Carpathian Journal of Earth and Environmental Sciences, August 2019, Vol. 14, No. 2, p. 519 - 528; DOI:10.26471/cjees/2019/014/100

SOME SEDIMENTOLOGICAL EVIDENCE OF THE HISTORICAL METALLURGY ACTIVITY – A CASE STUDY FROM SOUTHERN POLAND

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Abstract: The aim of this study was to identify and characterise sedimentological evidence of the functioning of historical metallurgy at the chosen areas of river valleys near the former ironworks in Brusiek (Mała Panew River Valley) and Białogon (Bobrza River Valley). An interdisciplinary approach was employed, using a wide range of methods. In the first stage historical sources were analysed in order to obtain information about the selected former ironworks. In the next step field research was carried out. In the next stage of the research exposures of the sediments, core drillings, petrographic analysis, SEM analysis, radiocarbon datings and antrhacological analysis were made. The type and thickness of metallurgical waste from the former ironworks in Brusiek were determined on the basis of the analysis of sediments from an exposure in the high terrace of the river and material from boreholes in the metallurgical channel. These were: mainly green enamel after iron smelting, slag blocks, bricks, fragments of carbonate rocks, charcoal and charcoal ash layers. The dating of organic matter accompanying anthropogenic layers indicates its contemporary character, i.e. their origin dating from the end of metallurgical production. Analysis of the sample of metallurgical slag enabled it to be determined that the iron that was smelted in the ironworks in Busiek most probably derived from bog iron ore. Through the petrographic analysis of sediments from the exposure in a high terrace in Brusiek, sediments from the metallurgical channel in Brusiek, and sediments from the location of the metallurgical pond in Białogon, the presence and content of anthropogenic matter in sediments which was not visible to the naked eye was determined. Additionally, based on analysis of the variability of the sediment layers as well as their fractions and structure, it was possible to reconstruct the changes in sediment deposition at the Białogon site. Layers with a high content of anthropogenic material in sediments may indicate more intense human activity during the deposition of these sediments.

Key words: smelter pond, dam, slags, human impact

1. INTRODUCTION

Historically, man has produced multifarious changes to the landscape through ironworking. During the Middle Ages the most important technical innovation was the use of water power in ironworking which enabled the introduction of high bloomery furnaces in the 11th century and blast furnaces in the 16th century (Raab et el., 2005). The environmental impacts of these industries were large, not only for the floodplains but also for the adjoining slopes and plateaux, which were deforested and subsequently affected by soil erosion as a result of the large demand for wood and charcoal as the primary energy source for the smelting process in the furnace (Raab & Völkel, 2005). The most frequent and most visible remains of historical metallurgy today, are the remains of charcoal hearths in which charcoal was burned in the past. On the basis of the research carried out so far, over 200,000 such remains have been identified in Poland (Rutkiewicz et al., 2019). This study presents other sedimentological evidence of the historical metallurgy than the remains of charcoal hearths. The study was carried out in chosen areas of river valleys near the former ironworks in Brusiek (Mała Panew River Valley) and Białogon (Bobrza River Valley) (Fig. 1). There are good and reliable historical descriptions of the selected locations. The aim of this study was to identify and characterise sedimentological evidence of the functioning of historical metallurgy in river valleys at the chosen sites.

