RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

Typological and production-technological study of selected finds decorated with the mosaic enamel technique in the 2nd–3rd century AD

Typologická a výrobně-technologická studie vybraných nálezů zdobených technikou mozaikového smaltu ve 2.–3. století n. l.

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The article focuses on a specific group of Roman Period finds from Bohemia with mosaic or millefiori enamel decorations. The study examines various artefacts, including disc fibulae, balteus fittings, glass beads, and a seal box, all identified as Roman-provincial imports. Disc fibulae adorned with millefiori enamel have been discovered throughout the Barbaricum, with notable concentrations in the Tisza and Elbe river regions. Although Roman-provincial circular balteus fittings are less common, recent discoveries in Bohemia have expanded their known distribution. Both fibulae and balteus fittings predominantly date to the period surrounding the Marcomannic Wars and the first half of the 3rd century AD. Glass beads are typical grave goods in women's burials from the Late Roman Period. Mosaic glass beads, though less common, are primarily found in rich female graves dating to the 3rd century AD. A central aim of this study is to investigate and compare the production technologies employed in creating millefiori enamels. To achieve this, analytical methods such as micro-XRF, SEM/EDS, and LA-ICP-MS were utilised to determine the composition of the glass and metal substrates. Additionally, the design of selected glass beads was examined using computed micro-tomography (micro-CT) scanning.

Roman period – millefiori decoration – enamel decoration – fibulae – beads – archaeometric analyses

Tento text se zabývá specifickou skupinou nálezů z Čech s výzdobou mozaikového/millefiori emailu nebo skla, které pocházejí z doby římské. Pro účely našeho výzkumu byla vybrána skupina nálezů sestávající z destičkovitých spon, kování římského opasku (balteu), skleněných korálků a jedné pečetní schránky. Všechny patří do široké skupiny římsko-provinciálního importu. Destičkovité spony zdobené millefiori emailem se sice objevují v celé oblasti barbarika, nicméně koncentrují se v Polabí a Potisí. Kruhová kování balteu jsou podstatně vzácnějším artefaktem, přesto v Čechách evidujeme několik nových nálezů. Jak tyto spony, tak i kování balteu se objevují především v období tzv. markomanských válek a v 1. polovině 3. století. Skleněné korálky pak představují typické nálezy v ženských hrobech mladší doby římské. Mozaikové korálky však patří k méně početné skupině skleněných korálků a objevují se obvykle v bohatých ženských hrobech 3. století. Jeden z hlavních cílů této studie je průzkum technologií použitých při výrobě millefiori emailu. Analytické metody micro-XRF, SEM/EDS a LA-ICP-MS byly použity pro stanovení složení skla a kovového podkladu. Konstrukce vybraných skleněných korálků byla prozkoumána počítačovou mikrotomografií (micro-CT).

doba římská – výzdoba millefiori – emailová výzdoba – spony – korálky – archeometrické analýzy

Introduction

Thanks to surface prospecting with the use of metal detectors, there has been a significant increase in recent years in metal finds, which were considered quite exceptional in previous

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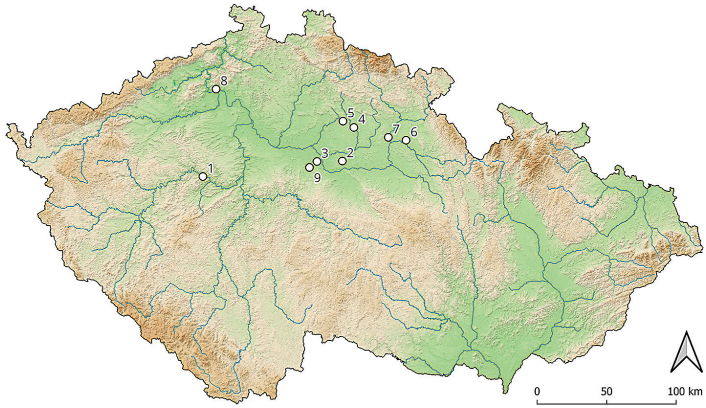

Fig. 1. Map of selected artefacts presented in the article 1 – Stradonice; 2 – Lipec; 3 – Sokoleč; 4 – Chotělice; 5 – Češov; 6 – Jeníkovice; 7 – Plotiště nad Labem; 8 – Litoměřice; 9–11 – Plaňany.

decades. A typical example are artefacts imported from the Roman Empire. In this article, we focus on a specific group of finds with mosaic and millefiori enamel decoration. The term 'enamel' refers to frit, i.e. crushed glass powder coloured with the appropriate metal oxides, which is firmly fused to a metal substrate under high temperatures (*Urbanová 2015*, 21–23). In the case of artefacts with millefiori/mosaic enamel, this is a pit enamel technique, where small blocks of glass were placed on a metal base (often supplemented with a fine coloured frit with a lower melting point); the enamel fused to the substrate under high temperatures (750–800°C). The surface was then levelled and polished. The earliest finds produced by the glass mosaic technique appear already in ancient Egypt, from the second half of the 2nd millennium BC; however, the real heyday of the mosaic technique came in the Hellenistic period. The most important workshops were to have been located in Ptolemaic Egypt (*Price 2002*, 112). For simpler patterns of mosaic glass, various combinations of coloured segments were used, either for the creation of glass vessels or for polychrome decoration on a metal base. For the more complex millefiori technique, several pre-prepared glass rods had to be joined together. This bundle of rods was then carefully heated and pulled to reach lengths of up to several metres. The coloured rod could then be cut into smaller segments that looked like a stylised flower or spiral in section (*Antonaras 2012*, 19).

Finds of mosaic glass are uncommon in the territory of the Barbaricum. Fragments of mosaic and millefiori vessels from the Stradonice and Staré Hradisko oppida can be dated from the 2nd century to the beginning of the 1st century BC and are associated with the Canosa and Antikythera-Delos groups (*Venclová et al. 2015*, 223). In the 1st century BC, mosaic glasses were widespread in Italy, where workshops for their production were also to have been located (*Price 2002*, 114). In the Roman Period, we also come across small finds made with this technique, including a set of game pieces from rich inhumation grave no. 1 at Emersleben (*Becker et al. 2006*, 49, Taf. 128: 3). Another peculiar application of the millefiori enamel technique is found on metal pyxides from Roman-provincial territory, especially in the western provinces (Gaul and the Rhineland), where their production can also be assumed. The mosaic enamel technique is used mainly on small functional objects such as fibulae and the fittings of belts and a horse harness dated to the 2nd–3rd century AD (*Thierry 1962*, 67). However, mosaic/millefiori glass was also widely used in the production of beads.

For the purposes of this study, diverse groups of artefacts were selected primarily for investigating and comparing the employed production technologies (*Fig. 1*; *Fig. 2*; *Online Supplementary Material 1*). To this end, the micro-XRF, SEM/EDS and LA-ICP-MS analytical methods were utilised to help determine the composition of the glass and metal substrate and to characterise the millefiori technique in greater detail. The design of the selected glass beads was investigated using computed micro-tomography scanning (micro-CT); for more details of analytical methods, see *Online Supplementary Material 2*.

Materials

Seal box

The 'Stradonice' collection at the National Museum in Prague includes a lid from a seal box (no. 1). Relatively simple U-shaped boxes are typical for the Republican Period, whereas square boxes are less common. The majority of cases involve bone boxes, while a small number of bronze boxes are also known (these occur in greater numbers in the Augustan Age). These finds could be Roman-provincial imports from the 1st century BC, but local imitations are another possibility (*Kysela 2020*, 183).

Based on finds from Augusta Raurica, the first seal boxes with enamel decoration can be dated to the end of the 1st century AD, with the greatest boom in the 2nd century AD. The production and use of Roman enamel boxes ends roughly at the end of the 3rd century AD (*Bateson 1981*, 50; *Derks – Roymans 2002*, 92; *Furger et al. 2009*, 49). Finds of seal boxes come from civilian settlements, but urban sites predominate greatly over rural settlements. Perhaps the largest concentration of seal box finds comes from the area of the Limes (*Derks – Roymans 2002*, 93).

The find of the seal box lid from Stradonice (*Fig. 2*: 1) can be identified as a 'Blattförmige Siegelkapseln 2b' type after *Furger et al. 2009*, or as Group 1 after *Bateson* (*1981*), which is one of the most widespread types in the provincial environment. Boxes of this type have an elongated pear shape, the edge of the lid is slightly convex and the shorter edge has one eyelet for the hinge used to fasten the lid to the box itself. The closest parallels to the find from Stradonice are three seal boxes from Augst (*Furger et al. 2009*, Abb. 29: 4–5, Taf. 4: 28–30). Boxes of the 'Blattförmige Siegelkapseln 2b' type are most widespread in the Danube and Rhineland regions and also appear in Britain and parts of Gaul (see *Furger et al. 2009*, Abb. 33). Our lid is characterised not only by richer polychromy, but also by a gilded surface (see *Fig. 8*). This type of artefact represents an exceptional decorative technique to which there are no parallels in the large assemblage of seal boxes from Augst. However, we can mention the golden lid of a seal box from Carnuntum (*Humer 2009*, 170).

While the find of the seal box from Stradonice is certainly a remarkable representative of Roman-provincial products, it is necessary to take into account the unclear circumstances of its discovery. The first illustration of this artefact dates back to the early 20th century (*Píč 1903*, 48–49, Tab. XIII: 33). The assemblage of artefacts from Stradonice comes from several private collections, the creation of which was quite chaotic, and the assemblage contains evidence of both fakes and artefacts originally acquired outside the territory of Bohemia. Finally, *J. L. Píč* himself (*1903*, 48) states that the find of the 'enamel plate'

Fig. 2. 1 – Seal box, Stradonice, Beroun district; 2 – Exner III 30 disc fibula, Lipec; 3 – Exner III 30 disc fibula, Sokoleč, Kolín district; 4 – Exner III 22 disc fibula, Chotělice, Hradec Králové district; 5 – Exner III 48/51 circular fibula, Češov, Jičín district; 6 – Balteus fitting, Jeníkovice, Hradec Králové district; 7 – Balteus fitting, Plotiště nad Labem, Hradec Králové district; 8 – Balteus fitting, Litoměřice, Litoměřice district.

comes from the old collection of the National Museum, where it was labelled as the Podmokly find. He also states that the find comes from the private collection of Professor Wydra, which was to have contained artefacts from the Stradonice hillfort (i.e. it also contained artefacts from other sites!). Given these circumstances and the uncertain provenance of some finds, it is advisable to view the collection from Stradonice with a dose of caution, and we can assume a completely different origin for selected artefacts. All of this also applies in the case of the seal box presented here. For the time being, finds of other Roman seal boxes are missing from the territory of Bohemia; moreover, in the area of the Stradonice oppidum, finds from the Roman Period form only a small and poorly identified group.

