ПРВИ АРХЕОМЕТАЛУРШКИ РЕЗУЛТАТИ НА ПРЕДМЕТИ ОД БРОНЗЕНО И ЖЕЛЕЗНО ВРЕМЕ ОД СЕВЕРНА МАКЕДОНИЈА
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Introduction

In contrast to numerous comprehensive studies on typology, chronology and symbolism of metal finds from North Macedonia,[1] metallurgical aspects were rarely in the focus of archaeological research. Thus, current knowledge about technology, raw material supply and provenance of raw materials for the Bronze and Iron Ages in this part of the Balkans is very limited.

The preliminary archeometallurgical investigation presented here included 54 metal finds from North Macedonia with a significant typological and chronological range. The Mycenaean sword from Tetovo from the 15th or early 14th century BC represents the oldest specimen among the analyzed objects,[2] followed by a variety of Late Bronze Age finds (pins, knives, swords, socketed axes) from Ulanci,[3] Manastir,[4] Štip[5] and Mali Do[6] (13th–11th centuries BC). Indicative of a transition between the Late Bronze and the Early Iron Age, according to Aegean chronology (11th–10th centuries BC), are finds such as the grip tongue sword of Vergina type from Sivec near Prilep[7] or the bow fibula of "Liburnian type" from Demir Kapija.[8]

The latest group consists of pendants and other jewelry from graves in Milci,[9] Bučinci[10] and Lisičin Dol[11] (9th–6th centuries BC). These decorative, lavish items, frequently described as Macedonian or

[1] To name just the most prominent ones: Bouzek J., 1973, 278; Bouzek J., 1974; Kilian K., 1975, 140; Garašanin M., 1983, 786; Vasić R., 1987, 680; Mitrevski D., 1999, 69; Harding A., 1995, 20; Чаусидис Н., 2017.

[2] Harding A., 1995, 21, pl. 4, 23.

[3] Videski Z., 2007, 318.

[4] Јовчевска Т., 2008.

[5] Garašanin M., 1983, 797.

[6] Папазовска А., 2019, 148.

[7] Harding A., 1995, pl. 22, 189; Pabst S., 2009, fig. 6.

[8] Vasić R., 1999, T. 24, 274.

[9] Пашиќ Р., et al., 1987; Хусеновски Б., 2005, 89; Хусеновски Б., 2015, 11; Хусеновски Б., 2017, 37.

[10] Videski Z., Temov S., 2005; Mitrevski D., 2007, 571.

[11] Митревски Д., 1999, 69; Videski Z., 1999, 97-99; Mitrevski D., 2007, 571.

Paeonian bronzes, originate from richly equipped female graves. Following the interpretation of D. Mitrevski[12] or N. Chausidis,[13] the female individuals with abundant jewelry sets could be connected with cult performance.

The majority of the other analyzed metals are also grave finds from sites such as Ulanci, Sivec or Mali Dol. Somewhat unclear is the context of the objects from Manastir. According to the original publication, the artefacts were encountered in stone and daub constructions with occasional appearance of burned human and animal remains.[14] The investigated area was described as a necropolis, but the grave catalogue or grave numeration is missing, which makes it difficult to assign the finds to a certain burial. Some of the discovered metals were obviously deposited very close to one other and could also represent smaller hoards within the abandoned settlement area. The last stage of the settlement in Manastir is characterized by a burnt layer, indicating destruction, most likely caused by impact from outside.[15]

The context of the Mycenaean sword from Tetovo is also uncertain, but in most publications this weapon has been addressed as "a probable grave find".[16]

Sampling and Methodology

The specific typological and chronological information for each artefact forms the basis for the sampling strategy. The samples were taken with a stainless-steel drill with a diameter of 1 mm; in total a maximum of 30-40 mg of metal powder was collected. Afterwards the holes were documented and then closed with a special ph-neutral green coloured resin,[17] in order to make it unrecognizable on the surface. In a first step, X-ray fluorescence analyses (ED-XRF)[18] were carried out to examine the concentration of the major-, minor- and trace elements. As a following step Multicollector Inductively Coupled Plasma-Mass Spectrometry (MC-ICP-MS) was applied to determine the lead isotope ratios[19] of the objects. These analyses were carried out at the Curt Engelhorn Centre Archaeometry, Mannheim. In order to establish an analytical baseline for comparing the results of the copper-based objects found in North Macedonia, it was also necessary to include results of analyses from the surrounding regions.[20]

ED-XRF Results

The obtained results offer the possibility for several different considerations. Chemical analyses of trace elements (ED-XRF) enable the comparison of objects among themselves and the best-case recognition of first clusters that point to similar metallurgical background and/or raw material supply for certain chronological or/and regional groups. Although it is possible to make some general observations about the copper ores used to produce the metal, the XRF does not provide information about provenance of raw material. More reliable for this purpose is lead isotope analysis, which was in this case applied to the sword from Tetovo (Fig. 5).

Within the first step, the trace element concentrations of As, Ag, Bi, Ni and Sb of metals from North Macedonia were combined in double logarithmic diagrams to detect possible correlations or differences (Fig. 1).

[12] Митревски Д., 1999, 69; Mitrevski D., 2007, 563.
[13] Чаусидис Н., 2017, 849.
[14] Јовчевска Т., 2008, 16-22.
[15] Папазовска А., 2019.
[16] Harding A., 1995, 21.
[17] Mixture of cosmoloid H80 (acid free) and microcrystalline green coloured special wax.
[18] Lutz J.- Pernicka E., 1996.
[19] Niederschlag et. al., 2003.
[20] Gavranović M.-Mehofer M., 2016.

Clearly distinguishable from all other finds are two samples from the Mycenaean sword (from the blade and from the rivet), both characterized by a very low nickel concentration (Lab. Nr. MA-186791 and MA-196192) (Fig. 1 and Fig. 2). Compared to other finds from North Macedonia, the two samples from the sword contain significantly less silver and antimony, which could be an indication of a different copper source. To be underlined is the fact that the two samples from the sword do not overlap, meaning that they do not originate from exactly the same copper alloy. The differing tin value in the blade (9%) and in the rivet (4%) is additional evidence that the blade and the rivet were made of at least two diverse alloy charges. Thus, even if the copper comes presumably from the same source(s), the production of the sword and the rivets obviously included at least two different alloy mixtures.