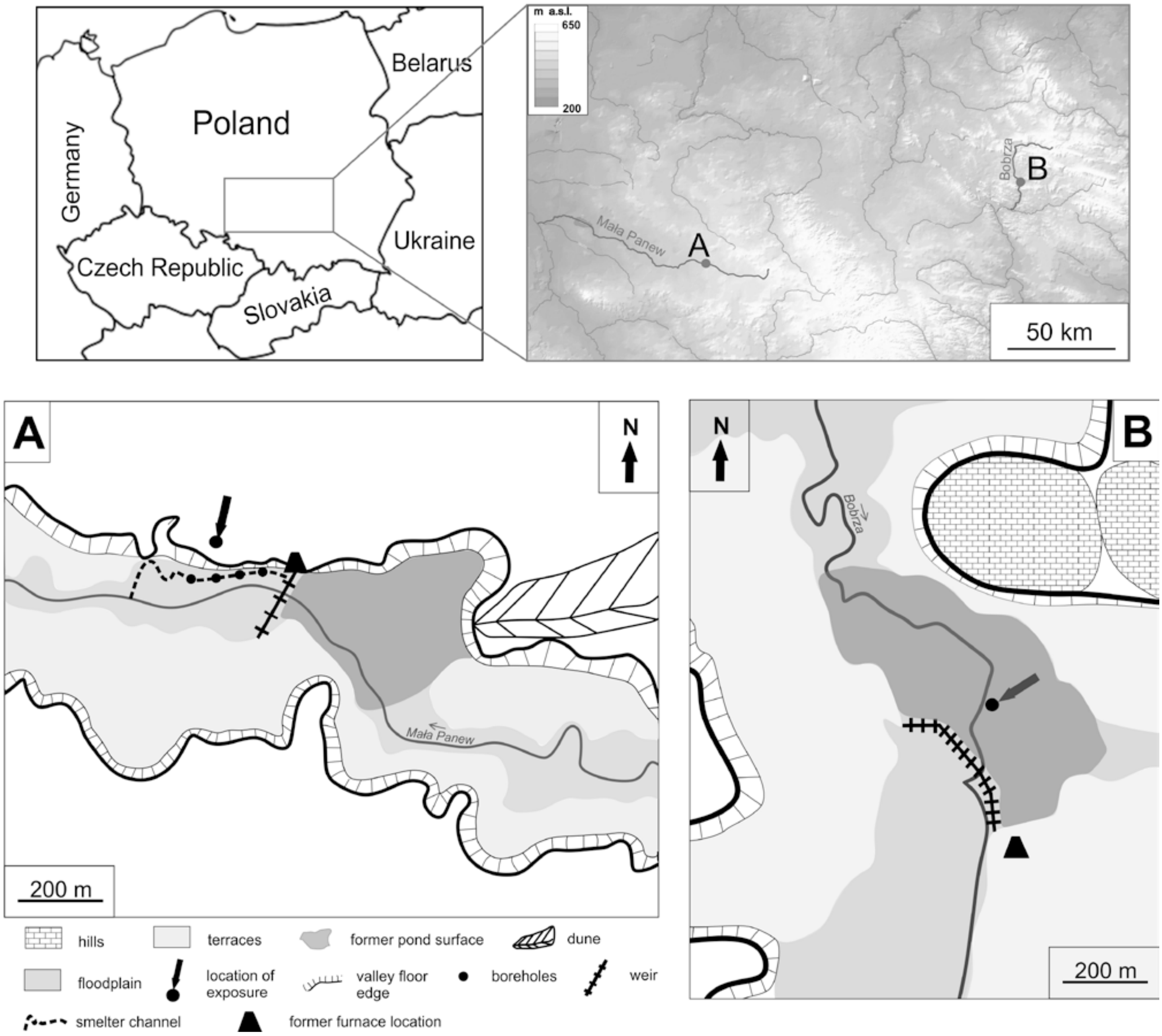

Figure 1. Location of the study area: A - area around former ironworks in Brusiek; B - area around former ironworks in Bobrza.

2. STUDY AREA AND HISTORICAL BACKGROUND

2.1. The Mała Panew River and the Brusiek ironworks

The Mała Panew is a right bank tributary of the River Oder. It is 132 km long and the mean annual discharge is 8.97 [m^3/s]. The Mała Panew drains 2037 km^2 of the Silesian Upland and Lowland covered with Quaternary sands. It is a meandering, sand-bedded river flowing through forested areas (Kondracki, 2000; Włodek, 1976). The Mała Panew river is characterised by the occurrence of numerous meanders with different radii of curvature, characteristic for areas with forested banks (Dynowska, 1971; Malik, 2005). According to Roździeński's poem from 1612, the ironworks in Brusiek was founded in the 14th century. The exact year of establishment of the facility is unknown (Goszyk, 2001). There is a description from 1511 regarding a metallurgical pond near the smelter in Brusiek (Szczech, 2001). From 1768, there was a bloomery and newly built blast furnace about 10 metres high. Iron ore was processed here. In 1824, a blast furnace in Brusiek permitted the production of 17,000 hundredweight of pig iron per year. In 1884, the ironworks stopped production (Adamczak, 2005). The blast furnace was dismantled in the 1950s.

2.2. The Bobrza River and Białogon smelter

The Bobrza River is a meandering, partially regulated river, with a sand and sand-gravel bed. It is 48.9 km long and the mean annual discharge is 1.81

[m^3/s]. The area of its basin is 375 km². During the Vistulian, the valley was under the influence of a periglacial climate. At that time, a loess cover was deposited. During interglacial periods the deposits were gradually washed out (Burchard, 1978). The bottom of the Bobrza valley is filled with sand and gravel deposits that form river terraces. On the Holocene terrace, there are local deposits of peats and alluvium (Rutkiewicz & Gawior, 2016). The first record referring to the operation of an ironworks in Białogon dates back to the beginning of the 17th century (Zdanowski, 1928; Pazdur, 1957; Guldon & Kaczor, 1994). There was a mill on the site of the ironworks which operated until 1814, however the date of its creation is unknown (Stępkowski & Guldon, 1981). In the years 1814-1817, Aleksander's Ironworks was built here on the initiative of Stanisław Staszic (Pazdur, 1957). Copper and silver were smelted and processed, and household goods were also produced. From 1827, a reorganisation and reconstruction of the inactive plant was carried out due to a lack of copper ores (Szczepański, 1997). In 1966, the ironworks was transformed into the Kielce Białogon Pump Factory, which is still in operation today.

3. MATERIAL AND METHODS

An interdisciplinary approach was employed, using a wide range of methods. In the first stage historical sources were analysed in order to obtain information about the selected former ironworks. In the next step field research was carried out. The sediments were exposed in a high level terrace, near the former ironworks in Brusiek. The exposure profile was oriented on a perpendicular axis to the current river channel. In addition, several other smaller soil pits were made in the high terrace. The occurrence of individual layers of sediment and the type of fractions and artefacts building up these layers were determined on the basis of organoleptic analyses. Four impact drillings were made using a core probe in the metallurgical channel located in the bottom of the Mała Panew floodplain. Boreholes were made to a depth at which too much sediment hydration made it impossible to bring them to the surface. Due to the unusual type of sediments, all the individual layers filling the channel were described on the basis of organoleptic analysis. At the Białogon site an exposure of the deposit was made on the site of the former pond near the smelting dam. It was possible to make this exposure due to the deep incision of the contemporary channel of the Bobrza River into former pond sediments. The sediment profile was described using the lithofacial code of Miall, modified by Zieliński (Zieliński & Pisarska-Jamroży, 2012).

