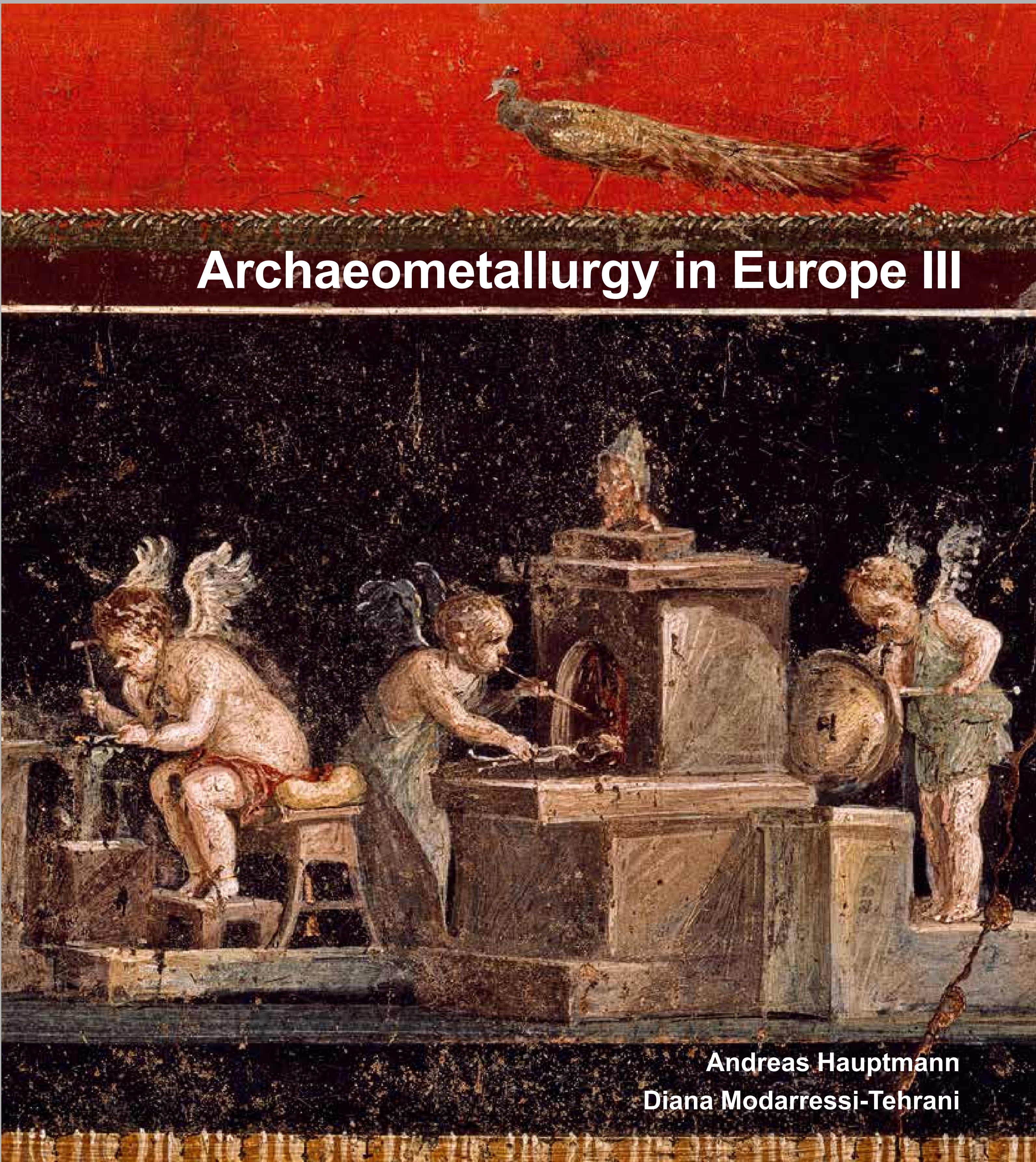
DER ANSCHNITT

ZEITSCHRIFT FÜR KUNST UND KULTUR IM BERGBAU

BEIHEFT 26

Archaeometallurgy in Europe III



Andreas Hauptmann
Diana Modarressi-Tehrani

Archaeometallurgy in Europe III

Archaeometallurgy in Europe III

Proceedings of the 3rd International Conference
Deutsches Bergbau-Museum Bochum

June 29 – July 1, 2011

Editors
Andreas Hauptmann
Diana Modarressi-Tehrani

Bochum 2015

Montanhistorische Zeitschrift

Der ANSCHNITT. Beiheft 26

= Veröffentlichungen aus dem Deutschen
Bergbau-Museum Bochum, Nr. 202

Cover

Domus Vettiorum / Casa dei Vettii, Pompeii (Campania, Italy, 63-79 BC), which was excavated in 1894. Section of a Pompeii-style scenic fresco showing Erotes and Psyches in a gold assay laboratory. In the left corner, scales for weighing gold are put on a table. Next to it, one of the Erotes is working with a small hammer on an anvil. On the right side, an assay furnace is shown. Another of the Erotes is holding a small crucible with pincers with the right hand while using a blowpipe with his left hand, supplying the fire with air. The large bellow for the assay furnace is driven by the third of the Erotes.

