Archaeometallurgic Investigations in Slovenia
A History of Research on Non-Ferrous Metals
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Abstract
The first investigations of the chemical composition of archaeological artifacts in Europe were carried out in the 18th century. A decisive change occurred in the first half of the 20th century when the development of new analytical methods enabled measurement of very small quantities of material and a large number of analyses could thus be performed. This marked the start of systematically planned spectral analyses, particularly of prehistoric artifacts made of copper and copper alloys, at numerous European laboratories.

Systematic chemical research of Late Bronze Age metal objects in Slovenia began in 1988. This research was initiated by the Department of Archaeology (University of Ljubljana) and organised by the National Museum of Slovenia and the National Institute of Chemistry in Ljubljana. The research, including also metallographic analyses, is directed towards a better understanding of the technology involved in the acquisition and production of copper and copper alloys. The results of our investigation contribute to the archaeological understanding of the role played by the territory of Slovenia during the transitional period of the 11th/10th century BC.

A SUMMARY OF EUROPEAN STUDIES

Among humanistic sciences it is particularly the study of prehistoric ages that increasingly involves the natural sciences. The desire to completely understand the early development of human societies and their environments, together with the lack of written records, is leading archaeologists to broaden the scope of their investigations with a variety of natural scientific investigations from biological, anthropological and medicinal to geological, mineralogical, metallurgical and others. In addition to the standard archaeological methods of stratigraphy, typology and relative chronology, the use of chemical analyses and physical methods has increased. Due to their precise nature and rapid development of technical capabilities, archaeology is able to constructively fulfill its determinations. The use of physical methods is particularly successful in investigations concerning raw materials such as metal, stone, clay, amber and glass, where analyses of the chemical composition help in determining the origin, extraction, processing and distribution of material as well as finished products.

Chemists first took an interest in the composition of archaeological finds already towards the end of the 18th century as they began to examine Roman coins, glass and bronze objects. Chemical analyses of a larger amount of finds were first published in the 19th century, as well as articles in which natural scientists compare the composition of archaeological metals to their origins.
and chronological classifications (Caley 1967). A possible reason why these topics then failed to draw the attention of archaeologists was that analyses at that time did not yet generate results that were constructive enough to compensate for the damage done by taking samples from the finds. The chemical analytical method at that time required a considerable sample (1-2 g), while it only enabled the measurements of elements with high values and was not sufficient for successful research of metals (Pernicka 1998a). A decisive change occurred in the first half of the 20th century with the development of new analytical methods enabling the measurement of even very small amounts of material. In addition to the chemical wet analysis in use at the time, a new instrumental analysis method - optic emission spectroscopy (OES) - began to be applied in the beginning of the 1930’s. Due to its properties - such as a more rapid course of analysis, the requirement of a smaller sample (50 mg and less), the capability of revealing elements in traces, a graphic analysis record in the form of a spectrum - this method was quickly recognized for analyzing archaeological finds. It was the first method which allowed a very large number of analyses to be carried out and thus stimulated the beginning of systematic investigations, especially of prehistoric metals (Winkler 1935; Pernicka 1990).

A history of the first spectral investigations has already been thoroughly discussed and evaluated (Härke 1978; Sangmeister 1998), and in particular from the point of view of applied analytic methods (Pernicka 1984; 1990); consequently, only a short review shall be contributed here. The greatest complex of methodically planned analyses was carried out during the period between the thirties and seventies of this century. Investigations unfolded within numerous collaborating laboratories in Europe. Copper and bronze finds from the Eneolithic and Early Bronze Age were the most frequent objects of analysis (approx. 60 000), followed by gold finds (approx. 4 500), and analyses of other metals (iron, antimony, tin and silver) and other materials, predominantly pottery. Glass, fine pottery, flint and obsidian, were also analyzed, although much fewer. All investigations shared the same basic purpose - to determine the composition of the products and the origin of the raw material.

The first period, during which the leading laboratories were located in Halle, Vienna, Stockholm and Leningrad/St. Petersburg, was marked by the publication of analyses carried out in Halle (Otto, Witter 1952), including also the analysis of select prehistoric finds from Slovenia. During the next period, after 1946, when the network of collaborating laboratories expanded through all of Europe laboratories in Stuttgart, London, Oxford, Rennes, Lyon, Milan, Moscow, and elsewhere joined the investigations - Vienna and Stuttgart assumed the leading roles. The main aim of the Vienna team, under the leadership of R. Pittioni, was to determine the origins of ores, on the basis of which a relation between the ore deposit and the artifact could be established. This is why systematic field survey was performed in addition to spectral investigations of ores, although limited to the region of Austria (Pittioni 1957; 1959). Unfortunately, only semiquantitative results were applied during the analyses: the composition of elements was not recorded in percentages, but rather using symbols representing the presence, absence or trace of an element. This approach proved to be inappropriate as these results cannot be expressed quantitatively and therefore are not applicable for precise comparisons (Christoforidis et al. 1988; Pernicka 1990). On the contrary, the Stuttgart team, under the leadership of S. Junghans, decided to run a project within a European framework. More or less chronologically limited to the Copper and Early Bronze Ages this investigation incorporated spectral analyses of artifacts, as well as a comparison of their compositions. The analyses were grouped regarding the contents of five elements (arsenic, antimony, silver, nickel and bismuth). This provided the basis for regional groups of copper products to be determined as well as the local sources of raw material (Junghans et al. 1960; 1968: 1974). The Stuttgart laboratory completed its investigations in the 1970’s, as did most other laboratories, with the exception of Moscow. Beginning in the 1960’s, a group led by Černych has been carrying on systematic investigations concerning ore provenance (Černych 1992: 1998).

The superb work carried out by these laboratories, all using the same, excellent new analytical method, nevertheless failed to produce a final answer concerning the origin of the ore. Their results underwent critical evaluation and revision. The critical discussion concerning the interpretation of results from the Stuttgart laboratory was especially severe. It was demonstrated that the majority of established groups cannot be reliably allocated, either in time or space, and that the processing of results ensued from metallurgically oversimplified hypotheses on the copper ore sources, its processing and manufacture. In fact, the analyses failed to solve the main problem - the origin of the ore. Several critiques were also directed towards the reliability of the analyses carried
out in Stuttgart (e.g. Boomert 1975; Coles 1982). Later examinations reinstated the analytic reliability of the Stuttgart investigations, once a large number of comparative analyses were carried out on individual elements using new methods (NAA and AAA) demonstrating the relatively small (30 %) deviation of the Stuttgart results. E. Pernicka, who took a detailed interest in reexamining the results, evaluated them to be a reliable bank of information well worth supplementing (Pernicka 1984; 1990). The famous group laboratory work was thus concluded. According to several estimations, the greatest number of analyses were carried out in Stuttgart, Vienna and Moscow - a total of at least 400 000 which is the number currently recorded in the Stuttgart database. The entire number could indeed add up to twice as much together with the unpublished analyses still preserved in the Moscow laboratory (Pernicka 1998a).

