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Provenance studies on Late Neolithic amber ornaments from North-East Poland

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ABSTRACT

The area of North-East Poland was in prehistory, and still is today, an area with easy access to amber as a raw material, as is evidenced in part by numerous Late Neolithic (3rd millennium) amber workshops located in the Gulf of Gdańsk and Żuławy Wiślane (Vistula Fens). Given this fact, it is surprising that only a few finished amber products have been recovered from this area. Among them are unique ornaments from the Late Neolithic sites Ząbie 10, Supraśl 3, and Supraśl 6. The preliminary analysis showed that these amber artifacts differ from the products manufactured by local groups located in the territory of modern Poland. The selected artifacts were subjected to in-depth stylistic and technological analysis to identify their provenance, taking also into consideration the type of raw material used in their production by means of FTIR analysis. Stylistic analysis showed that several specimens have analogies amongst the amber beads known from the Bell Beaker phenomenon. However, most of the beads under study are unique, and there are no analogies among any Neolithic ornaments in Europe. In addition, it was found that the specimens from Ząbie 10, Supraśl 3, and Supraśl 6 had perforations drilled with a metal tool, not a flint drill bit, which was previously unheard of in this part of Europe. The FTIR analysis revealed the use of local amber, including its different varieties i.e., succinite, gedano-succinite and gedanite. It also revealed its varying state of preservation. This may be useful for exploring the environmental context in which these artifacts were deposited.

Keywords: Provenance studies, Amber ornaments, Late Neolithic, North-East Poland, Stylistic and technological analysis, FTIR spectroscopy

Introduction

In the 3rd millennium BC on the coast of the Gulf of Gdańsk and in Żuławy Wiślane, located in the old delta of the Vistula River, there were numerous amber workshops associated with the communities of the Rzucewo culture (Mazurowski 2006). These workshops dealt with the acquisition of raw amber, its initial processing, the preparation of finished products, and probably its distribution. Considering the large number of known amber sources in this region, it is surprising that such a small number of finished amber products (ornaments) have been found in the neighboring area of North-East Poland. So far, only fifteen sites with amber finds have been recorded there, twelve of which are related to the Globular Amphora culture (nine are graves and three are loose peat finds). Moreover, most of the amber artifacts recovered from these twelve sites were lost during the Second World War (Table 1). Three of the fifteen sites are well-documented, through contemporary research at the Late Neolithic sites of Ząbie 10 (Masurian Lake District), Supraśl 3, and Supraśl 6 (North Podlachian Plain), and therefore could be subjected to a comprehensive analysis regarding their amber finds (Manasterski et al. 2001, 2021; Manasterski 2009); (Fig. 1). A total of 59 unique amber artifacts, including various beads and pendants, were discovered there. They were found in symbolic contexts – in graves and associated with five ritual features. A preliminary analysis revealed characteristics of a foreign provenance. This was evidenced primarily by their stylistic attributes, which were in most cases unprecedented in this part of Europe — the unique attributes of these finds are their shapes, proportions, sizes, and types. Regarding Ząbie 10, these were rectangular and squared beads with W- and V-shaped perforations. In the case of Supraśl 3 and 6, these were cylindrical beads unknown in this part of Poland during the earlier Neolithic period. Interestingly, amber pendants were found that also have no analogies in this part of Europe. In particular, the drilling technique, which involved the employment of a metal tool, was hitherto unknown in this area. The foreign provenance of these finds was also suggested by the context of their discovery, which indicates relations with Bell Beaker societies from the Atlantic coast (Manasterski et al. 2020; Manasterski et al. 2021; Manasterski et al. 2022). This raised the question of whether these artifacts were imports or locally made ornaments. Of note, earlier results of FTIR spectroscopy pertaining to four ornaments from sites 3 and 6 at Supra´sl, indicated the use of succinite (Baltic amber) — commonly found in the area of Northern Poland (Kwiatkowska 2015). The aim of the present research is to determine the cultural affiliation of the amber artifacts recovered from Ząbie 10, Supraśl 3, and Supraśl 6, to examine the technology through which they were made, and to identify the raw material used for their production using FTIR spectroscopy. All these data are intended to provide an insight into the provenance of the ornaments under discussion. Amber artifacts from the same period, made in amber workshops in the vicinity of Niedźwiedziówka village in Żuławy Wiślane, served as a comparative local collection.

Materials and Methods

The objective of the present study is to determine the cultural affiliation of the 59 available amber ornaments from the Late Neolithic sites of North-East Poland, to characterize the technological methods applied in their production, and to identify the raw materials from which they were made. All were subjected to macro- and microscopic analysis to determine the type of ornament, identify visible traces of processing, and specify the varieties of raw amber used in their production. In terms of identifying the types of ornaments, the typologies of Mazurowski (1983), Kwiatkowska (1996), and Beck and Shennan (1991) were used. The following criteria were analyzed: the shape and morphology of individual beads (diameter, length, width, thickness), and the location and number of perforations, as well as how the perforations were made straight, V-shaped, W-shaped), and the shape of their edges. To study technological aspects of their production, the degree of polishing was analyzed, as were traces of other manufacturing activities (i.e., flaking and cutting). The shape of the drilled perforations and the marks left by drilling were also examined. In the case of technological analysis, the latter was supported by macro- and microscopic analysis using an OPTATECH STX 12 microscope. In order to determine their cultural affiliation, literature on the subject and many years of experience in the analysis of amber records from the area of Central and Eastern Europe were used (e.g., Manasterski and Kwiatkowska 2015; Kwiatkowska and Manasterski 2016; Manasterski and Kwiatkowska 2018). The variety of raw amber was distinguished by exposing individual specimens to white light that did not generate heat. The results of the observations were compared with the data for individual varieties included in the works of Mazurowski (1983) and Leciejewicz (2005). It should be noted, however, that the vast majority of these ornaments were covered by a thick layer of post-depositional accretions, meaning the search for traces of processing and the determination of amber variety were significantly impeded or impossible to carry out. Apart from macroscopic typological division of amber (i.e., analysis based on the degree of amber transparency; after Mazurowski 1983; Leciejewicz 2005), non-invasive Fourier-transform infrared spectroscopy (FTIR; Edwards and Farwell 1996; Murillo-Barroso et al. 2018; Shashoua et al. 2006; Pastorelli et al. 2012; Pastorelli et al. 2013a; Pastorelli et al. 2013b) was used to determine the raw amber type. The FTIR spectrum of natural Baltic amber — succinite — is well-known and characterized as the most recognizable spectral pattern among fossil resins in the world (Langenheim and Beck 1965; Beck 1986; Kosmowska-Ceranowicz 2015; Wagner-Wysiecka 2018). Its main feature is an almost horizontal region within 1260–1200 cm^{-1} preceded by a peak at 1160 cm^{-1} called the “Baltic shoulder” (Beck 1986) (Fig. 2). The infrared spectra of investigated objects were compared with reference curves for fossil resins, namely Baltic amber (succinite) (Kosmowska-Ceranowicz 2015). In addition, it was necessary to account for changes in fossil resins as a result of their long-term deposition in unfavorable environmental conditions, namely exposure to the oxidative action of air, changes in temperature, and moisture.

2.1. Macro- and microscopic analysis

All 59 available Late Neolithic amber artifacts from North-East Poland were subjected to macro- and microscopic analysis. Of these, 50 pieces representing various types of beads belonging to a necklace, a belt, and two bracelets came from grave 120 at Ząbie 10 (Fig. 3). Eight pieces were found in four ritual features (no. 1, 2, 5, 6) at site Supraśl 3, and one piece came from ritual feature no. 30 discovered at site Supraśl 6 (Fig. 4).

2.2. Find contexts of the analyzed amber artifacts

In order to understand the context and origin of the amber artifacts, the three relevant sites are briefly presented below, together with their approximate chronological affiliation:

2.2.1. Ząbie 10

Ząbie 10 is a multi-period site situated in the Masurian Lake District on a former island of Lake Łańskie (Fig. 1). The site was excavated between 1997 and 2012, and revealed the remains of socio-economic activities associated with various Late Neolithic and Early Bronze Age populations, including the Globular Amphora culture, Corded Ware culture, Bell Beaker phenomenon, Neman cultural sphere, Mierzanowice culture, Iwno culture, and the Early Trzciniec culture, as well as more modern artifacts (Manasterski, 2009). The occupation of the site is associated with the Late Neolithic and Early Bronze Age, dated between 2890 and 1880 cal. BC (Manasterski 2009; Pospieszny 2015). Four graves discovered in the center of the island come from this period. Among them, the richest was grave 120 belonging to a middle-aged man, who died from a head injury (Fig. 3). He was covered with white lake chalk and equipped with 50 amber beads. The artifacts formed the pattern of a necklace (21 components), a belt (22 components), and two bracelets (three and four components respectively). The artifacts were badly weathered and damaged. During excavation, the first bead broke into several tiny pieces the size of sugar crystals. Therefore, the remaining 49 beads were conserved in situ prior to collection so that they could be extracted intact. However, the limestone chalk that filled the perforations in the beads made it impossible to fully observe their shape in most cases (Fig. 3.E). Observation of the perforation was possible only in beads that had broken at the location of V-shaped and W-shaped drilling and in repaired specimens (e.g., Fig. 6.1,1a).