The majority of the other samples from North Macedonia can be divided into two clusters that more or less correspond with the chronological distinction of the objects. The first cluster includes samples with higher nickel concentration that appears to be indicative of Late Bronze Age finds. Most of the analyzed Late Bronze Age metals from Manastir (four socketed axes, three pins and a knife[21]), Ulanci (two pins with thickened neck of Fortuna type from grave 80 and a spearhead[22]) and Mali Dol (a pin with nail-shaped head and thickened neck from grave 28, two mace-head pins from grave 29, a nail with profiled head from grave 30 and a pin with slightly thickened, perforated neck from grave 43[23]) all have also comparable values when it comes to the proportion among nickel-silver, nickel-arsenic and nickel-antimony (Fig. 1, all triangles). A similar chemical composition is attested also for the pin with thickened neck from Fortuna near Štip (Fig. 1, triangle in the LBA group).[24]

Very few analyzed Late Bronze Age objects differ from this cluster. The first one is a knife from inhumation grave 28 in the cemetery of Mali Dol (Lab. Nr. MA-196219) (Fig. 1,3).[25] Interestingly, all other analyzed metals from Mali Dol, including also a pin from the same grave, expose comparable composition and build a coherent group (Fig. 1). The knife with rectangular grip with no rivets from grave 28, however, stands out due to a much lower amount of nickel and antimony than the other objects from the graveyard (Fig. 1,3). In terms of typological determination, the knife is assigned to a local variant marked by incised lines along the spine of the blade.[26] Similar knives are known mostly from the sites along the middle Vardar valley or from the area that is conceived as the territory of the Ulanci group of the Late Bronze Age.[27] Based on results of XRF analysis, it is not possible to provide a definite answer regarding the different chemical composition of the knife, but it can be assumed that the production of bronze objects from Mali Dol involved different raw materials.

In the case of two other outliers, it is significant that they both belong to a somewhat later period (11^{th}–10^{th} century) of the transition to the Early Iron Age.[28] Their differing chemical composition of the copper alloy is therefore probably connected with the chronology.

The first object dating to this time is a loop bow-fibula with two knots of so-called "Liburnian type" from the grave in Demir Kapija[29] (Fig. 3,1) that stands out with the highest amount of silver among all analyzed objects and the highest amount of antimony of all Late Bronze Age objects (Lab. Nr. MA-196291) (Fig. 1,1). The graves from North Macedonia, Greece and the western Balkan equipped with this type of jewelry date mostly in the 11^{th} or early 10^{th} century BC,[30] which

[21] Јовчевска Т., 2008, Т. XXV, 1-4; Т. XXVI, 1-3; ТXXVII, 3.
[22] Kilian K., 1975, 91; Videski Z., 2007, 318.
[23] Папазовска А., 2019, Т. XXIII, 1-а, g. е.
[24] Garašanin M., 1983, T. 110,1
[25] Папазовска А., 2019, 131-132.
[26] Папазовска А., 2019, 128.
[27] Mitrevski D., 2003, 46; Видески З., 2006, 92.
[28] Vasić R., 1999, 46; Pabst S., 2009, 34; Pabst S., 2013, 111.
[29] Vasić R., 1999, 45-46, T. 24,274
[30] Корошец Ј., 1956, 107; Vasić R., 1999, 46; Teržan B., 2007, 161; Pabst S., 2009, 24.