Investigations of metals persisted on into the third phase, which is considered effective from the late 1970’s onwards and is still ongoing today (Pernicka 1998a). As already mentioned the results from the second phase of investigations were less than encouraging. To determine the relation between the product and the ore deposit proved to be much more arduous a task than initially anticipated. A study of trace elements in copper ore demonstrated that the variability of the elemental concentrations within the same ore deposit is rather large. It often coincides with the element pattern from another ore deposit. It seems that the main reason for differences in the ore composition is its position in the parent rock, which is related to the exposure to atmospheric conditions. It has been finally realized that all comparisons of trace element compositions in ores and artifacts are questionable. At the same time, the influence of metallurgical processes (melting, alloying, casting) performed on the metal on its way from the mining place to the smith’s workshop proved to be highly significant regarding the elemental composition of an artifact (Craddock, Giumlia-Mair 1988).

It seems that the driving force of the third period of investigations remained the desire to determine the ore provenance despite the failure of previous efforts. New analytic methods, developed during the 1980’s, greatly contributed to new attempts. Due to the low limits of detection, they are enabling the measurements of very small quantities of elements (traces). Those which are destructive require only several ten milligrams of a sample; if non-destructive, the investigated object needs to measure only a few centimeters. Atomic absorption spectroscopy (AAS), neutron activation analysis (NAA), X-ray fluorescence (XRF and PIXE) and inductively coupled plasma - atomic emission spectroscopy (ICP-AES) and mass spectroscopy (ICP-MS) are most frequently used to analyze copper alloys. AAS and NAA are qualitative and quantitative methods, since they determine the type and amount of each element. However, the former method requires a long time and the latter method is very expensive (it requires an atomic reactor); consequently, these two methods are more appropriate for analyzing smaller numbers of objects and for testing results from other analyses. XRF and PIXE are semiquantitative methods, determining only the surface composition of an object. ICP-AES is a qualitative and quantitative method, it is precise regarding trace elements, as well as inexpensive in comparison with other methods. It enables a relatively simple and simultaneous determination of a very large number of elements (up to 70) from a very small sample. It also successfully overcomes the problem of nonhomogeneity. Despite the destruction of the sample (the recommended sample amount is cca 50 mg to enable result verification), this method was estimated as one of the most suitable methods for analyzing large numbers of archaeological metal objects (Pernicka 1984; 1990).

Lead isotope analysis has brought on a new zealoussness for investigation of the ore provenance, in addition to secondary ion mass spectroscopy (SIMS), which was introduced recently for tracing selenium and tellurium in copper (Adriaens; Adams 1996; Adams et al. 1997). Lead isotope analysis is based on the ratio between three lead isotopes in copper which remains unchanged despite all physical and chemical processes through which a metal passes from the ore to the final product. A lead isotope ratio from an ore deposit can thus be obtained from a certain number of ore analyses which are then compared with the lead isotope ratio of the artifact. If the patterns do not match, it can be concluded that this ore deposit was not the source for the particular artifact. This analytical method was initiated in the investigations on the Late Bronze Age copper deposits and oxide ingots in the eastern Mediterranean on Crete, Cyprus and Sardinia (Gale, Stos-Gale 1982). It should be emphasized that, during the 1980’s, the first investigations on

1 Gale, Stos-Gale 1986a; 1986b; Gale 1989; Lo Schiavo et al. 1990.
ore deposits and metal finds dating to the Eneolithic and Early Bronze Age were established in the classic territories of the earliest metallurgy - in the Near East, Asia Minor and the eastern Mediterranean (Muhly 1985). Among currently running investigations are German projects probably of the largest scale. Support from the Volkswagen fund promoted these investigations to strengthen the role of natural sciences in humanities, i.e. to support the development of archaeometry. Between the years 1987 and 1997 the support was primarily intended for the development of archaeometallurgy. A series of large-scale projects were carried out during this period, which incorporated collaborating researchers from the Max-Planck Institute for Nuclear Physics in Heidelberg and for Chemistry in Mainz, the Württemberg Regional Museum in Stuttgart, the Institute for Prehistory at the University in Heidelberg and the RGZM in Mainz, as well as others. The above mentioned areas in the Near East, Asia Minor, the Aegean and the eastern Mediterranean, as well as the Balkans - more precisely Serbia and Bulgaria, were included in the research plan with the intention to solve the problem of ore provenance. The development of copper and bronze metallurgy during the Early Bronze Age in Europe, more precisely the region of the Unjetice culture (central and eastern Germany), has been investigated since 1990 (Krause 1998). Investigations of tin bronzes and tin deposits in Uzbekistan and Tajikistan have also been under investigation recently (Pernicka 1998c; Alimov et al. 1998).

Investigations of artefacts concerning the technological procedures of extracting, producing and alloying metals also augmented alongside investigations of ore deposits, with English researchers taking the lead. These investigations are evidently not run systematically, as are the German investigations, yet they are replete with brilliant ideas, observations and determinations from the field of metallurgy (Craddock 1978). Early metallurgic skills are gradually being revealed through precise studies of the type and quantity of elements, as well as through the knowledge of the basic principles of metallurgic processes and various experimental efforts (Merkel 1990). A series of investigations was dedicated to Bronze Age metallurgy and trade in the eastern Mediterranean - Cyprus, Crete and Greece, in the western Mediterranean - Sardinia and Spain (Rothenberg and Blanco-Freijero 1981), and also the British Isles (Northover 1980; 1982b).

Analyses of objects dating to later periods and archaeometallurgical investigations of smaller areas in Europe are also increasing. Systematic investigations of copper, copper alloys and metallurgical activity during the Middle and Late Bronze Ages were carried out in Switzerland (Rychner 1990; Rychner, Kläntschi 1995), as well as analyses of Middle and Late Bronze Age hoard finds and analyses of La Tène bracelets in the Czech Republic (Frána et al. 1995 and 1997), metallographic investigations of bronze products in Italy (Antonacci Sanpaolo et al. 1992; Casagrande et al. 1993; Bietti Sestieri et al. 1998), analyses of products dating to the Early Bronze Age and hoard finds dating to the 10th century BC from Rio de Huelva in Spain (Roira 1995; Rovira and Gómez-Ramos 1998), and also individual smaller complexes of analyses and studies of bronze objects from the Iron Age, such as those in the region of Caput Adriae (Giumlia-Mair 1996; 1998) and Switzerland (Northover 1998).