2.2.2. Supraśl 3

Supraśl 3 is a multicultural site situated on a small sandy elevation in the swampy area of the Supraśl River Valley, located on the North Podlachian Plain, and excavated in 2014–2017 (Fig. 1). In the middle of this sandy prominence, four ritual features were discovered (Fig. 4.1-4) (Manasterski et al. 2020).

They contained diverse eco- and artifacts associated with the Bell Beaker cultural package, common to the Western and Eastern European variants of this phenomenon (see Manasterski et al., 2020). Among them were a few burnt and highly fragmented human and animal bones, vessel fragments, various stone and flint artifacts, one amber pendant, and seven amber beads (Wawrusiewicz et al. 2015; Manasterski 2016; Januszek et al. 2017; Manasterski et al. 2020). These are exceptional finds, because until their discovery in North-East Poland, no Bell Beaker materials had been identified there. Due to their contents, the features from Supraśl 3 do not have direct equivalents among the other published features of the Bell Beaker phenomenon from the area where this cultural phenomenon occurs (Manasterski et al. 2020, 2021). Analysis of the pottery indicated that the site may have been in use between 2500 and 2000 BCE.

2.2.3. Supraśl 6

Supraśl 6 is a multicultural site situated at the edge of a sandy floodplain of the Supraśl River, located on the North Podlachia Plain in the Supraśl River Valley, and excavated in 2010–2014 (Fig. 1). The discoveries included, inter alia, traces of the Neman cultural sphere and the Bell Beaker phenomenon (Wawrusiewicz et al. 2015). Next to an ephemeral gully used for shelter, a ritual feature was found (Manasterski et al. 2021). It was a stone hearth, under which a small bag had been placed that contained various ecofacts and artifacts, including an amber pendant (Fig. 4.5). There were also five vessel fragments: Three from Bell Beaker vessels and two from syncretic vessels that had characteristics derived from both the Bell Beaker phenomenon and the Neman cultural sphere. Based on typological analysis, the site has been relatively dated to between 2500 and 2000 BCE. It is also important to note the geological context of deposition. The amber ornaments from Ząbie 10, Supraśl 3, and Supraśl 6 come from areas with periodic groundwater fluctuations. This phenomenon is very intense in the spring after winter thaws and in autumn after prolonged rainfall. These archaeological sites are located on small sandy elevations among peat bogs and swamps. These areas were drained at the end of the 19th and the beginning of the 20th century. Since then, the typical groundwater level has been below these features. However, it increases at least twice a year. Amber ornaments within features 1, 2, 5, and 6 from site Supraśl 3, and feature 30 from site Supraśl 6, were deposited in sand, which was very dry during excavation. However, in 2016, after heavy thaws and summer storms, the Supraśl 3 and 6 sites were flooded during the summer, and such a situation could have happened many times since the deposition of these artifacts, leading to their intense degradation and weathering. Additionally, grave 120 from Ząbie 10, in which amber artifacts were deposited, was covered with lake chalk. However, it seems that this treatment had some anthropogenic aspect. In order to compare the results of our analysis on the amber finds from Ząbie 10, Supraśl 3, and Supraśl 6, we selected a series of locally produced amber artifacts from the amber workshops of the Rzucewo culture discovered in the vicinity of Niedźwiedziówka village located in Żuławy Wiślane (Figs. 1, 5). The context of the amber workshops in this area is characterized below:

2.2.4. Niedźwiedziowka

In the 3rd millennium BC, in the area of Żuławy Wiślane, in the Nowy Dwór Gdański District, there were numerous amber workshops spread over an area of approximately 30 km^2 (Fig. 1; Mazurowski 2014). However, the best-known archaeological area where they occurred is in the vicinity of Niedźwiedziówka village, where the most abundant group of raw amber sources related to the processing of amber artifacts were found. Amber was processed by the members of the Rzucewo culture, whose settlements were located mainly on the south-eastern shores of the Baltic Sea. Aside from the many finished amber products, tens of thousands of amber objects have been found in the amber workshops, including nuggets of raw material, processing waste, damaged items, and preforms. The marshy environment of Żuławy Wiślane, which is an area of the former Vistula Delta, contributed to the excellent preservation of archaeological amber artifacts. This made it possible to observe traces of processing and to reconstruct the chaîne opératoire (Mazurowski 1985; Kwiatkowska 1996). Courtesy of the Polish Academy of Sciences Museum of the Earth in Warsaw, analyses were carried out on 452 amber artifacts of diverse character, including nuggets of rejected raw material, and preforms bearing processing marks, as well as finished ornaments. The items were subjected to macro- and microscopic analyses, the purpose of which was to search for specimens stylistically and technologically similar (including drill marks) to the ornaments from Ząbie 10, Supraśl 3, and Supraśl 6. Seven specimens belonging to the following groups were selected for FTIR analysis:
- lumps of raw material (including split and/or cut nuggets with evidence of quality testing)
- artifacts used for practical training (abandoned pieces with multiple remodeling marks)
- production waste (chunks and flakes);
- damaged pieces representing various phases of the manufacturing process;
- finished ornaments.

2.3. FTIR spectroscopy

Fourier-transform infrared spectroscopy was conducted on 24 amber artifacts — Ząbie 10 (10 specimens), Supraśl 3 (8 specimens), Supraśl 6 (1 specimen), and amber workshops near the Niedźwiedziówka village (5 specimens) (Figs. 3, 4, 5; Table 2). As a reference, spectra registered for samples of geological succinite of confirmed provenance — Gdańsk Delta — were used (EWW — private scientific collection). FTIR ATR (diamond crystal) spectra were registered using a Thermo Scientific iS10 spectrometer with 32 scans and a 4 cm^{-1} resolution. Reflectance spectra were ATR and base line corrected using standard spectrometer software. All spectra were normalized to the highest peak in the spectrum i.e., ν C-H in methyl group band at ~ 2930 cm^{-1} . All registered spectra and spectral data are presented in the Supplementary Material. FTIR spectra were recorded and deposited in the International Amber Association (IAA) repository with sample labels shown in Table 2. The interpretation of FTIR spectra was based on general rules of band assignment for functional organic group vibrations (Schrader 1995; Larkin 2011; Kosmowska-Ceranowicz 2015; Wagner-Wysiecka 2018; Kiemle et al. 2019). The obtained spectra were compared with published data and additional reference spectral material.

3. Results

3.1. Macro- and microanalyses

All the amber artifacts from grave 120 discovered at the site of Ząbie 10 are nodular beads of round or rectangular/square prism shape, with faceted edges and V- or W-shaped perforations (Figs. 3.E, 6.1,1a; 7). The perforations were made in a two-step process. First, the perforations were drilled perpendicularly using a tool with a diameter of approximately 3–4 mm to achieve small channels located on both sides of the bead. Second, the channels were drilled once again at an acute angle using another tool with a diameter of approximately 1–1.5 mm, most probably using a metal tool as was verified with experiments (Fig. 6.6,7,7a). The goal of this process was to connect both channels and finish the perforation. Interestingly, three specimens were broken along the line of the V-shaped perforations and remodeled by drilling cylindrical perforations using a tool with a diameter of approximately 1 mm. Unfortunately, the artifacts were extremely fragile and badly weathered. Therefore, complete identification of all processing marks on the surface was impossible (Fig. 6.1,1a). The amber discoveries from Supraśl 3 include a pendant, six cylindrical beads, and one nodular bead (Fig. 4.1a, 2a, 3a, 4a; 7). The pendant was made from a natural nugget of amber by shaping some areas to achieve even surfaces. The artifact was deposited complete, but in the course of excavation the section with the perforation was broken off, which made the identification of drill marks impossible (Fig. 4.3a). The cylindrical beads were broken before deposition and placed within the features, as is indicated by the homogeneous weathering on all surfaces. The perforations were drilled with tools ranging from approximately 2 to 3.5 mm in diameter, and the tools left fine scratches (Fig.6.3). V-shaped perforations in the nodular bead were drilled in the same manner as in the specimens from Ząbie 10 (Figs. 3.E:Z1.Z5.Z11. Z13; 7). All specimens were badly weathered, which precluded the analysis of, e.g., grinding marks on the surface, but allowed for the observation of internal cracking (Figs 3.C,E; 7). The amber pendant from Supraśl 6 (Figs. 4.5a; 7) was made in a similar manner to the corresponding specimen from Supraśl 3. A small natural nugget of amber was used to produce the ornament by smoothing the surfaces and making a perforation. The perforation was drilled vertically from two sides using a tool with a diameter of approximately 1.5 mm, but the cylindrical channels were not perfectly connected and their walls bear fine linear traces (Fig. 6.4). The artifact was eroded, presenting a thin layer of weathering, which made it difficult to carry out a technological analysis; however, it was possible to conclude that the object had no visible cracks. Comparative material from amber workshops located in the vicinity of Niedźwiedziówka included seven artifacts belonging to different finds categories, as mentioned in subsection 2.2.4. Importantly, no secondary weathering on the worked pieces were observed. This made it possible to identify the individual amber working processes. The production of items included five steps (Figs. 5.B,C; 7):