A petrographic analysis was made of the pond sediments in Białogon, sediments from the exposure in the high terrace near the ironworks in Brusiek, and deposits from the metallurgical channel in Brusiek. The analysis was carried out on those sediment levels in which the anthropogenic material was not visible to the naked eye. At the Białogon site, 15 904 grains from 17 samples of pond sediments were analysed. At the Brusiek metallurgical channel site, 5 634 grains from 13 samples were analysed. For 5 sandy samples from the exposure in the high terrace near the ironworks in Brusiek, several thousand grains were analysed, without counting. After wet sieving, a fraction of 0.5-1 mm was isolated from the material as the most suitable for petrographic analysis. The analysis was performed using binoculars at 10-40 times magnification in reflected and transmitted light. To describe the content of individual components, the modified Kukukazu Doi method used by Racinowski was used, allowing one to separate three subsets of ingredients (Racinowski, 2002). From the middle part of the profile in the high terrace near the ironworks in Brusiek, fragments of metallurgical slags were collected. From the fragments obtained a sample was obtained for analysis in the form of a thin section. Petrographic analyses of the thin section were undertaken at the Faculty of Earth Sciences in the University of Silesia using an Olympus BX-51 microscope to constrain textural and microstructural relationships. These petrographical observations were used to select representative samples for subsequent scanning electron microscope analyses of the mineral phases studied. Backscattered electron (BSE), and secondary electron (SE) imaging of the malachite and its surrounding calcite were carried out on a Philips Xl 30 ESEM/TMP scanning electron microscope (SEM) equipped with an EDS (EDAX) detector at the Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland. The analytical conditions were: 10 s counting time per element, 15 kV accelerating voltage, and 20 nA beam current. Fragments of organic matter that occurred in sediments were dated using the radiocarbon method. Radiocarbon dates (14C) were made at the Absolute Dating Laboratory in Krakow (laboratory code: MKL). For the calibration of the radiocarbon data, the OxCal v4.2.3 program has been used (Ramsey & Lee, 2013) with atmospheric data from Reimer (Reimer et al., 2013). Samples of organic matter were also submitted for anthracological analysis. The study was carried out in line with the rules commonly applied in anthracological analyses. The charcoal underwent taxonomic identification based on the observation of wood anatomy. The samples were observed at the magnification range of 100 to 500x, in reflected light, with the use of an Olympus BX53M metallographic microscope and Stream Essentials 2.1 micro-imaging software. The analyses were performed by Ms Agata Sady from the Silesia Museum In Katowice.

4. RESULTS

4.1. Brusiek - metallurgical channel site

On the basis of field measurements, it was determined that the length of the metallurgical channel is 455 metres, and its average width is 5 metres. Through the impact drillings, four sediment cores were obtained that filled the metallurgical channel (Fig. 2).

Core I - on the basis of organoleptic analysis, a layer of post-production waste was found, consisting mainly of few-centimetre fragments of green enamel, slag, brick and small fragments of carbonate rocks. This layer reached a thickness of 196 cm. At a depth of 80 to 83 cm inclusions were found in the form of fragments of wood which were radiocarbon dated to 1670-1943 cal AD (95.4%), (45 ± 80 BP; MKL-3621). From a depth of 196 to 290 cm, the filling of the channel consisted of homogeneous fine-grained sands. At a depth of 230 cm, the colour of these deposits changes from steel grey to grey orange. The whole sediment profile is characterised by a massive structure (Fig. 2A). According to the results of the petrographic analysis, there is a clear decrease in the content of anthropogenic material in the sediments in the lower part of the profile, from over 20% initially to 2%. Quartz grains predominate (Fig. 2).

In core II, a layer of post-production material was also found. From the ground surface up to 15 cm, the filling of the channel consisted of a mixture of green enamel fragments, bricks, fragments of carbonate rocks and organic matter of varying degrees of decomposition. At the depth of 15 to 130 cm there was a layer of sand with a few centimetres of fragments of green enamel. From the depth of 130 to 200 cm there were homogeneous fine-grained sands as in the case of core I (Fig. 2A). The content of anthropogenic matter in the lower part of the profile is small (9%), like in core I, and also decreases almost to 0 (Fig. 2).

Core III - from the ground surface to 35 cm this is characterised by the presence of a layer that is a mixture of green enamel fragments and organic matter with varying degrees of decomposition. Next, in the profile there are sands with green enamel extending to a depth of 100 cm. Furthermore, to a depth of 200 cm there are the fine-grained sands mentioned in earlier cores, with a colour change from 130 to 135 cm and from 170 to 200 cm (Fig. 2A).

The results of the petrographic analysis revealed a content of anthropogenic material of more than a 20% in the sediments in the lower part of the profile, which decreases to 2% with increasing depth (Fig. 2).

