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Traces of historical metallurgy and charcoal burning in the Daleszyce region (southern Poland)

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Remains resulting from historical iron smelting and charcoal burning in the Daleszyce region (Holy Cross Mountains, Poland) have been examined using a combination of analysis of archival map data, historical literature review, digital elevation models, and absolute dating techniques (radiocarbon and dendrochronological dating). We identify and document sites associated with iron smelting and charcoal production, in the form of extensive remnants of bloomeries, ironworks, iron ore extraction shafts, and charcoal hearths, confirming the significant role of metallurgy in shaping the historical landscape. Radiocarbon and dendrochronological dating indicate that iron smelting and charcoal production were active between the 16th and 19th centuries. The environmental impact of metallurgy, particularly deforestation, and its contribution to local economic development, is highlighted. These findings serve as a foundation for further interdisciplinary research on historical metallurgy in Central Europe.

Key words: historical metallurgy, charcoal burning, iron smelting, radiocarbon dating, dendrochronology, Holy Cross Mountains.

INTRODUCTION

The Holy Cross Mountains region, due to its natural richness, including notably in iron ore, has long been a site of various human activities (Orzechowski, 2007). As shown by previous studies (e.g., Bielenin, 1992, 1993; Przychodni, 2002, 2006; Orzechowski, 2007) iron has been smelted in the area as early as antiquity and continued into the period of Roman influence. At that time there was a huge smelting centre in the Holy Cross Mountains, of compact character and mainly in the north-eastern foothills of the Łysogóry range. Iron was produced in cauldron-shaped furnaces with above-ground shafts, commonly called bloomeries (dymarki; Orzechowski, 2007). Three sites with traces of ancient smelting production (residues of smelting slag) were recorded in the study area in the village of Napęków (AZP 86-65) (Przychodni, 2006). In addition, studies of the peat bog in Słopiec made by Szczepanek (1982) demonstrated a correlation of pollen curve changes with the functioning of ancient metallurgy in the Holy Cross Mountains in the 11th century. Peat thickness here reached 5.05–5.15 metres (Szczepanek,1982). Mining, smelting and processing of iron in the area of the Holy Cross Mountains and its periphery also took place in the Middle Ages and historical times (Sedlak, 1976; Orzechowski, 2007; Kalicki et al., 2019, 2020; Rutkiewicz et al., 2019; Przepióra and Kalicki, 2024). However, it was already a different type of metallurgy, using water power and water wheels, and a different type of furnace, with the change from bloomeries to blast furnaces. Smelting plants were located in river valleys, and the smelting district operating here consisted of many scattered plants in various river basins (Drogosz and Cedro, 2020). According to the Archaeological Picture of Poland (AZP), iron production sites from the Late Middle Ages (13th–14th centuries) were also recognized in the study area, and fragments of iron slag from production in bloomeries in the vicinity of Napęków (6 sites) and in the vicinity of Smyków (one site) have been found (mapy.zabytek.gov.pl/nid/).

Charcoal production was essential for the development of this activity (Rutkiewicz et al., 2017, 2019; Rutkiewicz and Malik, 2019; Rutkiewicz and Kalicki, 2022). Charcoal burning was the primary method of producing charcoal until the early

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20th century. Wood burning took place in piles of wood, arranged in a dome shape and covered tightly with clay, soil or draped with turf. The wood was burnt in the charcoal hearths with a small, controlled access of air to produce charcoal by dry distillation. The charcoal obtained in this way has a higher calorific value than wood and is therefore a more economic fuel type if it needs to be transported over longer distances. Moreover, it was a better high-energy fuel necessary for smelting iron ore (Hollingdale et al., 1999; Groenewoudt, 2007; Hirsch et al., 2018).The smelting of the ore itself took place in bloomeries, i.e. ancient smelting furnaces in which iron was obtained by reducing oxide iron ores at high temperatures generated by burning charcoal. Bloomeries had the form of furnaces that were partially buried in the ground and were for single use (Bielenin, 1992, 1993; Przychodni, 2002, 2006; Orzechowski, 2007, 2013). In the case of single use bloomeries after the smelting process was completed, the above-ground part of the bloomery was destroyed and the buried part together with the slag was left behind. These remains are today a valuable source of information on prehistoric iron metallurgy (Bielenin, 1959a, 2005; Suliga, 2006; Bielenin and Suliga, 2008; Orzechowski, 2012; Przychodni and Suliga, 2016; Kupczak et al., 2024). During the medieval period, bloomery evolved slightly to become what was called a medieval or modern bloomery. It differed from ancient shaft-cauldron furnaces, commonly referred to as bloomeries, in that it was of permanent construction as opposed to the "one-off" ancient bloomery. It was also, of course, much larger in size (Kołodziejski, 2020). There is no description of a Polish bloomery from the 12th–16th centuries. Only the metallurgist poet W. Roździeński gave some remarks (in a poem) about its construction. "The body measured 142 142 99 cm, and the mortar – crucible had a diameter of 42 cm and a depth of 28 cm. The bellows and hammers were driven by water power" (Kmieć, 2000). At the turn of the 16th and 17th centuries, blast furnaces were introduced in the Polish lands, replacing the medieval bloomeries (Nowak, 2020) for the slag and an artificial air draft was forced using bellows.

The iron obtained in the bloomery furnaces was soft, contaminated with slag and had the form of lumps of sponge iron, known historically as "blooms", so further processing was required to obtain material suitable for producing tools or weapons. To obtain hard iron, blooms had to be removed from the furnace and forged with the addition of charcoal. Forging increased the degree of carbonisation and transformed the soft iron into steel. This took place in forges, where the metals smelted from the ore were treated or converted using a hammer driven by the energy of a waterwheel. The hammer mills were also the place where semi-finished and finished metal products were shaped.

The development of metallurgy was therefore inextricably associated with charcoal production on a large scale (Rösler et al., 2012; Raab et al., 2015, 2022; Rutkiewicz et al., 2017, 2019; Deforce et al., 2021; Słowiński et al., 2024), because the smelting furnaces required this high-energy fuel, and due to the fact that charcoal was a reductant of oxide iron ores in the smelting process.

In the area of the Holy Cross Mountains, the production of iron and charcoal has a long history dating back to the 4th century. The existence of both these forms of human activity is well documented in historical sources (Bielenin, 1959b, 1973, 1992, 2006; Radwan, 1959). Remnants of related infrastructure are also still evident in the area, such as iron ore extraction shafts, remains of charcoal hearths, bloomeries, ironworks, and dams, ponds and channels, which were built to dam up the water needed to power water wheels and other mechanisms (e.g., Kaptur, 2014; Chrabąszcz et al., 2017; Przepióra, 2017; Przepióra et al., 2019; Aksamit et al., 2019; Rutkiewicz et al., 2017, 2019; Kalicki et al., 2019, 2020; Fularczyk et al., 2020; Kusztal et al., 2020; Kusztal, 2022).

This study documents the remains of historic iron smelting and charcoal burning in the vicinity of Daleszyce city and describes their environmental and historical context. For this purpose, we have utilised various methods: analysis of archival cartographic documents, historical literature search, inspection of digital elevation models as well as age determination, namely radiocarbon dating and dendrochronology. This study serves as a case study and a basis for further research.

