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First evidence for the forging of gold in an Early Bronze Age Site of Central Europe (2200–1800 BCE)

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A R T I C L E I N F O

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A B S T R A C T

Evidence of gold processing in the fortified site of Bruszczewo (Poland) is the first testimony of the production of gold artefacts in a domestic Early Bronze Age site of Central Europe. This paper highlights the potential of macrolithic tool ensembles as a key element for the recognition of metallurgical work processes. Moreover, it presents an optimised methodological approach to tackle the application of stone tools in metallurgical production, based on technological characterisation, use-wear analysis, portable X-ray fluorescence, transmission electron microscopy and energy dispersive X-ray spectroscopy. Finally, the absence of gold sources in Central Europe raises the question about the origin of the metal, constituting an especially striking issue, as gold was a raw material of restricted access. As Bruszczewo was one of the few enclosed Early Bronze Age sites north of the Central European Mountain Range, the patterning of metal processing (including gold) sheds light on the mode of the production of metal artefacts, apparently restricted to central sites of power, which controlled the communication trails.

1. Introduction

Besides the immense and extraordinary importance of gold objects in the ritual sphere, evidence of the production of gold objects in European prehistoric domestic sites is rare, despite the large number of gold objects in early centers of metallurgy (Needham and Sheridan 2014; Meller 2014; Legarra Herrero, 2014; Hansen 2014; Klemm and Klemm 2014; Stos-Gale 2014). Until today, no evidence of gold workshops is documented from European Neolithic or Chalcolithic sites. Even for the Early Bronze Age (EBA), the only evidence for the production of silver tools comes from the El Argar site of Tira del Lienzo, a few kilometres away from La Bastida (Spain) and dating around 2200–1800 BCE (Lull et al. 2014; Delgado-Raack et al. 2016). At the site forging tools and anvils appeared, which were related to the forging and polishing of also silver tools.

Taking this into account, the evidence for gold artefact processing at Bruszczewo is the first testimony of the production of gold artefacts in a domestic EBA site of Central Europe. Although different analyses of gold items, e.g. of Únětice burials and hoards, have been conducted until the present day (cp. Lockhoff and Pernicka 2014), the management of gold inside a settlement can directly be tracked for the first time with the exceptional finding from Bruszczewo. The Bruszczewo site is located 60 km southwest of the city of Poznań, not far from the river Oder, western Poland. Known since the 1960s, the site, which main occupation phase is 14C- and dendro-dated to the Early Bronze Age, has been investigated by an international team of scientists since the 1990s (Czebreszuk and Müller 2004; 2015; Müller et al. 2010; Czebreszuk et al. 2015).

The significance of this finding in Bruszczewo is all the more important, because especially in the Únětice Complex gold artefacts are mainly restricted to the rich graves in the few large burial mounds (Leubingen, Helmsdorf and Łęki Małe, which is only 14 km distance from Bruszczewo) and rich hoards (among others Dieskau and Nebra) (Meller 2014). These are golden ring jewellery (especially different loop rings, lock rings), but also massive bracelets with stamp ends, eyelet pins, tubular wire beads, golden arm rings and even golden axes. In addition, golden hilt bands appear on the Nebra swords and different

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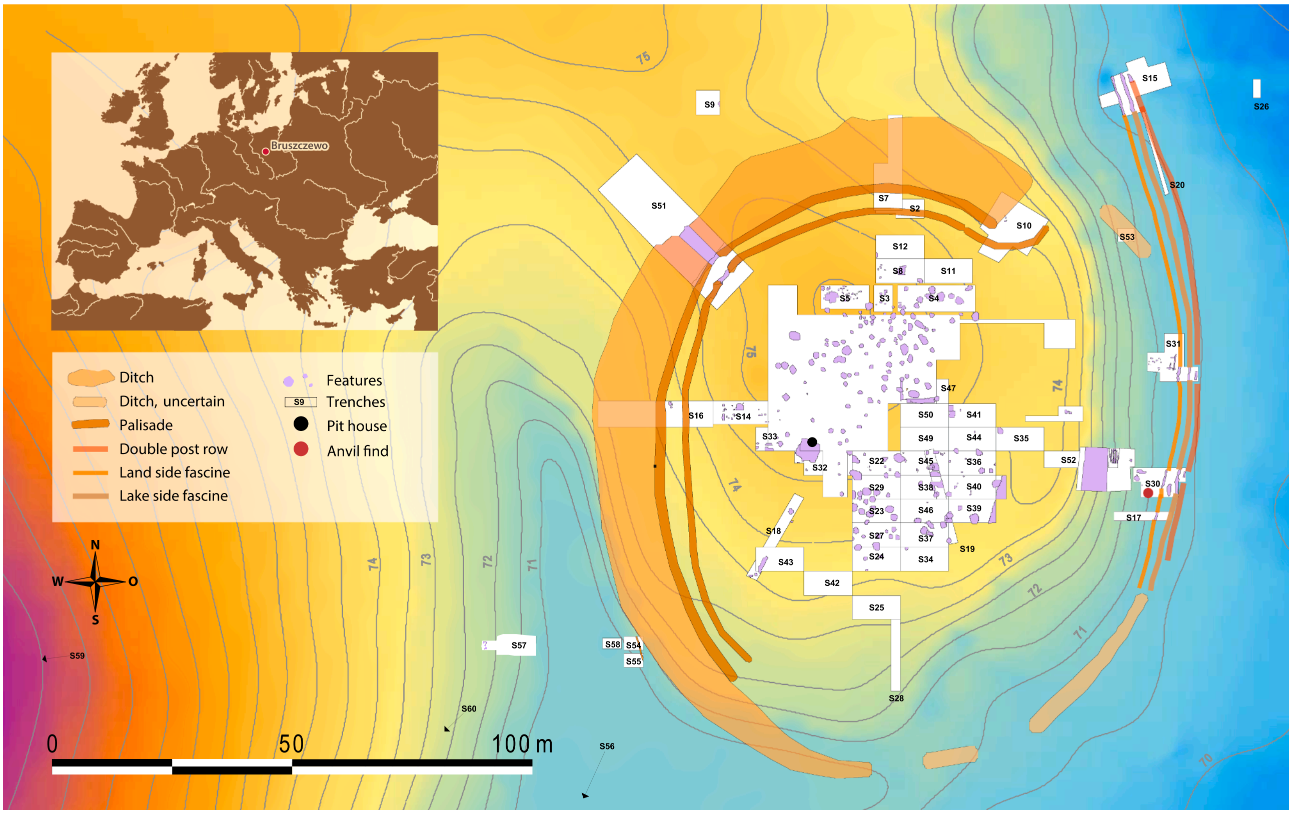

Figure 1. The location of the site Bruszczewo 5 on the terrace with the wet area in the east (blue).

gold batches on the Nebra disc.

As Bruszczewo is situated at the eastern border of the early metal working areas of the Early Bronze Age (EBA) groups, the linkage of copper and gold processing describes a unique pattern: the production of gold artefacts seems to be integrated within general metal working processes at this fortified site and therefore did not play a separate role. Taking into account the association of golden artefacts with the few richest graves and depots of the Unetice society, the evidence of the processing of gold tools at the fortified domestic site Bruszczewo and of gold spiral rings within the nearby richly Łęki Małe burial mounds, a highly sophisticated EBA center of power is indicated (Müller and Kneisel 2010).

2. EBA gold processing and Bruszczewo

2.1. Evidence of gold processing in the European Neolithic, Chalcolithic and Early Bronze Age

The earliest known processed gold objects in European prehistory are known from burial 43 in Varna, Bulgaria (ca. 4600 BCE) (Leusch et al. 2014; Krauß et al. 2014) and worked gold and silver from the kurgan of Maikop, Kuban area, South Russia (ca. 4200 BCE) (Hansen 2014). The earliest silver artefact is known from the Aegean (ca. 4100 BCE), where a major boom in gold and silver objects is visible much later from around 3100 BCE onwards (Gale and Stos-Gale 1981; Legarra Herrero 2014; Stefani 2015).

Gold working traditions in Central, North and Northwest Europe are testified by gold artefacts from around 2450 BCE until 1700 BC. In Central Germany and Britain gold occurs first in Bell Beaker context after 2500 BC (Meller 2014; Needham and Sheridan 2014), in Scandinavia gold was used since the late Neolithic after 2000 BC (Kaul 2014).

In South Europe gold and silver occurred mostly since around 3300 BC: Finds of silver and gold are documented from the Final Neolithic for Sardinia, Italy and southern France (Grazia Melis, 2014), from Iberia gold artefacts have been known since the end of the Neolithic (3100 BC) (Rovira Hortalá et al., 2014), silver since the end of the 3rd millennium (Lull et al. 2014: 560).

In the eastern Mediterranean gold finds from northern Greece are known as early as the 5th millennium, but the number of finds remains rather small (Andreou and Vavelidis 2014: 456 tab. 3). The EBA slag finds from Vardaroftsa are doubted by the authors (Andreou and Vavelidis 2014). Despite a small quantity of gold finds, clear evidence of gold processing comes from the Toumba of Thessaloniki from the 2nd millennium. There, traces of gold were found in a crucible dating to the Late Bronze Age (Vavelidis and Andreou 2008).

In South Aegean, some gold and silver finds are documented from the Final Neolithic (4500-3100 BC) onwards, with a concentration on Crete and the Peloponnese (Zachos 2007; Legarra Herrero 2014). Some finds of litharge indicate silver production already from the end of the Neolithic (4200-3100 BC) (Kakavogianni 2008; Georgakopoulou, 2007). In general, silver seems in the Aegean more connected to copper metallurgy networks and processing than gold (Legarra Herrero 2014).

In West Asia remains of silver cupellation, the process of silver extraction, are found at sites as Arisman, Iran and Habuba Kabira, Syria from mid of the fourth millennium. Written sources from the 28-27th century B.C. name a silversmith (Helwig 2014). In Syria gold work has been proven since the early 3rd millennium and ceased growing at the end of the 3rd millennium (Prévalet 2014).

While within most of the European cases, gold and silver are merely used as a value to display prestige and status through a kind of conspicuous consumption, the textual evidence from Ebla in Northwestern Syria confirms that gold and silver "were used as economic equivalent values of the Near East to measure other goods" at the latest around 2500 BCE (Meller et al. 2014: 12).