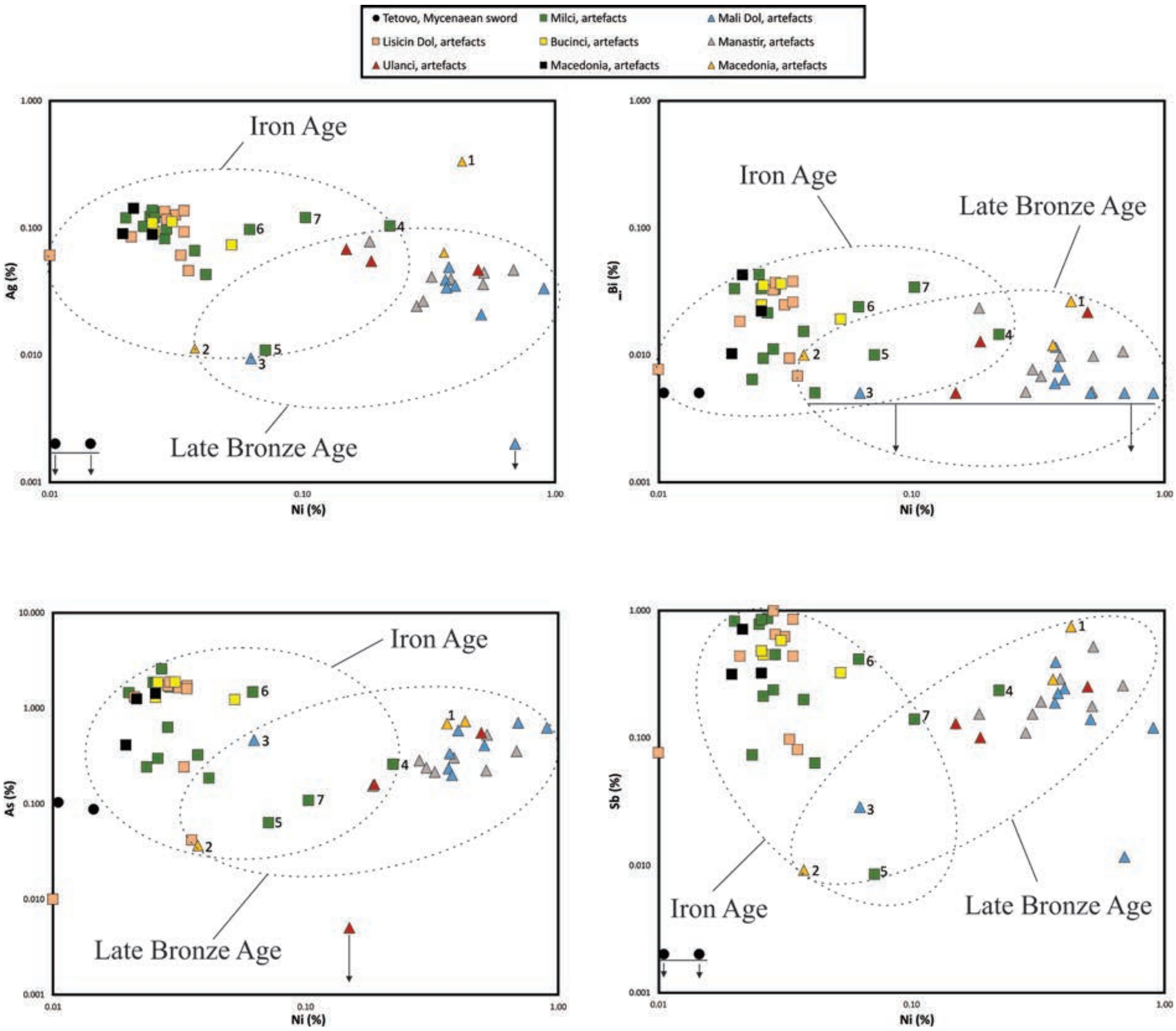

*Fig 1.*In the double logarithmic diagrams of the trace element concentrations, it is recognizable that the Late Bronze Age objects (triangles) form a well separated group from the Iron age artefacts (squares). Numbers 1-7 correspond with the artefacts in Fig. 2 and Fig. 3. ©M. Mehofer, University Vienna.

is considerably later than the finds from Manastir, Ulanci and Mali Dol (13th–12th century BC). Worthy of note is also the assumption of R. Vasić that the fibula from Demir Kapija could represent an import from the south (Greece) since it has a specific bow decoration, not observed on other finds of this type from North Macedonia.[31]

The second object with a significant gap to the LBA cluster is a grip tongue sword from Sivec, Prilep[32] (Fig. 3,2) with a very low nickel and antimony concentration in relation to all other analyzed finds (Lab. Nr. MA-186790) (Fig. 1,2). In terms of typological classification, the sword from Sivec with two rivets on the shoulder, slender long blade and fishtail ending of the grip shows close similarities with iron swords from the cemetery at Vergina.[33] S. Pabst described similar swords made of bronze and iron as a regional form from the southern and eastern Balkans that emerged around the 11th century BC under the influence of classical grip tongue swords of Reutlingen type from central

[31] Vasić R., 1999, 46.

[32] Гарашанин М., et al. 1971, 19, 54 кат. 207; Митревски Д., 1997, 307, кат. 52; Harding A., 1995, pl. 22, 189.

[33] Kilian-Dirlmeier I., 1993, 113-115.

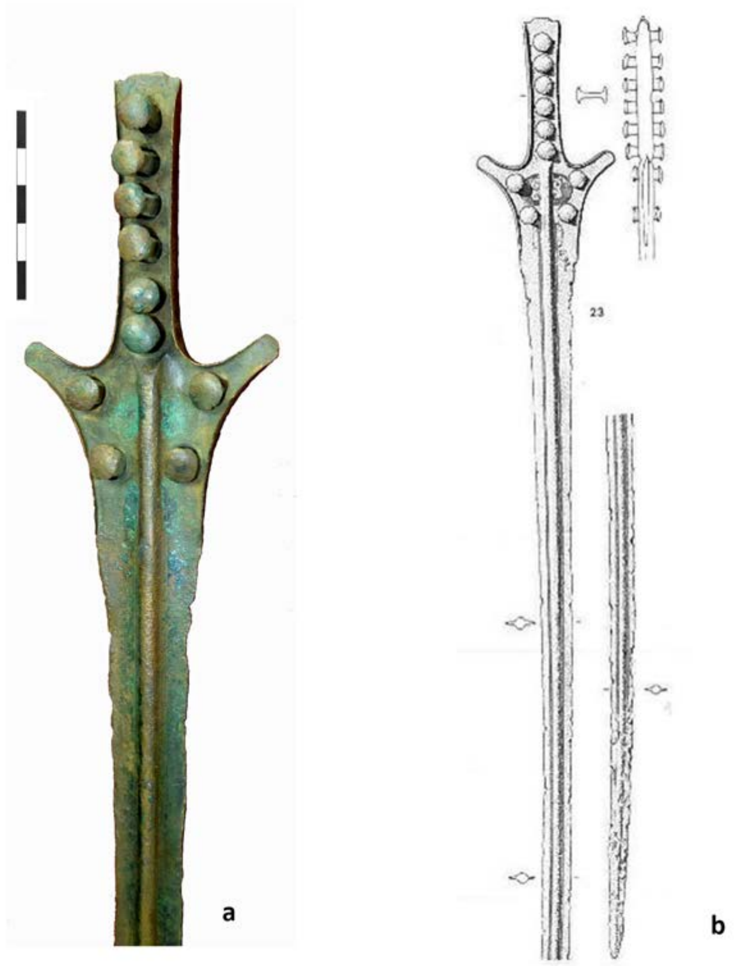

Fig. 2 Sword from Tetovo, a). Photo, M. Gavranović
(Archaeological Museum of Republic of North Macedonia, Skopje), b). after Harding 1995.

Europe.[34] Furthermore, she also stressed the correlation between the Vergina type and swords of the so-called "Dalmatian type", assuming that the area of origin of this weapon type could be located in the western Balkans.[35] The connection between the sword from Sivec and the iron swords from Vergina is additionally underlined by the fact that the bronze sword had iron rivets, which according to D. Mitrevski are the oldest iron artefacts in North Macedonia.[36] The difference to observe is in the number of grip rivets, since swords from Vergina have one or two, while the find from Sivec has three grip rivets, which is again an attribute more characteristic for the Reutlingen type from the 12th century BC.[37] The differing chemical composition of the sword from Sivec in relation to other analyzed Late Bronze Age finds is therefore not surprising, given that this weapon dates in the transitional period between the Late Bronze and the Early Iron Age following the chronology of the southern Balkan area[38] and that the probable area of origin is to be sought in other regions of Southeast Europe (western Balkan).

