THE IAEA TECHNICAL COOPERATION PROJECTS ON THE APPLICATIONS OF NUCLEAR TECHNIQUES FOR CULTURAL HERITAGE RESEARCH

A NEMZETKÖZI ATOMENERGIA ÜGYNÖKSÉG EGYTTMŰKÖDÉSI PROGRAMJAI A NUKLEÁRIS MÓDSZEREK ALKALMAZÁSAIRÓL A KULTURÁLIS ÖRÖKSÉG KUTATÁSÁBAN

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Abstract

The International Atomic Energy Agency was founded in 1957. Its mission was declared as to foster the safe and peaceful applications of the atomic energy and nuclear technologies. The four major fields of its activity are: 1, Nuclear and Radiation Safety, 2, Nuclear Energy, 3, Human Health and 4, Isotope and Radiation Technology Applications. Among the various applications of nuclear techniques, forensic and cultural heritage studies have become of more and more importance. In this paper, I give an overview of the Technical Cooperations on cultural heritage research, launched by the IAEA in the last decade.

Kivonat

A Nemzetközi Atomenergia Ügynökség (International Atomic Energy Agency – IAEA) 1957-ben alapított független nemzetközi szervezet, amelynek deklarált küldetése az atomenergia és a nukleáris technológiák biztonságos és békés felhasználásának elősegítése – amint azt mottója, „Atoms for Peace" is kifejezi. Tevékenységét a tagországok kutatóinak, szakembereinek munkáján keresztül négy fő területen végzi: 1, nukleáris biztonság és sugárvédelem, 2, nukleáris energia, 3, egészségügy valamint 4, az izotóptechnika, ill. sugártechnológia különböző alkalmazásai. Az alkalmazott kutatások közül egyre növekvő szerepet kapnak az ún. „nukleáris törvényszéki" vizsgálatok, valamint a kulturális örökség tárgyainak kutatása. Az alábbi összefoglaló írásban áttekintjük az elmúlt évtizedben az IAEA által a kulturális örökség vizsgálata tárgyában indított regionális együttműködés programok (ún. „Technical Cooperation"-ok) főbb jellegzetességeit.

KEYWORDS: INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), NON-DESTRUCTIVE, NUCLEAR TECHNOLOGY, CULTURAL HERITAGE, TECHNICAL COOPERATION, COORDINATED RESEARCH PROJECT

KULCSSZAVAK: NEMZETKÖZI ATOMENERGIA ÜGYNÖKSÉG, RONCSOLÁSMENTES, NUKLEÁRIS TECHNIKÁK, KULTURÁLIS ÖRÖKSÉG, TECHNICAL COOPERATION, COORDINATED RESEARCH PROJECT

Introduction

The International Atomic Energy Agency (IAEA) was founded in 1957. The slogan of the worldwide independent organisation is known as "Atoms for peace" within the United Nations. Its mission is to promote the safe, secure and peaceful use of nuclear technologies together with Member States and multiple partners worldwide. The homepage of the Agency can be found at https://www.iaea.org/. The Agency carries out its European Regional activity through four thematic areas: 1, Nuclear and Radiation Safety, 2, Nuclear Energy, 3, Human Health and 4, Isotope and Radiation Technology Applications – including nuclear forensics, medical, environmental, food & agricultural, industrial and cultural heritage applications. The applications of nuclear technology or more precisely, the applications of ionizing radiation used to be on top in the 1960s and 1970s. Various nuclear-based methods have been widely applied in industry, agriculture and medicine. Nowadays, the nuclear methods are gradually replaced by non-nuclear ones in the above fields, but in nuclear forensics and in the cultural heritage applications, nuclear methods are still preferred – mainly thanks to their non-destructive feature. In this paper and in the other few in this volume, we present the talks given on 12 January 2016 at the Budapest Neutron Centre, on the occasion of scientific visit of Maria Isabel Garrido Prudencio and Maria Isabel Marques Dias from the Universidade Técnica de Lisboa, Instituto Superior Técnico, Instituto Tecnológico e Nuclear, Portugal and Ziga Smit from Faculty of Mathematics and Physics, University of Ljubljana.

We would like to acknowledge the importance of the IAEA in fostering the co-operation of the participating countries in the field of Heritage Science.

Discussion

The overview of the Technical Cooperations of the IAEA

Let's overview, how nuclear techniques can contribute to the family of social sciences, including archaeology, art history, restoration and conservation.

During the investigation of a historical object, the first things to describe are their characteristics, such as its appearance, material(s) made of, technology of production and, last but not least, its age. For characterisation (determination of raw material composition, structure, degree of corrosion) and also for dating, various analytical methods can be applied. Obviously, the non-destructive and non-invasive methods are almost exclusively preferred. Among the archaeological dating methods, usually the C-14 method is considered as a nuclear one.

The results of the characterisation and dating studies can provide data for pure social sciences, such as archaeology, or may serve as background information for conservators or restorers.

On the other hand, high dose gamma radiation can be an effective tool to perform conservation treatment on cultural heritage objects, i.e. to destroy harmful insects or fungi. In this view, the IAEA divides the field of Applications of Nuclear Techniques for Cultural Heritage Research into three main tasks: characterisation, dating and preservation. Later on, authentication was also included, i.e. to distinguish original from counterfeit art objects, using non-invasive nuclear techniques.

As the importance of non-invasive nuclear techniques has been recognized, the IAEA has launched a series of European regional Technical Cooperations (TC) since 2005, with an increasing number of participants and with widening scientific activity within the Cultural Heritage applications.

The first TC (with a serial number of RER1006) was running from 2005 to 2007. Its title was "Nuclear Techniques for the Protection of Cultural Heritage Artefacts in the Mediterranean Region". Its main objective was to contribute to the study and preservation of cultural heritage through the establishment of a sub-regional network of the project counterparts and end-users. In the beginning, there were only ten participating from the Central and South-Eastern European / Mediterranean countries in the project: Albania, Bosnia and Herzegovina, Croatia, Greece, The Former Yugoslav Republic of Macedonia, Malta, Romania, Slovenia, Serbia and Turkey. Invited experts from Western European leading institutions (for instance Prof. Cornelius Ponta from Grenoble, France) took part, too.

The second TC (RER8015, entitled "Using Nuclear Techniques for the Characterization and Preservation of Cultural Heritage Artefacts in the European Region") was running between 2009 and 2012. Its objective was to improve the characterization and preservation of cultural heritage artefacts using nuclear techniques with special emphasis on gamma irradiation treatment to consolidate degraded materials. Not only the scope, but also the number of participating countries indicates the growing interest in the topic. Already 23 countries – Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Hungary, Kazakhstan, Latvia, Lithuania, Malta, Montenegro, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Tajikistan, The Former. Yug. Rep. of Macedonia and Turkey – and even more invited experts from Grenoble, C2RMF Louvre Laboratory, France and from ENEA-UTTMAT, Rome took part. It was the first time when Hungary and Portugal joined the team.

The third TC (RER0034, entitled "Enhancing the Characterization, Preservation and Protection of Cultural Heritage Artefacts") lasted from 2012 to 2013 and its objective was to improve the characterisation, preservation, protection and authentication of cultural heritage artefacts by effective utilisation of nuclear analytical techniques and radiation technology. This project was a natural extension of the previous one, with the same participants and more or less the same work plan.

The objective of the last one between 2014 and 2015 (RER0039, entitled "Extending and Diversifying the Application of Nuclear Technology in Cultural Heritage") was defined as enhancing cultural heritage knowledge and its contribution to socioeconomic welfare. As it was indicated in the title, this project intended to achieve a synthesis of the efforts and achievements of the previous TCs.

During the course of the consecutive projects, the participating countries offered their research infrastructure and expertise into various bi- and multilateral co-operations among them. Many participating countries operate research reactors, accelerator-based ion beam laboratories, C-14 laboratories, other lab based or portable spectroscopic devices (XRF, XRD, IR-, and Raman-spectroscopy) and they possess the knowledge to utilise them in cultural heritage research.

Participation of Hungary

Hungary takes part in the series of the Technical Co-operations since 2009. The country is represented by three Academic research institutes, which geographically belong to two major centres: The Centre for Energy Research and the Wigner Research Centre for Physics constitute the Budapest

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Neutron Centre (BNC). Here, many experimental stations are operated, connected to the Research Reactor. At the BNC, a set of methods, like PGAA, TOF-ND, SANS, NAA, RAD, PIXE are available for mostly non-destructive studies. Scientists here have extensive experience in the field of cultural heritage research since back to the end of 1990s. The other important centre is the Institute for Nuclear Research (Atomki) in Debrecen, where the scientists perform high quality research in the cultural heritage field since the 1990s. At the Atomki, the Laboratory of Ion Beam Applications and the Hertelendi Laboratory of Environmental Studies (HEKAL, which operates the C-14 laboratory) have significant results in the field.

Main achievements and perspectives of the IAEA TCs

During the years, several important achievements have been realised within the TCs, which could not have been done without the support of the IAEA. In the following, we just give a list of the most significant ones.

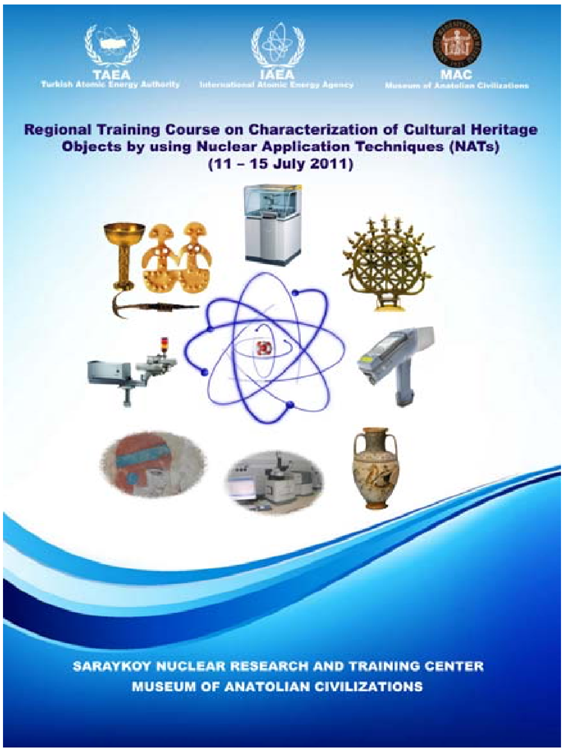

Fig. 1.: Poster of the "Regional Training Course on Characterisation of Cultural Heritage Objects by using Nuclear Application Techniques" in Ankara, 2011.

1. ábra: A 2011-ben Ankarában tartott "A kulturális örökség tárgyainak vizsgálata nukleáris módszerekkel" c. regionális tanfolyam plakátja

Fig. 2.: In situ application of a hand-held X-Ray Fluorescence analyser for the non-destructive examination of the traces of polychromy remained on the surface of ancient marble sculptures (Kunst Historisches Museum, Vienna, source: IAEA homepage)

2. ábra: Hordozható röntgenfluoreszcens spektrométer múzeumi alkalmazása. Festék-maradványok vizsgálata egy antik márvány szobor felületén. (Kunst Historisches Museum, Bécs, forrás: IAEA honlap)

First of all, a sub-regional network has started to form between the participating countries including bi- and multi-lateral collaborations between nuclear- and humanistic science. Furthermore, the IAEA facilitated the establishment of formal co-operations within two European regional initiatives of CHARISMA and SPIRIT.

As a result of the IAEA activities, the integration of different nuclear techniques for radiation treatment and characterization has significantly increased and an attempt towards standardisation has been done. Efforts towards the harmonisation of analytical and CH inventory data at the regional level have also been made, especially by distribution and measurements of reference materials (e.g. alloys) through proficiency tests.

In order to disseminate the knowledge and expertise, high quality regional training events focusing on nuclear techniques applications in cultural heritage have been organised by the participating institutions. Particularly successful courses were held for instance about the application of handheld XRF equipment in Ankara 2011 (**Fig. 1.**), at the Seibersdorf IAEA Laboratory in 2013 (**Fig. 2.**), and about the C-14 dating in Debrecen, Hungary, 2015.

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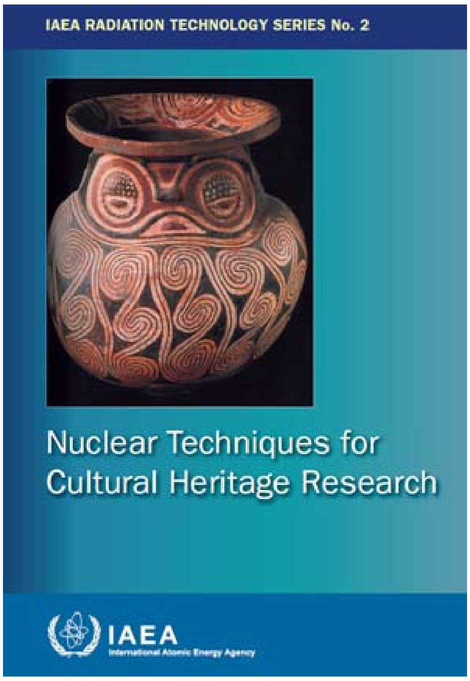

Fig. 3.: The cover of the IAEA Radiation Technology Series No. 2, Vienna, 2011.

3. ábra: A Nemzetközi Atomenergia Ügynökség "Radiation Technology Series No. 2" c. kiadványának (Bécs, 2011) borítója.

As an outcome of these forums, several guidelines, technical documents, scientific and promotional publications have been published either by the IAEA (IAEA Radiation Technology Series No. 2, 2011, **Fig. 3.**) or by the individual researchers of the community. These publications become available to the member states. Furthermore, an online platform was established to give an opportunity to find up-to-date information, partners, etc. on the field of Heritage Science (**Fig. 4.**). Also, reports on each participating country's activities can be found at http://nuclculther.eu/.

Last, but not least the IAEA gave a hand to many of the participating countries to improve their technical capabilities. For instance, developments have been done in new C-14 laboratories in Azerbaijan, Ukraine and Turkey, in a LA-ICP-MS laboratory in Bulgaria. For some countries, such as Serbia or Turkey, procurement of handheld XRF instruments has become available.

In spite of the many achievements, however, many things remained to improve. Below, the most important future tasks are listed:

1, If possible, standard procedures and guidelines in application of nuclear techniques in Heritage Science need to be developed and followed. 2, Experts have to develop the mechanism of cross-border sharing of information and the databases of analytical studies. 3, More sufficient collaboration between member states is still needed with promotion and sharing of technical expertise. 4, An improved outreach towards stakeholders is needed in promotion of nuclear techniques applied to Heritage Science. For this purposes, a viable website platform imperative for networking between member states in this area.

Being aware of the tasks remained, a new project already started and further more are planned to apply for. A Coordinated Research Project (CRP F23032) entitled "Developing radiation treatment methodologies and new resin formulations for consolidation and preservation of archived materials and cultural heritage artefacts" is already running with participation of Poland, Romania, Croatia, Turkey and Portugal. Other ideas to launch a CRP or TC on characterisation, dating or preservation of cultural heritage objects are considered.