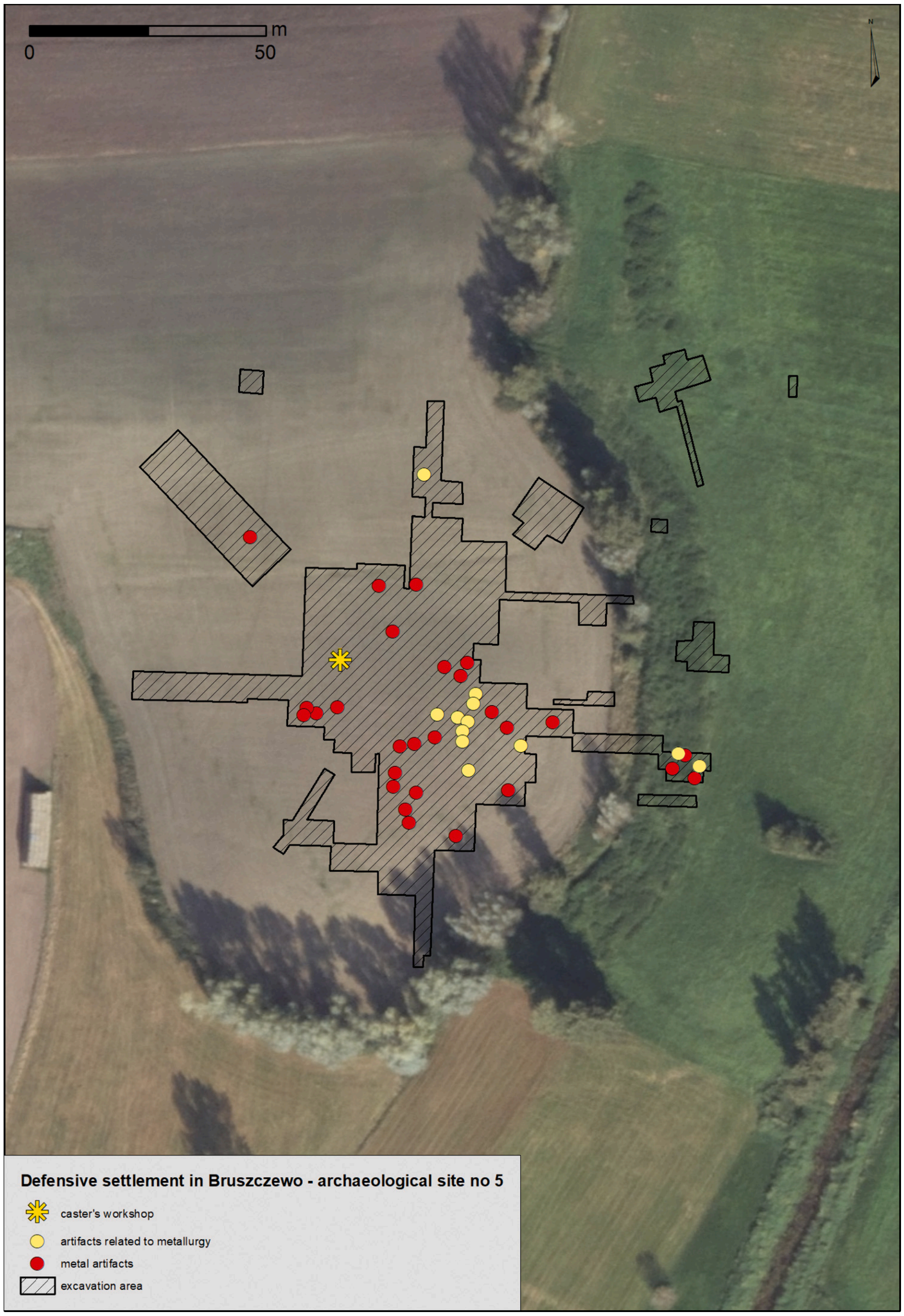

Figure 2. Distribution of metal finds (red), artifacts related to metalworking (yellow) and location of remains of the caster's workshop (yellow asterix) (Graphics: C. Bahyrycz).

2.2. The economic, social and cultural context: EBA Bruszczewo and its networks

The new evidence for gold processing derives from EBA Bruszczewo 5, which is situated on a fluvio-glacial, sandy terrace promontory at a basin that was originally a big lake measuring ca. 32 ha. Nearby, the 'princely' tombs of Łęki Małe are located, which contain rich grave goods including gold objects (Kowiańska-Piaszykowa 2008). The site is geographically located at one of the narrowest transitions of the Berlin-Warsaw glacial valley. Bruszczewo has been excavated by different archaeological teams of the Archaeological Museum Poznań, the Adam Mickiewicz University (AMU) in Poznań and finally in a joint Polish-German project that is still ongoing and headed by Janusz Czebreszuk of AMU Poznań and Johannes Müller of Kiel University (Czebreszuk and Müller 2015; Kneisel 2011; Müller et al. 2010; Kneisel et al. 2008).

At the earliest around 2200 BCE, 1.2 ha of the former peninsula were cut off from the hinterland by a huge ditch (measuring 4.5 m deep and 19.5 m wide) and a palisade. Both were repeatedly renewed (Müller and Czebreszuk 2003). Evidence of domestic activities and architecture were preserved, including rubbish pits, remains of semi-subterranean huts and also larger houses of EBA type (Fig. 1).

Cereal processing with storage facilities, the slaughtering and consumption of domesticated and wild animals, the production of items made of wood, bone, and antler as well as textile production and also evidence of a metal workshop have been verified (Kneisel 2013a; Kneisel 2010a; Czebreszuk and Müller 2004; Makowiecki 2015; Schäfer-Di Maida and Kneisel 2019). Amber beads hint towards the role that the inhabitants played in amber barter and perhaps in the production of

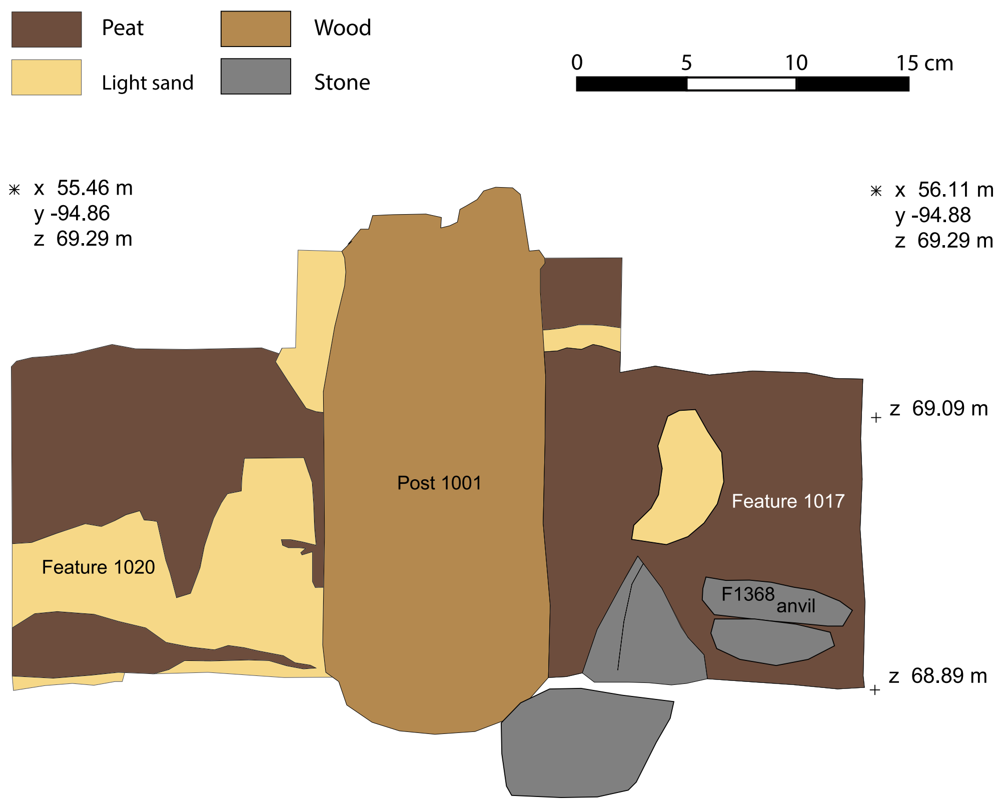

Figure 3. The profile of the post with the stone setting and a drawing of the planum. The dark colour arises from the refilling of the already removed post.

amber items. The fortified site of Bruszczewo is one of the few EBA regional centers known in Central Europe (Müller and Kneisel 2010).

With regard to the production of metal artefacts, tuyères, moulds, tin-bronze metal droplets, half-finished and finished products made of tin-bronze in primary and secondary contexts are reported – remnants of a metal workshop (Fig. 2) (Czebreszuk et al. 2004; Czebreszuk 2021; Silska 2012).

Traces of metallurgical activities were dispersed within different parts of the settlement, for example, smelting drops are found in daub remains of house no. 2 within the eastern area of Bruszczewo (Müller et al. 2015). Different copper alloys were used from ca. 2200–1600 BCE (Rassmann 2010). Continuous metal processing took place, lasting at least until 1650 BCE. Both copper and tin were imported, the former probably from the eastern Alpine area, the latter presumably from the

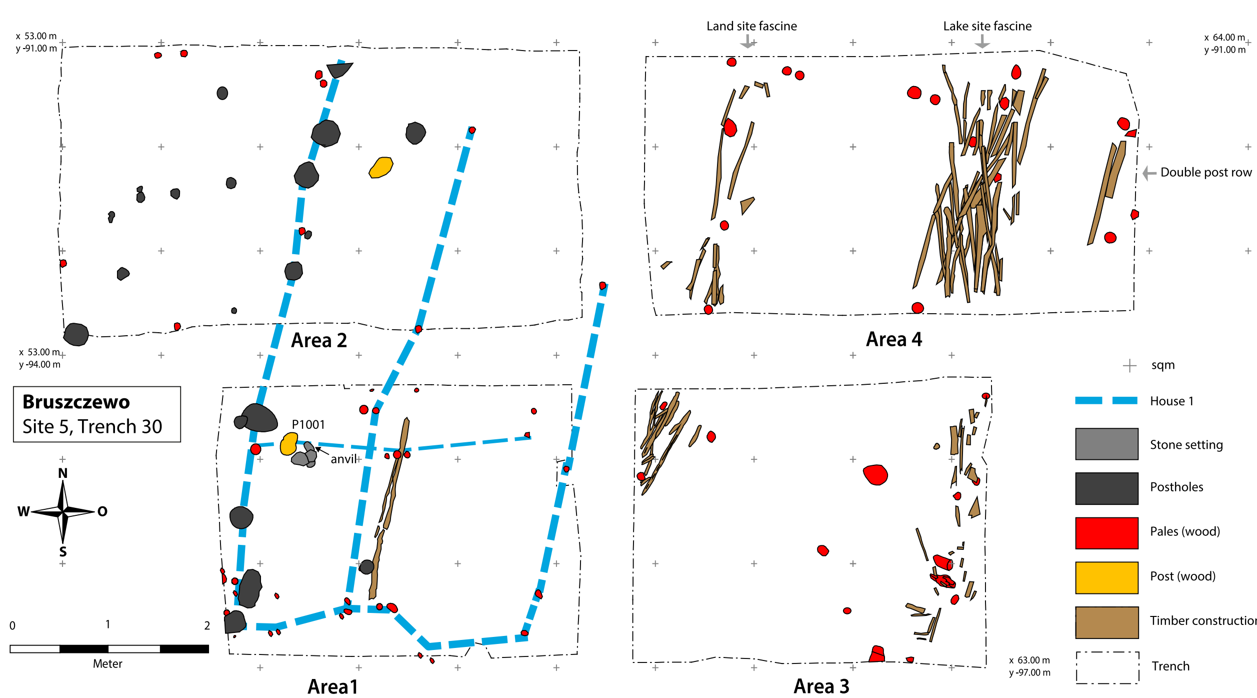

Figure 4. Trench 30 in the wet area with the reconstruction of house 1.

west, probably Hercynian sources (Kneisel and Müller, 2011). Craftsmen from Bruszczewo also used or invented new production technologies, as evidenced by the finding of an eyelet bronze pin (so-called 'Ösenkopfnadel'), which was cast in an early cast-on technique (Kneisel 2013b). Another example of complicated smelting technology is the dagger found in nearby Przysieka Polska, a site located ca. 2 km to the east of Bruszczewo on the opposite shore of the lake. In this case, single-use cast with a hollow place in the handle was achieved after a clay core was used (Schwenzer 2004).