[34] Pabst S., 2009, 22, Abb. 6
[35] Pabst S., 2009, 23. See also Bouzek J., 1985, 126; Harding A., 1995, 55; Teržan B., 1990, 60.
[36] Митревски Д., 1997, 26; Pare C., 2017, 32.
[37] Pabst S., 2009, 22.
[38] Kilian K., 1975, 11; Pabst S., 2013, 109.

Fig. 3 Late Bronze Age outliers (corresponding to the number in the diagram) 1. Bow fibula from Demir Kapija 2. Grip tongue sword from Sivec; 3. Knife from Mali Dol, grave 28 (Archaeological Museum of Republic of North Macedonia in Skopje, Photo M. Gavranović, A. Papazovska).

In summary, one may conclude that the analyzed Late Bronze Age objects, aside from discussed outliers, form a relatively coherent cluster that could result from a similar raw material basis. Nevertheless, some of the objects like the knife from grave 28 in Mali Dol reveal certain deviations. At this stage, it is not clear if this distinction is caused by diverse sources on a local level (e.g., two veins of the same deposit area) or because the copper originates from some other, more distant regions. The other two outliers (a sword from Sivec and a large bow fibula from Demir Kapija) firstly are chronologically later, and secondly both types have wider distribution in the Balkans. However, although both are exceptional among the finds from North Macedonia, these two objects do not have a nearly similar chemical composition, which leads to the assumption that they are probably products of different metallurgical backgrounds.

The second distinct cluster within the XRF analysis is represented by Iron Age finds. They include four items from grave 12 in Bučinci (a bird cage pendant, bronze pyxis, bracelet and a bird pendant)[39], four pieces from the famous grave 15 in Lisičin Dol (pyxis, belt disc, crescent-shaped pendant and a curved, open-work pendant with animal representation)[40], two bronzes from grave 338 in Lisičin Dol (bow fibulae with round foot plate and composite open-work pendant with bird

[39] Temov S., 2007, 657-665; Mitrevski D., 2007, Fig. 11.

[40] Митревски Д.,1999, Т. III, 6.3.4.1

depictions)[41] and three composite open-work pendants from grave 357 in Lisičin Dol [42] as well as a series of finds from the cemetery in Milci near Gevgelija from graves Nr. 23 (double loop bow fibula with triangular foot),[43] Nr. 31 (spectacle fibula with iron pin of Milci type),[44], Nr. 48 (pyxis),[45] Nr. 54 (spectacle fibula with figure eight loop of Vergina type),[46] Nr. 56 (pin with bowl-shaped head),[47] Nr. 99 (open-work belt disc),[48] Nr. 111 (composite open-work pendant with bird depictions, triangular open-work pendant with bird cage pendants and wheel-shaped pendant with three bird cage pendants),[49] Nr. 125 (lyre-shaped pendant)[50] and Nr. 150 (triangular pendant and a small fibulae of Phrygian type). Samples have been taken also from an animal-shaped pendant from Valandovo,[51] a pyxis with bird depictions from Dedeli[52] and from the lid of a pyxis from Grčište.[53]

The chronological frame of the sampled Iron Age objects, mostly belonging to the group of so-called "Macedonian Bronzes", is set between the late 9th and early 6th centuries BC.[54] With regard to the chemical composition, most of the analyzed finds cluster together in one group characterized by considerably lower nickel concentration as compared to the Late Bronze Age finds (Fig. 1). Only metals from Milci cemetery show a wider range of different trace element concentrations, whereas the bronzes from Bučinci, Lisičin Dol, Dedeli and Grčište expose a mutual resemblance pointing to similar raw material and technology. One object, which can be classified as an outlier, is a bow fibula with round shaped foot plate from grave 338 in Lisičin Dol (Fig. 1, square with lowest nickel value, on the line). This specimen differs in all concentrations from all the other Iron Age finds. Its measurement results are affected by corrosion from the surface and therefore these concentrations - especially the tin concentration (14%) - have to be treated with caution. From the typo-chronological perspective, the fibula represents one of the characteristic regional forms of the late 9th and 8th centuries BC in an area between Kosovo and the Vardar valley in North Macedonia.[55] Hence, there is no strong archaeological indication that fibula from grave 338 in Lisičin Dol could originate from some other region.

Regarding the several objects from the Milci necropolis in an outlying position in relation to the Iron Age cluster (Fig. 1,4-6), it is symptomatic that they all belong to archaeological bronze types of wide, supra-regional distribution.

The first one is a double-loop bow fibula with triangular foot and incisions on the bow section ("false twisting") from grave 23 (Fig. 4,4) with the lowest nickel amount of all Iron Age objects (Lab. Nr. MA-196198) (Fig. 1,4). The big triangular foot of the fibula is decorated with incised hatched triangles along the edges.[56] This specific jewelry type is characteristic for the western Balkan area with most finds coming from graves and settlements of late 8th and early 7th centuries in eastern and central Bosnia.[57] Other examples are known from northern Croatia (Sotin) and western Serbia

[41] This grave is not yet published yet. We want to express gratitude to the excavators of the necropolis Strahil Temov and Zlatko Videski for all information.

[42] Also still not published. We want to express gratitude to the excavators of the necropolis Strahil Temov and Zlatko Videski for all information.

[43] Пашиќ Р., et al., 1987, T. 25,623; Vasić R., 1999, T. 27,322.

[44] Vasić R., 1999, 31, T. 9,119; Pabst S., 2008, 94.

[45] Mitrevski D., 2007, Fig.6,1.

[46] Vasić R., 1999, 37, T. 15, 204; Pabst S., 2008, 39.

[47] Митревски Д., 1991, T. 1,1.

[48] Хусеновски Б., 2018, Fig. 4.