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Fig. 4.: The starting page of the IAEA RER 0034 TC project web site, 2012, http://nuclculther.eu/

4. ábra: A Nemzetközi Atomenergia Ügynökség RER 0034 TC sz. együttműködési programjának honlapja, 2012, http://nuclculther.eu/

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NAA APPLIED TO HETEROGENEOUS LITHIC ARCHAEOLOGICAL ARTEFACTS - DIFFICULTIES AND ADVANTAGES FOR PROVENANCE ESTABLISHMENT

NEUTRONAKTIVÁCIÓS ANALÍZIS ALKALMAZÁSA RÉGÉSZETI KŐANYAGON – EREDMÉNYEK ÉS PROBLÉMÁK A SZÁRMAZÁSI HELY AZONOSÍTÁS VIZSGÁLATOKBAN

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Abstract

Instrumental neutron activation analysis (INAA) is a sensitive, precise and accurate technique, and allows obtaining simultaneously the concentration of a large number of chemical elements. The small amount of sample required for INAA is a huge advantage when dealing with Cultural Heritage materials. Nevertheless the chemical results obtained for these small samples analyzed must be representative of the object, which becomes difficult when dealing with heterogeneous materials like chert. INAA applied to very small flakes of the core from the same chert artefact has shown to be a promising methodology to identify chemical fingerprints contributing to the establishment of provenance and human mobility in ancient times.

Kivonat

A neutronaktivációs vizsgálat (INAA) érzékeny, pontos és megbízható összetétel vizsgálati módszer, amely egyszerre számos kémiai elem mennyiségi meghatározását teszi lehetővé. Kis mennyiségű mintát igényel, ami különösen fontos a kulturális örökség körébe tartozó tárgyak vizsgálatánál. Ugyanakkor fontos, hogy a kis mennyiségű minta kellőképpen reprezentatív legyen a tárgy egészére, ami inhomogén anyagok vizsgálata esetében kritikus lehet. Ugyanarról a magkőről származó apró pattintékok vizsgálatával teszteltük a módszer alkalmazhatóságát kova eszközök lelőhelyének azonosítására. Az eredmények hozzájárulhatnak a származási hely azonosításhoz és ezen keresztül az őskori mozgáskörzetek vizsgálatához.

KEYWORDS: LITHIC ARTEFACTS, INAA, CHEMICAL HETEROGENEITY, MICRO-INVASIVE METHODOLOGY, PROVENANCE

KULCSSZAVAK: KŐESZKÖZÖK, INAA, KÉMIAI HETEROGENITÁS, ALACSONY RONCSOLÁSI SZINTŰ VIZSGÁLAT, SZÁRMAZÁSI HELY VIZSGÁLAT

Introduction

Chert has been extensively used since pre-history to obtain tools as scrapers, hand axes and arrowheads due to its hardness and conchoidal fractures, which allows obtaining sharp blades. The identification of the geographical location where the raw materials occur may contribute significantly to trace human mobility.

Chert is a dense cryptocrystalline variety of quartz, slightly translucent to almost opaque (Brandl 2014). Inclusions of organic compounds, metal sulphides, and various metal oxides and hydroxides can cause the different colours (dark gray with shades of brown, red, or yellow, and sometimes white), and may lead to a heterogeneous chemical composition. So, besides a general low content of most chemical elements in chert, this heterogeneity may difficult the use of the chemical composition of these archaeological artefacts to distinguish chert from different sources. Therefore, it is important to evaluate the content differences of the larger number of chemical elements as possible within a same chert fragment. Due to the high value of cultural objects the amount of sample to be taken for analysis must be none (non-destructive techniques), or very small (micro-invasive techniques). Several works have been performed using a great variety of analytical methods to identify the sources of chert artefacts found in different archaeological contexts (Malyk-Selivanova et al. 1998; Costopoulos 2003; Allard et al. 2008; Kasztovszky et al. 2008; Crandell 2008; Bustillo et al. 2009; Hughes et al. 2010, 2012; Shackley 2011; Gauthier et al. 2012;).

Eixea et al. (2014) and Roldán et al. (2015) were able to discriminate two chert types from the Eastern part of Spain - the “Domeño type” (Villaverde et al. 2008), and the “Serreta type” (Molina et al. 2010, by using multivariate statistical analysis applied to data obtained by energy dispersive X-ray fluorescence spectrometry

(EDXRF), and the crystalline index of quartz obtained from the X-ray diffraction (XRD). However several sub-types previously identified macroscopically (Eixea et al. 2011) could not be differentiated by those methods. More recently Prudêncio et al. (2016) reported that instrumental neutron activation analysis (INAA) of small flakes from the same flint fragment of archaeological artefacts from archaeological sites from Eastern Spain allowed to differentiate flint types and variants.

In this work the methodology using INAA to evaluate the natural heterogeneity of chert fragments and its use to contribute for the establishment of chert provenance, is discussed.

Methods

A number of different analytical techniques have been applied to characterize archaeological materials with varying degrees of success, but all of them need to have multi-element capability and sufficient sensitivity to detect traces of elements in the various matrices. Among these techniques the analytical method with one of the longest and most successful histories of application for provenance research has been instrumental neutron activation analysis (INAA) (Julig 1995; Glascock 2004; Glascock and Neff 2003; Glascock and Speakman, 2008; Prudêncio 2009). INAA is a sensitive technique useful for quantitative multi-element analysis of major, minor, and trace elements. This technique involves the irradiation of a sample by neutrons to make the sample radioactive followed by gamma spectrometry to determine the amounts of different elements present in the sample. INAA has a number of advantages over most other analytical methods when investigating archaeological specimens. In fact the preparation of archaeological materials for analysis by INAA is extremely easy in most instances a representative sample may be only a portion of the sample weighed and place in an appropriate container (100-200 mg) (micro-invasive technique), which is very important when dealing with cultural materials that must be preserved.

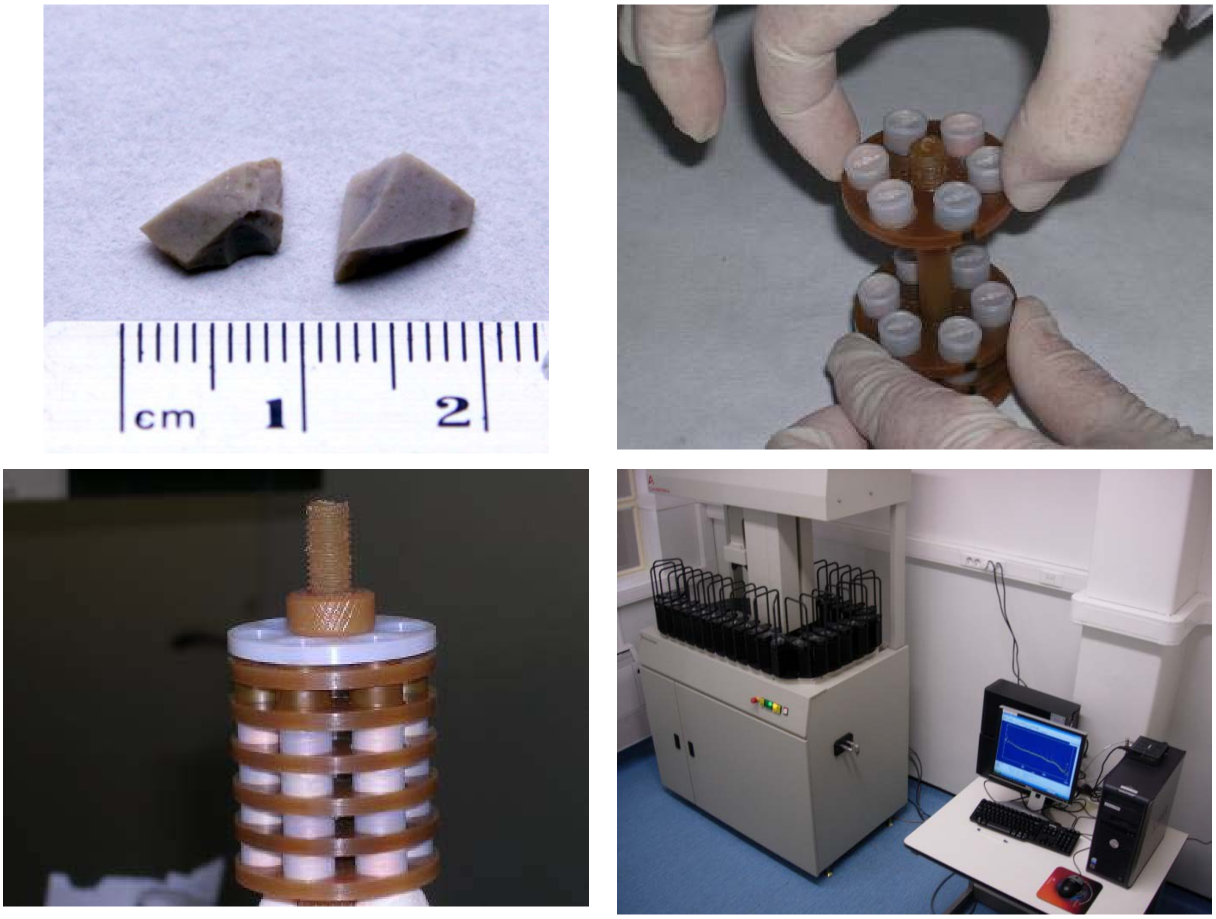

Fig. 1.: Photographs of: flakes of the core of a chert fragment; polyethylene vials with samples and reference samples powders; container ready to be used for long irradiations in the Portuguese Research Reactor (CTN, IST); counting room of the INAA laboratory of CTN.

1. ábra: Kova szilánkok; műanyag fiolák a porított mintákkal és referencia anyagokkal; a Portugál Kutató Reaktornál használt mintatartó, előkészítve a hosszúidejű besugárzáshoz; a Portugál Kutató Reaktor Neutronaktivációs Laboratóriumának számláló helyisége

Despite the small amount of sample required for INAA, the sample analyzed must be representative of the artefact, which becomes very difficult if the cultural objects are made of heterogeneous materials. Thus, when dealing with cultural heterogeneous materials like chert three issues are important: (1) to use the fewer amounts of sample as possible; (ii) to assess eventual heterogeneity; and (iii) to identify chemical fingerprints. The big question is: how to solve this issue? Recently, Prudêncio et al., 2016 presented a methodological approach applying INAA to small samples (in a micro-invasive way) from heterogeneous chert fragments. The analytical method applied included (**Fig. 1.**): (i) 2-3 small portions (less than 1g) of the core of each chert fragment prepared separately; (ii) powder samples for analysis of the geological and archaeological fragments obtained by drying for several hours at 30ºC, and ground in a corundum mortar to avoid contamination; and (iii) INAA – irradiation and gamma-spectrometry. Gamma spectra were obtained with measuring times of 6 hours per sample and standard in order to reduce the error associated with the peak areas determination. The chemical contents of Na, K, Fe, Sc, Cr, Co, Zn, Ga, As, Br, Rb, Zr, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Th and U were obtained. Instrumental errors are in general to within 5%, and occasionally within 15%. Details of the analytical method may be found elsewhere (Gouveia et al., 1992; Prudêncio, 2009). Corrections are made for the interference from uranium fission. It is well known that the presence of U in samples interferes in the determination of several elements concentration by instrumental neutron activation analysis. This is partly due to the identity of some 235U fission products with radionuclides formed by radioactive capture of neutrons on those elements (nuclear interference), and also to the fact that the γ-rays emitted by some fission products cannot be resolved from γ-rays emitted by radionuclides of interest produced by (n,γ) reaction (spectral interference). The extent to which the interference may affect the accuracy of the determination depends on the ratio of the concentrations of the element to be determined and of U in the sample, as well as on the irradiation conditions and cooling time. So corrections for the determination of rare earth elements (REE), zirconium and barium must be done (Gouveia et al. 1987; Martinho et al. 1991).

Discussion

The results obtained by Prudêncio et al. (2016) for chert fragments of archaeological artefacts and geological outcrops has shown that INAA applied to small samples (circa 150 mg) of the core of the fragment (micro-invasive technique) appears to be a suitable method to characterize and differentiate chert from different sources in a micro-invasive way. In fact, analyzing 2 - 3 samples of the same fragment, the relative standard deviation of the chemical contents obtained for each element may reach very high values, reflecting how the concentration of some elements may vary within the core of the same chert fragment (**Fig. 2.**).

Also the same element may be homogeneously distributed in some chert cores, and very heterogeneously distributed in other chert cores (for example Zr and Hf).

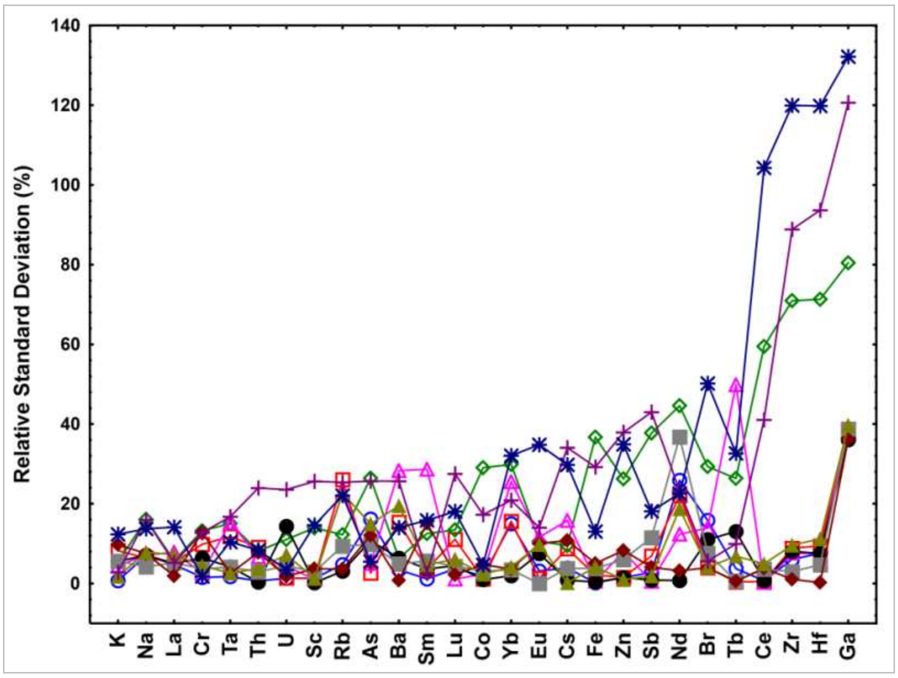

Fig. 2.: Relative standard deviation (RSD) for the concentration obtained of 27 chemical elements in flakes (n=2-3) of the core of chert fragments (data from Prudêncio et al. 2016)

2. ábra: Magkövekből származó minták méréséből meghatározott 27 kémiai elem koncentrációjának relatív szórása (relatív standard deviációja – RSD), n=2-3 megismételt mérés esetén (Prudêncio et al. 2016 nyomán)

Thus this micro-invasive methodological approach, with a careful analysis of the chemical results obtained by INAA for each lithic archaeological artefact or geological fragment, and the identification of chemical fingerprints (chemical elements homogeneously distributed inside the core of a certain type of chert) may contribute significantly for the establishment of chert sources.

