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NEUTRON INVESTIGATIONS OF A ZINC LAMP OF UNKNOWN ORIGIN FROM THE ACADEMIA GEORGICA TREIENSIS ARCHAEOLOGICAL COLLECTION (ITALY)

The Academia Georgica Treiensis is one of the oldest Italian Academies, founded in the 15th century – with the name of Academia dei Sollevati – for the main interests of poetry and literature. Influenced by the Enlightenment ideas, in the 18th century the Academy decided to reconsider its interests »encouraging rational and practical studies to improve agriculture and industry and to honour sciences, literature and arts« (Benigni 1939). The archaeological collection of the Academy was established by the noble family Teloni, Counts in Treia, Italy, from the late 18th until the late 19th century.

The collection has been recently reorganised and inventoried: it is composed of more than 500 objects from the Prehistory and Classical Antiquity, mostly of unknown origin. It contains different types of artefacts, e. g. armours, metallic and ceramic table-ware, jewels, lamps, bricks and different tools (Stortoni 2000; 2004; 2012). In 2012 an interdisciplinary research was initiated on this material and a couple of metal objects have been selected for a neutron-based archaeometric investigation. The analyses were performed at the research institutes of the Budapest Neutron Centre which has a long tradition in application of neutrons for cultural heritage research (Kasztovszky/Rosta 2012). The European CHARISMA project provided the transnational access to the advanced scientific instrumentations.

The present case study focuses on one single item from the collection, an oil lamp that proved to be unique in several aspects drawing more attention to its production and date (**fig. 1**). The lamp is characterised with six elongated and voluted radial nozzles of ogive-shape tip. Three of them are decorated

Fig. 1 The investigated oil lamp from the collection (weight: 904 g; width: 20 cm; height: 5 cm; the bottom is 5.1 cm in diameter). – (Photo E. Horváth).

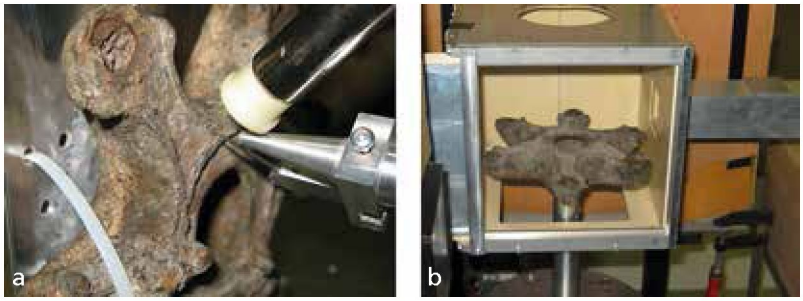

Fig. 2 The lamp during the (**a**) PIXE and (**b**) PGAA investigation. – (Photo Z. Szőkefalvi-Nagy / Z. Kis).

with different bearded faces representing the mythological figure Silenus (Stortoni 2012, 12). Originally, it could have been hung by means of three vertical hooks. Based on the type and the supposed bronze material, it was considered as an ancient artefact from the Imperial Roman Period (Stortoni 2012, 142 inv. no. 507).

The primary goal of our investigation was the accurate description of this object identifying its alloy composition as well as reconstructing its manufacture and the way of use. Results of our observations and measurements were aimed to provide the basis for a comparative study. In the collection – apart from a few coins – this example was supposed to be the only bronze artefact from the Roman Imperial Period. We intended to improve our knowledge about the potential production area and clarify its relation to the regional metalworking activity. However, the material composition data and technological details proved to be unusual, having no analogies from the Roman Period. For that reason our objectives and the initial goal has been reconsidered. Apart from the material and technological characterisation, the origin and authenticity, date and past history of the object was brought into focus as well.

Methodology

Our investigation has been performed through a multistage process at macroscopic, microscopic and large-scale analytical levels. At BNC we had the opportunity to combine complementary large-scale techniques and apply a unique science tool kit already proved to be effective in several cases (Mödlinger et al. 2013; Rehren et al. 2013). The selected methods needed no sample preparation; all of them are non-destructive and non-invasive.

Optical microscope analysis carried out by a binocular stereomicroscope allowed us to scrutinise the object and document surface characteristics of its manufacture and use[1]. Applying the external beam particle induced X-ray emission (PIXE), a large-scale surface technique, the elemental composition of the base material could be determined on the upper layer of the lamp. These measurements also provided analytical data about the occurring surface enrichments (**fig. 2a**)[2].

