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BRONZE BRACELETS DEPOSIT FROM NIEWIERSZYN BY THE PILICA RIVER

ABSTRACT

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In the autumn of 2017 in Niewierszyn in the Aleksandrów commune, a deposit of two bronze bracelets was discovered. The discovery site was on the edge of the Pilica floodplain terrace.

The bracelets were almost identical in size and ornamentation. Also, the chemical composition of the bronze from which they were made was very similar. It may be hypothesised that the ornaments were made by the same manufacturer, probably at a similar time. Based on the analysis of the form and ornamentation, the bracelets in question can be dated to HA1. This dating corresponds to the settling of the areas in the Pilica river basin by communities associated with the Konstantynów Łódzki group, characterized by features of the early Urnfield culture. Virtual modelling of casting and an experimental cast were used to elucidate the manufacturing technique. Apart from a chronological and cultural analysis, the text attempts to show the hoard against a wider (micro-regional) settlement background, including through potential visibility analysis.

Keywords: Bronze Age, Central Poland, Konstantynów Łódzki group, deposit, bracelets
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DISCOVERY DESCRIPTION

In November 2016, a member of staff in the Museum in Piotrków Trybunalski was contacted by an individual who had come across two bronze bracelets buried underneath a thin layer of earth (Fig. 3). This man, an angler, reported that he discovered the hoard by accident while digging bait for fish. On arrival at the indicated site, the finds were secured. In the process of scrutiny, the bracelets were determined to have been laid in a shallow pit at a depth of 30 cm. The pit filling consisted of light grey topsoil sand. Apart from the bracelets, a few pieces of charcoal were found at the bottom. No other relics could be found. Upon examination, the site of the finds was drawn and photographed for documentation and a report on the archaeological work was produced. The documentation along with excavated findings was passed on to the then Voivodeship Bureau of Monument Conservation in Łódź, Department in Piotrków Trybunalski. The excavation site was located in Niewierszyn, Aleksandrów commune, Piotrków Trybunalski district, on the edge of the floodplain of the right bank of the Pilica River (Fig. 1; 2). The circumstances of the discovery allowed the set of bracelets to be recognised as an intentional deposit which, due to the form of relics and ornamentation, was initially associated with the population of the Konstantynów group.

The place where the deposit was laid was on the edge of the Pilica floodplain terrace, on its right bank (Grzybkowski and Kutek 1966). This level was built of Pleistocene river sands. Below the edge of the terrace lay Holocene floodplain sands.

TYPICAL FEATURES OF THE RELICS

The bracelet denoted "A" (Fig. 4: a, b; 5: a) was made from spirally coiled bronze rod with a characteristic lentoid cross section, which in its central part was 1.35 cm wide and 0.73 cm thick. The ends of the spirals tapered, and they were slightly rounded. The adornment was formed by coiling the rod in such a way that it formed two coils with the ends overlapping by about two centimetres on each side. The diameter of the bracelet was 7.6 cm with a weight of 175 grams.

The object was adorned with a group of perpendicular and diagonal lines going towards the edge (Fig. 5: b). In some parts the diagonal lines were separated with a group motif of very short lines. The layout of short lines was in turn perpendicular to the diagonal

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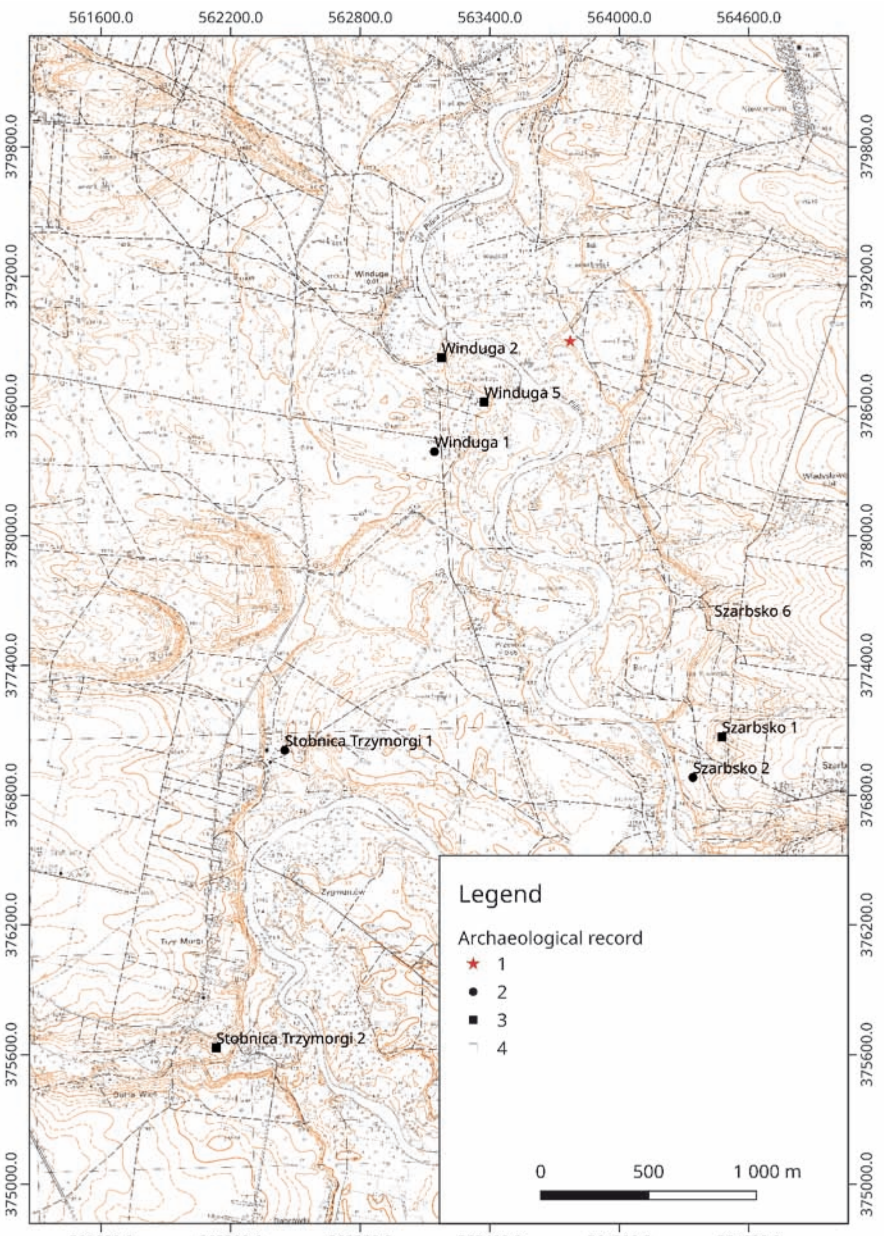

Fig. 1. Location of the deposit of the bronze items against the background of the planigraphy of archaeological sites. Based on the topographic map in the scale 1: 10000 in the 1992 system, from the resources of GUGiK. Symbols (according to the AZP nomenclature):
1 – location of the bronze item deposit; 2 – cemetery; 3 – settlement; 4 – trace of settlement.
Prepared by R. Janiak and J. Sikora

Fig. 2. Niewierszyn, Piotrków Trybunalski district.
The discovery site marked with an arrow, sight from the west. Photo by J. Ziętek

lines. The decoration was carved in such a manner that only neighbouring edges were covered with it. It was particularly noticeable in the way the edges of the spiral were ornamented only in the central part of the coil. The external parts were not decorated with the line motif. In the central part of the perimeter (which is equivalent with the widest section of the rod), it is clearly visible that the ornamentation was placed also on the edge of the bracelet as well as on the faces of the coil.

The second bracelet, denoted here "B" (Fig. 4: c, d; 5: c) is 7.3 cm in diameter. It was designed in the identical manner. The same metal rod type with lentoid cross section with its ends tapering was used. It was also made of two coils. Compared with bracelet "A", the object showed considerable similarity in terms of the ornamental motif and the manner it was arranged (Fig. 5: d). However, certain differences can be noted. The first distinction is that in the central part of the spiral, both rims were decorated with thick lines corresponding with each other. Such a practice gave the bracelet a sort of symmetry. Another difference is the covering of the rims of the central part of the bracelet with a decorative pattern on a much shorter section. In the middle part the spiral was 1.25 cm wide and 0.6 cm thick with the weight of 150 grams. Measurements indicate that the ornament on "B" was smaller and consequently lighter. Thus, the different parameters of the two objects may lead to different conclusions during the reconstruction of the methods and a design style.

Fig. 3. Niewierszyn, Piotrków Trybunalski district. The bronze bracelets included in the deposit. Photo by J. Słomska

Fig. 4. Niewierszyn, Piotrków Trybunalski district, Deposits of the bronze objects: bracelet A (a, b); bracelet B (c, d). Photo by J. Słomska

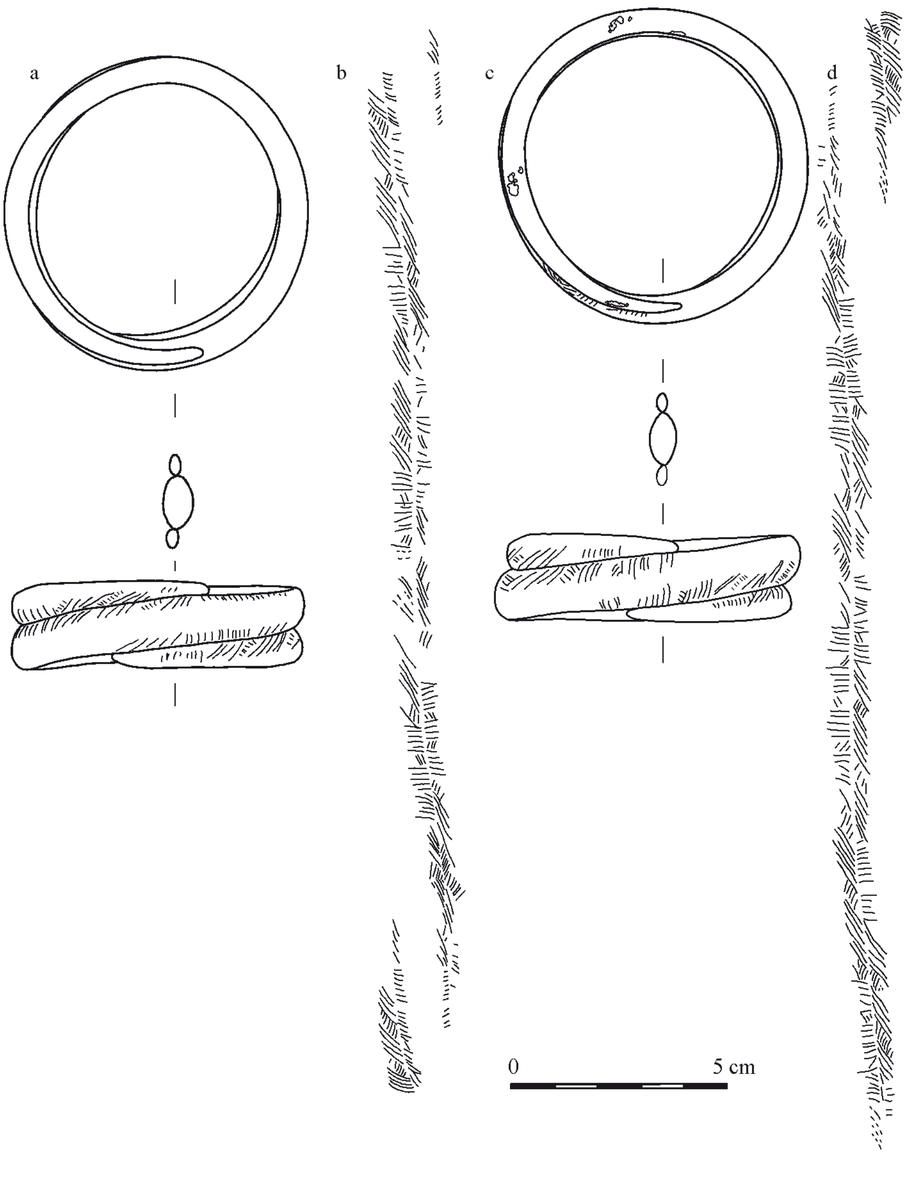

Fig. 5. Niewierszyn, Piotrków Trybunalski district.
Deposits of the bronze objects: bracelet A (a); decoration of bracelet A (b); bracelet B (c); decoration of bracelet B (d). Drawn by R. Janiak