The production of bronze artefacts displays local (or regional) specificity, which is indicated, for example, by the increased presence of bracelets (Thuringian type). One half of a stone casting mould used for these types of artefacts was found in Bruszczewo (Silska 2012). The main sites for the deposition of metal objects in the region (probably also those manufactured in Bruszczewo) were "princely graves" located in Łęki Małe (15 km north of Bruszczewo), where several dozen bronze items and seven gold rings (so-called 'Noppenringe') were found (Kowiańska-Piaszykowa 2008).

In EBA Bruszczewo, bronze metallurgy was practiced with the implementation of innovative technologies, probably in constant contact with other metallurgists to the south and the west, and exchange networks towards the Baltic zone, where amber was bargained against metal artefacts (Kneisel et al. in print; Müller and Kneisel 2010). Different spheres of production show a wide range of contacts, reaching from North Poland to Hungary, and thus reflecting the influence of this site in regional and supra-regional contexts.

2.3. Discovery and context

Around 1800 BCE, this site was expanded to the east with a new lake site fortification and the construction of four new houses, which have been dendro-dated to 1797–1787 BCE (Ważny 2010; Heußner and Ważny 2010). In this area a total of 382 macrolithic tools were recovered, 129 of them belong to the EBA. Most of the artefacts were involved in percussive activities, but also grinding artefacts and abraders were documented. Multifunctional tools bearing evidence of percussion and abrasion are frequent (Delgado-Raack et al. 2020b). Specialized tools related to the production of metal artefacts are rather scarce in this area of the settlement, since only three metal forging anvils (including the one presented in this paper) and one sharpener were identified.

In the context of the new EBA house 1 (feature 1017/1020) (Kneisel 2010b; Szydłowski 2015), which was located directly east of the lakeside fascine, the analysed anvil was located. The anvil (F1368) was found in the wet area of the settlement in a layer belonging to house 1 and is part of a bigger stone setting, which belongs to a post of the house (Fig. 3). The anvil dates earlier than the house, as it was used secondarily as a wedge for the post. The house construction dates from the beginning of 19th century to the beginning of 18th century BCE. In relation to the dendro-dates from the nearby fascine (Ważny 2010), a dating to the early 18th century BC is most likely. In contrast to the many pales, the whole stem was used and cut even at the end. This probable roof-supporting post could not be driven into the ground. A posthole and some stone support were needed (Fig. 4). The anvil is thus older than the house structure.

Detailed investigation has shown that the anvil was used in two ways: initially in metal working, and subsequently in reuse as secondary building material in the mentioned structure. The artefact is broken into at least seven fragments, showing many cracks and breaks affecting its general morphology as well as a darker colour on its obverse, which suggests that it had been exposed to combustion in the structure. As the anvil was secondarily used, the date of the house construction is a *terminus ante quem*. According to the earlier settlement traces from the site, the anvil could have been in use from 2200 BC onwards, ending up in the stone setting at the latest at the start of the 18th century BCE. It is very likely that the anvil was originally used at the very beginning of the Early Bronze Age occupation of the settlement.

3. Methods

3.1. Macroscopic analysis: general technological features

The importance of macrolithic tools derives mainly from their good preservation in the archaeological deposits and their participation in numerous productive processes. During the last decades, macrolithic artefacts have proved to be paramount archaeological remains for any palaeoeconomic study of prehistoric societies and, more specifically, for the characterisation of past metallurgical work processes. Apart from the finished metal objects themselves, which are concentrated in ritual contexts such as burials and hoards, metallurgical evidence during the EBA is scarce or sometimes fully absent. As the incipient metallurgical technology hardly left any evidence in the archaeological record and metal objects were regularly re-melted, the work equipment involved in this production process becomes a key element for the visibility of this technology in settlement contexts.

This study follows the protocols particularly established for the analysis of macrolithic tools. Since the first proposal presented in the 1990s (Risch et al. 2002), new databases reaching up to several thousand artefacts have enriched the inventory system with additional technological and functional aspects (Delgado-Raack 2008), new artefact categories (Delgado-Raack and Risch 2006; Delgado-Raack and Risch 2008), innovative analytical procedures (Delgado-Raack and Risch 2006; Delgado-Raack and Risch 2008; Delgado-Raack 2008; Delgado-Raack et al. 2016) and residue analysis (Ache et al. 2017).

Macroscopic features, such as the types of raw materials, dimensions, weight and morphology, are directly linked to the conception that human beings had for the tools they used and they are at the same time a result of it. The determination of the type of rock used for the production of macrolithic artefacts has been traditionally a research topic for the definition of raw material supply systems. Nowadays, knowledge about the type of rock and its petrographic nature (i.e. texture, grain size, porosity, etc.) is understood to be necessary in order to correctly assess use-wear patterns observed on their surfaces and to interpret the material which the artefact came into contact with. Moreover, this kind of data has been recently included in the analysis of the mechanical properties associated with the tools, aimed at answering questions about their efficiency during use and the production derived from their participation therein (Delgado-Raack et al., 2009; Dubreuil et al. 2015; Delgado-Raack et al. 2020a). Our petrographic approach was based on non-destructive macroscopic observation of the specimens, using habitual petrographic procedures such as a field loup (20x magnification), rock guides (Rudolph 2008; Rudolph 2010) and specialised publications on the geomorphological context of the site and its surroundings (Bork, 2010; Hildebrandt-Radke, 2010; Hildebrandt-Radke, 2015).

Equally relevant for the functioning of a tool are its dimensions and weight, as the wider the contact area and the heavier the tool, the faster the work process will be in terms of production per unit of time. Finally, the recording of macroscopically observable work traces is just as critical as observations at a microscopic level. They are frequently responsible for the overall morphology of the tool, which at the same time offers determinant information for the interpretation of the movement performed by the artefact (Adams et al. 2009).

3.2. Mesoscopic analysis: specific technological features

The used surface of the anvil was mainly covered by highly reflectant particles that were clearly a result of adhesive wear (Adams 2002). These residues made it difficult to observe the original surface in an extensive area. At the same time sampling the surface with replicas (for example, silicone or epoxy) would have added the risk of introducing in the analysis elements not belonging to the stone surface. Therefore, a low power magnification approach was applied for the use-wear analysis. The surface was mainly observed and described at level 1 of observation, defined by Adams et al. (2009: fig. 6.3) as "development of topography", and exceptionally individual grains were identified and included in the analysis (Adams et al. 2009: fig. 6.4).

For the purpose of this analytical step, a stereoscopic loupe Olympus Japan VM VMT with up to 100x magnifications was implemented, which was available in the Institute of Prehistoric and Protohistoric Archaeology of Kiel University. The loupe was coupled to a digital camera, allowing the graphic recording of characteristic use-wear traces.

The study of use-wear traces was done following the standardised procedure designed for the recording of the qualitative features of wear, i.e. linear traces, polish/sheen, levelling, pits and grain extraction, and fractures and grain edge rounding (Adams et al. 2009; Delgado-Raack 2008). For the interpretation of the use-wear pattern and other technological and contextual aspects, additional archaeological, experimental and ethnographic reference materials concerning forging artefacts were taken into account, which are addressed in section 4.

During the observation of surfaces under the stereoscopic loupe, the next microscopic analytical phase of the study was prepared, tracking suspicious adherences of plastic appearance of external origin to provide a basis for the subsequent sampling strategy for residue analysis (see below).

3.3. Microscopic analysis: residues

Chemical analyses (for example, Energy Dispersive X-Ray Analysis, Neutron activation, X-ray fluorescence synchrotron spectroscopy) substantiating metal remains on early metallurgical macrolithic tools are still scarce, although they are starting to be applied as some recent case studies show. Few examples on tools related to mining activities (i.e. picks and percussors) and the first mechanical processing of mineral (i.e. stones with cupules) in copper ore exploitations exist for the Chalcolithic (Caricola et al., 2020; Hamon et al., 2009; Delgado-Raack et al., 2014) and the Bronze Age (Delgado-Raack and Gómez-Gras, 2017; Montero-Ruiz, 2017). Moving along the metallurgical chaîne opératoire, metal residues have been identified on some forging tools coming from Bell Beaker contexts, such as graves recovered in Künzing-Bruck (Bavaria, Germany; Bertemes et al. 2000; Bertemes and Heyd 2002), Těšetice, Turovice, Hulín 1, Hulín- Pravice 2 and Opatovic (Moravia, Czech Republic; Peška 2016; Bertemes et al., 2000), the cremation burial of Zwenkau (Central Germany; Conrad 2011) and the hoard of Hengelo-Elderinkweg (Netherlands; Drenth et al. 2016)[1]. These tools are carefully manufactured anvils and hammer stones, but also simple pebbles, bearing remains of gold and copper, and exceptionally, silver. The only EBA forging tools with preserved metallic adherences known to the authors come from two workshops, originating from EBA. In all cases, forging tools were part of a stone toolkit, which also included polishing/sharpening tools and the forged metal – silver in the case of Tira del Lienzo (Spain: Delgado-Raack et al. 2016) and bronze in the case of Ploneour-Lanvern (Brittany: Hamon et al. 2020). Finally, metallic remains have also appeared on a few artefacts related to the final stages of metal manufacturing, such as touchstones and whetstones (see for example Shell 2000).

At this point it is important to state that metallic remains have been often optically detected previous to compositional microanalysis and described as traces "of golden appearance" or "strikes with a shiny metallic appearance" (Freudenberg 2009; Delgado-Raack et al. 2016; Boutoille 2019). Considering our experience, the above-mentioned technological and use-wear analyses should always precede residue analysis in order to properly search for possible adherences. These previous steps allow (**a**) the recognition of mechanically worn surfaces and their distinction from natural ones, (**b**) the differentiation between manufactured (passive) and used (active) surfaces, (**c**) the avoidance of time-consuming processes and unnecessary resource expenses, and (**d**) the scrutiny of the functional interpretation based on use-wear analysis. In other words, only a deep knowledge about the types of surfaces will ensure that observed residues really appear restricted to the used surface/s and thus support a given functional interpretation.