Apart from the surface techniques, the neutron-based analyses formed the most essential part of our experiment. Neutrons penetrate through coating and corrosion layers deep into the object without substantial attenuation. This property makes them ideal for non-destructive and non-invasive bulk analysis of both elemental and phase composition as well as for identifying bulk topology or inside content. Neutron analytical methods were applied to explore the compositional or microstructural characteristics of the investigated artefact.

Material and technological traits of the lamp were studied applying time-of-flight diffractometer (TOF-ND) (Káli et al. 2007). The analysis aimed the quantitative bulk characterisation of the phase composition and the structural properties of the metallic constituents of the alloy. Also possible traces of the past treatment (mechanical or thermal) were observed in the crystallographic texture[3]. The bulk ele-

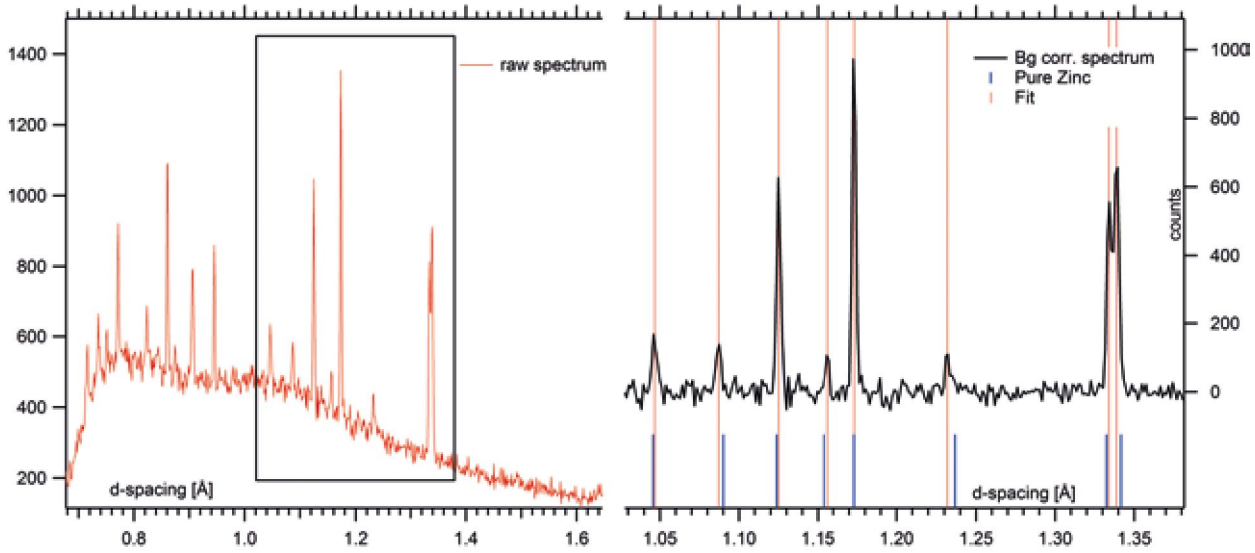

Fig. 3 The raw TOF-ND spectrum and the fitted peak positions. The anisotropic torsion of the unit cell ($\Delta a/a_0 = +0.0015$, $\Delta c/c_0 = -0.0038$) indicates that the solute atom is copper. – (Graphics Gy. Káli).

mental concentrations of the alloying components were identified by prompt gamma activation analysis (PGAA)[4]. Both the major components and a variety of minor or trace elements were possible to detect. The measurements allowed us to confirm the compositional data derived from diffraction analysis. Neutron induced prompt gamma spectrometry station (NIPS-NORMA) has been designed for investigation of larger objects of dimensions up to 20 cm × 20 cm × 20 cm (**fig. 2b**). Additionally to the bulk composition measurements, the set-up made possible to perform neutron radiography (NR) of the selected parts, and to combine imaging methods with elemental analysis based on (n, γ) reaction (Belgya et al. 2008).