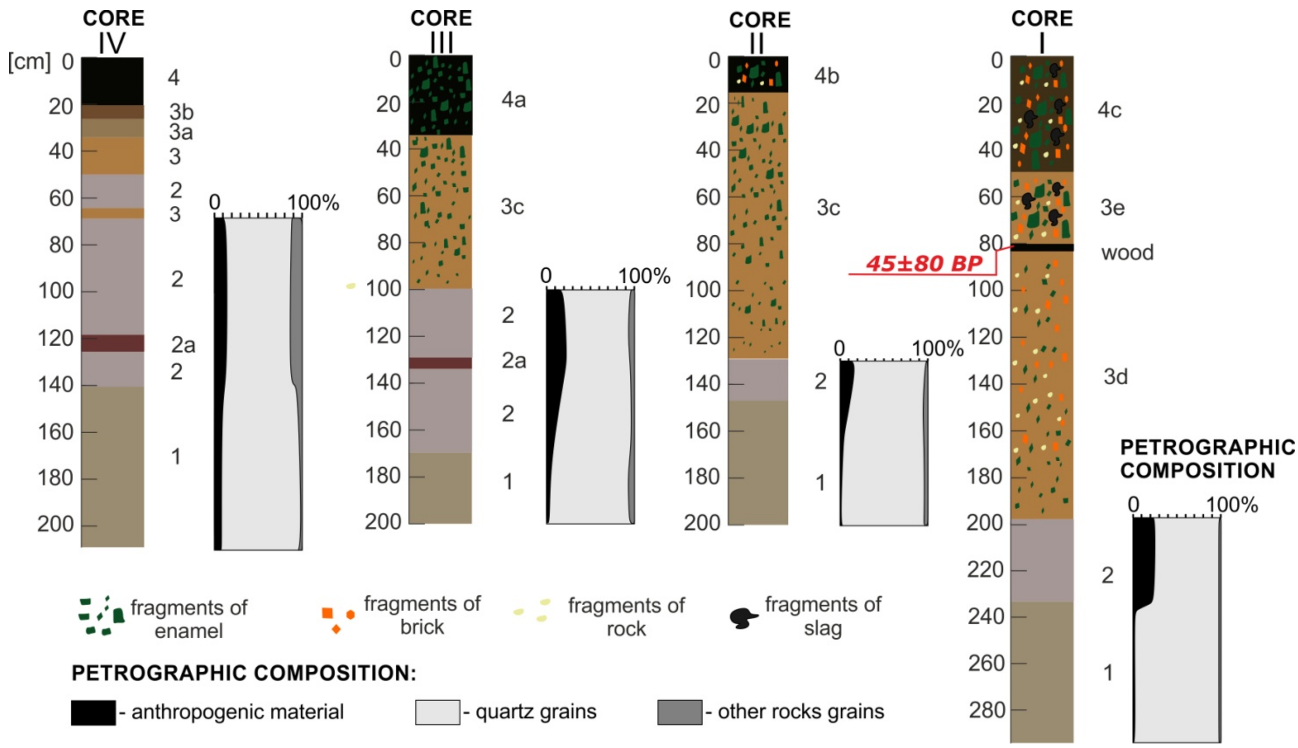

Figure 2. The filling of the metallurgical channel next to the ironworks in Brusiek and the petrographic composition of the sediments: 1,2,2a- homogenous clays of different colours; 3,3a,3b- homogenous sands of diferent colours; 3c- sands with fragments of enamel; 3d- sands with fragments of enamel, rock and brick; 3e- big fragments of enamel, rock, brick and slags with sands; 4- organic matter; 4a- organic matter with fragments of enamel; 4b- organic matter with fragments of enamel, rock and brick; 4c- big fragments of enamel, rock, brick and slags with organic matter.

The last core IV differs from the previous ones by a lack of anthropogenic material visible to the naked eye. From the ground surface to a depth of 20 cm, the occurrence of organic matter with different degrees of decomposition was found. Then from 20 to 50 cm, varying coloured unsorted sands are present. From 50 to 213 cm, the profile is represented by fine-grained sands (identical to the previous profiles) with a layer of medium-grained sands at a depth of 65 to 69 cm. The results of the petrographic analysis reveal the presence of anthropogenic material, the content of which is almost constant from a depth of 70 cm to the end of the profile and ranges from 4 to 6% (Fig. 2).

As a result of the petrographic analysis, the material in the 0.5-1 mm fraction can be divided into three basic groups:

- quartz grains, 71.9% to 95.5% of all grains,
- grains of various types of rocks, usually magma and fine-grained sandstones, quartzites, siltstones and claystones, constituting from 1.2% to 12.1% of all grains,
- anthropogenic material constituting from 0.9% to 24.6% of all grains.

The main items observed in the anthropogenic material analysed were fragments of green glass with a smaller or larger amount of fine air bubbles and porous black and slag enamel. In addition, fragments of clear glass with air bubbles, quartz grains stuck with tar, bricks, lime mortar, and charcoal occur.

4.2. Brusiek - high terrace site

The sediment profile in the high terrace is characterised by the occurrence of an anthropogenic layer from the ground surface down to 40 or even 100 cm depth, with a width of fewer than five metres of exposure. The anthropogenic layer lies directly on fluvial sands with a deformed horizontal stratification (Fig. 3). The analysis of the sand layer, in the 0.5-1 mm fraction, showed almost exclusively quartz grains with a small admixture of magmatic and sedimentary rock grains. The material of anthropogenic origin is so limited here that it can be treated as a trace/contamination of the sample (less than 1 permille) and at the same time is present in the whole layer analysed. These are fragments of green glass with air bubbles, quartz grains glued with tar and charcoal. The analysis was based on the identification of tens of thousands of grains, without counting. The anthropogenic layer in this exposure can be divided into sub-layers 2, 3 and 4 (Fig. 3).

