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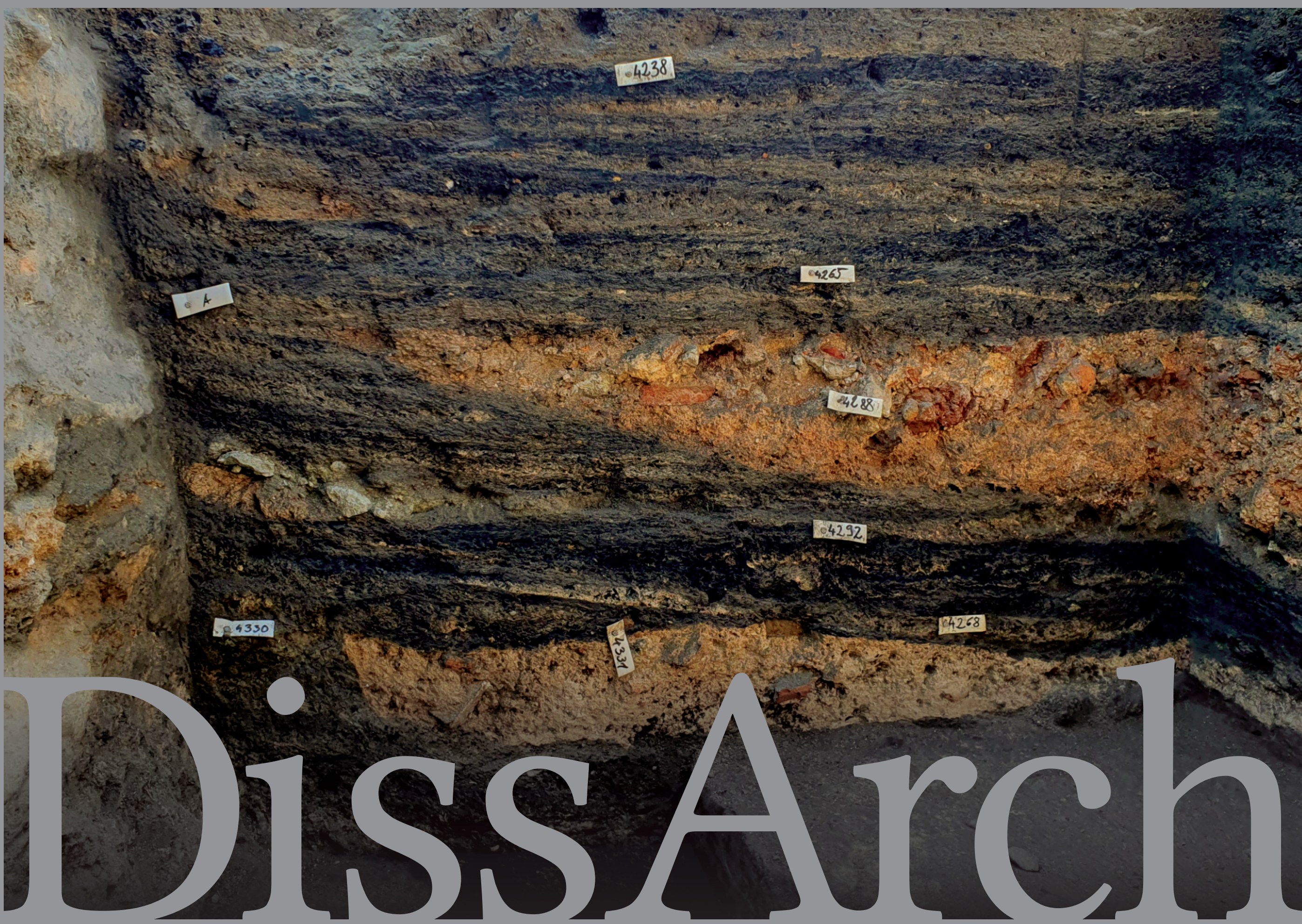

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Hrádok nad Váhom

Bronzeworking equipment from an Urnfield Culture site in the Carpathians

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Abstract: In the Bronze Age, the initial production of sheet metal vessels was limited to specialised workshops in eastern Mediterranean centres such as Troy or Mycenae, spreading slowly to the European hinterland. In this sense, the recently discovered hoard at Hrádok in Western Slovakia, dated to ca. 1225–1175 BC, represents the earliest and most complete set of bronzeworking tools in Central Europe, providing a deeper understanding of the making and decorating of bronze vessels in an Early Urnfield environment. Through a comprehensive evaluation of tin content analysis results of copper alloy vessels from western Eurasia, the spread of this most advanced contemporary technology could be reconstructed, highlighting the importance of such research in understanding the processes leading to the emergence of the Urnfield power structures and centralised political control over secondary metallurgy (the production of artefacts from already processed raw materials) in Europe in the Bronze Age.

Keywords: metallurgy; workshop; sheet bronze vessels; Late Bronze Age; Urnfield Culture

Introduction

The way Urnfield bronze vessels were hammered[1] is an advanced metalworking technique reflecting the influence of the metalworking practice related to the Aegean palaces[2] and representing a connection between them and some distant workshops in the Nordic and Atlantic regions of Europe.[3] However, this technique is still poorly understood due to the lack of known elite workshops and their locality;[4] our current knowledge is based almost exclusively on artefacts without an archaeological context that do not hold enough information to reconstruct the respective *chaîne opératoire* with certainty.[5] The idea of identifying metal workshops and outlining their supply areas based on the distribution of artefact types or stylistic elements rather than technological ones was the starting point of the typological approach dominating research for decades.[6] Generally, these workshops left only scarce archaeological traces, such as furnaces, crucible fragments, or copper alloy fragments;[7] therefore, the reconstruction of the production process was based on simple, theoretical chemicophysical models of modern metalworking.[8]

1 Childe 1949.
2 Reeves 2003.
3 Thevenot 1998.
4 Nessel 2019.
5 Armbruster 2000.
6 Jockenhövel 1986.
7 Ilon 2015.
8 Brepohl 1980.