METHODOLOGY OF PHYSICOCHEMICAL EXAMINATIONS OF BRACELETS

The examinations of the chemical composition on the surface of the bracelets were performed by the X-ray microanalysis method EDS – X-ray energy dispersion. A scanning microscope JEOL JSM-6610LV integrated with the MiniCL-GATAN Cathodoluminescence

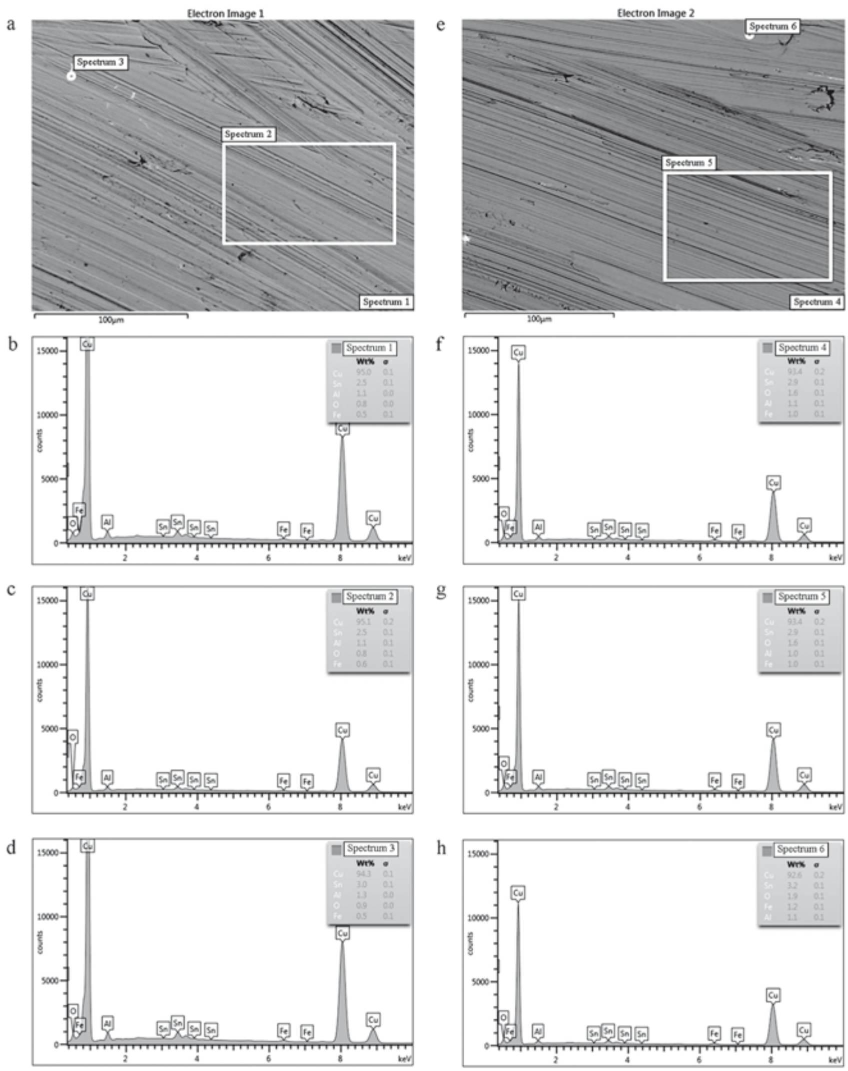

Fig. 6. Photographs and chemical analysis results, bracelet A (a-d) and bracelet B (e-h): a, e – photographs of the analized areas; b, f – from the maximal surface area (Spectrum: 1 and 4); c, g – from a selected area (Spectrum: 2 and 5); d, h – from a point (Spectrum: 3 and 6). Prepared by B. Januszewicz

Table 1. Chemical composition of CuSn3 tin bronze per test casting

Chemical composition, %										
Zn	Pb	**Sn**	P	**Fe**	Ni	Si	Te	As	Sb	Ag
0.136	0.142	**3.23**	0.0088	**0.0428**	0.095	0.003	0.027	0.0131	0.0152	0.0031
Al	S	**Cu**	Other							
1.29	0.0039	**94.9**	0.0901							

Imaging System and Oxford Instruments EDS X-MAX 80 systems as well as a backscattered electron activation system EBSD NordlysMax were used for the investigations. The tests were carried out with the use of the EDS AZtecEnergy software.

The specimens for the analysis were prepared by removing the surface oxide film (from an area as small as possible, to reveal the uncorroded material). The examined bracelets were placed in the chamber of the microscope and the optimal test parameters were established, *i.e.*: working distance 10 mm, accelerating voltage 20 kV, beam current 60, analysis time 120 seconds. The analysis of the chemical composition was performed for the following areas: the total surface area is shown in the photograph, a selected area and a point (Ø1 μm).

A 3D scan of the bracelet A (Fig. 6) was carried out using a 3D ATOS Core scanner with GOM Scan software. Reference marks with a diameter of 1.5 mm were fixed to the bracelet to fold the scans using GOM Scan software. The geometric dimensions of the scanned bracelet were determined using GOM Inspect software for inspection, ensuring complete processing of the mesh, 3D inspections and reporting.

Simulations of the process of pouring, cooling and solidification of tin bronze in a ceramic mould (heated to 150°C) in the investment casting technology were carried out using professional software MAGMA 5.4 from Magmasof®.

The test casting was made of tin bronze CuSn3 with the chemical composition shown in Table 1. This alloy was obtained after diluting the commercial casting alloy CuSn12-C (PN-EN 1982:2017-10 – English version) by the addition of Al– EN AW-1070A (PN-EN 573-3:2019-12 – English version), Fe (ARMCO Pure Iron) and Cu (Copper Cathodes Grade A).

The chemical composition of CuSn3 bronze intended for test casting was tested on a stationary emission spectrometer type SPECTROMAXx.

CHEMICAL COMPOSITION TESTS

Figure 6: a-h shows photographs of the surface of bracelets A and B as well as the results of the chemical composition analysis performed on areas of different sizes: the maximal surface area, a selected area and a selected point. For both bracelets, Figure 7: a-c shows a compilation of the analysis results from the maximal area – from the surface area presented in the photographs (Fig. 7: a), from the selected area (Fig. 7: b) and the selected

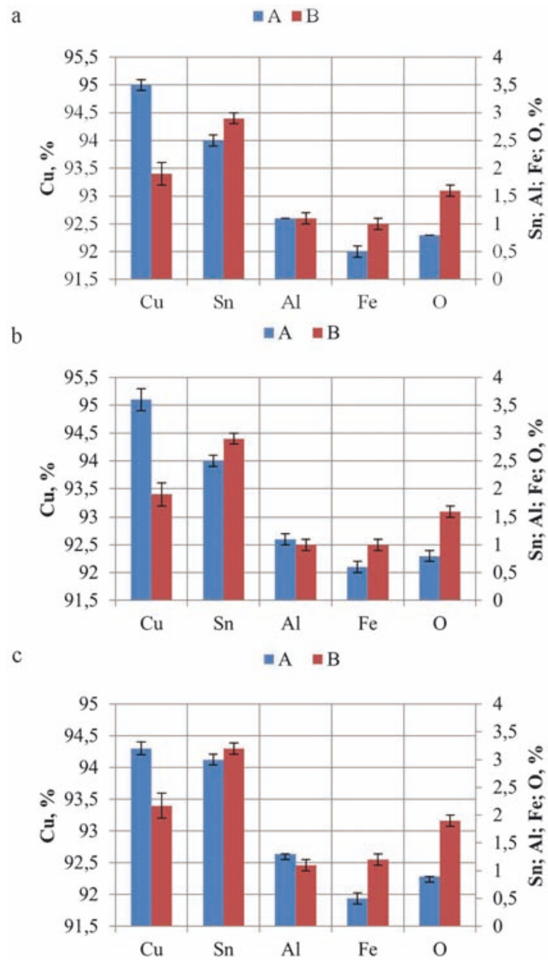

Fig. 7. Compilation of the chemical composition analysis of bracelets A and B:
a, e – from the maximal surface area (Spectrum: 1 and 4); b, f – from a selected area (Spectrum: 2 and 5); c, g – from a point (Spectrum: 3 and 6). Prepared by B. Pisarek

point (Fig. 7: c). It can be inferred from the presented analyses that both bracelets were cast from tin bronze (alloy CuSn) with a tin content within the scope of 2.5-3.2%.

Due to the historical value of the bracelets, to identify the alloy's microstructure components, no microsections involving damage to the bracelets' external surface were made. The identification of the microsection components of the examined bronze can be performed theoretically, by way of analyzing the characteristic temperatures of the phase transformations and the scopes of the phase equilibrium concentrations in the Cu-Sn system. Figure 8: a, b shows phase equilibrium diagrams for the Cu-Sn system (up to 40%

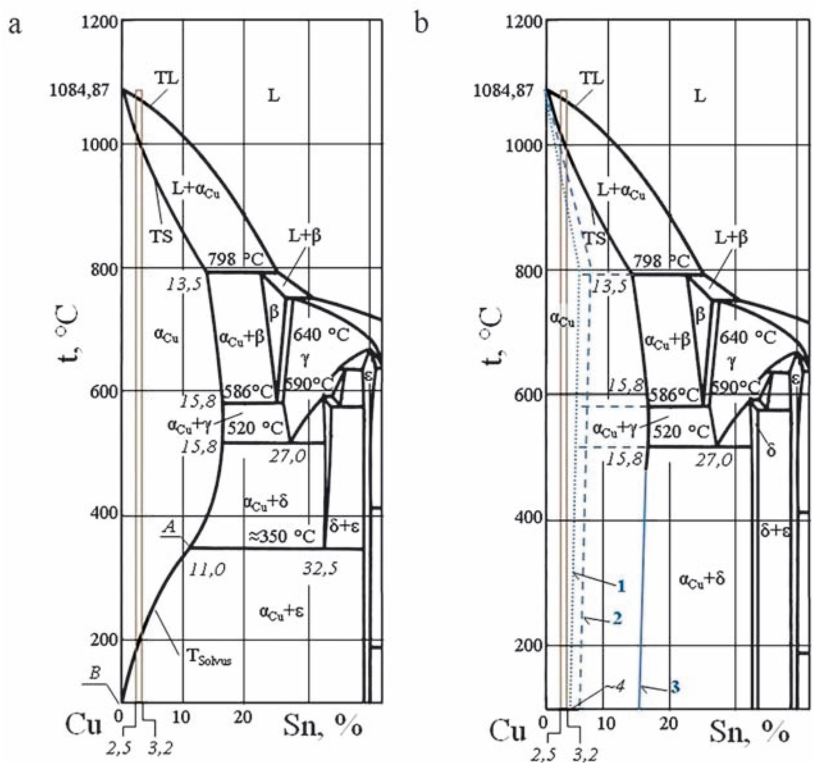

Fig. 8. Phase equilibrium diagram of alloys CuSn (up to 40% Sn): a – stable (based on: Saunders and Miodownik 1990), b – metastable (based on: Schad and Warlimont 1972); 1 – gravity die cast; 2 – sand mould cast; 3 – especially slow cooling. Prepared by B. Pisarek

Sn): stable (Saunders and Miodownik 1990) and metastable (Schad and Warlimont 1972). To melt bronze with this chemical composition, the former needed to be superheated over the liquidus temperature $TL_{(3\%\ Sn)}$≈1080°C by about 100-150°C. According to the phase equilibrium diagram (Fig. 8: a, b), after the alloy has been cast into the mould, its whole volume solidifies in the temperature scope of TL and TS (solidus temperature) as one phase α_{Cu}.