Exner III 30 disc fibulae

The first variant of Roman-provincial fibulae with millefiori decoration discussed here consists of a circular plate, the face of which is not structured in any way and is only framed by a low perimeter border. The entire decorative surface is filled with millefiori glass set in a chequerboard pattern. Although the fastening mechanism can be either hinged or with a coil spring, most of the imported artefacts in the Barbaricum are documented with a spring. For the first time, we present two examples of fibulae from Lipec (no. 2) and Sokoleč (no. 3) (*Fig. 2*: 2 and *Fig. 2*: 3). These rank alongside five previously published finds of this type in Bohemia, which were summarised not long ago by *E. Droberjar* (*2016*, 503, 506). While the fibula from Lužice near Chomutov probably also comes from a settlement context, the circumstances of the find from Plzeň-Valcha, which has not yet been described in the literature, are still unknown. The fibulae from Lipec and Sokoleč can be classified among unstratified finds from topsoil in the area of multicultural settlements, just like the fibula from Nová Ves I near Kolín. That is why – especially in the context of other evidence of these fibulae abroad – the find from children's grave 207 in Opočno near Louny, where a pair of these fibulae was found, is valuable (*Pleinerová 1995*, 29, 86, Taf. 37: 1–2, 73).

These fibulae can be classified as the Exner III 30 type (*Exner 1941*, 107–108, Taf. 14: 6), or also the Thomas 'c' (*Thomas 1966*, 132–134), Böhme 41z (*Böhme 1972*, 38, Taf. 26: 1007–1015), Ettlinger 45.5 (*Ettlinger 1973*, 123), Jobst 27c (*Jobst 1975*, 109, Taf. 45: 307), Riha 7.14.4 (*Riha 1979*, 189–191, Taf. 61–62; *Riha 1994*, 161–162, Taf. 42), or as the Grumeza IA (*Grumeza 2015*, 192) or Vaday III/1/1/3 (*Vaday 2003*, 326, Fig. 5). The rich citation apparatus documents the wide spread of this type of fibula, which is found practically throughout the Rhineland and the Danube Region, usually also on the Limes, and is therefore not exceptional even in the Barbaricum. A number of researchers believe they were produced in Gaul (summarised by *Vaday 2003*, 326). Compared to other enamelled fibulae, these fibulae are assigned a relatively later date, usually as late as the first half of the 3rd century (*Exner 1941*, 107–108; *Böhme 1972*, 37; *Ettlinger 1973*, 123; *Jobst 1975*, 109; *Vaday 2003*, 326; *Mączyńska – Urbaniak 2006*, 133–134).

An inventory of Exner III 30-type fibulae was carried out in the Barbaricum in the 1960s by Sigrid Thomas; at that time, it consisted of 13 finds concentrated in the Elbe river region. While it is certainly understandable that after nearly 60 years we can expand this list somewhat (see *Online Supplementary material 3*; *Fig. 3*), it seems that the trend of concentration of these fibulae in the Elbe river region remains unchanged. However, we cannot ignore the fact that 10 of these fibulae are recorded in the Tisza river region occupied by the Sarmatians (*Vaday 2003*, 326, Fig. 5), which is another reason their minimal representation in the Middle Danube Region, i.e. in Lower Austria, Moravia and Slovakia, is striking. Poland is also represented by only a single grave find from Kowalewko in Greater Poland.

A more detailed analysis of the sources reveals one remarkable connection. Although well-documented grave finds involving Exner III 30-type fibulae are scarce in the Barbaricum, they point to one recurring phenomenon. In several cases of grave finds, these fibulae were found in pairs: grave 157 from Očkov (which, however, was not fully published; see *Kolník 1965*, 187, Fig. 3: 8, 4: 3), grave 230 from Kowalewko in Greater Poland (*Skorupka 2001*, 67, Tabl. 70: 230/1–2) and grave 207 from Opočno near Louny (*Pleine-*

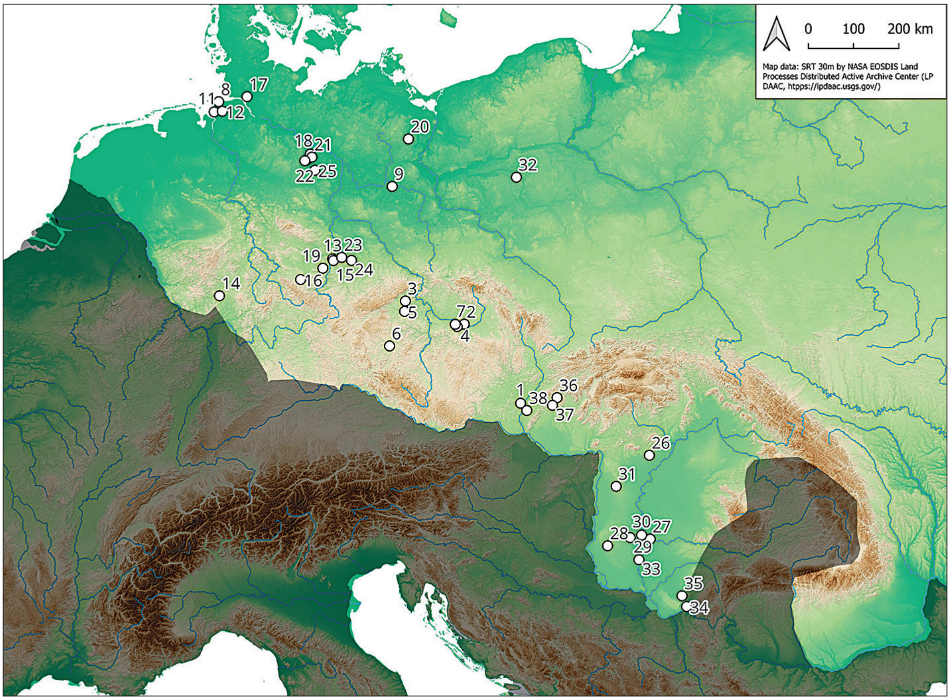

Fig. 3. Map of Exner III 30 disc fibulae in the Central European Barbaricum. 1 – Bernhardstahl; 2 – Lipec; 3 – Lužice; 4 – Nová Ves I; 5 – Opočno; 6 – Plzeň-Valcha; 7 – Sokoleč; 8 – Altenwalde; 9 – Berlin-Mariendorf; 10 – Cheine; 11 – Feddersen Wierde; 12 – Flögeln; 13 – Freyburg; 14 – Gießen; 15 – Großjena; 16 – Haarhausen; 17 – Hodorf; 18 – Lüchow; 19 – Mattstedt; 20 – Potzlow; 21 – Rebenstorf; 22 – Rockenthin; 23 – Schkortleben; 24 – Wiederau; 25 – Zethlingen; 26 – Füzesabony; 27 – Kiszombor; 28 – Madaras; 29 – Mórahalom; 30 – Szeged-Tápé; 31 – Pusztavacs; 32 – Kowalewko; 33 – Ada; 34 – Bela Crkva; 35 – Vršac; 36 – Beckov; 37 – Očkov; 38 – Závod.

rová 1995, 29, 86, Taf. 37: 1–2, 73). In the case of older finds from often destroyed cemeteries, multiple fibulae of this type sometimes occur; however, it is no longer possible to say whether they were originally part of the same grave, e.g. Cheine in Saxony-Anhalt (*Becker et al. 2006*, 71, Taf. 98: 6–7, 11). Also noteworthy is the association of a trio of plate fibulae in grave 874 at the Zethlingen site in Saxony-Anhalt, where one of the fibulae is represented by the Exner III 30 type, while the other two are Germanic plate fibulae in the shape of a boar (*Leineweber 2021*, 65, Taf. 108: 1). As such, the context of the same fasteners, or at least fasteners of a similar type, in a single grave is repeated here. It is the popularity of domestic plate fibulae in the Elbe river cultural circle that may explain the popularity of their Roman-provincial counterparts. These fibulae are commonly said to have been worn by women in a provincial environment (*Böhme 1972*, 37; *Vaday 2003*, 326, 375–377), and it is worth noting that barbarian plate fibulae are also typical for female graves (e.g. *Meyer 1969*, 48). In the Central European Barbaricum, a pair of clasps are recorded in two children's graves, the gender of which could not be specified: Opočno near Louny and Kowalewko. Conversely, in grave 425 from the Sarmatian cemetery in Madaras, this fibula was deposited with a young girl (*Vaday 2003*, 398).

Exner III 22 disc fibula

This plate fibula variant is also a circular fastener. However, its face is divided by a partition into a central circular field and an outer orbital field (*Exner 1941*, 102–103, Taf. 13: 2–3). This fibula differs from the Exner III 23 or 26 types by a lower number of concentric circular fields and also by the absence of a central circular projection (button). Not all examples of this variant are filled by the millefiori technique like the find from Chotělice (no. 4) published here (*Fig. 2*: 4). Alternatively, this type can also be designated as the Böhme 41y (*Böhme 1972*, 38, Taf. 26: 998–1004), Ettlinger 45.3 (*Ettlinger 1973*, 122), Riha 7.13 (*Riha 1979*, 188–189, Taf. 61: 1607; *Riha 1994*, 161, Taf. 42), or Vaday III/1/1/1/1 type (*Vaday 2003*, 324, Fig. 4). It also belongs to the broadly conceived type 'a' after Thomas, which includes all circular fibulae with a concentrically articulated face, regardless of whether they have a central button or protrusions along the edge (*Thomas 1966*, 126–130).

The problem of finding more precise analogies to the fibula from Chotělice lies in the generally considerable diversity of circular plate fibulae, where different specimens may contain features of several types, regardless of any typological system. However, it is certain that the artefact from Chotělice did not have a central button, which is widespread in many types of circular Roman-provincial fibulae. Other aspects that complicate a more accurate typological classification of these fibulae are the damage caused by the heat of cremation in the case of finds from cremation graves, or the poorly rendered illustration of these fibulae, as is commonly encountered in older literature. A few finds can be cited that resemble the Chotělice specimen in at least certain features: a fibula from Gießen in Hesse, although it has lost its enamel (*von Uslar 1938*, 197, Taf. 22: 50, 24: 15; *Thomas 1966*, 158); Körner in Thuringia, reputedly from an inhumation grave (*von Uslar 1938*, 210, Taf. 22: 52; *Thomas 1966*, 162); and finally, these could include a disc fibula with a concentrically articulated plate with lost enamel inlays from Hodorf in Schleswig-Holstein (*Thomas 1966*, 161). S. Thomas describes two relatively similar fibulae with millefiori from the Latvian sites of Gailiši and Piltene (*Thomas 1966*, 126, 158, 167). In the Sarmatian territory of the Tisza river region, similar fibulae are recorded from the Tápiószele and Adács sites, both from female graves. A close parallel from Lower Austria is represented by a surface find from Ringelsdorf (*Adler 1994*, 583, Abb. 884). Plate fibulae of this type are apparently not as widespread in the Danube river region as in the Rhineland (*Exner 1941*, 103; *Feugère 1985*, 368–370; *Riha 1994*, 161), which probably also had an effect on their weaker representation in the territory of Poland (*Mączyńska – Urbaniak 2006*). We can date these fibulae, like other related variants, from the second half of the 2nd century to the first half of the 3rd century (*Thomas 1966*, 127–130; *Feugère 1985*, 371; *Riha 1994*, 161).