The conference Archaeometallurgy in Europe III
was supported by

Keyence

Analyticon

MLS GmbH

Zeiss

Thermo Scientific

Springer Verlag Berlin Heidelberg
New York

Redaktion
Diana Modarressi-Tehrani, Andreas Hauptmann

Layout
Rolf Krause

Titelgestaltung
Karina Schwunk

Druck
Grafisches Centrum Cuno GmbH & Co. KG

Bibliografische Informationen der Deutschen Bibliothek

Die Deutschen Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http/dnd.ddb.de abrufbar.

ISBN 10: 3-937203-74-5
ISBN 13: 978-3-937203-74-4

Anschrift der Geschäftsführung und der Schriftleitung:
Deutsches Bergbau-Museum
Am Bergbaumuseum 28 - D-44791 Bochum
Telefon (02 34) 58 77-0
Telefax (02 34) 58 77-111

Einzelheft 9,– €, Doppelheft 18,– €;
Jahresabonnement (6 Hefte) 54,– €;
kostenloser Bezug für die Mitglieder der Vereinigung
(Jahres-Mitgliedsbeitrag 50,– €)

Archaeometallurgy in Europe III

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Editorial

This volume comprises a range of articles, which were submitted and selected from all the presentations given on the International Conference ”Archaeometallurgy in Europe III”, held from the 29th of June to 1st of July 2011 at the Deutsches Bergbau-Museum Bochum, Germany.

The present volume is the third in the series “Archaeometallurgy in Europe” , capturing the spirit of the successful series of international conferences on this special theme of research. The first conference “Archaeometallurgy in Europe” had been organized by the Associazione Italiana di Metallurgia and took place in Milano, Italy, from the 24th to the 26th of September 2003. The second conference was held in Aquileia, Italy, from the 17th to the 21st of June 2007. It was also organized by the Associazione Italiana di Metallurgia.

The splendid idea to launch this conference series, a scientific series of meetings limited to the countries of Europe, came from the late Prof. Dr. Walter Nicodemi, formerly President of the Assoziazione Metallurgia di Italia. Thanks to the efforts of Dr. Alessandra Giumlia-Mair, Merano, these conferences have developed into increasingly productive events with a high scholarly quality. Since then three conferences have taken place and the fourth meeting is at an advanced stage of preparation and will take place in Madrid, Spain, from the 1st to the 3rd June 2015.

The title of the conference series covers a research field which is a distinctive part of archaeometry, and which so far was usually included as one of the topics in the program of the “International Symposium on Archaeometry” (ISA), organized every third year at different locations in Europe and in the United States. However it is our opinion, that in the last decade archaeometallurgy has developed as a very important research field, and we are observing a large number of scholarly activities all over the world. We are convinced that such an important topic needs to be organised and presented in conferences specifically dedicated to this field. Therefore the topic of this conference is the history of metals and metallurgy primarily in Europe, but it also includes other regions of the Old World.

The future prospects of the conference series are promising, especially because “Archaeometallurgy in Europe” constitutes an extremely useful broadening and a regional counterpoint to the well-established and successful conference series “The Beginnings of the Use of Metals and Alloys” (BUMA), which was launched in 1981 by Professors Tsun Ko, Beijing, China, and Robert Maddin, then Philadelphia, USA. The focus of the eight BUMA conferences held so far (the last one was held in Nara, Japan, in 2013) lays on the development of metallurgy in South-East Asia and the Pacific Rim. We firmly belief that the two conferences complement each other very effectively and should therefore continue to exist side by side.

With this special volume of *Der Anschnitt*, we are delighted to publish a selection of the lectures presented at the conference at the Deutsches Bergbau-Museum Bochum in 2011. Many of the authors contributed with very instructive and informative papers, which finally resulted in this volume.

We are very much obliged to all these authors who, with patience and persistence, cooperated with us and helped to shape this volume. We would also like to thank the reviewers who decisively contributed in the improvement of the scientific level of this volume.

Our thanks go first to all those colleagues and friends who helped to organize the conference in 2011. The former director of the Deutsches Bergbau-Museum, Prof. Dr. Rainer Slotta, and the present director, Prof. Dr. Stefan Brüggerhoff encouraged and promoted our efforts to organize this scholarly meeting. Dr. Michael Bode, Dr. Michael Prange, and Prof. Dr. Ünsal Yalçın supported the conference planning and realization in every aspect. Many colleagues of the staff of the Deutsches Bergbau-Museum, and many of the students working in our research laboratory offered their assistance and help.

