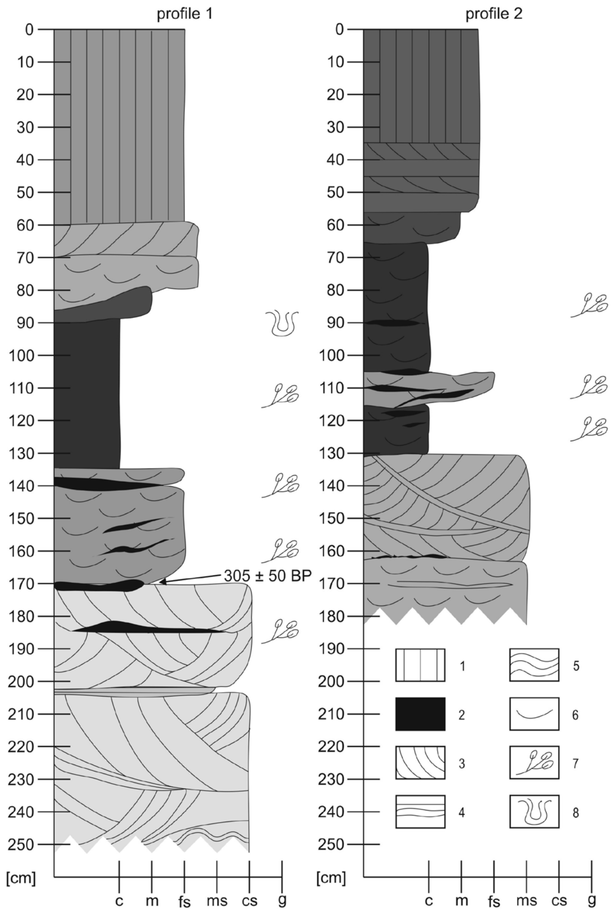

Fig. 9. *Two sediment profiles exposed in the bank of the Mała Panew River upstream of the Brusiek ironworks (Brusiek1 study site): 1 – soil, 2 – layers composed of organic material, 3 – cross-bedding, 4 – horizontal bedding, 5 – wavy bedding, 6 – flaser ripple bedding, 7 – plant macrofossils, 8 – soft sediment deformation (load structures), c – clay, m – mud, fs – fine sand, ms – medium sand, cs – coarse sand, g – gravel.*

We do not know how big are the gaps between the youngest dated rings and the terminal rings in each sample. Finally we have no information whether particular pieces of charcoal are fragments of the same or different tree specimens. The results indicate that only pine wood was used for charcoal production — regardless of the species composition in the neighbouring forests. Potentially the natural forest communities of the area were pine-oak forests with deciduous riparian forests in river valleys. From the 19th century onwards spruce (*Picea abies*) forest monocultures have been introduced into the area. For charcoal production thick tree stems were mainly used which means that besides intentional selection of tree species for burning, the wood was also carefully prepared in order to obtain the best quality fuel.

The fine grained character of sediments exposed in the banks of the Mała Panew River upstream of Brusiek village (Brusiek1 study site) which divide laminated sandy deposits suggests that they were deposited in stagnant water, so in a water body of a pond or lake. It does not however determine the origin of the water body as a smelter pond. Fine grained deposits with a high content of organic material are commonly accumulated in oxbow lakes and next exposed in eroded banks (Klimek, 1996; Kaczmarzyk *et al.,* 2008). However the sedimentary sequence described is widespread in the banks of the Mała Panew channel on the Brusiek1 study site. It occurs in almost all bank undercuts upstream of the Brusiek smelter up to Drutarnia village. This means that fine-grained sediments were deposited over an extensive area which confirms data from historical sources on the large backwater range of the smelter pond reaching Drutarnia village (Goszyk, 2001; 2004). A large smelter pond with a weir already existed in Brusiek in the 17th century which is confirmed by radiocarbon dating of the lacustrine deposits studied, while historical sources have only confirmed the existence of the pond from the 18th century onwards.

There are no traces of human-made changes in the shoreline and bottom of the pond, we can assume that the weir banked up water which filled the valley bottom forming a large smelter pond.

6. CONCLUSIONS

The settlement in Regolowiec, in the Mała Panew basin, already existed in the 17th century, so some decades earlier than has been mentioned in historical sources. Dendrochronological dating of wooden piles forming the core of the weir damming the Bziniczka River allows us to state that the smelting settlement was older than has been widely acknowledged. We have also found that the weir was repaired after damage, caused probably by floods.

The charcoal that was used as a fuel for iron processing in the ironworks in Brusiek by the Mała Panew River was produced at the turn of the 17th-18th centuries. The results confirm historical written records indicating that ferrous metallurgy was particularly prosperous in the period. Pine wood from large trunks was used for charcoal production. In the first half of the 17th century in Brusiek, upstream of the ironworks, a large smelter pond was constructed which filled the bottom of the Mała Panew valley with water. The pond was older than is indicated in historical records according to which it was founded in the 18th century.

The research conducted shows that field and laboratory studies based on dendrochronological dating and the analysis of lacustrine deposits of smelter ponds can allow one to reconstruct the development of historical ferrous metallurgy. Dendrochronological dating and sedimentary analyses can allow one to verify the time when former smelting settlements existed – information which until now was based on often uncertain historical records.

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