[49] Хусеновски Б., 2018, Nr. 16, Nr. 18. and Nr.6

[50] Хусеновски Б., 2018, 40.

[51] Archaeological Museum of North Macedonia in Skopje, Inv. 849.

[52] Archaeological Museum of North Macedonia in Skopje, Inv. 1224.

[53] Archareological Museum of North Macedonia in Skopje, Inv. 846.

[54] Bouzek J., 1974. 280; Kilian K., 1975, 84; Vasić R., 1987, 717; Митревски Д., 1991,15; Pabst S., 2008, 618.

[55] Митревски Д., 1991, 156; Vasić R.,1999, 54–55, T. 63B

[56] Vasić R., 1999, T. 27,322

[57] Gavranović M., 2007, 163.

(Stapari).[58] The fibula from Milci appears currently as an isolated point on the distribution map, in a remote position from the main concentration.[59] To a certain extent, the results of the XRF analyses corroborate the archaeological assumption that the fibula from grave 23 in Milci could be of a different manufacture or raw material origin than most of the other analyzed Iron Age finds from North Macedonia.

The second specimen from Milci with marked distance to the Iron Age cluster is the spectacle fibula with iron pin from grave 31/35.[60] (Fig. 4,5) Among all finds from Milci, this is the object with the lowest concentration of silver, arsenic and antimony (Lab. Nr. MA-196200) (Fig. 1,5). Based on the section of the bronze wire (rhombic on the outside of the spectacle discs), S. Pabst defined a spectacle fibula of Milci type which, except at Milci, included only two other distant finds from central Croatia (Prozor) and western Slovenia (St. Lucija).[61] Hence, currently it is not possible to narrow down the presumable area of origin of this jewelry type. In terms of chemical composition, the fibula differs considerably from other Iron Age objects from North Macedonia, suggesting use of different raw material and/or production in another workshop. In grave 31/35, the spectacle fibula was associated with a set of bow fibulae, arm spirals and pottery, which all indicate a female individual.[62] Among all hitherto uncovered graves in Milci, the burial 31/35 belongs to the oldest ones (9th or early 8th century BC).

The third significant outlier is a spectacle fibula from grave 54 in Milci, which belongs to the Vergina type according to S. Pabst[63] or the Haslau-Regelsbrunn type according to R. Vasić.[64] (Lab. Nr. MA-196199) (Fig. 4,6). Comparable fibulae appear mostly in northern Greece, North Macedonia and Albania between the 10th and 8th centuries BC.[65] In terms of chemical composition, the fibula from grave 54 displays somewhat different values than the majority of the finds from Milci with marginally lower nickel concentration (Fig. 1,6), but at this point it is not possible to speculate about possible origin or raw material.

The chemical composition of the pin with bowl-shaped head (Fig. 4,7) from grave 56 in Milci shows no clear bond to any of the clusters or groups (Lab. Nr. MA-196206) (Fig. 1,7). This is an object with the second highest amount of nickel among all Iron Age finds (next to the double loop fibula with triangular foot) and an arsenic concentration similar to that of a spectacle fibula of Milci type (Fig. 7). The pin was found together with an iron grip tongue sword and dates to the 8th century BC.[66] Analogies in the wider area of the Balkans are rare. One similar piece with bowl-shaped head was discovered in a cremation grave at Bajnici in northern Bosnia, together with a set of iron items (spearhead, knife).[67] Pins of this type occur far more frequently in northern Italy during the same period (8th century BC).[68] The lack of any archaeological and archeometallurgical affiliation to the domestic repertoire point to the fact that the pin with bowl-shaped head from Milci is presumably of foreign origin. Consequently, the appearance of this jewelry in North Macedonia is probably attributed to supra-regional connections and exchange of people or goods.

Regarding the Iron Age cluster with finds from Bučinci, Lisičin Dol and with the majority of objects from Milci (Fig. 1), only general remarks can be made. Typical for most of the analyzed "Macedonian Bronzes" is a low nickel and relatively high antimony value, while silver and arsenic

[58] Vasić R.,1999., 52.
[59] Gavranović M., 2007, Fig. 8.
[60] Пашиќ Р., et al., 1987, T. 11; Vasić R., 1999, 31, T. 9, 19; Pabst S., 2008, Fig. 9.
[61] Pabst S., 2012, 94.
[62] Pabst S., 2008, 617
[63] Pabst S., 2012, 39.
[64] Vasić R., 1999, 37.
[65] Kilian K., 1975, 107; Pabst S., 2012, 40.
[66] Митревски Д., 1991, T. 1.; Vasić R., 2003, 94.
[67] Čović B., 1987, 238.
[68] Pare C., 1998, 311.

amounts are comparable with the Late Bronze Age objects (Fig. 1). Compared to the Late Bronze Age, the main difference is the use of copper with a significantly lower nickel concentration, which could be the consequence of altered supply networks and inclusion of new raw material sources in the production of metal objects.

Lead Isotope Analyses - Sword from Tetovo

The results of XRF analyses highlighted the isolated position of the sword from Tetovo (Fig. 2) in comparison to other samples from North Macedonia (Fig. 1). Based on typological determination as a Mycenaean sword of type C1 following N. Sandars' typology[69] or type 1b according to I. Kilian-Dirlmeier,[70] but with no exact analogies among finds from Greece or Cyprus, the question was to what extent the analytic results could support the hypothesis about the foreign (Aegean) provenance of the sword. This is the reason why the sample from the blade was additionally examined with lead isotope analyses. This method was applied with the aim to include or exclude ore deposits as possible sources of the copper used in the production of bronze. The comparison of lead isotope ratios of ore deposits and finished products is the most common method to examine the provenance of the copper, since the lead isotope signature remains unchanged regardless of actions in between (smelting, alloying, heating).[71] The main premise for the provenance analyses is a broad database of lead isotope signatures for copper ore deposit areas or large series of ingots (Fig. 5). In the wider

Fig. 4 Iron Age outliers (corresponding to the number in the diagram) 4. Double loop bow fibula from Milci, grave 23; 5. Spectacle fibula from Milci, grave 31/35; 6. Spectacle fibula from Milci, grave 5; 7. Pin with bowl-shaped head from Milci, grave 56. (Archaeological Museum of Republic of North Macedonia in Skopje, Photo M. Gavranović, A. Papazovska).