Finally, our thanks go to Mrs. Karina Schwunk and Mrs. Angelika Wiebe-Friedrich who performed the editorial work, design, and layout for this volume.

Andreas Hauptmann
Diana Modarressi-Tehrani

Contemporaneously to the conference in 2011 a volume with abstracts on every lecture given and every poster presented was published:

2011 HAUPTMANN, Andreas, MODARRESSI-TEHRANI, Diana & PRANGE, Michael (eds.), Archaeometallurgy in Europe III. Abstracts. METALLA, Sonderheft 4, 2011.

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Production of arsenical copper at the beginning of the 3rd millennium BC

Summary

Perennial excavations carried out at the tell site Çukuriçi Höyük uncovered inter alia a settlement area composed of two phases dating in Early Bronze Age 1, or from 2900–2750 cal BC in absolute terms. Both settlement phases included complex buildings for mainly domestic use. Besides ordinary household activities, intensive metallurgical activities were identified by excavating the settlement areas under study and carrying out scientific analyses. Metallurgical workshops with up to now 49 furnaces and fireplaces as well as associated finds were found in two EBA 1 settlement areas (trenches S1–S4 and M 1) of the tell. They indicated that metal processing took place in all living quarters of both EBA settlements. The large amount of tools allowed us to identify all the production stages of various metal objects. Especially the examined smelting debris that was found in the trenches S1–S4 provided useful clues with regard to the production of arsenical copper during the first half of the 3rd mill. BC. The presence of iron arsenide in the smelting debris attested to complex smelting processes going far beyond "normal" copper working and led to the question of arsenical copper production, a very interesting topic discussed by various scholars in recent times, e.g. with regard to the site of Arisman in western Iran.

Introduction

In the late 4th millennium and the first half of the 3rd millennium BC important changes in metalworking technology took place in Anatolia. On the one hand, it is described that the smelting of copper ore became more professional and organised and on the other hand this was the first time that bronze (as intentional copper-tin alloy) began to displace the arsenical copper used before (Yalçin 2000: 25-26). This can e.g. be observed in two bronze objects found in Beşiktepe at the West Anatolian coast (Begemann et al. 2003: 179, tab. 2)., dating to the settlement phase of Troy I Several excavated sites in Turkey have yielded fragments of crucibles, metal remnants, kilns, ore finds, slag, moulds and tools. Finds from Arslantepe, Çamlibel Tarlası, Murgul or Norşuntepe were particularly impressive (Zwicker 1980: 17; Lutz et al. 1991; Hauptmann & Palmieri 2000; Hess et al. 1997, 75; Schoop 2010: 191-201). Only a few settlements along the West Anatolian coast have to date been found that yielded definite evidence attesting the production or processing of metal in the late 4th and early 3rd millennium BC. The Late Chalcolithic and EBA layers in Liman Tepe and Bakla Tepe contained a blow pipe or crucible fragments (Erkanal 2008: 168; Kaptan 2008), which can be interpreted as evidence of copper processing having taken place on these sites. A casting mould found inside the walls of the settlement phase Troy I attested to metalworking there from as far back as the Early Bronze Age 1 onwards (Müller-Karpe 1994: 43). Archaeological evidence of very early metal processing in Greece and Aegean is also not particularly abundant (Alram 1996: 181; Zachos 2007; Tzachili 2008). The settlement Kephala Petras is one of a few interesting early examples on Crete. With regard to the slag embedded in the floor of a building complex dated to Early Minoan I, Yannis Papadatos assumes that it may have been introduced as part of the floor infills (Papadatos 2007: 161). Moreover, vitrified clay excavated in undisturbed Final Neolithic contexts (second half of the 4th millennium) allowed him to draw the conclusion that metal processing had taken place in the area (Papadatos & Tomkins 2013: 367). A lump of copper ore was also recovered from the Final Neolithic Room XIX in Phaistos on Crete, which can be considered as indication that metal was at least produced or melted there (Todaro & Di Tonto 2008: 183). Recent rescue excavations in the Attica region revealed further early remains of silver smelting and metal working in Koropi and Merenda (Kakavogianni et al. 2007: 49-52; Tzachili 2008). Considering these questions of early copper production and the technological state of knowledge in general in the Anatolian-Aegean world, the results from the Çukuriçi Höyük excavations and studies (Fig. 1) offered new insight or at least new data for this discussion.

Fig. 1: Localization of the Tell Çukuriçi Höyük in Western Anatolia (map by Ch. Schwall).