INVESTIGATIONS IN SLOVENIA

Investigations of metals in Slovenia were quite modest up to the end of the 1980’s compared with the analyses throughout Europe. Nevertheless, the first references of the chemical composition of metal finds are noted at the end of the 19th century and the beginning of the 20th century in publications of Müllner and Smid (Müllner 1892; Smid 1908). Slovenia was also included in the first spectral analyses of prehistoric copper and bronze finds carried out in laboratories in Halle and Stuttgart. Four pieces of raw material from the Črmošnjice Late Bronze Age hoard and one piece from the Jurka vas hoard, more than 40 primarily copper objects from the Ljubljana moor and other

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3 Pernicka 1998b; Krause, Pernicka 1996. I would like to thank A. Preložnik for bringing these articles to my attention.
4 Pernicka 1990 (1995), with rich references for all the mentioned areas.
smaller sites, as well as the majority of prehistoric gold jewelry have been analyzed. The reason for the deficiency of spectral analyses carried out by Slovene researchers was not so much due to Slovene archaeologists being uninformed, but rather primarily to a deficiency in funds necessary for these analyses. The considerable lack of interest of the majority of Slovene natural scientists to collaborate is also noticed. This situation might partly be explained by the extremely expensive nature of the majority of instruments for analytical methods (sometimes even an atomic reactor is required). Nevertheless, several analyses were indeed carried out due to friendly connections between the researchers on each side.

The first spectral analyses of eight prehistoric finds were initiated by S. Gabrovec in 1977. His friend and chemist, L. Kosta, together with colleagues, analyzed eight objects from the Udje hoard and from the Črmošnjice hoard (Kosta, Pihlar, Smodiš 1979). A combination of electrolysis, voltammetric methods and NAA was applied and ten elements were determined, also present in traces. The investigation was performed correctly, and also the interpretation of the results. According to current knowledge of characteristic element compositions of the Late Bronze Age metals, it can be said that the entire pattern of element compositions is in accordance with the average BA D-Ha A content of metals. The exception represents sample 7, which the authors also regarded as deviating from the other samples. The extremely high values of lead and zinc noted in this sample are highly unusual for this period and must be wrong unless the sample originated from another unknown archaeological site. These analyses proved that Slovene natural sciences could also apply the current instrumental methods (NAA) and the researchers were informed of the similar investigations throughout Europe. Unfortunately, the samples were published without inventory numbers, which renders a comparison of the results rather difficult. Their efforts also failed to motivate archaeologists to continue with further investigations in this topic.

The next analyses carried out in 1982 can also be assigned to the friendship of archaeologists and the natural scientist and physicist, Ž. Šmit. A. Pleteski and T. Knific selected two metal drops from a melting-pot and three samples of slag to be analyzed, as well as a group of seventeen various metal objects (mostly jewelry) from two archaeological sites, Pristava at Bled and Dlesc near Bodešče. Šmit applied a method of proton induced x-ray emission analysis (PIXE). This method is nondestructive, however the analysis is limited to the thin surface layer of the object (up to a depth of 0.01-0.1 mm). It can serve only as a starting point for evaluating the composition of the whole object, with an approx. 10% accuracy. The researched objects were selected from three chronological periods (Roman, Early Middle Ages and Slavic) and from two sources (a settlement and a cemetery) with the intention of determining possible connections between the content of the melting-pot and the finished products (Šmit 1983). The analyses indicated that the composition of copper alloys corresponded to metallurgical principles, at least as far as the lead and tin content is concerned. It differed from the composition of drops in the melting-pot. However, the composition of the alloys did not seem characteristic for the individual chronological period. The slag proved to be iron and thus without any connection to the remaining objects. The selection of objects analyzed was of course too small and they were selected from too many various contexts to enable any sort of wider conclusions. This is what the author was also well aware of. It is not evident whether the author attempted to compare his analyses with current similar studies elsewhere in Europe.

The attempt of Ž. Šmit and P. Kos to solve numismatic problems with the same method followed. Sixteen small Norician silver coins from Celje and a part of the large Norician silver coins from the Bevke Celtic coin hoard were analyzed with the intention to determine the reason for variation in the weight ratio of the same type of small silver coins from two mints, at Magdalensberg (Kärnten, Austria) and at Celje (Slovenia). The coins from Celje are by a third lighter in weight than those from Magdalenska gora (Šmit, Kos 1984). As the surface analyses did not show any essential differences in the silver content, three small silver coins were cut in half to measure the concentration profiles. It was determined that the interior of the coins contains a much lesser quality silver than the surface. However, the results from the surface analyses could not serve for the determination of

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3. He thus enabled the possibility of nondestructive investigations of the object surface, e.g. tinning.
the average content of silver in the coins. This was probably the first, although modest, chemical study of an archaeological problem initiated by a numismatic. This investigation would still seem from today’s point of view a test of the analytical capabilities of a method rather than an organized attempt, to solve a numismatic problem.

