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Transformations of Metal Supply during the Bronze Age in the Carpathian Basin

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This paper presents recent research questions which have been raised and methods which have been used in the study of Bronze Age metallurgy in connection with available natural resources (ores) in and around the Carpathian Basin. This topic fits in the most current trends in the research on European prehistoric archaeology. Given the lack of written sources, copper and bronze artifacts discovered in settlement and cemetery excavations and prehistoric mining sites provide the primary sources on which the studies in question are based. The aim of compositional and isotope analysis of copper and tin ores, metal tools, ornaments, and weapons is to determine the provenience of the raw materials and further an understanding of the *chaine operatiore* of prehistoric metal production. The Momentum Mobility Research Group of the Institute of Archaeology, Research Centre for the Humanities studies these metal artifacts using archaeological and scientific methods. It has focused on the first thousand years of the Bronze Age (2500–1500 BC). Multidisciplinary research include non-destructive XRF, PGAA (promptgamma activation), TOF-ND (time-of-flight neutron diffraction) analyses and neutron radiography, as well as destructive methods, e.g. metal sampling for compositional and lead isotope testing, alongside archaeological analysis. Microstructure studies are also efficient methods for determining the raw material and production techniques. The results suggest the use of regional ore sources and interregional connections, as well as several transformations in the exchange network of the prehistoric communities living in the Carpathian Basin.

Keywords: Copper Age, Bronze Age, metallurgy, scientific analysis, exchange networks

Introduction

Given the lack of written sources from the period in question, an important research question is simply where did the raw materials, used by prehistoric communities come from. If we determine the provenance of stone and metal raw materials, we can venture hypotheses regarding the connections among prehistoric groups. Over the course of the past decade, montan-

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archeological research (*Montanarchäologie;* archeology of raw material mining) and archeometallurgy have proven the existence of several prehistoric copper ore mining sites in various European regions. As a result, most current research trends in the archaeological study of the Copper and Bronze Ages are connected to scientific analyses of metal artifacts discovered in settlement and cemetery excavations, as well as ores found at prehistoric mining sites.[1]

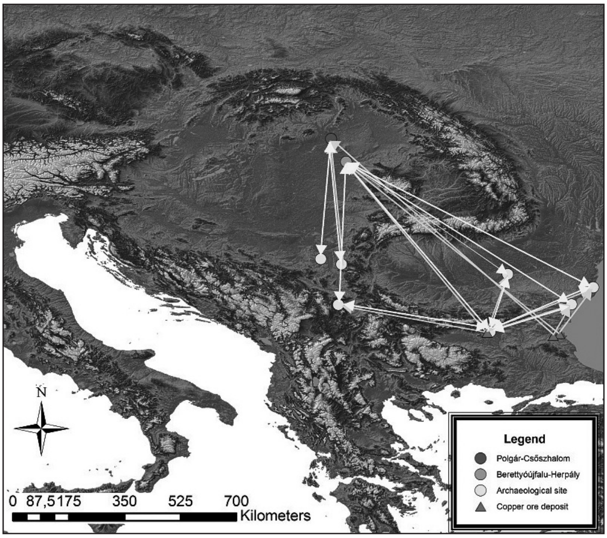

Figure 1. Map of social interactions based on the archaeometallurgical analyses of the first copper artifacts in the Carpathian Basin[2]

In the central areas of the Carpathian Basin metal, ores were not available, or in a very small amount.[3] Compositional analysis of the first small items of copper jewelry, which appeared in the late Neolithic period (the fifth millennium BC), revealed that they were made of high-purity copper. Thanks to recent lead isotope analyses, the conclusion has been reached that these artifacts came to the Carpathian Basin from communities living in the vicinity of mines in Serbia and Bulgaria (Fig. 1).[4] The very few lead isotope data so far indicate that they are objects that were imported from the Balkans even in the Copper Age, possibly with the use of mines in the Slovak Ore Mountains and the eastern Alpine

1 Stöllner, "Montan-Archaeology"; Pernicka et al., "Lead Isotope Analyses."

2 Siklósi et al., "New Data on the Provenance," Figure 34.

3 Ecsedy, "On the early development," 218–20; Szabó, "A késő bronzkori," 24; Szabó, *A dunántúli urnamezős*, 69; Czajlik, *A Kárpát-medence;* Czajlik, "Lokaler, regionaler."