According to the stable phase equilibrium diagram (Fig. 8: a) (Saunders and Miodownik 1990), the bronze cools down in a single phase to T_{solvus} – the temperature of Sn solubility change in phaseα_{Cu}, which decreases with a temperature drop, forming precipitations of phase ε (Cu_3Sn) along the grain boundaries of phase α_{Cu}. Due to the relatively low concentration of the Sn additive in the bronze, the precipitations of phase ε will be small and in relatively low amounts. And so, the microstructure of this bronze will probably consist of two phases: α_{Cu} and ε.

Table 2. Minerals used to obtain Cu (based on *Przeróbka kopalin miedziowych* 2007-2008)

Nuggets	Sulfide ores				Oxide ores
Native copper	Covellite	Chalcocite	Chalcopyrite	Bornite	Cuprite
Cu	CuS	Cu_2S	$CuFeS_2$	Cu_3FeS_2	Cu_2O
99.9 % Cu	66.50% Cu	79.80% Cu	34.57% Cu	63.33% Cu	88.22% Cu

Table 3. Minerals used to obtain Sn (based on *Przeróbka kopalin cynowych* 2007-2008)

Sulfide ores			Oxide ores
Teallite	Stannine	Cylindrite	Cassiterite
$PbSnS_2$	Cu_2FeSnS_4	$6PbS{\cdot}6SnS_2{\cdot}Sb_2S_3$	SnO_2
30.51% Sn	27.61% Sn	26.54% Sn	78.77% Sn

In turn, it can be inferred from the study (Schad and Warlimont 1972) that, in casts solidifying at different cooling rates, depending on the thermal conductivity λ of the mould material (Fig. 8: b) (a cast in a steel gravity die λ=58 W/m·K, a cast in a sand mould λ=0,70 W/m·K, especially slow cooling λ<0,20 W/m·K), the microstructure of the examined bronze can remain as a single phase, consisting of a metastable phase α_{Cu} supersaturated with Sn, or as two phases, with the Sn concentration in the alloy over ~4%, consisting of phases $\alpha_{Cu}+\delta$ (δ is the supercooled eutectoidal phase containing about 35% Sn, crystallizing in the alloy after its supercooling below 520°C).

The characteristic minerals used to obtain copper have been presented in Table 2 (Processing of copper minerals) and those for tin – in Table 3 (Processing of tin minerals).

According to data in the literature (Coghlan 1975; Oudbashi *et al.* 2012), a tin content in bronze at the level below 2-3% can be caused by impurities in the ores which were used to melt the bronze.

It can be inferred from the presented literature analyses as well as from the performed investigations that the examined bronze was melted from a stannine copper-tin ore (Table 3). The ore contains about: 30% Cu and 28% Sn as well as 12% Fe and 30% S. The examined tin bronze contains an elevated concentration of Fe within the scope of 0.5-1.1% Fe, while the Sn content is insignificant. The iron dissolves in the copper to about 4% at., and so, it is localized mainly in the α_{Cu} solution or it forms intermetallic phases. The lack of S concentration in the examined bronze is probably caused by the process of sulphide ore roasting in an oxygen-containing environment's air, as a result of which volatile sulphur dioxide SO_2 is formed. The reduction of sulphide ores at elevated temperatures was invented in ancient times (Gowland 1921) probably by accident. As a result of facing a fireplace with copper ore chunks, at the elevated temperature of the fire, the ore underwent reduction. This did not remain unnoticed by the contemporary man, who, on finding metallic copper grains in the ash, identified the obtained metal as native copper, well-known at those times.

In the pyrometallurgical process, in the Bronze Age, ores, were melted in furnaces made of mud and clay (Shrivastva 1999; Craddock 2000) – clay in the area of Poland contains about 11.5-28.19% Al_2O_3 (Kostecki 1961; Cieśla *et al.* 1983). The melted bronze contains CuO particles, which, as a result of a reaction with Al_2O_3, leads to a synthesis $CuO+Al_2O_3 \rightarrow CuAl_2O_4$ (Hu *et al.* 2016) generating spinels. It should be presumed that the presence of Al and O in the examined bronze is probably caused by the presence of spinels $CuAl_2O_4$.

FORMAL AND STYLISTIC ANALYSIS OF THE BRACELETS

The characteristic features of the shape of the bracelets, important from the point of view of identification of the potential technology of their manufacture, include:

• the spiral arrangement of coils of approximately constant internal diameter,

• no sharp edges or marks of possible mechanical treatment,

• three parts can be identified in the shape of the bracelets:

– one part covering the central coil of the spiral with an (approximately) constant cross-sectional area along the radius of curvature of the bracelet,

– two ends of a spiral with a diminishing cross-sectional area along the radius of curvature of the bracelet;

• the characteristic radii of curvature can be distinguished on the cross-sectional area along the radius of curvature of the coils, respectively:

– in the top part of the cross-sectional area, r_t,

– in the bottom part of the cross-sectional area, r_b,

– on the outer surface of the cross-sectional area R_o,

– on the inner surface of the cross-sectional area R_i;

• the ornamentation is present on the external surface of the bracelets closer to the top and bottom of the coils respectively.

Due to the characteristic shape of the bracelet in its central part (the middle coil) as well as the ends of the spiral (all bracelet sections are rounded), it was assumed that the shape of the bracelet could be obtained by the lost wax casting technology.

Analysing the geometry of the bracelets and their ornamentation, the following hypotheses were adopted about the possibility of making them:

1) a straight bronze bar without an ornament was cast using the lost wax method, the ornament was made with a tool with a blade with a top angle close to 90° with regard to the casting bar, and then bent the rod into a spiral,

2) a spiral was cast by the lost wax method with the ornamentation made on the wax model using a tool with a blade with a top angle close to 90°.

Fig. 9. Bracelet A with adhesive reference marks. Photo by B. Pisarek

A 3D scanning method was used to measure the geometric shape and dimensions of the bracelets. Figure 9 shows the adhesive reference markers with a diameter of 1.5 mm on a selected bracelet, which enabling the computer folding of individual photos taken with the 3D scanner. Due to the fact that the central coil abutted the adjacent coils, it was not possible to scan precisely the surfaces in contact with each other.

Figure 10 a-g shows the analysis of the bracelet dimensions made with the GOM Inspect software. The internal diameter of the bracelet was estimated by means of a cylinder adjusted to its internal surface, a cylinder with a diameter of D=59.63 mm was determined.

The characteristic changes in the radii of curvature of the bracelet cross-section geometry are summarised in Table 4 and Figure 11a, b. The bracelet is characterized by a preserved parabolic tendency of changes mainly R_o, R_i and r_b with relatively high precision, with

Table 4. Diameter and curvature radii in bracelet cross-section geometry

	Placement (Fig. 10)									
	top (P-III)		t_m (P-I)		middle (P-IV)		m_b (P-II)		bottom (P-V)	
	d, mm	r(R), mm	*d*, mm	r(R), mm	*d*, mm	r(R), mm	*d*, mm	r(R), mm	*d*, mm	r(R), mm
r_t	$d_{30}=2.09$	1.05	$d_{22}=3.43$	1.72	$d_{34}=3.36$	1.68	$d_{26}=1.52$	0.76	$d_{38}=1.18$	0.59
r_b	$d_{31}=1.88$	0.94	$d_{23}=2.35$	1.18	$d_{37}=2.98$	1.49	$d_{27}=2.62$	1.31	$d_{39}=1.14$	0.57
R_o	$d_{33}=7.04$	3.70	$d_{24}=12.74$	6.37	$d_{36}=13.76$	6.88	$d_{28}=11.51$	5.76	$d_{41}=7.19$	3.60
R_i	$d_{32}=15.79$	7.90	$d_{25}=21.07$	10.54	$d_{35}=25.20$	12.60	$d_{29}=20.03$	10.02	$d_{40}=18.14$	9.07
(1 r(R)=d/2 rounded to two placements after a comma; r(R)_: t – top, b – bottom o – outer, i – inner										

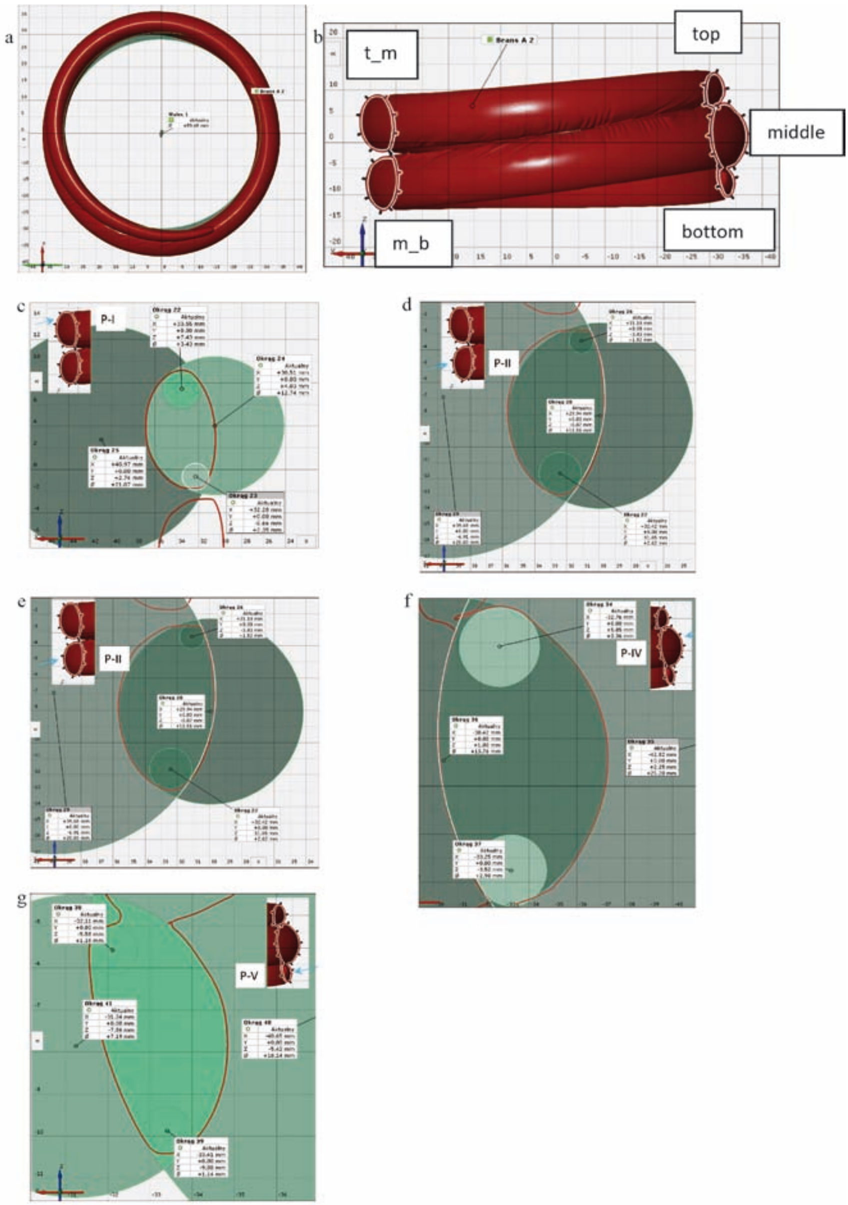

Fig. 10. Measurements of bracelet A geometry in GOM Inspect software: a – auto-fitting cylinder of the inner-side of the bracelet with diameter D=59.7 mm, b – bracelet cross-section lines in ZX plane, c – measurements of radius of curvature in P-I cross-section (circles from 3 points): d22-d25, d – measurements of radii of curvature in section P-II (circles of 3 points): d26-d29, e – measurements of curvature radii in section P-III (3 point circles): d30-d33, f – measurements of curvature radii in section P-IV (3 point circles): d34-d37, g) measurements of curvature radii in section P-V (3 point circles): d38-d41.
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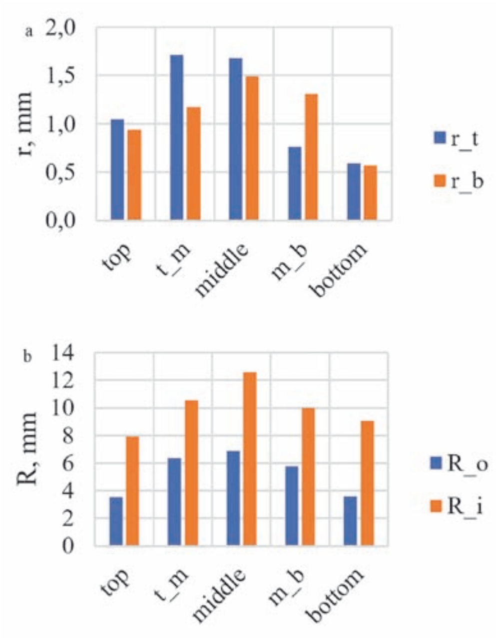