STUDY AREA AND ITS SUITABILITY FOR IRON SMELTING

The study area is located in the macro-region of the Kielce Upland, on the border of the mesoregions of the Holy Cross Mountains and Szydłowieckie Foothills (Richling et al., 2021; Fig. 1). The north-eastern and northern part of the study area is dominated by distinct bands of hills developed on outcrops of Paleozoic rocks. These are the Bielińskie, Orłowińskie, Ocieseckie, Cisowskie and Brzechowskie ranges. The relative heights here reach 200 m. In the south-western and southern part of the study area, the absolute heights are lower and the relief less varied. There are low hills developed on outcrops of Paleozoic and Mesozoic rocks. Between Daleszyce and Smyków, in the central part of the study area, there extends a large flat area occupied by peat bogs which are part of the Białe Ługi nature reserve (Fig. 1). The region described is contained within the boundaries of the Detailed Geological Map of Poland (SMGP) 1:50 000 (852), Daleszyce sheet (geologia.pgi.gov.pl-/mapy/?page=Kartografia-geologiczna). An essential element that allowed the existence of iron smelting was the presence of raw material in the form of iron ores. The ore-bearing horizon, which has been exploited in the vicinity of Daleszyce (Brzechowskie range), was called the ore-bearing Cuvinium or Lower Eifel ore-bearing clays in the older literature. It occurs in the Kielce region at the boundary between the Lower and Middle Devonian. It extends in a narrow belt from the vicinity of Porzecze by the Bobrza River in the west, through Miedziana Góra, the northern part of Kielce, Niestachów, Daleszyce, to Łagów in the east (Kozak et al., 2025). Iron ores exploited north of Daleszyce, in the foothills of the Koski, Podłaziana and Świnia Góra hills, were described by Czarnocki (1956). They belong to the Porzecze ore-bearing siltstone cell. Within it, there are irregular, nested ore bodies, consisting mainly of limonite and clayey ferruginides, and to a lesser extent of hematite (mainly in the form of so-called "hematite cream"). These deposits are located in the clay transition zone separating the Lower Devonian sandstones from the Middle Devonian dolomites (Kozak et al., 2025). Lower Devonian sideritic wackes belonging to the Haliszka Formation and Lower and Middle Devonian claystone with siderite belonging to the Barania Góra Formation contained more iron compounds (Tarnowska, 1995; Wójcik, 2015). Sideritic wackes were found in the vicinity of Borków and Belno villages, at the foot of the Sikorza and Żarnowica hills, on the slopes of Wał hill, and at the foot of the Kamionka, Kamień and Stołowa hills. Whereas, sideritic clays occurred on the Sikorza, Podłaziana, Świnia, Koska hills, north of Daleszyce and south of the Belnianka valley, on Hucisko, Skałka, Kamionka, Wrzosowa and Wreśnia hills, as well as on hills south of Borków and north-west of Szczecno (verbal information from Pedrycz, 2024; Fig. 2). Iron

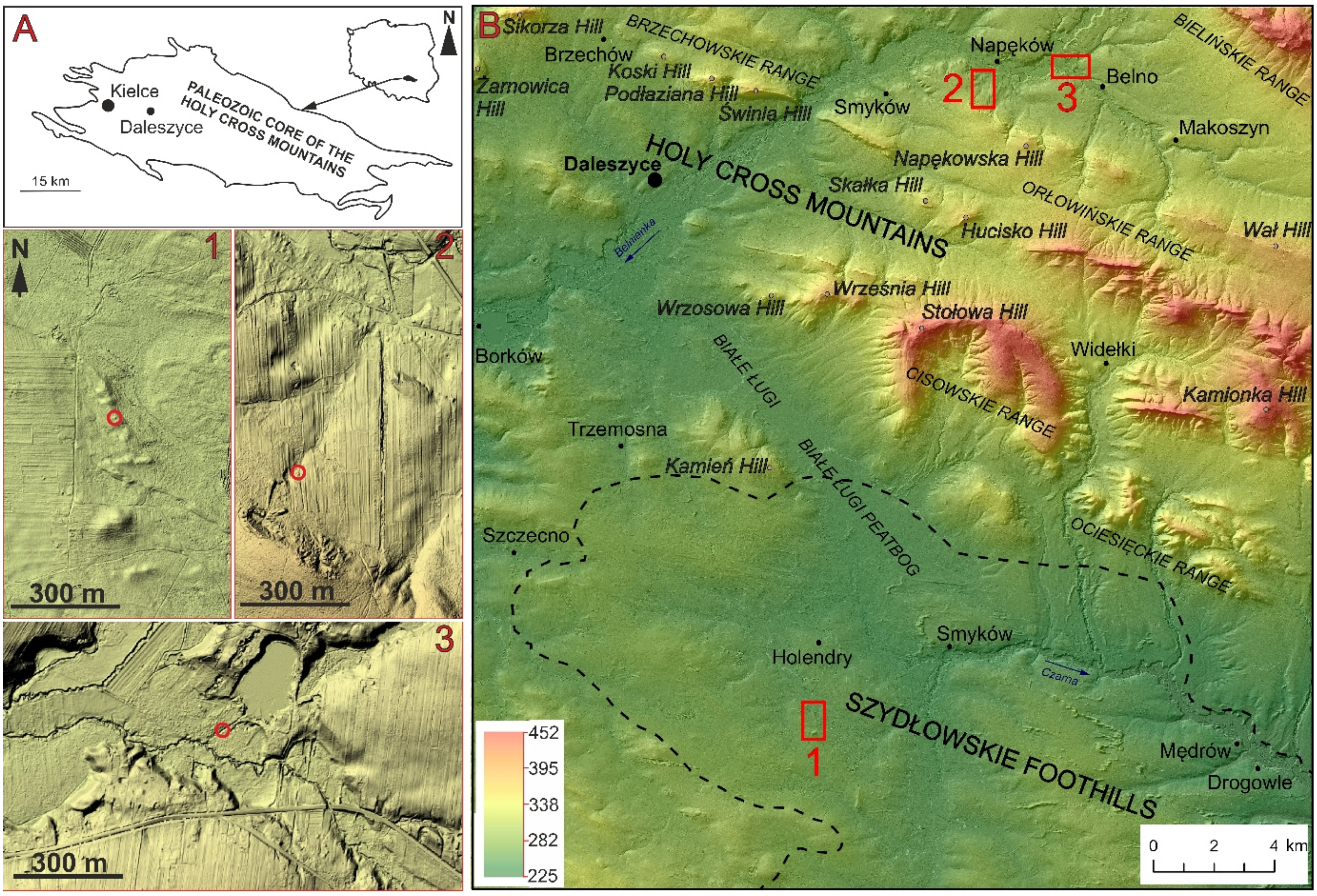

Fig. 1. Location of the study area and sites investigated

A – study area in the context of Poland and the Holy Cross Mountains; **B** – location of the sites investigated on a DEM (Digital Elevation Model) of the Holy Cross Mountains: 1 – Stara Huta, 2 – Napęków, 3 – Napęków/Belno. Shown also are enlargements of the map for individual research sites. DEM models created by Paweł Rutkiewicz based on Polish Geological Institute (PGI) data

ore was also extracted from bog iron ores which were common and readily available. These were extracted from the floodplains of the Belnianka and Czarna valleys, the wetlands adjacent to them and from peat bogs (Fig. 2).