The First Systematic Investigations

In view of all the above mentioned, rather random analyses, the appeal to Slovene archaeologists by B. Teržan for methodical spectral analysis of ores, metals and products from throughout Slovenia, remained almost unnoticed (Teržan 1983; 1989). Teržan firmly established the need for chemical investigations of metal through her accurate studies on geological, mineralogical, vegetational and archaeological evidence of early mining on Pohorje. At the same time, she also pointed out the extensive foreign experiences with spectral analyses of copper and copper alloys, which seems highly appropriate considering the development of archaeometallurgic investigations in Europe, which were right at this time, during the 1980’s, starting to flourish again. Following this appeal, an interdisciplinary project was announced in 1984/1985 at the Department of Archaeology, University of Ljubljana, under the title of “Archaeology of the Environment and Technologies”. B. Slapšak clearly defined the aims of the natural science investigations in Slovene archaeology, especially those of metal, pottery and glass wares. He emphasized the fundamental significance of questions concerning the origins, processing and transport of raw material and finished products. Unfortunately, this project was never realized. Nevertheless, Teržan did not give in and the initiative for metal analysis did not wane. Following the first international colloquium on the Bronze Age in Slovenia, a new appeal to Slovene natural scientists was directed in 1987 at the Bronze Age exhibition at the National Museum in Ljubljana to turn their professional interests also towards the past. This time the effort proved worthy and perhaps the critique in the daily papers was also helpful. The well considered selection of archaeological finds and the correct selection of analytical method proved to be decisive factors in initiating the first domestic systematic investigations. B. Teržan, as the initiator and the leader of investigations, selected hoard finds from the Late Bronze Age and B. Orel selected the analytic technique (ICP-AES). He also coordinated the financial support which could afford a larger number of analyses. The enormous number of analyses so easily recognized in investigations elsewhere in Europe seemed to be the condition sine qua non for attaining useful results. This could hardly be achieved only on the basis of friendly collaboration with researchers. The appropriate financial means for such analyses would have to be provided. The selection of finds was the result of numerous factors. Perhaps the primary factor was the greater amount of metal finds from the Late Bronze Age as compared to the earlier periods in Slovenia. The nature of these finds also seems important, as the vast majority are from hoards. These were considered very suitable for the initial analyses as their specific compositions promised interesting results. The majority of hoards contain relatively large groups of the same type of artifact, thus enabling reliable, statistically supported processing and a comparison of results within the individual groups, as well as between the various groups (fig. 1). Our aim was to attain a large enough number of systematically performed analyses which we could compare with the corresponding analyses elsewhere. As the ICP-AES method requires a sample, the selected objects were again, suitable for drilling, due to their size and solidity. It was easy to cover the traces of sampling (which was excellently executed by the National Museum Conservation Laboratory) and to preserve a large enough amount of the sample for eventual verification of the results.

The National Institute of Chemistry in Ljubljana hospitably “opened their doors” to us in 1988. The Laboratories of Analytical Chemistry (V. Hudnik) and Spectroscopy of Materials (B. Orel) decided to participate. The National Museum agreed to the one-year specialization of one of its staff (Z. Milić, a chemist) in ICP-AES techniques and the Research Council of Slovenia financially supported it. N. Trampuž Orel was allowed, at the same time, to dedicate a large part of her time to archaeometallurgic topics to be able to organize all further investigations. The entire project was also strongly supported by the Museum leadership.

11 Popit I., Bronasti maček v žaklju, Delo, Friday, 22nd May 1987, 4. I would also like to mention the article by M. Budnar, Institute of Jožef Stefan, who a month later, also in the Delo newspaper, presented, as a natural scientist, the possibilities of the PIXE method for use in archaeology.
The first analyses were carried out upon the material kept in the store-department of the National Museum of Slovenia - approximately one hundred analyses by the end of 1989. Our initial and unpretentious wish to determine the metal composition and structure was finally coming true. The first results were encouraging - copper-tin alloys were noticed in artifacts and pure copper in plano-convex ingots from the first two hoards. Variations in the tin content suggested a deliberate alloying. Moreover, lower amounts of tin noticed in sickles compared to the higher amounts of tin in axes, swords and spears suggested a production of deliberate copper-tin alloys for different purposes, i.e. for tools or weapons (Trampuž Orel et al. 1991). It was then decided that the investigation would be extended to all hoards from the southeastern Alpine region, dating to the Ha A and Ha B periods. The National Museum had to appeal to more than ten museums throughout Slovenia and in neighboring countries for samples. Our colleagues in Slovenia, Austria and Italy agreed to cooperate without delay and generously allowed for the sampling of objects and taking of photographs. I would like to acknowledge them again.

The Purpose of Investigations

The extent of our future work seemed large enough to demand a set of clearly defined aims of research. In contrast to most European archaeometallurgical investigations concerning the origins of ore, our studies, aided by the appropriate quantitative and qualitative analyses, were directed towards determining the technological processes involved in melting, alloying and casting metals. Researches carried out in our vicinity, in the Trident, the South and North Tirol and in the Eastern Alps, are primarily concerned with revealing traces of
Bronze Age mining and smelting of copper ores, as well as experimental work (Piel, Hauptmann, Schröder 1992; Čierny, Weisgerber, Perini 1992). 

Investigations thematically similar to ours, concentrated on artifact production, have been underway since 1987 in Italy, although they contain either metallographic analyses (Casagrande et al. 1993; Antonacci Sanpaolo, Canziani Ricci, Follo 1992) or they are based upon the XRF method (Bietti Sestieri et al. 1998), whose imperfections in terms of systematic research have already been accounted for. The extensive investigations of copper and copper alloys in Switzerland represent thematically the closest research to ours, regarding the analytical method and the chronological period. The results enabled researchers to define the production areas for metal artifacts in the western Alps (Rychner 1981, Rychner; Kläntschi 1995). It was these results that we started to compare with our studies in the southeastern Alpine metallurgy (Trampuž Orel, Klemenc, Hudnik 1993).

**Work Approach**

Due to eventual verifications of our analyses, it was decided to publish the entire procedure, from the acquirement of samples, sample preparation and standard solutions, the selection of 12 elements to analyze (Sn, Pb, Fe, As, Sb, Ni, Co, Zn, Bi, Mn, Ag and Cu), the selection of spectral lines and detection limits to the problems concerning the representativity and homogeneity of the samples (Klemenc et al. 1992). Regarding the processing of results it was determined from the very start that the analyses within individual hoard finds will be joined into groups that represent objects of the same type - i.e. the analysis of sickles are followed by the analysis of axes, spears, etc. The total of the average values of all elements was added at the end of each group of analyses. We were especially careful with the chronological classification of the finds when comparing results. First a comparison of analyses within the same chronological level was carried out and the pattern attained was then compared with the new chronological level. As the analyzed finds originate from various parts of Slovenia, we were also cautious of any possible geographic variation. Therefore all results were initially processed inside each individual site. A better overview of the chemical and archaeological properties of the individual groups was thus attained. Comparisons within and between the groups were easier, and the exceptional chemical contents were more noticeable. This was a new way of presenting chemical analyses of archaeological objects that was not yet evidenced elsewhere among the published analyses of the time, at least not as consistently as it was presented in all our publications.13

**Investigation Objectives**

It soon became evident that the analyses would be capable of providing answers to much more demanding and complex questions than those initially anticipated. Our objectives were therefore set in accordance with the following questions which guided our investigations over the next ten years:

1. Are the differences in the alloy compositions dependent on: a) different degrees of development in prehistoric metallurgy; b) different chronological periods; c) different sources of raw materials; d) diverse purposes of the finished products?

2. Is it possible to determine the process of smelting and alloying metals by analyzing plano-convex ingots and cast ingots?