I. cutting and flaking marks, which were associated with dividing amber nuggets and with the preliminary shaping of the ornaments; II. scraping of the uneven surface with a sharp-edged tool;

III. coarse polishing (grinding) to correct the uneven surfaces;

IV. drilling of perforations with diameters ranging between 3 and 6 mm, and either conical (drilling from one side) or hourglass (drilling from both sides) shaped with thick scratches on the surface (Fig. 6.2,2a,5);

V. fine polishing and smoothing of the surface on finished products.

3.2. Investigation by FTIR spectroscopy

The material from Ząbie 10 was identified as succinite and is characterized by a relatively large diversity of spectral patterns. Bands of the stretching vibrations νC=O group are mostly located below that typical for carboxylic acid esters at 1736 cm^{-1}, i.e., 1728–1712 cm^{-1}, which is the characteristic region for stretching vibrations of the carbonyl group in carboxylic acids. Band characteristics for unsaturated moieties, namely vinylidene γR2C=CH2 at 888 cm^{-1}, is of low or extremely low relative intensity, which in connection with the lack of observable peaks at 1642 (alkenyl νC=C) and 3080 (ν=C–H) cm^{-1} points to crosslinking of the polymer matrix as a result of the maturation or degradation of material. Spectra registered for objects Z25, Z13a, and Z17 (Fig. 8a) resemble spectra of matured geological samples of succinite (Fig. 2), especially the spectrum registered for Z25, taking into account the trace of a Baltic shoulder and the relative intensities of bands corresponding to oxygen-bearing functional groups (at ~ 1716, 1258 and 1160 cm^{-1}). More, but not strongly, affected are the spectra of samples labeled Z27, Z24a, and Z13 shown in Fig. 8b, characterized by a more distorted horizontal region of the Baltic shoulder and a change in the relative intensity of bands at 1160/1258 and 1715/1160 cm^{-1}. Such a spectral pattern was reported by authors for archaeological samples of succinite (Angelini, Bellintani 2017; Murillo-Barroso et al. 2018; Wagner-Wysiecka 2018). The characteristic Baltic shoulder for the succinite horizontal waveform is completely absent in samples labeled Z1, Z11, and Z12 (Fig. 8c). Namely, bands at ~ 1243 and 1165 cm^{-1} have almost the same relative intensities, perfectly visible in the spectrum for Z1, and less pronounced in the spectra of Z11 and Z12. This distinguishes these spectra from the spectral pattern characteristic of succinite, where the Baltic shoulder is a horizontal region of the spectrum where band 1160 cm^{-1} is of relatively high intensity. What is more, a change in the position of the band of stretching vibrations of the carbonyl group towards lower wavelength values is concurrently observed. A similar spectral pattern is characteristic of the gedanite type (or eventually gedano-succinite for Z12 and Z11) (Stout et al. 1996; Kosmowska-Ceranowicz 1999; Kosmowska-Ceranowicz 2015; Fuhrmann, Borsdorf 1986; Fuhrmann 2010). This can support a possible Baltic origin (Sambia Peninsula) for the investigated resins. However, it must be taken into account that the samples from grave 120 in Ząbie 10 came from amber ornaments which were covered with lake chalk. This may explain why the analysis of this particular material suggests the presence of inorganic material belonging to the carbonates group, due to the presence of peaks at 2515, 1795, 877 and 721 cm^{-1} (Fig. 8d); (So et al. 2020). Dominating in these spectra is a very strong and broad band at 1418 cm^{-1} , corresponding to the carbonate asymmetric stretching vibration band (Fleet et al. 2004; Bruckman, Wriessnig 2013). These spectral data point to the presence of calcite in an inorganic matrix alongside the resinous material. The presence of this substance is also seen in succinite spectra as a peak of low intensity at 874 cm^{-1} . Eight samples from Supraśl 3 and one object from Supraśl 6 were also subjected to FTIR analysis and identified as succinite (Fig. 9). The investigated objects were deposited in a sandy matrix. For four objects, 2.2, 5, 6 (Supraśl 3) and 30 (Supraśl 6), the registered FTIR spectra show a spectral pattern pointing to the maturation of the material: bands at 3080 and 1644 cm^{-1} are not observed and a signal of γR2C=CH2 at 890 cm^{-1} has a low or only trace intensity. However, it is worth noting that the position of the band corresponding to a stretching vibration of the νC=O group in carboxylic acid esters ~ 1736 cm^{-1} , even though observed as broad peak, is typical for succinite, and both an almost horizontal trace of a Baltic shoulder and the relative intensities of bands 1160/1258 and 1715/1160 cm^{-1} are well- preserved. In contrast, for certain other samples from Supraśl 3, namely 2.1, 2.3, 1.1, and 1.2, the maturation process is connected with a more significant change of material i.e., the loss of volatile compounds—esters—visible as a shift of the band of stretching vibrations of the C=O group to lower wavenumber values ~ 1720 cm^{-1} , corresponding to a higher carboxylic acid content in the material. Moreover, the relative intensities of bands 1160/1258 and 1715/1160 cm^{-1} are more or less changed (in spectra registered for objects 1.2 and 1.3). For object 2.4 (Fig. 9b), two spectra were registered which show a spectral pattern with a negative Baltic shoulder slope—a typical spectral trace for strongly weathered succinite (Beck 1986). Representative FTIR spectra registered for objects from Supraśl 3 and 6 are shown in Fig. 9 and the main spectral bands with their assignments in Table 3. For comparative studies, a series of material samples from amber workshops near the Niedźwiedziówka village deposited in the Polish Academy of Sciences Museum of the Earth in Warsaw was investigated by FTIR spectroscopy (Fig. 9c, Table 4). For all samples labeled 1

N-7 N, the spectral pattern identifies the material as succinite with a relatively low degree of maturation. In all registered spectra bands, which are attributed to unsaturated functionalities i.e., 3080 (ν=C–H), 980 (γRHC=CH_2), and 890 (γR_2C=CH_2) cm^{-1}, are well-observed. A band corresponding to the stretching vibrations of alkenyl residues at ~ 1644 cm^{-1} is observed as a low intensity signal, probably due to overlapping with a broad signal with maximum at 1733 cm^{-1}. The presence of the last-mentioned band identified the dominating ester character in the resinous material. The features of the spectral pattern listed above show that the material (1 N-7 N) strongly resembles geological samples of succinite with an almost perfect horizontal Baltic shoulder waveform.