The Belnianka valley and the valleys of its tributaries (including the Nidzianka) are also distinctive in the topography of the area. The rivers of the Holy Cross Mountains region were of great importance for human economic activities. It was in them that ironworks and smelters were often located, as well as dams, ponds and canals. The flowing waters, properly managed, provided energy to drive water wheels and other mechanisms (Nowak and Jagodziński, 2020). For example, the average gradient of the Belnianka is 11.04‰, which classifies it as an upland river (Ludwikowska-Kędzia, 2000). In addition, the natural narrowing of the bottom of Belnianka valley was also used to build dams and create smelting ponds, providing the possibility of damming up the waters.

In turn, for the charcoal hearths and charcoal burning, areas with sandy substrates were of great importance. It was also significant that these were adjacent to marshy or swampy areas because the proximity of wetlands prevented the spread of possible fires associated with the coal burning (Deforce et al., 2013; Raab et al., 2015, 2017). Charcoal production provided the heating energy required for smelting activities. The development of metallurgy in the area was facilitated by the vast expanses of forests. The Holy Cross backwoods and other nearby forests formed an excellent base for meeting the needs of charcoal burning (Drogosz and Cedro, 2020). Particularly abundant in the past, deciduous forest communities with dominant beech trees provided an excellent resource in the form of hardwoods, which were preferred by metallurgists as more calorific than coniferous wood. Historical conditions, involving the extraction of beech as a high-calorific wood resource, were also significant for the physiognomy of the phytocenoses and their species composition (Piwowarski, 2020). These forests are close to natural in character, although in some places the dominance of fir in the stands appears to be the result of past human economic activity (increased harvesting of beech, mainly for glassmaking and, in the 18th-19th centuries, for iron smelting) (Szczygielski et al., 2020).

All of these natural factors, together with the abundance of timber from the surrounding forests, created favourable conditions for the development of ore mining and smelting. In the vicinity of Daleszyce, the most famous ironworks and smelters were located in Makoszyn, Belno, Napęków, Smyków (Belnianka valley), Szczecno (Wojciechów), Smyków (Czarna valley), Mędrów and Drogowle (Kalina, 2002, 2023a, b, d; Drogosz and Cedro, 2020).

MATERIALS AND METHODS

ANALYSIS OF ARCHIVAL CARTOGRAPHIC DOCUMENTS

At the initial stage of the work, archival cartographic documents (Fig. 3) and an Archaeological Picture of Poland (AZP) were analysed to determine the location of dams and former ironworks reservoirs in river valley bottoms. Then, based on a

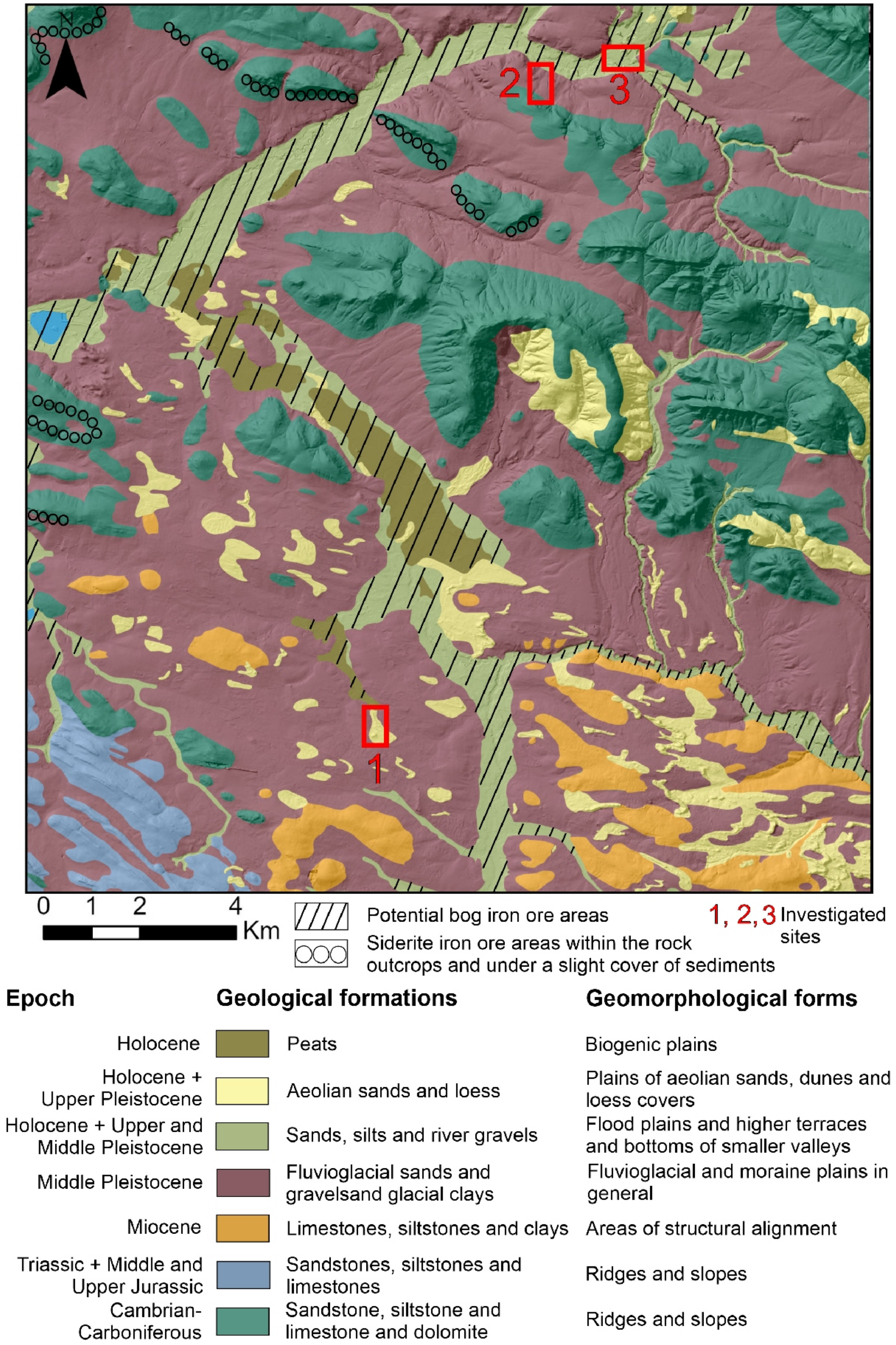

Fig. 2. Simplified geological and geomorphological sketch of the study area, according to Filonowicz (1976)