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NON-INVASIVE NUCLEAR TECHNIQUES APPLIED TO STONE IDOLS FROM PRE-HISTORICAL PERDIGÕES SITE: A CONTRIBUTION TO UNDERSTAND INTERACTION NETWORKS

RONCSOLÁSMENTES NUKLEÁRIS TECHNIKA ALKALMAZÁSA PERDIGÕES ŐSKORI LELŐHELYRŐL SZÁRMAZÓ KŐ IDOLOKON: ADATOK AZ KAPCSOLATI HÁLÓZATOK MEGISMERÉSÉHEZ

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Abstract

Perdigões is a large ditched enclosure dated from the Late Neolithic to the Late Chalcolithic/Early Bronze Age (cal BC 3400-2100), located in Reguengos de Monsaraz municipality (Évora district, South Portugal). Hexogen raw materials as ivory, variscite, cinnabar were recorded and several objects made of locally available raw materials show stylistic criteria that seem to reveal external provenances.

This paper will address a specific assemblage of objects: stone idols and stone recipients recorded in funerary contexts. This assemblage presents different typologies and raw materials, apparently marble or limestone, suggesting different origins for these artefacts, since both rocks do not occur locally, but regionally or even longer distance.

One of the main goals of this work is to determine the nature of the used raw materials, by studying the composition of a set of stone idols and ritual stone vessels, together with geological samples (marbles and limestones), trying to evaluate the degree of compositional homogeneity between items and possible areas of origin, thus contributing to understand the interaction network in which Perdigões was involved. Another important achievement of the study was to determine whether Prompt Gamma Activation Analyses (PGAA) could be successfully used to trace the source(s) of those artefacts made of carbonate rich raw materials.

The analysis of obtained results, particularly the statistical results obtained by Principal Component Analysis (PCA) and clustering methods applied on the chemical contents, clearly detach five groups between the stone idols, while the vase sample analyzed has also a different chemical behaviour. The analyzed stone artefacts from Perdigões show signs of both nearby and long distance procurement, as well as of unknown attribution.

Kivonat

Perdigões, az. i.e. 3400-2100 között fennálló település a mai Reguengos de Monsaraz város területén található. (Évora, Dél- Portugália). Távoli nyersanyagok – elefántcsont, variszcit, cinnabarit – bizonyítják kiterjedt külső kapcsolatait. Ez a tanulmány egy különleges tárgycsoporttal foglalkozik, kőből készült idolokkal, amelyek sírmellékletként kerülnek elő. Különféle típusok és nyersanyagok figyelhetők meg ezek között, többnyire márványból vagy mészkőből készültek, amely nyersanyagok a lelőhely közvetlen közelében nem fordulnak elő. Vizsgálataink célja az idolok nyersanyagának alaposabb megismerése volt, egy sorozat kő idol és néhány kőből készült edény anyagának kémiai összetétel vizsgálatával, amelyek mellett márvány és mészkő összehasonlító mintákat is mértünk. Vizsgáltuk a tárgyak összetételének egységes voltát, és összehasonlítottuk adatainkat a feltételezhető származási területről gyűjtött összehasonlító mintákkal. A vizsgálatok célja Perdigões település kiterjedt kapcsolatrendszerének jobb megismerése volt. A vizsgálatok másik célja a prompt gamma aktivációs analízis (PGAA) alkalmazási lehetőségeinek megismerése volt karbonátos anyagú kőzetek lelőhely azonosítására. Eredményeink szerint, amelyeket statisztikai módszerekkel (főkomponens analízis és klaszter-elemzés) értékeltünk ki, a kő idolok között öt csoportot tudtunk elkülöníteni a kémiai összetétel alapján. A kőedény ezektől összetételében különbözött. A vizsgált összehasonlító minták alapján a kő idolok részben helyi, részben távolsági eredetűek, de találtunk eddig azonosítatlan nyersanyag forrásból származó példányokat is.

KEYWORDS: PGAA; STONE IDOLS; PREHISTORY; PERDIGÕES SITE

KULCSSZAVAK: PGAA; KŐBŐL KÉSZÜLT IDOLOK; ŐSKOR; PERDIGÕES LELŐHELY (PORTUGÁLIA)

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Introduction

The Perdigões site is one of the largest known Portuguese Chalcolithic ditched en-closures, occupied during the 4th-3rd millennium B.C. (Valera et al. 2014a) in the Reguengos de Monsaraz region, in the South of Portugal. Like all the large ditched enclosures of southern Iberia, the site presents a significant amount and variety of hexogen objects, frequently made of exotic and nonlocal raw materials (Valera et al. 2012a; 2012b).

In the case of Perdigões enclosure, hexogen raw materials as ivory, variscite, cinnabar were recorded and several objects made of locally available raw materials show stylistic criteria that seem to reveal external provenances. Pottery artefacts include all the typical morphologies of the Late Neolithic and Chalcolithic of the South West of the Iberian Peninsula and there are differences between the style, production technology and provenance of funerary and settlement pottery (Dias et al. 2005).

This paper will address a specific assemblage of objects: stone idols and stone recipients recorded in funerary contexts. This assemblage presents different typologies and raw materials, apparently marble or limestone, suggesting different origins for these artefacts, since both rocks do not occur locally.

One of the main goals of this work is to determine if diverse raw materials resources were used, by studying the composition of a set of stone idols and ritual stone vessels, together with geological samples (marbles and limestones), trying to evaluate the degree of compositional homogeneity between items, as well as possible areas of origin, contributing to understand the interaction network in which Perdigões was involved. Another important achievement of the study was to determine whether Prompt Gamma Activation Analyses (PGAA) could be successfully used to trace the source(s) of those artefacts made of carbonate rich raw materials.

It is a well-known debate the problem in sourcing carbonate rich artefacts due to the fact that macroscopically they may look similar, even if they come from different source. From a mineralogical point of view, they are almost pure $CaCO_3$ with a very heterogeneous mixture of impurities. In this case of carbonate artefacts, especially those deriving from the metamorphic evolution of previous carbonates (marbles), are often rather similar to each other in many respects (i.e. mineralogical, physical–structural and chemical), and thus difficult to identify. Due to the fact that impurities are generally heterogeneous in this kind of geological source, a significant overlap with other sources may occur.

Another important issue related with the analysis of these artefacts is the fact that the objects involved are often unique in nature. To achieve the main goals, and regarding the importance of these stone artefacts, only non-invasive analysis was possible, respecting the physical integrity of the material/ object. PGAA is one of the new techniques available to deal with this problem.

Methods

The non-invasive method PGAA was applied to both stone idols, stone vessels, and potential raw materials. Its basis is the radioactive capture of neutrons, or the (n,γ) reaction. During this nuclear reaction, an atomic nucleus captures a thermal or sub-thermal neutron, and emits a number of gamma photons promptly. Because of the low intensity of external neutron beams, PGAA can be considered non-destructive, and is applicable to samples that must be preserved intact and do not require sample preparation, being positioned directly in the neutron beam. The PGAA facility used was the one from the Budapest Neutron Centre, which has become a leading laboratory for applications of PGAA in archaeometry (Szilágyi et al. 2012; Kasztovszky, et al., 2004). For the statistical interpretation of the PGAA data, only the oxides/elements which were above the quantification limit in most of the samples were used i.e. CaO, CO_2, LOI (H_2O), SiO_2, Fe_2O_{3t}, MnO, K_2O, Mg, B, Ti, Cl, Sm and Gd.

The stone artefacts

Seven limestone samples (Moleanos limestone: MOL-1, MOL-2, MOL-3; Lioz limestone: LIOZ-1, LIOZ-2, LIOZ-3; Tavira breccia BT) and four marble samples (MNR, MAL, MBC, MER) were analyzed from nearby sources (~40Km the "marble triangle" Estremoz – Borba – Vila Viçosa, in Alentejo's northeast), moderate distance areas (~130 Km - limestone from Tavira, Algarve) and c) remote areas (160 to 200 Km -Limestones from Pêro Pinheiro and from the Maciço Calcário Estremenho MCE). Regarding artefact samples, thirteen stone idols from the cremation contexts (PDI-1 – PDI-13) and one votive vessel (PDV-7) from a tholoi tomb were analyzed (**Fig. 1.**).

Fig. 1.: Stone idol from cremation funerary context and stone vessel from tholoi tomb of Perdigões enclosure.

1. ábra: Kőből készült idol hamvasztásos temetkezésből és kőedény a Perdigões-i körárkos település halomsíros temetkezéséből

Results

In the studied samples CaO is the prevailing major component, ranging from 50 and 57 wt% in artifact samples, and between~51 to ~56 wt% in the geological samples. All analyzed samples have a relatively low MgO concentration (< 2 %).

The studied geological samples are all included in calcitic type marble and pure limestone, but the breccia Tavira sample (BT) is a limestone more enriched in Mg. Regarding the artifact samples, they are all pure limestones / calcitic marbles.

The SiO_2 content in the marble samples range from 0.64% to 3.7%, in the limestones ranges from 0.27% to 2%, and in the stone idols from 0.09% to 2.9%.

The alkali elements, such as Na and K, were below detection limit in almost all the samples, or were detected in a few stone idols.

The other oxides contents are generally low. Iron oxide (Fe_2O_3 Total %) and titanium oxides were detected in most of the samples.

We can infer L.O.I by the content of volatiles (CO_2, H_2O) present in the samples. In general, the sums of both values are high, indicating high volatile content and by implication high carbonate content.

Regarding trace elements, immobile trace elements such as the Rare Earth Elements (REE) are usually important for provenance determination. With PGAA we have determined Sm and Gd. Gadolinium were detected only in two geological samples, and in a few stone artefacts, and Sm was not detected in two idols and in the vase.

Boron contents of limestones are generally low, and are only elevated when the clay or organic contents are high.

PGAA results correspond to the bulk sample, and idols have not been cleaned from surface deposits, and in some of them it appears in considerable amounts, particularly as crashed bones and soil. A special care was taken in order to evaluate if analyzed chemical contents might have been enlarged due these contamination, and not specifically to the nature of geological source, but no correlation was directly established.

The analysis of obtained results, particularly the statistical results obtained by PCA and clustering methods applied on the chemical contents (**Fig. 2.**), clearly detach five "groups" between the stone idols, while the vase sample analyzed has also a different chemical behaviour (Dias and Valera, in press). Each of these five groups is made of only a few samples (2-3 samples), enhancing the difficulty in establishing geochemical fingerprints in these materials. Even so, it was possible to establish that PDV-7 is an extreme outlier, and the idols PDI 3 and PDI-11 even clustered together, have differences among them and with the others. Also some correlation was established between these five "groups" and the potential raw materials.

Among geological samples, those from the nearby sources in the same "marble triangle" have chemical heterogeneities that enhance the difficulty in establishing geochemical fingerprints in these materials. However, some correlations were possible to establish. For Groups 3, 4 and 5 artefacts the most likely source includes samples from the "marble triangle" Estremoz – Borba – Vila Viçosa. The medium distance area sample - Tavira Breccia, like the later doesn't present any chemical affinity with the analysed artefacts. Considering the remote areas geological samples don't point to be a source for the stone idols, but stone vessel is the only sample that has chemical similarity with a limestone sample from the MCE.

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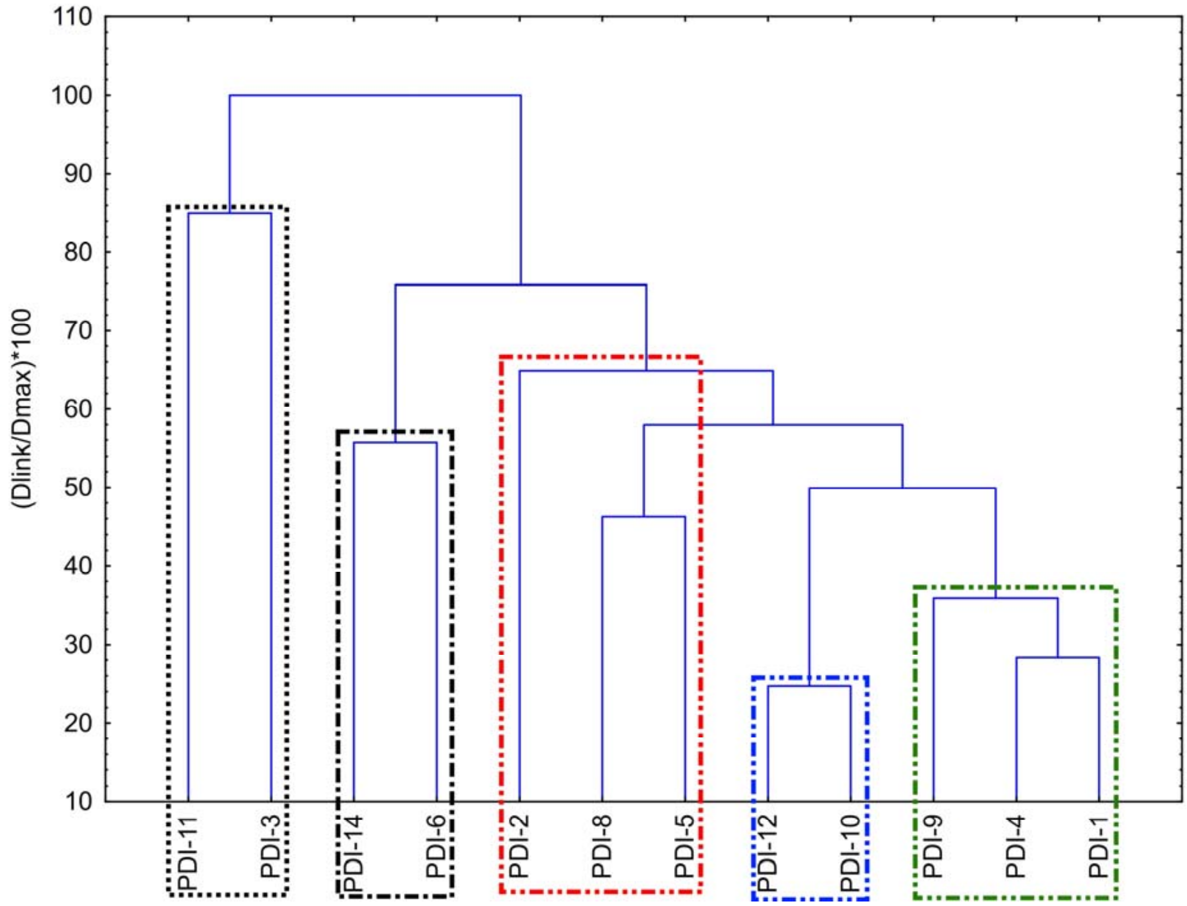

Fig. 2.: Cluster analysis: joining (tree clustering) for the stone idols, with chemical elements obtained by PGAA as variables (standardized), by using the unweighted pair-group average as amalgamation (joining) rule and the Euclidean distances as distance measurement.