[69] Sandars N., 1963, 121.
[70] Kilian-Dirlmeier I., 1993, 47.
[71] Pernicka E., 1990.

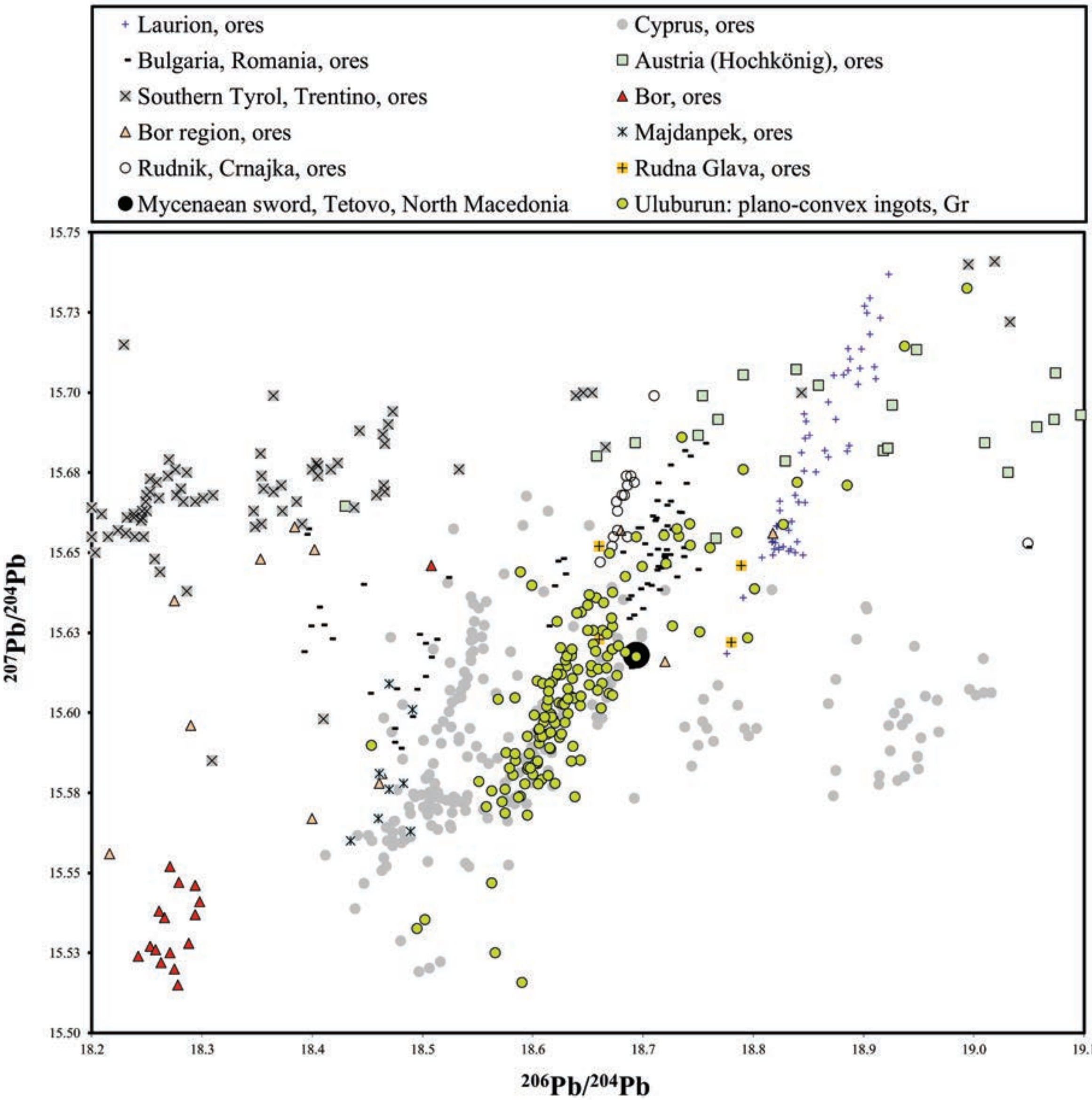

Fig. 5 The lead isotope diagram presents a combination of various ore deposits in Austria, Cyprus (grey circles), Bulgaria, Romania and Eastern Serbia with the Mycenaean sword of Tetovo (black circle) and the oxhide ingots from the shipwreck of Uluburun (green circles) Data sources: Pernicka et al. 1993, 26 Tab. 8; Stos-Gale 1996, 384 Tab. 2; Gale u. a. 1997, 241–246 Tab. 2–6; Pernicka et al. 1997, Tab. 168 Tab. A5; Stos-Gale u. a. 1998, 122 Tab. 2, 3a, 4, Pernicka et al. 2016, 54 Tab. 5, 55 Tab. 6.

Balkan area, the lead isotope signatures are available for deposits in Eastern and Central Serbia and Bulgaria. Other regions with sufficient amount of data include Cyprus, North Italy (South Tyrol and Trentino) and Austria (Hochkönig-Mitterberg). Large series of lead isotope data exists also for ingots from the Uluburun shipwreck (Fig. 5).

The lead isotope values of the copper used for manufacture of the blade from Tetovo fall clearly into the cluster of copper deposits from Cyprus and corresponding ingots from the Uluburun shipwreck (Fig. 5),[72] while the nearby deposits from Eastern Serbia and Bulgaria can be excluded as a possible

[72] Stos-Gale Z., et al., 1998, 122 Tab. 2, 3a, 4.

ore source. This result increases the probability that the sword from Tetovo actually originates from the Aegean-Mycenaean world and not from a local workshop. There is also a possibility that some of the local workshops used copper raw material from Cyprus, but the archaeological record is currently not supportive of this assumption.