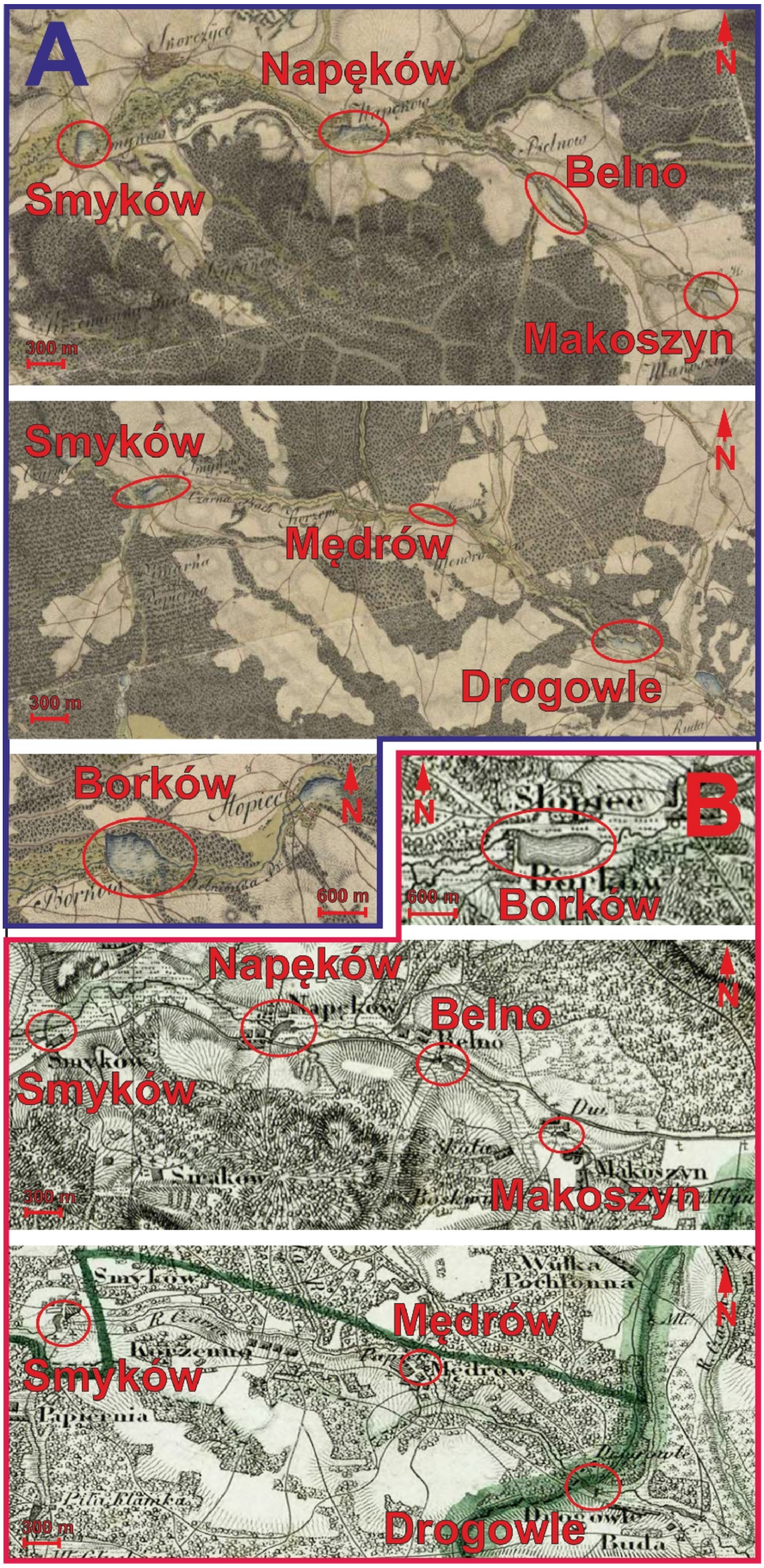

Fig. 3. Parts of archival maps showing localities where dams and ironworks as well as smelting reservoirs were operated

A – map of Western Galicia (Mapa Galicji Zachodniej, 1804); **B** – topographical Chart of the Kingdom of Poland (Topograficzna Karta Królestwa Polskiego, 1843)

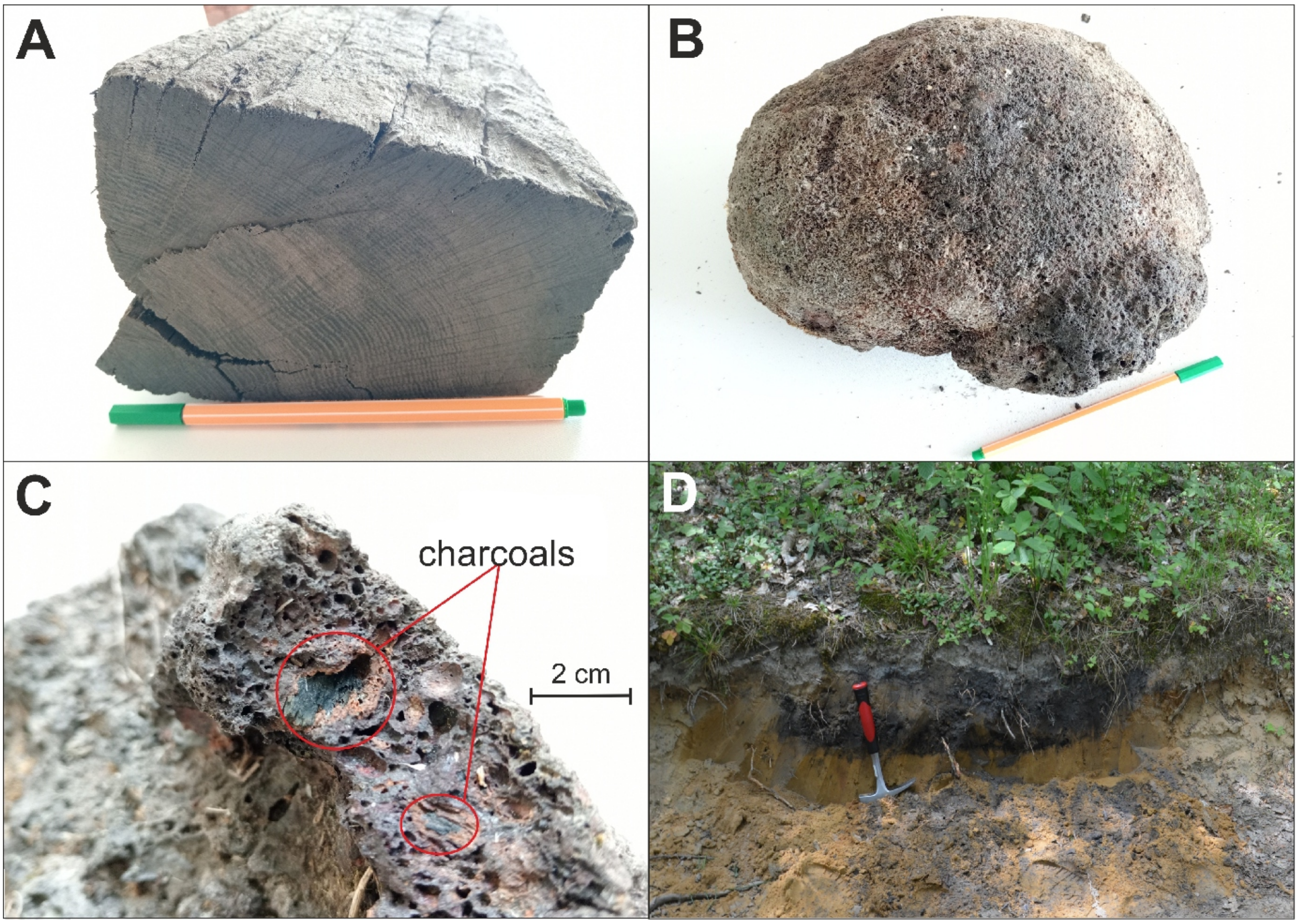

Fig. 4. Smelting remnants from the study sites

A – wooden beam (with visible tree-rings) from the Napęków/Belno site; **B** – lump of slag from the Napęków/Belno site; **C** – charcoal incorporated into smelter slag from the Napęków/Belno site; **D** – internal structure of sediments in a charcoal hearth remain crossed by a road

review of historical literature, information on the time of their functioning was obtained for the objects selected (Radwan, 1956; Wyrobisz, 1968; Sedlak, 1976; Kalina, 2002, 2023a–e; Drogosz and Cedro, 2020).