Exner III 48/51 open-work circular plate fibula

The fourth example presented here of a plate fibula decorated using the millefiori technique is an incomplete fibula from Češov (no. 5; *Fig. 2*: 5). This artefact combines the features of the Exner III 48 and 51 types; multiple narrow spokes, which originally converged into the central wheel (wheel hub), are characteristic of the Exner III 48 type. The placement of the spokes indicates that there were originally six. As this part of the fibula is unfortunately broken off, the form of the central hub is unknown (i.e. flat or with a button). The Exner III 51 type is suggested by 12 small lobe-like projections on the perimeter (*Exner*

1941, 112–113, Taf. 16: 4, 7).[1] The catch mechanism of the needle of the Češov fibula is a hinge, which is common for other examples of these fibulae presented by K. Exner.

Open-work fibulae are usually called fibulae in the shape of spoked wheels (Radfibeln) and can be classified according to a number of typological systems: Böhme 42e (*Böhme 1972*, 39, Taf. 27: 1040–1041), Ettlinger 40.2 (*Ettlinger 1973*, 112, Taf. 12: 15–16), Jobst 28 (*Jobst 1975*, 112, Taf. 45: 314–316), Feugère 28a (*Feugère 1985*, 372–377, Pl. 156: 1957–1959), Rey-Vodoz 7.26 (*Rey-Vodoz 1986*, 168, Pl. 13: 210), Riha 7.25 (*Riha 1994*, 173, Taf. 46: 2925), or Vaday III/8/3/2 (*Vaday 2003*, 354, Fig. 19). S. Thomas also refers to them as type 'e' (*Thomas 1966*, 137–139).

Although an exact analogy to the Czech fibula is difficult to find, a certain analogy from Poland is a fibula from Słopanowo in the Łódź Voivodeship, though it is a four-spoke wheel type (*Mączyńska – Urbaniak 2006*, 153, Ryc. 3: 6). Similarly, it is possible to name three fibulae of the Vaday III/8/3/2 type from the Tisza river region (*Vaday 2003*, Fig. 19). A fibula from Farsleben in Saxony-Anhalt is interesting for a different reason: the plate fibula with millefiori decoration on the surface of the circular frame was found in a 5th-century female inhumation grave. This fibula was secondarily modified by breaking out the middle section with spokes for use as a buckle (*Thomas 1966*, 156). Although it is not a type that would be close to the find from Češov (in addition, it is a representative of relatively large fibulae), it nevertheless proves that these fibulae were so aesthetically interesting even in the following centuries that they could also be used for secondary purposes. These fibulae are traditionally dated to the 2nd or early 3rd century AD (e.g. *Thomas 1966*, 139; *Böhme 1972*, 39).

Balteus fittings

Roman fittings for military belts (baltei) are not very common finds in Bohemia (*Musil 1994*, 5, Abb. 3: 1–2). These can be divided into two basic groups. The first category is composed of circular fittings in a wide range of profiles without enamel, the second of enamelled circular fittings. Far more finds of artefacts from the first group have been made (*Oldenstein 1976*, Taf. 84–86). For many years, the only evidence in Bohemia of fittings of Roman baltei with preserved enamel was the artefact from grave 772 in Plotiště nad Labem (no. 7; *Fig. 2*: 7) (*Rybová 1979*, 371, Fig. 37: 2; *Rybová 1980*, 147, Fig. 14; *Jílek – Horník 2017*, 67, Fig. 4: 8, 13: 6).

The review of older finds carried out for the purpose of creating this article uncovered another balteus fitting in the collections of the National Museum. It is a fragment of a circular fitting with millefiori glass from Litoměřice (no. 8) (*Fig. 2*: 8) which had previously been published numerous times as a fibula (*Preidel 1930*, 75, Abb. 82; *Svoboda 1948*, Taf. 7: 3; *Sakař 1970*, 32; *Droberjar 2016*, Abb. 6: 12); however, traces of a catch or a cross-piece for the axis of the winding are missing from the back side. In contrast, there is a fragment of a cast rivet, which, in terms of construction, makes this the same type of fitting as the artefact from Plotiště nad Labem. A more distant parallel is found at the Szwajcaria

[1] However, lobe-shaped or semicircular protrusions in various numbers on the edge of the fibulae are a feature that also appears on other types of circular plate fibulae, e.g. those without open-work or tutulus-like fibulae (see *Exner 1941*).

cemetery in Poland. This fitting was also initially misinterpreted as a fibula (*Thomas 1966*, 171, Taf. 9: 1; cf. with *Nowakowski 2001*, 109, Taf. IV: 5).

In 2022, another artefact from Jeníkovice (no. 6) in east Bohemia was added to these two fittings (*Fig. 2*: 6). The circular plate from thick sheet metal is divided by partitions into four segments. The first two rings are filled with millefiori glass. Visible on the reverse is a massive rivet running through the middle of the plate. All three fittings have the same construction. The fittings consist of a circular plate with a border and concentric circles filled with millefiori glass. In the middle of the fitting is a hole with a fastening rivet. The fittings differ from each other in the number of concentric circles, the colour of the glass and the smaller decoration placed inside the glass bands. Another common feature is plant and chequerboard motifs. These are common in fittings of a military nature, as is the alternation of two glass colours (*Benea 2016*, 782, 785, Abb. 6). Fairly close parallels to the Jeníkovice fitting are found in Dacia–specifically in the Tibiscum camp (*Benea 2016*, Fig. 5: 21), where even the production of bronze objects and enamel is documented from the middle of the 2nd to the 4th century. As such, Dacia can be considered as one of the possible production centres. Exceptionally well-preserved pieces of discoid belt ornaments, the decorative composition of which is very similar to our finds, also come from Mušov-Burgstall – the central location of the Roman army from the period of the Marcomannic Wars (*Hložek et al. 2015*, 39–41, Fig. 8–11).

Starting in the 1st century, baltei were used exclusively by officers in the Roman army alongside the more common waist belt to carry swords (*Przybyła 2010*, 93). The broader spread of wide baltei occurred in response to changes in Roman army gear in the second half of the 2nd century, when shorter gladii were gradually replaced by longer spathae. The longer and heavier weapon required a different carrying method (*Bemmann – Hahne 1994*, 407). Balteus fittings from the Roman fort of Niederbieber prove that they were used in the Roman military environment from the end of the 2nd century and during the 3rd century (*Oldenstein 1976*, 230). Roman balteus fittings appear in the Elbe-Germanic cultural sphere primarily at the turn of the 3rd century (*Oldenstein 1976*, 230; *Przybyła 2010*, 94, 96, note 4, Abb. 2). In the northern and eastern parts of the Barbaricum, these fittings spread later during the 3rd century (*Kaczanowski 1992*, 179–180).

Beads

For the purpose of research, three mosaic glass beads, part of one of two necklaces, were selected from a rich female inhumation grave of the Late Roman Period from Plaňany (*Beneš* in *Lutovský et al. 2023*, 671–673). The selection of beads for research was conditioned by the specific type/pattern in the mosaic glass technique. Bead no. 9 (*Fig. 4*: A–B) belongs to group XXIII and type 366d (barrel-shaped bead with coloured millefiori forming a chequerboard motif) after *Tempelmann-Mączyńska* (*1985*), or to compound glass group XIII/2 after *Gopkalo* (*2008*). Beads from this group are spread throughout the entire Barbaricum. *Gopkalo* (*2008*, 58) mentions the occurrence of this type in assemblages from the Northern Black Sea Region as early as the 1st–2nd century AD. A similar situation is also observed in the Central European Barbaricum, where they appear in rare instances in assemblages from the Early Roman Period (*Tempelmann-Mączyńska 1985*, 60). As a certain parallel, we can mention fragments of two barrel-shaped millefiori beads of blue-green translucent glass with a pattern from yellow, bright red opaque glass, which

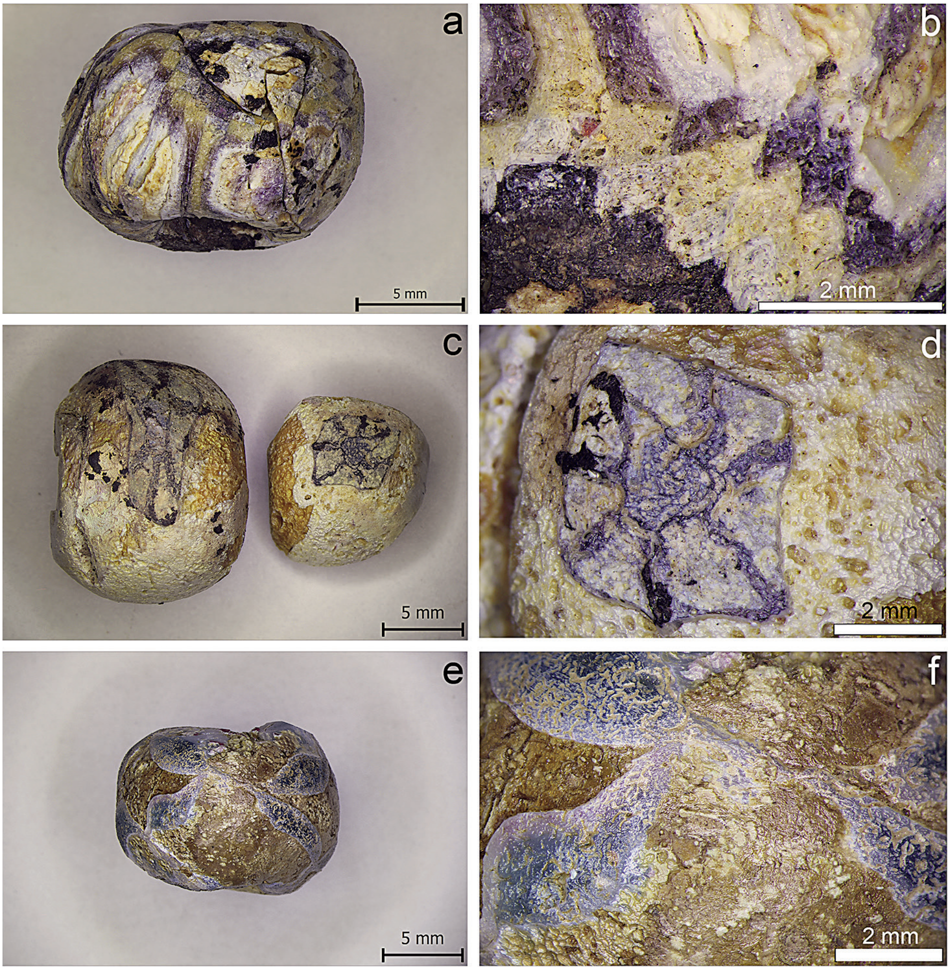

Fig. 4. Glass beads from the rich female grave in Plaňany: a–b – bead with a chequerboard motif, Plaňany no. 9; c–d – bead with simple floral motif, Plaňany no. 10; e–f – bead with floral motif, Plaňany no. 11.

come from disturbed graves in Dobřichov-Třebická. Another three beads of this type come from grave 861 from Třebusice (*Droberjar – Motyková 2023*, Tab. 258: 14–16), which can be dated on the basis of a plate fibula in the shape of a boar to the second half of the 3rd century (*Reszczyńska 2017*, 339). Multicoloured millefiori beads with an irregular chequerboard motif also come from other sites, including cremation grave 4 from Eischleben dated to the 3rd century (*Dušek et al. 2017*, 50, Taf. 91: 1).