2. ábra: A kő idolok klaszter analízise a PGAA adatok alapján. A csoportképzés módszere a súlyozatlan páronkénti csoportátlagok számítása volt, közelségüket az euklidészi távolságok alapján határozták meg.

Conclusions

Therefore, the analyzed stone artefacts from Perdigões show signs of both nearby and long distance procurement, as well as of unknown attribution. More than a half (57%) appears to have been made of materials from the marble triangle Estremoz – Borba – Vila Viçosa. Only one artifact, the only stone vessels analyzed, point to long distance materials (in particular MCE limestones). The rest do not match the analyzed raw materials and are from unknown sources.

The traditional idea that these objects in Alentejo might have come from the Lisboan Peninsula is now nuanced. Only the vessel from the tholoi tomb is compatible with the Estremadura limestones. This seems to suggest that, not just the tholoi tombs and the pits with cremations present different architectures, different body treatments (Valera et al., 14b), different material assemblages, but that these particular set of object have also different raw materials with different provenances.

This study, although preliminary, shows that this line of inquiry comprising the use of PGAA has potential to contribute to the definition of the spatiality of the Perdigões interaction network and to the characterization of the diversity existing between the several funerary contexts already excavated at the site.

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METAL ANALYSIS WITH ION-BEAM METHODS

FÉMVIZSGÁLATOK IONNYALÁB ANALITIKAI MÓDSZEREKKEL

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Abstract

A review presents application of PIXE spectrometry using in-air proton beam on the metal archaeological objects from Slovenia. Among the copper-based alloys, the examples include analysis of prehistoric bronze, analysis of coloured metals used for the Roman military equipment, the introduction of brass, analysis of medieval bronze fiery weapons, and analysis of aluminum bronzes in modern coinage. The silver objects represent artefacts from the Late Iron Age including Celtic coins, and medieval silver coins of the 12th-13th c AD. Special techniques describe profile measurements with differential PIXE and mapping of the 3rd c. AD Roman coins.

Kivonat

A tanulmány összefoglalja a Szlovéniában régészeti fémtárgyakon alkalmazott PIXE spektroszkópiai vizsgálatok újabb eredményeit. A réz alapú ötvözetek körében a bemutatott példák őskori bronztárgyakra, római fegyverekre és sárgaréz tárgyakra, középkori lőfegyverekre és a modern kori pénzverésben használt alumínium-bronz ötvözetekre terjednek ki. A vizsgált ezüsttárgyak késő-vaskori kelta éremleletek és középkori ezüstpénzek az i.sz. 12-13. századból. A speciális technikai megoldások közül ismerteti a PIXE segítségével történő profil méréseket és i.sz. 3. századi római pénzérmék elemtérképeit.

KEYWORDS: PIXE, COLORED METALS, NUMISMATICS

KULCSSZAVAK: PIXE, SZÍNEZETT FÉMEK, NUMIZMATIKA

Introduction

Metal objects are relatively well resistant against aging and represent an important part of surviving cultural heritage. Analysis of metals provides us with quite important knowledge about the technological knowledge of ancient people. We can learn about production recipes, supply routes of raw materials, not at last, the metal composition can even apply some dating possibilities. The known examples include the impurity pattern of the Bronze Age alloys, or the introduction of brass into the Roman world. Mechanical properties may answer if the alloys were prepared on purpose, like forming a hard cutting edge and a flexible blade resistant to shocks and twisting. Technically, all this questions may be answered by bulk analysis, but a thick patina layer covering the object surface often hinders access to the bare metal. Sampling is then the obvious solution, but the decision rests with museum curator if the damage caused to the object is worth of the deduced information. Surface-sensitive methods may represent another approach to the problem, especially for the objects made of precious metals (Šmit et al. 2000) and those that were cleaned and polished during the restoration process. For the objects with patina, removing the patina in a small area is often tolerated as the original look of the object is easily restored. Ion beam methods can provide an efficient surface analysis, as they are fast and for metals virtually non-destructive. In this contribution, we shall briefly describe the basic properties of the method of proton-induced X-ray emission analysis (PIXE), specific examples with the combined analysis using proton-induced gamma rays (PIGE), and review the problems that were studied at the facilities of Jožef Stefan Institute in Ljubljana.

Experimental details

The experiments were performed at the Tandetron accelerator with 2.2 MV nominal voltage. Typically, protons of 3 MeV output energy were used and the proton beam was extracted into air through a thin metal foil. Experiments in the air provide simple changing of the analyzed object, fast

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and easy selection of the measuring points, and allow analysis of objects irrespective of their size. Two types of exit windows were generally used in our experiments: an 8 µm aluminum or a 2 µm tantalum foils. The advantage of aluminum is absence of energetic X-ray lines that would enter the detector through scattering, while the advantage of tantalum is its low energy gamma background. Due to stopping in the exit window and in the air gap between the exit window and target, the actual impact energy at the target was about 2.77 MeV. The excited X-rays were detected with a Si(Li) detector of about 150 eV energy resolution at 5.89 keV. As the inner shell ionization cross sections rapidly decrease with the increasing atomic number, absorbers were used to attenuate the X-rays produced in lighter atoms. For most purposes, a 0.3 mm thick aluminum absorber provides good balance between copper and tin X-ray lines in bronzes; however, the disadvantage of this setting is reduced sensitivity for iron, as its lines coincide with the escape lines of copper. For obtaining the concentrations of copper and lighter elements, additional spectrum was measured using a 6 cm air gap between the target and detector as the only absorber. For silver–copper alloys encountered mostly in coins, a 0.1 mm aluminum absorber typically allowed good balance between copper and silver lines, yet allowing sufficient sensitivity to iron. We also experimented with a cobalt foil as a selective absorber for copper X-rays, but were not able to calculate its transmission function precisely enough. X-ray intensities were deduced from the X-ray spectra using the AXIL program (Van Espen et al. 1977), while the elemental concentrations were calculated by the independent parameter method developed in the lab (Šmit et al. 2005). The main feature of this code is correction for the secondary fluorescence and normalization of concentrations to 100%. For the analysis of patinas, it is also possible to treat the target as a mixture of chemical compounds defined by the user. For monitoring the accuracy of the procedures, the brass standard NIST 1107 (containing 1.066±0.015 % Sn) and modern coins of known composition were analyzed periodically as an unknown target. The accuracy of analysis is typically within ± 5%. The normalization to 100% may not work properly if the alloy contains light metals (aluminum or beryllium). These elements are efficiently detected through their gamma lines (see Sec. 3.6). A dedicated numerical procedure was also developed for the measurement with differential PIXE, which allow reconstruction of concentration profiles (see Sec. 3.7).

Examples

Prehistoric bronzes

Archaeological bronzes are, except for certain water finds, thickly covered by patina layer, so sampling or surface polishing is required. In Slovenia, the pioneering work on bronze analysis was done by N. Trampuž Orel using the method of atomic emission analysis (ICP AES) and sampling the objects by drilling (Trampuž Orel 1996). These works resulted in two important results: the impurity pattern for the Ha A and Ha B (Kalakaca horizon) differed. The total amount of impurities is generally smaller than 2% in Ha A period and up to several percent in Ha B, showing the mining transition from oxide copper ores to more involved polymetallic ones. It was further found that the bronze produced varied according to function: the sickles that were sharpened by hammering contained less tin than the objects intended for cutting and thrusting.

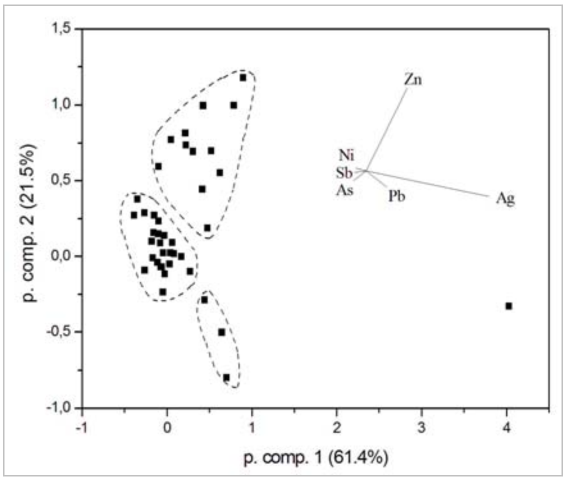

Fig. 1.: Distribution of bronzes from Koszider according to the principal component analysis based on six major impurity elements (Sánta 2011). Three major groups are evident, the main discriminating elements being silver and zinc.

1. ábra: A Koszider korszak bronzainak csoportosítása főkomponens analízissel, hat fő szennyező elem koncentrációja alapján (Sánta 2011). Három csoport egyértelműen elkülönül, a legfontosabb elkülönítő elemek az ezüst és a cink..

Though we analyzed several bronze objects by PIXE preparing the surface by polishing, systematic publication has not appeared yet. The only study that was published in detail is analysis of a small number of samples from south Hungary dated to Middle Bronze Age (Sánta 2011). The impurity

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pattern of bronzes shows three characteristic groups (**Fig. 1.**), which may stimulate finding relation with known ore deposits. For this purpose, the compositional data have to be complemented with the analysis of lead isotopes.

PIXE analysis is particularly efficient for the analysis of iron-reach bronzes known as aes rude, that was circulating in Italy and neighbouring countries since the 6th c. BC. The content of iron typically exceeds several percent, so sufficient precision of the composition is achieved measuring just one spectrum with an aluminum absorber of 0.3 mm thickness.

Roman military equipment

The analysis of Roman military equipment is interesting from the point of technology. It is possible to identify basic materials as well as those used for soldering, riveting, gilding and tinning. Most of the finds we analyzed come from the River Ljubljanica that connected the Roman *municipium* Nauportus, present Vrhnika, with Aemona, now within the borders of present Ljubljana. One of the conspicuous objects analyzed was the medallion of Augustus. It was cast of a very common and cheap lead-tin alloy and silvered on the front side (Istenič 2003). The objects of the so-called Hoard of Vrhnika were made of a qualitative silver alloy containing more than 90% Ag and the objects contained gold inlay (Šmit et al. 2005).

Brass

Most of the Roman objects analyzed were weapons or their parts, like daggers and swords and their scabbards. It was surprising that brass as material was discovered on a scabbard that was traditionally belied to be made of bronze, as the object predated the year 23 BC when the Augustan money reform formally introduced brass for coin nominals of *dupondii* and *sestertii* (Šmit & Pelicon 2000). The archaeologist J. Istenič then initiated a systematic study of Roman bronzes that can precisely be dated on archaeological ground (Šmit et al. 2005). It was found out that brass – as least in the area of Eastern Alps – came into wider use around 60 BC and therefore predates significantly the Roman brass coinage, which appeared in some small issue during the last years of the reign of Julius Caesar (Istenič & Šmit 2007). Brass was further discovered as material of swords scabbards excavated in South-Eastern Slovenia that were made in Late Iron Age style (Šmit et al. 2010). J. Istenič interprets this finding as a matter of cultural relations between the Romans and their barbaric subjects, the Celts in our case. She proposes the objects were made in Roman workshops as gifts for barbaric noblemen who were still attached to their Late Iron Age artistic style (Istenič & Šmit 2014).

Brass objects that occasionally appeared during the first millennium BC were very likely result of using copper ores mixed with zinc minerals. Typically, they contain a few percent Zn, while the brass containing about 20% Zn is result of a demanding cementation process. Around 100 BC brass was widely used for the coins in certain cities of Asia Minor that were or came under the rule of Pontic king Mithradates VI. The king probably used brass coinage as a kind of monopole that helped him paying for his expansionistic politics (Smekalova 2009). The collision with Roman interests induced three major wars, and in 63 BC Mithradates was finally defeated by Pompey and lost his life. During the aftermath period brass gradually spread into the Roman world. In our subsequent analysis we analyzed coins minted by Mithradates VI in Asia Minor (**Fig. 2.**) as well as the brass coins that were used in by Celts in the Gaul during the middle part of the 1st c. BC (Fajfar et al. 2015a). The analysis showed that selenium appears as an important impurity that can point to the ore sources in the eastern part of the classic world, from where the brass spread towards the west.

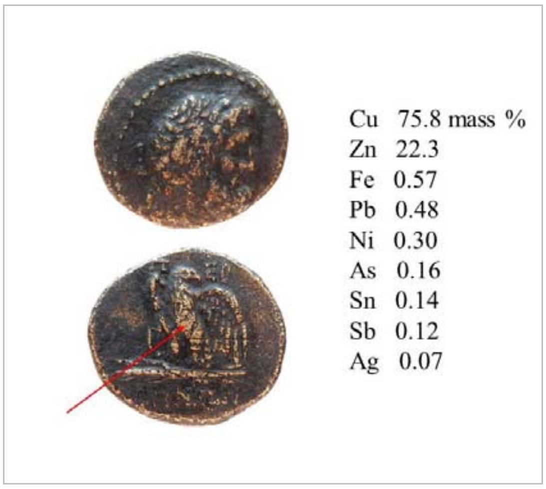

Fig. 2.: Analysis of a 1st c. BC brass coin from Pergamon, measured in the patina-free area on the eagle body (marked with an arrow).

2. ábra: I. e. 1. századi, Pergamonból származó sárgaréz érme kémiai elemzése, a patinamentes helyen mérve (ld. a vörös nyilat)

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Fiery weapons

Among medieval bronzes, we analyzed three fragments that belonged to medieval early fiery weapons (Fajfar et al. 2015b). They were found in the vicinity of three medieval castles and were identified as fragments of the barrels that evidently exploded. Though precise dating and typology were lacking, the barrels very likely represented the earliest fiery weapons, the so-called hand guns or *handgonnes*. They were rather simple weapons that consisted of a metal tube fixed to a plain straight wooden handle. Having no firing mechanism they were usually ignited by a heated iron or a slow-burning match. Most handgonnes did not survive the introduction of powder in granular form that had a much higher explosive effect (Hogg 1996). With our analysis we wanted to identify the material used for manufacturing of the weapons and possibly also to find out what was the reason for their insufficient strength. All three pieces were made of copper alloys; as iron was also commonly used for production of handgonnes, copper alloys were probable selected because of ease of manufacture, as the barrel can be relatively simply produced by casting. According to the surviving records from a castle in Slovenia, iron and copper alloys handguns were equally represented (Lazar 2015). One of the barrels was produced of an alloy with tin and zinc, the so-called gun metal. The reason for its explosion was probably not material strength but improper casting or drilling as the bore was visually rather eccentric. The other two fragments were cast of bronze with a high amount of antimony; virtually the bronze composition was indistinguishable from the alloys used in prehistory. Antimony makes the bronze brittle, the two barrels then exploded because of improper material.

La Tène silver objects and coins

Silver objects spread during the Late Iron Age, together with silver coins since the 2nd c. BC. Analysis of Celtic coins was one of our earliest archaeometric tasks (Šmit & Kos 1984). At that time, we were interested about the net content of silver, as we believed it might explain the systematic weight differences between different archaeological sites. Unfortunately, the coins appeared very inhomogeneous, showing a silver-rich mantle around a base silver core (**Fig. 3.**). This finding discouraged our further work on the coins, as PIXE could only provide the surface concentrations.