Early Bronze Age Settlements at Çukuriçi Höyük, Western Turkey

Since the beginning of the systematic research carried out at Çukuriçi Höyük[1] in 2007, seven different settlement phases dating from the early Pottery Neolithic period to the Early Bronze Age (3rd mill. BC) were identified with the help of excavations, artefact studies and radiocarbon dates (Horejs 2008; Horejs 2009; Horejs et al. 2011; Horejs 2013). The tell is situated on the mid-Aegean coastline at the mouth of the Küçük Menderes river, close to the Late Antique city of Ephesos in a very favourable settlement area, where only very few prehistoric sites have to date been excavated (Horejs et al. 2011: 35-37 Fig. 3). This lack of research possibly distorted our image of the whole region which appears to have been integrated in supra-regional exchange systems in prehistoric times as much as in later periods (Ladstätter 2011). As discussed in detail elsewhere (Bergner et al. 2009; Horejs et al. 2011: 48-50, Fig. 11), compared to other sites obsidian was a raw material that was used in remarkable amounts throughout all periods and was imported mainly from the Aegean island of Melos. In terms to the focus of this paper, the Early Bronze Age remains uncovered at the tell, offered a complex picture of activities conducted in the excavated area. Trenches S1–S4 revealed two settlement phases that were defined as ÇuHö IV and III. Based on the