Bead no. 10 (*Fig. 4*: C–D) can be classified in group XXIII, type 362a_h (barrel-shaped bead with a simple rosette motif). This is a relatively popular type that is also known from Bohemia. We can list seven beads of this type from the inhumation grave of Prosmyky 1 dated to the second half of the 3rd century (*Blažek 1995*, 144–145). Another bead with decoration in the form of a solitary rosette comes from disturbed graves at the Opočno cemetery (*Pleinerová 1995*, Tab. 78: 28). A bead of the same type was found in the assemblage from grave 12 at Ichstedt dated to the first half of the 3rd century (*Dušek et al. 2017*, 77, Taf. 89: 2). Based on finds from Central Europe, we can state that beads of type 362 are mainly found in graves dated to the 3rd century and their use continues until the beginning of the 4th century (*Tempelmann-Mączyńska 1985*, 59).

Due to the distinctive floral motif in the form of a four-leaf clover, bead no. 11 (*Fig. 4*: E–F) can be roughly linked to type 356b (barrel-shaped bead with a floral motif). As a parallel from our territory, we can mention the find from grave 63 in Dobřichov-Třebická, a barrel-shaped terracotta-red bead with a motif of blue-white leaves or rosettes (*Píč 1892*; *Sakař 1970*, 25–29). A bead of a similar type comes from grave 1188 in Plotiště nad Labem (*Rybová 1979*, 377–378). Two heat-deformed green glass beads with yellow-white leaf decoration come from grave 930 in the same cemetery (*Rybová 1979*, 373). Type 356 beads are already found in assemblages dated to the 2nd century (*Tempelmann-Mączyńska 1985*, 59), and their use continues in the Late Roman Period. The motif of a simple coloured rosette or leaves also appears on beads from the Migration Period, albeit with more complex ornament (*Koch 2001*, 160–163, Taf. 8).

The beads presented here are part of grave goods from a rich inhumation grave dated to the second half of the 3rd century. It is a necklace made of glass and amber beads that appears in most of the rich female inhumation graves from the Late Roman Period, with the beads even numbering up to several dozen. For example, a necklace from a rich woman's grave in Žiželice was composed of 78 amber and 282 glass beads (*Blažek 1995*, 150–152). In the previous period, these are isolated pieces. However, the occurrence of beads with millefiori/mosaic decoration in the Roman Period in the territory of Central Europe is not completely common. Within a single assemblage, their number is in the single digits.

Chemical and technological analysis

Glass

Most of the glasses we evaluated can be classified as natron glasses with a characteristically low content of MgO and K_2O (up to c. 1.5%) and a certain amount of CaO (up to c. 8%) (*Freestone 2021*; *Basso et al. 2014*, 238). The exception seems to be red glasses, for which in some cases a higher content of potassium and magnesium oxide was determined (despite 2% in baltei fittings from Litoměřice and Jeníkovice, fibulae from Sokoleč and bead no. 10 from Plaňany, if we consider 'reduced composition') as well as a higher phosphorus content (these differences are discussed in the text regarding red glasses).

The colours of translucent glasses depend on the colouring elements or ions (elements in their ionic form are integrated into the network structure of the glass matrix). The most common colourants found in ancient glass are Fe^{2+}, Fe^{3+}, Mn^{3+}, Cu^{2+} and Co^{2+} ions (*Gedzevičiūtė et al. 2009*, 19–20; *Basso et al. 2014*, 238). Without an intentionally added colourant such as copper or cobalt, the colour of the glass depends largely on the amount and oxidation state of the present iron (commonly added to the glass, e.g. in sand). The Fe^{2+} ion is responsible for the pronounced bluish colour, while the ferrous Fe^{3+} ion is responsible for the much less intense yellow. The majority of glasses contain iron in both oxidation states (Fe^{2+} and Fe^{3+}), giving rise to a range of green and bluish shades (*Freestone – Stapleton 2015*, 64). The Fe_2O_3 content is c. 0.4% in Roman glasses (for glasses of the early imperial period according to *Freestone – Stapleton 2015*, 64).

Manganese and antimony oxides (so-called decolourising agents) were intentionally added to some glasses to change the blue-green colour of glass with a predominant Fe^{2+} content to a less pronounced yellowish Fe^{3+} colour. For Roman glasses of the 1st–4th century, two basic groups are distinguished according to decolourising agents: *Roman-Sb* (glass decoloured with antimony; produced in Egypt) and glass produced in the Levant (*Roman-Mn*). We also often encounter a 'mix' of these groups, *Roman Sb-Mn*, which is the result of recycling glasses with different compositions, or by different decolourising agents. *Boschetti et al.* (*2022*, 7) lists thresholds for Mn < 250 ppm and for Sb < 30 ppm, below which both elements can be considered natural impurities of the silica source. *Schibille et al.* (*2017*, 1226–1231) specifies individual groups as follows:

(a) The *Roman-Sb* glass group is characterised by high antimony content and an MnO content of less than 0.025 wt%.

(b) Typical for *Roman-Mn* is a high content of MnO (> 0.025 wt%) and low antimony (or Sb_2O_5); below the detection limit of their analytical technique, c. 0.03 wt%.

(c) *Roman Sb-Mn* glass is characterised by these contents–MnO > 0.025 wt% and Sb_2O_5 > detection limit around 0.03 wt%.

However, for our studied assemblage, this division is rather 'unusable', because most of the glasses are opacified by particles with an antimony admixture, so it is not possible to distinguish whether antimony was introduced into the glass as a decolourisation agent or as an opacifier. The possible introduction of antimony or manganese with the colouring raw material also cannot be ruled out. However, for a smaller group of samples, it was possible to use this division as follows: two non-opacified blue glasses have contents of up to 20 ppm Sb (balteus fittings from Litoměřice and Jeníkovice, both with millefiori decoration). The *Roman-Mn* group can be assumed for these two samples. Glasses/enamels with a low MnO content (below 250 ppm) were found in the following artefacts (unless otherwise stated, this was white glass): the balteus fitting from Litoměřice (part of the flower motif), the fibula from Češov (again part of the flower), the fibula from Lipec (part of the millefiori decoration), the balteus fitting from Plotiště nad Labem (slightly higher MnO content of c. 300 ppm), bead no. 9 from Plaňany (white and yellow and green glass), bead no. 11 (white and red glass) and can therefore be classified as to antimony-decoloured glass. Even from this small list, it is evident that Roman-Sb-type glass is part of the millefiori segments and was also the raw material for the production of bead no. 9 and 11.

If coloured or opaque glass is desired (these properties are combined in the resulting colour shade), additional raw materials must be added. *Brems* and *Degryse* (*2014*) list the following elements related to the (de)colouring of ancient glass: Mn, Co, Ni, Cu, Zn, As, Ag, Sn, Sb, and Pb. Some of these elements do not influence the colour of the glass, but they occur as impurities in the mineral (de)colourants. Elevated concentrations of these (de)colourant-related elements (over 1,000 ppm) suggest that they were deliberately added to the glass batch to influence the colour of the resulting product. Concentrations between about 100 ppm and 1,000 ppm are typically interpreted as indications of glass recycling. These levels were used in evaluating glasses in this work.

Non-opacified glass

The assemblage contains a smaller amount of glass that can be assessed as non-opacified glass. These are the blue parts in the millefiori decoration of the balteus fittings from

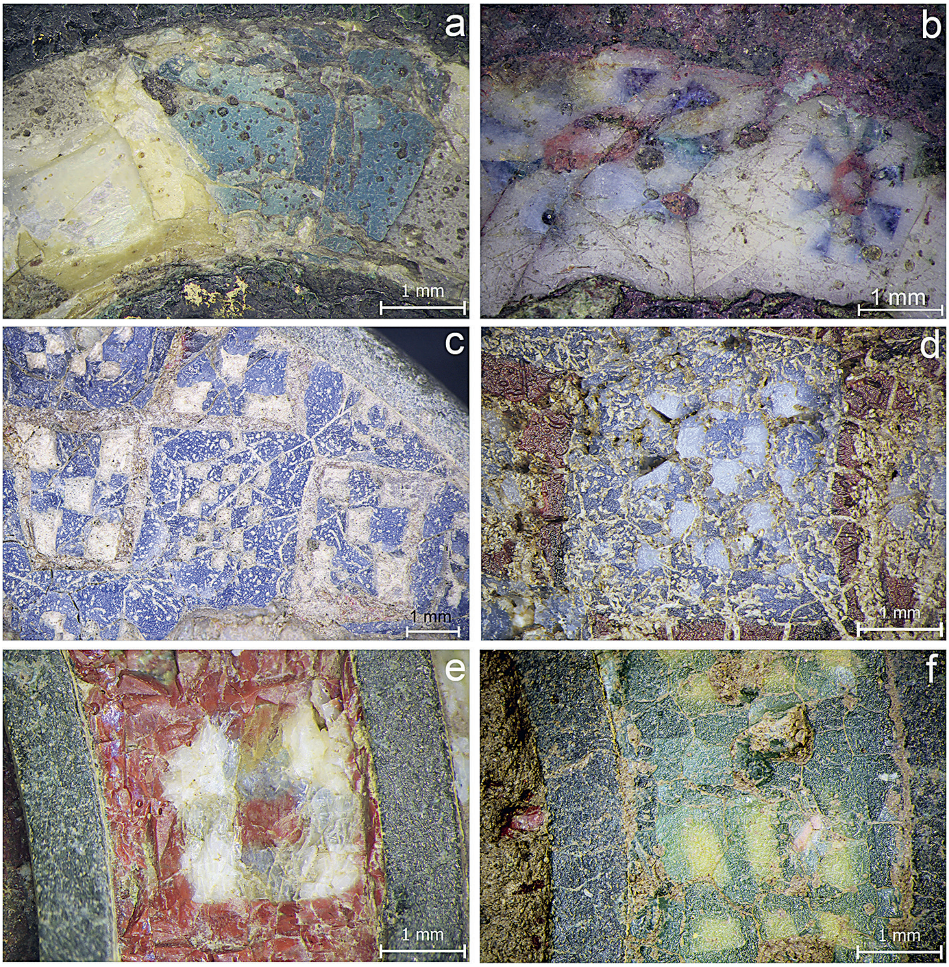

Fig. 5. Examples of the representation of coloured glass: a – detail of enamel on the lid of the seal box; b – balteus fitting from Litoměřice – detail of surface, non-opacified glass was found in the blue segments of the flower and dark discs; c – detail of fibula from Sokoleč, millefiori decoration; d – another type of millefiori decoration, fibula from Lipec; e and f – segments from decoration of balteus fitting from Jeníkovice.