DIGITAL ELEVATION MODEL

In the next stage of the work, DEMs (with a resolution of 1 m) were inspected and forms related to smelting and charcoal burning as well as iron ore mining were identified. (DEM models were created by Paweł Rutkiewicz based on PGI data).

Forms identified on the DEMs were verified by fieldwork. An overview of selected forms was made using exposures from road scarps or animal burrows. Particular attention was paid to the remains of charcoal hearths, due to their frequent occurrence.

AGE DETERMINATION

During the field surveys, samples were collected from the forms identified and from sediments related to iron smelting. Among the samples taken were charcoals, slags and fragments of wood. This research material was subjected to absolute dating, carried out in the Laboratory of the Silesian University of Technology, in the Division of Geochronology and Environmental Isotopes in Gliwice.

RADIOCARBON DATING

Radiocarbon dating was performed on three charcoal samples and one wood sample (see Fig. 4 and Table 1).

Charcoal samples were taken from two charcoal hearth remains. One was located at the foot of Napękowska Mount, a few kilometres south of the former ironworks at Napęków, and the other was situated on a dune in the vicinity of the hamlet of Stara Huta, south of the village of Holendry (Figs. 1.1, 2, 3 and 4D). Charcoal fragments were also obtained from a lump of smelter slag (Fig. 4B, C).

A wooden beam selected for dating (Fig. 4A) came from the structure of a former smelter building.

The lump of slag and the beam were excavated from the alluvium of the Nidzianka River, near its mouth into the Belnianka River, during excavation of his deposit by Mr Walenty Pawlik and submitted for this research.

Radiocarbon dating was performed using accelerator mass spectrometry (AMS), following commonly accepted protocols (Piotrowska, 2013; Ustrzycka et al., 2025). All samples underwent chemical pre-treatment to remove potential contaminants from the sedimentary environment. A standard acid-base-acid (ABA) preparation was used for this purpose.

In the case of the wood sample, the first step involved extraction using a *Soxhlet* apparatus with organic solvents (toluene and ethyl alcohol) to remove resins. The next step included standard ABA preparation, while the final step required the use

Table 1

Sample descriptions

Sample name	Material	Context and sample description	Lab. code	Type of chemical pretreatment and obtained product
Huta Stara K2-PR-3	charcoal	charcoal hearth remains; 15 annual growth-rings, spruce	GdA-7370.1.1.	ABA → charcoal
Napęków K3-PR-2	charcoal	charcoal hearth remains; 5 annual growth-rings, pine	GdA-7371.1.1.	ABA → charcoal
Napęków K4-PR-1	charcoal	a lump of slag; 15 annual growth-rings, pine	GdA-7372.1.1.	ABA → charcoal
Napęków K1-PR-4	wood	beam from the smelter building; 164 annual growth-rings, oak	GdA-7373.1.1.	Soxhlet+ABA+Bl → holocellulose

Chemical pre-treatment: Soxhlet – extraction in Soxhlet apparatus; ABA – acid-base-acid preparation; Bl – bleaching

of sodium chlorite to remove lignin. This step is called bleaching (Bl). As a result, the final product was holocellulose, which is the best wood fraction for radiocarbon dating (Hajdas et al., 2017).

After chemical pre-treatment, the samples were combusted and graphitized using the *AGE-3* system, equipped with a Vario Micro Cube elemental analyser (Němec et al., 2010; Wacker et al., 2010b). They were then subjected to radiocarbon concentration measurement using a *MICADAS* accelerator mass spectrometer, manufactured by IonPlus (Synal et al., 2007; Wacker et al., 2010a). The resulting radiocarbon ages were calibrated using the *IntCal20* calibration curve (Reimer et al., 2020) and the *OxCal v.4* calibration program (Bronk Ramsey, 2009).

DENDROCHRONOLOGICAL DATING

For dendrochronological dating, only one sample, the wooden beam, was selected because only this wood had a sufficient number of growth rings. In the first step, this fragment of beam was prepared for dendrochronological measurements. For this purpose, a wood transverse section was carefully cut with a sharp knife to obtain a clearly visible growth-rings surface. Then, the anatomical structure of wood was observed to identify its taxonomical affiliation. Next, the ring width was measured with 0.01 mm precision using the *LINTAB* system and *TSAP Win* computer program (Rinn, 2003). The measurement sequences of growth-ring width obtained were averaged and compared with available master chronologies to determine the age of this sample. In this case standard chronologies published by Tomasz Ważny (https://www.ncei.noaa.gov/access/paleo-search/) were utilised.

RESULTS

Studies of archival cartographic documents, an Archaeological Picture of Poland (AZP), a review of historical literature and a browsing of maps in the form of DEMs, followed by field surveys, made it possible to select and identify the areas of occurrence of smelters, ironworks, charcoal hearth remains and dams. Subsequently, samples of charcoal and wood were taken from these research sites for laboratory analysis to determine their absolute age. On the AZP there are no monuments at the locations of former smelting plants indicated. One monument was noted on the AZP, i.e. a wooden mill in the village of Belno, but it dates back only to the 19th century. As noted above, only a few sites of ancient smelting slag and a few sites of medieval smelting slag have been recorded on the AZP.

STARA HUTA SITE

This site comprised remains of a charcoal hearth identified within a dune (Fig. 1B). This is an individual form at a considerable distance from other charcoal hearth remains. In the study area, scattered charcoal hearth remains (Fig. 5J) are far fewer than those clustered in groups (Fig. 5H, I). For the investigation, one charcoal sample (Stara Huta K2-PR-3) was collected from the wall of an animal burrow. Field observations and DEM analysis showed that the diameter of the charcoal hearth was ~14–15 m. The AMS dating results (GdA-7370.1.1; Table 2 and Fig. 6) indicate two probable ranges for the burnt wood: 1683–1735 AD (25.8%) and 1803–1930 AD (69.6%).

NAPĘKÓW SITE (NAPĘKOWSKA MOUNT)

This site enclosed charcoal hearth remains, identified at the foot of Napękowska Mount (Fig. 1B). This form was not visible in the field (due to dense shrubs) and additionally was strongly obliterated, but thanks to the DEM analysis it was possible to identify it correctly.

One sample of charcoal (Napęków K3-PR-2) was collected for analysis. The sample was extracted from the scarp of the field road that crosses the charcoal hearth remain. This intersection exposed the internal structure of the charcoal hearth together with a distinctive black layer of charcoal and wood ash (Fig. 4D). From field observations and DEM analysis it was concluded that the form was 14 m in diameter. The AMS dating results (GdA-7371.1.1; Table 2 and Fig. 6) indicated that the burnt wood may have originated between 1680 and 1740 AD (25.5%), or between 1752 and 1763 AD (2.5%), or between 1800 and 1941 AD (67.5%).