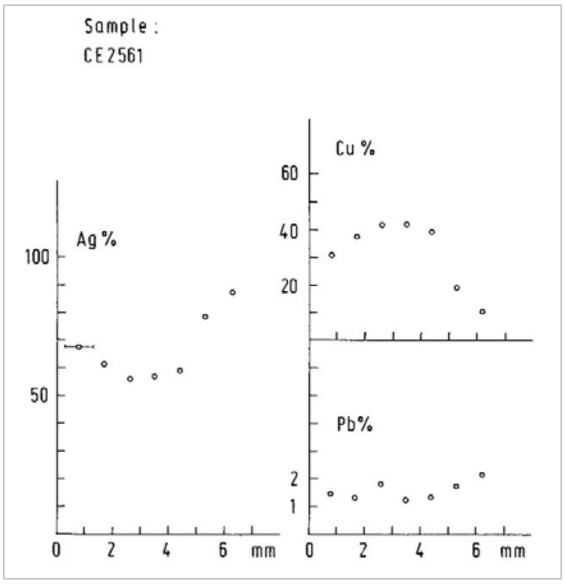

Fig. 3.: Profile scan of a small silver Celtic coin, showing silver-enriched crust and base-silver core (Šmit et al. 1984). The coin was cut to half and measured by a 1 mm collimated beam from rim to rim.

3. ábra: Profil menti összetétel mérés eredménye kelta érmén. Jól látszik az ezüstben dúsult felület és a belső rész közötti különbség. Az érmét félbevágtuk, és 1 mm-es kollimált sugárral mértük peremtől peremig.

Occasional measurements that we did on some silver objects suggested that the impurity pattern consisting of a set of elements (zinc, tin, gold, lead, bismuth) may be characteristic of the silver source in spite of the objects being inhomogeneous. Our recent analysis involved silver objects discovered on the territory of Slovenia and included votive plaques, fragments of torques and brooches. For comparison, we also analyzed a set of Celtic small silver coins and contemporary Roman *denarii.* Some of the objects were made of a rather pure silver (>98%). Such pure metal was also encountered in some Roman coins, indicating a possible silver source. However, the impurity pattern suggested the source of silver was different for the Roman coins and Celtic silver, indicating the Celts were exploiting silver sources of their own (Laharnar et al. in print).

Medieval silver coins

During the 12th and 13th c. AD, active monetary activity is documented on the territory of the present Slovenia. A number of mints were founded along its eastern border, and their role is speculated to supply silver to the Hungarian kingdom on the east. Several hundred coins were analyzed from different mints, included locations in Carinthia north of the present Slovenian-Austrian border (Šmit & Šemrov 2006). The analysis showed that gold and bismuth were the discriminating elements, so we distinguished the silver between the gold- and bismuth types. The bismuth-type silver was used mainly in the mints of Carinthia and on the eastern border. Though our measurements of a few silver ores did not provide indicative results, we concluded that the bismuth type silver was mined in Carinthia. Part of it was spent in local mints in Carinthia, while the other part followed its commercial route to the eastern mints, from where it was traded further to the east. The eastern mints were abandoned after the 13th c. AD because of two political events: the Mongol invasion in 1241 and the victory of Habsburgs over the Czech king Othakar II. in 1278. Soon after that event, the Viennese pfennig became the leading currency in the area.

Aluminum bronzes

During the first half of the 20th c., different copper-based alloys were introduced for the low-nominal coins. Aluminum bronzes, for example, were found tarnish and wear resistant and non-allergic. Aluminum bronzes are hardly analyzable by PIXE as aluminum X-rays are strongly absorbed in any absorber, including in an air gap of a few centimeters. For analysis, we then used a combined PIXE-PIGE approach, detecting aluminum through its characteristic gamma rays of 844 and 1014 keV (Hirvonen & Lappalainen 1995). The algorithm was essentially the same we use for glass analysis, except that we switched off the option that every element is in its oxide form. Concentrations of aluminum were determined according to the glass standard NIST 620. The examples measured include coins minted around 1940 in Germany, Italy and Yugoslavia; some of them represent finds from the 2nd war world guerilla camps and are thus regarded as historic artefacts. The content of aluminum varied between 6 and 9%. For control purposes, we measured modern euro cents made of the alloy Nordic gold that contains 5% Zn. We reproduced this value within ±3% relative error. Regarding historic artefacts of non-documented origin, measurement of aluminum gamma rays can help to detect fakes.

Differential PIXE

The range of energetic protons in solids is well defined and measurement with a set of impact energies can be used to obtain the concentration profiles at the surface (Šmit & Holc 2004, Šmit 2005). The obstacle of the method is the inner shell ionization cross section that decreases very rapidly with decreasing proton energy. The contribution to the X-ray yield from the end part of the projectile trajectory is minute in comparison with the contribution from the first part, which makes the concentration evaluation algorithms rather sensitive to small variations of the X-ray yields. In our approach, we stabilized the numerical procedure by optimal selection of slices within the target according to the impact energies used.

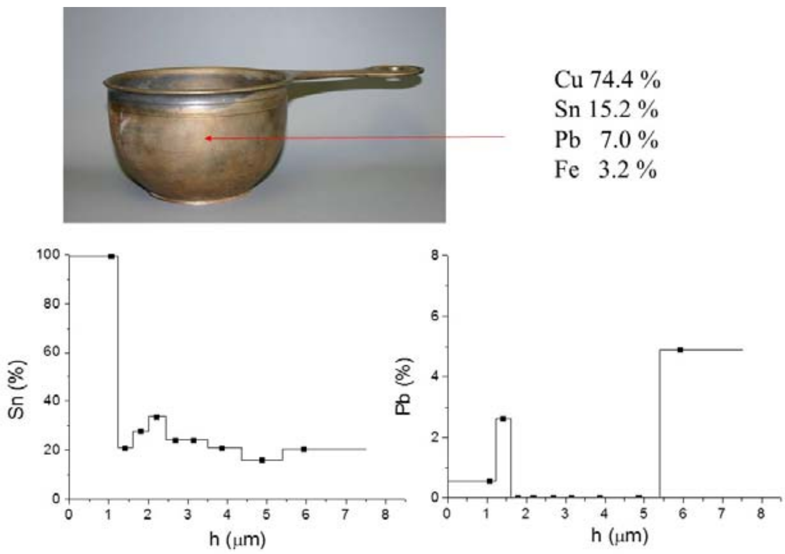

Fig. 4.:
A tinned layer on a bronze vessel measured by differential PIXE (Šmit et al. 2008). The bulk composition measured through the layer differs only slightly from the values obtained in the area with the tin layer washed away.

4. ábra:
Ónréteg kimutatása egy bronzedényen, differenciális PIXE technikával azonosítottak (Šmit et al. 2008). Az ónréteg alatt mért tömbi összetétel csak kis mértékben különbözik attól, ami az eltávolított ónréteg helyén mérhető.

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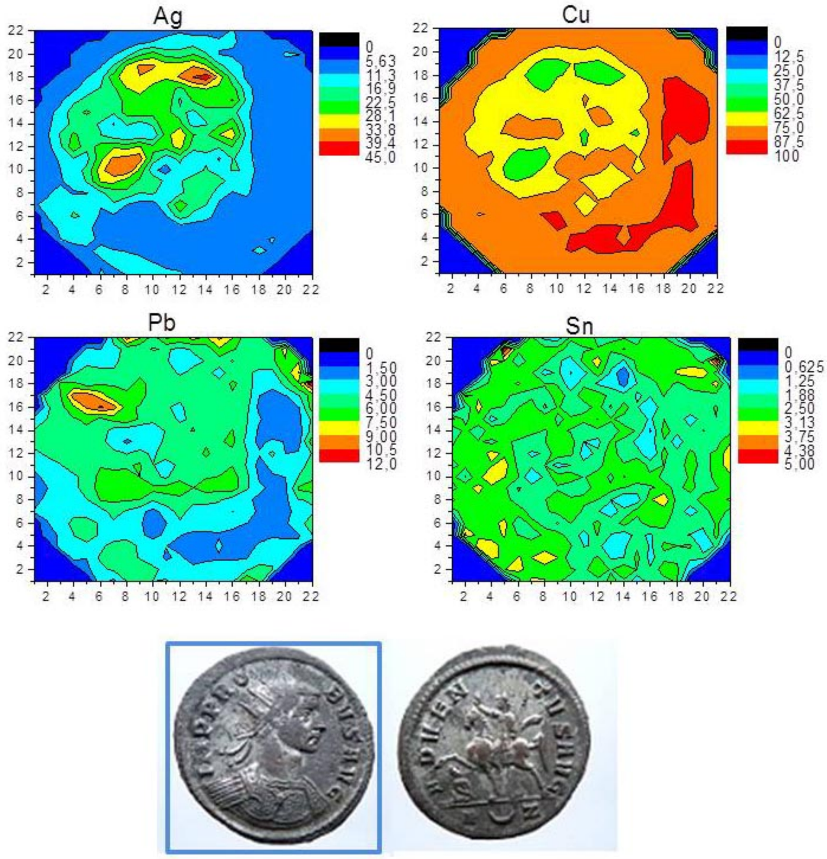

Fig. 5.:
Mapping of the surface of the coin of Probus (mint of Rome, 276-282 AD), showing silvering with a thin silver flush (Fajfar et al. 2015b).

5. ábra:

Vékony ezüstréteggel bevont Probus érme (római veret, Kr. u. 276-282) felszínén végzett elemösszetétel térképezés (Fajfar et al. 2015b)

The technique appeared particularly useful for detection of the gilding techniques. We recognized this during the analysis of gilded layers on the objects from Roman and Early Medieval Period, using a set of nine impact energies between 2.8 and 0.7 MeV (Šmit et al. 2008). Within the layer, we also observed a profile of mercury, which signalized that the technique used was fire or amalgamation gilding (Oddy 1993, von der Lohe 1994). Other types of plating, like silvering or tinning, can be characterized as well (**Fig. 4.**).

For measurement of plated layers, we also developed the method of Rutherford backscattering spectrometry (RBS) in helium atmosphere (Jezeršek et al. 2010). The method proved more accurate for determination of plated layer thickness, but could fail in the detection of mercury; in this case, one has to inspect in addition the PIXE measurement. We further used RBS to detect the intermetallic compounds of copper and tin on the tinned Roman brooch (Jezeršek 2010).

Mapping

Most modern set-ups using in-air beams are now able to do mapping measurements. In our case, this ability was achieved by developing the scanning mode software, as the set-up was initially equipped with xyz stepping motors (Fajfar et al. 2015b). The lateral resolution of the images is about 1 mm, determined by the beam width at half maximum of 0.8 mm (Jezeršek et al. 2010). Scanning measurements were done on the 3rd c. AD Roman coins, which imitated the luster of solid silver (Fajfar et al. 2015b). The coins were partly polished by use, so the mapping revealed which elements belonged to the surface and which to the bulk metal. We showed that the coins minted around 250 AD used combined silvering and tinning, which gave impression of the massive silver, while a coin of around 270 AD showed mere silvering with a thin silver layer (**Fig 5.**).

Mapping can also reveal the gilding technique. For example, fire or amalgamation gilding results in correlated maps of gold and mercury distributions.

Conclusion

PIXE based on an in-air proton beam can be efficiently used for the determination of coloured metal alloys of the historic periods. The measurement does not alter the objects, though the metals with patina have to be pre-prepared for the measurement by removing a small section of patina to expose the bare metal. The analysis can go beyond point surface measurements and allow rough profiling or mapping of certain areas. Further improvement of the set-up will include the focusing option of the beam, which would allow studies of smaller details and mapping with a higher resolution.

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SACHA - PORTAL: PLANS FOR AN ON-LINE INFORMATION CENTRE ON THE BASIS OF THE IAEA PROGRAM NUCLEAR TECHNOLOGY FOR CULTURAL HERITAGE

SACHA - PORTÁL: ON-LINE INFORMÁCIÓS SZOLGÁLTATÁS TERVEZET A NEMZETKÖZI ATOMENERGIA ÜGYNÖKSÉG KULTURÁLIS ÖRÖKSÉG VIZSGÁLATA TÁRGYÁBAN INDÍTOTT PROGRAMJA ALAPJÁN

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Abstract

On the initiative, and with the financial support of the International Atomic Agency (IAEA) a wide international program was launched for the application of nuclear techniques in the protection, and for the scientific analysis of cultural heritage. As part of this initiative, a project webpage was started within the RER 00034 program ("Enhancing the Characterization, Preservation and Protection of Cultural Heritage Artefacts"*, 2012-13). This dedicated webpage aimed at presenting partner institutions of the project and their results on the field of the application of nuclear techniques for arts and archaeology in the widest sense. The setting up of the webpage was financially supported by the IAEA and the technical and informatical background was provided by our Cypriot colleagues (Yiannis Parpottas and Demetris Kaolis). Acknowledging the usefulness of the webpage but also pointing at problems in contents, access and maintenance, on the closing meeting of the subsequent RER 0039 program (*"Extending and Diversifying the Application of Nuclear Technology in Cultural Heritage"*) the project participants suggested an expert meeting to evaluate and possibly enhance the project webpage. The solution suggested is a complete re-organisation and extension of the webpage, from a specific project webpage to the level of a portal establishing contacts between analysts and heritage experts. We hope that SACHA-portal (*Scientific Approaches to Cultural Heritage Artefacts*) will be implemented during the current year (2016).*

Kivonat

A Nemzetközi Atomenergia Ügynökség kezdeményezésére és támogatásával indított, a nukleáris technikák örökségvédelmi alkalmazásai tárgyú (RER 00034 számú) kutatási program részeként ("Enhancing the Characterization, Preservation and Protection of Cultural Heritage Artefacts"*, 2012-13) létrehozott egy dedikált weblapot a fenti projekt keretében működő partnerek (intézmények, kutatók és eredményeik) bemutatására. A weblap fenntartását anyagilag a NAÜ, technikailag a ciprusi kollégák (Yiannis Parpottas és Demetris Kaolis) vállalták fel. Elismerve a weblap hasznosságát, de figyelemmel tartalmi és gyakorlati problémákra, a 2015-ben záruló RER 0039 program (*"Extending and Diversifying the Application of Nuclear Technology in Cultural Heritage"*) a weblap értékelésére és újragondolására szakértői tanácskozást szervezett, amelynek során a weblap formai és tartalmi megújítását, átalakítását javasoltunk. A folyamatnak még az elején járunk, reméljük hogy a 2016. év folyamán kialakítható lesz a címben jelzett SACHA-portal (*Scientific Approaches to Cultural Heritage Artefacts*).*

KEYWORDS: SACHA-PORTAL, IAEA, CULTURAL HERITAGE, SCIENTIFIC ANALYSIS

KULCSSZAVAK: SACHA-PORTÁL, IAEA, KULTURÁLIS ÖRÖKSÉG, TERMÉSZETTUDOMÁNYOS VIZSGÁLAT

Introduction

The International Atomic Agency had several projects for promoting the application of nuclear techniques in the field of preserving and analytically investigating objects of art and archaeology pertaining to cultural heritage in general. The details of the recent projects are shortly summarised by Zsolt Kasztovszky in the same volume (Kasztovszky 2016). One of the major achievements of the current RER projects (notably, RER 0034, "*Enhancing the Characterization, Preservation and Protection of Cultural Heritage Artefacts*", 2012-13), was the construction of a website to promote dissemination of the results and enhance communication between project participants. The webpage operated between 2012 and 2015 at the RRL address http://nuclculther.eu. In the follow-up project, RER0039 ("*Extending and Diversifying the Application of Nuclear Technology in Cultural Heritage*", 2014-2015) it was determined that a task group should meet to improve the functionality of the website. This was partly necessary, because the project was terminating and the safe operation of the website could not have been guaranteed without financial supply of IAEA; moreover, we must admit that the information presented by the web-site was rather uneven and of limited access.