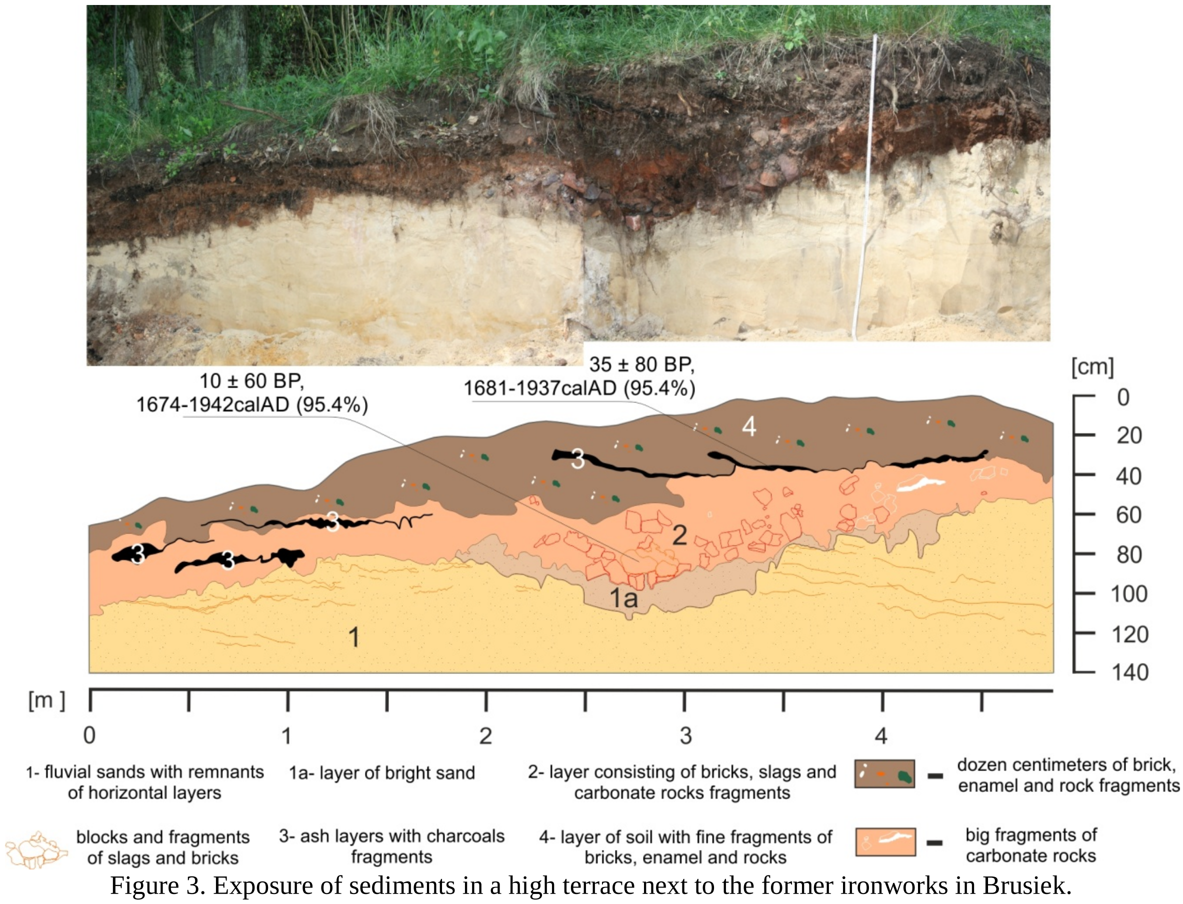

Figure 3. Exposure of sediments in a high terrace next to the former ironworks in Brusiek.

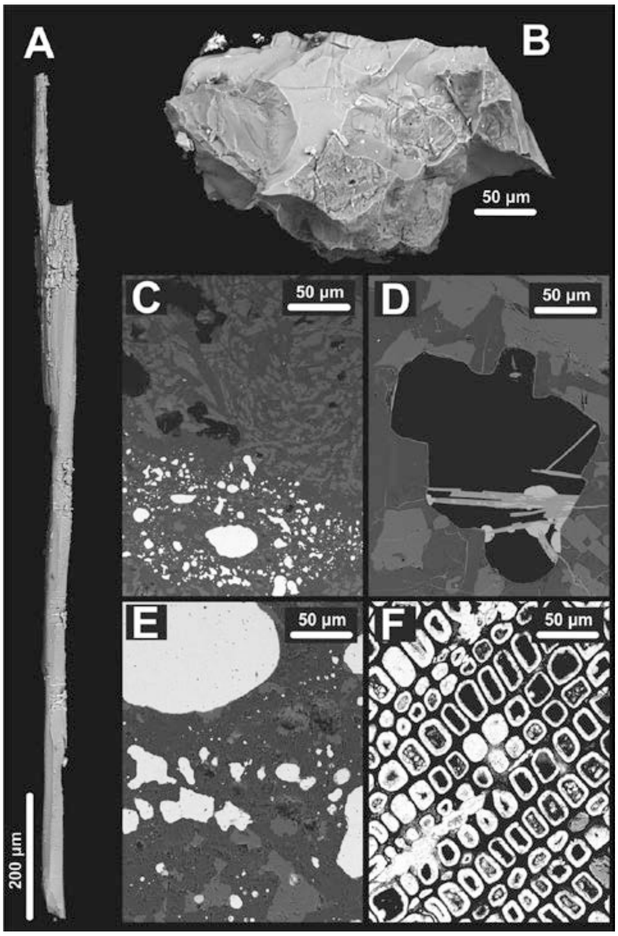

Figure 4. Scanning electron microscope (SEM) images of the slag sample taken from hand-picked fragments (A-B) as well as a polished slab (C-F). Needle-like glass (A) with composition Si>>Al>K>Fe. An example of the same massive glass-like material (B). Occasionally, melilite-like phases occur as elongated crystals up to 0.25 cm in size (C; the darkest parts). An example of cavity with secondary phases (calcite? And Fe-oxides; D). Internal texture with Mn-, Ti- and Fe-rich portions (E; light parts). Preserved charcoal fragment, which is partially filled with Fe-oxides and hydroxides.