Tin and lead

The differing tin concentrations of a blade and a rivet from the sword from Tetovo point to different alloys used for the manufacture of the sword. The higher concentration of tin in the copper alloy for the blade is expectable due to the requirement for hardness and elasticity of the material. The rivets of the grip were obviously made out of an alloy with a considerably lower amount of tin (Fig. 6). The low lead concentration in both alloys corresponds well with the values of oxhide ingots from the Uluburun shipwreck[73] and represents an additional indicator of the Aegean origin of the sword.

Given the amount of tin in other Bronze and Iron Age artefacts from North Macedonia, the present data suggests a relatively stable supply with no clear indications of shortage even in the later periods (Fig. 6). Only a few objects have a tin concentration below the average, with the bow fibula from Demir Kapija (1,8%) and the spectacle fibula of type Vergina from Milci (3,7%) as the most prominent examples (Fig. 7). Additionally, it is interesting that hardly any object reaches a 10% margin, regardless of their possible function (jewelry, weapon or tool) or dating.

The relatively low amount of lead in the Late Bronze (mean 0,2 %) but also in the Iron Age (mean 1%) is most probably transferred with the copper ore. Further intentional addition of lead into the copper alloy can almost certainly be ruled out in the case of the analysed metals from North Macedonia.

Conclusion and Outlook

The analytic results for Bronze and Iron Age bronzes provided the first insight into metallurgical development in the territory of North Macedonia and revealed the existence of several possible exchange networks on a supra-regional level.

The sword from Tetovo is apparently not only typologically but also technologically closely connected with the Mycenaean world of the 15th and 14th centuries BC (Fig. 2). In this context, it is noteworthy that the find from Tetovo belongs to a small group of Mycenaean swords from the central Balkans, together with objects from Iglarevo in Kosovo and Guvnište in the Morava valley.[74] While the two swords from the Iglarevo necropolis can be associated with type A after Sandars or rather a local adjustment of type A,[75] the single find from Guvnište corresponds with type 1b after Kilian-Dirlmeier, although it probably also represents a local adaptation.[76] The ongoing analyses of the objects from Iglarevo and Guvnište within the frame of the above-mentioned research project will, together with the results obtained for the sword from Tetovo, contribute to a better understanding of relationships between the central Balkans and the Aegean in the Late Bronze Age. The sword from Tetovo as well as a number of other finds emphasises once more the important role of North Macedonia in the interactions between Mycenaean civilisation and the Balkans.[77]

The other analysed objects are divided in terms of chemical composition into two chronological clusters with Late Bronze Age objects on one side and Iron Age metals on the other. With few exceptions, most of the finds from the Late Bronze Age sites Manastir, Mali Dol, Ulanci and Štip

[73] Hauptmann A.- Maddin R.- Prange M., 2002, 20–23 tab. 1.
[74] Jung R., 2017, 70.
[75] Harding A., 1995, 25.
[76] Filipović V.- Milanović D. - Milojević P., 2015.
[77] Videski Z., 2007a, 211.

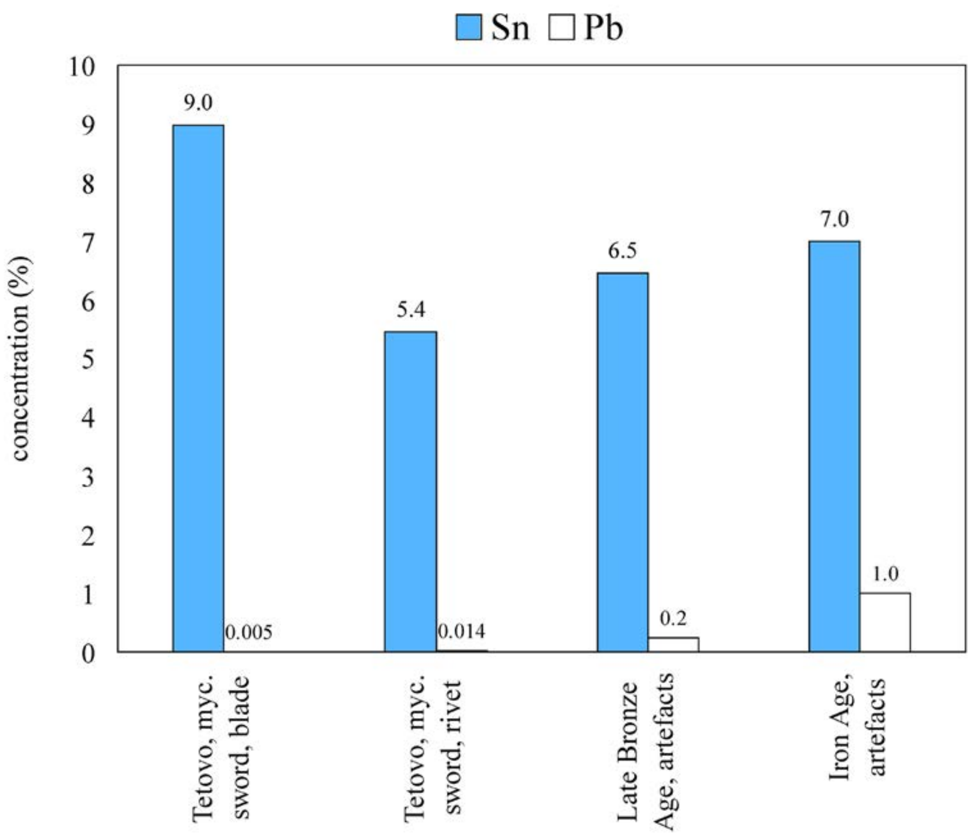

Fig. 6 The histogram shows a comparison of the tin (Sn) and lead (Pb) concentrations of the Mycenaean sword from Tetovo and the North Macedonian artefacts dated to the Late Bronze Age and Iron Age. ©M. Mehofer, University Vienna.

expose a similar composition that could indicate use of similar sources of raw material. Outliers like the bow fibula from Demir Kapija (Fig. 3,1) or the sword from Sivec (Fig. 3,2) are, however, an indicator for other networks that can be associated with exchange of materials or presence of non-local individuals.