3. Is it possible to identify the traffic and trade network and the craft circle to which the southeastern Alpine region belonged at the end of the Late Bronze Age and the beginning of the Early Iron Age?

The analytical work was continued in 1990 by S. Klemenc, who did a larger number of analyses within the framework of her master’s degree.14 In her master’s thesis,15 she presented the already published application of the ICP-AES method for investigating archaeological finds (Klemenc et al. 1992), as well as the use of the chemometric methods - the Principal Component Analyses (PCA) and the method of hierarchical grouping - for processing a large amount of multidimensional data.16

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13 Trampuž Orel et al. 1991, pl. 2 and 3 as well as all further publications of our analyses.
14 S. Klemenc’s master’s degree was supervised by V. Hudnik within the project that was financed by the Research Council of Slovenia; Klemenc was temporarily employed at the National Museum of Slovenia.
16 This is to the merit of J. Zupan, the researcher in the field of chemometrics at the National Institute of Chemistry in Ljubljana.
She also added a table of analyses which she had carried out (approximately 400 analyses for 11 hoard finds), while she concentrated on interpreting the compositions of plano-convex ingots rather than of artifacts (95 analyses for 7 hoard finds). It is quite satisfying that the archaeological initiative for analyses and the selected material served successfully as the subject matter of the master’s degree in chemistry. After all, there are not many young chemists in Slovenia who would opt for research work in archaeology rather than in chemical industry.

**Initial Results**

At this stage of investigations we decided to include metallurgical investigations restricted to single objects and ingots. The attempt of the metallurgic study on the extraction of copper, based on metallographic analyses of plano-convex ingots from Jurka vas, dates to this time (Paulin, Smolej 1993a; 1993b). M. Dobershek was invited to examine our hypothesis on the production of sickles from deliberate copper alloys with low amounts of tin, which could sustain regular whetting and forging (N. Trampuž et al. 1991). His microstructural analyses of three sickles with low tin content confirmed our expectations - the sickle blade was forged. He also discovered that fresh copper was used for making bronze alloys for sickles, as opposed to the remelted scrap bronze. The discovery of deliberate copper alloys with low tin used for the production of sickles in the workshops of the Carpathian craft circle craft circle was a novelty, compared to other investigations elsewhere and especially in Western Europe, where larger amounts of tin were added to copper irrelevant of the type of artifact. Our metallurgical research also confirmed that at least select sickles found in hoards were used as harvest tools. This is in contradiction with the widely spread opinion that the primary role of those sickles was of a votive or pre-monetary nature. The discovery that fresh copper was used for casting sickles during the Late Bronze Age also speaks against the general conviction that only remelted scrap bronze was used for new products during the Late Bronze Age (Trampuž Orel et al. 1996).

The number of chemical analyses had increased in the meantime by the helpful work of V. Kos. Already 928 analyses were performed on finds from 23 hoards by 1995. The project became one of the few current, extensive investigations of Late Bronze Age artifacts in Central Europe. Such a large number of results presented an obstacle at the time. The importance of applying computer-statistical methods became inevitable. Furthermore, we also needed a new collaborator, a chemist, to continue with future analyses. However, young Slovene chemists were, quite understandably, faced with better perspectives in the pharmaceutical industry than in archaeometallurgy. At that moment, D. J. Heath, an environmental scientist, solved our problem when he came to Slovenia in 1995 and joined us. Despite his decision, which was primarily to "make a living", he was immediately enthusiastic about our investigations and deeply involved in archaeological problems, as no other researchers had been so far. Due to his computer processing of the results and his willingness to heed to the problems and needs in archaeology, the first six years of research were excellently concluded. The results were published, according to the plan made by B. Teržan, together with a presentation of all hoards and individual finds from the Bronze Age in Slovenia (Teržan 1996; Trampuž Orel, Heath, Hudnik 1996).

**Conclusions**

The results of this investigation show that the composition of copper alloys in our Late Bronze Age hoards depended on the technological knowledge of ancient smiths as well as upon the various sources of raw material. The period between the 12th and 11th centuries BC (the Ha A period) is characterized by various types of copper alloys with tin; the smiths carefully selected the alloy relevant to the type and purpose of the finished product. A resilient and malleable bronze, which was attained by adding a small enough amount of tin (approximately 4%) to copper was most suitable for sickles. The sickle made of ductile bronze could sustain a frequent, alternate whetting and forging necessary for maintaining a sharp blade that would not break. Copper alloys with a larger amount of tin (6%-9%) were also produced, resulting in a hard bronze suitable for striking weapons (swords, spears) and tools (axes). This bronze sustained whetting, although the higher amounts of tin prevented it from requiring...
hammering (fig. 2). This economical approach to tin was first discovered through our investigations. It was also statistically well supported and hypothetically linked with products of the Carpathian craft circle, due to the typological similarities of the Slovene artifacts (Trampuž Orel et al. 1991). The link was also confirmed later by Liversage (1995). He arrived at similar conclusions through Stuttgart analyses of sickles, axes and swords from the Late Bronze Age hoards (of the IVth and Vth level after Moszolics) in Pannonia along the upper Tisa river. It should be stressed that smiths in western parts of Europe failed to display such metallurgical expertise with tin alloys (Craddock

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18 Trampuž Orel, Klemenc, Hudnik 1993; Trampuž Orel, Heath, Hudnik 1996. The same craft-circle was recently determined by typological classification of sickles from Slovenia (P. Pavlin, Bronzezeitliche Griffzungensicheln mit Y-Motiv, Arch. vest. 48, 1997, 27-40.)
1978; Rychner 1995). This additionally increases the significance of metallurgy in the Carpathian region. This data adds to our understanding of the close links between the social communities in the area extending from the Friuli region at the west to the southeastern Transdanubian region at the east and the Austrian Styria to the north (Turk 1996). Additionally, we may assume that during the last two centuries in the 2nd millennium BC, the population of the Slovene region was incorporated in the economic and perhaps also political sphere of the Carpathian region (fig. 3).

Research revealed a noticeable change in the technology and use of raw materials during the transition to the 1st millennium BC. Lead is not represented as a pure metal but always as a binary alloy with copper or as a ternary alloy with copper and tin, in objects and ingots, often in surprisingly high amounts. It is quite evident that smiths already knew the role played by lead in obtaining a higher quality in cast objects. That this technology was also in use in the region of Slovenia is confirmed by numerous finds of fragments of shaft-hole axes, primarily from hillforts in Inner Carniola, almost all of which are made of copper alloys with high amounts of lead. The fragments are supposed to be used by a local smith to improve the quality of casting (Trampuž Orel, Heath 1998).