In both techniques used in this study, the sampling strategy for the residue analysis was intentionally focused on selected zones, on which use-wear was especially evident, and other so called "neutral" zones where use-wear was clearly absent (i.e. broken surfaces or "passive" surfaces).

3.4. Portable X-ray fluorescence (pXRF)

The pXRF technique has proven to be very useful as a prospective way of confirming microscopic and mesoscopic observations. However, since it is a technique with a large diameter of analysis (8 mm diameter) with respect to the surface of the residues of interest and also has a capacity for penetration that can go beyond the thickness of the residue observed under the microscope, part of the results will correspond to the lithology of the support where the mineral or metallic particle is embedded. This involves two additional difficulties to a technique that is considered to be semi-quantitative or directly qualitative (Orfanou and Rehren 2015). On the one hand, the lithology of the support may naturally contain metallic minerals of interest and, on the other hand, the readings of embedded particles will always give very low concentrations, close to the detection limits of the equipment. All these determining factors mean that in the studies of residues, it is necessary to complement them with other more precise elemental analysis. In addition, a sufficient number of comparative analyses between neutral and active zones have been carried out to be able to positively discriminate the lithology of the support of the residues observed under the microscope. The results obtained subsequently by TEM-EDX confirm the usefulness of pXRF in this type of study.

The used measuring device was a portable Thermo Niton pXRF Analyzer LLC (available at the Cluster of Excellence ROOTS of Kiel University). The technical adjustments for the measurements are summed as follows: modus (Mining Cu/Zn); time setting (120 ppm of which 30 Main, 30 Low, 30 High, 30 Light); energy beam diameter 8 mm; detection limit 1–20 ppm for trace elements, under helium. Control measurements were done according to standards.

3.5. Transmission Electron Microscopy (TEM) and Energy Dispersive X-ray Spectroscopy (EDX)

The technical adjustments of the TEM are as follows: FEI Tecnai F30 G^2 STwin; 300 kV; (FEG-Cathode); spherical aberration coefficient Cs=1.2 mm, equipped with a Si/Li Detector (EDAX System) for EDX-Analysis.

4. Experimental and ethnographic references

The technological features observed on the artefact during the first phase of the study suggested a possible relation with forging activities. Plastic shaping techniques such as sheeting, folding or bending need stone anvils and hammers (Armbruster 2006, 2010). The work process consists in beating out a metal object (for example, wire, sheet or blade) by hammering, which results in a material displacement that reduces its thickness and homogenizes its surface. Therefore, the stone surface must be smooth in order to favor homogeneous striking that preserves the integrity of the metallic surface. These artefacts are often (but not

[1] In the case of Hengelo, results must be taken with caution. Although neutron activation analysis showed the presence of copper and gold, subsequent SEM-EDX analysis did not allow the recognition of such elements (Drenth et al. 2016). In addition, metallic remains (Cu and Fe among other elements) found on two cushion stones coming from a dredging context attributed to the Late Neolithic (LNI) in Groß Sarau (Northern Germany), have been interpreted by the author to be probably postdepositional (Freudenberg 2009).

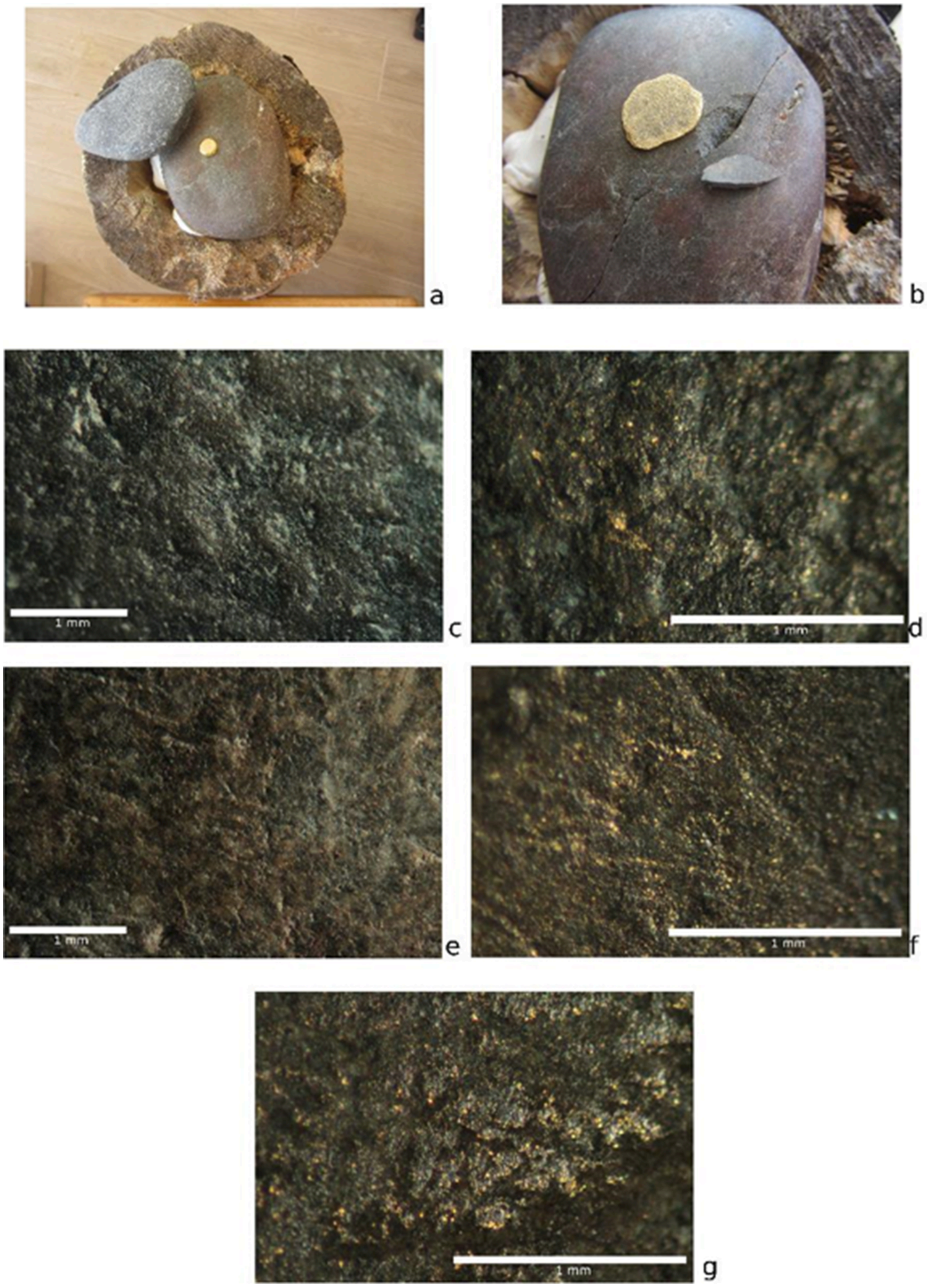

Figure 5. (a) Experimental anvil and hammer stone used for 30 minutes sheeting of a gold nugget. (b) State of the gold piece at the moment of breakage of the anvil (note the detached flake and the break crossing the stone obliquely). (c) Unused surface of the hammer. (d) Surface of the hammer used for gold sheeting, showing gold particles scattered along the stone surface. (e) Unused surface of the anvil. (f) Surface of the anvil used for gold sheeting, showing gold particles located on the medium and low areas of the stone surface. (g) Surface of the anvil used for polishing the gold sheet during 10 minutes, showing gold particles restricted to the high areas of the stone surface (note the oriented disposition of residues).

always) intentionally arranged and carefully prepared before work, thus originating the characteristic morphologies shown by the so called "cushion stones" and axe shaped hammers with blunted edge. At archaeological level, artefacts like these were first recognized by Butler and van der Waals for the Bell Beaker Complex (Butler and van der Waals, 1967). Since then, the empirical basis has exponentially grown, especially the so called "smith graves" are crucial archaeological contexts representing this kind of artefacts at a paneuropean level (Boutoille, 2012; Delgado-Raack and Risch, 2006; Fitzpatrick, 2002; Freudenberg, 2009; Bertemes, 2004; Brandherm, 2010; Delgado-Raack, 2008; Boutoille 2019; Drenth et al. 2016).

The available ethnographic and iconographic information offers some clues for the working process itself and the management (placement and handling) of anvils and hammers. On a wall painting found in the tomb of Rekhmire (Thebes, middle of the 2nd millennium BC), goldsmiths are depicted managing a cobble directly in the hand while beating on an anvil fixed in a wooden block (Armbruster and Comendador Rey, 2015). In a similar way, a Central Andean pre-columbian smith has been depicted in the Chronicle of G. Benzoni (1565; Historia del Nuevo Mundo cited in Carcedo 2017: 117) holding the hammer directly in the hand. Repairing of metal objects among the Damara (north of Twyfelfontein, Namibia) is done also holding the hammer without handle.

Fixing the stone anvil in a wooden stump has been documented in the archaeological record. In the Late Bronze Age dwelling of Auvernier (Lake Neuchâtel, Switzerland), a wooden block was found with a small stone anvil made of serpentinite embedded in it (Gross 1883, cited in Armbruster et al. 2019).

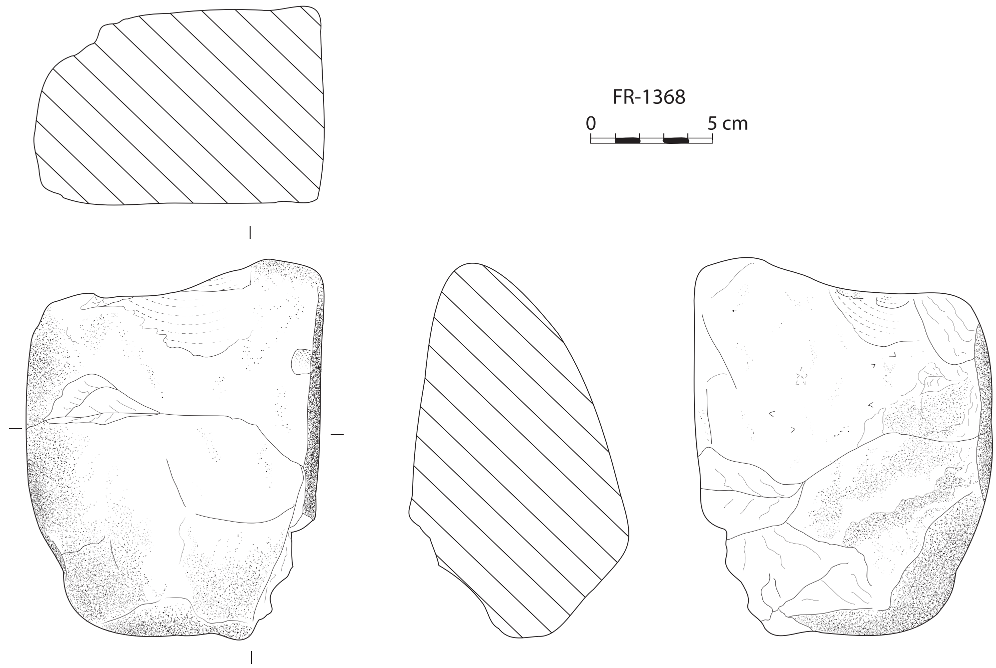

Figure 6. Anvil (F1368) found in an Early Bronze Age layer of Bruszczewo.