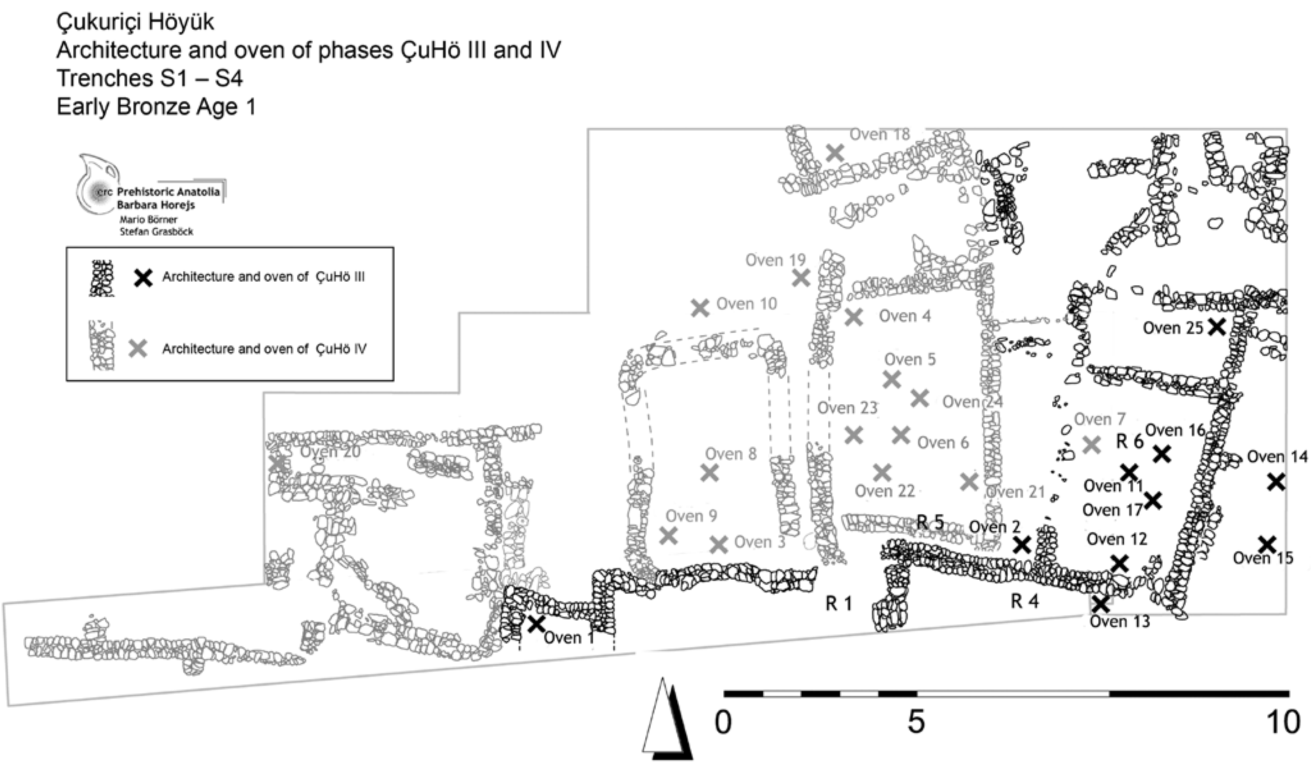
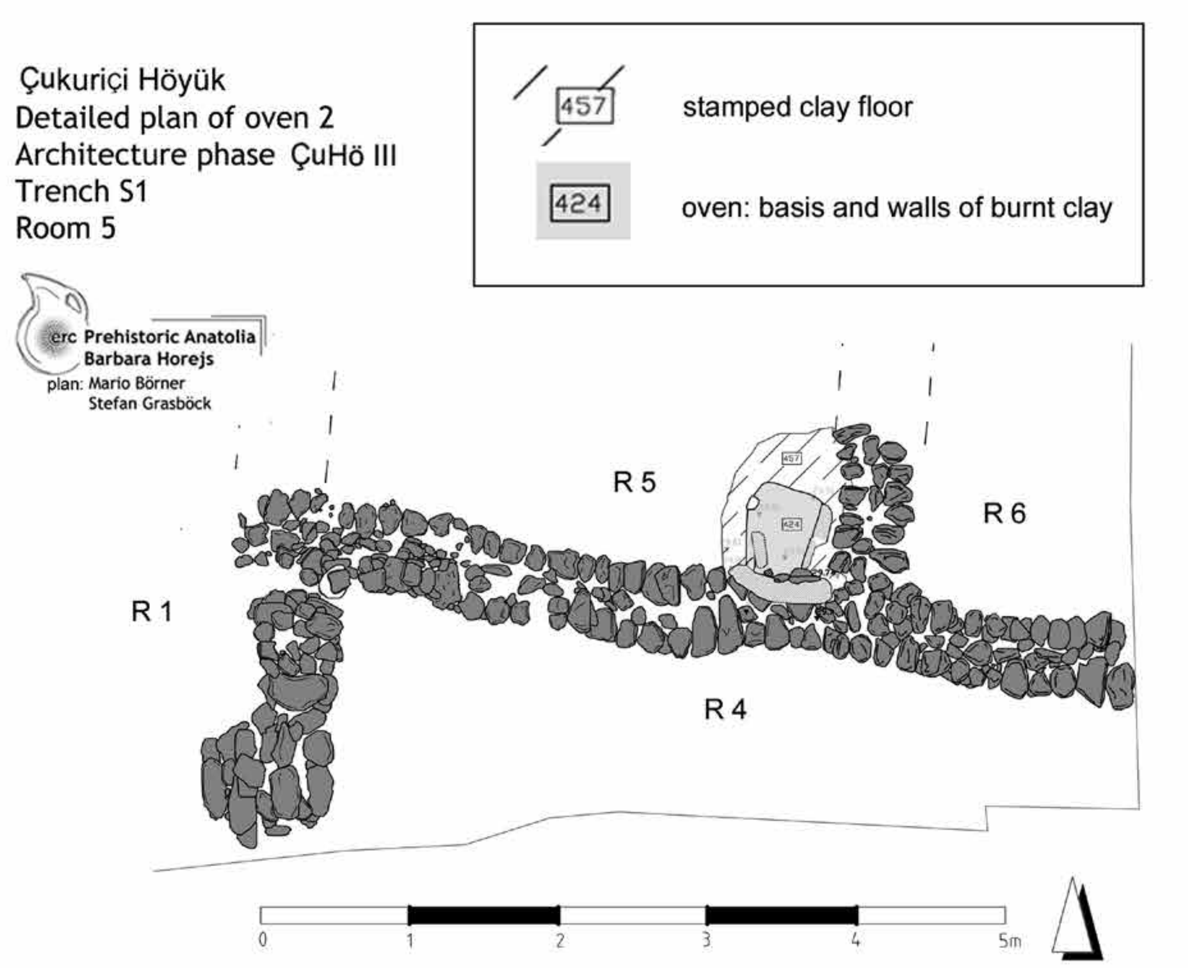


Fig. 2: Architecture and bowl- and horse-shoe shaped furnaces and fireplaces (=oven) of the settlement phases ÇuHö IV–III (plan by M. Börner and St. Grasböck).

results of geophysical surveys, paleogeographical studies and analyses of old aerial photographs[2] the area on today's southern edge and highest part of the tell appears to have originally formed its centre.