4 Siklósi et al., "New Data on the Provenance."

region.[5] We can suppose that the development of local metallurgy began in the Copper Age.[6]

Analysis of Bronze Age Artifacts in Central Europe

The metalwork of the Bell Beaker culture (around 2500 BC), which began to emerge at the dawn of the European Bronze Age, is an important research topic, mainly because artifacts used by these communities were the first metal objects in the western part of Europe. On the basis of the available data, scholars outlined a uniform metal type, the so-called *Bell Beaker metal*, which consisted of 98% copper with arsenic, antimony, and nickel impurities.[7] A selection of 1,943 trace element analyses of copper finds from the material of Central European communities (southern and central Germany, Bohemia, Moravia, and the Carpathian Basin) used between 4500 and 2000 BC resulted in a picture which differed from the western European Bell Beaker metal: the artifacts were categorized into 13 different groups. According to the compositional analyses, 65 of the 80 eastern Bell Beaker objects were made of tin-rich or fahlore coppers with varying impurities (antimony, arsenic, silver) and a small (less than 4%) amount of tin. The various dominant elements suggest that there was no uniform Bell Beaker metal in this region.[8]

Elemental composition data of the next period prove that the most widespread raw material of the Central European Early Bronze Age (from 2100 BC; contemporaneous with the 3rd phase of the Early Bronze Age and the Middle Bronze Age in Hungary)[9] was the so-called *Ösenring* metal, the characteristic fahlore type of the neck rings.[10] The latter copper, which contained silver, arsenic, and antimony impurities, has been associated with ore occurrences in the triangle of the Eastern Alps, Slovakia, and the Czech-Saxon Ore Mountain range based on the distribution area of the mentioned neck rings (Fig. 2).[11] Lead isotope

5 Schreiner, *Erzlagerstätten im Hrontal*; Csányi, "Das kupferzeitliche Gräberfeld"; Siklósi et al., "The spread of the products"; Siklósi, Szilágyi, "New data on the provenance."

6 Bondár, *A késő rézkori fémművesség*.

7 Needham, "Analytical implications"; Needham, "Copper dagger."

8 Merkl, "Bell Beaker."

9 P. Fischl et al., "Old and new narratives," Figure 1.

10 Schubert and Schubert, "Spektralanalytische Untersuchungen"; Pernicka et al., "Lead Isotope Analyses."

11 Junk et al., "Ösenringbarren"; Höppner et al., "Prehistoric copper production"; Radivojević et al., "The Provenance, Use, and Circulation."

tests which were used to arrive at more accurate determinations of provenance indicate that the raw material of these artifacts derived from the Slovak region.[12]

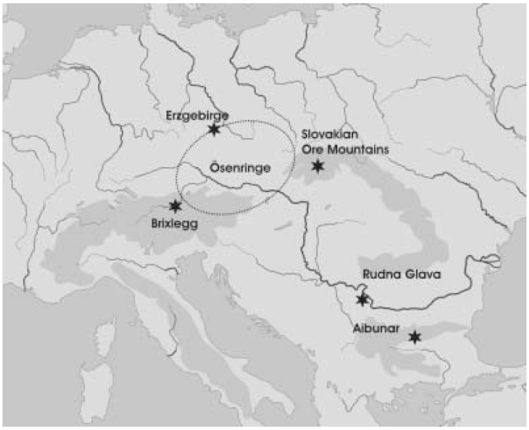

Figure 2. Prehistoric copper mining regions associated with *Ösenring* metal type[13]