Analytical results

Composition

The large-scale analytical data were consistent concerning the material composition. The obtained results revealed that the lamp was not made of bronze alloy – unlike it had been supposed. The TOF-ND data pointed out that metallic zinc was melted and cast during the manufacturing process. The analyses showed that the alloy contains an almost pure zinc phase, wherein only a very small amount of copper was detected as minor element. The amount of the copper is near to the maximum solubility (**fig. 3**). No significant amount of other phases was measurable (neither other metals nor epsilon brass). Apart from Zn and Cu, PGAA and PIXE analyses identified trace amounts of Sn, Pb and Fe as well (**fig. 4a-b; tab. 1**)[5]. However, these constituents could not have been in solid solution with Zn. They possibly represent further phases such as impurities, but certainly not alloying elements. Point measurements performed by PIXE made possible to document the enrichment of lead at the highly corroded part of the surface.

Technology

The optical microscopic examination affirmed that the lamp was cast. It revealed, however, that the applied technique was not the lost wax casting, typical for ancient Roman metal lamps (Bailey 1996, 24-50). The object was cast in two pieces which

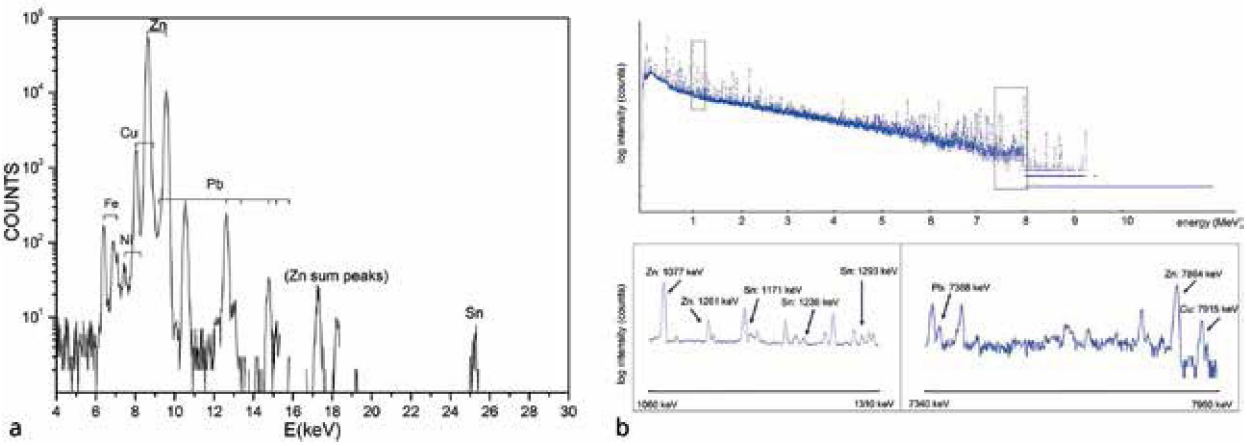

Fig. 4 The (**a**) PIXE and (**b**) PGAA spectra of the lamp with the characteristic peaks of Zn, Cu, Sn, Pb. – (Graphics I. Kovács / B. Maróti).

Fig. 5 The joint of the two parts of the lamp – side-view of the nozzles. – (After E. Horváth).

method	location	Zn	Cu	Sn	Pb	Fe	Ni
PIXE (wt %)	less corroded surface	88.65	2.61	3.40	4.88	0.48	tr.
	corroded surface	51.67	2.37	1.40	43.78	0.81	tr.
PGAA (wt %)	one of the projections	87.40	0.80	4.00	7.80	0.40	<D.L.
TOF-ND (wt %)	the upper part of the lamp	98.96	1.04	n.d.	n.d.	n.d.	n.d.

Tab. 1 Material compositional data of the investigated lamp – elemental composition: PIXE, PGAA; phase composition: TOF; tr.: traces; <D.L.: under detection limit; n.d.: non detectable.

were then presumably joined by soldering. The joint is clearly visible on the side of the object, especially on those nozzles, where the upper part is damaged (fig. 5). However, at this joint no soldering material could be observed or measured, possibly since the lamp is covered by a very thick corrosion layer. The natural greyish colour of the zinc appears only in a few spots (fig. 6a). The details of the ornamentation pointed out the use of a poorly designed mould. Also the casting process was carried out carelessly resulting in cracks and deformations on one of the nozzles (fig. 6b). The surface is very rough and a plenty of small bubbles indicates that it was not processed after the casting – neither chasing nor polishing was performed (fig. 6c). Even traces of any mechanical or thermal treatment could not be identified by TOF-ND in the microstructure.