Large and heavy natural stones with flat surface used as anvils have been observed for example among Peruvian recent smiths (Carcedo 2017: Fig. 68b) or the Dogon blacksmiths (Mali, West Africa), who construct their workshops around them (Armbruster et al. 2019). Nonetheless, for plastic shaping of metal objects hardwood blocks can also be used as anvils.

Opposite to ethnographic observations and description of metal forging processes, experiments involving stone artefacts for the plastic shaping of metal objects are still scarce. As a result, there is a lack of bibliographic references describing the behavior of stone artefacts as well as metals and their indicators left on stone artefacts (use-wear analysis). Available data come from three experiments performed on silver, copper and gold sheets, respectively. Despite other physical and chromatic differences, all these three elements have a similar Mohs hardness, namely 2,5-3 and they can be easily worked through hammering.

The first experimental results come from previous forging experiments developed by one of us on a hole copper tube (Delgado-Raack 2008: 155-158; Fig. 2.2.6). The tube wall was 1 mm thick, and it was worked with a micrograbbro pebble shafted in an oak stem, and on a small gabbro stone anvil embedded in an oak trunk. The first anvils' active surface was mechanically cut and manually worked to a flat morphology. Edges were let at 90°, and the artefact was completely embedded until the active surface reached the upper level of the trunk. Soon after work started, this anvil had to be replaced due to the detachment of some flakes from the edges, which made the anvil unsuitable. Subsequently a gabbro pebble with a convex-straight active surface was used as anvil. The metal piece to be worked was pre-heated several times and hit from both sides while displacing it longitudinally under the hammer. The procedure ended successfully after 150 minutes, with 30 cm of the tube hammered into a sheet, in which walls were pressured one against the other and their thickness reduced to the half. Additionally, the folding of its ends was attempted, but material never welded due to the low temperature reached. Soon after the work process began, active surfaces of both hammer and anvil started showing cuprous particles scattered along the surface (Delgado-Raack 2008: Fig. 2.2.42). By increasing wear, a trend towards homogenization was recognised in which high topography developed to a rounded and shiny reflective surface while some anfractuosities were filled up with copper colored particles (Delgado-Raack and Risch 2006; 2008).

The second forging experiment was done in the context of the North German Neolithic (Freudenberg 2009). A circular 40 mm diameter sheet of 26.1 g sterling silver was striken during 4.5 hours and reduced from 2 to 1 mm th. with the aid of stone hammers and an anvil inserted in a wooden block. Both hammers and anvil were mechanically manufactured to rounded and smooth surfaces. Blows were applied regularly working from the center towards the edges without altering its circular shape. This procedure was repeated 20 times and each time the piece was previously annealed. The hammer was handled directly in the hand. The "technique of releasing it upon impact on the workpiece and resuming on springback" came out to be only efficient with the heaviest of the hammers used. The main observation done on the active surfaces of hammer nr. 4 and anvil nr. 1 is the development of a highly reflective silver layer (Freudenberg 2009: fig. 14).

A third experiment has been recently done by one of us for the purpose of this paper as a first attempt to gold sheeting. A small pure gold nugget (24 carats) of 7.5 mm w., 4.5 mm th. and 3 g was hammered in cold state for the manufacturing of a sheet. The anvil initially used was a fine-grained microgabbro pebble with a rounded contour and a straight to slightly convex active surface, which was embedded in an oak trunk (Fig. 5, a). The hammer was also made of microgabbro, being the grain coarser. In this case, one of the rounded edges was prepared to a small nearly straight facet. The hammer was hold in the hand while seating in front of the trunk. After half an hour of easy percussion work on both sides of the gold nugget, the anvil started to break along an intern fissure crossing the pebble obliqually (Fig. 5, b). Until that moment, the gold piece had been already worked out to a circular sheet of 20 mm w. and 1 mm th. with the described equipment. In the framework of an experimental program, which is still in progress, the work was finished with another equipment. Nonetheless, the first stage of the experiment was enough to observe the development of a regular and shiny stain on the stone anvil, and to a much lesser extent on the hammer. This difference could be due to the finer grain size of the anvil, which would have favored the gold to be adhered. Under the stereoscope, the anvil's active surface looked extensively covered by gold particles, while the hammer showed small particles scattered along the surface. In both cases, residues appear attached to the deepest points of the relief (slopes and low topography; Fig. 5, d and f). This mechanism

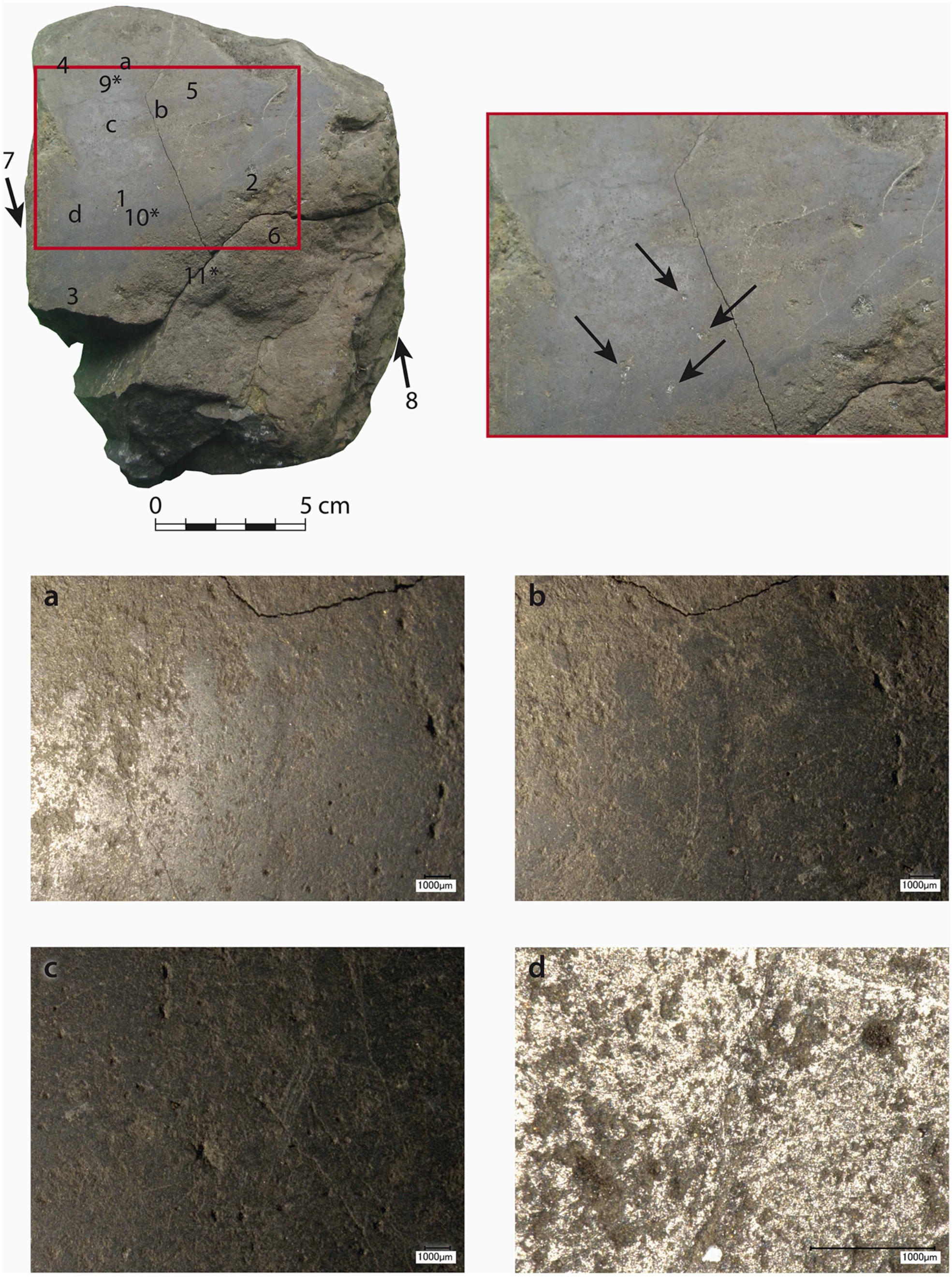

Figure 7. Anvil (F1368) from Bruszczewo showing use-wear traces on the forging surface: (a) Levelled and shiny polished surface; (b) similar area of the surface with single long and fine striations scattered on it; (c), a group of short, fine and parallel striations and at least one pit in the middle of the picture; (d) a single long striation crossing along a levelled surface, covered by a shiny adherences. Numbers 1–8 signalise the sample points measured by pXRF; numbers 9*–11* signalise the sample points measured by TEM-EDX (see below).

can be explained through the perpendicular forces acting on the gold particles, which were displaced towards the edges of the most outstanding points and pushed into the anfractuosities. Opposite to it, the gold distribution pattern obtained for gold polishing looked completely different. The obverse of the same anvil was used for 10 minutes in frictional contact with the gold sheet in a forth and back movement. Since the movement performed on the stone surface implied horizontal abrasive force, gold particles adhered to the high topography, i.e. the most exposed areas (Fig. 5, g). As a result, the weft built by residues was closer than in the case of the sheeting process.

Although not all three experiments were done by the same person and for the same purpose, they all address some common questions. Firstly, it seems clear that the morphology of stone tools influences the working process. Sharp edges often result in breaks of the stone surface that can easily splinter and damage the metal object. Thus rounded edges are needed, whether carefully manufactured or selected among natural pebbles. Secondly, metal sheeting leaves adherences on both stone surfaces as soon as blowing between stone and metal begins and intensifies during work. At least, silver and copper let residues in preheated state, while gold was worked in cold state and also let residues adhered to both hammer and anvil. Nonetheless, these are first attempts to systematically observe how metal sheeting may have developed during EBA. One of the main difficulties is the observation of experimental stone surfaces itself, since metal remains usually cover them extensively. This makes it hard to compare experimental samples with archaeological ones, in which the presence of optically recognizable metallic adherences is rather an exception. Moreover, the presence of residues alone does not allow discerning between cold and hot hammering, as both favour their adhesion to the stone surface. To do so, the removal of adherences from the experimental surfaces would be necessary in order to assess the observation of experimental as well as archaeological use-wear under the same conditions. At the present state

Table 1
PXRF data of the sampling on the anvil (F1368). The position of the measured points ID 1-8 can be read from Figure 7.