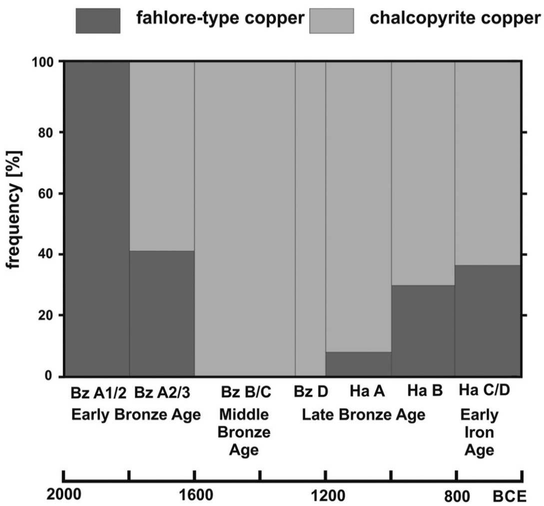

Figure 3. Abundance of copper with fahlore and chalcopyrite signatures produced in the eastern Alps from the beginning of the Bronze Age to the Hallstatt period based on the compositions of approximately 1200 prehistoric metal artifacts from Tyrol, Salzburg, and southern Bavaria[14]

In the 1960s and 1970s, the transformation of the raw material used at the beginning of the Central European Middle Bronze Age (contemporaneously

12 Duberow et al., "Eastern Alps"; Radivojević et al., "The Provenance, Use, and Circulation," Figure 7.

13 Höppner et al., "Prehistoric copper production," Figure 7.

14 Radivojević et al., "The Provenance, Use, and Circulation," Figure 10.

with the transition from the Middle to the Late Bronze Age in Hungary) was detected by the Stuttgart metallurgy project (*Studien zu den Anfängen der Metallurgie* or SAM project).[15] This metal type, which contained arsenic and nickel, spread in a wide region of Europe, also called *Einheitskupfer* or eastern Alpine copper. The new unified metal type, based on lead isotope data, was associated with chalcopyrite ores (Fig. 3) of the Mitterberg region, situating to the south of Salzburg.[16] According to the most recent radiocarbon dates, these ore sources were exploited from the 16th to the 14th centuries BC.[17]

Analysis of Bronze Age Artifacts in Hungary: State-of-the Art and New Perspectives

As we have seen, research on Eurasian copper raw material has provided important data, although questions still remain regarding the origin of copper ores used by Bronze Age metalworkers in the Carpathian Basin.

Research on metal finds has intensified over the course of the past two decades in Hungary as well. Re-dating of the earliest axes from the 3rd millennium to the end of the 4th millennium provided important data concerning raw materials. Based on an evaluation of the Stuttgart database, 21 axes of the Bányabükk hoard prove that Copper Age and the earliest Bronze Age axes were made of pure copper. The raw material of later Fajsz-, Corbasca-, and Kömlőd-Kozarac-type axes[18] show a more varied picture, with fahlores containing impurities at 1–2%, namely arsenic, antimony, and silver. Occasional low nickel content suggests a mixture of ores.[19] This indicates that the raw materials the natural impurities of which made it possible to produce harder tools were sought and were not the result of intentional alloying.[20]

Analyses of metal finds from Bell Beaker burials (2500–2200 BC) were also begun. According to the findings, the raw materials out of which the daggers

15 Schubert and Schubert, "Spektralanalytische Untersuchungen."

16 Duberow et al., "Eastern Alps"; Pernicka, "Analyses of Early Bronze Age"; Radivojević et al., "The Provenance, Use, and Circulation."

17 Pernicka et al., "Bronze Age Copper," Figure 5–6.

18 Junghans et al., *Kupfer und Bronze*; Hansen, "Metal in South-Eastern"; Dani, "The Significance of Metallurgy"; Szeverényi, "The Earliest Copper Shaft-Hole Axes."

19 Junghans et al., *Kupfer und Bronze,* vol. 1–3; Junghans et al., *Kupfer und Bronze,* vol. 4; Krause, *Studien zur kupfer- und frühbronzezeitlichen*, Datenbank, Anr. 8952–8971, 8987, 10937, 10939, 12501–02, 12504, 12515, 13402–13409, 14419, 48801, 48807, 48841.