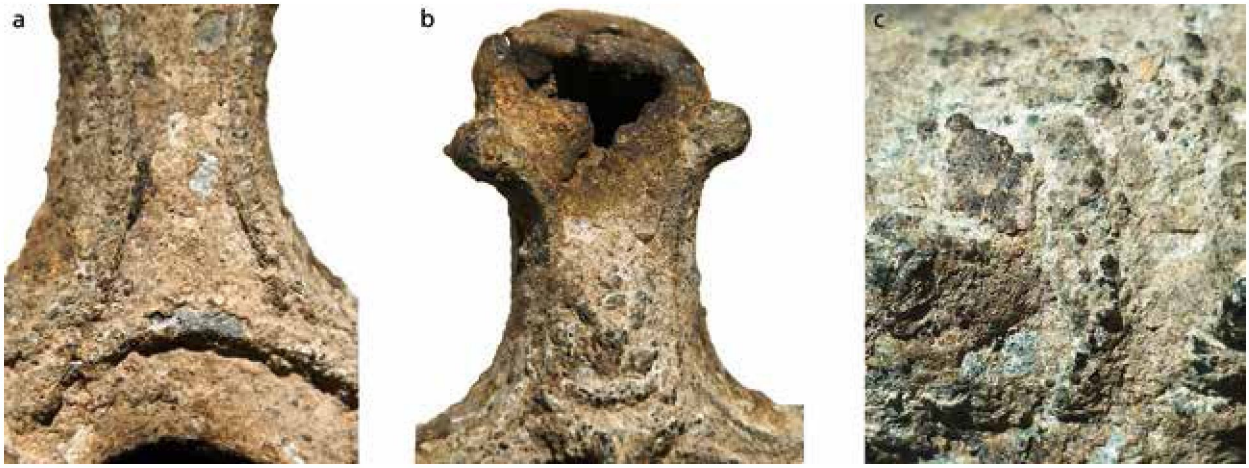

Fig. 6 Macro photographs and micrographs of the lamp: **a** thick corrosion layer with some greyish spots of the original surface. – **b** the cracked and deformed nozzle. – **c** the untreated surface. – (Photo E. Horváth).

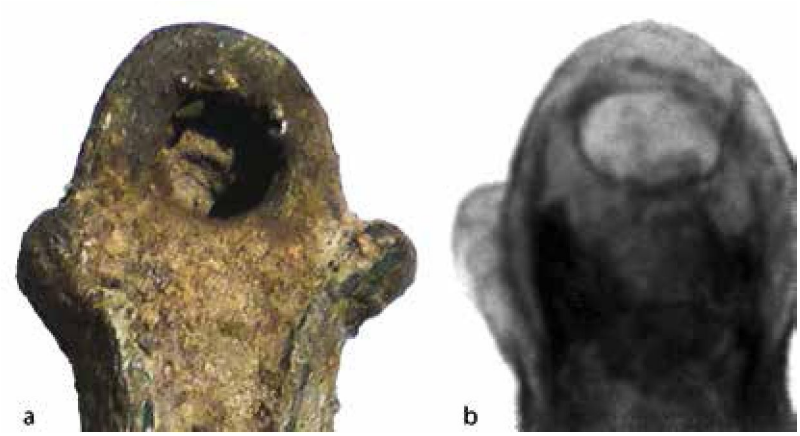

Fig. 7 **a** carbon residue around the wick-holes. – **b** NR image on one of the nozzles of the lamp. – (Photo E. Horváth; NR image Z. Kis).

Use

Microscopic examinations also provided essential information about the usage. The dark contours observed around the wick-holes showed that the lamp was really in use, the flame may have deposited carbon residues on its surface (fig. 7a). In contrast, our investigation did not give evidence of either the date or the frequency of the use. The captured neutron radiographic image did not reveal any hidden remains of the inner construction or the past content of the lamp (fig. 7b).

Discussion

Analogous lamps

Numerous types of oil lamps dated to the Imperial Roman Period have multiple nozzles. They are characterized with a great variety of materials, shapes and designs. Metal lamps are relatively rare objects and the lamp under discussion represents an unusual form among them, although it has a few analogues. The closest parallel is an example from the British Museum (Bailey 1996, pls 42-43 Q 3659)

Fig. 8 A close analogy of the investigated lamp from the British Museum. – (After Bailey 1996, pls 42-43 Q 3659; photos © Trustees of the British Museum).