ID	ID	Contextual information	Fe %	Ti %	Ca %	K %	Al %	Si %	S %	Mg %	Ce ppm	Ba ppm	Cd ppm	Ag ppm	Nb ppm	Zr ppm	Y ppm
318	1	Forging surface (pit filled up with a white substance)	10.73	0.92	6.16	0.40	12.83	28.10	1.35	12.34	137	510	11	8.62	5	81	21
319	2	Forging surface (pit filled up with a white substance)	11.00	1.06	6.29	0.37	9.32	23.07	1.60	8.77	115	488	11	< LOD	5	93	20
320	3	Forging surface	10.17	1.04	6.66	0.32	11.93	27.62	0.84	9.17	140	543	11	< LOD	5	89	24
321	4	Forging surface	9.95	1.05	6.35	0.47	12.07	27.64	1.00	9.84	127	521	11	< LOD	5	82	20
322	5	Forging surface	10.64	1.15	6.11	0.51	9.08	24.17	1.34	8.51	150	533	< LOD	13.85	5	99	24
323	6	Periphery of forging surface	11.47	1.23	5.62	0.33	7.81	20.86	0.97	7.60	122	442	< LOD	< LOD	< LOD	107	22
324	7	Surface opposite to the forging one	10.52	1.05	6.04	0.32	9.10	22.59	0.89	7.00	128	458	11	< LOD	5	89	19
325	8	Surface opposite to the forging one	11.11	1.23	5.67	0.46	7.84	23.58	0.51	7.66	114	503	11	< LOD	8	100	23

ID	ID	Contextual information	Sr ppm	Rb ppm	As ppm	Au ppm	Hg ppm	Zn ppm	Cu ppm	Ni ppm	Co ppm	Mn ppm	Cr ppm	V ppm	Cl ppm	P ppm
318	1	Forging surface (pit filled up with a white substance)	197	13	49.82	251.19	< LOD	132	108	444	< LOD	2169	388	286	256	3
319	2	Forging surface (pit filled up with a white substance)	180	<LOD	25.43	13.22	< LOD	121	26	395	< LOD	2640	370	285	204	1
320	3	Forging surface	236	7	37.33	18.30	< LOD	112	90	283	< LOD	2262	448	255	209	2
321	4	Forging surface	237	27	50.45	224.29	12	138	60	264	< LOD	2319	402	307	183	4
322	5	Forging surface	166	20	31.10	225.25	14	140	32	316	< LOD	2540	467	284	218	3
323	6	Periphery of forging surface	116	< LOD	26.12	< LOD	< LOD	156	< LOD	292	< LOD	3194	455	376	190	0
324	7	Surface opposite to the forging one	221	8	29.10	< LOD	< LOD	123	< LOD	265	< LOD	2435	439	266	222	2
325	8	Surface opposite to the forging one	137	15	15.92	< LOD	< LOD	166	< LOD	288	< LOD	3104	364	346	228	1

of the art, a cold working of gold on the anvil of Bruszczewo cannot be excluded.

5. Results

For the manufacturing of the artefact, a basaltic pebble stone was used as raw material (Fig. 6), which might have been picked up from the fluvio-glacial materials deposited in the immediate vicinity of the settlement (Bork, 2010; Hildebrandt-Radke, 2010).

However, in order to favor the artefact integrity no thin section analysis was made. As a result, we can neither rule out any of the following sources of basalt found in Neolithic/Bronze Age contexts on the Polish Lowlands: either local sources with erratic material or two distant areas – the Sudetes Mountains or Volhynia (Chachlikowski and Skoczylas 2001; Chachlikowski 2013). The raw material can be described as a compact, fine-grained basalt, with a very dense and massive lithology, ranging in weight up to 2867 g and measuring 159 mm l., 112 mm w. and 97 mm th. It has an asymmetrical morphology with an irregular plan view, an approximately triangular long section and a rectangular cross section. Apart from the active forging platform, the only surface which seems to have been modified is the upper one, where a few flakes have been removed from the edges adjacent to both the obverse and the reverse. The limits of the negatives appear smoothed due to the transformation of the forging platform, suggesting that these blows were probably done at some point before the preparation of the active surface. While the biggest negatives are conchoidal, there are also step fractures, which indicate a perpendicular rather than an oblique blow. Oblique blows would have been expected if we were dealing with retouching evidence. Accordingly, it is likely that before using it as anvil, the upper, more or less bevelled edge of the pebble was occasionally implemented in percussion against a hard material.

The most interesting surface of the anvil is its active surface, located at the back of the pebble. It is not an even surface, as the lower half shows a quite irregular relief. This lower part was left unused while the upper more exposed part was intensively worn to a flat surface in an area of ca. 103 x 90 mm (Fig. 7). Although the top and left angles are approximately 90°, edges are clearly rounded. Bottom and right limits of the active surface are rather diffuse following the natural sinuosity of the surface. Based on the size and extension of the active surface, the artefact was not managed in the hand, but used as static element, probably embedded in a wooden piece or in the floor. In this sense, the anvil cannot be considered a classical cushion stone, as first described by Butler and van der Waals (1967). Nonetheless, if we have a nearer look at the morphology of these tools, it becomes clear that a wide variety of shapes do exist ranging from rectangular or trapezoidal regular prisms to more irregular massive forms, even in the same archaeological context (see for example, Delgado-Raack and Risch 2006; Drenth et al. 2016; Boutoille 2019).

According to the use-wear analysis, the active surface of the artefact was used for forging metal objects. It is likely that the forging surface was prepared previously to use in order to regularise the relief, but use-wear traces seem to have masked manufacturing evidence. The process of attenuation of manufacturing traces has been described for other forging artefacts (hammers as well as anvils (Delgado-Raack and Risch 2008)). The model illustrates the development of wear, starting from a natural water-worn surface, through the fine grinding of the surface and

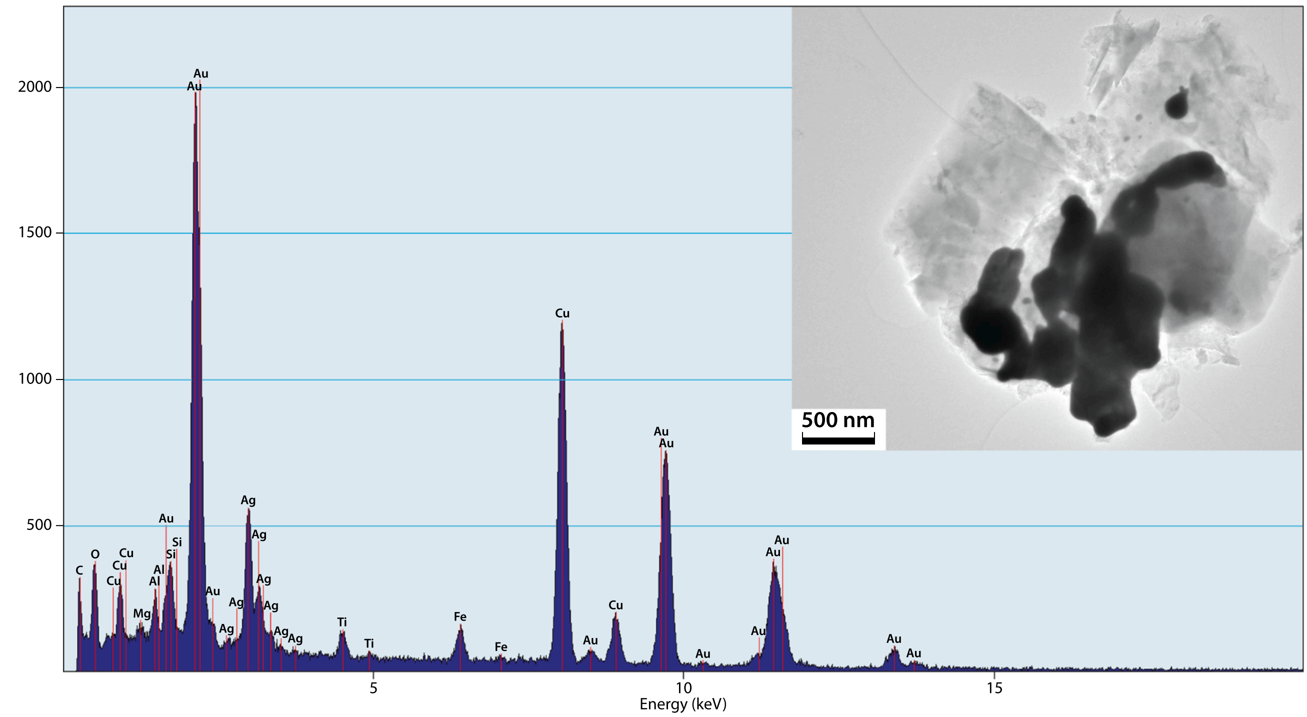

Figure 8. Spectrum related to one of the gold-nuggets measured by TEM-EDX, showing the presence of gold and silver and copper. The copper signal probably derives predominantly from the copper grid used as a sample support in the TEM. The inset shows the TEM bright field image with the noble metal particles (dark contrast) in a silicate environment (grey contrast).

the formation of striations, until the final flattening and "blurring" of the borders of those striations at the microscopic level. The critical mechanism in this process is the compression force acting on the anvil's surface from a hammer that blows on the metal sheet positioned on the anvil.

The main wear pattern affecting the forging surface is a generalised levelling, which forms wide and extremely flattened *plateaux*, covered by a shiny polish (Fig. 7a). At higher magnification, some small anfractuosities can be observed between these *plateaux*, in which wear did not penetrate, showing a more rugged topography as a result (Fig. 7d). Other anfractuosities are filled up with shiny particles of golden appearance. As a result, a tendency can be recognized that combines the obliteration of previous traces occupying the most exposed topography of the surface, on the one hand, and the addition of an alien substance in the lower topography (adhesive wear; Adams 2002), on the other hand. Taking into account the technological features of the anvil, the most likely hypothesis is that these particles originated from the metal worked object, placed in between the anvil and the hammer hitting it. During this plastic shaping, metal particles would have been detached and pressed into the anfractuosities.

Occasionally, striations of different types have been recorded (Fig. 7b–d) that are scattered along the surface. Some of them are straight striations, others are curved; they can be short as well as long and they can appear singularly or grouped. Moreover, some small and shallow pits were observed on the surface, a few of them filled up with a white substance (Fig. 7 top). As both striations and pits were clearly cut into the flattened relief, they should be considered to be the result of unintentional or accidental slides and scratching of different (probably hard, mineral matter, or even the stone hammer itself, when directly contacting the anvil) objects against the forging surface during use. These traces would never have been very abundant on the surface. As in forging activities, a flat relief is required in order not to damage the metal sheet, especially when it gets progressively thinner. Thus, it can be expected that periodical maintenance tasks would have taken place on the forging surface. The presence of striations and pits on the anvil stands for the last use-stage of the artefact, whose active surface was no more repaired just before it was abandoned.