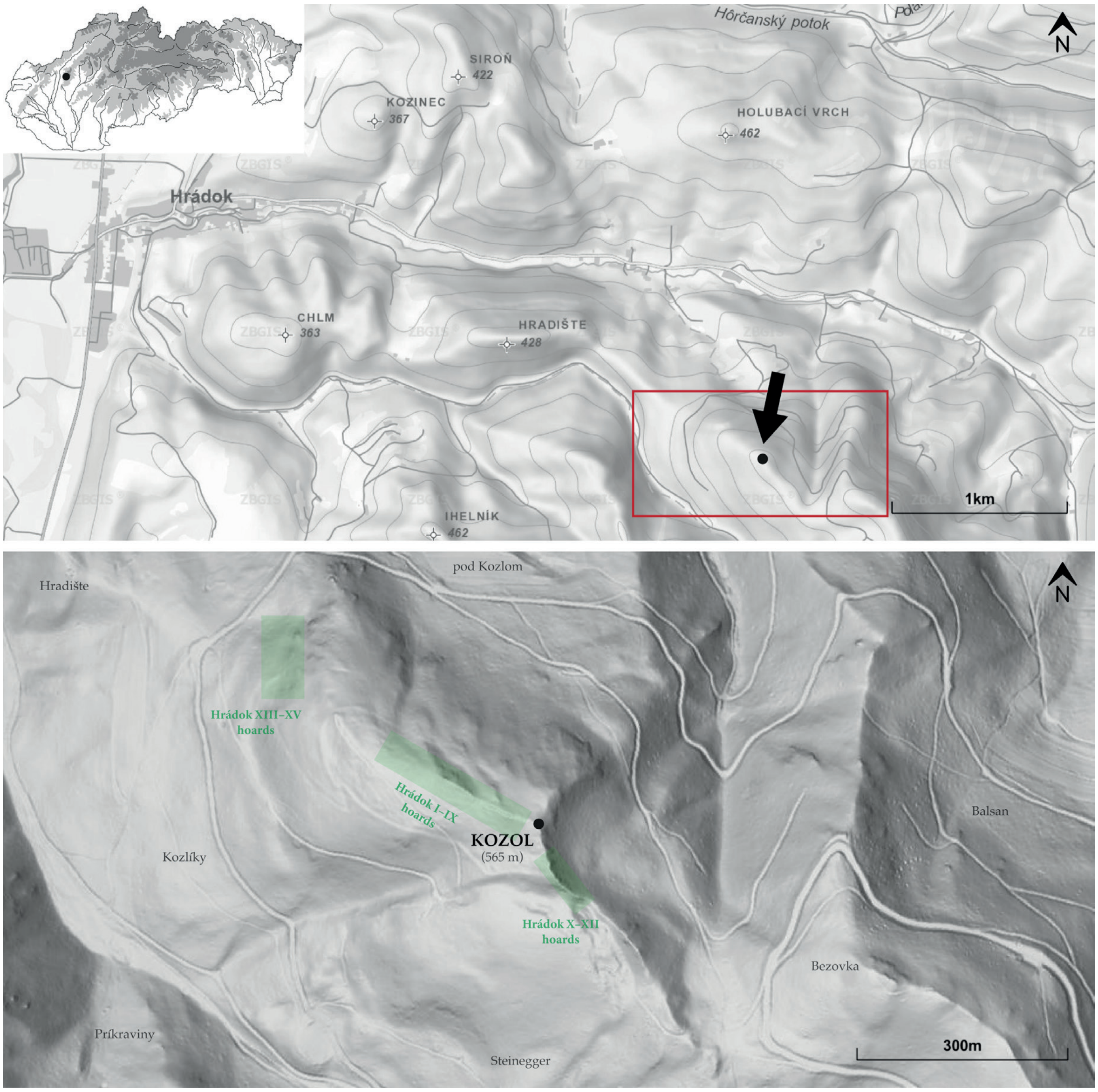

Fig. 1. Hrádok nad Váhom, Kozol site. Location of the hoards within the territory of Slovakia.

From a chronological point of view, relatively small sheet metal artefacts appeared in the Carpathian Mountain Range in a wide variety of shapes only from the Early Bronze Age, but such types were already known from the Early Eneolithic.[9] Large objects, such as greaves (*Beinbergen*)[10] or wide belts (Szeged–Sieding type),[11] subjects of great interest to researchers,[12] became a characteristic feature of the Carpathian Bronze Age from the time of the Tumulus Culture. The sheet metal artefacts made in these early phases were basically flat; however, metallurgy advanced, and metalsmiths' skills and understanding of the related processes improved fast, bringing about significant innovations and a rapid change in technology at the time when the first bronze vessels appeared in the Br D period, as reflected by the development of relief decoration and three-dimensional items, primarily in context with the emergence of an Urnfield warrior elite that followed a southeast

9 Točík 1964, 142; Farkaš *et al.* 2023.

10 Hänsel 1968, 214.

11 Langenecker 1994, 269–272.

12 Mozsolics 1967, 76; Kilian-Dirlmeier 1975, 100–103.

European pattern in social representation.[13] The striking similarity of items in Central and Southeastern Europe indicates production organised on a supra-regional level and that all metalsmiths must have had an identical or at least similarly high level of metallurgical knowledge, which presupposes systematic training.[14]

Although the precise dating of the spread of the know-how of sheet metal vessel making is subject to debate—this technique did not spread with peoples or cultures expanding their dwelling areas—its transfer to the Carpathian Basin took place via splitting and relocating (by 'filiation', i.e., individuals from specialised workshops participating in the creation of new workshops) craftsmen from the Mycenaean workshops after the collapse of the palace centres in the late LH IIIB and IIIC periods (ca. 1300–1200 BC).[15] It was during this period in the Western Carpathians, i.e., the Velatice–Baiersdorf ceramic complex that the first Velatice (Gusen, Friedrichsruhe)[16] and Blatnica-type (Fig. 4)[17] bronze cups were produced and used for serving alcoholic beverages at the feasts—referred to in archaic and classical Greek sources as *symposiums*[18]—of the elite.[19] The morphological similarity and limited scatter of such objects suggest centralised production,[20] corroborated by the notion that hammering is an extremely advanced technique requiring years of training and practicing to master, as well as generations of metalsmiths to develop.[21] Therefore, the new conditions allowed experienced craftsmen to work for other patrons and improve their skills and technical knowledge by pooling their discoveries and innovations.[22] A higher-than-ever degree of specialisation and limited access to this knowledge and technology could subsequently lead to these metalsmiths concentrating power and wealth on a scale larger than ever before.[23]

Material and methods

Description of the hoard

Hoard I discovered at Hrádok nad Váhom (Fig. 2) is a set of 34 deposited bronze objects representing the complete toolkit of a specialised Urnfield metal workshop. The set includes tools for sophisticated working techniques such as casting, wire drawing, and bronze sheet processing (hammering, riveting) and decoration by engraving or punching. It consists of six tools for forging (Fig. 2.1–2,5–6,13), including static (anvil) and mobile elements (hammers), one of which can be used either way (Fig. 2.5). The set also includes a wide variety of tools for decorating and elaborating metal sheets: punches (Fig. 2.7–11), a swage block (Fig. 2.12), tongs (Fig. 2.22–24), gravers and chisels (Fig. 2.16–18), as well as a drawplate (Fig. 2.11) and another tool for drawing and twisting wires (Fig. 2.19–20). The hoard also incorporates an unusual two-part metal (perhaps bronze) mould for casting chain links (*Ringgehänge*; Fig. 2.3–4), as well as seemingly unrelated objects like tanged sickles (Fig. 2.33–34), button-like round items (Fig. 2.14–15), and hoop or ring objects (Fig. 2.25–32), the latter perhaps part of a complex composite horse harness. As the hoard could only be reconstructed from

13 Mödlinger 2017, Fig. 1.2.
14 Sherratt – Taylor 1989.
15 Sherratt – Taylor 1989.
16 Prüssing 1991.
17 Novotná 1991.
18 Burkert 1985.
19 Piggott 1959.
20 Patay 1990.
21 Molloy – Mödlinger 2020.
22 Overbeck 2018.
23 Armbruster 2013.