A new type of a raw material is also available in abundance - ingots, (cast in molds). Contrary
to the simple plano-convex ingots, the cast ingots, just by their shape, indicate the new type of metal to be processed. The copper used for products during this period is quite different to that used during the previous period, as it contains high amounts of impurities, primarily antimony, and can thus be attributed to sulphide ores of the Fahlerz type. Again, our research was faced with the need for collaboration with geologists (U. Herlec) and metallurgists (A. Paulin). Their studies were concentrated on the new types of metals. According to the composition of some of our ingots, classified as “speiss” (D. Heath), it was supposed that not only deposits rich with tetrahedrite were worked during this period, but also deposits with more complex ores containing, also other minerals rich with cobalt and nickel (Paulin et al. 1999). Archaeologically insufficiently researched deposits of these types are also located in our vicinity in various parts of the Alps and in central Italy. The distribution of artifacts most similar to those found in Slovenia, especially those containing considerable amounts of lead, ranging from wheel-shaped pendants to shaft-hole axes and ingots, is primarily in the regions west of Slovenia (central and northern Italy, Switzerland). On the one hand, this suggests that the use of leaded copper alloys spread from the Apennine peninsula toward the regions on the north and east, including Slovenia (fig. 4); while on the other hand, this distribution is revealing an almost diametric contradictory situation where the region of Slovenia found itself in the 1st millennium BC in comparison to the earlier periods. Trade and social contacts, influenced by the technological

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**Fig. 4:** Slovenia in relation to the Apennine peninsula at the beginning of the Ha B period (11/10th-9th centuries BC), as indicated by the results from spectral analyses.

*Sl. 4:* Razmerje Slovenije do Apeninskega polotoka v začetku Ha B obdobja (11./10.-9.st. pr. n. š.), kot ga kažejo rezultati spektralnih analiz.
novelettes linked the region of Slovenia primarily with the northern Adriatic, Friuli and the Paduan lowlands and possibly also central Italy on the one hand and the Alpine valleys in the north and west on the other. New deposits, including those with complex ores and metal trade evidently represented important reasons for new “western” contacts, and probably also new trade routes. The valley of the Soča river and its tributaries, as well as the Idrija and Cerklice regions started to play an important role. The research conclusions are in the perfect agreement with the wider view of cultural and economic connections, as considered by Teržan, between the eastern Mediterranean and the Alps (which incorporated also the western Balkans and the Italian peninsula) during the 11th/10th centuries BC. The new situation is directly related to the prospecting new ore deposits and the spread of the new technologies of copper as well as iron (Teržan 1995; 1996).

The research results (some have attracted the attention of the wider European region) were stimulative enough to advocate the continuation of our work (Hänsel 1998; Jockenhövel 1998; Frâna et al. 1997). We would like to confirm our current results on finds from neighboring regions and compare them with the chemical pattern of different chronological periods. We are particularly interested in the metal technologies at the end of the Late Bronze Age and at the beginning of the Iron Age, as it could prove to be essential for our understanding of the origins of ironworks in the Slovene region.

Recent investigations, mostly from the past two years, of individual metal objects or objects linked with the processing of metal during prehistoric, as well as other periods, should not be overlooked. The same is true for archaeometric investigations of other types of materials and chronological periods, including amber and resin, pottery, glass and stone tools, as well as dendrochronological and magnetometric investigations.

The Purpose of Archaeometallurgic Investigations

A review of investigations in Slovenia demonstrated that a larger part of metal research (as well as other materials) was directed toward individual objects and answering questions, usually referring to the unknown composition of a metal or other material. These otherwise successful investigations contributed satisfying answers to some extent. They also proved to be obligatory for completing the “identification card” for each find and for good quality conservatory treatment of the object. However, they failed to contribute

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19 Select investigations were the result of the conservation work, such as Z. Milej, J. Rant, I. Nemec. Uporaba neutronsko radiografije pri konzerviranju rimskega bodala. Argo 40/1, 1997, 135-141; J. Rant et al., Proc. of the 4th Int. Conf. on NDT of Works of Art (Berlin 1994) 31-40 and J. Rant et al., Proc. of the 5th World Conf. (Berlin 1997) 742-749. Others are the result of archaeo-

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towards a better understanding of the role of the Slovene region during the archaeological periods in general, and the prehistoric period in particular. They did, however, contributed to the comprehension that systematic investigations are a necessity in order to reach this aim; the scientific potential and the perfectly technically equipped natural science institutes in Slovenia enable this. Despite such high quality support from the natural science, it would be, of course, futile to expect successful results from a research in the absence of a well considered archaeological plan. The problems concerning archaeometallurgy are integral and they usually exceed the boundaries of smaller regions. Collaborating natural scientists, who have yet to be trained in archaeometallurgy, therefore need a full assistance and relevant information from responsible archaeologists. Clearly defined archaeological topics, incorporating the entire region, as well as accurately considered and extensive selection of finds, originating from firmly classified contexts, are needed for a well planned project. The optimal analytical method and a suitably selected interdisciplinary research team, in which archaeologists need to contribute equivalently and actively collaborate with natural scientists in the processing and interpretation of results, are also necessary. The Ministry for Science and Technology in Slovenia casually supported these types of research in the past, for which we are grateful. Since 1998 a regular support to natural scientific researches in the humanities started; it is hoped that this will contribute in systematic archaeometric investigations, including archaeometallurgical ones. The recently established Field Research Center, led by the main archaeological institutions (Institute of Archaeology of the Scientific Research Centre of the Slovene Academy of Sciences and Arts, the Department of Archaeology on the University of Ljubljana, and the National Museum of Slovenia) is a step in the right direction.


Začela uveljavljati nova instrumentalna uporabljane omogočil meritve zelo majhnih količin snovi. Poleg do tedaj (1-2 g), omogočala pa je meritve elementov z visokimi rezultatov, ki bi bili dovolj uporabni, glede na škodo, ki so zanimiva, morda tudi zato, ker tedanje analize še niso dajale odrečilveno (Caley 1967). Za arheologe ta tematika ni bila predmetov in članki, v katerih naravoslovci poskušajo primer.

19. st. izvirajo prve objavljene kemijske analize večjega števila zanimati kemike, ki so že proti koncu 18. st. pregledovali in razširjali surovine in tudi izdelkov. Zdi se, da je sestava arheoloških predmetov najprej začela zanimati kemike, ki so že proti koncu 18. st. pregledovali, da je treba pri obravnavi postale vse primerjave vsebnosti elementov v rudi z izdelkom.