Task-group meeting in Vienna

The main criticism on the RER 0034-0039 webpage was its limited impact. It was used as a „homework" by the more conscientious partners – and not used at all by the others. The contents were uneven and deficient. It shared the fate of many project webpages with the disadvantageous exception that it was not used even for organising intra-group events because the participants for the projects were selected from meeting to meeting, on the basis of application, by the national coordinators. The partners recognised that there is something wrong with this and blamed – as usual – the IT parts. Now, the informatical solution of any webpage cannot substitute actual contents and regular update. A living webpage is sustainable because it is necessary; it is answering some need on behalf of the community, smaller or larger.

On the occasion of the closing meeting of the RER 0039, these questions emerged again. As the partners were obviously interested in further collaboration beyond the actual project, a task group was formed to investigate the possibilities of continuing and improving the webpage. The task group meeting was held in the IAEA Centre in Vienna last year, 24-26th November 2015. The participants of the meeting were Velibor Andric (VINCA Institute of Nuclear Sciences), Matthew Grima (Heritage Malta), Anastasios Lagoyannis (IAEA), Katalin T. Biró (Hungarian National Museum). and Demetris Kaolis (IT-expert).

The results of the discussion and suggestions for further action were summarised in an official report submitted to IAEA (Andric et al. 2015). The main point was to extend scope and audience by raising the webpage to the level of a portal dealing with the interrelation of art, archaeology and science. This new portal-to-be was named SACHA as an acronym for *Scientific Approaches to Cultural Heritage Artefacts*. Its main objective is planned to be "*merging science to cultural heritage*", to provide a forum for scientists, conservators, CH experts of various fields to find the best practice and easy and clear ways to deal with intricate problems of interdisciplinary work in this field. The "task group" re-classified itself as an administrative committee to foster and manage this new portal. Realising the complexity of the problem, we suggested the convoking of a body of experts termed Scientific Committee. Main fields of scope were considered, in accordance with results and fields of interest within the RER projects. Suggestions were made for SC members.

What has happened since the Vienna meeting?

In fact, not too much – at least not as much as we would be happy to see. The former webpage (http://nuclculther.eu) was revoked and the new site (http://sacha-portal.com/) was opened, so far with the title page only. SC members were invited to join the idea from the main fields of archaeometry and conservation, and recently informed on their „group identity". The main tasks and next steps for the AC were put forward and accepted.

So we can form a pessimistic and an optimistic view on SACHA and its future. The pessimistic view is that as we are all loaded more than enough with things to do anyway, and manage an interactive thematic portal is just one burden too much. The optimistic view is just to say that SACHA answers an existing need on behalf of analysts and CH experts and should be fostered and grown, hopefully used and living to the advantage of the field of archaeometry and conservation.

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EARLY IRON AGE SETTLEMENT AT GYŐR-MÉNFŐCSANAK–SZÉLES-FÖLDEK IN THE LIGHT OF ARCHAEOZOOLOGICAL FINDS (NORTHWEST HUNGARY)

A GYŐR-MÉNFŐCSANAKON FELTÁRT KORA VASKORI TELEPÜLÉS AZ ARCHAEOZOOLÓGIAI LELETEK TÜKRÉBEN

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Abstract

By putting it in an archaeological context, the paper deals with the analysis of the Early Iron Age (Ha C-D) animal bone material of the site which has been unearthed at Győr–Ménfőcsanak. The results of archaeological and archaeobotanical examinations are also supported by archaeozoology; the natural environment of the Early Iron Age lowland settlement contained belts of forests and groves, in addition to the cultivated areas. One part of the settlement provided a suitable place for the people for farming and livestock keeping. The inhabitants of the agrarian settlement carried out subsistence farming. In keeping domestic animals, ruminants (cattle 35.7%) and sheep and goats (collectively 29.86%) were prevalent, yet, keeping of hens – which were rare in those days – has been proved by not only a few bones but also the eggshell fragments of them. The ratio of animals hunted and fished for barely exceeds 10%, yet, numerous species – among them the brown bear which is met with sporadically in flatland and even beaver and sturgeon – can be found.

Kivonat

A tanulmány a Győr–Ménfőcsanakon feltárt lelőhely kora vaskori (Ha C-D) állatcsont anyagának régészeti kontextusba helyezett elemzésével foglalkozik. A régészeti és archeobotanikai vizsgálatok eredményeit az archeozoológia is alátámasztja: a kora vaskori síktelepülés természetes környezetét a megművelt területeken túl erdős-ligetes övezetek alkották. A település határának egy része a lakosság számára alkalmas helyet nyújtott a mezőgazdálkodásra és állattartásra. Az agrárjellegű település lakói önellátók voltak, háziállattartásukban a kérődzők (szarvasmarha (35,7%), juh és kecske (együttesen 29,86%) domináltak, de az ebben az időben még nagyon ritka tyúk tartását nemcsak néhány csontja, hanem tojáshéj töredékei is igazolták. A vadászott–halászott állatok aránya alig haladja meg a 10%-ot, azonban számos faj, köztük a síkvidéken csak elvétve előforduló barnamedve, de a hód és a viza is megtalálható.

KEYWORDS: NORTHWEST HUNGARY, MÉNFŐCSANAK, HALLSTATT CULTURE, ARCHAEOZOOLOGY, FISH BONES, EXAMINATION OF EGGS

KULCSSZAVAK ÉSZAKNYUGAT-MAGYARORSZÁG, MÉNFŐCSANAK, HALLSTATT KULTÚRA, ARCHAEOZOOLÓGIA, HALCSONTOK, TOJÁSVIZSGÁLAT

Introduction

The research of Early Iron Age settlements could be enriched by a significant material of finds between 2009 and 2011. South of the city centre of Győr, the systematic excavation of another part of the already known archaeological site complex to be found on the confines of Ménfőcsanak – which was once an independent village – took place. The excavation was performed under the guidance of the archaeologist Gábor Ilon, by the archaeologists, technicians and site helpers of the National Heritage Protection Centre (hereinafter called "NÖK") – which was closed down at the end of 2014 – of the Hungarian National Museum and of the team of the regional bureau N° 2 of NÖK, based in Szombathely. After the liquidation of NÖK, the complete material of finds from the region – thus, also the one being the subject-matter hereof – has been transferred to the central repository of the Hungarian National Museum that can be found in Daróci utca. Important groups of finds of several archaeological periods came to light in the above years.

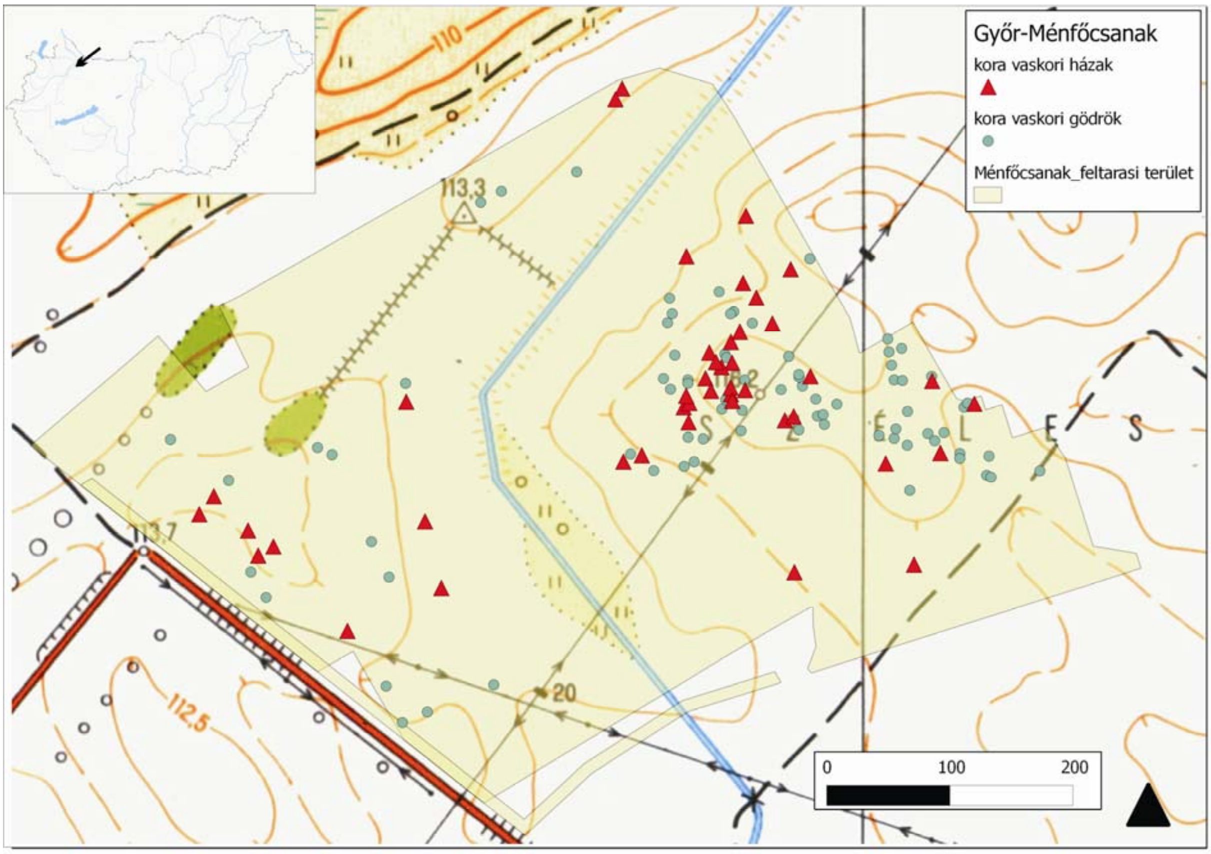

Fig. 1.: The site Győr-Ménfőcsanak with the Early Iron Age objects, houses (red), pits (blue) (the map was drawn up by Éva Ďurkovič and István Eke)

1. ábra: Győr-Ménfőcsanak lelőhely a kora vaskori objektumokkal. A térképet Ďurkovič Éva és Eke István készítette.

The site has been known in archaeological research from the 19th century on. After the emergence of the first sporadic relics from the Bronze and Iron Ages, several explorations have been performed in the area; including those under the guidance of Sándor Mithay and András Uzsoki (1968). In the 1990s, the research workers of the Archaeological Institute of the Hungarian Academy of Sciences assisted, besides András Figler, Eszter Szőnyi and Péter Tomka, in the preventive excavations of the route of motorway M1 (Jerem et al. 1992; for more details, see Ďurkovič 2014, 18-21). The material of animal bones to be disclosed within the scope of the following study is the result of an excavation of an extent bigger than ever before, carried out between 2009 and 2011. It forms an integral part of the material of finds of the Early Iron Age (Ha C-D) settlement which has been explored on an area of almost 28 hectares. It adds to its significance that the material of finds of this kind from numerous preceding excavations has, unfortunately, not been disclosed to date (**Fig. 1.**).

The full area of the Early Iron Age settlement which has been unearthed at Győr–Ménfőcsanak is not known. Based upon its situation and surroundings, it fits completely into the Early Iron Age system of settlements according to our current knowledge. The lowland settlements of the eastern Hallstatt culture can also be found on the terraces of bigger or smaller rivers. The needs of the people who made a living by farming could be met in the neighbourhood of the settlement, such as the source of water, the land that could be cultivated as well as raw materials for building and handicraft. 238 features from the Early Iron Age have been unearthed at the site. Interpretation and determination of the archaeological features have been carried out according to the evidence of already known lowland settlements of the Early Iron Age. Accordingly, square semi-subterranean building or parts of them could be reconstructed. The overwhelming majority of pits in the settlement served presumably as pits for storing food or waste. Post-structure houses – built on the surface – cannot be separated and reconstructed, in spite of several thousand of postholes which have been unearthed in the settlement. At the same time, the semi-subterranean buildings also had a structure rising above the ground (see, for instance, the reconstructions of Late Iron Age houses by Lőrinc Tímár: Tímár 2010). Determining the functions of the objects is partly hypothetical and is founded on analogies. The semi-subterranean buildings can be interpreted as dwelling houses and/or farm buildings. Regarding the question of dwelling houses, we can see different opinions in the archaeological literature even nowadays. Determining the function of Early Iron Age buildings with a rectangular ground plan – with a pit dug into the ground – is not unambiguous; presumably no uniform answer or definition exists (see, for instance, Lauermann 1996, for the weaving houses determined as farm buildings at Győr–Ménfőcsanak see Ďurkovič 2015a). The majority of settlement pits may have been used for storage; based upon the material of finds of them partly for storing food as, for instance, the corn storage pit unearthed at Sopron-Krautacker (Schwellnus 2012, 531: object N° 205) and for dumping waste, respectively. In some cases they can be evaluated as raw material extraction pits, i.e. clay extraction pits (Schwellnus 2011, 363: Sopron–Krautacker, Stegmann-Rajtár 1996, 453: Bratislava–Dúbravka, Ďurkovič 2014, 47: Győr–Ménfőcsanak). The features indicating different buildings and pits formed an irregular system. Although the disturbance of objects made the analysis more difficult, smaller units and households may still be presumed. Similar smaller units have been reconstructed at the settlements Göttlesbrunn and Horn by M. Griebl and next to Wien-Oberlaa by Ch. Ranseder, respectively as well as at the Early Iron Age settlements Sereď and Smolenice by S. Müller (Müller 2012). For more details on the smaller households that may be presumed at Győr–Ménfőcsanak see the work by Eva Ďurkovič (2015b). In accordance with the conditions of the area, higher lying parts of the settlement have shown denser and more intensive occupancy (Fig. 1). As reflected by the archaeological finds, this area , in fact the small stream running through the area excavated, i.e. the right high bank of the Pándzsa brook which has been controlled by now, was probably inhabited over a longer period of time. In the lower lying region of the eastern bank of the stream the archaeological features formed a relatively loose structure. This part of the settlement provided a place suitable for farming and livestock keeping.