Litoměřice and Jeníkovice (*Fig. 5*: B, E), the dark glass in the fitting from Litoměřice, the fibulae from Češov and bead no. 9 from Plaňany (green glass). The chemical composition table shows that the antimony content (a frequent component of opacifiers) is very low in these samples (e.g. only tens of ppm in the glasses of the artefacts from Litoměřice). However, according to the overall composition, the glasses can be classified as coloured. In the case of both of the aforementioned balteus fittings, blue-colouring copper ions (c. 900 ppm Cu) and cobalt (up to 1,398 ppm Co in sample 2) are represented. In the case of dark glass (the fitting from Litoměřice and the fibulae from Češov), the shade is influenced by the high content of Fe_2O_3 in higher percentage units compared to the aforementioned 0.4%. In the case of bead no. 9, the dark glass is influenced by a higher content of manganese (1.4%) and probably also iron.

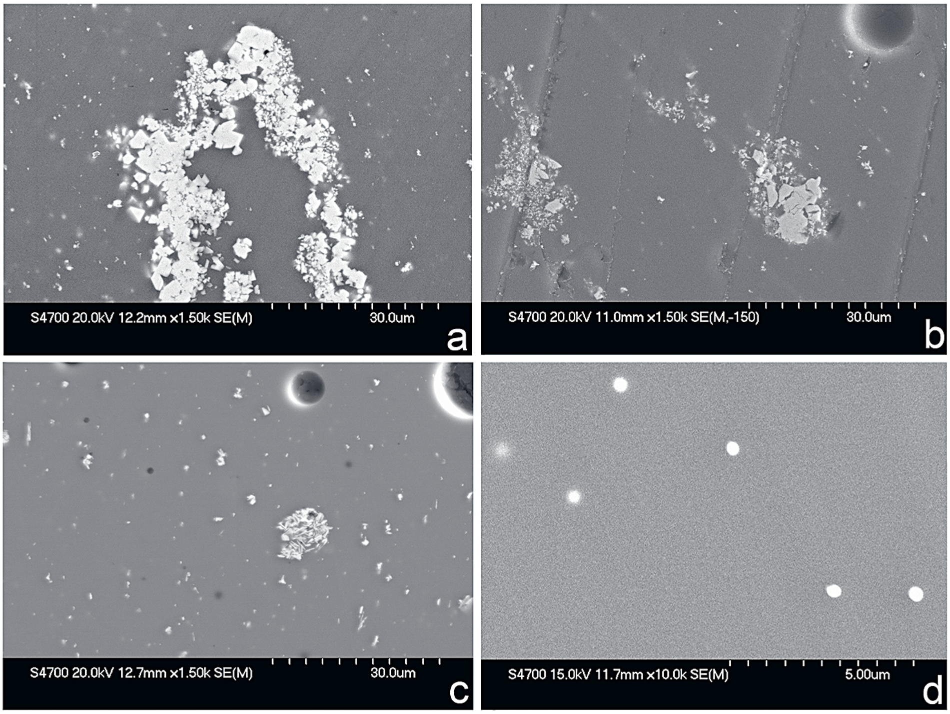

Fig. 6. Scanning electron microscopy images: a – aggregates of microcrystals containing calcium and antimony in white enamel, Lipec fibula; b – microcrystals containing tin in white enamel, seal box lid; c – microcrystals in yellow enamel, balteus fitting from Jeníkovice; d – nanoparticles of metallic Cu (probably), Lipec fibula.

Opaque white glass

Three basic groups of white glasses/enamels can be distinguished: (a) white enamel on the lid of the seal box (see *Fig. 5*: A) is completely different from the other glasses mainly represented by the opacifier (SnO_2) and a higher content of manganese and iron; (b) a group with a higher MgO content and low MnO up to 250 ppm (balteus fittings from Litoměřice and Plotiště, fibulae from Češov, Lipec, bead no. 9 and 11 from Plaňany); and (c) samples not meeting the previous criteria (balteus fitting from Jeníkovice and fibula from Chotělice).

Higher MgO contents (c. 3.3% MgO) were also described for white enamels in the work of *Henderson* (*1991*, 69–70), albeit without more specific conclusions. This clearly distinguishes the analysed glasses in the presented work, indicating different workshops or raw materials. As noted above, in our white enamels with higher MgO, a relatively low Mn content was also determined (max. 300 ppm), whereas in the other samples this is nearly 600 ppm, or even higher (even this could be a certain fingerprint). *Schibille* (*et al. 2020*, 6) also describes similar conclusions for white glass tesserae of the 4th century (from the Roman villa at Noheda, Spain). The glass tesserae contain MgO (2.76% on average) and low amounts of Al_2O_3 (1.95%) and MnO (c. 300 ppm). Based on this, the author concludes that these samples may be Roman-Sb glass (similar to ours). On the other hand, a slightly

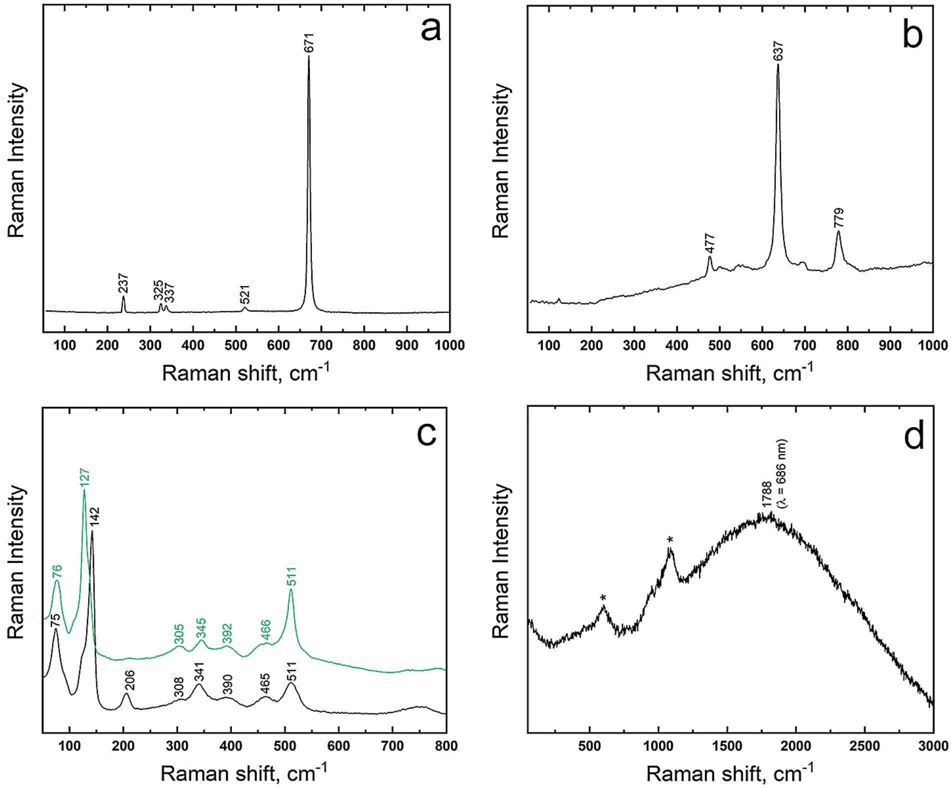

Fig. 7. Examples of Raman spectra for opacifiers contained in enamels: a – $CaSb_2O_6$, balteus fitting from Jeníkovice; b – SnO_2 phase, seal box lid; both white colours; c – $Pb_2Sb_2O_7$ (green line, green enamel); $Pb_2Sb_{2-x}Sn_xO_{7-x/2}$ (black line, yellow enamel; both balteus fittings from Jeníkovice; d – Cu° phase; red enamel, fibula from Chotělice.

higher amount of lead (tenths of a percent) was detected in samples with a lower magnesium content (e.g. the balteus fitting from Jeníkovice).

The colouring of most white glasses is caused by the presence of calcium antimonate crystals (white crystals). The Sb_2O_5 levels are mainly in the range of c. 4% up to 9% (the fitting from Jeníkovice, part of the millefiori segment, see *Fig. 5*: E). The Raman spectroscopy method confirmed the $Ca_2Sb_2O_7$ and/or $CaSb_2O_6$ phases in the white glasses (see *Fig. 7* and *Online Supplementary Materials 4*). Similar phases were also found, e.g. in the work of *Gedzevičiūtė et al.* (*2009*) on Roman millefiori glasses, and in a paper evaluating mosaic cubes from the 2nd century AD (*Basso et al. 2014*). *Gedzevičiūtė et al.* (*2009*) describe the individual phases, including the Raman bands, as follows: hexagonal $CaSb_2O_6$ is characterised by Raman bands at 234, 323, 517 and 666 cm^{-1} and orthorhombic $Ca_2Sb_2O_7$ displays characteristic Raman bands at 318, 367, 472, 624, 781 and 821 cm^{-1} (in the cited author's work, these are synthetically prepared phases). Similarly, *Basso et al.* (*2014*) states that the $CaSb_2O_6$ phase shows a strong band at 670 cm^{-1}, followed by less intense bands at 236, 323, 340, and 520 cm^{-1}. For $Ca_2Sb_2O_7$ it is then 480 and 633 cm^{-1} and less intense at 322, 370, 790 and 832 cm^{-1} (for a comparison with our samples, see *Fig. 7*: A, B). The results measured for the glasses evaluated in this work correspond well to these data. Opacifiers of the calcium antimonate type were also commonly used for other colours to dampen their hue.

A completely different opacifier was found in the white glass of the seal box lid. This was SnO_2, which is also confirmed by the tin content detected by the LA-ICP-MS method (nearly 14,000 ppm Sn compared to tens of ppm found in other white glasses). Typical Raman bands are at 474, 633 and 775 cm^{-1} according to *Gedzevičiūtė et al.* (*2009*, 27).

Opaque blue glass

The blue colouring of glasses is the subject of many works (*Gratuze et al. 2018*; *Zlámalová Cílová et al. 2021*), which also discuss the various raw materials used over the centuries. Blue opaque glass was represented on fibulae from Sokoleč, Češov, Lipec and Chotělice and baltei fittings from Jeníkovice and Plotiště. The blue colouring of these glasses is produced by cobalt (c. 850–2,000 ppm Co) and copper (c. 1,000–2,600 ppm Cu).