Prve obdobje, v katerem so bili vodilni laboratoriji v Halleju, so bili preveč opogumljajoči. Izkazalo se je, da je povezava med elementi sestave znotraj istega rudišča dokaj široka in da se pogosto celo prekriva z vzorcem iz druga rudišča.


Veliko delo, ki so ga opravili omenjeni laboratorijski redniho in enako metodo, vendar ni dalo dokončnega odgovora o izviru rude. Rezultati so doživeli kritične ocene in revizije, posebno pri stuttgartske projektu je bila kritika ostra do interpretacije rezultatov. Pokazalo se je, da je večine ustvarjenih skupin ni mogoče zanesljivo razporejiti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško preveč skupin ni mogoče zanesljivo razporediti niti v času niti v prostoru, in da je delobava rezultatov izhajala iz metalurško.
sestave izdelka upoštevati vpliv metalurških postopkov (taljenja, legeranja, vlijanja) v katerih so bili opravljeni (ali: skozi katere gre) na kovini na poti od rudnika do končnega izdelka v livarjenih rokah (Craddock, Giu mâ-Mair 1988).

Lahko bi rekli, da je kljub neuspehu v dotednjih raziskavah še vedno ostala živina sila tretjih obdobja raziskovanja barvnih kovin želja, da bi odkrili rudni izvor. K temu so veliko pri-
pomogle nove analitske metode, ki so se razvile v 1980-tih in s katerimi je mogoče meriti zelo majhne količine snovi (sled-
ne elemente), oziroma imajo zelo nizke meje zaznavnosti. So nesporo, vendar zahtevajo le miligramske količine vzorca, ali pa so nesporo, vendar mora biti preiskovanje predmet velik nekaj centimetrov. Za analiziranje bakrovih zliti (torej izdelkov) se največ uporabljajo atomska absorpcijska spektroskoopia (AAS), na
tronska aktivacijska analiza (NAA), fluorescensa rentgenskih zerkov (XRF in PIXE) ter atomska emisijasna spektroskoopia z induktivno sklopileno plasmo (ICP-AES) in masna spektroskoopia (ICP-MS). AAS in NAA sta kvalitativna in kvantitativna metodi, torej razkrijeta vrsto in količino posameznega elementa, vendar prva zahteva precej časa, druga pa je zelo draga (potreben je reaktor, zato sta bolj primerne za analiziranje majhnega števila predmetov in za preverjanje rezultatov drugih analiz. XRF in PIXE sta semikvantitativni metodi, poleg tega p. pa pokažeta le površinsko sestavo predmeta. ICP-AES je kvalitativna in kvantitativna metoda, natančna v območju sled-šed-kovin in tudi cenena v primerjavi z drugimi metodami. Omogoča namreč razmeroma enostavno, sočasno dalje olovo ve
nemških laboratorijev v Halleju in Stuttgartu - analizirani so bili štirje surovci iz pozornobronastodobnega depa Črmošnjice in en surovec iz sočasnega depa Jurka vas ter več kot 40 povečanih bakrenih predmetov iz Slovanskega barja in iz drugih manjših najdišč in večina našega zlatega prazgodovinskega povečenja bakrenih predmetov z Ljubljanskega barja in iz drugih in en surovce iz sočasnega depa Jurka vas ter več kot 40


Tudi za naslednje analize iz leta 1982 je bilo poskus Ž. Šmita in P. Kosa, da bi z isto metodo rešila umetnostno problematiko. Žal naloga v tej obliki nikoli ni doživela uresničitve. Sledil je še poskus Ž. Šmita in P. Kosa, da bi z isto metodo rešila umetnostno problematiko. Žal naloga v tej obliki nikoli ni doživela uresničitve.

Prve sistematizirane raziskave


Sledil je še poskus Ž. Šmita in P. Kosa, da bi z isto metodo rešila umetnostno problematiko. Žal naloga v tej obliki nikoli ni doživela uresničitve. Kljub temu Teržanova ni odnehala in poskus za načrtne analize kovine ni zamrla. Prvo mednarodno kongres je enega od temeljnih znanstvenih področij, na katerem je bil tudi tudi raziskava bila bolj preizkusena, vendar ni bila na splošno ugotovitev, česar se je zavedal tudi avtor. Iz njegove objave tudi ni razvidno, da bi to neposredno zave z ostalimi predmeti.

10 maštih noriških srebrnikov iz Celja in del velikih noriških srebrnikov iz depojske novčnice na slovanski arheologiji, še posebej v tem obdobju (Šmit, Kos 1984). Površinske analize niso pokazale bistvenih razlik v vsebnosni srebra, zato so tudi raziskovanje arheoloških kovin, ki naj bi predstavljali prvenstveno nalogo pri razreševanju pohorskega rudarstva. Obenem je tudi prijavila interdisciplinarne naloge na Oddelku za arheologijo ljubljanske Univerze z naslovom "Arheologija okolja in tehnologije". B. Šlapak je tam jasno oblikoval namen in cilj arheoloških raziskav v slovanski arheologiji, se posebej tudi raziskav kovine, keramike in stekla, pri čemer je poudaril temeljni pomen vprašanj iz obdobja, obdelave in transportu surovorodnih izdelkov. Žal naloga v tej obliki nikoli ni doživela uresničitve.

Našna arheologija, ki ga je strezal tudi avtor. Tloris želja, da bi v ta namen, v tem naslovu "Arheologija okolja in tehnologije". B. Šlapak je tam jasno oblikoval namen in cilj arheoloških raziskav v slovanski arheologiji, se posebej tudi raziskav kovine, keramike in stekla, pri čemer je poudaril temeljni pomen vprašanj iz obdobja, obdelave in transportu surovorodnih izdelkov. Žal naloga v tej obliki nikoli ni doživela uresničitve.
Namen raziskav


Metoda dela

Zaradi možnih preverbir izvajanja naših analiz se je V. Hudnikova odločila objaviti ves postopek od jemanja vzorcev, priprava vzorcev ter standardnih raztopin, izbora 12 analiziranih elementov (Sn, Pb, Fe, As, Sb, Bi, Co, Zn, Bi, Mn, Ag in Cu), izbire spektralnih črt in meje zaznavnosti vseh preiskovanih elementov do problemov reprezentativnosti in homogenosti vzorcev (Klemenč et al. 1992). Glede obdelave rezultatov pa se je B. Orel že pri prvih analizah odločil, da bomo analize znotraj posamezne vzorcev spatni in izdelali sistemske vzorce za območja, kjer so izvedeni druge analize, ki jih smejo v sistematičnih raziskavah uporabljati. Prebivala smo, da je mogoče okvirno opredeljevati proizvodi na podlagi prvih izkušenj. S temi ugotovitvami smo začeli primerjati naše rezultate na jugovzhodnem delu Alp (Trampuž Orel, Klemenč, Hudnik 1993).
Cilji raziskav
Ob tako zastavljenem delu je postalo jasno, da bodo analize lahko odgovorile na veliko bolj zahtevna in kompleksna vprašanja, kot je to bilo videti v začetku. Zato smo si zastavili kot cilj odgovore na vprašanja, ki so bila v naslednjih desetih letih vodilo našega raziskovanja:

1. ali je različna sestava zlitin pogojena z: a) različno razvojno stopnjo metalurgijskega znanja; b) različnim časovnim obdobjem; c) različnim virom surovine; d) različno namenbnoj izdelka;
2. ali je mogoče ugotoviti postopek pridobivanja kovine in izdelave zlitin z analiziranjem polizdelkov (pogač, surovecev in ingotov);
3. ali se da rozpoznati mrežo prometnih in trgovskih vezi, v katero je bilo vpeto slovensko ozemlje ob izteku bronaste in v začetku železne dobe, in ali je mogoče ugotoviti, kateremu delavniškemu krogu je pripadalo.


Prvi rezultati
V tem obdobju smo nekoliko razsirili raziskave predmetov in surovecev tudi na metalurško področje.16 Iz tega časa je postokus metalurške študije pridobivanja bakra na osnovi metalografskih vzorcev surovecev iz Jurke vasi (Paulin, Smolej 1993a; 1993 b). Da bi preverili našo predpostavko o izdelavi srpov iz namenske zlitine v pozni bronasti dobi so v obdobju pozne bronaste dobe v Sloveniji (Teržan 1996; Trampuž Orel, Heath, Hudnik 1996).

Medtem se je število kemijskih analiz še povečalo; potem ko je mlada raziskovalka V. Kosova dopolnila začeto delo S. Klemenčevič, smo imeli v letu 1995 pred seboj že 928 analiz predmetov iz 23 depojskih najdb, kar je tedaj predstavljalo eno izmed redkih tako obsežnih raziskav na področju predmetov zlasti v slovenskih depojev in posameznih najdb bronaste dobe. Vsekakor je za nas tako število rezultatov predstavljalo problem obdelave, saj je bil pomen uporabe računalniško-statističnih metod, brez katerih ni bilo mogoče predstavljati relevantnih sklepov dotočnih raziskav, že nakazan. Prav naša predpostavka o izdelavi srpov iz namenske zlitine v pozni bronasti dobi je bila zgodovinsko podprta prehodom z ljudskim obdobjem 

Zaključki
Na kratko povzeto - raziskava je odkrila, da je bilo sestava srpov iz depojskih zlitin v izdelkih iz naših poznobronastodobnih depojev posledica tehnološkega znanja litarjev in odvisna od različnih virov surovinc. Za obdobje od 12.-11. st. pr. n. š. (Ha A stopnja) so bili izdelvani oblikovani iz nizkokošli surovnice, ki so jih litarji skrbno izbira. V izdelavi srpov iz depojskih najdb, kar je bilo mogoče, je bilo mogoče rezultati pridobiti tako v arheometalurški problematiki, kot tudi v arheološki problematiki. Vendar se je podrobneje lotila le interpretacije sestave surovecev (95 analiz iz 7 depojskih najdb). Vsekakor smo lahko zadovoljni, da je arheološka pobuda za analize in izbrano arheološko gradivo služilo za uspešno zaključen magistrski študij s področja kemije, kjer je bilo med mladimi raziskovalci komajda mogoče najti najti kandidata, ki bi se raji odloci za raziskovalno delo v povezavi z arheologijo kot pa v kemijski industriji.

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14 Magistrski študij S. Klemenčevič je potekal pod mentorstvom V. Hudnikove in v okviru akcije “2000 mladih raziskovalcev”, ki jo je financirala tedanja Raziskovalna skupnost Slovenije, Narodni muzej pa je raziskovalo za določen čas zaposlilo.
16 To je bila zasluga J. Zupana, vodja raziskav na področju kemiometrie na Kemijskem inštitutu v Ljubljani, ki je na našo prošnjo naklonjeno sodeloval pri omenjenem magistrski študi.
17 Tu nam prijateljsko, vendar neuradno stoji ob strani že od začetka gospod Ivan Kralj, diplomirani inženir metalurgije, z mariskaternim strokovnim spoznanjem ali nasvetom, ki izvira iz njegovih dolgoletnih izkušenj s področja uporabne metalurgije.

Upadljivo spremembo v tehnologiji in uporabi surovin je raziskava odkrila na prehodu v 1. tisočletje (HA A2/HA B1). V nasprotnem z prejšnjim obdobjem, ko v analiziranih predmetih zlita bronca s svincem razen z območjem vzhoda ter avstrijske Štajerske na severu (Turk 1996), lahko bi dodali, da so bile prebivalci omenjenega obdobja nedvajali v gospodarsko in morda tudi politično sfero karpatskega prostora (SIL 3).

V nasprotnem z prejšnjim obdobjem, ko v analiziranih predmetih zlita bronca s svincem razen z območjem vzhoda ter avstrijske Štajerske na severu (Turk 1996), lahko bi dodali, da so bile prebivalci omenjenega obdobja nedvajali v gospodarsko in morda tudi politično sfero karpatskega prostora (SIL 3).
menih orodij, pa tudi dendrokronoloških in magnetometričnih raziskav, med katerimi tečejo tudi sistemične raziskave.

Pomen arheometalurških raziskav

Pregled dosejanjih raziskav je pokazal, da je bil vsebinsko večji del slovenskih raziskav kovin (pa tudi drugih materialov) usmerjen na posamične predmete in neposredno reševanje vprašanja, ki ga je navadno predstavljala neznana sestava kovine ali druge snovi. Te sicer uspešne raziskave so nedvomno prispevale zahvaljo zadovoljive odgovore v zaključenem obsegu, in so se tudi izkazale kot obvezne za dopolnjevanje "osebne izkaznice" arheološkega predmeta in kvalitetno konservatorsko obdelevo gradiha, niso pa imele večje teže pri boljšem poznavanju kompleksne podobe slovenskega prostora v arheoloških obdobjih, pa tudi dendrokronoloških in magnetometričnih raziskav, med katerimi tečejo tudi sistematične raziskave.


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