4. Discussion

In the Late Neolithic and at the beginning of the Bronze Age there was massive extraction and use of amber by prehistoric communities. Areas characterized not only by the natural presence of amber deposits, but also by an abundance of amber processing workshops, include the Baltic coast (cf. Gimbutas 1965; Kosmowska-Ceranowicz 2015; Mazurowski 2014). In this case, the South-East Baltic basin proves to be the most prominent (Czebreszuk 2011), with Gdańsk Bay and Żuławy Wiślane as the most important regions (Mazurowski 1987; 2014). This entire area was not only a center for extraction, but also for the processing and distribution of amber products (e.g. Mazurowski 1983; Czebreszuk 2011). Given such vibrant workshops, it is all the more surprising that so few finished finds of amber products come from the nearby area of North-East Poland, all dated to the Late Neolithic period. The oldest amber ornaments are associated exclusively with the Globular Amphora culture and were found in graves or during the dredging of bogs and wet meadows (Okulicz 1973). Even if there are fifteen such sites identified to date, finds from only three, Ząbie 10, Supraśl 3, and Supraśl 6 (discussed here) have been preserved; these sites are associated with the local syncretic groups of the Paraneolithic Neman cultural sphere and the Chalcolithic Bell Beaker phenomenon. Interestingly, no amber ornaments are known from the Neman cultural sphere. The situation is different for amber objects associated with the Bell Beaker phenomenon. These are quite diverse, with the only common form between the different provinces of the Bell Beaker phenomenon being the circular nodular beads with a V-shaped perforation, which, however, differ in their formal details (Hájek 1957; Mazurowski 1983; Du Gardin 1998; Beck, Shennan 1991; Czebreszuk 2011; Drenth 2017). In addition, they may have been accompanied by other forms that are considered to be locally specific. One such form is a type of small cylindrical bead, essentially restricted to Great Britain. In the case of these amber ornaments, it is difficult to find references in the literature regarding their manufacturing processes. Usually, the authors of relevant studies mention flint tools for making perforations. This is highly probable as the amber workshops of Western and Eastern Europe in operation at that time, regardless of their cultural background, employed a similar technological sequence of amber processing, within which the use of flint drill bits is indicated by manufacturing traces in the form of uneven conical or hourglass-shaped perforations, with uneven walls and “thick” scratches (Mazurowski 1985; Beck, Shennan 1991; Bulten 2001; Piena, Drenth 2001; Drenth 2017). However, in the case of the British Isles, it was found that some of the perforations had small diameters and regular wall courses, which may have been drilled with a copper or bronze tool instead (Beck, Shennan 1991). In the case of the finds from Ząbie 10, Supraśl 3, and Supraśl 6, we have evidence for three distinct types of ornaments: the most numerous (50 specimens) are nodular beads with V-shaped (36) and W-shaped (14) perforations, cylindrical beads (7 specimens), and pendants (2 specimens). Among them, only four round nodule beads with V-shaped perforations drilled from the flat side and 7 cylindrical beads do not present any difficulties regarding their cultural provenance. The nodular specimens (regardless of the material from which they were made) can be considered typical of the Bell Beaker phenomenon attested across almost its entire range (Hájek 1957; Du Gardin 1998; Drenth 2017; Wentink 2020). Cylindrical beads, on the other hand, appear to be specific to Great Britain, although nodular forms were occasionally found there too (Beck, Shennan 1991). In contrast to those mentioned, nodular beads with square and rectangular outlines do not have any amber counterparts in the Bell Beaker material. Only bone specimens from Spain show some similarities (Harrison 1977). Square amber specimens with, however, different morphology and dimensions, are known only from graves of the Złota culture in Southern Poland (Mazurowski 1983). It is much more difficult to identify relevant comparative material for the W-shaped perforated beads, which, apart from the finds from Ząbie 10, have no analogues in Western and Central Europe. However, a similar drilling method was recorded for amber products with a different morphology from graves of the East European Volosovo culture, occupying the upper Volga basin. Although, even there, this manner of drilling was rare (Kostyleva, Utkin 2000). Unfortunately, we cannot say much about the manufacturing techniques used to prepare the shape of the ornaments and for their initial processing, as any traces were obliterated during the grinding and polishing of the surface, and, in many cases, especially among the artifacts from Ząbie 10, their surface was heavily weathered. Nevertheless, we can offer some circumstantial conclusions on this subject. These are delicate ornaments. When it comes to the specimens from Ząbie 10, although some of them are of considerable size, they are relatively thin and made in accordance with a single design. Their proportions indicate a conscious choice of size, as they are arranged from the smallest specimens at both ends of the necklace, belt and bracelets, to the largest ones in the center. Moreover, one can get the impression that a quite consistent color of raw material was used, which in the case of amber is quite difficult to achieve and requires careful selection of the variety, possibly necessitating matching from different nuggets. All these features point to the initial conception of these ornaments as forming part of a single set, which guided their manufacture. Due to the specific selection of the raw material, and therefore its great value, its potential loss during the manufacturing process must had been minimized. For this reason, a technique of “thread” cutting, rather than splitting, was probably used for dividing and shaping the beads. It is also likely that scraping with the edge of the “knife” was dispensed with, and that only coarse grinding followed by fine grinding (polishing) was used, after which the ground surfaces remained giving the ornaments an “envelope” shape. Similar economization of the raw material was applied by drilling with a metal rather than a flint tool. For these reasons, single specimens as well whole sets of beads that form the necklace, belt, and bracelets can be considered unique, especially as there are no direct analogues. In the case of both pendants, which are characterized by a drilled perforation, no surface treatment, and at most a slight degree of shape correction, it is difficult to pinpoint an unambiguous provenance, although they seem to be mainly associated with the Baltic zone. They have been recorded in the material of the Single Grave culture in the Netherlands, Denmark, and Germany, the Rzucewo culture of Poland and Lithuania, the Corded Ware culture in Latvia, and the Pit-Comb Ware culture in Finland (Mazurowski 1983). One of the analogous specimens comes from the encampment of the Rzucewo culture at Pieniężno (Łowiński 1987). It is the closest artifact of this type with regard to the objects from Supraśl 3 and 6, which may prove the provenance of these ornaments. However, apart from the formal and metrical similarity, nothing can be said about its manufacture, as this artifact has been lost. From a sketch of one of its sides made by its finder, it can be deduced that the diameter of the perforation was about 3 mm and it had a funnel-shaped (or hourglass-shaped) outline. This would indicate that it was made with a flint drill bit, and in this way it differs from the finds from Supraśl 3.

The most informative characteristic, from the point of view of the present research, is the method of making perforations. The main distinguishing attribute of the non-local technology is the tool used. The results of the macro- and microscopic research showed that a flint drill bit was used in the production of the analyzed ornaments from the vicinity of Niedźwiedziowka village. This corresponds with observations made by R. F. Mazurowski, and research on amber items from amber workshops in the north of the Netherlands (Mazurowski 2014; Drenth 2017). Its use on specimens left channels with a diameter between 3 and 6 mm, as well as of conical or hourglass shape with visible thick scratches. The technology from Ząbie 10, Supraśl 3, and Supraśl 6 used a much thinner tool that left channels of approximately 1.5 mm in diameter. Experimental and comparative studies carried out in recent years with the use of flint, bone, and copper tools have shown that perforations of cylindrical, rather than conical or hourglass, shape were made with the use of the latter (Popkiewicz 2016).

This indicates the high degree of specialization of the maker of these objects, since the application of a proper tool is relevant to the type of item produced. Thanks to the use of a metal (copper or bronze) drill bit, it is possible to obtain precise and delicate perforations with a small diameter (1–2 mm), which is of particular importance in the case of small and thin ornaments. This last statement refers especially to V-shaped perforations, where the drill perforations meet inside the ornament, creating a kind of stirrup that makes it possible to attach (sew) them together or to a substrate. In the case of some of the ornaments from Ząbie 10 we are dealing with W-shaped perforations, which are in fact a combination of two V-shaped perforations. This is a particularly important technological procedure for relatively thin beads, which have otherwise large dimensions. The use of single V-shaped perforations would have caused cracking of the attachment stirrups that may lead to their breakage. By introducing W-shaped perforations, two stirrups were created in one ornament, thus doubling the number of attachment points and distributing the negative stresses in these sensitive areas more widely. These perforations could not be drilled with a flint tool in such thin material. It would have produced funnel-shaped channels that were too large, which would have significantly weakened the resulting stirrups, or even removed too much material for a stirrup to have been formed. In the case of the Supraśl beads, the situation is slightly better due to their compact form. However, even in this case, drilling with a a flint drill bit would result in too great a loss of raw material, which would lead, on the one hand, to thin and weak bead walls, liable to cracking, and, on the other hand, to a significant loss of precious raw amber material. At this point, taking into account both the shape and the drilling method, it should also be noted that the cylindrical specimens from Supraśl are the first examples of such ornaments from the Late Neolithic and Early Bronze Age in Poland, or even within Central and Eastern Europe. The observations presented here and their conclusions indicate that, in this aspect also, these ornaments should be regarded as unique in the given area and time period.

The use of a copper or bronze tool is found exclusively in amber products discovered in Bell Beaker contexts on the British Isles (Beck, Shennan 1991). Therefore, it should be inferred that this cultural environment possessed such tools and the ability to use them. This does not mean, however, that the ornaments from North-East Poland were made in the British Isles, because there is no clear evidence of amber workshops functioning there at that time. Perhaps we are dealing here with an as yet unidentified place where, on the one hand, sufficient quantities of good quality raw amber material were available, and, on the other hand, metal tools were used in their manufacture. It is also possible that at that time there were “itinerant” jewelers who processed this raw material and made ornaments to special order, as is evidenced by the unique set of 50 ornaments from Ząbie 10.

The results of the technological analysis could be helpful here. However, in the case of the ornaments from sites Ząbie 10, Supraśl 3, and Supraśl 6, it is not possible to reconstruct the full technological process used to make the ornaments, and in two cases no information regarding their processing is available at all, because, similarly to the majority of amber objects from that period, they underwent a strong weathering process. This process led, at best, to the formation of a thicker or thinner weathered "coat" on their surface, and at worst to their complete disintegration into small "crystals". Only amber and artifacts originating from its processing, kept in a constantly wet environment, and preferably without access to air, as was the case of the ambers from the vicinity of Niedźwiedziówka village, could survive in an almost unchanged state until the present day. These conditions makes it possible to fully reconstruct both the steps in the process of making the ornaments from the latter, and to preserve, and thus identify, the traces left by the tools used at that time. Based on the similarities observed both in the workshops of Western Europe and those of Żuławy Wiślane, it can only be assumed that the process was uniform, and that the only possible difference consisted of the use of tools made of different raw materials, though similar in form. However, even if the technological processes cannot be completely identified in the case of the archaeological finds from the Masurian Lake District and Northern Podlasie, it should be emphasized that the beads from Ząbie 10 are characterized by stylistic homogeneity, segregation in terms of their size, the high quality of craftsmanship, which is reflected in the planning of the product as a whole, the skill of the maker, and access to top-quality raw material. The amber ornaments from Supraśl 3 and 6 are simple and small artifacts with marks of processing with metal "jeweler's" tools, which were not used in Central or Eastern Europe at that time.