Fig. 11. Characteristic tendencies of changes of curvature radius in the geometry of bracelet cross-sections. Prepared by B. Pisarek

a maximum for the "middle" position (Fig. 11: a, b). Only the radius of curvature r_t does not have a preserved tendency to change, as in the case of the above mentioned radii, the maximum value of the radius is shifted to the area t_m (Fig. 11: a).

In order to verify the first hypothesis, the process of casting a simple tin bronze rod was traced by simulating the casting and solidification of the bronze in a mould using the MAGMA software. Three technological variants of the arrangement of the casting of the bar and the gating system were proposed. The gating system was designed using information contained in the literature (Nessel 2012). Figures 12-14 (a-d) show, respectively, the mould model (a), quality of the differential mesh (b), location of hotspots (c), and as a result of their lack of feeding, location of shrinkage cavities in the casting, location of gas and shrinkage porosity in the bar casting (d).

According to variant III (Fig. 14), a rod with geometry close to the curvatures in the analysis cross-sections of the bracelet was cast. The prepared mould made of Green Sand and Facing Sand (mullite clay) was poured with CuSn3 bronze.

The surface of the cast was polished and then on the surface prepared in such a way an ornament was made in a shape characteristic for those observed on the bracelet. Due to the relatively high hardness of the alloy it was not possible to made the ornaments on the surface of casting with use a cold chisel with a blade with an angle close to 90° and hammer.

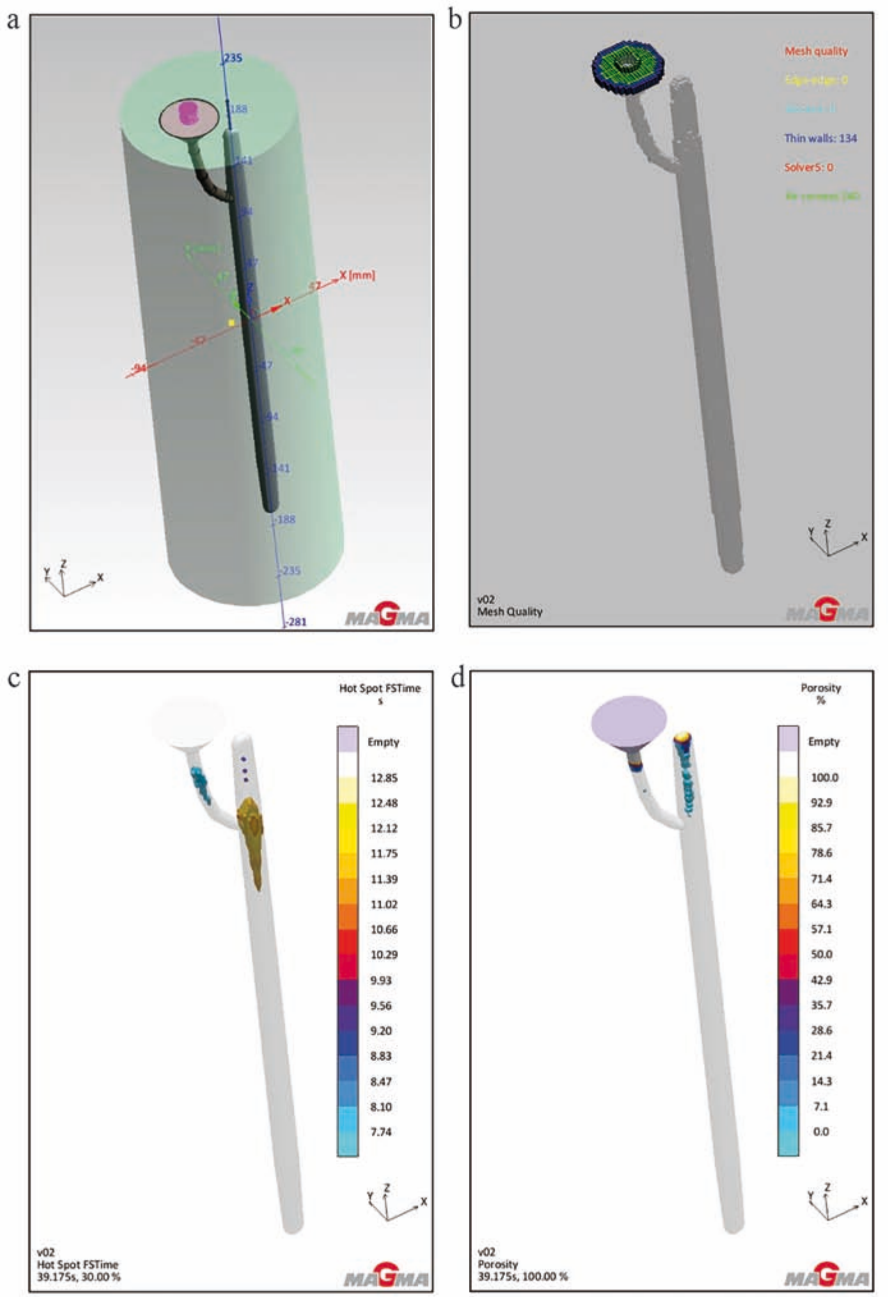

Fig. 12. Casting of tin bronze bar – technology variant I: a – position of the casting in the mould, b – quality of the differential mesh, c – position of the shrinkage cavity, d – the distribution of shrinkage and gaseous porosity. Prepared by B. Pisarek

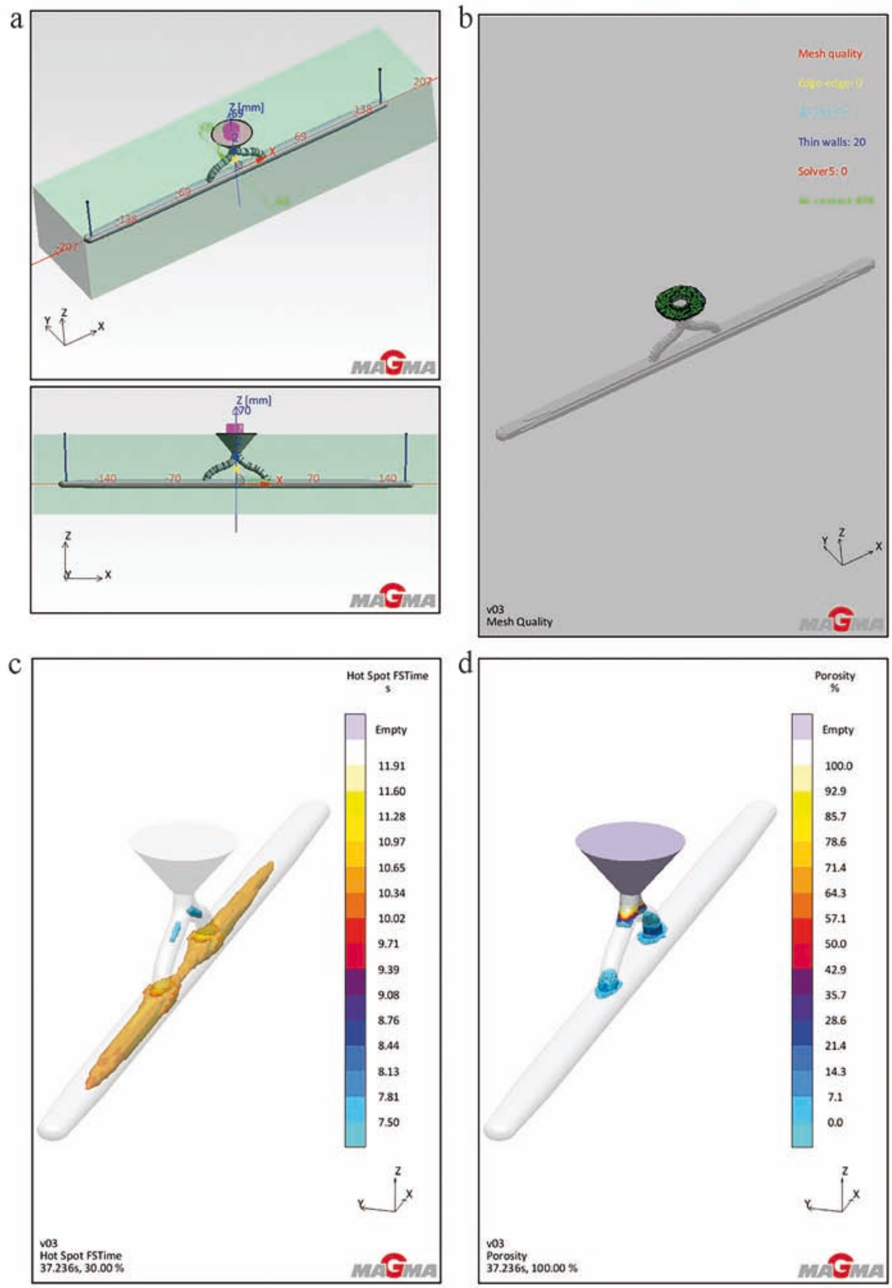

Fig. 13. Casting of tin bronze bar – technology variant II: a – position of the wax model in the mould, b – quality of the differential mesh, c – position of the shrinkage cavity, d – the distribution of shrinkage and gaseous porosity. Prepared by B. Pisarek