Both EBA settlements consisted of rectangular houses with one or more rooms, some of them joined together to form complex buildings (Fig. 2). The buildings and the intermediate free areas (courtyards and streets) were composed of several occupation surfaces represented by renewed floors, repaired walls or changing installations, while their main features remained in constant use in each phase. The settlement structures from the older phase ÇuHö IV were largely covered over by levelled layers providing the substructure for ÇuHö III constructions, resulting in a clear stratigraphical distinction between both phases. Although the latest occupation phase ÇuHö III represents a reorganization, all characteristic elements of the older phase ÇuHö IV were continuously remodelled. These continuous features are not only indicated by building techniques, the essential composition of the settlement and the orientation of the buildings, but also by their inventories, installations and therefore their principle functions, too. As it has already been suggested in the discussion of typical inventories from both phases, the buildings in the excavated area primarily fulfilled domestic functions (Horejs et al. 2010: 9-11; Horejs et al. 2011: 42-46). The assemblages were clearly dominated by pottery and animal bones as well as botanical remains from household activities (Schachner 1999: 6) (storage, cooking, preparing and consumption) and the typical tools and equipment of simple crafts[3]. The spectrum of finds does not make any building or area stand out, which corresponds with the generally homogenous appearance of EBA settlements both excavated and surveyed by geophysics (Börner in preparation). At first sight, the settlement plans and the inventories represent a typical EBA settlement with distinct analogies within the wider region, for instance in Emporio, Poliochni, Thermi or Troy I (Lamb 1936; Blegen et al. 1950; Hood 1981; Kouka 2002). In this context, the installation of various metal workshops in both EBA phases at Çukuriçi Höyük remains surprising. So far, 26 bowl- and horse-shoe shaped furnaces and fireplaces[4] have been found in the trenches S1-S4, which represents simultaneous metal crafts conducted there. For instance furnace 2 in room 5 (phase ÇuHö III) represents a typical horseshoe-shaped example built into the corner of a room. It is preserved to a height of 0,45 m (Fig. 3). This furnace was constructed of stamped clay and mudbricks, which were bright red from being exposed to the heat and flames during its period of use.

In trench M1 22 rooms with the remains of 23 further fireplaces were excavated. Concerning their size and shape they correspond very well with the rooms found in the trenches S1-S4. Due to modern destructions by the owner of the land nearby no remains of settlement phase ÇuHö III were found in this area. The well stratified layers of this trench can be assigned to the settle-



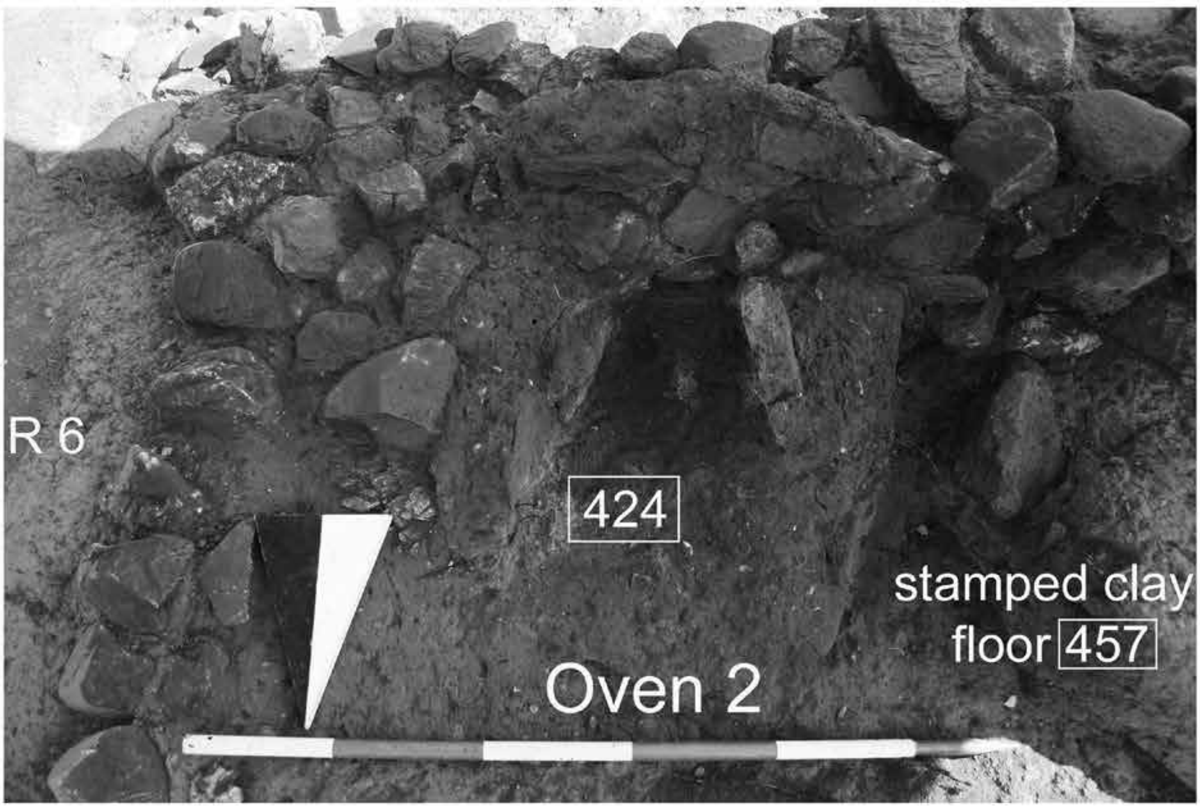


Fig. 3: Detailed plan of horse-shoe shaped furnace 2 (= Oven 2) in room 5 of phase ÇuHö III dating in EBA 1 (plan by M. Börner and St. Grasböck; photo: L. Toriser)