The contents of these colouring ions are completely different in bead no. 11 from Plaňany, namely only 39 ppm Co and a relatively high Cu content (9,851 ppm). Due to the higher content of Sn (1,179 ppm) and Zn (924 ppm) in the glass of the bead compared to mostly units of ten with other glasses (or enamels), it is possible to conclude that copper was added 'in the form of the oxide scale formed upon heating scrap bronze', or brass (e.g. after *Freestone 2021*). A difference in the white glass compared to the other white glasses/enamels in the assemblage was also found for this bead. The detected Sb content is c. 9,000 ppm, while for white enamels this value starts at c. 27,000 ppm Sb. It is obvious that the bead is different from the other glasses in the assemblage. A higher tin content (c. 1,200 ppm Sn) was also found in the blue-green enamel on the lid of the seal box. Enamel contains high amounts of copper (nearly 22,000 ppm Cu), but cobalt is again present in relatively small amounts (units of ppm).

Another difference in this assemblage appeared in the PbO content. While for non-opacified blue glasses the value of Pb was determined to be 39 ppm, for the glass of bead no. 11 from Plaňany it was 1,990 ppm, for the enamel of the lid from Stradonice c. 3,400 ppm, so for most opacified glasses the values are considerably higher (even over 20,000 ppm Pb). Even in the aforementioned mosaic cubes from Noheda, PbO was determined in the range $1.00\% < PbO < 2.13\%$ for certain blue and turquoise glasses. *Schibille* (*et al. 2020*) states that this may be due to the use of a lead-rich antimony ore, a calcination procedure that involved the use of lead to refine the antimony minerals, or simply the result of recycling processes.

As another possible criterion for classifying blue glasses (or determining raw materials), *Gratuze et al.* (*2018*, 5) mentions the CoO/NiO ratio. His work charts the use of cobalt-based dyes in glass during the first millennium AD. For Roman glass, the following range of the ratio $24 < CoO/NiO < 54$ is given, which at the end of the 4th century AD changes to lower values. A relatively consistent value of c. 26 was found for blue enamel fibulae from Sokoleč, Češov, Lipec and the balteus fitting from Plotiště. A higher value (40) was determined for the balteus fitting from Litoměřice (blue in millefiori decoration) and the range of the value was beyond the limit for bead no. 11 from Plaňany (only 2) and the fibula from Chotělice (~17).

However, the resulting colour shade of all opacified samples was affected by the presence of an opacifier based on calcium (calcium antimonates). In addition to this opacifier, the mineral romeite $(Ca,Fe,Mn,Na)_2(Sb,Ti)_2O_6(O,OH,F)$ was identified in the turquoise enamel of the lid of the seal box. *Basso et al.* (*2014*, 241) describes the occurrence of the romeite phase separately and together with calcium antimonate opacifiers.

Yellow and green glasses

Another group of evaluated glasses/enamels is in shades of yellow or green (see *Fig. 5*: F). The green colour of the glasses is certainly influenced by the Cu content (up to nearly 30,000 ppm compared to about 400 ppm for yellow glasses). A clear connection was found between the content of antimony and lead (components of opacifiers of green and yellow glasses). Some glasses also have higher tin contents (hundreds higher, up to nearly 2,000 ppm for sample 6). *Schibille* (*et al. 2020*, 12) assumes the introduction of tin with a lead raw material (for the yellow tesserae). The dependency of lead and tin was also found in yellow glasses in our assemblage and can therefore be added to this observation. However, in the case of green glasses, there is more of a connection between the content of copper and tin, so the possibility of introducing tin together with copper, e.g. in the form of a copper alloy or some slag, comes into consideration.

Both green and yellow enamels have a relatively high PbO content (higher percentage units of PbO; the exception is bead no. 9 from Plaňany), which is related to the identified opacifier. $Pb_2Sb_2O_7$ was confirmed by Raman spectroscopy. Raman bands of this phase at 142, 332, 450 and 506 cm^{-1} were described, for example, in *Gedzevičiūtė et al.* (*2009*, 26). In combination with blue glass, this yellow opacifier produces the resulting green shades. In the case of yellow glass, the contents are copper (max. 300 ppm Cu) and cobalt (single-digit ppm Co), so the blue component of the glass has no effect and only the colouring caused by yellow opacifier remains.

A certain shift was generally observed between the Raman spectra of green and yellow enamels. While the characteristic intense band at 140 cm^{-1} (stretching vibration of Pb-O) was determined (by us) in the case of yellow enamels, the band shifts to c. 127 cm^{-1} in the case of green enamels. As mentioned above, both types of enamels contain tin and certain modifications of the structure (in the sense of Sn-modified lead antimonates) can therefore be expected. According to the literature (*Vandini – Fiorentino 2020*), the spectrum (*Fig. 7*: C) shows a typical decrease of the band at about 511 cm^{-1} (symmetric stretching of the SbO_6 octahedron), which indicates lead antimonate with tin. Lead-tin antimonate is quite uncommon in Roman mosaic glass, and authors (*Basso et al. 2014*, 242) propose a hypothesis of the *corpo* (opacifier-rich glass added to the base glass) as a technological expedient, because the intentional addition of lead and antimony compounds to a soda-silicate glass would cause the dissolution of lead oxide and the crystallisation of calcium antimonate instead of lead antimonate. The raw materials used to prepare the *corpo* were mainly lead and antimony compounds, probably sulphides, such as galena (PbS) and stibnite (Sb_2S). Tin, present in the crystal lattice of antimonates, could have been introduced in the batch from the gangue of minerals used as raw materials for the preparation of the *corpo*. Other traits typical for this substitution include a shoulder at about 450 cm^{-1} and appearance/increase band at about 330–350 cm^{-1} (*Basso et al. 2014*, 241).

Red glasses

The red enamel samples have a different composition than ordinary natron glass. The contents of MgO, P_2O_5, K_2O, SrO are higher – these components are indicators of plant ashes. Again, glasses have higher contents of lead, but also of iron. In the case of red glasses, lead helps achieve the red colour. Moreover, enamels containing lead have a lower viscosity, which facilitates workability; the lead content is also undoubtedly adjusted for good enamel-metal substrate thermal expansion mismatch agreement. *Henderson* (*1991*, 73) also describes a higher iron content (1.87%) in red enamels with a similar composition. It is the content of iron or another reducing agent (including plant ash) that is necessary for the creation of a red colour.

According to the literature (e.g. *Basso et al. 2014*, 239; *Schibille et al. 2020*, 7), the red glasses of this period are coloured and simultaneously opacified with elemental copper or Cu_2O (cuprite) particles. The second phase forms dendrites in the glass, which were not observed, and thus the presence of copper particles can be assumed.

In red glass coloured by copper metallic particles, the Raman spectra may indirectly reveal the presence of Cu° nanoparticles only through the modification of the polymerisation degree of the silica network around the metallic particle (*Basso et al. 2014*, 244). This is evident in *Fig. 7*: D. According to *Colomban* and *Schreiber* (*2005*, 888), it can be added that the discussed polymerisation degree is visible in Raman spectra of red $(Cu°)_n$-containing glasses at c. 550 and 1,080 cm^{-1} cm.

Schibille et al. 2018 states that copper particles are more likely to form in glass with a lower copper content in the presence of a reducing agent[2] such as iron, as previously noted. Conversely, the formation of cuprite particles is common in glasses with high copper and lead contents. Sub-micrometric particles varying from 100 to 200 nm in size, homogeneously interspersed in the glassy matrix, were found, e.g. in a red mosaic cube dated to the 2nd century AD (*Basso et al. 2014*, 243). Similar particles are also visible in our sample see *Fig. 6*: D.

All the samples (in our work) coloured by Cu contain minor amounts of Sn mainly between 1,148 ppm (bead no. 10 from Plaňany) to 12 972 ppm (enamel lid of seal box from Stradonice). This could be taken as an indicator of the use of bronze instead of pure copper as an admixture to the glass melt (*Basso et al. 2014*, 244; this work lists for Sn glasses ~1,600–2,900 ppm). However, the enamel of the Stradonice[3] artefact again differs in its overall composition; nearly 13,000 ppm Sn was found compared to the other enamels with values in the range of c. 1,250–3,500 ppm. In contrast, a very low Sn content was found in bead no. 11 from Plaňany (22 ppm). Both of these samples also differ from the others in their Sb content, where 653 ppm Sb was determined for the seal box and 11,614 ppm for the bead (the other samples are in the range of c. 1,100–4,180 ppm). Differences were also found in the PbO content, which is up to 0.5% in the beads, up to 10% in enamels.

Metals

Fibulae from Sokoleč, Lipec and Chotělice, as well as balteus fittings from Jeníkovice and Plotiště nad Labem, were made of a lead-tin bronze alloy with a small share of zinc (Zn = 1.7–4 wt%) (for details, see *Online Supplementary Materials 5* – Tab. 3). The Sn content is relatively uniform in the 8.5–11 wt% range. According to the share of lead, two

[2] An oxidising atmosphere produces divalent Cu and therefore a light blue translucent glass (*Gedzevičiūtė et al. 2009*).

[3] The sample also contains a higher amount of As (833 ppm compared to lower tens in the other samples).

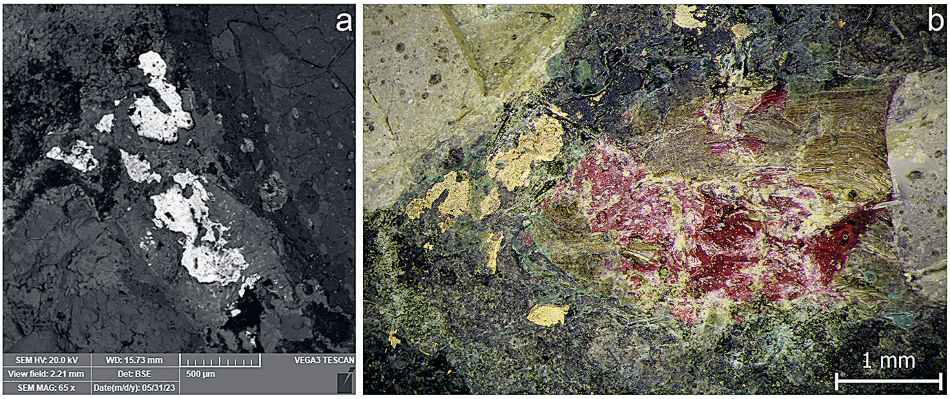

Fig. 8. a – Detail of traces of gilding on seal box lid from Stradonice, Tescan Vega 3 LMU scanning electron microscope (SEM); b – detail of gilding with Olympus SZX9 stereo microscope.

basic groups can be divided with a higher proportion of Pb from 7.4 to 9.1 wt% (Lipec, Chotělice and Češov) and with a lower proportion of Pb from 2.9 to 3.6 wt% (Sokoleč, Jeníkovice and Plotiště). The studied artefacts can be assigned to groups 20/21 after *Riederer* (*1998*, 200). The high content of lead in the alloy in this group of artefacts indicates the deliberate alloying of bronze with lead. A lead-tin bronze alloy with a lower share of zinc was widely used in Roman-provincial products (cf. *Vích et al. 2020*, 177). A lower share of zinc indicates subsequent recycling of brass and other copper alloys, which is typical of 2nd–3rd-century AD finds (*Rehren 2002*, 150). This phenomenon can be observed both in the Roman-provincial territory and also in the Barbaricum (see e.g. *Vích et al. 2020*, 176–177; *Čisťakova – Beneš 2024*, 43–52).