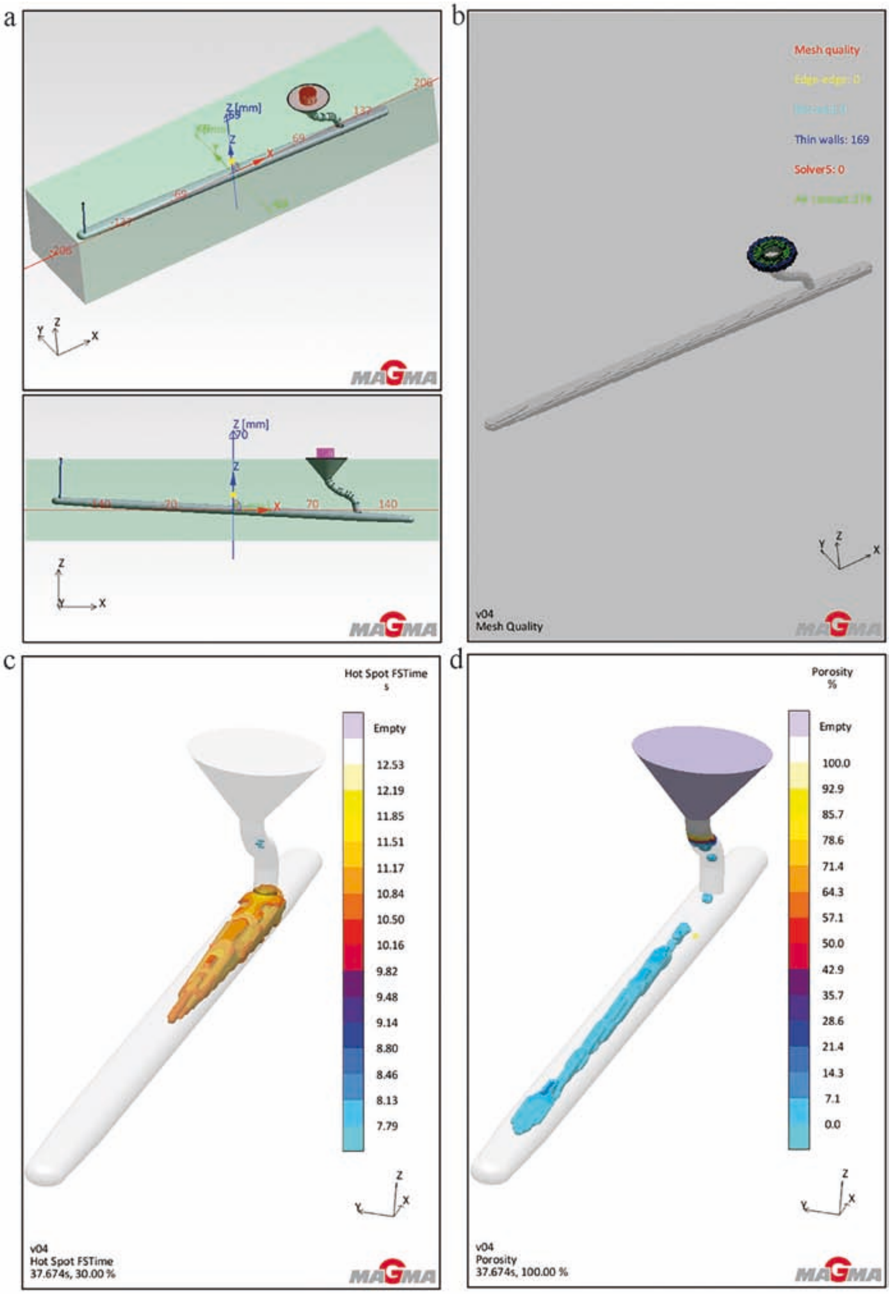

Fig. 14. Casting of tin bronze bar – technological variant III: a – position of the wax model in the mould, b – quality of the differential mesh, c – position of the shrinkage cavity, d – the distribution of shrinkage and gaseous porosity. Prepared by B. Pisarek

An attempt to apply the ornament on a casting with this method required a lot of energy of hitting the chisel with a hammer, which caused plastic deformation on the opposite side of the bar. For this reason, a notch was made on the casting of the bar by file, in the shape of a ornament like observed on the bracelet. Then the bar was coiled into the shape of a bracelet in the process of cold working at ambient temperature (t_{amb}= 23°C). Figure 15 (a-d) shows, respectively: the cast bar (a), its surface after polishing (b), the shape and arrangement of the ornament (c) and the bracelet coiled from the casting of the bar (d).

Compared to the polished bar (Fig. 15: c) with the ornament made on its surface, the following changes were observed as a result of plastic deformation on the surface of the coiled bracelet:

• the surface of the bracelet has become matt (Fig. 15: b, d),

• as a result of exceeding the bending strength of the alloy on the surface of the bracelet, cracks are formed (Fig. 15: d),

• the ornament has deformed, the distance between the lines of ornaments observed from the centre to outside of the bracelet increases – initially parallel lines spread (Fig. 15: c, d).

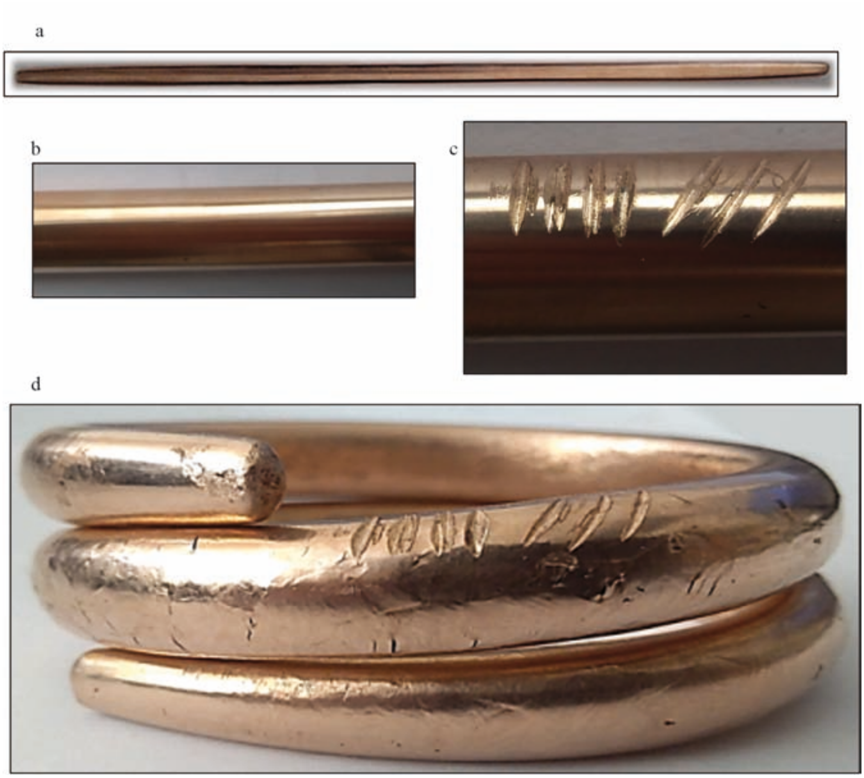

Fig. 15. CuSn3 alloy bracelet: a – casting of the bar, b – surface of the bar after polishing, c – the shape and arrangement of the ornament, d – a bracelet wrapped from casting bar. Prepared by B. Pisarek

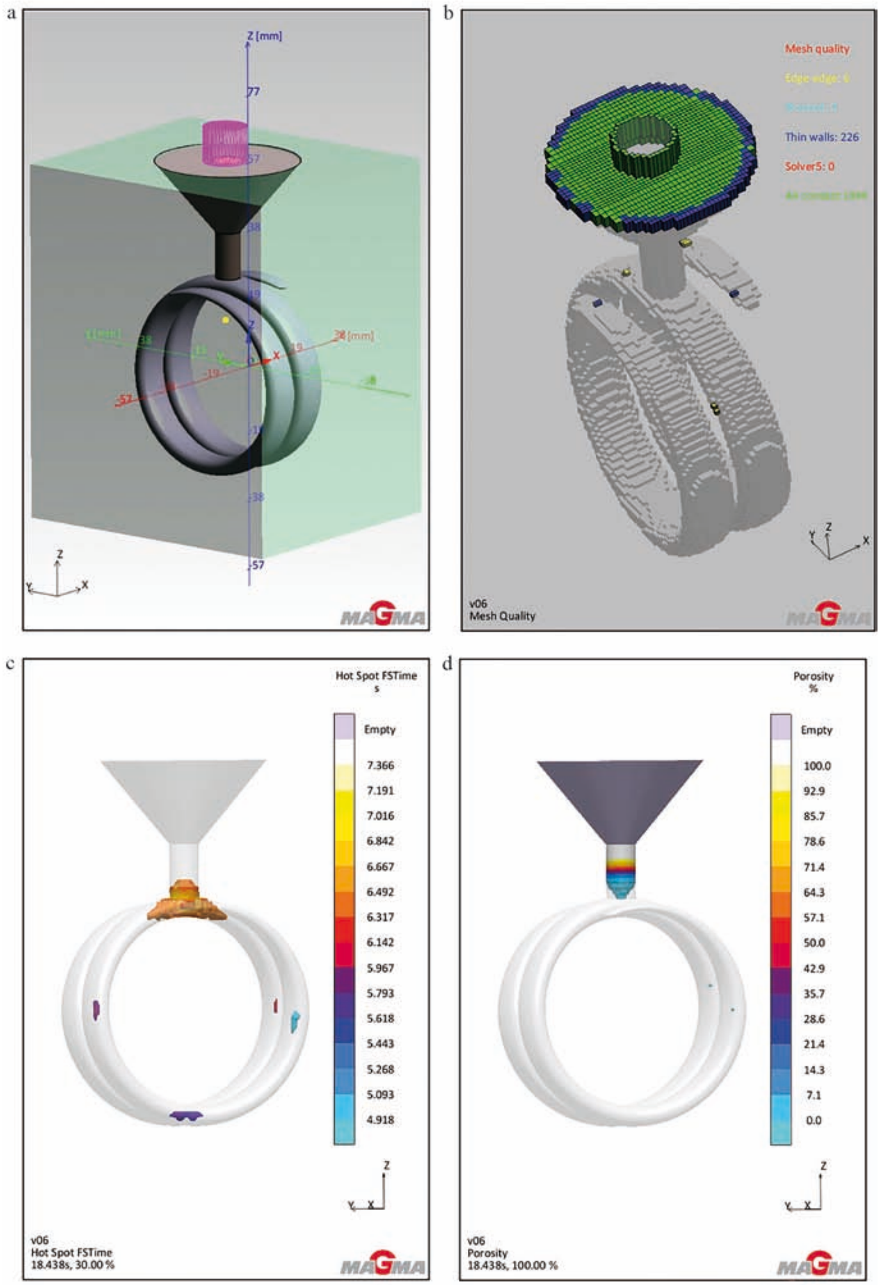

Fig. 16. Casting of tin bronze spiral – technology variant I: a – position of the wax model in the mould, b – quality of the differential mesh, c – position of the shrinkage cavity, d – the distribution of shrinkage and gaseous porosity. Prepared by B. Pisarek