ment phase ÇuHö IV. The excavated rooms form two west-east orientated set of buildings, one in the northern part and one in the southern part of trench M 1. Between them a small way was observed. Most of the fireplaces were situated it the corner of a room, six of them were placed in the centre of a room (Horejs 2013: 7-8). The excavation revealed many finished objects and two ore pieces. The numerous finds comprises weapons like a flat axe, chisels, needles, pins and few small metal-bars representing semi-finished products and raw metal. Although the archaeometallurgical analyses of these artefacts are not finished yet we can mention that the metal artefacts found in these rooms can be correlated with those excavated in the trenches S1-S4 (Horejs 2013: 7).

The construction of the bowl- and horse-shoe shaped furnaces, their phases of use and remodelling as well as their surrounding working zones – especially in the trenches S1-S4 – allowed us to identify metal workshops in this living quarter dating to the Early Bronze Age (Horejs et al. 2010).

Relative and absolute dating of Çukuriçi Höyük IV and III

Summarizing the already discussed dating of both EBA phases at Çukuriçi Höyük (Horejs et al. 2011; Horejs & Weninger, in print), it should be pointed out that the relative chronology is based on pottery that reflects the style of a broader Western Anatolian horizon with some links to the Eastern Aegean islands. The analyses of assemblages from closed contexts from the using horizons of two rooms from both phases (room 19: ÇuHö IV and room 1: ÇuHö III) synchronises them with Troy I, Beycesultan XIX–XVII, Aphrodisias Pekmez LC4–EB1/2, Yortan, Emporio V–IV, Thermi and Poliochni blue and led to the relative dating of Çukuriçi Höyük IV–III to EBA 1.

Thanks to 10 radiocarbon dates of short-lived as well as of charcoal samples analysed, modelled and discussed by B. Weninger (Horejs & Weninger, in print), it was possible to obtain an independent absolute chronology for the site. The actual date for both phases can be fixed between 2900 and 2750 cal BC, which corresponds to Troy I early in particular.

Metal working on the tell

During the on going excavations in the centre of the tell, many metallurgical installations were found which can clearly be linked to metallurgical activities at this site. The following discussion will focus on the results of objects which were found in the trenches S1-S4 in the centre of the tell (Horejs 2013). Especially in rooms 1 and 2 a large amount of metallurgical equipment (Fig. 4.) came to light, which indicated, that metal workshops were located in this area (Horejs et al. 2010, 10; Mehofer (in print)). These assemblages formed the basis for the following archaeometallurgical analyses. On the one hand several bowl-shaped furnaces and fireplaces, that were situated in the centre of the room were excavated and on the other hand oval or "horseshoe" shaped constructions, built against the wall, were revealed. One may imagine these furnaces as a horseshoe-shaped construction built of clay, similar to those known from Norşuntepe and İkiztepe. Metal objects as well as metallurgical ceramics were found throughout the whole excavation. The main finds were needles and pins with pyramidal head, mace-headed pins or pins with rectangular head which are characteristic Early Bronze Age finds. Many fragments of crucibles and blowpipes were among the finds, similar to those known from other Early Bronze Age sites such as Kuruçay and Norşuntepe. They indicate that crucible smelting was carried out at the site. Numerous moulds for rod ingots provide evidence, that metal was collected, melted and cast into different standard sizes on the tell (Horejs 2009: 363, Fig. 6; Horejs et. al. 2011: 15, Abb. 4-5; (Mehofer (in print)). Of particular interest among the finds was a block anvil and hammerstone used for forging the metal by shaping bars into finished objects. During working, the anvil was embedded in wood or a similar material to hold it in place. Additionally, copper prills - waste from the casting process - were found inside of some bowl- and horse-shoe shaped furnaces and fireplaces as well as in several strata of room 1 (EBA 1) along with other remains of metalworking. In conclusion, we may state

Fig. 4: The metallurgical ensemble, found at Çukuriçi Höyük, comprises numerous crucibles, moulds, blow pipes, tools, semi-finished as well as finished products dating in EBA 1. Photo: N. Gail/OEAI).

that intensive metal working was carried out on this tell. The large number of moulds demonstrated, that metal was not only worked, but also accumulated and used for re-trading. This made it possible to reconstruct a complete *'Chaîne opératoire'* – from the raw material to the finished objects – and allowed us to identify a developed system of metalworking at Çukuriçi Höyük. In comparison with other Early Bronze Age 1 sites, the amount of metal objects (all in all 173 pieces) and metallurgical finds discovered here is exceptional; other West Anatolian settlements such as Troy, Beşiktepe or Demirçihöyük for example have only yielded up to 28 metallic artefacts in their EBA 1 layers.