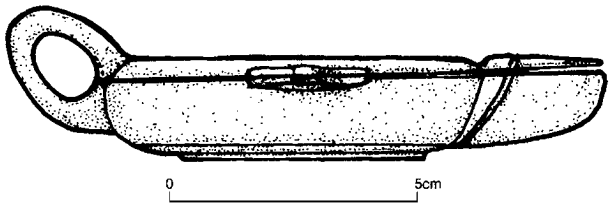

Fig. 9 The side-view of the replica from the British Museum. – (After Bailey 1996, pl. 163 Q 3976; photo © Trustees of the British Museum).

(**fig. 8**). This large lamp has seven voluted radial nozzles. Between each of the nozzles the body is ornamented with well-detailed human masks and the filling-hole is surrounded with a band of vine decoration. In spite of the resemblance, it has a more elaborated design than the zinc lamp. They also differ from each other in two fundamental aspects, i. e. raw material and manufacturing process. This analogous lamp is made of brass, cast in one piece likely by the technique of lost wax casting (Bailey 1996, pls 35-36 Q 3649). On the other hand, for lack of archaeological context its ancient origin is disputed.

We have to take into account that Roman copper alloy artefacts have often been imitated, copied or faked; for instance, several forgeries and reproductions are in the collection of the British Museum (Bailey 1996, 123-124). One of them shows a technology and construction very similar to the analysed zinc lamp – it is made of two brass pieces soldered together (Bailey 1996, 124 pl. 163 Q 3976) (**fig. 9**). Another modern imitation, we cannot consider as a relevant analogue, is a bronze lamp with seven voluted radial nozzles from the collection of the Museum of Fine Arts in Budapest (**fig. 10**). Nevertheless, some of the analogues have a clear archaeological context, such as the oil lamp with five nozzles unearthed in Pompei. This less ornamented piece has been catalogued as a bronze cast artefact having a solid surface covered with green patina (Valenza Mele 1981, 78).

Fig. 10 A modern imitation from the Museum of Fine Arts in Budapest (inv. no. 51.2864). – (Photo © Museum of Fine Arts, Budapest).

Zinc production

The presence of zinc among the alloying elements is always of great significance as the way of its use may indicate the possible earliest date of the production (Hook/Craddock 1996, 150-152; Craddock/Eckstein 2003; Craddock 2009, 147-148). High-purity zinc is a base material unexpected from the Classical Antiquity. Due to the high volatility of metallic zinc and the reactivity of the zinc vapour, producing zinc metal was a technological challenge before the industrial discoveries in the early modern period. Considering the few historical and archaeological sources relevant to the metallurgical processes in the Antiquity and Middle Ages, it is concluded that until the early 19th century, metallic zinc was available only as a by-product of the zinc-rich lead ores smelting (Craddock 1998, 1; 2009, 146). However, the amount of the gained zinc was practically insufficient for manufacturing large objects. Hence, in case of the investigated lamp, compositional data query its authenticity raising other hypotheses about its origin. Also the technical details of the casting process argue against the ancient date of the lamp. The use of the two-piece mould instead of the lost wax casting suggests a modern, 19th century product (Bailey 1996, 123-124).

The owner

Only scanty information is available about the origin and past of this lamp. A donation letter, signed on 9th September 1972 certifies that it forms the part of a very old collection of the Teloni family, constituted before 1870. This noble family resided in Treia until the beginning of the last century and listed among others an eminent member of the clergy (Arnone/Burattini 1951, 61). At the turn of the 18th-19th centuries Mgr. Francesco Ansaldo Teloni was the bishop of Macerata and Tolentino. As a connoisseur of the humanistic sciences and the author of several literary works he developed important friendships with the contemporary scholars. Due to his life and personality, he is supposed to be the family member who

founded the discussed collection. Based on his personal contacts established during his numerous journeys and stays in Italy, he might collect (as gifts, exchanges and purchases) a large group of artefacts from various regions of the peninsula – including both archaeological materials and pastiches or even fakes. The zinc lamp might have been used by him during liturgy.