20 Shalev et al., "Investigation of early copper-based alloys," Table 2.

and pins were made usually consisted of pure copper (98–99%) with antimony, silver, lead, and tin impurities.[21]

Based on several metal analyses, neck rings, hair rings, spiral arm rings, pins, and daggers from the end of the Early Bronze Age (Fig. 4) which were excavated in western Hungary (2100–1900 BC)[22] were manufactured from fahlore copper rich in trace elements, such as antimony, arsenic, and silver.[23] Copper artifacts containing arsenic and nickel, beside fahlore copper ornaments and tools are known from cemeteries of the same period which were discovered in eastern Hungary.[24]

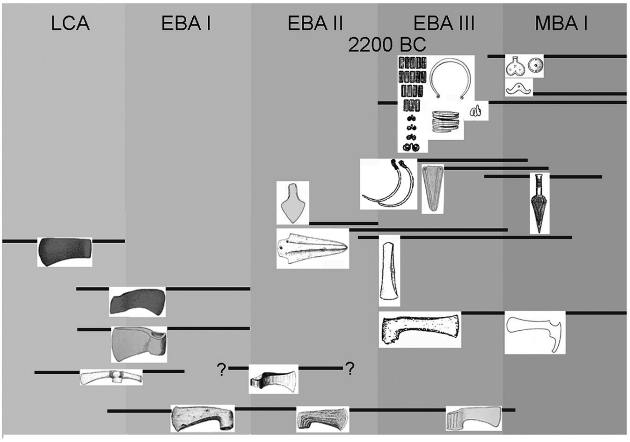

Figure 4. Typochronology of metal finds from the dawn of the Early Bronze Age until the first period of the Middle Bronze Age in Hungary[25]

At the beginning of the Middle Bronze Age (2000/1900 BC), tin bronzes appeared with 4–10% tin, which is a clear indication of intentional alloying (Fig. 5).[26]

Optical emission spectroscopy analyses of the aforementioned Stuttgart metallurgical project provided 116 data for Middle Bronze Age metallurgy of Western Hungary based on samplings of five hoards of Transdanubian

21 Endrődi et al., "Technological study."

22 Mithay, *Bronzkori kultúrák*, III.t.1–7; Junghans et al., *Kupfer und Bronze*; Költő, "Megjegyzések az Ordacsehi-Csereföld"; Somogyi, "A kisapostagi kultúra"; Kiss, *Middle Bronze Age*,176.

23 E.g. *Ösenring* and Singen copper; Krause, *Studien zur kupfer- und frühbronzezeitlichen*, Datenbank, 39.

24 Krause, *Studien zur kupfer- und frühbronzezeitlichen*, Datenbank; P. Fischl and Kulcsár, "Tiszán innen Dunán túl," Table 2.

25 P. Fischl et al., "Old and new narratives," Figure 9.

26 Shalev et al., "Investigation of early copper-based alloys," Figure 4; Kiss, "Arany, réz és bronztárgyak," Figure 1.

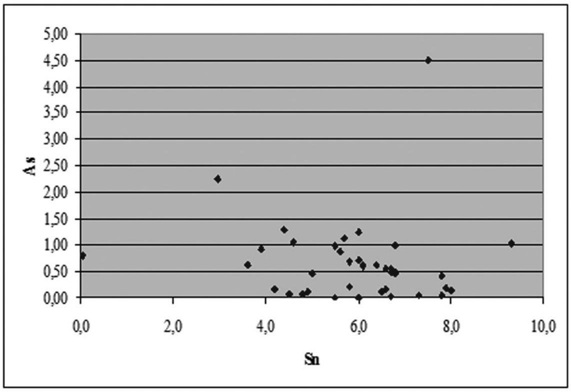

Figure 5. Tin–arsenic chart based on artifacts of the Zalaszabar hoard, Western Hungary

Encrusted Pottery (1800–1600 BC; the so-called Tolnanémedi horizon) and artifacts of a burial from the same period. The findings indicate that 80% of the local ornament types were made of the characteristic fahlore type *Ösenring* copper alloyed with tin.[27] Compositional analyses of the Zalaszabar hoard from the same period suggest that tools and jewelry, which were found together in hoards, were manufactured with the use of several casting procedures.[28]