Sub-layer 2 predominantly consists of one and a half dozen centimetres of irregularly shaped slag, several several centimetre fragments of bricks or whole bricks and few-centimetre fragments of rocks. Several centimetre fragments of charcoal were embedded in the slag body. Layer 3 consists of ash formed from charcoal and also contains very fine, several millimetre fragments of charcoal. A layer of ash and charcoal occurring at a depth of about 40 cm was dated to 1674-1942 cal AD (95.4%), (35 ± 80 BP MKL-3314). Defragmentation of the charcoals made it impossible to recognise their species. Layer 4 is a mixture of the modern soil level and a large number of several-centimetre fragments of green enamel with an admixture of small fragments of bricks and rocks (Fig. 3). Eight charcoal fragments embedded in blocks of slag were subjected to palaeobotanical analysis, among which 4 fragments were recognised as Scots pine (*Pinus sylvestris*), one fragment as spruce/larch (*Picea abies / Larix* sp.), one fragment as a coniferous tree and two unmarked fragments. The results of radiocarbon dating of these charcoals is 1681-1937 AD (95.4%), (10 ± 60 BP; MKL-3315). Observations of a sample of slags using a scanning microscope (Fig. 4) revealed the presence of an amorphous substance (enamel) in association with anthropogenic crystal phases. They are mainly represented by iron oxides (hematite, magnetite?) and silicates/aluminosilicates (including akermanite, gehlenite). There were also zones enriched with metallic iron, which sporadically undergo weathering. A characteristic feature of the sample analysed was the presence of carbonised plant tissues, whose cells are inlaid with iron oxides, iron sulphides (pyrites) and simple carbonates (calcite).

Bobrza - former smelter pond site

Sands with a massive structure were found (Sm) at a depth of 160-180 cm in the lower part of the profile, over which was deposited a layer of sands (142-160 cm) with trough cross-stratification (St). Then, at a depth of 125-142 cm, there is a layer of massive silts (Fm). Gravelly sands with cross-stratification have been deposited on silts (SGt) (90-125 cm), which are separated by a layer of crushed slag at a depth of 116-118 cm. At a depth of 65-90 cm there is again a layer of silts with a massive structure (Fm). At the depth of 59-65 cm there is a layer of sand with thinning with a massive structure (SFm), which in turn are covered with another layer of massive silts (Fm) (50-59 cm). In the upper part of the profile, there are sands with a deformed structure (Sd) (40-50cm). In the top part of the profile, a soil level has developed with a thickness of 40 cm (Fig. 5).

The petrographic analysis allowed the identification and division of the sediments into three groups:

- quartz grains,
- grains of various types of rock: mostly fine-grained sandstones, quartzites, and sporadically also feldspars and calcite,
- anthropogenic grains: pieces of hard coal, glass of different colours, metallic grains and slags.

The petrographic analysis carried out showed, in the absence of any anthropogenic material, the domination of quartz grains in the 180-160 cm band. The contribution of anthropogenic material increases sharply in the layer at a depth of 160-145 cm, even up to over 80%. Sediments in the 145-95 cm depth range, are characterised by an increase in the percentage of rocks with a low (about 10%), but constant, presence of anthropogenic material. In the 95-75 cm layer, the proportion of anthropogenic material increases rapidly again, this time to around 40%. In the 75-65 cm layer, the proportion of rock increases and the content of anthropogenic material decreases. The content of anthropogenic material clearly grows again at a depth of 65-40 cm (slightly above 50%) (Fig. 5).

5. DISCUSSION

5.1. Sedimentological evidence of metallurgical activity in Brusiek

Based on the exposure of sediments in the high terrace at the site of the former ironworks in Brusiek, it was possible to identify post-production remains of metallurgical activity. It was particularly important to identify large blocks of slag. Fragments of slag in the sediments of the areas near the former metallurgical centres are one of the most frequently found remains of historical metallurgy (Hodgkinson, 2004). A characteristic feature of the slag investigated was the presence of burned tissues of plants whose cells are encrusted with iron oxides/oxyhydroxides, iron sulphides (pyrite) and simple carbonates (calcite) (Fig. 4). Few-centimetre long fragments of charcoal were also embedded in the slag mass. This is undeniable proof that charcoal was used here for smelting iron ore. Based on the analysis of the charcoal species, it was determined that the following species were used: Scots Pine (*Pinus sylvestris)* and Spruce / Larch (*Picea abies / Larix* sp.). The result of the radiocarbon dating of these charcoals is 1681-1937 AD (95.4%), (10 ± 60 BP MKL-3315). Unfortunately, the age of the sample does not allow precise determination of the age of the metallurgical artifacts. The composition of the slags, represented mainly by iron oxides and silicates/aluminosilicates, is typical of early medieval slags originating from bloomeries. Another feature of this type of alloy is the release of small amounts of metallic iron that occasionally undergoes weathering. In such slags, dendritic or spherulitic iron ore minerals are also present, perhaps in this case magnetite (Ratajczak & Rzepa, 2011). This description corresponds well to the composition of the slag investigated. In the bloomery process, the slag began to form at a fairly low temperature of 900°C. The presence of hematite can also be associated with the weathering of iron