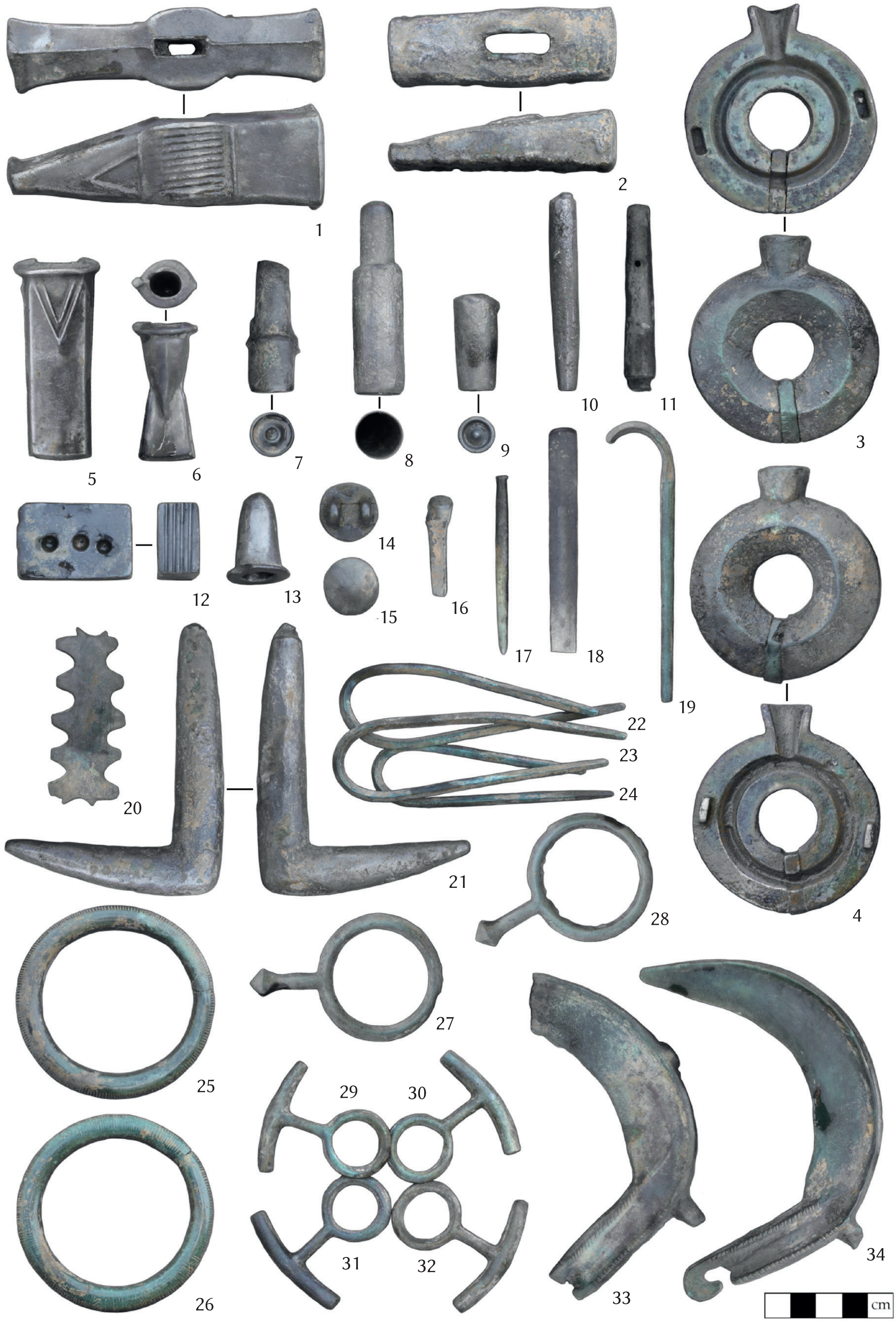

Fig. 2. Hrádok nad Váhom (I). Metalworking equipment from Urnfield context (ca. 1225–1175 BC).

digital images and the report of a local, and the descriptions presented here are based on said images instead of the artefacts themselves, the study does not include information on their size and cross-section, nor drawings of the artefacts in focus.

Cultural context

The Velatice–Baierdorf ceramic complex (ca. 1325–1025 BC; Fig. 4) is a Late Bronze Age Urnfield cultural unit in the territory of today's Western Slovakia,[24] Lower Austria,[25] and Southern Moravia,[26] displaying the typical features of the Urnfield civilisation emerging from a Middle Bronze Age (Tumulus) substrate.[27] The spatial and chronological distribution of sheet metal[28] artefacts indicate that the earliest techniques for crafting sheet bronze vessels[29] and armour (helmet, shield, greaves) were developed here, within the temperate zone of Europe,[30] as part of the so-called 'Urnfield package', i.e., a gradual militarisation driven by competition between communities in Central Europe.[31] Within this horizon, the burial mounds of the warrior elite *(Prunkgräber)* from Očkov[32] and Velatice[33] offer evidence of social differences between armed men, some of whom were buried with weapons, luxury jewellery, and vessels.[34] Thus, advanced metallurgy most likely operated under the patronage of the armed elite, who likely possessed a sophisticated metal workshop centre such as the one reconstructed at Pobedim-Hradištia,[35] surpassing ordinary workshops in workmanship quality, organisation, and scope of production.

Find context

The high-altitude microregion of Kozol (at 565 m a.s.l.; Fig. 1) lies about 4 km east of Hrádok nad Váhom municipality (Trenčín Region). It is a protected Velatice settlement[36] in a mountain pass connecting the Váh and Nitra regions, which facilitated establishing and maintaining cross-cultural contacts with the Čaka ceramic complex.[37] The place got into the focus of national attention for a series of illegal excavations in 2007–2012, which resulted in the looting of fifteen metal find assemblages in three concentrations. All deposits have been traded abroad, leaving, in the case of the hoard in focus, only a reliable eyewitness report on the discovery and photographic documentation behind for research to work with. The looted hoards were deposited on northwestern slopes, characterised by prominent plateaus and difficult-to-reach terrain, and contained a remarkable amount of bronze jewellery, hammered vessels, and gold wire. The settlement was likely a metalworking centre of the Velatice Culture; some deposits may belong to metallurgical facilities, while some were hidden in context with armed conflicts between the communities in the area,[38] reflecting a period of social instability around 1200 BC.