Testing of the Koszider type hoards and several ornaments and tools from the end of the Middle Bronze Age in Hungary demonstrates a transformation in the use of raw materials similar to contemporaneous Central European Middle Bronze Age, with the dominance of so-called *Einheitskupfer* or containing arsenic and nickel.[29] In connection with the research on the find assemblage of the famous Nebra Sky Disc, dating to the 16th and 15th centuries BC and discovered in the region of Halle (northeastern Germany), elemental analyses of the axes of the Hajdúsamson hoard, axes and a sword from Vámospércs and Téglás were performed. As in the case of the material of the Nebra finds, the compositional data all match the mentioned eastern Alpine copper (with two exceptions from Téglás). This research yielded the first lead isotope data from Hungary confirming the association of the mentioned raw material with the chalcopyrite ore mines of the eastern Alpine region. Investigations of the Apa hoard, which has close typological relations to the weapons from Hajdúsámson,

27 Kiss, "The Life Cycle"; Kiss, *Middle Bronze Age*, 141–42, Fig. 39.

28 Kiss, "Arany, réz és bronztárgyak," Figure 3.

29 Schubert and Schubert, "Spektralanalytische Untersuchungen"; Liversage, "Interpreting composition patterns"; Krause, *Studien zur kupfer- und frühbronzezeitlichen*; Duberow et al., "Eastern Alps"; Pernicka, "Analyses of Early Bronze Age"; Pernicka et al., "Lead Isotope Analyses"; Radivojević et al., "The Provenance, Use, and Circulation."

and other contemporaneous find assemblages suggest that, in addition to Alpine and Slovak raw materials, ores from other regions of the Carpathians (in the area of Baia Mare and the Apuşeni Mountains) were also processed (Fig. 6).[30]

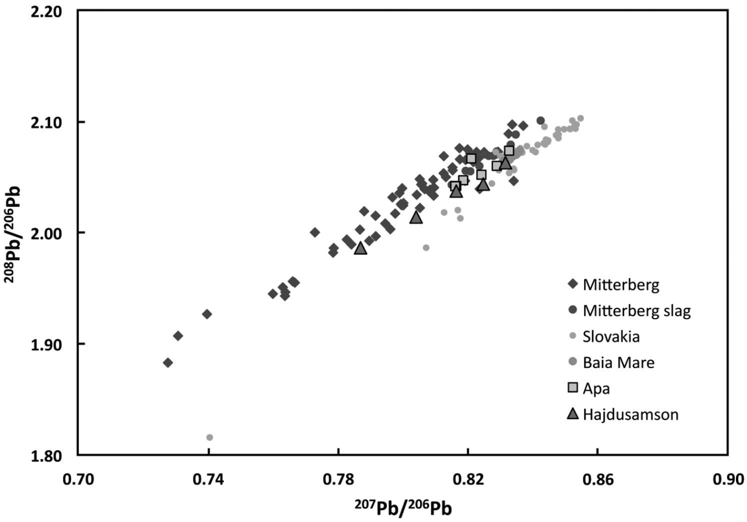

Figure 6. Lead isotope ratios of the objects from Apa and Hajdúsámson and of copper ores from Mitterberg, the Slovak Ore Mountains and lead ores from Baia Mare[31]

We have seen that data concerning elemental compositions suggest large trends, but the exact provenance of raw materials and the *chaine operatiore* of production need further confirmation.

The project of the Momentum Mobility Research Group of the Institute of Archaeology, Research Centre for the Humanities aims to study metal artifacts of the abovementioned period during the first thousand years of the Bronze Age in Hungary (2500–1500 BC). We analyzed ornaments, weapons, and tools from precisely dated inhumation and cremation burial assemblages of the Bell Beaker period (2500–2200 BC) and the Early and the Middle Bronze Ages in eastern and western Hungary (Fig. 7–8).