As the observed use-wear pattern is closely related to forging surfaces and the existence of adhesive wear was recorded, residue analysis was performed in order to:

(**a**) find out if any adherences due to the original use of the pebble were still left, and

(**b**) check the consistency of the initial functional interpretation based on use-wear traces.

Therefore, a first exploratory attempt was made with the aid of the portable X-ray fluorescence (pXRF) technique, applying a sampling strategy aimed to track residues on the forging surface. Five points were measured directly on the forging surface in areas where use-wear was most intense (Fig. 7, no. 1–5). Data was compared with other surface areas on the periphery of the active surface, where use-wear was absent (Fig. 7, no. 6), as well as from the opposite unmodified side of the pebble (Fig. 7, no. 7–8). At first glance, there are some elements present at all measured points that can be linked to traces of the rock composition, including at least Si, Al, Mg and Ca (Table 1).

As a tentative interpretation of this data, Si and Al could correspond to silicate, Mg to olivine and Ca to plagioclase or pyroxene contained in the basaltic rock. Furthermore, and probably more interesting, all measurements on the active surface provided copper and gold remains in a very clear and homogeneous pattern. These are elements absent in other points measured beyond its limits. Additionally, two of the gold-bearing points featured silver, which could be related to gold.

After the first results from pXRF, a quantitatively more accurate technique was applied with the aim to demonstrate the metallurgical nature of adherences found on the forging surface. The anvil was analysed by Transmission Electron Microscopy (TEM) and Energy Dispersive X-ray Spectroscopy (EDX) using a similar sampling strategy as in the former analysis.

Three samples were taken through superficial scraping of the artefact, two of them from the forging surface (Fig. 7, no. 9*: forging surface and no. 10*: white inlay filling up a small pit) and one from the inside of

Table 2
Gold and silver ratios for the gold nuggets found on the forging surface of anvil F1368 at position 9*. EDX spectra (point analyses) were quantified with the software package "TEM imaging and analysis" (TIA) from FEI company. The metal atom concentrations were corrected for absorption and the spectral background was subtracted. The standard-less quantification was performed without thickness correction.

Sample	Atom % Ag	Line	Atom % Au	Line	Ratio Ag:	Au
Gold particle 1	28.94	L	71.05	L	1:	2.46
Gold particle 2	25.53	L	74.46	L	1:	2.92
Gold particle 3	30.94	L	69.05	L	1:	2.23
Gold particle 4	32.66	L	67.33	L	1:	2.06
Gold particle 5	30.71	L	69.28	L	1:	2.26
Gold particle 6	30.84	L	69.15	L	1:	2.24
Gold particle 7	32.02	L	67.97	L	1:	2.12
Gold particle 8	20.58	L	79.41	L	1:	3.86
Gold particle 9	34.55	L	65.44	L	1:	1.89
Gold particle 10	33.43	L	66.56	L	1:	1.99

the pebble (Fig. 7, no. 11*). Samples were placed on the copper TEM grids, each fitted with an extremely thin (~15 nm) carbon layer and analysed morphologically and chemically.

Sample no. 9* (Fig. 7; Fig. 8) provided several images of morphologically striking and dark particles under bright-field imaging conditions.

Their chemical composition defines them as gold-rich particles with a ratio of ca. 2/3 Au and 1/3 Ag (Table 2), which confirms a considerably high presence of silver in them.

Other elements, such as Mg, Al, Si, Na or Ca, could correlate with the presence of the basaltic rock, as was already noted for the pXRF. In association with this sample, a nickel and a copper particle have been additionally identified. The presence of copper in the sample material can be inferred from a strong Cu-L line in the relevant EDX spectrum (Fig. 8), but a quantitative determination of the Cu content of the Au particles is not possible due to the used Cu grid.

In sample number 10*, dark particles were also found (in a bright-field contrast), corresponding to the substance filling up a small pit, but their composition is rich in Fe, S and O. According to this pattern, these adherences should be interpreted as iron ores probably coming from post-depositional processes occurred once the anvil was abandoned and covered by sediment. In the wet area, strong post-depositional processes of bog iron ores around roots and artefacts in the soil were observed.

Finally, the results obtained for the interior of the pebble (Fig. 7, no. 11*) are consistent with the composition of the basaltic rock, as the presence of elements, such as Si, O, Al, Fe, Mg, Ca, Na, can be related to a silica-bearing material. Any evidence of noble metal is absent. This data is also coincident with those originating from pXRF.

To summarize, the anvil found in Bruszczewo was used in the plastic shaping of gold and maybe copper containing metal, coming into direct contact with it through compressive processes, which were provided by successive blows with a stone or wooden hammer. We do not know how long or intensively the anvil was used. We do not know either if the objects forged on the anvil had all the same or different compositions (for example, gold objects vs. copper objects) or if they came from a natural ore or even from an alloy. Being gold the main element preserved on the anvil we still do not know in which state it was worked, although experimentally we found that cold hammering of a gold sheet could have left a similar pattern of residue distribution as the one documented on the anvil's surface (see above). All these issues need to be addressed in (a) a broad experimental program of gold, copper and silver manufacturing and (b) a comparison with the composition of gold and other metal artefacts recovered from burials, e.g. in the near-by barrows of Łęki Małe.

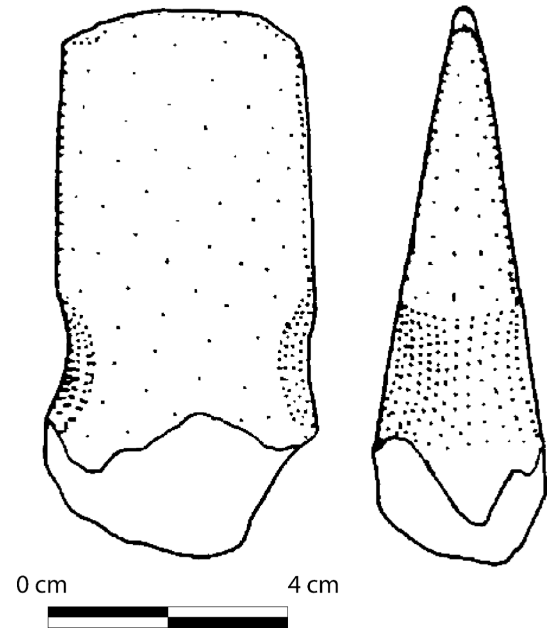

Figure 9. Axe fragment from Bruszczewo with a blunted edge and evidence of hafting, possibly used as a forging hammer (Honig 2004: 251 Fig. 121,234).

6. Interpretation

The use-wear analysis developed on the item F1368 has led to its interpretation as an anvil used for the forging of metal objects during the Early Bronze Age in Bruszczewo. Moreover, the discovery of remains of noble metals through residue analysis performed by pXRF and TEM-EDX suggests that at least gold and probably also copper were forged on this anvil. The fact that the house, in which the tool was reused as building material, was burned and the tool itself broken, would not have affected the integrity of metal residues hafting on its surface, since stone reacts at much lower temperatures than metal. While the melting temperature for gold and copper lays slightly over 1000 °C, stone can split up at around 150 °C (Meier et al. 2009).

Forging equipment is composed of two reciprocal parts, of which the anvil is the static one. Regarding the mobile part of the forging equipment, no clear forging hammer was found among the macrolithic tools recovered in the wet area of Bruszczewo (Delgado-Raack et al. 2020b). Nonetheless, a fragment of an axe is known from Bruszczewo, showing a clearly blunted edge and evidence of hafting in its proximal third (Fig. 9).

This artefact has been interpreted in former publications as a tool for metal working (Honig 2004; Szydlowski 2015). We can also not exclude the use of wooden, bone or antler artefacts in combination with the anvil. It is noteworthy that wooden remains are very abundant in Bruszczewo (Kneisel and Kroll 2010), although wooden tools appear to be rare.

The high percentage of silver in Bruszczewo hints towards the use of *Berggold* (Borg 2010), as no tin (Sn) was confirmed by the analyses. The A3 gold of Hartmann has on the average a comparable gold/silver relation (76% Au, 23% Ag, 0.3% Cu and in some cases 0.1–0.2% Sn), in principle also similar to Nebra gold (Borg 2010; Hartmann, 1970). If we compare the Au/Ag values of the Bruszczewo-IDs with the Au/Ag and Au/Cu values for other EBA Bronze artefacts and natural gold from Thuringia, Transylvania and North Hesse – at least regarding the Au/Ag values – the figures also confirm Hartmann's A3 gold in Bruszczewo (Borg 2010).

No metal deposits are known so far in the region of study. The high silver content of the gold particles is consistent with Hartmann's group A3 (Hartmann 1970), which includes gold objects with >20% silver

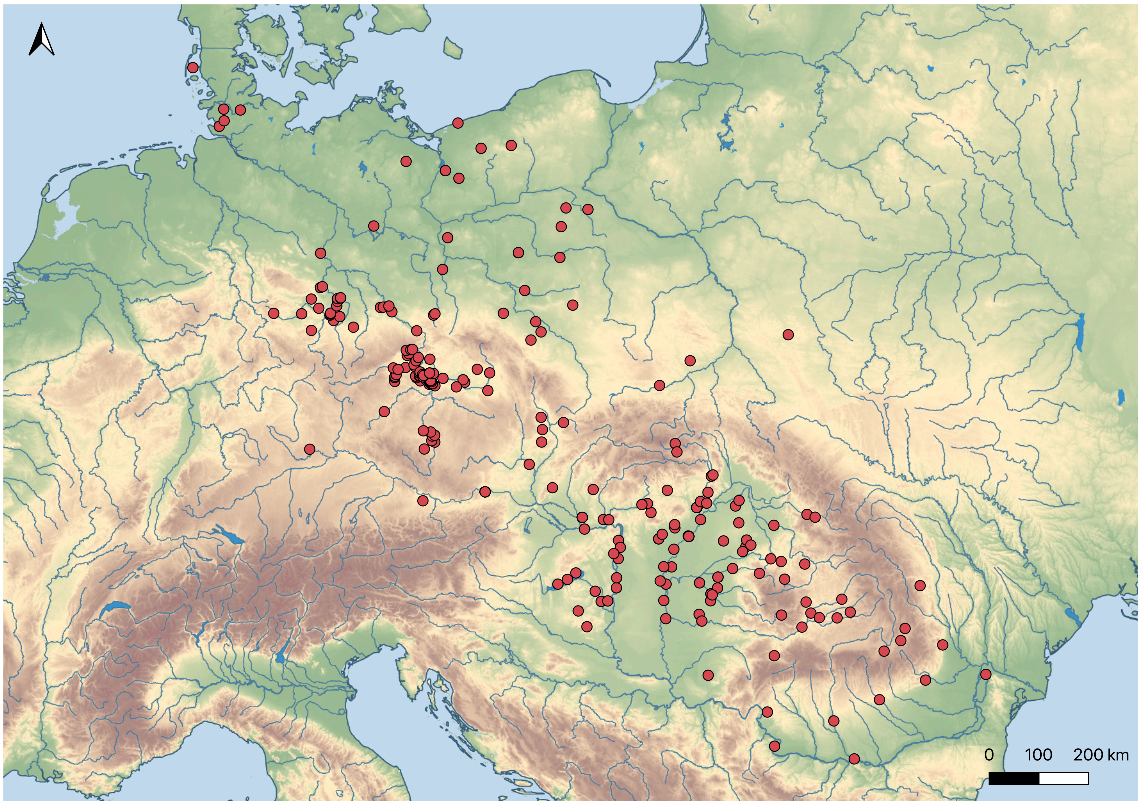

Figure 10. Distribution of EBA gold finds in Central and Southeast Europe (cf. Supplement: EBA gold artefacts).

distributed in Denmark and Central Europe (subgroup A3D). Gold objects with a high silver content are not unusual in the Únětice context as the hoard of the Nebra Sky Disc and other funerary contexts, such as Leubingen, Helmsdorf and Oberweschen, show (Lockhoff and Pernicka 2014). So far, only few deposits have been analysed, but the use of alluvial gold from Thuringia is one possibility (Borg 2010). A second possibility is given by a study about the geochemical characterisation of natural gold from the British Isles suggesting that (**a**) a high amount of silver in gold can occur in nature and (**b**) such gold could have its origin in the Cornish region (Ehser et al. 2011).