24 Paulík 1972.
25 Lochner 1986.
26 Říhovský 1961.
27 Cavazzuti *et al.* 2022.
28 Novotná 1991, Taf. 15.
29 Prüssing 1991, 16.
30 Childe 1949; von Merhart 1969.
31 Ondrkál 2022.
32 Paulík 1994.
33 Belcredi *et al.* 1989.
34 Sicherl 2004.
35 Studeníková – Paulík 1983.
36 Nešporová 2001.
37 Paulík 1963.
38 Ondrkál 2023.

Tin content meta-analysis

Using tin (Sn) bronze for making vessels is a complex technology formed by various (cultural, social, economic, and technological) processes and demands; it emerged and spread in neighbouring regions gradually and asynchronously.[39] The evaluation of the tin content analysis results of sheet bronze vessels in Western Eurasia, presented below, has yielded evidence of indirect technological knowledge transfer throughout the continent in the Bronze Age, highlighting the main trends. The related data were collected from the spectrometric databases of the SAM I and II projects *(Stuttgarter Metallanalysen)*,[40] SMAP, and OXALID,[41] the second series of *Prähistorische Bronzefunde*,[42] the AM USSR,[43] and studies of regional significance.[44] Only the results of XRF/OES analyses of samples taken from the metal core of the artefacts were included; omitting the results of surface samples was necessary because the composition of the patina, a surface corrosion layer, deviates from that of the original alloy.[45]

The evaluation is based on 53 samples from the Mediterranean zone and 121 samples from Urnfield territory. It must be emphasised that the results obtained by different spectrometric methods (OES, XRF, NAA, etc.) have been evaluated jointly, albeit those may not be compatible. Due to repairing, which is often overlooked, we also cannot exclude the possibility of a slight distortion in the body of evidence.[46] To eliminate inconsistency, only data obtained from samples taken from the vessel body have been included in the analysed set, as rivets, handles, and applied elements tend to have a significantly different composition.[47] The data set represents a large area and, thus, a scope rarely investigated, which, despite the problems described above, may allow for a deeper understanding of the various operations involving the production of sheet bronze vessels in the Urnfield complex.

Results

Macroscopic observations

The macroscopic analysis of the set of artefacts presented in this paper has revealed that their transformation, maintenance, and use resulted in highly regular, polished work surfaces like those required for sheet metal processing. From a physical point of view, they have some common characteristics like grey colouring and resistance to corrosion, indicating that they were made from raw material with a high tin content, making them resistant to impact. The types of the artefacts and, accordingly, the characteristics and positions of their active surfaces show considerable variability. The hammerheads (Fig. 2.1–2,5) have remarkably wide (9.3, 7.1 and 5.6 cm^2), straight or slightly convex, heavily worn faces, no edges, blunt butts, and highly polished sides. This is important because the size of the working face is connected directly with the dimensions of the processed sheets.[48] A hammer with a slender V-shaped working surface (Fig. 2.6) is a specialised tool associated with

39 Sherratt – Taylor 1989.

40 Junghans *et al.* 1968; Junghans *et al.* 1974.

41 Stos-Gale – Gale 2009.

42 Jacob 1995; Dietz – Jockenhövel 2016.

43 Chernykh 1993.

44 Thevenot 1991; Piningre *et al.* 2015; Ondrkál 2020.

45 Pernicka 1990.

46 Gogâltan 1993; Tarbay *et al.* 2023.

47 Pietzsch 1968; Born 1997.

48 Fregni 2023a, 53.

metalworking.[49] Based on their wide but relatively flat faces, these hammers could be, when paired with a small smoothing hammer (no. 13; *Ballhammer, Treibfaust*), ideal tools for producing relatively large, convex bowls.

The design and high degree of surface transformation of both sides of the rectangular anvil[50] (Fig. 2.21) suggest that it served as a static piece attached to a tree stump or another base. Two pattern punches with rounded edges (Fig. 2.7,9) are opposite parts (*matrix* and *patrix*) of a two-part pattern punch for metal sheets, while a hollow punch with sharp cutting edges (Fig. 2.8) allowed for the effective cutting out of the stamped pattern; considering their matching size and shape, these three tools were clearly designed to be used together. A side of the swage block (Fig. 2.12) features three hemispherical depressions with slightly damaged edges, while its side bears four parallel grooves. The tongs (Fig. 2.22–24) represent the simplest folded variant of the type; their arms became partially deformed in use. The uneven surface oxidation of the casting mould (Fig. 2.3–4) appears as dark green discolouration, rarely revealing visible traces of casting defects such as microcracks, signs of a fibrous laminar structure, or damage caused by a sharp object upon removing a casting from it. From a technological point of view, the objects that are not part of the toolkit (Fig. 2.14–15,25–34) are likely worked specimens with marks of post-casting enhancement such as hammering, decoration, and the removal of casting surplus (the remains of the casting seams are barely discernible, appearing as U-shaped depressions in the surface).

Typochronology

The respective framework of metal typology and its relation to pottery chronology are well established. Based on typological classification, most objects could be assigned to Reinecke's chronological phases Br D and Ha A1, representing 1225–1175 BC. Of the two heavy shaft-hole hammers (Fig. 2.1–2), each equipped with two working surfaces with a variable quadratic cross-section *(Schaftlochhämmer)*,[51] the morphological characteristics and decoration of No. 1, a unique specimen, reflect supra-regional connections between the shaft-hole hammers with cast decoration *(Winkelmuster)* in the Carpathian Basin and undated anvils from Tour de Langin, Zürich-Wollishofen[52] (a simpler version of hammer no. 2 (Fig. 2.2) is a type known from the Urnfield find material of the Swiss region (Zürich, Domat-Ems).[53] no. 5, a socketed hammer with a cast V pattern (Fig. 2.5), represents a flagship socketed axe variant in the Carpathian Basin in the Aranyos and Kurd horizons (Br D/Ha A–Ha A1),[54] which also persisted into the Ha B phase.[55] Although the number of 'bent anvils' similar to no. 21 (Fig. 2.21) (from Velem-Szent Vid, Questembert, and Sipbachzell)[56] is currently too small to provide a satisfying answer on the provenance of the variant, it clearly indicates the remarkable connections related to the trade of hammers and anvils in the Carpathian Basin and Western Europe.[57] The two-part bronze mould for hoop or link casting (*Ringgehänge*; Br D2–Ha B3)[58] is unique in the Carpathian Basin, and metal moulds are rare in European prehistory in general.[59]