A lead-tin brass alloy (CuZnSnPb) was identified for the fibula from Češov and the balteus fitting from Litoměřice; (Zn = 7.3–7.9 wt%). Tin contents vary between 6.8 and 9.5 wt%, and in the range of 5.1–7.4 wt% in the case of lead. On the reverse side of the balteus fitting from Litoměřice, a thread was soldered with lead solder, which in its elemental composition corresponds to lead brass with an approximate zinc content of Zn = 22.3 wt% and lead Pb = 7.9 wt% (here it is appropriate to consider evidence of secondary repairs). These quaternary alloys of copper, tin, lead with a medium share of zinc (5–10%) can be assigned to category 21 after *Riederer* (*1998*, 200). Ancient brass (aurichalcum) could contain from 5 to 28 (30) wt% Zn in the alloy. In Bohemia, we encounter artefacts with a higher share of Zn as early as the Late La Tène period (*Bursák et al. 2022*, 2–3). In the 1st century AD, we still encounter finds with a higher share of Zn = 23 wt%. In the course of the 2nd and 3rd centuries, the zinc content in brass begins to decrease, and already in the 3rd century a significant decrease is seen in the concentration of zinc in brass to 5–7 wt% (*Droberjar – Frána 2004*, 444). The use of brass as a substrate for enamel is debatable, as the released zinc diminishes the adhesion of the vitreous substance to the metal substrate (*Bateson 1981*, 86; *Hložek et al. 2015*, 41). In the case of our finds, it is brass with a lower share of Zn, which may not have affected the final product as a result.

The seal box from Stradonice made of lead bronze is somewhat different in its elemental composition. However, the bronze alloy in this case contains only a trace amount of zinc, probably an impurity from the ores used in the production of copper. The lead content of this artefact is also high and represents a deliberate alloying of the bronze alloy with lead. The surface of the artefact was gilded with a gold alloy in some places, especially in the area of the decorative circle (*Fig. 8*). The gold alloy contains c. 6.1 wt% Ag and 3.2 wt% Cu. The analysis also confirmed the high content of mercury Hg = 9.3 wt% in the gilding layer. The analyses indicate that the artefact was fire gilded, a technique well known from the Hellenistic period from the 3rd century BC in the Mediterranean area. Traces of mercury gilding are less numerous on Republican and Early Imperial finds, but amalgam gilding becomes the most common method already in the 2nd century (*Giumlia-Mair 2020*, 5–7).

Discussion

Finds of artefacts decorated with combined or millefiori enamel belong to the group of Roman-provincial products, which are also documented in the territory of the Barbaricum. Their production required specific skills associated with glassmaking technology. Standing out from the examined assemblage is the lid of the seal box from Stradonice, which is characterised by an unclear provenance, a specific technological design, but also a different composition of enamels. Here it is appropriate to think not only about the possibility of a foreign origin, i.e. that the artefact was assigned to the Stradonice collection by mistake, but at the same time the possibility of a period forgery cannot be ruled out. However, the production technology, which is typical for the Roman-provincial environment, testifies against this conjecture. Amalgam gilding was used from the Hellenistic period until the middle of the 19th century (*Giumlia-Mair 2020*, 5). The composition of the used enamel also corresponds to Roman products, even though the white segment was represented by a different opacifier compared to the other enamels. The detected SnO_2 opacifier was used since the 2nd century BC (*Wedepohl 2003*, 28; *Henderson 2013*, 77). $Ca_2Sb_2O_7$ and/or $CaSb_2O_6$ were detected in the remaining finds. The use of antimony as an opacifier began already in the middle of the 2nd millennium BC, specifically in Egypt and the Middle East, and over time it also appeared in Europe in the Late Iron Age and in the Antique environment (*Moretti – Hreglich 2013*, 31).

Although fibulae and balteus fittings at first glance represent a relatively uniform assemblage, differences can also be found here. Fibulae from Sokoleč and Lipec are characterised by decorative enamel made with the millefiori technique (*Fig. 5*: C, D). Despite the apparent similarity of these two fibulae, attention should be drawn to minor differences in design, where the fibula from Lipec is characterised by the uneven arrangement of a chequerboard pattern. A highly interesting element is the use of red glass to join the millefiori blocks in the fibulae from Lipec and Sokoleč (and many other Exner III 30-type fibulae found in the Barbaricum). This is a technological element, since the softening point of red lead glass is lower (650–750°C) than that of ordinary glass (800°C) (*Bateson 1981*, 86; *Henderson 1991*, 65). The red glass powder could thus serve as a kind of binder for the small cubes of the millefiori pattern, when the pattern was created, for example, using individual blocks of millefiori glass that could be joined together using glass powder. The glass mass was subsequently connected to a monochrome substrate by heating (*Henderson 1991*, 65–67). At the same time, it is a visually effective element, serving as a contrasting background for the blue and white pattern. Red glass used in enamelling is considered one of

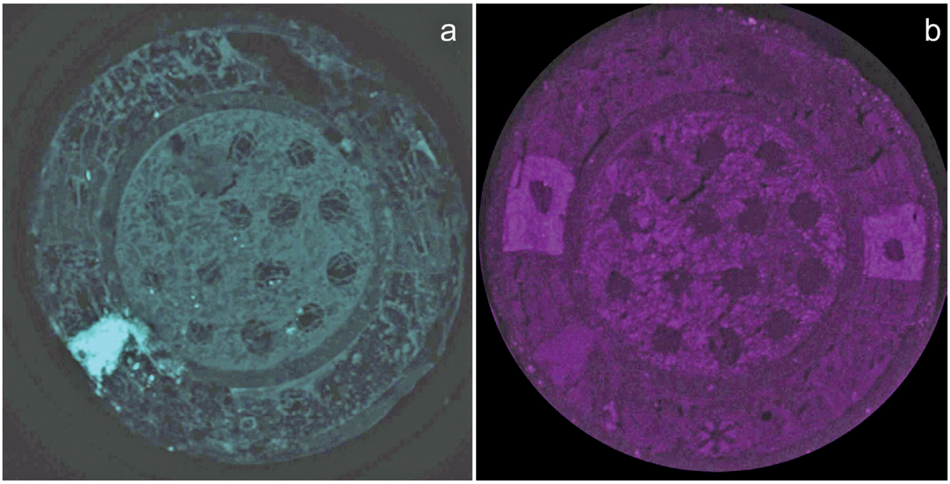

Fig. 9. Surface mapping of surface enamel layer of the fibula from Chotělice by micro-ED-XRF: a – Fe; b – Mn.

the most difficult colours to produce. In the case of all red glasses, this is a specific type characterised by a higher share of K_2O, MgO and P_2O_5, which indicate the use of ash. In this case, we can rule out accidental contamination during melting, as this is a procedure associated with achieving better conditions for reduction and would improve the formation of the red colour, acting as a nucleant for the Cu particles (*Bandiera 2022*).

The study of the plate fibula from Chotělice revealed interesting findings regarding its original pattern. For the non-destructive survey of individual elements, surface element mapping was used (see *Fig. 9*) The survey revealed decoration in the form of the mosaic technique and small elements produced by the millefiori technique. An iron inlay was also identified. In the case of enamel fibulae, this is an atypical element, and we can assume that it was used for the purpose of repairing damage to the pattern. The edge border formed by a yellow-turquoise chequerboard pattern is close to a similar element from the balteus fitting from Jeníkovice and belongs to other popular patterns in the millefiori technique (*Bateson 1981*, 92–93). $Pb_2Sb_2O_7$ was detected, which was used both to opacify glass and to colour it yellow since the Bronze Age (*Freestone 2021*, 249–251) and was commonly used in prehistoric Egypt and Mesopotamia (*Wedepohl 2003*, 22). From a technical perspective, it is a fibula with coarser craftsmanship characterised by asymmetrical and poorly legible patterns.

In contrast, balteus fittings from Litoměřice and Jeníkovice were finely crafted products. We can observe artfully executed patterns on the fitting from Jeníkovice in the form of a coloured chequerboard. The fitting from Litoměřice is also characterised by finer patterning and it also features other motifs typical of the millefiori technique – eyes. Yet another element can be observed on the fitting from Litoměřice – a floral motif, which also appears on the fibula from Češov. Even in this case, it is a relatively popular and frequent motif for millefiori enamel.

A separate group consists of beads from Plaňany produced using the millefiori and mosaic glass technique. The internal structure of the beads was determined using a CT survey (*Fig. 10*). Bead no. 9 is characterised by the fact that the pattern is formed by sintering