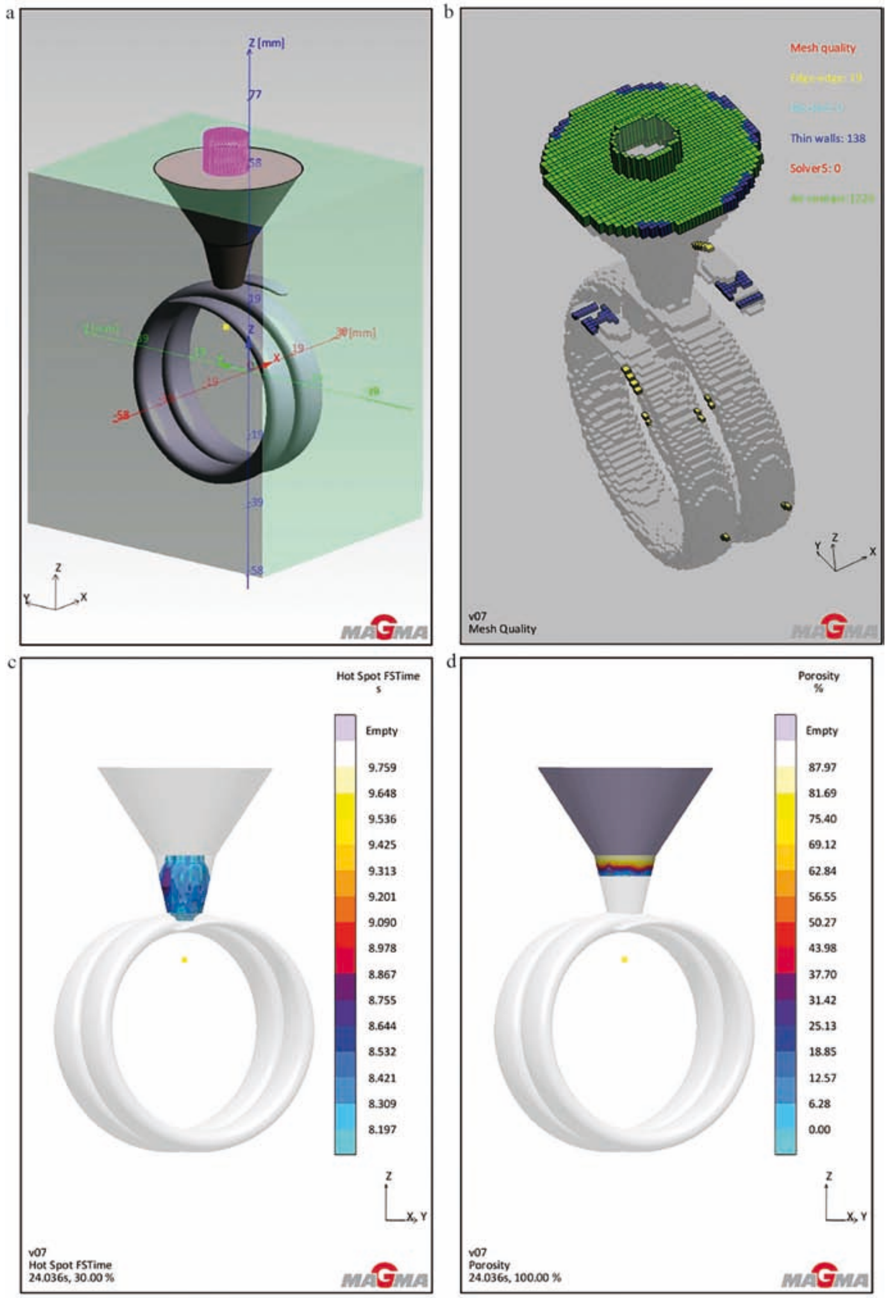

Fig. 17. Casting of tin bronze spiral – technology variant II: a – position of the wax model in the mould, b – quality of the differential mesh, c – position of the shrink cavity, d) the distribution of shrinkage and gaseous porosity. Prepared by B. Pisarek

On this basis it can be concluded that the ornament had to be made on a wax model and not on a finished casting in the form of a bar. The observed phenomena strengthen the conviction that the ornament was made directly on the wax model of the coiled bracelet. Especially, that the bracelets do not show any traces of cold working or other smithing work, even if it was, on a limited surface, *e.g.* after cutting off the gating system – which makes the second hypothesis about the bracelet technology realistic.

To support the selected hypothesis, the process of casting the coiled tin bronze spiral was traced by simulating the casting and solidification of tin bronze in a mould using the MAGMA software. Two technological variants of the arrangement of the spiral as a casting, and gating system were proposed. Also in this case the gating system was designed using the information contained in the literature (Nessel 2012). Figures 16-17 (a-d) show, respectively, the mould model (a), quality of the differential mesh (b), location of hotspots (c), and as a result of their lack of feeding, location of shrinkage cavities in the casting, location of gas and shrinkage porosity in the bar casting (d). It results from the conducted simulations that it was possible to cast the spiral – bracelet by appropriately modifying the gate supplying liquid metal from the pouring basin to the cavity which shaping casting. This change consisting of changing the shape of the gate from cylindrical (Fig. 16: a) to conical (Fig. 17: a) makes it possible to obtain a casting of bracelets without internal defects in the form of shrinkage cavities or porosity (Fig. 16: c, d; 17: c, d). Both the pouring basin and the gate supplying the alloy to the moulding cavity of the coil as a casting together form a so-called feeder, effectively compensating for the volumetric shrinkage of the solidifying liquid tin bronze.

The high quality of the differential meshes (Fig. 12; 13; 14: b; 16; 17: b) – the lack of almost any faulty cell arrangements of the so-called thin walls, edge-edge or blocked types – in the area of the differential elements of the casting allows us to claim a very high probability of the crystallization process and formation of defects in the analysed castings according to the presented simulation results.

THE DEPOSITS FROM NIEWIERSZYN SET IN TIME...

Determining the deposition time for the bracelets may be problematic. This is due to the presence of only two items in the deposit, which are basically not different in terms of form and ornamentation. On the other hand, it is the presence of two ornaments of the same type in the deposit that could indicate the time of their manufacture. According to Blajer (2001, 179), such a phenomenon was supposed to be characteristic of phase BrB2-BrD.

An important premise concerning the chronology of the deposit is the formation of its ornaments. It should be stressed that these ornaments are similar to pairs of ornate bracelets from a deposit in Sieniawa, Przeworsk district (Blajer 1999, 200, pl. 160: 3, 4) or in Maćkówki, Przeworsk district (Blajer 1999, 179, 180, pl. 89: 5, 6; 90: 5, 6; 91: 4, 6). Even though the bracelets from Niewierszyn have two coils, the overlapping of the ends is clearly visible. Such an orientation of the ends in ornaments of this type in relation to each other has not often been encountered in Poland. In light of the comments noted on the above-cited Sieniawa and Maćkówka deposits (Blajer 1987, 129; 1999, 59-60; 2008, 21, 23), the frequency of this manner of positioning the endings in relation to each other would only increase from the HA1 phase. At the same time, hoop ornaments of the Sieniawa type were identified as a group characteristic of the early stage of development of the Tarnobrzeg group of the Lusatian culture.

Another feature linking the objects from Niewierszyn and Maćkówka is also worth noting. It concerns the weight of two bracelets from the Maćkówka deposit (Blajer 1999, 180, tables 89: 5, 6). The weight of these artefacts was 170 g and 155 g, respectively. For comparison, the weight of the artefacts from Niewierszyn was 175 g and 150 g. These data points may seem interesting, but it is impossible to draw too far-reaching conclusions. Another feature that connects the bracelets from the deposits compared here is their lenticular cross-section (Blajer 1987, 126, pl. 11: a, b).

In contrast to the formation of the bracelets from Niewierszyn, the ornamentation placed on them differs from the manner of adornment of the Sieniawa type artefact. First of all, it lacks regularity and repeatability. When compared to similar groups, such a decorative motif should be considered extremely rare. The ornamentation in the form of diagonal lines on the edge of the rim was represented on an epaulette with spiral shields from an unknown locality in Silesia. In this case, it was only a complement to the transverse lines, and it was placed only in the area of contact between the ends of the rim and its transition into the shield. This epaulette was classified as of the Miłosław type (Ludów variant), and the time of its occurrence would most likely be set in the BrB2 phase (Blajer 1984, 23, 24, 27, pl. 15 :45; 1999, 80).

It should be noted that the condition of the outer surface of the bracelets did not show any signs of wear/destruction that could lead to the survival of the ornamentation only in vestigial form, at the edges of the rod. This is most likely the effect of a deliberate action. However, since its realization did not refer to the decorative motifs that existed at that time, it is difficult to use this element as a dating feature.

Based on the above data, the creation of the Niewierszyn bracelets should be dated to the HA1 phase. Thus, they extend the list of artefact groups classified as the Kutno-Raszew type, attributed to the Konstantynów Łódzki group (Blajer 1999, 121-123).

...AND IN SPACE

When trying to establish the spatial relationship that could have connected the site of the Niewierszyn deposit with the contemporary prehistoric settlement, we can rely almost exclusively on the findings from the AZP (Polish Archaeological Record) research. First, the information concerning areas 77-55 and 77-56 (Błaszczyk 2000, 175-177) was used. The amount of information published is important but modest in quantity. One should take a closer look at the settlements that functioned in the Bronze Age III (some of them also earlier) in the relevant part of the Pilica course.

On the right bank of the Pilica, about 0.5 km south of the deposit's discovery location, there are three sites of the Trzciniec Culture in Szarbsko; Site 1 (77-56/7) was considered a relic of the settlement, dating back to Bronze Age II. The next site in the same town, designated 2 (77-56/8), probably corresponds to a cemetery of similar chronology. However, it was also emphasized that the relationship of this site with the Trzciniec culture was not certain. The third site in Szarbsko, designated 6 (77-56/62), was considered a prehistoric settlement trace (without specific dating).

A little further, towards the south-east, there were two sites in Dąbrówka: 2 (77-56/35) and 4 (77-56/37), both considered relics of Trzciniec culture settlements from the Bronze Age II. Due to the small distance between them and the identical dating, it can be assumed that they originally constituted one larger settlement.

In turn, on the left bank of the Pilica River, opposite the place where the deposit was laid, there are three other attention-worthy sites. Two of them, Winduga Site 1 (77-56/23 – burial ground?) and Winduga Site 5 (77-56/66) are dated to Bronze Age II/III and Bronze Age II, respectively. In the case of the latter site (settlement), its connection with the Trzciniec culture has raised some doubts. The second settlement in Winduga, at Site 2 (77-56/24), was only generally dated to prehistory. South of the site complex in Winduga, there is a settlement trace of the Trzciniec culture in Przewóz at Site 3 (77-56/3), which dates to Bronze Age II.

The picture of the settlement that can be associated with the deposit in Niewierszyn is complemented by two sites in Stobnica. The first is the cemetery at Site 1 (77-56/13), the use of which falls in Bronze Age III (Wiklak 1964; Kaszewski 1975, 126). One hundred graves were discovered in this necropolis. The second is the settlement in Stobnica at Site 2 (77-56/14). As a result of the excavations carried out there, it was found that it was established in the same period (Wilkak 1984; Kaszewski 1975, 126). Both the settlement and the cemetery were assigned to the population representing the Konstantynów Łódzki group. In this part of the cluster of settlements, the presence of the Trzciniec culture settlement from Bronze Age II at Site 22 in Stobnica (77-55/13) should also be indicated. It was located west of Site 2.

The above description suggests that the cultural landscape of the part of Pilica situated between Niewierszyn in the north and Stobnica in the south was dominated by the relics of settlement of the Trzciniec culture. However, during the AZP research, doubts arose as to the function and chronology of the sites. The youngest and, at the same time, the only ones examined by excavations are two sites of the Konstantynów Łódzki group: the cemetery and the settlement in Stobnica, which can be dated back to the Bronze Age III. In his work, Wiklak (1964, fig. 2) indicated the presence of materials from the Konstantynów Łódzki group at two sites in Szarbsko and Winduga. At this time, it is difficult to identify them with any of the above-mentioned sites in these locations. However, a question should be asked whether the ceramic material, often sparse, discovered on the surface of the sites, should really be associated with the Trzciniec culture? [The authors of this publication have had multiple opportunities to compare pottery of the Trzciniec culture and products classified in the Konstantynów Łódzki group, which allowed identification of many common characteristics (*e.g.*, production technology, treatment of the outer surface) between these historical artefacts (see Wiklak 1964, 60). This could have been the basis of the unrealistic classification of vessel fragments found on the surface of the sites. The condition of such ceramics, the degree of their fragmentation, and the lack of ornamented fragments should also be taken into account]. Or maybe some part of these sites should be included in the clusters of the Konstantynów Łódzki group? Under no circumstances should this suggestion be treated as an objection to the author of the study results of the AZP research. One should also remember about other "weaknesses" of the results of the AZP research and their use in studies on the settlement network in prehistory. Recently, such remarks were included in the monograph of four bronze deposits from Karmin, Milicz district (Baron *et al.* 2019, 104-108). On the other hand, the one hundred burials in the cemetery in Stobnica are an important indication of the greater settlement potential of the Konstantynów Łódzki group in this specific area.