NAPĘKÓW/ BELNO SITE

One sample taken from the site was in the form of a lump of smelting slag, with charcoal embedded in it (Fig. 4B, C) and the second one was a fragment of a wooden beam, a remnant from the construction of a smelter located in the Napęków-Belno area (Fig. 4A).

Radiocarbon dating of charcoal (Napęków K4-PR-1) embedded in the smelting slag found near the former ironworks at Belno and Napęków, allowed an age of between 1448 and

1631 (95.4%), with a high probability that this was the beginning of this time interval 1448–1524 (62.7%) (GdA-7372.1.1; Table 2 and Fig. 6).

On the basis of dendrochronological studies, the beam was identified as oak (*Quercus* sp.) wood with a sequence of 164 annual growth rings. The preserved timber has no sapwood layer. This indicates that the beam was a structural element and the wood from which it was made was most probably de-barked and hewn. Dendrochronological dating demonstrated that the measured growth-rings span the years 1391–1554 AD. However, to determine the date when the tree was felled, the unknown number of heartwood rings that may have been removed during de-barking, as well as the average number of sapwood rings defined for the area, i.e. 12(–6/+7), must be added (Zielski and Krąpiec, 2004). That is, a minimum of 12–6=6 and a maximum of 12+7=19 sapwood rings. Thus, the earliest possible date for the cutting of this tree was 1560 AD (Table 2 and Fig. 6).

In addition to dendrochronological analysis, two growth-rings were taken from this beam for radiocarbon dating. These were rings positioned as 38 and 39 in the measurement sequence, counting from the pith (Napęków K1-PR-4; Table 2 and Fig. 6). After growth-ring 39 therefore, another 125 rings (years) occurred in wood that have to be added to the AMS date. Moreover, the unknown number of removed heartwood rings and the minimum number of sapwood rings must be taken into account also in this case. The AMS dating results (GdA-7373.1.1; Table 2 and Fig. 6) indicated that the beam wood may have originated between 1397 and 1446 AD (95.4%). Thus, it is necessary to add to this date at least 125+6=131 years, resulting in a date of between 1541 and 1564 AD. Figure 6 shows the excellent agreement between the ^{14}C and dendrochronological dating results of this sample.

BELNIANKA AND CZARNA VALLEYS

During DEM analyses, clearly visible remains of dams partitioning the valley bottoms were identified (Fig. 5A–G). Six such forms were recognised in the Belnianka valley and four in the Czarna valley. These dams ranged from ~150 to 500 m in length and from a few to >10 m in width. Their locations were similar to those seen on archival maps (Fig. 2). Hence, it can be assumed that all or most of them functioned for the use of ironworks and smelters. Occasionally a smelter relief channel was still visible next to the dam (Fig. 5A). For the most part, however, the dams and basins of the reservoirs have been heavily eroded or destroyed, and the dams have been utilised for the construction of the present roads. In the village of Borków on the site of a former smelting pond (Kalina, 2023a), a large reservoir used for recreation and retention exists now.

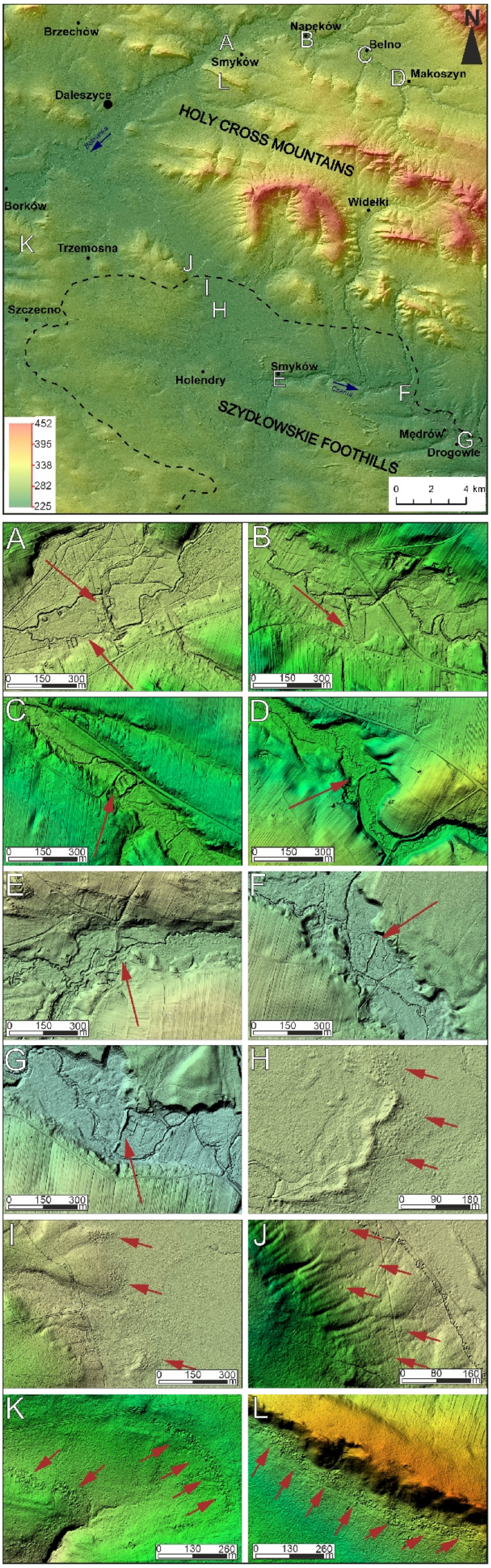

Fig. 5. DEM showing

A – remains of the dam and smelting channel in Smyków (Belnianka valley); **B** – remains of the dam and the road running along it in Napęków; **C** – remains of the dam in Belno; **D** – remains of the dam in Makoszyn; **E** – remains of the dam in Smyków (Czarna valley); **F** – remains of the dam in Mędrów; **G** – remains of the dam in Drogowle; **H** – clusters of charcoal hearth remains on the dune near the Białe Ługi peat bog; **I** – clusters of charcoal hearth remains near the Białe Ługi peat bog; **J** – single, scattered charcoal hearth remains; **K**, **L** – iron ore extraction shafts; red arrows indicate the objects described

Table 2

Results of radiocarbon and dendrochronological dating

Sample name	Lab. Code	Conventional ^{14}C age [BP]	Calibration results 68.3% confidence intervals [cal AD]	Calibration results 95.4% confidence intervals [cal AD]
Stara Huta K2-PR-3	GdA-7370.1.1	107±27	1695–1725 (19.9%) 1813–1839 (17.5%) 1845–1852 (4.0%) 1869–1871 (1.4%) 1877–1916 (25.5%)	1683–1735 (25.8%) 1803–1930 (69.6%)
Napęków K3-PR-2	GdA-7371.1.1	126±26	1688–1710 (11.0%) 1718–1730 (5.9%) 1807–1822 (7.2%) 1832–1893 (33.9%) 1905–1925 (10.2%)	1680–1740 (25.5%) 1752–1763 (2.5%) 1800–1941 (67.5%)
Napęków K4-PR-1	GdA-7372.1.1	380±26	1457–1505 (49.8%) 1596–1617 (18.5%)	1448–1524 (62.7%) 1571–1631 (32.7%)
Napęków K1-PR-4	GdA-7373.1.1	510±27	1410–1433 (68.3%)	1397–1446 (95.4%)
Napęków K1-PR-4	GD-50	Heartwood: 1391–1554 AD Sapwood: 12(-6/+7)		