The described composition of Bruszczewo and other gold artefacts with correspondingly high silver values raises the question about the relations of the metal exchange in the EBA on a supra-regional European level. It is striking that with the Transylvania link, which was raised already by Hartmann's group A3, a possible interaction with the Aegean might also be discussed. For example, Stos-Gale has outlined that EDXRF analyses of 10 gold beads and 2 gold diadems from Mycenaean shaft tombs show a content of about 16% silver (Stos-Gale 2014). As analyses of Egyptian artefacts display a wider range of silver and copper values then those from south-eastern Europe, the origin of Mycenaean gold from the Baia Mare district in Transylvania or other south-eastern European sources, as already proposed by earlier researchers (e.g. Hänsel 1977), seems likely, including the recently excavated Ada Tepe Hill gold mine in southern Bulgaria (Popov 2012). While many metal artefacts of the Aegean EBA were produced from Aegean silver and lead mining in the Argolid (Laurion) or the Cycladic islands of Siphnos, an inflow of gold of Carpathian origin into the Aegean and even the possibility of tin from the ore mountains are still discussed. In this respect, the Bruszczewo gold might be seen as a part of these supra-regional connections to south-eastern Europe.

In respect to the already mentioned possible link to South Britain, new analyses on northwest European items are interesting. For the rich record of gold artefacts from the Irish Chalcolithic and EBA, which also display a high silver content of typically 9,5% to 14,5 %, an origin from south-west England was proposed in recent studies (Standish et al., 2014). Pb-isotope and major element analyses exclude an origin from a north Irish source as proposed earlier (Warner et al. 2010), but favor an origin from south Britain (Standish et al., 2014, 219-220),. Combined with archaeological evidence, the idea of a huge metal producing center in the first half of the third millennium BCE in south-west England was developed, already proposed for tin a long time ago (Penhallurick, 1986), but now also including gold. Thus, the origin of the gold inlays of the Nebra disc was located here, although the lead isotope analyses also are in line with a possible source in the Bohemian Erzgebirge (Ehser et al. 2011).

7. Conclusion

Traces of gold processing exist from the first half of the existence of the Bruszczewo settlement. We cannot exclude that this activity took place later, but we can be sure that this was not a frequent practice compared to bronze metallurgy. Bronze processing had a different character. Many traces of this activity remained in various parts of the settlement and they are represented by different varieties of copper (from stages II to IV acc. to Krause and Rassmann (Rassmann 2010)). The present study proves that gold was sheeted in Bruszczewo until around 1800 BCE, which processed raw material perhaps originating from alluvial gold from e.g. Thuringia, from the British Isles or from a south-east European source – i.e. material that prevailed in the entire Únětice area. Therefore, the inhabitants of the Bruszczewo settlement were undoubtedly participants of supra-regional social processes and networks e.g. between the Aegean and Central and Northwestern Europe. Despite the geographically peripheral location of the settlement within the Únětice area, the inhabitants were nevertheless engaged in the center of the formation of power structures. This is confirmed not only by the so far unique gold working in a Central European EBA settlement, but also by the 'princely' grave barrows in Łęki Małe, where the power structures of the Bruszczewo population were visualized and

Table 3
List of Polish gold and silver finds from the Early Bronze Age (2200–1600 BC).

ID	Site	Context	Find	Reference
1	Barwice	Grave II, urn grave in stone packing	2 noppenrings	Kersten 1958, 88, no. 828–830, tab. 94; Sarnowska 1969, 154; Zich 1996, 543, cat. L6; Kozłowska-Skoczka 2012, 122
2	Drzeńsko	Deposition under a big stone	2 noppenrings	Kersten 1958, 90, no. 856, tab. 96; Sarnowska 1969, 156; Zich 1996, 544, cat. L26
3	Gniezno	Found in 1938 during the excavation of a medieval fortification in the lowest layer	Small golden willow-leaf-shaped ring (Weidenblattring)	Knapowska-Mikołajczykowa 1957, 39, fig. 18; Machnik 1978, 119, fig. 46.1; Zich 1996, 567, cat. Q12
4	Inowrocław-Mątwy	In an urn	Scarfed dagger	Knapowska-Mikołajczykowa 1957, 49, fig. 42; Machnik 1978, 119, fig. 46.3; Zich 1996, 561, cat. P29; Bronzezeit, 2013, vol. II, 466
5	Kraków-Nowa	Grave 13/63	5 golden rings	Kadrow & Machnik 1997, 15–16; Hachulska-Ledwos 1967, tab. II, 4–8
6	Kurcewo	Deposition	Curved gold wire with round diameter: 9.3 cm; thickness: 0.1 cm; weight: 4 g	Blajer 1990, 116, tab. LI.1
7	Legnica	After Gedl 1983, 66 inhumation after Hofmann 1940, 9, fig. 3 und 9 urn grave	2 noppenrings	Hoffmann 1940, 9, fig. 3, 9; Gedl 1983, 66; Zich 1996, 226, cat. R50c
8	Łagiewniki	From cemetery	Golden wire length approx. 50 cm	Sarnowska 1966, 26
9	Łęki Małe	Barrow 1, grave A	Noppenring	Kowiańska-Piaszykowa and Kurnatowski, 1954, fig. 12.7
10	Łęki Małe	Barrow 1, grave D	3 noppenrings	Kowiańska-Piaszykowa and Kurnatowski, 1954, fig. 27.7–9
11	Poradz	Stone cist	Noppenring	Kersten 1958, 80, no. 761; Zich 1996, 226, cat. L80; Czebreszuk & Kozłowska-Skoczka 2008, 56, plate 27.12
12	Radłowice	Settlement	Earring	Lasak 1988, fig. 1.h
13	Skarbienice	After Knapowska-Mikołajczykowa, stone cist grave, after Sarnowska, deposition in a vessel	2 small golden rings	Knapowska-Mikołajczykowa 1957, 74–75; Sarnowska 1969, 139; Zich 1996, 228, cat. P60
14	Stryjów	Grave under barrow (grave no. 4)	Golden leaf ornament	Budziszewski et al. 2016, 405
15	Szczecin-Płonia 2	Grave 1	Angular bent gold band	Kozłowska 2004, 87
16	Szczecin-Płonia	From a grave	4 spiral rings of thin gold band	Kersten 1958, 58, tab. 56.576; Sarnowska 1969, 216, fig. 73a; Kozłowska 2004, 86
17	Śliwin	Stone cist with inhumation	Spiral finger ring	Sarnowska 1969, 218; Zich 1996, 227, cat. L93c; Kozłowska-Skoczka 2012, 125
18	Wąsosz	Deposition or barrow, found on a sandy hill	Ornamental plate of gold foil, 5 rings of thin gold wire	Knapowska-Mikołajczykowa 1957, 85–87, fig. 110, 111; Zich 1996, 564, cat. P65 m,n
19	Werenikopole	Single find	Lockenring	Sarnowska 1969, 204; Machnik 1978, 119, fig. 46.2; Zich 1996, 229, cat. T197
20	Wrocław-Oporów	Grave LVII/67	Small gold ring in 3 fragments	Sarnowska 1969, 236; Zich 1996, 227–8, cat. S513a
21		Single find, found 1932 during gardening at 0.5 m depth	Spiral of gold wire with 2.5 turns	Knapowska-Mikołajczykowa 1957, 91, fig. 121; Sarnowska 1969, 205; Zich 1996, 228, cat. T209
22	Żerniki Górne	Grave 79	Gold ring	Kempisty 1978, 142, fig. 186.4, 5
23	Tomice	Grave no. 32	2 silver noppenrings	Romanow 1973, 120, fig. 66c

palpable through burial practices in the landscape.

In general, gold artefacts in EBA Poland are concentrated in the western part of the country (Fig. 10, Table 3). The settlement of Bruszczewo, located in a context of a wide network in which, among others, amber and metal were exchanged, could have acted as a key agent in the control and production of some precious raw materials and/or objects at the border of the early metal producing groups. It is very likely that this settlement was a kind of a "gate" through which Baltic amber reached different parts of the Únětice world and, *inter alia,* could have been transferred to the centre of Únětice settlement in the Czech Basin (Ernée 2012). The amber route to the Mycenaean area probably began here, reaching the southern region during the 18th century BCE (Czebreszuk 2011). Bruszczewo was an early central place with far-reaching connections and with different kinds of workshops that produced and developed commodities: firstly for regional demands involving conspicuous consumption, secondly for supra-regional demands from other regions that furthered 'international' exchange, existing earlier than structures known from, e.g. Mycenae or Malia.

Author contributions statement

S.D.-R., J.K., N.E. and U.Sch. did the analyses and J.M., S.D.-R., J.C., J.K., M.S. and M.J. wrote the main manuscript. S.D-R., J.K., J.C., M.J and U.Sch. prepared the figures. All authors reviewed the manuscript.

Data availability statement

All data generated or analysed during this study are included in this published article (and its Supplementary Information file).

CRediT authorship contribution statement

Johannes Müller: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. **Selina Delgado-Raack:** Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Nicolau Escanilla:** Formal analysis, Writing – review & editing. **Lorenz Kienle:** Formal analysis, Writing – original draft, Writing – review & editing. **Jutta Kneisel:** Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Janusz Czebreszuk:** Writing – original draft, Writing – review & editing, Visualization. **Mateusz Jaeger:** Writing – original draft, Writing – review & editing, Visualization. **Marzena Szmyt:** Writing – original draft, Writing – review & editing. **Ulrich Schürmann:** Formal analysis, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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