49 Nessel 2023, 73.

50 Using the term by B. Nessel (Nessel 2019, 19).

51 Nessel 2019, 64.

52 Mozsolics 1945, 53–57; Ehrenberg 1981; Nessel 2010, Taf. 2a.

53 Rychner 1979; Primas 1986, Taf. 143.

54 Mozsolics 1985, 33; Gogâltan 2005.

55 Tarbay 2016, 95–96.

56 Ilon 2015, Fig. 35.5; Armbruster *et al.* 2019, Fig. 14.

57 Overbeck 2018.

58 Tarbay 2022a, Fig. 3; Tarbay 2022b, 40–41, Fig. 2.3–2.4.

59 Kibbert 1984; Blažek *et al.* 1998; Baron *et al.* 2014; Overbeck 2018; Ilon 2022.

The punch and die set of nos 7–9 represents an archaic technique for pressing and cutting out thick metal sheets (Fig. 2.7–9), practised between the Br D and Ha A1 phases (Enderndorf, Přestavlky, Mögeldorf, Plavecké Podhradie).[60] The pattern it produced appears almost exclusively on bronze helmets of the Paks type (Fig. 3),[61] known mainly from the Br D–Ha A1 phases (Pamuk);[62] however, an advanced concentric circle pattern variation appears on younger artefacts, including bronze belts (Keszőhidegkút)[63] and hammered gold jewellery (Velem-Szent Vid).[64] The swage block (Fig. 2.12) with three sub-spherical depressions, which enable the sheet to be decorated in relief with a repoussé knob-like pattern, represents a novelty in the Carpathian Mountain Range. Swage blocks are rare finds, appearing throughout Europe and representing an innovation of Br D/Ha A metalworking. Such tools are also known from Génelard, Larnaud, and Fratelia in France;[65] however, it is difficult to assess whether and to what extent the specimen discovered in the Carpathian Basin is related to these.

With Ha A1 analogies (Lengyeltóti II, Nadap),[66] no. 20, a saw-shaped artefact with a decorative function (Fig. 2.20), has the highest chronological value of all the finds. Based on their morphological characteristics and decoration, nos 25 and 26, two round bracelets with round profiles and simple line- and fishbone patterns (Fig. 2.25–26), represent an archaic Early Urnfield (Br C/D–D) element in the western Carpathian Mountains.[67] Uioara 8-type sickles appear in thousands in the Br D–Ha B1 period; the variant (2.A.0) nos 33 and 34 (Fig. 2.33–34) represent concentrate in the Br D/Ha A1–Ha A1 phases[68] with an epicentre in the Carpathian Basin.[69] The typological monotony of the bronze items unrelated to the metalworking toolkit in the Hrádok I hoard is only disturbed by nos 27–32, parts of a unique horse harness (Fig. 2.27–32), which, in lack of analogies, could not be classified and dated this way.[70]

Chaîne opératoire

The reconstruction (Fig. 3) has revealed some physical aspects of the metalsmithing craft affecting the working practices of Urnfield smiths and the roles of individuals in the workshop, facilitating the proposing of highly reliable functional interpretations. The assemblage was identified as a metalworking toolkit because 22 pieces, almost two-thirds of all finds in the hoard, could be linked with this activity, representing a large spectrum of operations; the reconstructed technology implies the use of also wooden and stone tools at different stages of the *chaîne opératoire*.[71] These artefacts were very likely used in a large-scale workshop with a systematic work organisation,[72] involved in sophisticated working phases, including possibly the casting of bronzes and gold in two-piece moulds, the hammering and bending of metal sheets, the drawing and coiling or twisting of wires, the straightening and profiling of bars, as well as the annealing, soldering, riveting, decorating, embossing, and polishing of all objects.

