

Interdisciplinary Poster Received Honorable Mention from The Society for Archaeological Sciences

The poster “Diachronic Changes of Ancient Egyptian and Nubian Metallurgy: Case study of material from the Egyptian Museum of Leipzig University“, whose main authors are Jiří Kmošek (University of Chemistry and Technology in Prague) and Martin Odler (Czech Institute of Egyptology, Faculty of Arts, Charles University in Prague), received honorable mention in the Best Student Poster Award competition at the 41st International Symposium on Archaeometry. The symposium took place from 15 – 21 May 2016 in Kalamata (Greece). The poster presents the first phase of the analysis of ancient Egyptian copper and bronze artefacts from the collection of the Egyptian Museum of Leipzig University. The award has been bestowed by the Society for Archaeological Sciences (USA) since 1998 and the authors of the posters are the first students from the Czech Republic to be included on the list. This honorable mention is even more important because the archaeometallurgy of copper and metal artefacts in general has never been studied systematically at the archaeological departments of the Faculty of Arts, Charles University in Prague.

The project ***Early Copper Metallurgy in Ancient Egypt – a case study of the material from Ägyptisches Museum der Universität Leipzig*** is focused on the analysis of a selected corpus of artefacts from the Ancient Egyptian and Nubian sites, deposited in the collection of Ägyptisches Museum der Universität Leipzig. The project is based on interdisciplinary cooperation of the humanities and natural sciences. There are three main institutions involved in the project: Czech

Institute of Egyptology, CUFA, represented by its PhD candidate Martin Odler, an archaeologist specializing on copper and bronze artefacts; Institute of Chemistry and Technology in Prague represented by Bc. Jiří Kmošek, a specialist in material science and archaeometallurgy; and Ägyptisches Museum der Universität Leipzig represented by the curator of the collection, Dr Dietrich Raue. The project is financed by the Grant Agency of Charles University, project no. 38715, and last year was also financed by Internal Grant Agency of ICT, project no. 10681501.

The analysed material was found mostly at the Egyptian sites Abusir, Abydos and Giza and at the Nubian site Aniba. The artefacts represent an outline of the development of Ancient Egyptian metallurgy in more than one and half millennium, from the Dynasty 1 (ca. 3100 – 2900 BC) almost until the end of the New Kingdom (ca. 1200 BC). A detailed report on the first results of the project will be published in the journal *Prague Egyptological Studies* (in Czech, with an English summary).

Diachronic changes of ancient Egyptian and Nubian metallurgy

Case study of material from the Egyptian Museum of Leipzig University

Jiří Kmošek⁽¹⁾, Martin Odler⁽²⁾, Tereza Jamborová⁽¹⁾, Kateřina Šálková⁽¹⁾, Martina Kmoníčková⁽¹⁾ and Šárka Msallamová⁽¹⁾

⁽¹⁾ Department of Metals and Corrosion Engineering, University of Chemistry and Technology in Prague, Technická 5, 166 28 Prague, Czech Republic, kmošek@gmail.com

⁽²⁾ Czech Institute of Egyptology, Faculty of Arts, Charles University in Prague, Celetná 20, 110 00 Prague, Czech Republic, martin.odler@gmail.com



Figure 1 – Photo documentation of the set of analyzed artifacts arranged into chronological groups. The numbers are inventory numbers of the AMEC collection.

INTRODUCTION

The Ägyptisches Museum – Georg Staudt – der Universität Leipzig (AMUL, Germany) holds an important collection of ancient Egyptian and Nubian artifacts. The sampled 86 artifacts represent the development of ancient Egyptian metallurgy in more than one and a half millennia, from Dynasty 1 (ca. 3100 – 2900 BC) until almost the end of the New Kingdom (ca. 1200 BC). The most important assemblages are from the (Early Bronze Age) Dynasty 1 Abydos (Borner 1923), Dynasty 2 Tomb of King Khasekhemwy at Abydos (Kuhn 2011) and the Old Kingdom cemetery at Giza (Staudt – Hölzl 1991). The largest sampled corpus is from the Nubian site Archa, from the Middle Bronze Age Nubian C-Group Cemetery II and from the Late Bronze Age New Kingdom Cemetery 5 (Staudt 1935 – 1937). The sampled artifacts can be divided into several morphological categories: full-size tools, model tools, full-size vessels, mirrors and other metal objects (e.g. bolts). A diachronic change of the ore sources and technology as well as other issues can be studied in detail on the corpus (see Methodology and the discussion of the results).

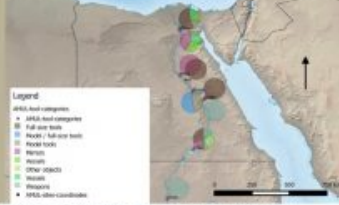


Figure 2 – Map of Egypt and Nubia with marked locations of the examined set of artifacts.