Multidisciplinary analyses of chemical composition are provided by non-destructive XRF, PGAA (prompt-gamma activation), and TOF-ND (time-of-flight neutron diffraction) analyses in cooperation with the Budapest Neutron Centre (Centre for Energy Research). XRF results can only be interpreted for the surface, while bulk area was analyzed by PGAA.[32] Neutron radiography and TOF-ND are

30 Pernicka et al., "Lead Isotope Analyses."

31 Ibid., Figure 20.

32 Maróti et al., "Non-destructive analysis."

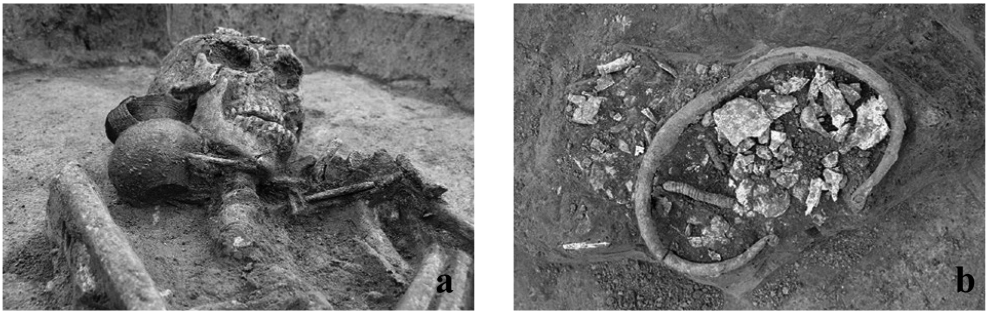

Figure 7. Metal ornaments from inhumation and cremation burials of the Middle Bronze Age cemetery excavated at Bonyhád

applied in order to determine production techniques (see summary of research facilities and relevant technologies available for the archaeometallurgical testing in Hungary).[34] It is important to note that while post-casting elaboration was formerly identifed by destructive microstructure analysis we could detect the hardening of the edge of flanged axes without any destruction of the artefacts (Fig. 8).[35]

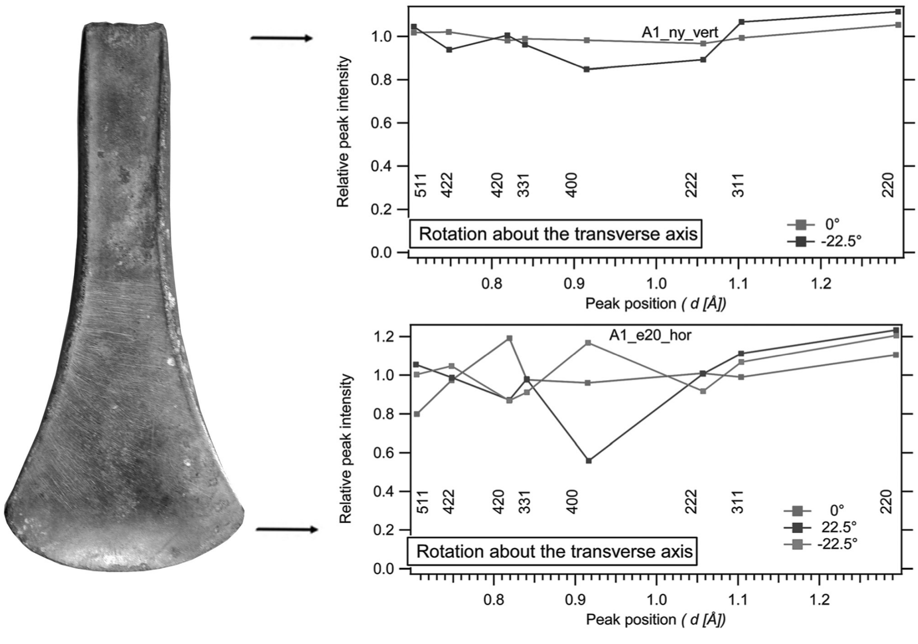

Figure 8. Texture results of the TOF-ND analysis of the flanged axe from Zalaszabar at the neck, and at the edge of the axe