Acknowledgements

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Notes

1) The analysis was performed at the Instituto Istruzione Superiore »Matteo Ricci« – Macerata, Italy.
2) In this technique selected spots of an object of practically any size and shape can be bombarded by energetic protons, and the characteristic X-rays produced are used for qualitative and quantitative analysis of the irradiated volume. The spot size can be varied in the 0.8-3 mm range; hence small particularities of the samples can be individually analysed. The sensitivities are in the range of 50-1000 ppm, they vary with the elements and depend also on the matrix composition (Gyódi et al. 1999).
3) TOF-ND was set up for the wavelength band from 1.4 to 3.2 Å. The detector position was fixed at 176° (back scattering geometry) and the total flight path was 25 m. At these conditions, constant $2.6 \cdot 10^{-3}$ Å FWHM Bragg peaks were measured in the 0.7-1.6 Å *d*-spacing range. To eliminate the effect of the possible preferred orientation and the background from the corrosion and crust, the positions of the valuable peaks were determined by multiple peak fit and the lattice parameters of the *hcp* system (*a* and *c*) were fitted for the set of peak data, taking into account the uncertainties in the weighting.
4) The method is based on the detection of characteristic prompt gamma photons that originate in (n, γ) nuclear reactions. For the analysis, a selected part of an object is irradiated with a collimated beam of cold neutrons, and the emitted characteristic gamma photons are detected simultaneously. In principle, PGAA enables quantitative measurement of all the chemical elements, but the detection limits depend strongly on the neutron absorption cross-sections of the given nuclei (Révay 2009).
5) Applying PIXE, the limits of detection (LOD) of Sn, Pb and Fe are 1000, 1200 and 160 ppm, respectively. In case of PGAA elements Sn and Pb are the most difficult to identify, with detection limits above 1000 µg/g.

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Summary / Zusammenfassung

Neutron Investigations of a Zinc Lamp of Unknown Origin from the Academia Georgica Treiensis Archaeological Collection (Italy)

The complementary application of the different non-destructive and non-invasive analytical methods provided relevant new information about the material, manufacture and use of the examined oil lamp. The binocular microscope observation facilitated the reconstruction of the manufacture and the usage of the lamp. The PIXE (proton induced X-ray emission) measurements served the quantitative analysis of major, minor and trace elements supplying data on the near-surface composition. The neutron investigations allowed us to determine the average bulk elemental composition, also providing a qualitative and quantitative assessment of the phase composition and the structural properties of the constituents. The identification of the compositional and technological details clarified the date and origin of the lamp. The metallic zinc raw material and the two-piece mould applied in the casting revealed that the artefact is not an archaeological object from the Imperial Roman Period but a copy from the 19th century, in style and shape reflecting the Roman lamps realised mostly in copper alloy and pottery.

Neutronenuntersuchungen an einer Zink-Lampe unbekannten Ursprungs von der Archäologischen Sammlung der Academia Georgica Treiensis (Italien)

Die sich gegenseitig ergänzende Anwendung der verschiedenen zerstörungsfreien und nicht-invasiven Untersuchungsmethoden lieferte wichtige neue Informationen über das Material, die Herstellung und die Verwendung der untersuchten Öllampe. Die Beobachtung mit dem Stereomikroskop ermöglichte die Rekonstruktion der Herstellung und der Verwendung der Lampe. Die PIXE (proton induced X-ray emission)-Messungen dienten der quantitativen Analyse von Haupt-, Neben- und Spurenelementen, indem sie Daten der oberflächennahen Zusammensetzung lieferten. Die Neutronenuntersuchungen erlaubten es, die durchschnittliche Elementzusammensetzung des Vollmaterials zu bestimmen, und sie ermöglichte uns auch eine qualitative und quantitative Einschätzung der Zusammensetzung der Phasen und der strukturellen Eigenschaften der Bestandteile. Die Identifikation der technologischen Details und der Materialzusammensetzung klärten die Datierung und die Herkunft der Lampe. Das Rohmaterial metallisches Zink und die zweiteilige Form, die beim Guss verwendet wurde, verrieten, dass das Artefakt kein archäologisches Objekt aus der römischen Kaiserzeit ist, sondern eine Kopie des 19. Jahrhunderts, die in Stil und Form den römischen Lampen ähnelt, die meist aus Kupferlegierungen und Ton gefertigt wurden.

Keywords

PGAA / neutron radiography / optical microscopy / TOF-ND / PIXE / metalwork