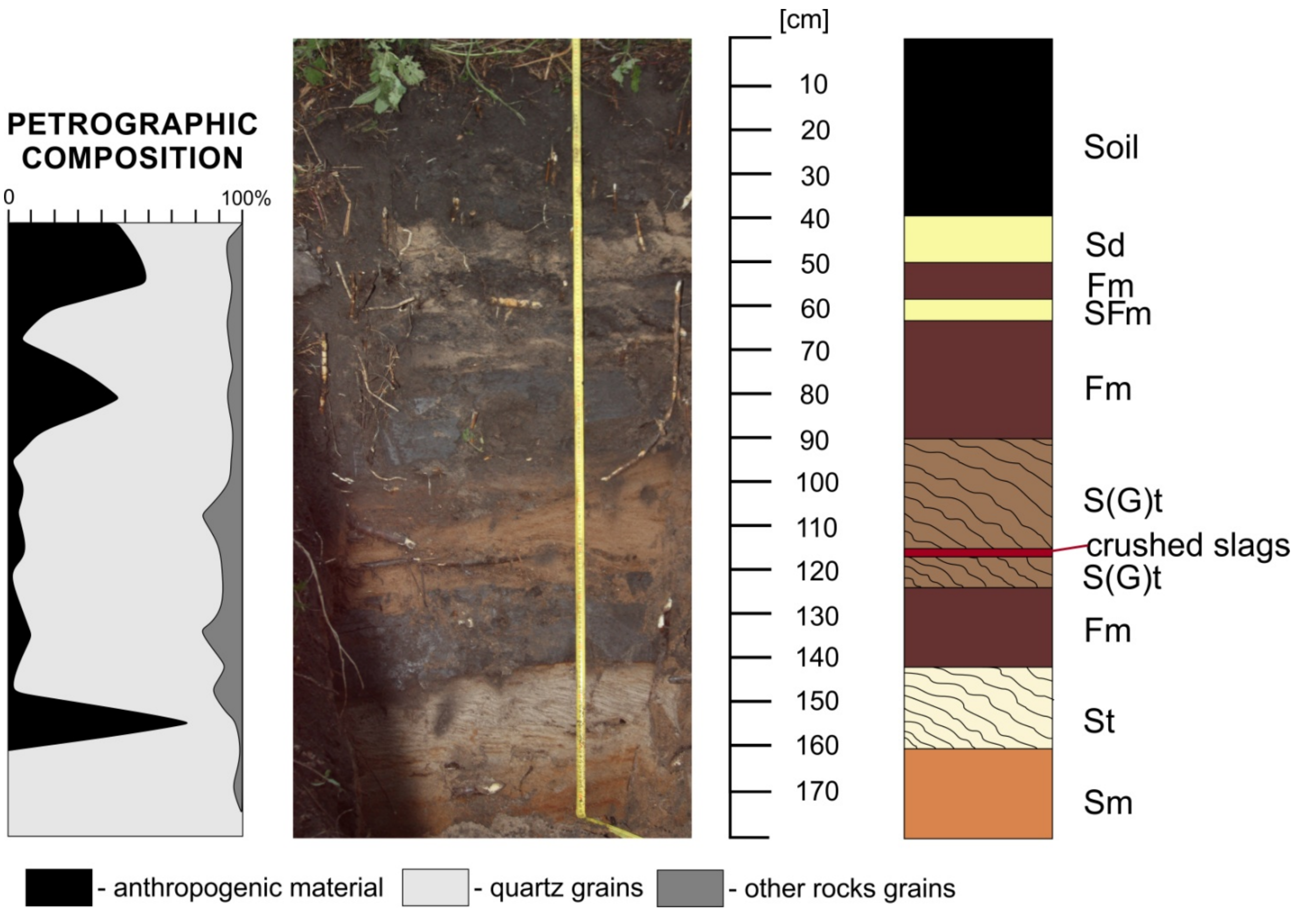

Figure 5. Sediment exposure on the site of the former metallurgical pond near the ironworks in Białogon.

compounds that gives the slag a characteristic red colour. The final stage is hydration and the formation of iron hydroxides, as well as the crystallisation of other secondary phases, including calcite (Jonczy, & Gawor, 2016). The chemical composition of the slags analysed indicates that iron from commonly occurring bog iron ores was melted here. Green enamel in very large quantities in the soil layer, as well as in the metallurgical channel, is a typical waste generated during the smelting of iron. Green enamel is characterised by a smooth, crack-free surface and the green colour of the enamel is probably related to the presence of Fe^{2+} ions in its chemical composition (Jonczy, 2012). It is worth to mention that post-production waste can be at the origin of the contamination by heavy metals of the surrounding region and additionally affect the vegetation (Lehout et al., 2018). Fragments of bricks found in the exposure of sediments in the high terrace and in the metallurgical channel are probably remnants of the blast furnace and earlier refinery-works in which iron ore was smelted. Fragments of limestone can be remnants of the melting product used in the production of iron. A similar exposure of sediments in the Taunus and Westerwald Mts., (Western Germany) has been described by Stolz and Grunert (Stolz & Grunert, 2008). At a depth of 80 cm in the sediments of the flood plain examined, they found an accumulation of fragments of metallurgical slag containing fragments of the wall of a bloomery and burnt clays and pieces of charcoal. The dates from the exposure in the high terrace and from the metallurgical channel are very young and the measurement error is high. This may be due to the fact that the constant sedimentation of deposits on these sites has been disturbed from time to time, and previously deposited older artifacts have been removed. This is probably the material coming from the end of the production of the former ironworks in Brusiek. The ironworks and their buildings, as well as dams and ponds, were often destroyed by catastrophic floods (Goszyk, 2001). Research has also been conducted on the structure of the sediments exposed in the bank of the Mała Panew river near the former ironworks in Brusiek (Malik et al., 2015). In the profile, a layer of fine-grained deposits was found which has been associated with the existence of a metallurgical pond at this location. The layer rested on organic matter which was dated to the 17th century. Historical sources, on the other hand, inform us that the owner of the Brusiek ironworks had a metallurgical pond from at least 1511 (Szczech, 2001). The date of the final interruption of the dam and the drainage of water from the pond is unknown. The filling of the metallurgical channel could be associated with the cessation of production in this location and the demolition of buildings and dikes or inaccurate management of the centre. Below the levels of metallurgical waste accumulated in the channel, the content of anthropogenic material drops sharply. In this way, the boundary is visible between deposit sedimentation in conditions of human activity and that outside of this activity. Unfortunately, the date of the organic matter retrieved from the material filling the channel does not provide the opportunity to determine the time of its operation. We can only conclude that part of the sediment, deposited above the dated wood fragment, comes from the modern period (the 20th century). Other exposures made in the high terrace also revealed the presence of green enamel, fragmented brick fragments and carbonate rocks, as well as layers of black ash, in various configurations.