33 Kovács et al., "Auf Mitteleuropa," Figure 2.

34 Szabó et al., "The possibilities and limitations."

35 Kiss et al., "From inhumation to cremation."

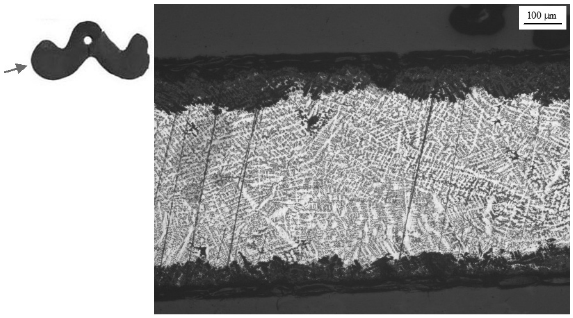

Figure 9. Dendritic structure of an as-cast pendant from Zalaszabar[36]

We perform destructive metallographic examinations on some objects, selected on the basis of non-destructive analyzes, in cooperation with the specialists of the Department of Materials Science of the University of Miskolc and the Department of Solid State Physics of the University of Debrecen (Fig. 9). We also study the effect of cremation to the microstructure of the bronze jewelry found in cremation burials.[37]

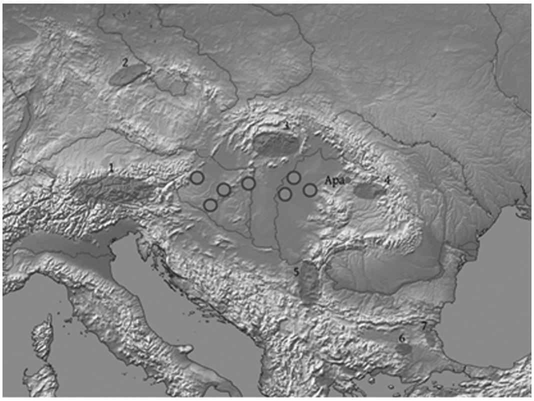

Figure 10. Multidisciplinary analyses of Bronze Age finds from Hungarian Early and Middle Bronze Age sites (Balatonakali, Budakalász, Nagyrév, Polgár, Sárrétudvari, Zalaszabar, Zsennye) with Central European prehistoric copper mining sites[38]

There are 42 ongoing lead isotope measurements (Fig. 10) performed in collaboration with the Curt-Engelhorn Archaeometry Center in Mannheim. The significance of these lead isotope analyses is emphasized by the fact that, with the exception of the above mentioned nine objects from the region of Debrecen, no additional lead isotope data were available from the inner areas of the Carpathian Basin.

36 Kiss et al., "A zalaszabari bronzkincs."

37 Kiss et al. "A zalaszabari bronzkincs"; Kovács et al., "Technológiai megfigyelések."

38 Map after Pernicka et al., "Lead Isotope Analyses."

Our results complement the research performed in the 1960s and 1970s and over the course of the past two decades. Changes in raw material use over time show similar tendencies to those in Austria and other parts of Central Europe. Though compositional data are still matter of discussion,[39] results suggest that, in the Early Bronze Age, copper ores which were mined in the territory of present-day Slovakia were used.[40] Based on some artifact types dating between 2800 and 1500 BC we can suppose networks of relationships which stretched over long distances. In the case of these artifacts, the question has arisen as to whether they were manufactured at and exported from the same workshop or they are locally made copies that indicate long-distance connections among Bronze Age communities.[41] E.g. lead isotope data concerning the weapons from the Hajdúsámson treasure and other swords and axes found near Debrecen suggest that the raw materials with which they were made originated from the Eastern Alpine region. The decoration motifs on these weapons, however, indicate that they were made locally in the Tisza region.[42] The findings summarized here indicate interregional connections, as well as several transformations in the exchange network of the prehistoric communities living in the Carpathian Basin.

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39 Radivojević et al., "The Provenance, Use, and Circulation"; Szabó et al., "The possibilities and limitations."

40 Kiss et al. "People and interactions."

41 Kovács, "Auf Mitteleuropa"; David, "Eine mit Spiralhakenranken"; Stockhammer, "The Dawn of the Copy"; Kiss, "The Bronze Age burial."

42 Dani et al., "The Hajdúsámson hoard – revisited."

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