60 Müller-Karpe 1959, 288; Jockenhövel 2003, 111; Salaš 2005, 61; Bartík – Čambal 2018.

61 Clausing 1991.

62 Mödlinger 2017, 47.

63 Mozsolics 1985, Taf. 35; 106.

64 Ilon 2015, Taf. 16.

65 Medeleţ 1995; Thevenot 1998; Armbruster 2008.

66 Mozsolics 1985, Taf. 107; Jankovits 2017, Taf. 80.

67 Mozsolics 1973, 59.

68 Pavlin 2023, 199–201.

69 Petrescu-Dîmboviţa 1978, 55.

70 Mírová 2019.

71 Mohen – Bailloud 1987.

72 Fregni 2023a, 52.

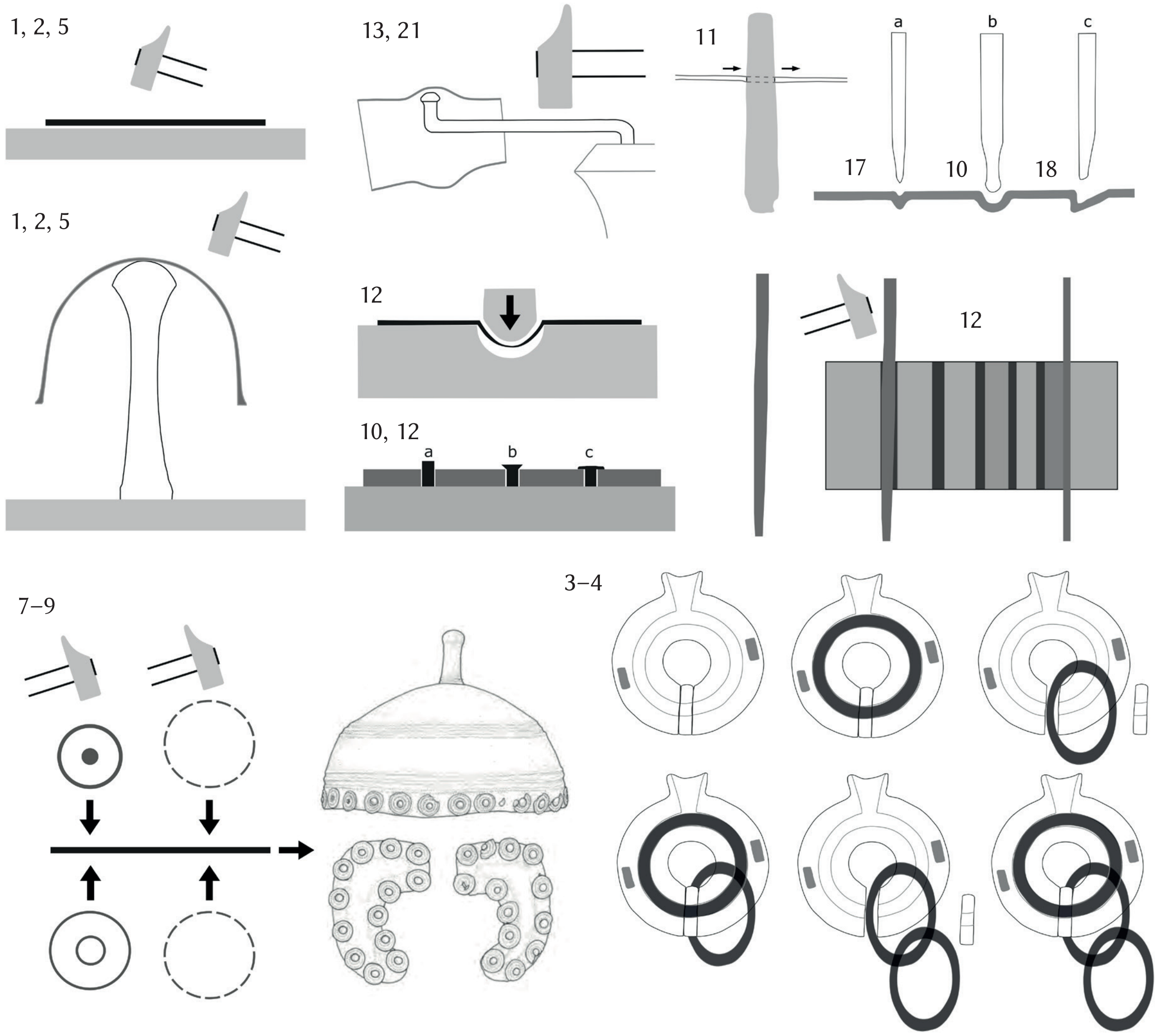

Fig. 3. Scheme of the metallurgical *chaîne opératoire* applied by the Hrádok-Kozol workshop.

About three hundred bronze hammers and seventy anvils are known from the Bronze Age of Europe.[73] Since spherical hammers *(Kugelhämmer)* are almost unknown in the Bronze Age,[74] metal sheet vessels were most likely made using hammers with a rectangular face, which also means that the blows were generally delivered to the outer side of the vessel.[75] Raising, the main phase of vessel hammering in Urnfield Culture workshops, is best suited for work with quadratic hammers; as such vessels usually start with a disc (all Urnfield-style vessels are radially symmetrical[76]) other types are not included here. The common practice of raising involved casting a thin blank first and stretching and shaping it by blows delivered with large hammers (Fig. 2.1–2,5), alternated with rounds of annealing until a thickness often less than 1 mm is achieved.[77] During raising, a wooden anvil or bick iron was probably used for supporting the metal around the point where the hammer stroke (as the metal takes up the shape of the anvil or bench peg, the material surrounding the point of impact shifts outwards). Accordingly, the rectangular anvil from Hrádok (Fig. 2.21) was more suitable for the final phase of raising, during which the sheet was being hammered while practically in the air,

73 Armbruster 2023, 13.

74 Nessel 2019, 33.

75 Clarke 2013.

76 Novotná 1991.

77 Armbruster 2000, 98.

supported only in the area of the impact point: the vessel could be held against the anvil at an angle of approximately 30° and rotated clockwise or counterclockwise between blows.

In the last step of production, a protruding belly was hammered from the inside of the vessel using a small spherical hammer (Fig. 2.13), which also served to level and smooth out the internal surface. Subsequently, decorative elements such as a knob-like pattern *(Gleich-Buckel-System)*[78] or concentric ribs were applied to the vessels or helmets from the inside with the help of the sub-spherical depressions and side grooves of a swage block (Fig. 2.12). Paired up with a spherical punch with a rounded head, the swage block could also be used to produce hemispherical sheet metal elements such as beads or appliques.[79] The last phase of production was caulking, i.e., hammering back the upper surface of the rim onto the wall to flatten and thicken it. This was usually carried out simultaneously with raising and finished after the shaping of the vessel was complete.[80] The rivet holes were most likely not cast but cut by punching from the outside (Fig. 2.17), while the rivets themselves could be cast or forged from a bar using a swage block and applied to the vessel with a semi-circular punch (Fig. 2.10). Paks-type bronze helmets (Fig. 3)[81] feature a decoration made of