Due to the above characteristics, especially those of the cultural and technological importance (non-local style and the use of a metal drilling tool), a detailed analysis of the raw material used for their production proved to be even more interesting. While the micro- and macroscopic analyses did not answer all questions regarding the types of resins, and the variable state of preservation of the artifacts, all these questions were addressed by the results of the FTIR spectroscopy measurements. The majority of the material from all three archaeological sites was identified as succinite, which underwent variable detectable physical and chemical transformations depending on the local environment. This result indicates that these materials were made from Baltic raw material. These data, combined with the results of the macro- and microscopic analysis suggest that the ornaments were not produced in the nearest workshops in Żuławy Wiślane, or in the North-Western zone of Europe, since different tools were employed for amber processing, and, to a certain degree, the processing techniques differed. On the one hand, this excludes these workshops, as the place of origin of these artifacts, but on the other it does not answer the question regarding their provenance. Owing to some stylistic similarities, it might be possible that the ornaments were produced in contemporary workshops that functioned along the coastal region of the Baltic Sea during the Neolithic. However, the published literature does not offer any information about the tools and processing techniques used in this area (e.g. Vankina 1970; Rimantienė 2001; Loze 2008; Butrimas 2016). They may also have been made of Baltic amber exported to other regions of Europe, related to the Bell Beaker phenomenon, such as the British Isles (Beck, Shennan 1991), but also the Mediterranean zone, where copper tools were also used in amber processing (e.g. Mazurowski 1983; Popkiewicz, Czebreszuk 2016). In this case, the artifacts might have reached North-East Poland together with their owners, which is suggested by the context of their deposition, associated with allochthonous Bell Beaker societies (Manasterski 2016; Manasterski et al. 2020; 2021; 2022). Another possibility is to assume that they were made of local raw material in the Baltic zone, and even in the area of North-East Poland. In such a case, it is most likely that these ornaments could have been made by an ''itinerant amber jeweler'' with the appropriate skills and set of jewelry tools, including metal drillingtools. In this case we would be dealing not with the actual import of wares, but with the import of jewelry skills and tools, and to some extent with a foreign style. While the amber ornaments from Supraśl 3 and 6 are quite common in the Bell Beaker environment, only differing in their manufacturing technique, the set of ornaments placed in grave 120 at Ząbie 10 indicates the implementation of a special and prestigious order, which would explain their uniqueness in this area.

The presence of further types of fossil resin is also interesting. A gedanite and two gedano-succinite ornaments were also identified among the samples. While the latter is identified only through scientific analysis, gedanite can sometimes be recognized macroscopically. One of its diagnostic features is that under weathering it gets covered with a dusty whitish layer. It is therefore important to consider whether the differences between these raw materials were also recognized in the past, and whether the qualities of the individual resins had their own significance.

The results related to amber weathering processes are equally promising. Archaeological amber objects are generally affected by degradation, both at archaeological sites and in museum collections, due to local environmental factors such as humidity, air, temperature, and light exposure (Pastorelli et al. 2011; Pastorelli et al. 2013a; Bisulca et al. 2012; Sadovski et al. 2021). Depending on the dominant type and intensity of their action, the changes in physical and chemical properties of amber can differ (Pastorelli 2011). However, at this point it is worth underlining that fossil resins, including succinite, due to their chemical nature, undergo constant natural maturation, which results in changes to their physical and chemical properties (Czechowski et al. 1996). Taking into account the different depositional conditions of the studied sources and the different weathering patterns, it could be suggested that post-depositional changes can become a method of identifying the environmental contexts in which other, e.g., archival amber artifacts were deposited. See, for instance, similar approaches used in relation to quartz grains in geology (e.g. Woronko, Pisarska-Jamroży 2015;

Woronko 2016) and recently in geoarchaeology (Klecha 2017). Therefore, it is worth considering the analytical potential of the FTIR method also in this case.

5. Conclusions

Despite the close proximity of areas rich in raw amber and their places of manufacture (e.g. Gdańsk Bay and Żuławy Wiślane), the area of North-East Poland is poor in terms of finds of finished amber products dated to the Late Neolithic. Micro- and macroscopic analyses of the ornaments from Ząbie 10, Supraśl 3, and Supraśl 6, provided interesting information related to amber processing techniques. After comparing them to material from amber workshops located in the vicinity of Niedźwiedziówka, dated to the same period, the results indicate that the ornaments were not produced in these workshops since not only were metal tools (copper or bronze) unknown at this time in this area, different production styles were employed. This excludes the closest workshops from Żuławy Wiślane as the place of origin for these artifacts.

The FTIR spectroscopy, however, showed that the ornaments from Ząbie 10, Supraśl 3, and Supraśl 6 were made mostly of succinite — amber found in the Baltic basin. This makes it even more difficult to determine their origin. The obtained results indicate that the amber ornaments may have been made outside the study area. However, they may also indicate that the ornaments were made by an itinerant amber jeweler, who used metal jewelry tools and a slightly different style and techniques for making ornaments than has been recognized from previous finds in the area of Central and Eastern Europe.

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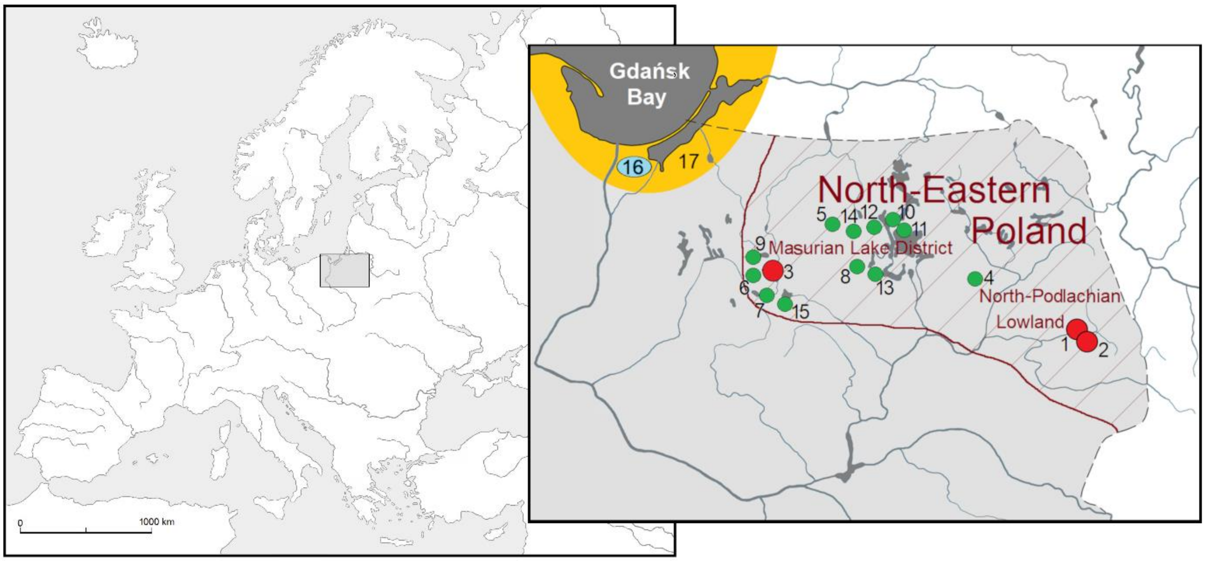

Fig. 1. Late Neolithic amber artefacts discovered in north-eastern Poland and the range of raw amber material in the area of the south-eastern Baltic Sea coast. 1-2 – ritual features of Bell Beaker culture from Supraśl 3 and 6 with amber ornaments, 3 – site Ząbie 10 and grave 120 with amber ornaments (Bell Beaker culture?), 4-15 – sites of Globular Amphora culture with amber ornaments (4 - ornaments impossible to identify, 5-15 - material were lost during the Second World War); 16 – amber workshops in the vicinity of Niedźwiedziówka village in Żuławy Wiślane; 17 – range of raw amber material in the area of Gdansk Bay overlapping with the range of the Rzucewo culture (acc. Jaskanis, 1971; Manasterski, 2009; Mazurowski, 2014; Manasterski et al., 2020; 2021).

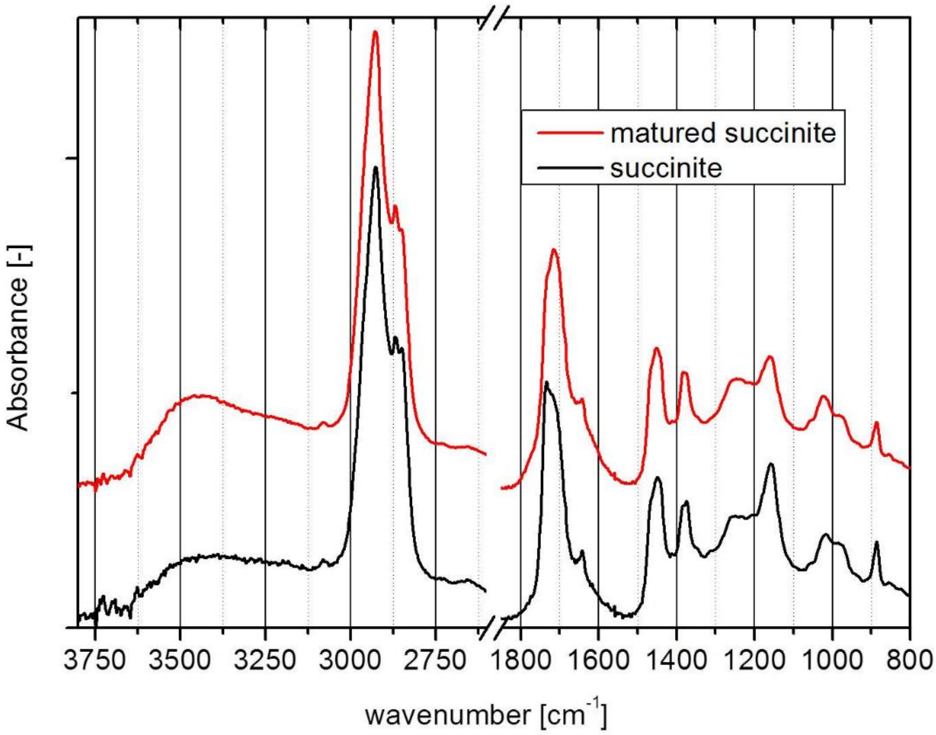

Fig. 2. Mid-FTIR (ATR) spectra of succinite: "fresh" geological sample (black line) and its comparison with the spectrum of matured geological (red line) material.