Nevertheless, in light of the collected information, the deposit from Niewierszyn should be associated with cultural phenomena contemporary with those included in the Trzciniec horizon 7 (HT7) in the case of Kujawy (Makarowicz 1998, 52). That complex was supposed to combine elements of the late Trzciniec culture and the initial phase of the Lusatian culture. Further considerations on this subject go beyond the scope of this study. It is hoped that in the future, archaeological research will allow verification of the findings regarding the settlement background accompanying the deposit in question.

The result of the chemical composition analysis of the bronze from Niewierszyn permits stating that stannite was used for their production. This raw material is found in the area of eastern Slovakia (Zlatá Baňa, Prešov district) and northern Hungary (Gyöngyösoroszi, Heves county, Alsó-Rózsa, Pest county). Another area of occurrence of this raw material is in Western Bohemia (Bozi Dar, Vernerov, Horní Slavkov, all of the Karlove Vary region), but also in the area of south-eastern Saxony (see *Mineralatlas*). The data presented here may only indicate the potential source of the raw material from which the Niewierszyn artefacts were made. Obviously it remains a hypothetical assumption whether this raw material reached the area around the Pilica River, for example, through intercultural connections from earlier times and functioning at the time corresponding to the existence of the Konstantynów group. In the case of the Trzciniec culture, the possibility of obtaining bronze material from the areas occupied by the settlement of the Otomani-Füzesabony culture has been suggested (Dąbrowski and Hensel 2005, 18; Makarowicz 2010, 165). From this perspective, the identification of Slovak and Hungarian ore deposits might be acceptable. The authors are aware of the fact that the presented hypothesis requires further studies. We must note that the work on the correction of this publication took place in the summer of 2020, in conditions of limited access to the library collections caused by the SARS-Cov-2 virus pandemic.

The small percentage of tin in the alloy (approx. 3%) allows for the classification of the bracelets into the group of low-tin bronzes. It can only be noted that objects with such alloying parameters were part of the products of the Trzciniec cultural circle (Makarowicz 2010, pl. 3.11), as well as the deposits of the Lusatian culture (Baron *et al.* 2019, 95).

AIRBORNE LASER SCANNING DATA ANALYSIS

The analysis of data from Airborne Laser Scanning measurements was carried out using ready-made LiDAR products in the form of rasters in the asc format made available by the Head Office of Geodesy and Cartography. The measurements were made and classified according to the methodology of the ISOK program (IT System for the Protection of the Country against Extraordinary Threats; http:/www.isok.gov.pl, see: Banaszek 2015; Zapłata and Ptak 2015, 102-105). Aware of the weaknesses that sometimes result from the classification of point clouds not adapted to the needs of archaeology (*cf.* Kiarszys and Szalast 2014), in this case the data were assessed as sufficient for the purposes of preliminary analysis. Geographic Information Systems software was used for this task: SAGA GIS (http://www.saga-gis.org) and Qgis (http://qgis.org) and RVT (Relief Visualization Toolbox, http://iaps.zrc-sazu.si/en/rvt#v) and Planlauf/Terrain (https://planlaufterrain.com). The used raster images (Digital Terrain Models) had a resolution of 1 × 1 m. During the analysis, a number of data visualization techniques were utilized: analytical hillshading, hillshading from multiple directions, slope gradient analysis, local dominance, simplified local relief model, sky-view factor, positive and negative openness (Kokalj and Hesse 2017).

As a result of the analysis, a significant number of features related to the Great War, and more specifically the Russian-Austrian battles in 1914, were recorded in the form of lines of trenches and tranches, fire posts, bunkers, dugouts and post-explosion craters. On the left bank of the river, in the upland area, at the height of the archaeological sites of Winduga, a significant number of regular mounds have also been recorded, which should be interpreted as the remains of late medieval and modern charcoal mounds. A connection with prehistoric settlements can be suggested with regard to a small group of earthworks, probable mounds, located 300-420 m north of the place where the deposit was hidden. 10 mounds with a diameter of approx. 13 to nearly 20 m, with a preserved height not exceeding 0.8 m, are located on the upper terrace of the Pilica valley, on the right bank of its current course, similar to the place where the deposit was hidden. A second presumed grouping of mounds was recorded in the vicinity of Site 1 in Winduga. Here, the potential mounds are much smaller and less preserved. They have a diameter of about 5-7 m and a height not exceeding 0.28 m. In the latter case, it is particularly interesting that the mounds are located in the vicinity of the archaeological site, defined as the presumed cemetery of the people of the Trzciniec culture (see Wiklak 1962).

VISIBILITY ANALYSIS

Although the reasons for the deposit of bronze items in this spot and not elsewhere are likely to never be fully elucidated, it appears that the influence of a particular location may have been due to the settlement context and the way the landscape is perceived and experienced (see Bradley 2017). This direction has been taken by research studies related to the so-called Landscape Archaeology (David and Thomas 2008; Iwaniszewski 2012; Banaszek 2015, 18-31). The perception of the landscape is modelled using a tool such as GIS and the visibility analysis generated by it (viewshed). Visibility analysis allows, as a model, the determination of the area potentially visible from a given place (Wheatley and Gillings 2000; Gillings and Wheatley 2020). Visibility analyses are still relatively rarely used, although several works have already been published in which an attempt was made to reconstruct the perception of prehistoric or early-historical communities by members of prehistoric or early-historical communities (see Zapłata 2009; Banaszek 2015; Łuczak and Piekalski 2017; Duma and Łuczak 2017; Baron *et al.* 2019, 127-157). In this analysis, the Qgis 3.14 software and the Visibility Analysis 1.2 plug-in (Čučković 2016) were used. The basis for the calculations were raster DEM files from ALS measurements, with a resolution of 1 × 1 m, provided by the Head Office of Geodesy and Cartography. The observer's viewpoint was set at 1.65 m, which is a standard practice in this type of study. The height of the observation point was set at 0.5 m. Shots corresponding to various scenarios were made:

– Visibility from the deposition point of the bronze items, thus modelling the potential range of sighting by the person or persons burying these items (Fig. 18).

– Visibility from the area of the nearest settlements, which correspond to the surface-located archaeological sites in Winduga, Sites 2 and 5 (Fig. 19; 20). In this way, we model the possibility of observing the deposition process or the place of deposition by the person/persons in the settlement area (remembering that at least a partial obstruction here could have been the above-ground buildings of the settlement).

We realize that there are a number of problems connected to visibility analyses generated in GIS. These include issues related to the accuracy of the Digital Terrain Model used, reciprocity of view (the fact that point B is visible from point A does not always mean that point A is visible from point B), the suitability of information about the contemporary terrain for modelling phenomena occurring in the past or problems with the absence of vegetation in the models used, which may have limited visibility (see Gillings and Wheatley 2001). Although researchers using visibility analyses sometimes use the results of paleoenvironmental analyses to argue, for example, the irrelevance of the forest cover factor

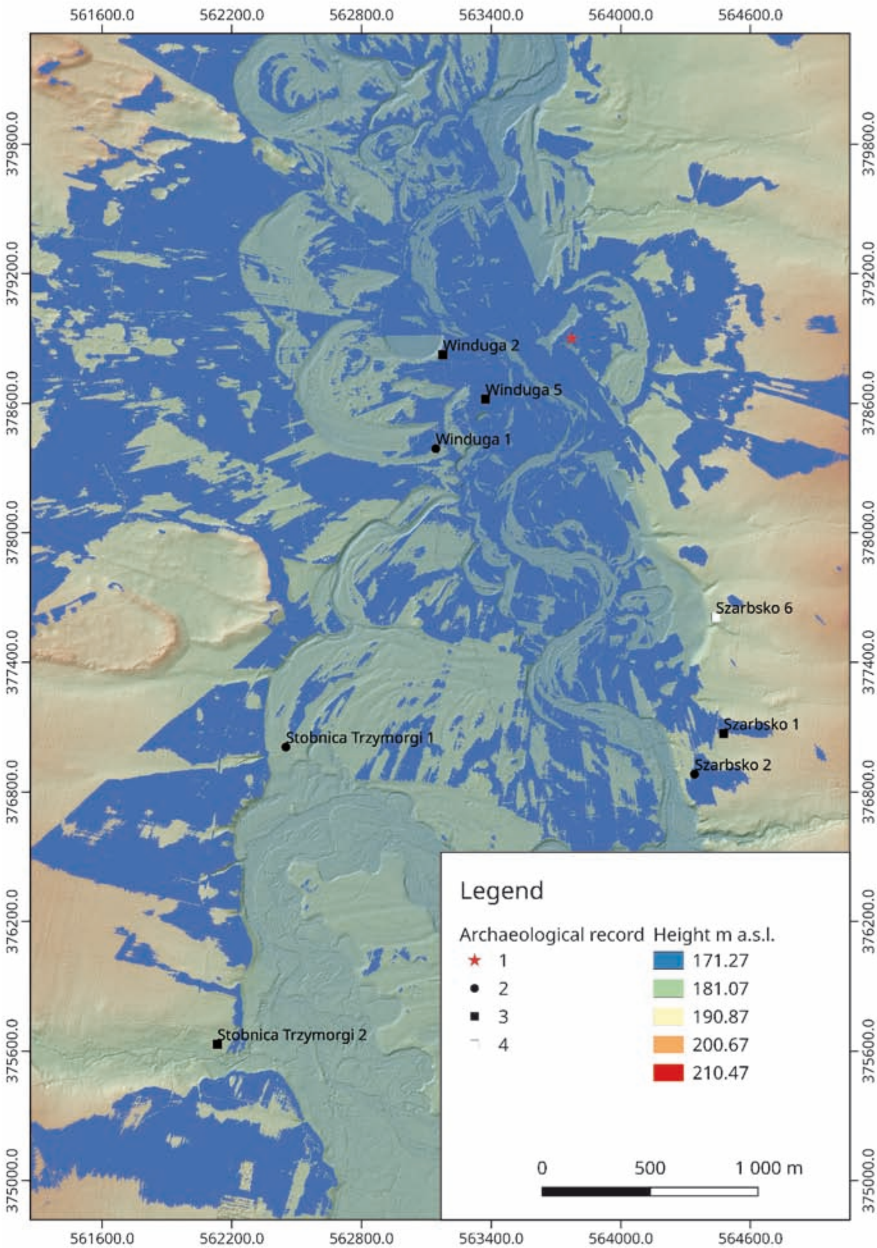

Fig. 18. Visibility from the place where the bronze items were deposited
(1 – deposit; 2 – cemetery/burial ground; 3 – settlement; 4 – settlement trace).
Based on the shaded Digital Terrain Model based on ASL measurements from GUGiK resources.
Prepared by J. Sikora