For samples dated using AMS, 68.3% and 95.4% confidence intervals are listed as results of calibration

DISCUSSION

The DEM analysis allowed identification of often poorly visible, indistinct or small remains of iron smelting and charcoal burning facilities. This is particularly relevant in the case of charcoal hearth remains, which have diameters of several metres (Rutkiewicz et al., 2019). In the study area, charcoal hearth remains are preserved mainly as a few clusters (8 have been tentatively identified). These are concentrated in small areas, mostly in a zone adjacent to the Białe Ługi peat bog (Fig. 5H, I). These clusters contain up to several tens of charcoal hearth remains (Fig. 5H, I). There are also single, scattered forms (Fig. 5J), but these occur rarely, occasionally in areas now transformed by agricultural activity. It can therefore be assumed that there were once more charcoal hearth remains, now destroyed or obliterated. The forms recognised are predominantly between 14–15 m in diameter and the clear pattern of this size range is evident. As known form previous studies, this is a ‘typical’ size for such objects; they also have a classically oval shape with several hollows around the perimeter of the form (Rutkiewicz et al., 2019), being similar to other objects from Belgium (Deforce et al., 2013), France (Dupin et al., 2017), Germany (Raab et al., 2019), Italy (Carrari et al., 2017), Latvia (Zunde et al., 2023) and Sweden (Eriksson and Glav Lundin, 2021). Charcoal hearths were mainly constructed on sandy ground, sometimes on or near sand dunes and often near to humid areas. The sandy ground was crucial because it has an ability to absorb the water and tar from the carbonised wood. The proximity to wetlands limited the possibility of spreading the fires which sometimes occurred when charcoal was manufactured.

Only the sample of Napęków K1-PR-4 (GdA-7373.1.1), the radiocarbon dating result, after calibration, yielded a distinct time range. For the remaining three samples, the radiocarbon dating result falls within a period when the calibration curve has a flat course with additional fluctuations. As a result, after calibration, we obtain two or three alternative calendar age ranges. Detailed analysis of the radiocarbon dates obtained from Stara Huta (K2-PR-3, GdA-7370.1.1) and Napęków (K3-PR-2, GdA-7371.1.1) show that these charcoal hearth remains probably originate from the 18th or 19th centuries. It is likely that the majority of charcoal hearths from these sites functioned to meet the requirements of the blast furnace at Wojciechów village (part of Szczecno). Historical literature reports that the inhabitants of the village of Trzemoszna, founded in the 19th century, were mainly employed in charcoal burning, especially for the needs of the Wojciechów smelter (Kalina, 2002, 2023e).

On the basis of the radiocarbon and dendrochronological dates obtained (samples Napęków K4-PR-1, GdA-7372.1.1 and Napęków K1-PR-4, GdA-7373.1.1) it can be stated that iron smelting, using charcoal from charcoal hearths, was already functioning between Belno and Napęków as early as in the 16th century or even the 15th century. Dendrochronological dating of a wooden beam, an element from the construction of one of the smelter buildings, determined the years 1391–1554 AD while radiocarbon dating of it indicated the years 1397–1446 AD (95.4%), +125 rings, which gives the interval 1522–1571 AD, corresponding with historical information regarding the bloomery operating in Belno between 1570 and 1674 AD.

In the study area, archival documents confirm the existence of other objects directly related to iron smelting (Kalina, 2023a, b). The beginnings of their functioning are also dated to the 16th century. In Belno, historical records mention a bloomery operating between 1570 and 1674 AD. Similarly, the earliest records of hammer mill activity in Makoszyn date back to the second half of the 16th century. (Kalina, 2023a, b). One of the older ones was also a ironworks in Smyków, built in 1613 AD (Kalina, 2023b). There are also two known ironworks in Napęków, built in 1619 and 1630 AD, where two bloomery furnaces worked. However, in 1782 AD these furnaces were no longer functioning (Kalina, 2023a). Moreover, there were also factories of this type in the valley of the Czarna River: for example, Mędrów, otherwise known as Głazowska, where there was a bishop’s bloomery with two wheels mentioned in 1576 AD and then in 1674 AD, and Drogowla, where there was a bloomery also with two wheels referred to after 1571 AD (Radwan, 1956).

Often in historical literature there is only general information about charcoal burning. This is not the case in the study area where archival records of the vicinity of Daleszyce and its ironworks and smelters report charcoal production in the village of Suków, located ~8 km west of Daleszyce. In this village char-