5.2. Sedimentological evidence of metallurgical activity in Białogon

The exposure of sediments on the site of the former metallurgical pond in Białogon is distinguished by levels of sediments accumulated during periods of human activity. Separation of these levels was mainly possible through petrographic analysis. This is the only way to recognise anthropogenic material in sediments when it is not visible to the naked eye. The sediments at the base of the exposure do not contain anthropogenic matter, which indicates their deposition under natural flow conditions. This is also confirmed by the trough-cross stratification of sands deposited by flowing water (160-142 cm). This type of sedimentation structure is typical for rhythmic sediment transport conditions (Falkowski & Górka, 2009). The content of anthropogenic material in the sediments increases to 80% above the cited layer (142-125 cm). Undoubtedly, this is the moment when human activity begins at this location. Fine sediments with a massive structure testify to the deposition of this material in stagnant water, which is identified with the presence of a metallurgical pond during this time. This is the first phase of the pond's existence at this location. The layer of gravel sands with cross-stratification (125-90 cm) of the trough, deposited over a layer of fines, gives information about the sudden change in flow conditions. Sediment transport and the deposition of thicker fractions were initiated. This incident most probably occurred as a result of failure of the dam, which caused a rapid increase in water energy. This part of the profile is also characterised by a very low content of anthropogenic matter (below 10%), which could have been washed away. The layer of sands noted was divided by a layer of crushed slag (118-116 cm). This material could have been transported by water from adjacent areas near the smelter pond where post-production waste was deposited. At a depth of 90-65 cm there is again a layer of fines with a massive structure, which indicates the next episode of a change in the conditions of sediment deposition and flow dynamics. Sediments of this layer have been deposited in stagnant water conditions. Despite the low content of anthropogenic material in the sediment, this level is identified with the next phase of the metallurgical pond in this place. At a depth of 65-59 cm there is a layer of sand with fines with a massive structure (SFm), which are covered with another layer of massive fines (Fm), (59-50 cm). Such a sequence of sediments is the result of a flood event during which the energy of water increased and the transport of thicker fractions from the upper parts of the catchment was started. The layer of fines indicates the re-presence of stagnant water. This part of the profile is identified with the final phase of the pond's existence, which was interrupted by flood events. The content of anthropogenic matter also increases, which was again supplied from areas adjacent to the pond. Finally, the last layer of fines sediment was covered by a layer of sand with a deformed structure (Sd) (50-40 cm) with almost 50% content of anthropogenic matter. A modern soil profile has developed over the sediment sequence described above. Similar sequences of sediments identified as pond sediments were recorded in the San basin, where tree trunks and numerous archaeological artifacts (slag, ceramics, parts of leather products) were identified in sediments (Kukulak, 2004). Pond sediment sequences are often successfully used for historical dating and reconstruction (Kukulak 2000; Malik et al., 2015). In the case of the sediment series tested here, however, no material suitable for dating has been found. Despite the lack of dating opportunities, it was possible to reconstruct the process of change in sediment deposition simultaneously indicating periods of human activity, visible in the form of layers in the metallurgical pond.

6. CONCLUSIONS

The conducted research allowed the following specific conclusions to be formulated:

- The type and thickness of metallurgical waste from the former ironworks in Brusiek were determined on the basis of the analysis of sediments from an exposure in the high terrace of the river and material from boreholes in the metallurgical channel. These were: mainly green enamel after iron smelting, slag blocks, bricks, fragments of carbonate rocks, charcoal and charcoal ash layers. The dating of organic matter accompanying anthropogenic layers indicates its contemporary character, i.e. their origin dating from the end of metallurgical production.
- Analysis of the sample of metallurgical slag enabled it to be determined that the iron that was smelted in the ironworks in Busiek most probably derived from bog iron ore.
- Through the petrographic analysis of sediments from the exposure in a high terrace in Brusiek, sediments from the metallurgical channel in Brusiek, and sediments from the location of the metallurgical pond in Białogon, the presence and content of anthropogenic matter in sediments which was not visible to the naked eye was determined. Additionally, based on analysis of the variability of the sediment layers as well as their fractions and structure, it was possible to reconstruct the changes in sediment deposition at the Białogon site.
- Layers with a high content of anthropogenic material in sediments may indicate more intense human activity during the deposition of these sediments.

Acknowledgments

This study was performed within the scope of the research Project no. 2017/25/N/ST10/01876 funded by the Polish National Science Centre (NCN). The authors wish to thank Agata Sady from the Silesian Museum in Katowice, Poland for performing palaeobotanical analyses.

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Received at: 25. 06. 2019
Revised at: 25. 07. 2019
Accepted for publication at: 26. 07. 2019
Published online at: 31. 07. 2019