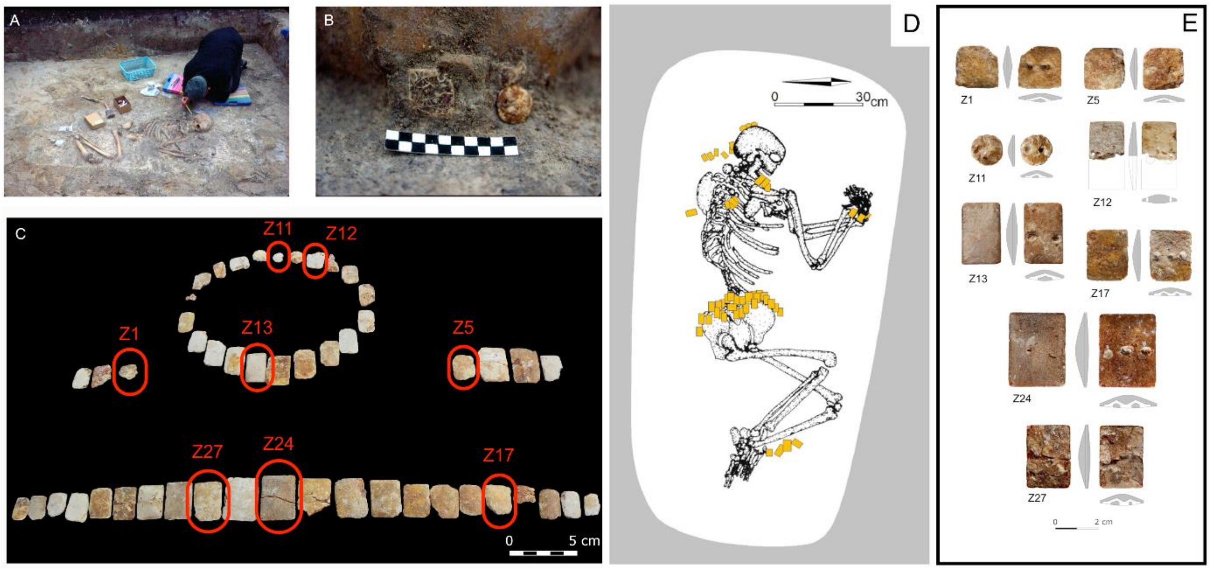

Fig. 3. Feature 120 at site Ząbie 10 in the Masurian Lake District. A – exploration of the burial with amber ornaments; B – state of preservation of the unearthed ornaments; C – supposed patterns of the amber beads in the necklace, belt and both bracelets (Z1,5,11,12,13,17,24,27 - artefacts investigated with FTIR spectroscopy); D – 3 – distribution of the amber beads within the grave; E – different types of amber beads (Z1, Z5, Z11, Z13 – with V-shaped holes; Z17, Z24, Z27 – with W-shaped holes; Z12 - broken bead with a hole drilled straight through); (acc. Manasterski et al. 2001, Manasterski, Kwiatkowska 2015 with authors' supplementary notes. (Photos: D. Manasterski, K. Kwiatkowska, A. Cetwińska and M. Bogacki).

Fig. 4. Features at site Supraśl 3 (1-4) and site Supraśl 6 (5) in the North-Podlachian Lowland. 1a – feature no. 1 during exploration 1b – amber artefacts in the fill of the feature; 2a – feature no. 2 during exploration, 2b – amber artefacts in the fill of the feature; 3a – feature no. 5 during exploration, 3b – amber artefact from the ceiling of the feature; 4a – feature no. 6 during exploration, 4b – amber artefact in the fill of the feature, (photos: D. Manasterski, K. Kwiatkowska and A. Cetwińska), 5 - feature during exploration 5b – amber pendant in the fill of the feature (acc. Wawrusiewicz et al. 2015; Manasterski et al. 2020) with authors' supplementary notes).

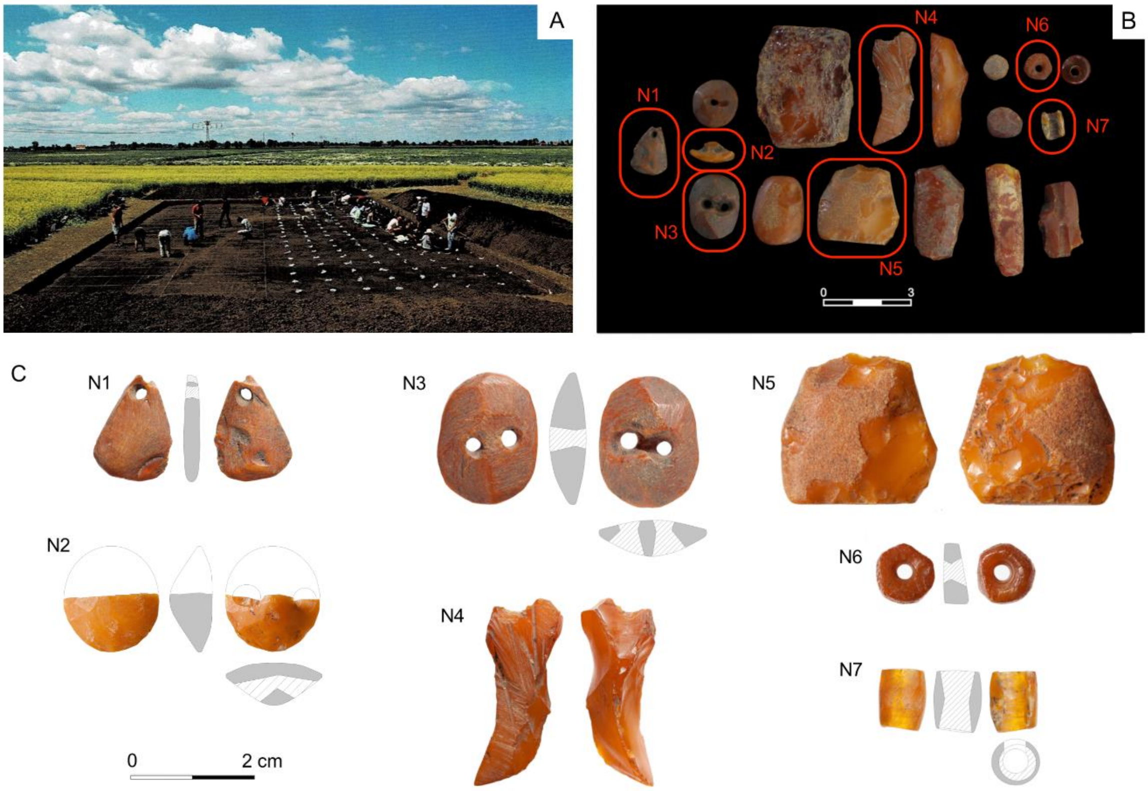

Fig. 5. Amber workshops in the area of Niedźwiedziówka in Żuławy Wiślane. A – archaeological research in 1997 acc. Mazurowski 2014; B – selected amber artefacts from amber workshops (N1-N7 - artefacts investigated with FTIR spectroscopy); C - artefacts investigated with FTIR spectroscopy. Materials from the collection of the Polish Academy of Sciences Museum of the Earth in Warsaw (Photos: K. Kwiatkowska, D. Manasterski, A. Cetwińska and M. Bogacki).