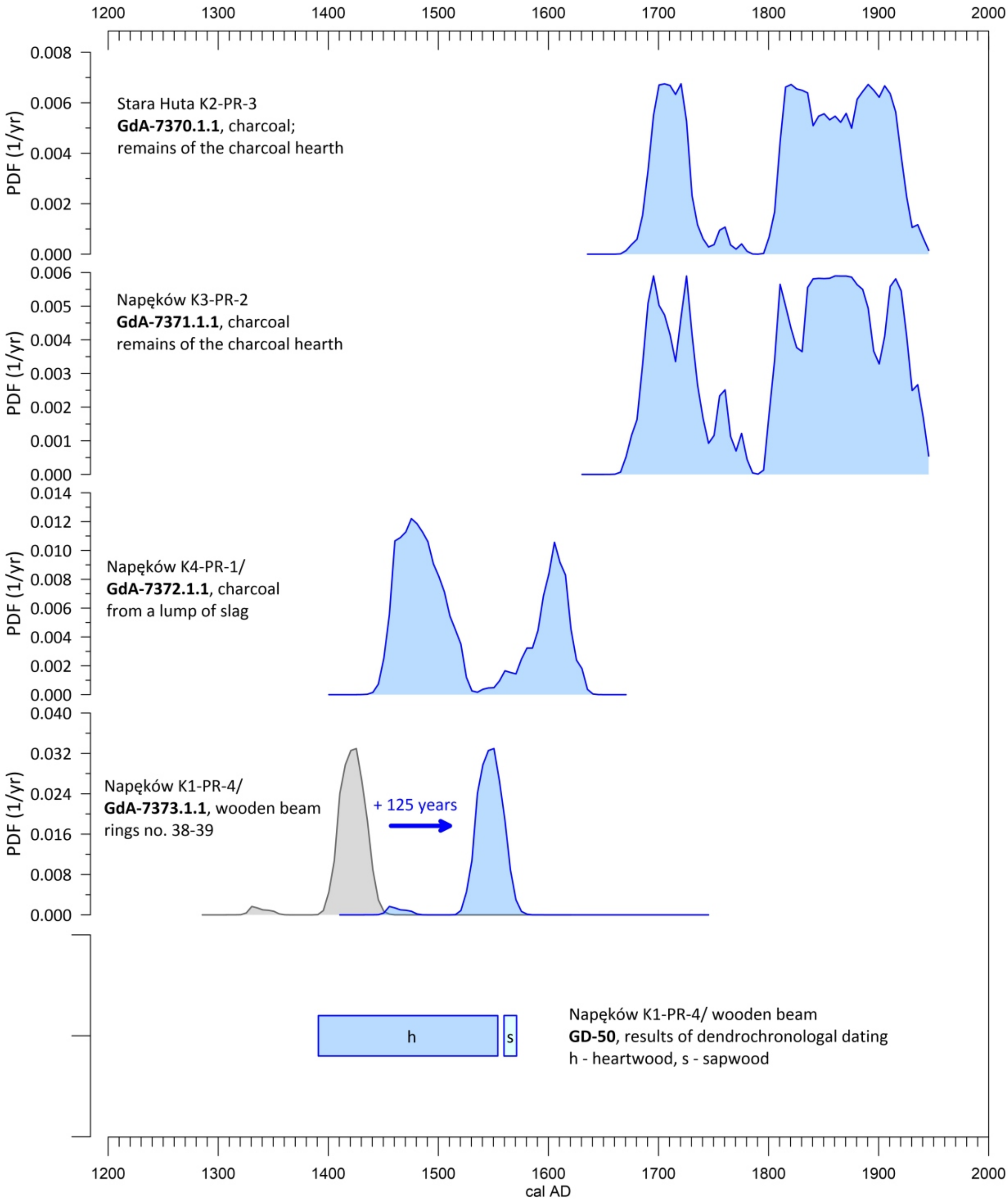

Fig. 6. Graphical presentation of the dating results

PDF – probability density function

coal was manufactured in the 17th century and transported to a smelter in Białogon (now part of Kielce city), ~10–12 km away (Kalina, 2023c). This indicates that charcoal burning did not serve only local consumption and suggests that the richness of the nearby forests allowed export of this fuel.

What is certain is that the development of the metallurgy was possible owing to the presence of iron ore on this territory. The local ironworks exploited rich nearby iron ore deposits through organized mining operations. It is known that for the needs of the Smyków ironworks in the Belnianka valley, its owner Andrzej Smyczka mined ore from Mount Koski (next to Mount Sikorza, near the village of Brzechów) in 1617 AD (Kalina, 2023b). In 1623 AD, the Bishop of Kraków dedicated ore from Mount Koski and serfs from the village of Skorzeszyce to these ironworks. The ore mine was called Florków and later also supplied ore to the ironworks in Napęków (Kalina, 2023b). There is also information about an iron ore mine, which probably started to be exploited at the end of the 16th century, near Borków (Kalina, 2023a). The first mention of this dates from 1602 AD. Ore from this mine was transported to the Makoszyn ironworks, which encompassed two forge furnaces and a bloomery. The description of the ironworks noted that there was no ore in the area and that it had to be transported from either Łagów or Borków (Kalina, 2023a). The DEM shows numerous shafts where iron ore was mined, and their locations coincide with the occurrence of rock formations containing iron ore noted above (Fig. 5K, L).

At this stage of the research, no attempt was made to analyse the mineral composition of the slags so as to establish whether they originated from the smelting of bog iron or siderite ore. Further work is therefore planned in the future.

In addition to iron mines and works, glass factories were established in this region early. In 1591 AD the glassworks of Wąsik and Widełki (area of the village of Widełki) were mentioned (Wyrobisz, 1968). The exploitation of glass factories required the harvesting of very large quantities of wood used as fuel for glass smelting. This caused rapid deforestation of adjacent areas, faster than in the case of charcoal burning (Wyrobisz, 1968).

Ultimately, the progressive degradation of natural resources was the cause of the decline of this industry. Gradually over time, the location of charcoal burning sites was relocated due to forest thinning. The closing of the ironworks was also most probably related to the advanced deforestation of the area and connected with a lack of wood for smelting iron ore the same as in some areas in the Old Polish Industrial District (SOP) e.g. the Czarna Konecka catchment area or in the Silesian Lowlands: the Mała Panew catchment area (Rutkiewicz et al., 2019; Kusztal, 2022). Based on the studies of Słowiński et al. (2024) we know that historical production and industrial activity in the territory of Poland resulted in the extension of forest boundaries, creation of midforest clearings, and intensive deforestation, especially in lesser Poland. In addition, studies by Zunde et al. (2023) from Engure area (Latvia) indicate that charcoal production had the effect of reducing the density and altering the composition of forest stands in the surrounding area, and also reduced forest cover. However, it was mainly changes in the economy and technology involving factors such as the replacement of charcoal by coking coal, and the unprofitability of mining ores with low iron content, that led to the termination of iron mining and smelting operations in the SOP (Kusztal, 2022). Over the centuries, iron smelting and charcoal burning disappeared from this area and the infrastructure associated with this iron metallurgy was used to construct other objects. For example, the Kielce-Łagów road was built on the causeway that dammed the waters of the Belnianka River for previous ironworks in Napęków.

CONCLUSIONS

This is the first time that charcoal hearth remains from the Daleszyce area have been identified and described. The internal structure of deposits observed within the charcoal hearth remains is characterised by black layers of charcoal and ash. The charcoal hearth remains are preserved in a few large clusters, concentrated in small areas. Single, scattered forms are rare, some being in areas transformed by agricultural activity. Therefore, it can be assumed that more charcoal hearth remains existed, but these have been degraded or obliterated. Most of the forms were between 14–15 m in diameter. Several remains of dams on the Czarna and Belnianka rivers have also been recognised. Most of these objects may be remains of original ironworks dams, or they occur in the same or similar locations as did the original dams. These are conjectures so far. We can only rely on old maps where there are former reservoirs and information from historical literature where the locations of forges or smelters are described, and compare this information with the dams visible on the DEM. There are no historical dams or factory remains in the historical records (AZP) at the locations surveyed. Only in the village of Belno near the dam is there a wooden mill from the 19th century, which has been entered in the records of monuments (AZP – maps.zabytek.gov.pl/nid/).

Radiocarbon dating of charcoal embedded in smelting slag indicated that iron smelting, using charcoal, was already functioning in the Belnianka valley between the villages of Belno and Napęków in the 16th century.

Age determination of a beam excavated from the Belnianka alluvium, in the vicinity of the former ironworks in Belno and Napęków, yielded the year 1560 AD (dendrochronological date) and gave a time range of 1522–1571 AD (95.4% probability; radiocarbon dating). This corroborates the historical records of a bloomery working in Belno in 1570 AD.

Radiocarbon dating of charcoal from charcoal hearth remains indicates that they probably originate from the 19th century. This shows that charcoal from the charcoal hearths was used for iron smelting still in the 19th century, possibly for the Szczecno (Wojciechów) blast furnace operating at that time. However, it cannot be ruled out that charcoal was also burned for other purposes (tar, potash, ashes).

The results presented in this paper are a continuation of research into historical metallurgy carried out by the lead author (e.g., Czarna Konecka basin, Mała Panew basin). This study expands the database of historical metallurgy into the territory of the Old Polish Industrial District and also represents the first research of this kind conducted for the area described in the article. This research concords with current research trends into historical metallurgy carried out in Europe e.g. Germany, Belgium, France, Italy and Latvia. Moreover, this work introduces new results that can help create a chronology of metallurgical objects (mainly charcoal hearths and slags) for the Holy Cross region based on radiocarbon and dendrochronological analyses. Future studies of historical metallurgy from this area and other sites should be supplemented with mineralogical analyses, such as SEM analyses of slags to provide information on surface mineral structure and elemental composition. Such studies, in turn, could be a prelude to determining the type of ore that was used to smelt the iron.

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