Pottery represented a significant part of the archaeological material of finds from the Early Iron Age settlement at Győr–Ménfőcsanak. The overwhelming majority of it is hand-built pottery, so-called household pottery. Although examination of pottery has not been possible so far, from the material extraction pits excavated as well as the analogies the conclusion can be drawn that the people who lived here made their articles for personal use all by themselves. Most of the types of utensils are represented through pots and bowls. Wheel-thrown wares, which have came to light sporadically, reflect the development of potter's craft (for detailed publication of the archaeological material of finds of the Early Iron Age settlement see Ďurkovič 2014, 62-108). Similarly to the majority of Early Iron Age sites, only a few metal finds have been unearthed at this site too. Among the flint implements, which can be assigned to this period with certainty, grinding and rubbing stones have been found in the first place. In addition to these objects, the examination of archaeobotanical samples has also shown the significance of farming. The importance of growing grains has become – among others – evident from the samples determined. (Examination results of the soil samples of the pit-house N° 210/7124 have revealed the majority of the species of grain – see Pető, Kenéz 2015, Fig. 6, 5; Ďurkovič 2016 in press). Based upon the results, the natural environment of the settlement contained belts of forests and groves, in addition to the cultivated areas (Pető 2013, 14).

From the examination of the Early Iron Age settlement part excavated at Győr–Ménfőcsanak and its archaeological relics the conclusion can be drawn that the inhabitants of the agrarian settlement carried out subsistence farming. Beyond the food grown, they could provide for themselves through handicraft (potter's craft and textile making – for more details see Ďurkovič 2015) and hunting and fishing. At the same time, the types of objects occurring within the material of finds have also confirmed that the people who lived in the settlement had constant contact with the Early Iron Age communities that lived in the neighbourhood. Based upon the evaluation of the material of finds and the results of the C14 examinations, which have already been published, the settlement part excavated at Győr–Ménfőcsanak was inhabited over the entire period of the Early Iron Age (Ďurkovič 2014, 141-154).

Archaeozoological finds

An animal bone material in large quantity has come to light at the site Győr–Ménfőcsanak. A part of it originates from objects which date back to the Early Iron Age. The group of finds consisting of 2,926 pieces contains, beyond the bones of domestic animals, the remains of many species hunted, fished for or gathered, among them those of shellfish. In addition to careful collecting by hand, flotation of the soil samples of 33 features has also been performed; 29 of them contained animal bones too. As an exception, the eggshell remains are also part of the archaeozoological analysis as they carry important information about the knowledge of livestock keeping of the people of the Early Iron Age.

Species	NISP	%	Minimum Number of Individuals
Cattle *(Bos taurus* L.)	902	35,7	10
Sheep *(Ovis aries* L.)	24	0,95	4
Goat *(Capra hircus* L.)	5	0,2	3
Sheep or goat (Caprinae G.)	725	28,71	15
Pig *(Sus domesticus* Erxl.)	335	13,27	14
Horse *(Equus caballus* L.)	112	4,44	4
Dog *(Canis familiaris* L.)	141	5,59	8
Hen *(Gallus domesticus* L.)	3	0,12	1
Domestic animals	***2247***	***88,98***	***59***
Red deer *(Cervus elaphus* L.)	170	6,73	7
Beaver *(Castor fiber* L.)	16	0,63	3
Roe deer *(Capreolus capreolus* L.)	13	0,51	3
Brown hare *(Lepus europaeus* Pall.)	7	0,28	2
Brown bear *(Ursus arctos* L.)	2	0,08	1
Red fox *(Vulpes vulpes* L.)	17*	0,04	1
European pond terrapin *(Emys orbicularis* L.)	9	0,36	1
Hunted species	***218***	***8,63***	***18***
Common carp *(Cyprinus carpio* L.)	1	0,04	1
Cyprinidae	5	0,2	1
Northern pike *(Esox lucius* L.)	1	0,04	1
European sturgeon *(Huso huso* L.)	1	0,04	1
Sturgeon (Acipenseridae sp.)	2	0,08	1
Zander *(Sander lucioperca* L.)	2	0,08	1
Fish (Pisces sp.)	28	1,11	-
Harvested species	***40***	***1,59***	***6***
Suidae	5	0,2	-
Anseriformes	2	0,08	1
Bird (Aves sp.)	13	0,52	-
Domestic or hunted species	***20***	***0,8***	***1***
Rodent (Rodentia sp.)	4	-	1
Other species	***4***	-	***1***
Small ungulate	145	-	-
Large ungulate	156	-	-
Other mammalia	7	-	-
Non identifiable bones	***308***	-	-
Riverine mussel (Unio sp.)	83	-	-
Snail (Gastropoda sp.)	6	-	-
Total	**2926**	**100**	**85**
* skeleton part			

Fig. 2.: List of species of the site

2. ábra: A lelőhely fajlistája

Beyond the list of species obtained from the data of animal bones, we are also seeking an answer to the question if our results tally with the results of other examinations in view of the one-time surroundings of the settlement. According to this, there may have been belts of forests and groves, beyond the cultivated areas.

Of the archaeozoological finds, the number of bones which can be determined at least on the level of a family or perhaps an order is 2,529. Fish bones, which cannot be determined, are also included in this category due to their significance. Accordingly, the major part of the material of finds (89%) is made up of the remains of domestic animals, yet, the amount of bones of species hunted and fished for is not negligible either (258 pieces). The joint ratio of species hunted and fished for comes to 10% in view of the determinable bones (**Fig. 2.**). Thus, it can be said that hunting and fishing only complemented the amount of meat which was obtained from slaughtering domestic animals. Nonetheless, they play an important role, because, in addition to the customs of meat consumption and hunting, we can draw a conclusion from the existence of them to the ecosystem in the surroundings of the one-time settlement, which was – as it appears from the list of species too – abundant in species. Due to the intermediate size of them, it cannot be decided regarding some bones of the material of finds if we are speaking about the domesticated or wild form of the given species, i.e. cattle and domestic pigs were smaller than aurochs and wild boars in the archaeological periods. The ratio of bones of this kind comes to 0.8%. Smaller amounts of bones of birds, which cannot be precisely attributed to species, have also come to light.

Most pieces in the material of finds can be interpreted as kitchen waste. Related bones of species kept for their meat have come to light only in a few cases among the bones chopped up more or less, i.e. 4-5 pieces at most. This means that the leftovers, the bones, of meat consumed were, in fact, thrown away and the animals or skeletal parts of the animals were not buried/dug into the ground as a whole. The latter can only be seen in case of dogs and foxes which did not play a role in meat consumption; fairly big related remains of several dogs and a fox have been found.

The anatomical breakdown of bones can be seen in **Fig. 5.**

Domestic animals

Based upon the quantity of bones, the order of frequency of domestic animals is as follows: cattle, small ruminants (more sheep, less goats), domestic pigs, dogs, horses, and hens.

Based upon the quantity of bones, the most frequent species was cattle; the 902 bone finds of them come to 35.7% of the determinable bones. The cattle bones originate from at least 10 individual animals of different ages. The majority of them were full-grown (adultus) specimens. Moreover, even older, maturus age, specimens occurred.

Fig. 3.: Animal bones from the Early Iron Age – 1 Broken shinbone of a dog, 2 Metatarsal bone of a red deer, 3 Jaw of a roe deer, 4 Thighbone of a beaver, 5 Jawbone of a brown bear with teeth, 6 Cleithra of a pike (the one on the left of the Early Iron Age (STR 7317), the other ones of the Late Bronze Age, Tumulus culture (STR 7765), Photograph of the bones of the pike: Alice M. Choyke

3. ábra: Kora vaskori állatcsontok: 1: törött kutya sípcsont; 2: gímszarvas lábközépcsont; 3: őz állkapocs; 4: hód combcsont; 5: barnamedve állcsont fogakkal; 6: csuka zárcsontok (bal oldali kora vaskori (STR 7317); a többi késő bronzkori (halomsíros kultúra (STR 7765). Fotó a csuka csontokról: Alice M. Choyke

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The number of almost full-grown (subadultus), young (juvenilis) and very young (infantilis < 1 year) individual animals was much lower. The mixed breakdown by age refers to the varied utilisation of the species; young animals were only slaughtered for their meat, whereas the power of older specimens and also cow's milk may have been used before using their meat. As the remains of full-grown specimens are in a majority, secondary utilisation of the species may have prevailed. The gender and withers height of 4 cattle could be determined on the basis of intact metacarpal and metatarsal bones by twos; the animals between 105 and 119 cm, on an average around 110 cm (Nobis 1954, Calkin 1960), were cows of small and medium stature which was typical in the Iron Age (Bökönyi 1974, 115, Fig. 9). Chop-marks can be found on 2% of the cattle bones, i.e. cut-marks and cleaver-marks. The majority of bones chopped up are ribs, but one can even find a few jaws, vertebrae as well as rump bones and forearm bones among them. Chewing marks by carnivores can be observed on a few finds, on bones rich and poor in meat alike.

Among small ruminants sheep and goats can be found alike. The bones of the two species are very similar. Hence, they can be clearly distinguished only in some cases. Of the sheep and goat bones of the material of finds 24 belonged to sheep and 5 to goats. It could not be determined of the remaining 725 bones which of the two small ruminant species they originate from. The bones of them provide collectively about 30% of the determinable finds. Thus, they are the second most frequent species after cattle. Notwithstanding that the number of bones of small ruminants lag slightly behind those of cattle, the number of individual animals is much higher than that of cattle; of 22 individual animals there were at least 4 sheep and 3 goats. Two of the sheep were full-grown specimens, one an almost full-grown and another one a young specimen. Two of the goats were also full-grown; only one animal was of juvenilis age. The breakdown by age of individual animals which can only be described as small ruminants is heterogeneous; almost the same quantities of bones of young and full-grown individual animals have come to light. Yet, the bones of individual animals of almost full-grown (subadultus) age have also been found. Younger animals were probably raised and slaughtered for their meat, whereas the secondary use of older animals may have also been important (wool, milk). The withers height could be estimated from five intact sheep bones, it was between 65 and 68 cm (Teichert 1975) which slightly exceeded the average value typical of the Iron Age (Bökönyi 1974, 171, Fig. 49). Chop-marks can only be seen on a few bones; for the most part they are vertebrae which may have been damaged on cleaving the vertebral column in two. There are jaws and ribs too. The quantity of chewed bones of small ruminants lags slightly behind that of cattle; spoke-bones and shinbones are the most frequent of them. A few more forearm bones are chewed finds of body regions containing meat. Among the finds which do not contain meat or contain only a very little of it, jaws as well as metacarpal and metatarsal bones can be found.

Its 335 finds make the domestic pig the third most frequent species at the site in view of the quantity of bones; they provide 13.27% of the determinable bones. However, its number of individual animals is higher than that of cattle. The majority of the at least 14 specimens are young (juvenilis) pigs, which refers to the primary utilisation of meat of the species. Yet, the bones of a full-grown and an older individual animal could also be found. Some intact bones made the estimation of the withers height possible; the pigs at the site were tall specimens of a size between 76 and 83 cm (Teichert 1969) which approximates the lower size limit of wild boars. Cleaver marks can be observed on the jaws, ribs and forearm bones. Chewed bones could also be found; chewing marks by dogs can be seen on the ends of several long bones.

The horse is the rarest animal among the mammal domestic animals in terms of meat consumption. The 112 finds of it equals 4.44% of the determinable bones. The lowest number of individual animals also amounts to 4 all in all. The remains of full-grown specimens are in majority among the bones. Although chop-marks can only be detected on a few bones, consumption of the meat of the species can be proved hereby. The bones of younger individual animals also refer – indirectly – to the utilisation of meat. Chewing marks by dogs can also be observed in the group of finds of kitchen waste character. This means that a part of the waste was unburied and dogs could get access to it. They originate by far the greater part from the shin and the ends of the feet which contain almost no meat. Yet, they can also be observed on one cervical vertebra. The withers height of the given specimen can be estimated by means of an intact metacarpal bone; with its height of some 127 cm (Vitt 1952) this horse is considered a horse of short stature in the Iron Age. The withers height of Iron Age horses can be put at 130-142 cm by far the greater part (Bökönyi 1974, 246, Table 3).

Among the 141 (5.6%) dog bones, 3 partial dog skeletons could actually be found, in addition to the objects which only contained a few dog bones. Beyond the dog skeletons, the bones of at least 5 individual animals could be identified, thus, the presence of altogether 8 dogs at least can be proved. The withers height can be estimated by means of the long bones of the partial skeletons; all three dogs were of average size of 49-52 cm (Koudelka 1884), had a similar physique and bodily structure.

At least one of these three dogs was verifiably a male dog, on the strength of its baculum. Three vertebrae in the lumbar region of the spine of the latter specimen ossified together as a consequence of irregular bone proliferation (spondylitis). The movements of the animal were probably rigid and it had difficulty standing up and suffered pains. The right thighbone of the animal was broken in its lifetime; traces of healing can be seen on the bone, however, it did not knit together. A fracture healed through axis deviation can be seen on the shinbone and the splinter-bone of another dog (**Fig. 3/1.**). The forearm bone of one of the dogs was chewed by another dog. This means that other dogs could get access to the carcasses. There are no direct proofs of the consumption of dog meat. Less and less bones which were broken or chopped up can be found after the Bronze Age. Yet, the results of other sites indicate that dog meat was consumed by the Scythians or even the Celts from time to time (Tugya 2010a, Tugya 2010b). The right half of the cleaved skull of a dog has also come to light in the fill around the fireside of one of the houses at Sopron–Krautacker (Jerem et al 1984, 155). Isolated local examples of the consumption of dog meat were not unknown even in 20th century Europe. Dogs chewed bones in large numbers at the site; chewed red deer and roe deer finds have come to light in addition to the bones of cattle, small ruminants, pigs, and horses. The quantity of bones which were completely eaten up by the dogs cannot even be estimated. In the first place, they made probably the smaller bones and the remains of younger individual animals disappear without a trace.

There are only three hen bones (0.12%) which probably originate from the same full-grown individual animal. This species was quite rare in the Early Iron Age; the earliest known hen bones can be dated back to the Late Bronze Age in the Carpathian Basin (Tugya 2016). Small hen bones with a thin wall can completely be eaten up – especially in case of young individual animals – by dogs or even people, thus, further reducing the chances that bones remain and can be found. Keeping hens is confirmed not only by the bones of them at Ménfőcsanak, but also by the eggshell remains of them – propagation of the species is indicated by the hatched eggshell fragments. The thickness of the shell of hen's eggs is generally between 0.3 and 0.35mm. It is typical of the hatched eggs that the mamillae terminate in a crater-like cavity on the internal mamillary layer of the shell.