METHODOLOGY

X-Ray radiography and X-Ray CT tomography – visualization of the constructions and mechanical state of the artifacts

Sampling – drilling of metallic material in the amount of 60–100 mg and sawing of 1x2x1 mm samples

X-Ray diffraction analysis (powder diffractometer Bruker AXS D8) – qualitative and semi quantitative phase analyses of powdered corrosion products and metallic phases (16 artifacts)

Energy dispersive X-Ray fluorescence spectrometry (X-Ray fluorescence spectrometer Spectro Hiden) – quantitative chemical analysis of the base composition of the artifacts (92 artifacts)

Optical microscopy (metallographic microscope Olympus PM13) – identification of metallic structures (31 artifacts)

Scanning electron microscopy with X-Ray energy dispersive analysis (TESCAN VEGA 3 with EDS analyzer Oxford Instruments INCA 320) – quantitative chemical microanalysis of structural phases and base composition (31 artifacts)

Vickers micro hardness testing (microhardness tester Future Tech FM 700) – analysis of mechanical properties – microhardness tests (27 artifacts)

Neutron activation analysis (in progress) – specification of ED-XRF results and identification of trace elements (Se, Te, Ag, Au, Pt, Ni, As, Sb, Bi, ... of 66 artifacts)

Lead isotopic analysis (in progress) – characterization of the geographic provenience of copper ores used in the production of 40 artifacts

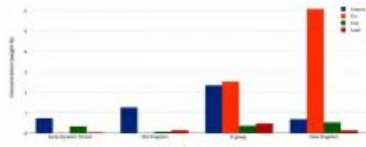


Chart 1 – Bar chart of the development of the chemical composition of copper alloy artifacts from the Early Dynastic period to the New Kingdom.

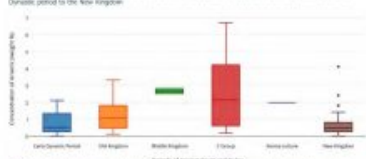


Chart 2 – Box plot chart presenting changes in the concentration of arsenic across the individual periods of ancient Egypt and Nubia.

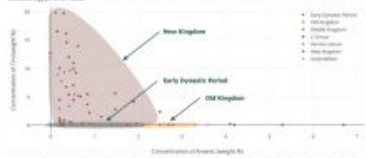


Chart 3 – Scatter plot of the values of arsenic and tin concentrations in artifacts from different periods and cultures.

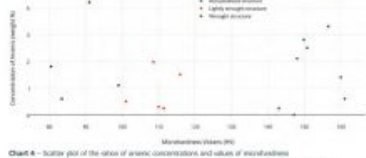


Chart 4 – Scatter plot of the values of arsenic concentrations and values of microhardness.

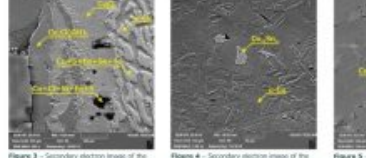


Figure 3 – Secondary electron image of the microstructure of sample 2359.

Alloy	Identification	Amount of artifacts	In corrosion use
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1
AS	As	1	From Dynasty 1

Table 1 – Amount of artifacts in the analyzed set of artifacts.

CHEMICAL COMPOSITION ANALYSIS

The copper alloys used for the production of the analyzed artifacts can be divided into groups based on their chemical composition. The most common artifacts were made of a tin bronze alloy, an arsenical copper alloy or copper with admixtures of arsenic, iron and lead. Six artifacts were identified as tin bronze with arsenic; they were most probably results of recycling of older artifacts made of arsenical copper. New artifacts from the New Kingdom were made of an alloy of tin bronze and lead bronze. One object was made of non-alloyed pure copper and one of alloy of copper nickel and arsenic. The most frequent elements in copper alloys are arsenic, tin, lead and iron. Arsenic was intentionally used for the alloying of copper at least from the Early Dynastic period; the concentration of arsenic reached the maximum in the Middle Kingdom. Starting with the Middle Kingdom, arsenic was gradually replaced by tin. Regular concentrations of arsenic did not exceed the limit of 4 weight percent. Higher concentrations are visible only in the production of the C-group culture in Nubia. The low concentration of lead seems to correspond to the concentration of arsenic, but it was not used intentionally, and not was iron.

METALLOGRAPHIC ANALYSIS

In most cases, the structures were formed by a single-phase solid solution of copper and arsenic or copper and tin. Only one full-size tool from the late Old Kingdom with 6 % of arsenic analyzed by metallographic methods contained a two-phase structure of a copper and arsenic rich γ phase (Cu_3As). A bronze vessel with 10 % of tin from Archa dated to Dynasty 18 contained a two-phase structure of a copper and non-equilibrium phase δ (Cu_2Sn). Three analyzed structures were formed by dendrites originating from the casting operations. The most frequent structures were formed by recrystallized or wrought grains with non-metallic inclusions in different states of deformation. These structures are corresponding to different thermomechanical techniques of metal processing, especially casting, annealing and hammering.