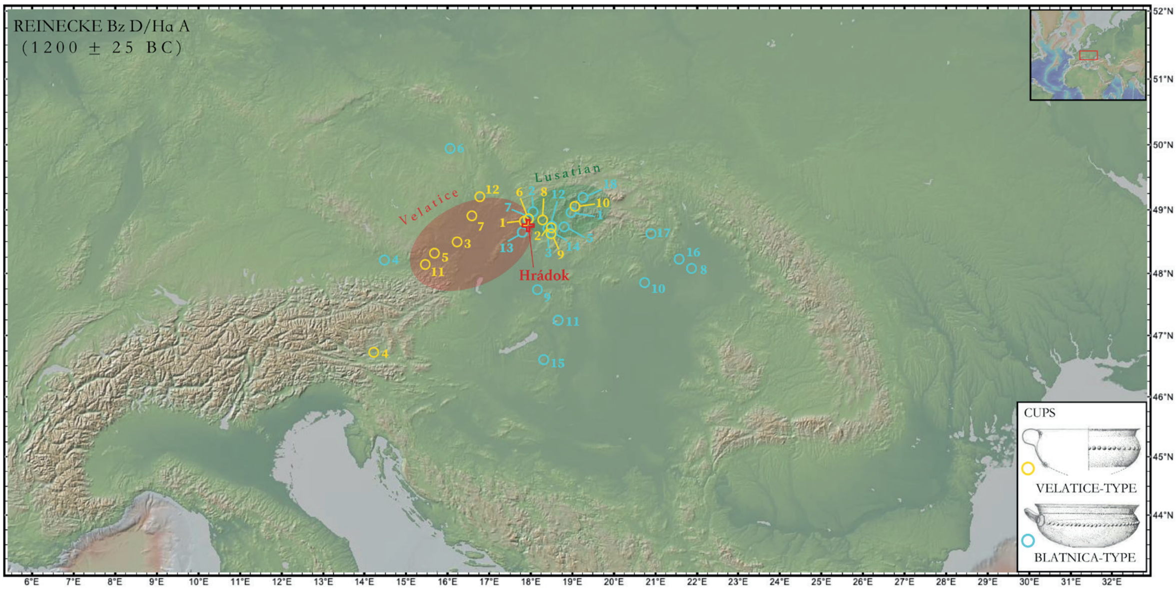

Fig. 4. Distribution of Early Urnfield cups and the respective ceramic cultures in the Bz D/Ha A period
Velatice (Friedrichsruhe)-type cups. 1 – Bošáca, SK (Bartík 2018, Obr. 3), 2 – Dolné Vestenice, SK (Ondrkál, in progress), 3 – Großmugl, AT (Prüssing 1991, Nr. 2), 4 – Haidach im Glantaal, AT (Prüssing 1991, Nr. 3), 5 – Inzersdorf, AT (Prüssing 1991, Nr. 4), 6 – Melčice-Lieskové, SK (2×; Ondrkál 2023, Nr. 3, 121), 7 – Mušov, CZ (2×; Salaš 2005, Tab. 208.122,123), 8 – Nitrianske Sučany, SK (Ondrkál, in progress), 9 – Oslany, SK (Ondrkál, in progress), 10 – Sklabinský Podzámok, SK (Pieta – Veliačik 2014, Obr. 5), 11 – Unterradl, AT (Prüssing 1991, Nr. 5), 12 – Velatice, CZ (Říhovský 1958, Obr. 8.8).
Blatnica-type cups. 1 – Blatnica, SK (4×; Novotná 1991, Nr. 4; Veliačik 2004, 57; Bartík 2007, Obr. 8.4), 2 – Dolná Súča, SK (2×; Pieta 2020, Abb. 4), 3 – Dolné Vestenice, SK (2×; Ondrkál, in progress), 4 – Enns, AT (Prüssing 1991, Nr. 6), 5 – Handlová, SK (Novotná 1991, Nr. 3), 6 – Chroustovice, CZ (Vích 2023, Obr. 3), 7 – Ivanovce, SK (Novotná 1991, Nr. 7), 8 – Kemecse, HU (Patay 1990, Nr. 80), 9 – Komárom, HU (Patay 1990, Nr. 74), 10 – Mezőnyárád, HU (2×; Patay 1990, Nr. 75, 76), 11 – Nadap, HU (8×; Patay 1990, Nr. 177–184), 12 – Nitrianske Sučany, SK (Ondrkál, in progress), 13 – Očkov, SK (Novotná 1991, Nr. 8), 14 – Oslany, SK (Ondrkál, in progress), 15 – Tamási, HU (Patay 1990, Nr. 77), 16 – Viss, HU (Patay 1990, Nr. 78), 17 – Zádielske Dvorníky, SK (Novotná 1991, Nr. 6), 18 – Žaškov, SK (Novotná 1991, Nr. 5).

78 Merhart 1952, 40; Fregni 2023b, 66.

79 Brepohl 1980, 233; Schorer 2023, 147.

80 Clarke 2013, 67.

81 Mödlinger 2017.

round and pressed metal sheet cutouts made with punches like nos 7–9 (Fig. 2.7–9) and riveted on the helmet parts.

Based on technological marks observed on some bronze vessels from the Middle Elbe Region in Deutschland, A. Pietzsch[82] and later by H. Born[83] replicated some processes related to their making. Their experiments greatly improved our understanding of metalsmiths' methods in the Urnfield complex. First, they annealed the cast round blank by reheating/softening it in a charcoal fire and cooling it in cold water. They started the next phase, shaping, by hitting the raw casting repeatedly with a 1 kg hammer, while later, they adapted hammer weight, executed blows with consideration to the specifics of the target area, and combined hammering with local annealing, thus achieving good results even in critical parts. The walls of Urnfield vessels were very thin (around 1 mm), and they found no significant link between the final wall thickness and vessel volume. They warn that special attention must be paid to the even distribution of material to avoid cracking, the danger of which is especially high in the final stages of production. Small mistakes in the early stages can cause irreversible problems that are not necessarily visible until the vessel is almost complete. The final shaping of the vessel from the inside can only be done with a relatively small, rounded hammer *(Ballhammer)*. Special attention must have been paid to the working surfaces of the decorating tools *(Lupfer-*, *Perlen-*, *Punkt-punze)*, which also often caused cracks. However, an organic sealant could have been used to seal the micro-cracks on the completed vessel.[84] The reconstruction of a medium-sized, decorated vessel weighing 90 g required 64 annealing stages and 42 working hours.[85] Other experimental studies on Bronze Age lathes have revealed that rotary motion tools were also used to produce annular gold ornaments.[86]

Tin content meta-analysis

The evaluation of the dataset of tin content analysis results of metal sheet vessels from Western Eurasia includes the illustration of the chronological distribution of the data points (Fig. 5). This has revealed that the earliest sheet vessel production in the area of the Anatolian trade network (ca. 2700–1700 BC) incorporated almost no effort to alloy, i.e., deliberately increase the amount of tin (Sn content 0–1%). This is rather surprising, considering especially that the material of copper artefacts was commonly alloyed with tin in the Near East in the Early and Middle Bronze Ages.[87] In the early stages of the Bronze Age, pure copper was preferred and more widespread because it was easier to work with than bronze: it is softer than bronze, thus easier to shape and process with simple tools, and less prone to cracking during hammering. Pure copper may also be easier to process when hot than bronze alloys, which could be advantageous for some methods of making and shaping vessels (as impurities in the alloy represent weak points with a potential for cracking).[88]

As the illustration displays, the technology of crafting bronze vessels by hammering was developed first at the Minoan palace complex of Knossos no later than in the MBA IIC phase (ca. 1650–1550 BC). At some stage, Cretan metalsmiths developed a method of making thin-walled bronze vessels (of an alloy with an Sn content of 8–12%) by mechanical shaping through repeated cold hammering and recrystallisation (annealing), followed by quenching to prevent the formation of brittle phases.[89]

82 Pietzsch 1968.

83 Born 1997.

84 Born 1997, 75.

85 Pietzsch 1968, 243.

86 Armbruster 2023, 5.

87 Yener – Vandiver 1993.

88 Shimizu 2010.

89 Mödlinger 2017; Fregni 2023a, 58.

This technique relatively quickly spread throughout the area of the Mediterranean trade network around 1550 BC at the latest and became developed considerably by craftsmen in Mycenaean workshops. The advanced technology included sophisticated procedures like diverse ways of fusion, cold-hammered inlaying, shaping vessels using a compass and turning wheel (an early type of lathe), casting, and hidden copper bracing, resulting in more elaborate end products.[90] Most samples from after the collapse of the Mycenaean palace complexes in the later LH IIIB and IIIC periods (around 1300–1200 BC) come from samples assigned to the Urnfield Culture and outline a fundamentally different geographical unit. Their tin content ranges from 5–16%, which is unsuitable for hot hammering as that requires a tin content lower than 7% or higher than 20–25%.[91]