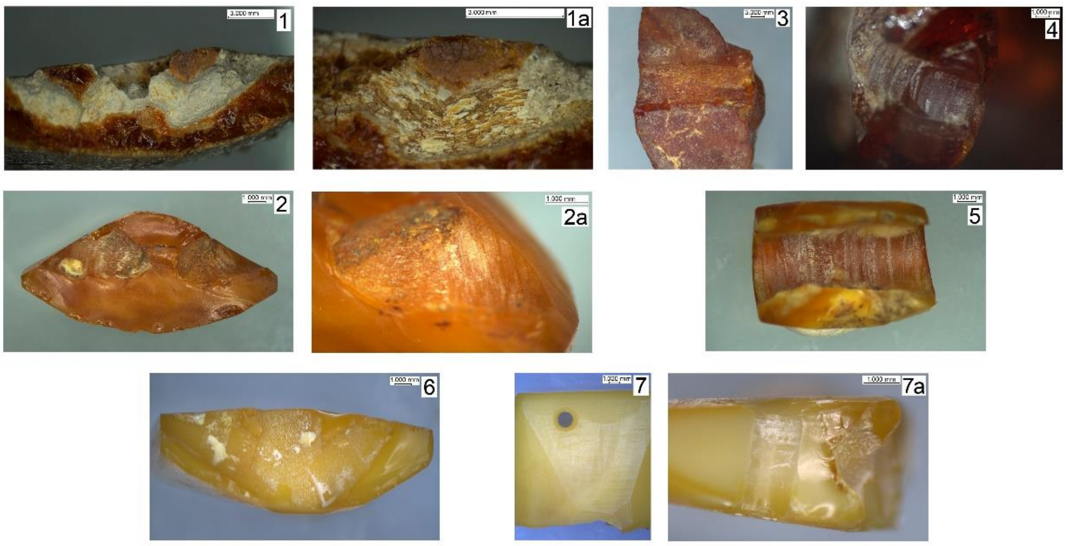

Fig. 6. Microscopic images of the holes drilled in the amber artefacts. 1,1a – Ząbie 10, W-shaped hole in a nodular bead; 2,2a – Niedźwiedziówka, V-shaped hole in a nodular bead; 3 – Supraśl 3, hole drilled in a cylindrical bead on both sides; 4 – Supraśl 6, lateral hole drilled in the pendant on both sides; 5 – Niedźwiedziówka, hole drilled in a cylindrical bead on both sides; 6,7,7a – one of replicas of nodular beads from Ząbie 10 with a W-shaped hole (6) and a lateral hole (7,7a) (Photos: K. Kwiatkowska and A. Cetwińska).

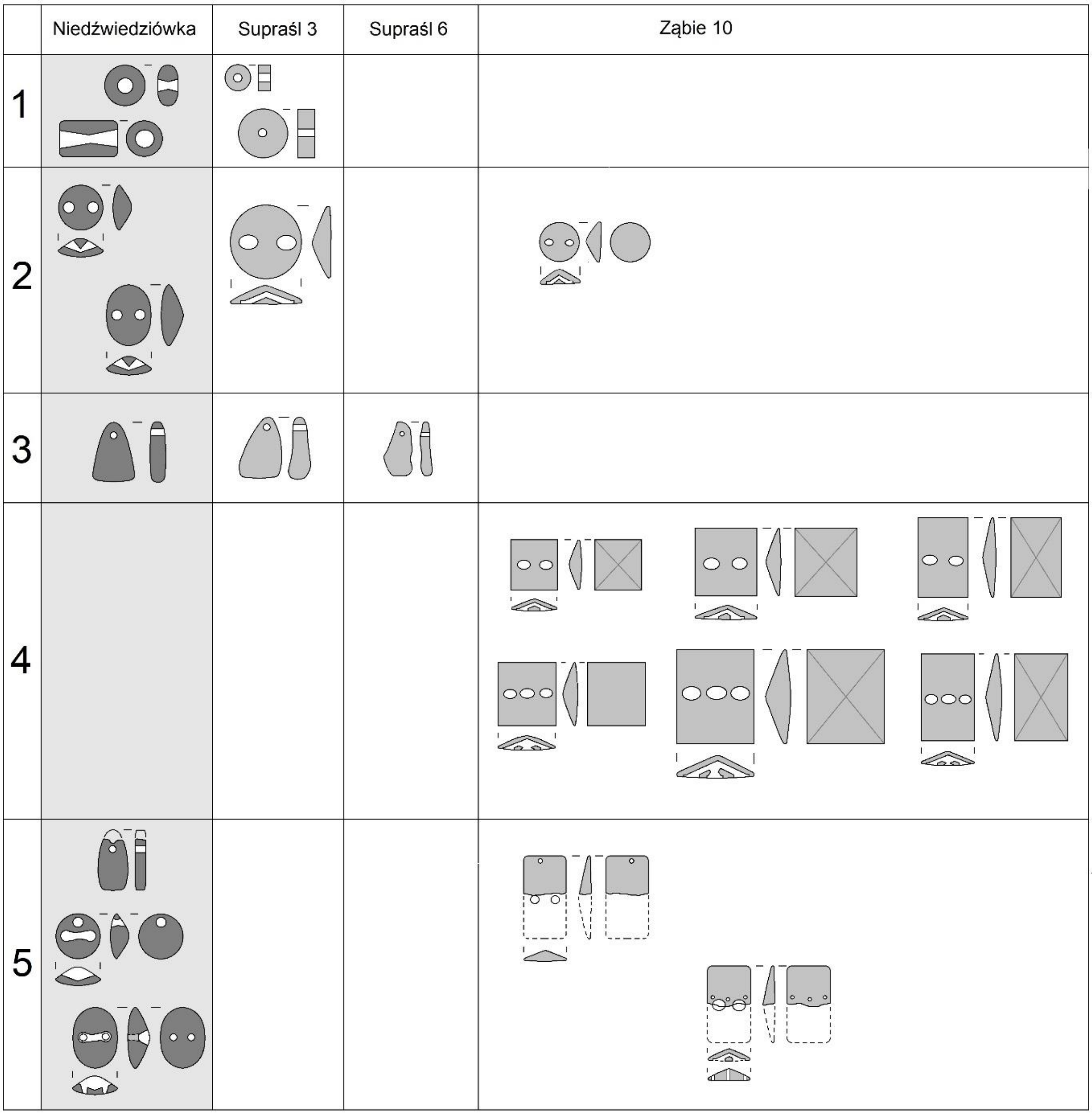

Fig. 7. Types of Late Neolithic ornaments from north-eastern Poland and from amber workshops in the vicinity of Niedźwiedziówka village in Żuławy Wiślane. 1 – cylindrical beads, 2 – round and oval nodular beads with V-shaped holes, 3 – pendants with lateral holes, 4 – square and rectangular nodular beads with V- and W-shaped holes, 5 – damaged and repaired ornaments.

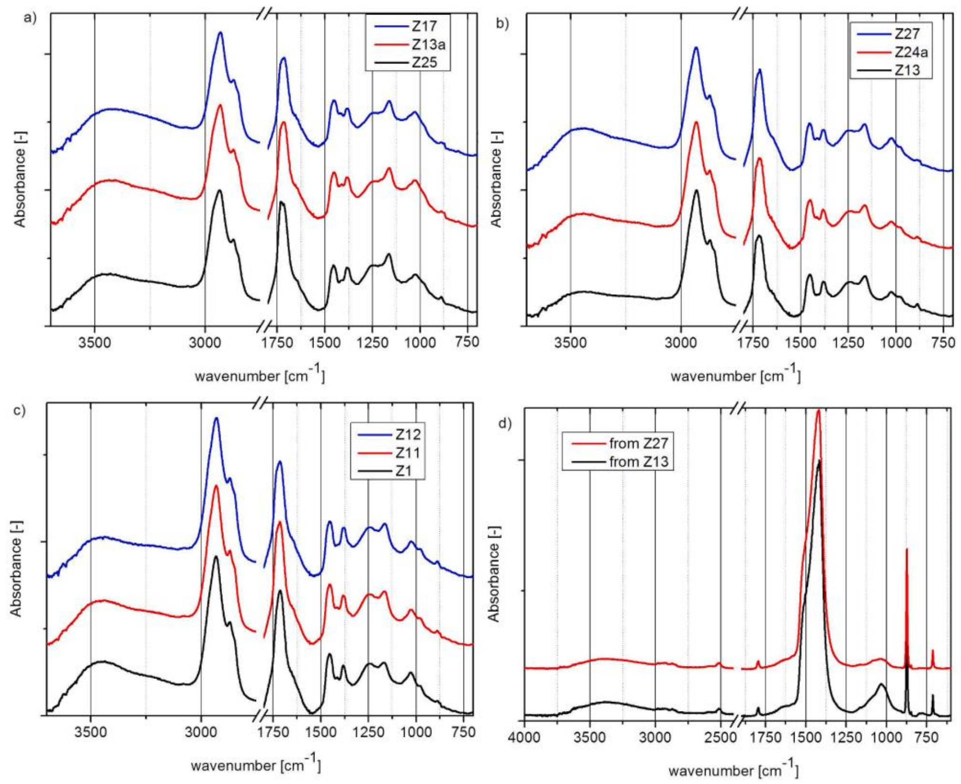

Fig. 8. Representative FTIR (ATR corrected, normalized) spectra of archeological material from Ząbie 10 site.