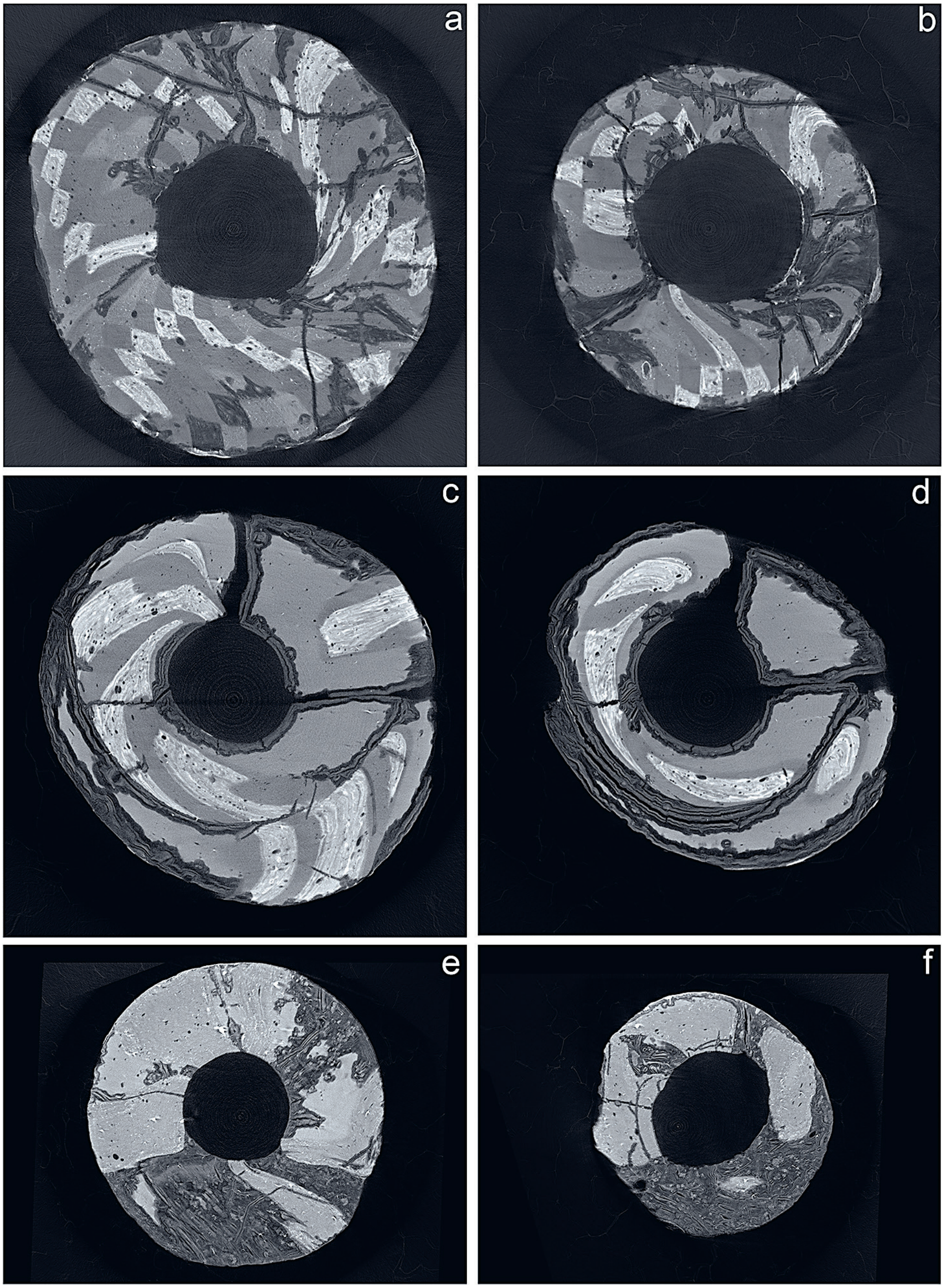

Fig. 10. a – Typical millefiori decoration in cross-section of bead no. 9. The different representation of shades of grey corresponds to glass segments with a distinct composition. b – The image of the section from the edge part of the bead clearly shows that the decoration is represented in the entire matrix. c – From the section of bead no. 10, one can infer the application of millefiori elements in red glass. Visible in the upper right is a nested segment made up of two types of glass; the three light stripes correspond to the white glass of the flower, while due to the streaking in the lower left it is clear that the segments with motifs are altered due to the shaping of the bead. d – In the border of the segment, it is evident that the flower decoration is no longer represented in the upper right part. e – The internal structure of bead no. 11 is more difficult to understand and considerable damage due to corrosion processes is evident (dark areas); however, the cutting of the individual glasses is visible in the right part, with the glass without white dots corresponding to the red glass and the white dots representing the larger opacifiers. For bead no. 10 and 11, the application of layers/decoration on the core can be ruled out based on the radial structure. f – In the edge parts, the glass of the bead is very corroded, and from all the photos (authors' archive) it appears that red glass is the least resistant glass to corrosion.

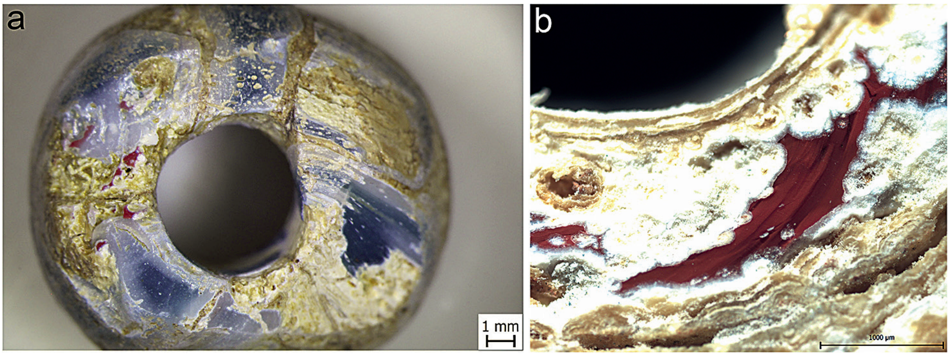

Fig. 11. Photography of red glass: a – bead no. 10, Plaňany; b – bead no. 11, Plaňany. Olympus SZX9 stereo microscope.

coloured rods into the desired patterns, as is known on millefiori vessels (*Antonaras 2012*, 19). Subsequently, the glass was shaped, resulting in the deformation of part of the patterns. In the case of bead no. 10 and 11, the individual coloured segments were set in a basic matrix of red glass, a technique that is also known with enamel (*Bateson 1981*, 92–93). In addition, it was revealed during the investigation that the examined beads were originally made of red glass, which changed its colour to white and/or yellow due to aggressive corrosion (*Fig. 11*).

The fibulae and balteus fittings presented here are typical representatives of Roman-provincial products, both in terms of their morphology and the material used in their production. For the individual artefacts, specific technological traits can be observed in the decoration, but also in the composition of enamels, thus testifying to the existence of different workshops. At the same time, two basic groups of glass from Egypt and the Levant can be recognised; these are the primary workshops that supplied the Roman-provincial glassworks. Based on the experimental production of enamel decoration, an open hearth or a smaller simple furnace would have been sufficient for the secondary workshops. For enamel workshops, we still lack direct evidence of this production activity. This craft activity can also be associated with glass workshops. *Thierry* (*1962*, 66) considers that the main production of artefacts with millefiori could have been concentrated in the territory of Gaul and in the Rhine provinces, i.e. areas famous for their glassworks. For example, such workshops can be assumed in the area around Cologne, a renowned glassmaking centre. Workshops may also have existed in Trier and Mainz (*Riha 1979*, 30). The production of fibulae is documented in Brigetio, where it is also assumed that enamel fibulae were produced (*Sáró 2020*, 117–118). In the territory of today's Belgium, we can mention a hypothetical workshop in the Roman Villa d'Anthée in the province of Namur (*Pelpel – Vernou 2019*, 260). Four ingots (blocks) of red opaque glass used for the production of red enamels were found in a vicus in Castelford (England). This material could also have been used as a foundation for millefiori. Based on numerous finds of fibulae, the existence of an enamel workshop can be assumed in the 1st–2nd century AD (*Bayley 2005*, 71–74). Evidence of enamel production also comes from the Dacian camps of Ilişua and Tibiscum (*Benea 2016*, 782–786, Abb. 6: 3, 4).

Conclusion

Artefacts decorated with mosaic and millefiori glass – imports originating from various Roman-provincial workshops – rank among visually attractive artefacts of the Roman Period. On the other hand, disc fibulae with millefiori enamel are typical representatives of plate fibulae and are found almost throughout the entire Barbaricum. Their concentrations in the Tisza and Elbe river regions show that they were especially popular here, almost exclusively in the furnishings of women's graves. After all, various plate fibulae are typical for them, whether they were artefacts of domestic (barbarian) or Roman-provincial origin. In the period around the Marcomannic Wars and in the first half of the 3rd century, various fibulae decorated with enamel represent a very widespread group; at the same time, this is the period in which imports of Roman-provincial fibulae to Bohemia culminated. Roman-provincial imports of militaria – represented in our case by circular baltei fittings with millefiori decoration – also peak at this time. However, due to the unclear provenance of the seal box found at the Stradonice oppidum, we can assume its origin outside the territory of the Czech Republic. Millefiori and mosaic glass decoration also appears on a group of glass beads, represented by three finds from a rich female grave from Plaňany dated to the second half of the 3rd century. Glass beads are among typical grave goods in women's graves of the Late Roman Period, though millefiori (and mosaic) beads rank among the less common bead types in our country.

A comprehensive archaeometric approach to artefacts of this type is rare not only in the Czech Republic. Specifically, less attention is paid to the study of enamels and information on their chemical composition, including trace elements, is nearly absent. The study determined that the composition of the glass used for the production of mosaic or millefiori enamel corresponds to Roman soda-lime-silica glass, i.e. so-called soda glass, which was produced in the Middle East and Egypt using natural natron. The exception is red glass, which is characterised by a higher percentage of PbO and a higher iron content; thus, additional raw materials added to the basic natron glass can be assumed. Higher shares of K_2O, MgO and P_2O_5 were also detected, indicating the use of plant ash as a reducing agent.

The analysed enamels contain a wide range of known dyes and opacifiers used in the colouring of Roman glass (specific phases were confirmed by Raman spectroscopy). The determined composition of the glasses indicates the use of different colouring raw materials and therefore different production workshops. This was evident in the case of blue glasses, which were also evaluated based on the CoO/NiO ratio, and then with white glasses, when various 'subtypes' of glasses could be distinguished on the basis of MgO. The represented opacifiers were predominantly antimony-based, with the exception of the determination of SnO_2, which is found in smaller quantities in glasses from this period. The antimony-based opacifiers make it impossible to classify the glasses into the typical groups of this period (Roman-Sb, Roman-Mn, or the recycled Roman-Sb-Mn type of glass). This fact should be taken into account when evaluating this type of opacified glass. It cannot be ruled out that the introduced raw material, or rather the admixtures and impurities, does not affect the overall composition of the soda glass. Glass corrosion and mechanical damage have a significant impact on the resulting colour of studied artefacts, e.g. the original red colour of the beads from Plaňany was heavily altered by corrosion process and was finally identified only on a micro-section.

It was confirmed during the investigation of the production technology of the studied artefacts that red glass, due to its composition and related properties, was used as a certain fixation medium/material. The use of micro-CT was highly useful in the study of manufacturing technologies. Using this method, the production of the Plaňany beads was clearly determined and the application of a mosaic strip to the glass core was ruled out.

Due to the composition and microscopic analysis of the surface, it was possible to focus on the technological specifics of millefiori glass production. Several objects belonging to the same typological group, such as fibulae from Lipec and Sokoleč, were probably produced in different workshops. A similar situation could be observed on the beads from the Plaňany female grave, where millefiori beads were made of different glass and with the use of various colouring raw materials. The fibula from Chotělice is characterised by poor craftsmanship, and there was also a later repair in the form of an iron inlay. Here it is appropriate to consider various provincial workshops that produced beads, fibulae and fittings for the barbarian market. It is thought that these workshops were located primarily on the Roman Limes, from where they could distribute products both within the provinces and beyond – into the Central European Barbaricum. A documented example of this type is represented by the workshops in Tibiscum (1st-century Tibiscum) on the border of the province of Dacia (*Benea 2004*). Judging by the distribution map of Exner III 30 plate-type fibulae presented here (*Fig. 3*), these workshops can be assumed on the Danube opposite the Sarmatian settlement in the Tisza Valley and in the Upper and/or Middle Danube Region opposite settlements of the Elbe Germans in Bohemia and in central and northern Germany. Since this is one of the first studies of Roman millefiori (enamel) artefacts in Central Europe, we cannot define the manufacturing circuits. For these purposes, it is necessary to expand the sampling set based on various artefacts with enamel decoration.

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