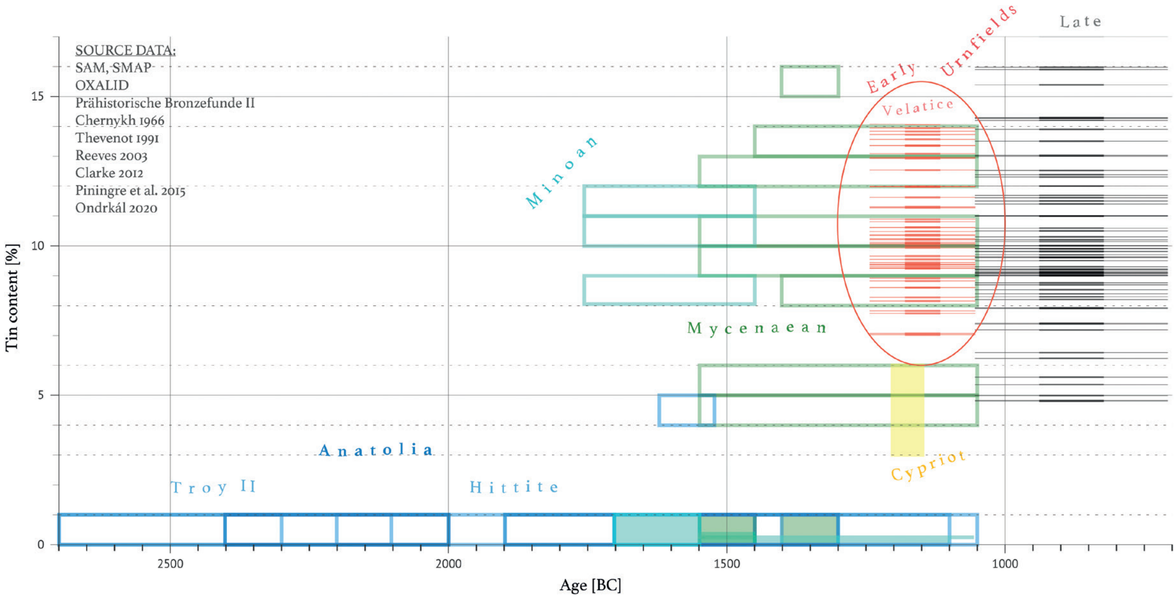

Fig. 5. Evaluation of the tin content of Bronze Age bronze sheet vessels from Western Eurasia (sources: SAM; SMAP; OXALID; *Prähistorische Bronzefunde* Ser. II; Chernykh 1966; Thevenot 1991; Reeves 2003; Clarke 2012; Piningre *et al.* 2015; Ondrkál 2020).

Discussion

The revealing of the technological knowledge associated with the metalworking toolkit in the Hrádok hoard led to the emergence of a novel field of research aimed at reconstructing how Early Urnfield communities produced their metal artefacts in well-organised metalworking centres.[92] The composition of this hoard is unlike others of the Kurd horizon,[93] characterised generally by weapons, tools, and jewellery for females and the absence of metalworking equipment. Composition-wise, analogies to the Hrádok I hoard are known from distant sites in Europe (Génelard, Murnau).[94] The find material of Kozol–Hrádok indicates very intensive and large-scale metalworking on the site, although no exploited mineral resources are known in the vicinity, suggesting that this central settlement possessed a remarkable capacity to mobilise huge amounts of resources, a large population, and a far-reaching distribution network, which, eventually, could lead to certain individuals establishing new power structures related to centralised political control over the local

90 Reeves 2003.

91 Srinivasan 2013.

92 Fregni 2023a, Figs 2–8.

93 Mozsolics 1985, Taf. 276.

94 Thevenot 1998; Nessel 2019.

metallurgical activity.[95] The composition of the metalworking toolkit in the Hrádok hoard follows a general European pattern, indicating that the metalsmiths using it had the same high level of metallurgical knowledge and skills as their peers throughout the continent, which in turn presupposes well-established and systematic training.

The evidence of large-scale, multi-phase production of bronze artefacts by communities of the Early Urnfield culture opens a rare opportunity to examine the emergence and development of a highly specialised craft at a time when the cultural 'periphery' represented by the Carpathian Mountain Range and the neighbouring 'core area' of civilisations (such as Mycenae) were undergoing major socio-political changes due to the collapse of palatial centres around 1250±50 BC.[96] In this sense, the presented collection is evidence of the appearance of innovative approaches in metallurgy and bronze processing within the Urnfield culture. Urnfield communities integrated techniques learned from the 'core area' and developed their own technology, which is particularly evident in the production of thin-walled bronze vessels. This 'Urnfield technology' includes decorating artefacts with concentric circles and a knob-like pattern *(Gleich-Buckel-System)* using punches (Fig. 2.7–9) and a swage block (Fig. 2.12), shaping vessel bellies with a small smoothing hammer (Fig. 2.13; *Ballhammer*; *Treibfaust*) or riveting metal to leather using a patterned punch (Fig. 3). The advanced two-part metal mould (Fig. 2.3–4), for producing links for chains, even surpassed the technical knowledge and skills of the Mediterranean metalworking circle: it was cast from metal in a multi-stage process and enabled producing a chain with inseparable links.[97] Such technological innovations resulted in the production of unique and unparalleled items, through which the craftsman could advertise his technical skills and knowledge, actively promoting them in diverse cultural milieus and regions.

Conclusion

The isolated site of Hrádok nad Váhom at Kozol (Western Slovakia) yielded a wide range of tools for metal processing, including two-part casting moulds, equipment for hammering and bending sheets, drawing and coiling/twisting wires, straightening and profiling bars, annealing, soldering, riveting, decorating, embossing and polishing. Ethnographic examples give evidence of the practice where solitary blacksmiths do not allow others to observe them working to prevent outsiders from learning the craft, thus ensuring the high value of their products.[98] The absence of spherical hammers in the Hrádok hoard supports the earlier assumption that sheet-metal vessels were crafted in Europe by raising on a high bowed wooden stake with a round face and that angular hammers work very well in all the respective hammering processes. The evaluation of the tin content of some metal vessels has also revealed that certain procedures, such as hot forging, could not be used because they required a bronze blank with a specific tin content. Since these vessels were created by cold hammering, annealing played a large role in their making.

The metalworking toolkit discovered in the Hrádok hoard corroborates the current view about the technological history of Europe in connection with the demise of the Mycenaean palaces in the 13th century BC when important metalworking centres specialised in sheet bronze processing emerged in the Carpathian region. Their products were widely distributed in northern and western Europe. The technique of making thin-walled bronze artefacts developed at Knossos and adapted by the Mycenaean workshop circle and, later, the Urnfield Culture indicates an active transfer of know-how between different cultures and regions. This suggests that technological development was not

95 Vandkilde 2021; Nessel 2023, 81.

96 Middleton 2024.

97 Vorlauf 1990.

98 Adair 1989.

an isolated phenomenon but rather the result of dynamic interactions between different communities: the collapse of the palace system and the related cease of monopoly allowed skilled craftsmen to work for other patrons, especially further north, where metalsmiths were limited by the absence of skills rather than the lack of metals. The expansion of the Urnfield Culture was determined not only by technological development; the emergence of a caste of heavy warriors with full armour, including a helmet, a cuirass, a shield, and greaves, also facilitated it. The first sheet-bronze armour was made in the western Carpathians at the beginning of the Urnfield civilisation.[99]

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99 Ondrkál 2022.

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