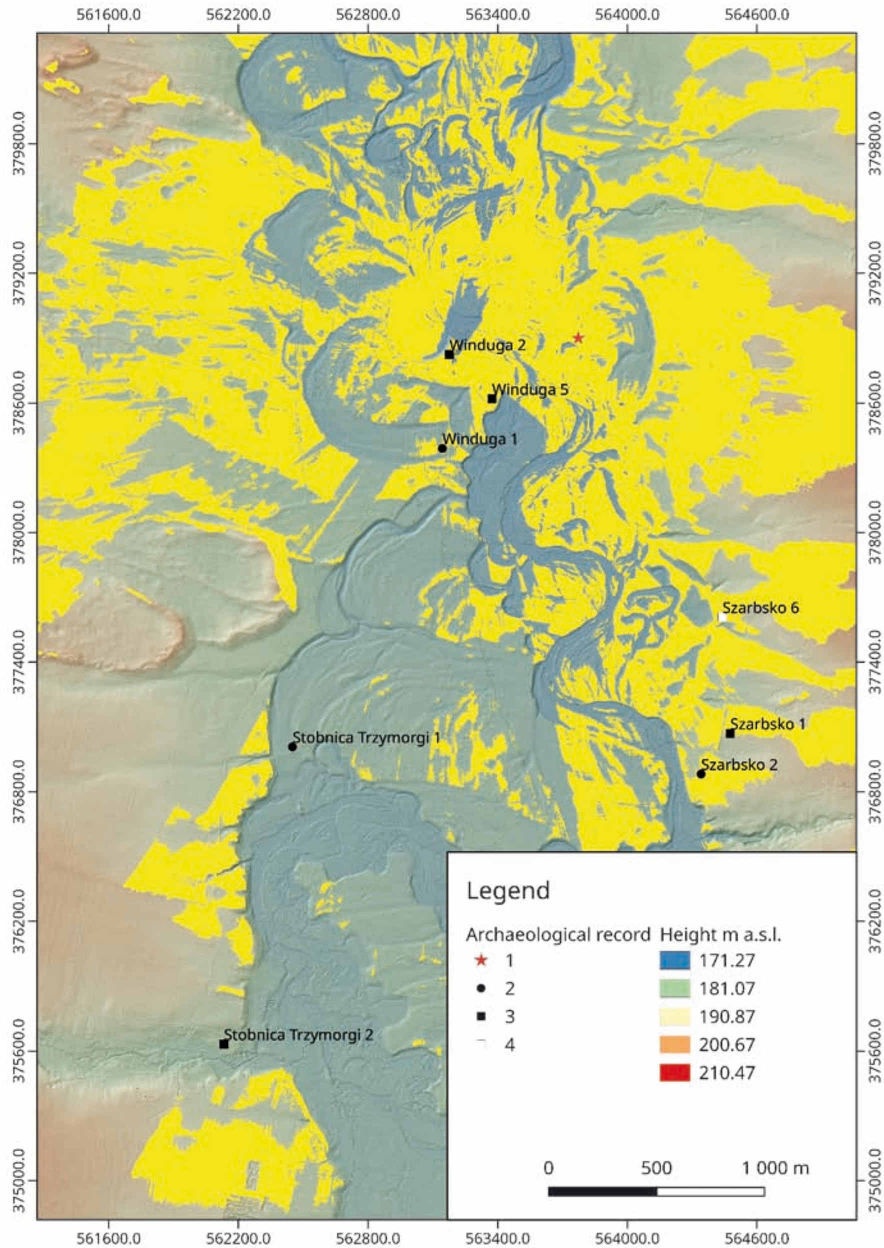

Fig. 19. Visibility from Site 2 in Winduga
(1 – deposit; 2 – cemetery/burial ground; 3 – settlement; 4 – settlement trace).
Based on the shaded Digital Terrain Model based on ASL measurements from GUGiK resources.
Prepared by J. Sikora

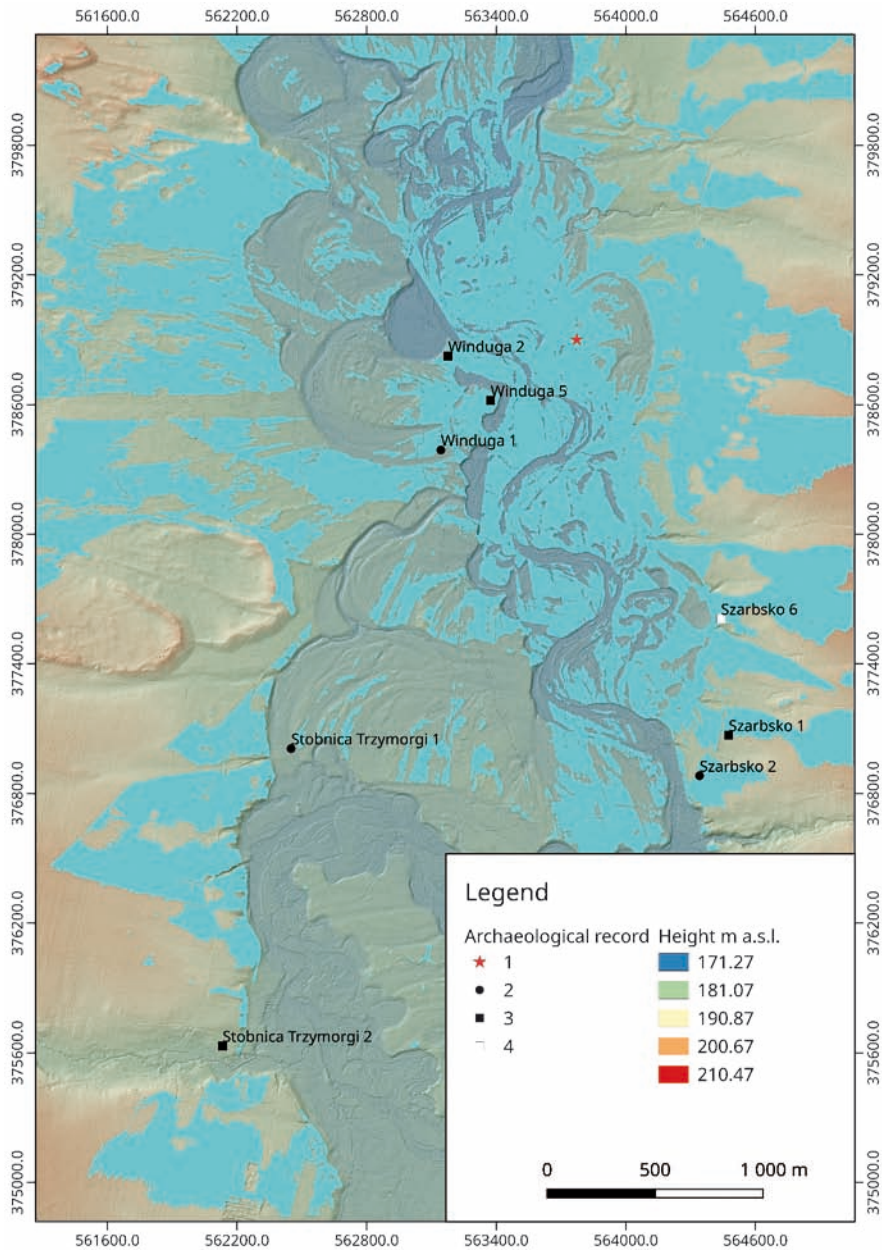

Fig. 20. Visibility from Site 5 in Winduga
1 – deposit; 2 – cemetery/burial ground; 3 – settlement; 4 – settlement trace).
Based on the shaded Digital Terrain Model based on ASL measurements from GUGiK resources.
Prepared by J. Sikora

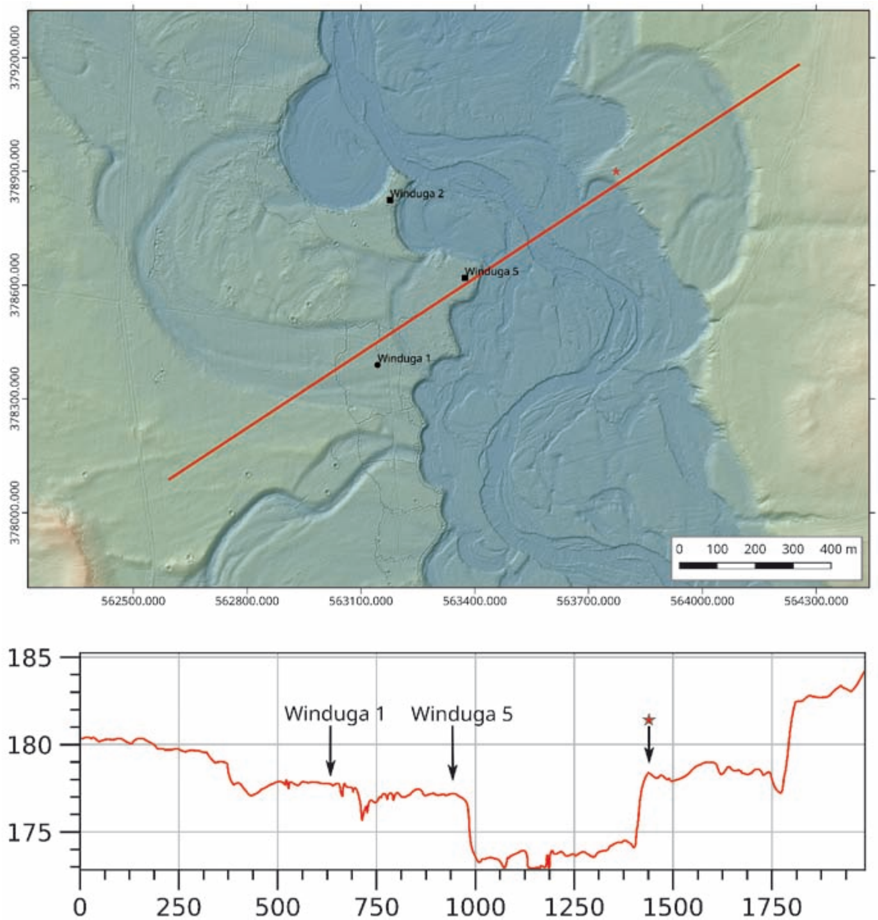

Fig. 21. Profile of the bottom of the Pilica valley in the area of the settlement complex in Winduga and the place where the bronze objects were deposited, based on the Digital Terrain Model from ALS measurements, from the GUGiK resources. Prepared by J. Sikora

(*e.g.* Friedman 2009), such studies, usually based on macroremains or pollen analyses, are not able to help locate specific trees that could obstruct visibility. An additional problem in this case is the use of data about the site location resulting from surface research carried out as part of the Polish Archaeological Record. The specificity of obtaining and the nature of these data do not allow for their precise dating. Therefore, the results should be treated as a model. They define potential visibility.

By analyzing the visibility from the place where the bronze items were deposited, we can assume that for the individual(s) laying the hoard in the ground, the complex of sites located on the left bank of the Pilica river (Fig. 21), within the raised terrace, in Winduga

Sites 2 and 5 (probably relics of settlements) and 1 (alleged burial ground, possibly containing mounds) was potentially clearly visible. The embankments of mounds located to the north of the deposition site, on the same bank of the river, should also have been perfectly legible, of course provided that they chronologically precede the deposit. Also, the sites in Szarbsko, Sites 1 and 2, located further south (from 1.45 to 2.1 km) on the same bank of the river, could have been visible. The possible visibility of the site complex in Stobnica Trzymorgi cannot be ruled out either. Therefore, it should be emphasized that a place with a very good potential sight of the cultural landscape of the Pilica valley in prehistory was chosen for the deposit of the bronze objects. Of course, we do not know to what extent this visibility could have been limited by various obstacles, such as vegetation or buildings.

From the area of the presumed settlements in Winduga Sites 2 and 5, the deposit site for the bronze items is also potentially well visible, as is the grouping of about ten mounds with an alleged burial function, located thanks to the analysis of ALS data and verified in the field. Taking into account the fact that the distances between the individual elements of this settlement complex are within 600-1100 m, it can be suggested that depositing the bronze objects could have been an element of building a whole, complex system of meanings and symbols in the ecumenical space.

CONCLUSION

The chronological position of the hoard from Niewierszyn, falling in the HA_1 phase, allows it to be associated with the horizon of the Kutno-Raszew hoards. In Central Poland, this horizon is connected with the Konstantynów Łódzki group. The two bracelets that are part of the hoard, are linked by form, ornamentation, similar parameters, and weight. In addition, they have a similar chemical composition. All these features lead to the conclusion that both bracelets were made in the same bronze workshop, probably within a short period of time.

The real reasons for depositing two bronze bracelets in the ground on the edge of the Pilica valley are probably beyond our ability to discern. It should be noted, however, that this hoard was relatively far from the settlement-cemetery complex of the Konstantynów Łódzki group, with which it was probably contemporary. At the same time, its location clearly refers to a small group of sites assigned to the people of the Trzciniec culture. It will remain an open question whether it was the presence of chronologically older settlements (and probably also graves) in this part of the Pilica valley that was the decisive factor in placing the deposit in this location.

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