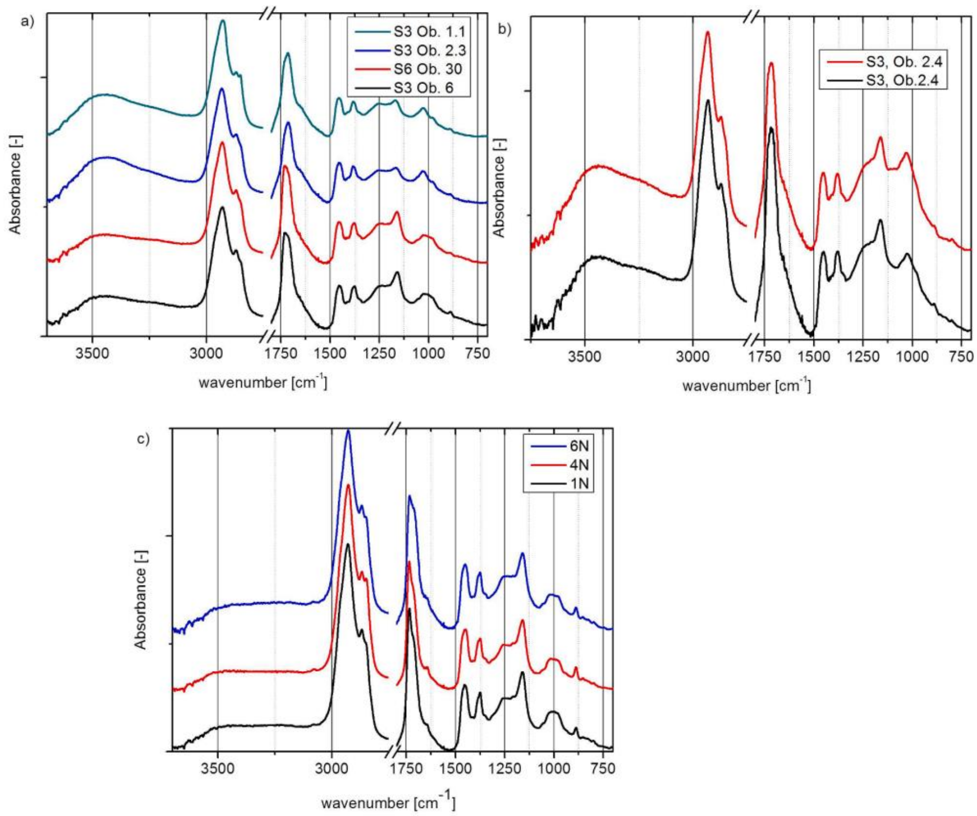

Fig. 9. Representative FTIR (ATR corrected, normalized) spectra of archeological material from a) Supraśl 3 (Obs. 1.1; 2.3. and 6) and Supraśl 6 (Ob. 30) b) Supraśl 3 (Ob. 2.4) and c) Niedźwiedziówka 1N, 4N and 6N sites.

Table 1
Late Neolithic (3rd millennium) amber ornaments from north-eastern Poland.

No.	Location/site	Context	Type of ornament	Availability	Reference
1	Site 3 in Supraśl, Białystok District	ritual feature (Bell Beaker culture?)	a cylindrical bead (6), a pendant (1), a round button-shaped with a V-shaped opening (1)	Podlachian Museum in Białystok	Wawrusiewicz et al. 2015
2	Site 6 in Supraśl, Białystok District	ritual features (Bell Beaker culture	a pendant (1)	Podlachian Museum in Białystok	Wawrusiewicz et al. 2015 Manasterski et al. 2020
3	Site 10 in Ząbie, Olsztyn District	grave (Bell Beaker culture?)	round buttons-shaped with a V-shaped opening (3), square and rectangular buttons-shaped with a 'V' and 'W'-shapedopening (45), broken (and repaired) rectangular buttons-shaped with a 'V'-shaped opening (2),	Faculty of Archeology, University of Warsaw	Manasterski et al. 2021
4	Brodowo, Grajewo District	grave (Globural Amphora culture)	small fragments of a trapezoid pendant (1?)	Podlachian Museum in Białystok	Jaskanis 1971
5	Bałdy, Olsztyn District	grave (Globural Amphora culture)	a disc	It was lost during the Second World War	Klebs 1882
6	Domkowo, Ostróda District	find in peat (found in peat-bog)	a disc (2)	They were lost during the Second World War	Klebs 1882
7	Łodwigowo, Ostróda District	find in peat (found in peat-bog)	a trapezoid pendant (1)	It was lost during the Second World War	Kunkel 1931
8	Małszewko, Szczytno District	grave (Globural Amphora culture)	fragments of few round buttons-shaped with a V-shaped opening	They were lost during the Second World War	La Baume 1943
9	Naprom, Ostróda District	grave (Globural Amphora culture)	fragments of round button-shaped with a V-shaped opening (1) and tubular beads (7)	They were lost during the Second World War	La Baume and Jaensch 1941
10	Rańsk, Szczytno District	grave (Globural Amphora culture)	round button-shaped (4), tubular beads (few), a disc	They were lost during the Second World War	La Baume 1943
11	Sąklity, Mrągowo District	find in peat (found in peat-bog)	a trapezoid pendant (3)	They were lost during the Second World War	Klebs 1882
12	Szczepankowo, Szczytno District	grave (Globural Amphora culture)	tubular beads (few), a trapezoid pendant (1), a button-shaped with a V-shaped opening (1)	They were lost during the Second World War	La Baume 1943
13	Szczytno, Szczytno District	grave (Globural Amphora culture)	a tubular bead (6)	They were lost during the Second World War	La Baume 1943
14	Trelkowo, Olsztyn District	grave (Globural Amphora culture)	fragments of few tubular beads	They were lost during the Second World War	La Baume 1943
15	Wierzbowo, Nidzica District	grave (Globural Amphora culture)	a tubular bead (31), an axe-shaped (6), ornaments shaped as tetragonal with frontal openings (1), a disc (1), a separator (1)	They were lost during the Second World War	Kniess 1938

Table 2
Archeological samples of resinous material subjected to FTIR analysis and their labeling.

Sample No.	Site	Object label	IAA repository No.
	Ząbie 10		
1		Z1	25445
2		Z5	25446
3		Z11	25447
4		Z12	25448
5		Z13	25449
		Z13a	25449a
6		Z17	25450
7		Z24	25451
		Z24a	25451a
8		Z27	25452
	Supraśl 3		
9		S3, Ob. 2.4	28118
			28118a
10		S3, Ob.6	28110
11		S3, Ob.2.1	28111
12		S3, Ob.2.2	28112
13		S3, Ob.2.3	28113
14		S3, Ob.1.1	28114
15		S3, Ob. 1.2	28115
16		S3, Ob. 5	28116
	Supraśl 6		
17		S6, Ob. 30	28117
	Niedźwiedziówka		
18		N1	25438
19		N2	25439
20		N3	25440
21		N4	25441
22		N5	25442
23		N6	25443
24		N7	25444

Table 3
Main bands in FTIR (ATR) spectra 1800–700 cm^{-1} for resinous material from Supraśl 3 (S3) and Supraśl 6 (S6).

Sample No.	Band assignment and position [cm^{-1}] $\nu C=O$	δ_{as} $-CH_3$, δ_{sym} $-CH_2$-, δ_{sym} $-CH_3$	νC-O, νC-OH, Baltic shoulder shape	νC-OH	$\gamma RHC=CH_2$	$\gamma R_2C=CH_2$
S3, Ob. 2.4	1719 1712	1450 1379	~1226 1163 negative slope	1027	–	889 (trace)
	1717 1712	1455 1379	~1230 1162 negative slope	1028	–	–
S3, Ob.6	1732	1455 1379	~1256 1159 almost horizontal	1020	–	890 (trace)
S3, Ob.2.2	1732 1727	1455 1377	~1250 1160 almost horizontal	1027	–	889 (trace)
S3, Ob. 5	1734 1726 1719	1455 1377	~1251 1158 almost horizontal	1025	–	–
S6, Ob. 30	1732 1727 1720	1455 1377	~1250 1160 almost horizontal	1027	–	890 (trace)
S3, Ob.2.1	1715	1456 1382	~1255 1166 almost horizontal	1027	982	–
S3, Ob.2.3	1712	1455 1383	~1255 1165 distorted	1031	981 (trace)	888 (trace)
S3, Ob.1.1	1716	1456 1383	~1255 1165 slightly distorted	1029	983 trace	889 (trace)
S3, Ob. 1.2	1716	1455 1382	~1254 1165 almost horizontal	1027	980 (trace)	–

Table 4
Main bands in FTIR (ATR) spectra 1800–700 cm^{-1} for resinous material - succinite from Niedźwiedziówka.

Sample No.	Band assignment and position [cm^{-1}] $\nu C=O$	$\nu C=C$	δ_{as} $-CH_3$, δ_{sym} $-CH_2$-, δ_{sym} $-CH_3$	νC-O, νC-OH, Baltic shoulder shape	νC-OH	$\gamma RHC=CH_2$	$\gamma R_2C=CH_2$
N1	1733	1644 (trace)	1455 1375	~1258 1159 almost horizontal	1000	–	889
N2	1733	1644 (trace)	1450 1376	~1256 1160 almost horizontal	1023	984	888
N3	1733	–	1450 1376	~1256 1159 almost horizontal	1027	982	889
N4	1736	1644 (trace)	1455 1374	~1256 1159 almost horizontal	1016	987	888
N5	1734	1644 (trace)	1455 1375	~1256 1161 almost horizontal	1023	982	889
N6	1733	1644 (trace)	1451 1375	~1252 1159 almost horizontal	1021	981	888
N7	1733	–	1455 1376	~1251 1160 almost horizontal	1031	985	888