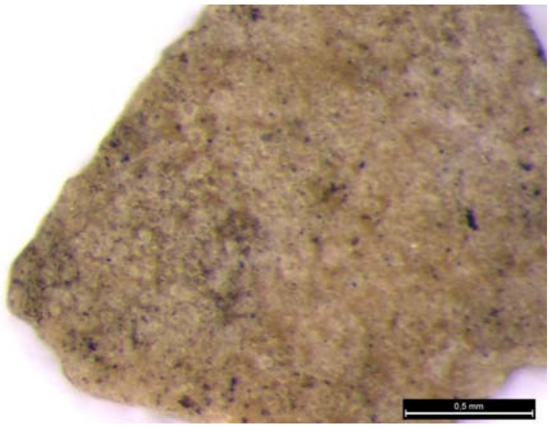


Fig. 4.: Eggshell fragment of a hatched hen's egg (60x magnification). Photo: Beáta Tugya

4. ábra: Kiköltött tyúktojás héjtöredéke (60x-os nagyítás). Fotó: Tugya Beáta

If an intact mamillary layer can be seen – the little calcareous supports (mamillae) are rounded-off – it means that the egg was not hatched (Jakab 1980, 312). In a hen's egg, the number of mamillae falling upon 1mm2 may be put at 57-173 (Sidell 1993, 13). 14 small eggshell fragments have come to light from the stratigraphic unit 7124; some of them are smaller than 1 mm2 and even the biggest one is of only 3x4mm size. In spite of the extremely small size of the fragments, a part of the samples could be analysed. The mamillary layer was craterlike in several cases, proving that the remains of a hatched egg came to light (**Fig. 4.**).

Species hunted, fished for and gathered

Based upon the quantity of bone finds, the order of frequency of species hunted and fished for is as follows: red deer, beaver, roe deer, European pond turtle, brown hare, carp varieties, brown bear, fox, and other fishes. Of the big games of the Carpathian Basin, the remains of aurochs and wild boar are missing from the material of finds.

The surroundings of the site were the natural habitat of red deer. One of the proofs for it is that this material from the Early Iron Age contains much more finds of red deer – in view of their quantity as well as ratio – than other groups of finds which contain generally a few pieces, 1-2 dozen at most. Those 170 pieces determined represent 6.73% of the complete material of finds which can be determined. The quantity of the finds of the species exceeds that of horses and it is higher in itself than the quantity of all the other species hunted and fished for taken all together. Antlers can also be found among the finds, yet, the feature of them is slightly higher than 10% in addition to bones. Thus, the outstanding quantity of deer finds is not due to gathering of cast antlers.

	Cattle	Sheep	Goat	Sheep or goat	Pig	Horse	Dog	Hen	Red deer	Roe deer	Brown hare	Brown bear	Red fox	Beaver
Antler									18	1				
Horn core	7	5	2	2										
Cranium+horn core	4	1	1	3										
Cranium+antler	24								2					
Cranium	23	1		5	16	2	6		3	1				
Nasal	5			1	2									
Maxilla	17			5	17	2	7		8			1		
Premaxilla	5			4					1					
Jaw	87			68	33	11	12		12	4				4
Hyoid	1													
Tooth	47			39	25	10	5		9					
Cleithrum														
Atlas	5			4	1	1	2		1					
Axis	9			4		2	2		1					
Cervical vertebrae	16			13	1	2	8							
Thoracic vertebrae	25			10	12		4		1					
Lumbal vertebrae	13			11	1	1	3							
Sacrum	2						1							
Vertebra indet.	2			2										
Costa	121			111	55	3	23		3					1
Scapula	27	1		19	20	2	5		5	1				
Humerus	43	6		31	33	7	9		7		1			
Radius	43	1		81	16	8	6		9		1			3
Ulna	10	1		9	16	2	5		3					3
Radius+ulna	4			7		1				1				
Carpus	7					1								
Metacarpus	31	3	1	41	4	9	3		13					
Pelvis	21			9	10	11	7		4					1
Femur	57			38	17	7	8	1	2		1			3
Patella	2													
Tibia	84			81	17	8	11	1	13		3			
Fibula					8									
Tarsus	7													
Astragalus	10		1	1	4	1			10					
Calcaneus	13			3	4	2	1		3					
Metatarsus	40	5		41	12	6	7	1	20	5	1	1		1
Metacarpus/metatarsus	2			25	1		1							
Phalanx I	26			4	7	7			12					
Phalanx II	9			1	1	2			8					
Phalanx III	6				1	2			1					
Penis bone							2							
Coracoideum														
Long bone	38			52	1				1					
Flat bone	9					2								
Skeleton							3						1	
Total	*902*	*24*	*5*	*725*	*335*	*112*	*141*	*3*	*170*	*13*	*7*	*2*	*1*	*16*

Fig. 5.: Anatomical breakdown of the animal bone material of the site Győr–Ménfőcsanak from the Early Iron Age

5. ábra: Győr-Ménfőcsanak lelőhely kora vaskori állatcsont anyagának anatómiai megoszlása

The majority of bones originate from body regions which do not contain any meat or contain almost no meat, i.e. skull, including the jawbone and jaw, as well as the ends of legs. The red deer finds originate from at least 7 individual animals; all of them were full-grown animals, with the exception of a young and an almost full-grown specimen. There are cut-marks on several reed deer finds; skeletal bones were chopped more rarely, whereas antlers oftener, as a basic material. Chewing marks can be seen on four finds. It rarely occurs that the size of individual specimens can be estimated. One intact metatarsal bone has come to light in the material of finds (**Fig. 3/2.**), originating from an individual animal with a withers height of approximately 129 cm (Godynicki 1965). It size matches that of today's red deer; the withers height of stags comes to 115-150 cm, whereas that of hinds to 105-130 cm in the Carpathian Basin (Páll 1982).

The 13 roe deer bones represent 0.51% of the finds and originate from at least 3 full-grown individual animals. Only one of the finds is an antler, the other ones are skeletal bones, i.e. jaws (**Fig. 3/3.**) and long bones. Similarly to the red deer, bones which contain almost no meat are in a majority. On one roe deer jaw chewing marks caused by a carnivore can be seen.

The quantity of beaver bones exceeds that of the roe deer; those 16% finds equal 0.63%. Of the at least 3 individual animals 2 were full-grown and one was young. The chop-marks to be seen on several finds show the utilisation of meat. Chewing marks caused by a carnivore can also be observed on some finds (**Fig. 3/4.**). Several chop-marks of different types were left on two jaws; cut-marks and cleaver marks alike.

Those 7 brown hare bones indicate 0.28% of the determinable finds; one young and one full-grown individual animal can be identified. Hare was hunted in the first place for its meat; however, the not too precious fur of it may have also been used.

Two bones of the brown bear hunted for its fur have been found; the fragment of the jawbone of a full-grown individual animal with an incisor and a canine sitting inside (**Fig. 3/5.**) and a metatarsal bone (metatarsus III.) which also indicates a full-grown animal. A chop-mark can be seen on the jawbone. Bear finds are fundamentally rear and at the sites in the Great Hungarian Plain especially as contiguous forests in higher lying areas serve as the habitat of the species. A bear which left its habitat provisionally may have been brought down or the people may have hunted even in far off areas or had even trade relationships through which they got access to the bearskin, even as dressed hide, containing the bones which were found. They may have used the fur of the bear and the consumption of its meat cannot be excluded either; the chopped jawbone may also be indicative of it.

17 contiguous bones of a full-grown fox have been found in one of the objects. Similarly to the bear, this species was also hunted for its fur even if no marks of skinning could be detected on its bones.

Only shell fragments of the European pond turtle have been found, plastron and carapace alike. As the bones of the species are missing, these are not the remains of an animal which hibernated, unsettled the object through digging in the same, where it then perished. In spite of the fact that its bones – or rather chopped bones – have not been found, its meat may have been consumed.

The total of fish bones is 40, a part of them originating from dredging. Its presence is a proof of fishing and consumption of fish. The remains of several fish species have been found; among them one bone each or some bones of carps, pikes, sturgeons and other carp and sturgeon varieties. At the sites in fluvial surroundings the number of them may reach even thousand pieces through dredging the complete fill of the objects. The only intact and measurable cleithrum has been found in the Early Iron Age building recorded as stratigraphic unit N° 7317 (**Fig. 3/6.**); the chord on the cleithrum (cl. c. l.; Morales and Rosenlund 1979) is 52.1mm long. This bone also originates from a pike of relatively small stature with a complete length of about 55 cm (Bartosiewicz 1990). Yet, its size makes it possible to estimate even with the naked eye how much bigger the individual animals the fragmental cleithra of which were found in the sacrificial pit of stratigraphic N° 7765, included in the Tumulus culture (Bz C phase) (Ilon 2014), had been (**Fig. 3/6.**). While smaller fishes could be obtained by gathering in stagnant waters after the rise too, the presence of pikes of this size is indicative of active fishing (hook and harpoon).

Shellfish may have been gathered seasonally in the nearby Pándzsa brook and the inundation area of the river Rába too, but they may have also deposited spontaneously in stagnant waters. Due to its high protein contents, shellfish was probably a valuable additional foodstuff. None of the cockleshells was pierced or formed which indicates that shellfish played a role in nutrition in the first place. Marks of burning or roasting and those of ash could not be detected on the cockleshells, i.e. they were either consumed raw (Gulyás 2009, 42, 46) or only the shellfish flesh was roasted or cooked.

Bone and antler tools

Another paper will deal in details with the bone and antler tools of the Early Iron Age found at the site. The scope of this study does not make the discussion and analysis of them possible. Two dozen tools have been found, 7 of them were made of the antlers of red deer and 17 of the skeletal bones of various species. Two of the antlers were used with safety as objects. One of them was an antler pick and the other one was a tool hollow inside and high polished outside with 3 small holes in its upper part. In one of the holes even an iron rivet remained.

The inside of the other antlers was often hollowed out and they were polished outside. They are considered as raw material for tools. There are also chisel- and awl-like pierced objects with polished surface among the skeletal bones.

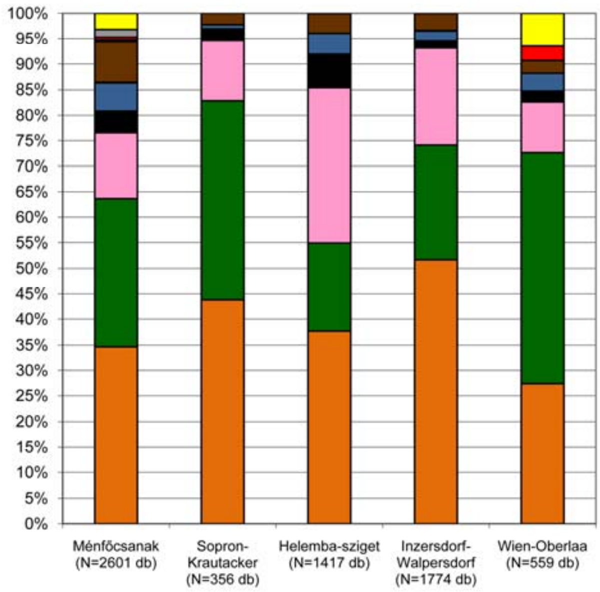
Comparison

The quantity of animal bones at sites which can be classed among the Hallstatt culture in the Carpathian Basin lags for the most part behind that of Ménfőcsanak. Moreover, only an insignificant number of animal bones analyses have, unfortunately, been published until now. The common characteristic of lowland settlements is that keeping of domestic animals prevails, but hunting is demonstrable at every site, the ratio of it being generally under 10-15% (**Fig. 6.**).

Comparing of the sites is made more difficult by the fact that the bone material of a few sites where the number of bones is at least 500, i.e. of a statistically reliable quantity, is known. Cattle are the most frequent species in case of the majority of the sites (e.g. at Helemba-Sziget (Bökönyi 1974, 367), Sopron–Krautacker (Jerem et al 1984, 151, Table. 3), at the Late Hallstatt Period La Téne culture site of Inzersdorf–Walpersdorf (Pucher 1998, 57, Tab. 1)). However, small ruminant was the prevalent species instead of cattle at the site Wien 10, Oberlaa (Czeika 2006, 350, Tab. 8). The sequence of species is generally as follows: cattle, small ruminants, domestic pig, horse, and dog. Based upon the examination of the bone material of nine Hallstatt Period settlements in Slovenia, the sequence of species was in 6 cases as follows: cattle, small ruminants, and domestic pig. The quantity of pig bones was in two cases higher than that of small ruminants and there was only one case where small ruminants were the most frequent species instead of cattle (Bartosiewicz 1996, 29, Table 1). 46 pieces of animal bones – bones of cattle, sheep and pigs – have come to light from the fill of a Late Hallstatt Period dwelling house in Csönge. Most of the bones originate here from sheep, whereas the smallest quantity of them from cattle (Fekete 1989, 135).

The classic sequence can be seen at the site Letenye–Egyeduta, where 17 bones have been found in two objects: the sequence of cattle, small ruminants and pigs can be established (Horváth 2012, 133).

Although in lower numbers, but the remains of horses and dogs can still be found in lowland settlements. Remains of hens – that proved to be rear in the Early Iron Age – have been found at the sites in Ménfőcsanak and Walpersdorf. The quantity of them is insignificant, only two or three pieces, however, they are all the more important.



	Ménfőcsanak (N=2601 db)	Sopron-Krautacker (N=356 db)	Helemba-sziget (N=1417 db)	Inzersdorf-Walpersdorf (N=1774 db	Wien-Oberlaa (N=559 db)
Cattle	902	156	535	918	153
Small ruminants	754	139	243	397	253
Pig	335	42	433	338	56
Horse	112	8	92	25	12
Dog	141	3	58	34	19
Hen	3			2	
Game	209	8	55	59	14
European pond terrapin	9				
Bird	13			1	16
Fish	40		1		
Riverine mussel	83				36

Fig. 6.: Comparison of the animal bone material of lowland settlements from the Early Iron Age

6. ábra: Kora vaskori síktelepek állatcsont anyagának összehasonlítása

Of the species hunted, red deer was the most significant everywhere, but bones of roe deer and brown hare could also be found in lower number. Of the big games of the Carpathian Basin, bones of aurochs and wild boar have only been found at every 2 sites of the four lowland settlements (Helemba–sziget, Inzersdorf–Walpersdorf). All four sites are situated in the neighbourhood of the Danube or its tributaries and the site of Sopron–Krautacker lies along the Ikva brook. Yet, the quantity of fish bones unearthed is very low. An appreciable quantity of fish bones and fish scale is only available from Ménfőcsanak, owing to the soil samples taken from the fill of the objects and elaboration thereof after dredging. No fish bones have been found at the sites Sopron–Krautacker, Wien–Oberlaa and Walpersdorf, only one (!) has been found even at Helemba as opposed to those 40 fish bones of Ménfőcsanak of which several fish species could be determined.

Summary

The archaeozoological results correspond to the archaeological observations and archaeobotanical examinations. The archaeological features formed a relatively loose structure in the lower lying region of the eastern bank of the stream running through the area unearthed. This part of the settlement provided a suitable place for the people for farming and livestock keeping. Keeping cattle and small ruminants on a large scale necessitated the existence of extended grazing grounds. The floodplain forests surrounding the streams had a beneficial effect on pig farming. Based upon the results, the natural environment of the settlement contained belts of forests and groves, in addition to the cultivated areas. They provided an excellent habitat for red deer, roe deer, and brown hare. Nearness of the site to water is shown by the fact that a relatively high quantity of bones of beavers and the shells of European pond turtles has also been found.

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