Microstructural description	Observed structure	In corrosion use
Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	casting + annealing	From Dynasty 1
Recrystallized grains of Cu alloy with dendrites	casting + annealing + hammering	From Dynasty 1
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Table 2 – Microstructural description and observed structure of the analyzed artifacts.

MICROHARDNESS TESTS

The microhardness of the tested arsenical copper alloys ranges between 30 and 140 Vickers hardness units. The results clearly indicate that microhardness depended more on thermomechanical processing of the artifacts than on the content of arsenic and its alloying effect. The hardness of artifacts with wrought structures and low concentration of arsenic is much higher than that of recrystallized structures with a high portion of arsenic.

Artifact	Inventory no.	Period	Material	Structure	As (wt%)	Sn (wt%)	Pb (wt%)	Fe (wt%)	Se (wt%)	Te (wt%)	Ag (wt%)	Ni (wt%)	Bi (wt%)	Sb (wt%)	Other
AS	1	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	2	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	3	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	4	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	5	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	6	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	7	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	8	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	9	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	10	From Dynasty 1	Copper	Recrystallized grains of Cu alloy with non-metallic inclusions and dendrites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3 – Parameters of the analyzed artifacts and results of ED-XRF and SEM/EDS chemical composition analysis.

Standard phases	Description	Occurrences
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
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AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1
AS	a solid solution of copper and other elements	From Dynasty 1

Table 4 – Identified structural phases in the analyzed set of artifacts.

CONCLUSIONS AND FURTHER RESEARCH

Arsenical copper was known in Egypt already in the Naqada culture. It is present in our corpus from the earliest artifacts of Dynasty 1. Arsenic was used as the main alloying element until the Middle Kingdom, when it was gradually replaced by tin. The hardness of artifacts was intentionally achieved by mechanical hardening other than using the alloying effect of arsenic. The production techniques of casting, alloying, annealing, hot or cold hammering and surface finishing were commonly used from the Early Dynastic Period. The largest part of the analyzed artifacts was made of rich sulphide copper ores, which is indicated by the presence of selenium and tellurium in non-metallic inclusions. The project is continuing by neutron activation analysis of all samples used for the identification of trace elements, and by lead isotope analysis of selected artifacts used for the characterization of the geographic provenience of the copper ores used for the production of copper. The results of neutron activation analysis and lead isotope analysis will enable detailed determination of the alloys used for the production of the sampled artifacts.

REFERENCES

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ACKNOWLEDGEMENTS

Dr. J. Kmošek, M. Odler, T. Jamborová, K. Šálková, M. Kmoníčková, Š. Msallamová. The study was supported by the Grant Agency of the University of Chemistry and Technology in Prague (Project No. 20/2018).

UNIVERSITY OF CHEMISTRY AND TECHNOLOGY PRAGUE

CZECH INSTITUTE OF EGYPTOLOGY

ÄGYPTISCHES MUSEUM LEIPZIG

The poster Diachronic changes of ancient Egyptian and Nubian metallurgy – Case study of material from the Egyptian Museum of Leipzig University

Abstract of the poster:

This poster presents archaeometric and archaeological study of a set of copper and bronze artefacts found at the sites of ancient Egypt and Nubia, which are deposited in the collection of Ägyptisches Museum – Georg Steindorff – der Universität Leipzig. Examined artefacts have been found at several important sites: Abydos, Abusir, Giza and Aniba. They represent the development of Ancient Egyptian metallurgy in more than one and half millennium, from the Dynasty 1 (ca. 3100 – 2900 BC) until almost the end of the New Kingdom (ca. 1200 BC). Analyzed set of 86 artefacts and almost 100 samples is covering different typological groups of the artefacts, such as full-size tools, their models, full-size vessels and mirrors, etc.

Detailed technical analysis has been carried out with the aim to obtain or specify information about chemical or structural artefact composition, using wide range of analytical techniques. All artefacts have been documented by X-ray radiography and more complex artefacts by X-ray tomography. Selected artefacts have been studied by metallographic methods in combination with micro hardness tests and SEM/EBSD analysis for better understanding of the mechanical and heat treatment production techniques. Chemical composition analyses were carried out by methods of XRF, SEM/EDS and NAA with the aim to characterize metals alloys and present admixtures. On the set of analyzed artefacts is clearly visible evolution of the alloys use across the studied periods and geographical areas. All obtained analytical data have been statistically evaluated in the context of spatial distribution, dating and function of the studied artefacts, in order to contribute to more detailed and accurate knowledge of metal production techniques and materials used in the Ancient Egyptian metallurgy.

poster in PDF

introduction photo: Part of the conference programme took place in the ancient theatre at Messen (photo Jiří Kmošek)