Closely associated in terms of chemical compositions is the majority of Iron Age finds from graves in Bučinci, Lisičin Dol and Milci. They form a specific cluster that is distinguished from the Late Bronze Age group with regard to the nickel concentration (Fig. 1). This fact can be attributed to the change of raw material source(s) which is not surprising if one bears in mind the significant chronological discrepancy. Nevertheless, it is remarkable that several outliers in the Iron Age group do correlate with forms not widely distributed in North Macedonia, such as a two-loop fibula with triangular foot (Fig. 4,4) or a pin with bowl-shaped head (Fig. 4,7). Together with the archaeological evaluation, the chemical composition is another piece of evidence that supports the foreign provenance of these objects.

At this point it is not possible to propose which copper ore sources played an important role for the bronze metallurgy in North Macedonia. Crucial for further investigations is not only an increased number of samples but also analytic assessment of the local copper ore sources, particularly in the Bučim area near Štip that is exploited until the present day. The prehistoric exploitation of local copper ore deposits for this region is still just a theory without clear tangible evidence. Therefore, one of the main goals of future research will be to examine possible use of copper ore sources from

Lab. no.	Cu	Fe	Co	Ni	As	Se	Ag	Sn	Sb	Pb	Bi	mus. no.	object	context	mus.no./ inv. no.	site
MA-186790	92	0.19	0.02	0.04	0.04	<0.005	0.011	6.3	0.009	1.14	<0.01	24	grip-tongue sword	Grave 2	24	Sivec
MA-196198	92	0.07	0.04	0.22	0.26	0.01	0.103	6.0	0.235	1.06	0.01	655	double-loop bow fibula with triangular foot	Grave 23	655	Milci
MA-196199	93	0.12	<0.1	0.06	1.47	<0.1	0.097	3.7	0.41	0.88	0.02	756	spectacle fibula with figure eight loop	Grave 54	756	Milci
MA-196200	93	0.16	0.01	0.07	0.06	<0.1	0.011	5.4	0.008	0.88	<0.01	683	spectacle fibula with iron pin	Grave 31/35	683	Milci
MA-196201	95	<0.05	<0.1	0.43	0.73	<0.1	0.33	1.85	0.74	0.56	0.03	43	loop bow-fibula with two knots	Grave?	43	Demir Kapija
MA-196206	90	0.28	0.04	0.10	0.11	<0.1	0.120	7.6	0.140	1.09	0.03	763	pin with bowl-shaped head	Grave 56	763	Milci
MA-196219	92	<0.05	0.05	0.06	0.46	0.006	0.009	6.9	0.029	0.11	<0.005	22669	Knife	Grave 28	22669	Mali Dol
MA-196192	94	0.13	0.01	0.01	0.088	0.009	<0.002	5.4	<0.002	0.014	<0.005	4460a	Mycenaean sword, rivet	Grave?	4460a	Tetovo
MA-186791	91	0.07	0.01	0.01	0.103	0.008	<0.002	9.0	<0.002	0.005	<0.005	4460	Mycenaean sword, blade	Grave?	4460a	Tetovo

Fig. 7. Chemical composition of the analyzed finds from North Macedonia as determined with energy-dispersive XRF. All values are given in mass percent. Zn was below the detection limit of 0.01 %, Te and Cd are below 0.005 % in all samples.

North Macedonia with the help of lead isotope analyses. Moreover, the larger series of lead isotope analyses will also enable us to trace the provenance of the copper in a supra-regional perspective and to compare the results from North Macedonia with available signatures for other deposit areas. For now, it appears obvious that Bronze Age metallurgists used different copper than the Iron Age communities. To pinpoint these sources will be one of the main tasks in the near future.

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ПРВИ АРХЕОМЕТАЛУРШКИ РЕЗУЛТАТИ НА ПРЕДМЕТИ ОД БРОНЗЕНОТО И ЖЕЛЕЗНОТО ВРЕМЕ ОД СЕВЕРНА МАКЕДОНИЈА

р е з и м е

Трудот се фокусира на интерпретација и евалуација на првата поголема серија аналитички податоци (анализа на елементи во трагови и изотоп на олово) од метални наоди од бронза и раното железно време од различни локации во Северна Македонија. Анализите се реализираат во рамките на неодамна започнатите проекти „Нови сознанија во друштвата за производство на метали од бронзеното време“, поддржани од Австриската научна фондација (FWF проект бр. P32095-G25) и „Македонски метали“ иницирани од Институтот за ориентална и европска археологија (OREA).) на Австриската академија на науките, Виенскиот институт за археолошки науки (ВИАС) и Археолошкиот музеј на Република Северна Македонија во Скопје и во соработка со Археолошките музеи во Велес и Гевгелија. Дел од анализите поддржа и Фондацијата д-р Антон Оелцелт-Њин на Австриската академија на науките.

Поради недостаток на аналитички пристап, сегашните сознанија за металуршката и технолошката позадина на производството на метали на база на бакар во Северна Македонија се недоволни. Целта на започнатиот проект е да се проценат можните металуршки и сурови мрежи за снабдување во дијахрониска перспектива помеѓу бронзеното и железното време или во времето помеѓу 15 и 6 век п.н.е. и да се разјасни динамиката на размена помеѓу праисториските групи на Балканот и во соседните земји и региони. Резултатите презентирани во овој труд укажуваат на постоење на различни металуршки мрежи во Северна Македонија за доцното бронзено време од една страна и за железното време од друга страна, што укажува на промени во технологијата и/или снабдувањето со суровини. Се истакнуваат и предмети датирани во времето на транзиција помеѓу доцното бронзено и железното време, кои јасно не се поврзуваат со ниту едно од двете главни кластери. Добро може да се идентификува како надворешно место во збирката на податоци, микенскиот меч од Тетово, кој се чини дека има егејско потекло, како што сугерираат резултатите од анализата на изотоп на олово. Друг прелиминарен исход е кохерентноста на таканаречените „македонски бронзи“ во однос на нивниот хемиски состав. Дополнително интересна е концентрацијата на калај на маса за време на набљудуваниот хронолошки опсег со само многу малку предмети кои содржат помали количества калај.

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