Chemical analyses

In addition to the archaeological classification, the metal objects were subjected to a detailed archaeometallurgical examination. They were analysed by various analytical methods in order to determine the metallurgical processes, the chemical composition and the lead isotope ratios of the metal. The ED-XRF analyses and the analyses by MC-ICP-MS were carried out in co-operation with Ernst Pernicka, Curt Engelhorn Centre for Archaeometry, Mannheim; the SEM analyses were carried out in the archaeometallurgical laboratory of the VIAS – Vienna Institute for Archaeological Science, University Vienna (Bietak et al. 2005).

The data obtained was set in relation to the copper and lead deposits known in Turkey and the Aegean region (Seeliger et al. 1985; Pernicka et al. 1984; Wagner et al. 1986; Pernicka 1987; Gale et al. 1985; Wagner et al.1989; Pernicka et al. 1990; Pernicka 1995; Begemann et al. 2003) in order to identify the provenance of the metal and to give insights into the metal trade and metal supply during the beginning of the Early Bronze Age. These archaeometallurgical analyses revealed that all objects were made of copper with a varying arsenic content of up to 5%, whereas tin could not be detected in any case. During the 4th millennium and the beginning of the 3rd millenium arsenical copper can be observed in metal from numerous sites in Anatolia and the Aegean like for example in Arslantepe, Beycesultan, Beşiktepe, Hacınebi, Ilıpınar, İkiztepe, Poliochni/Lemnos, Thermi/Lesbos and Yortan (Gale et al. 1985: 158, Table 4; Kunç 1986: 101, Tab. 1; Pernicka et al. 1990: 267, Tab. 1; Stos-Gale 1992: 155-177, Begemann et al. 1994: 214, Tab. 3; Özbal et al. 2002: 41; Hauptmann et al. 2002: 47, Tab. 3., 49, Tab. 5., 51, Tab. 7, 54, Tab. 8; Begemann et al. 2003: 178, Tab. 2). A detailed examination of the trace element contents shows, that the finds from the Çukuriçi Höyük generally correspond with objects from other West Anatolian and Aegean sites, whereas a comparison with Central and Eastern Anatolian objects reveals certain differences in the trace element contents: some of the objects found in the "royal tomb" of Arslantepe in Eastern Turkey, for example, generally had a higher nickel content.

Furthermore, these analyses revealed another exceptional object, made of a silver – copper alloy (Horejs et al. 2010: 16, Abb. 6, 2). This specific composition can also be observed in different metal objects from the same period like in objects from the "royal tomb" of Arslantepe, in a spearhead from Uruk-Warka or in four shaft hole axes found on the Balkans (Born & Hansen 2001; Hauptmann et al. 2002; Hauptmann & Pernicka 2004; Horejs et al. 2010: 27-28). In the context of the use of precious objects (gold, silver and silver-copper alloys) Svend Hansen was able to show, that weapons made of such metals were mainly discovered in graves and hoards of the social élite from the Balkans to Mesopotamia as part of an over-furnishing of these graves with objects made of these precious metals. Consequently, he interpreted this as evidence of a social élite, cultivating its image by "*following a 'code', which was widely accepted across a vast geographical area*" (Born & Hansen 2001: 48-50) during the Early Bronze Age. While the small fragment of a copper-silver alloy from Çukuriçi Höyük would certainly only have been used for the manufacture of an equally small item of jewellery like an earring, it still proves that the metallurgists at Çukuriçi Höyük had the knowledge of this particular alloy and were able to work it. As a consequence we may state, that they were aware of this wide-ranging 'code' of this 'social élite'.

Provenance studies and lead isotope analyses

Over the past number of decades a series of studies, focusing on mining archaeology and archaeometallurgical research in the Mediterranean world, have been carried out (Pernicka et al. 1984; Seeliger et al. 1985; Wagner et al. 1986; Pernicka 1987; Wagner et al. 1989; Pernicka 1995; Yalçin 2000: 23; Pernicka et al. 2003). Based on these studies it can be mentioned that Troy and the Troad in North-West Anatolia are relatively well researched from a 'metallurgical' point of view, while it must be stated that the remaining areas of the West Anatolian coastline still lack detailed studies on the expansion of metallurgy. In order to get a first insight into the various networks of distribution and trade, the data obtained from the objects found at the Çukuriçi Höyük was combined with published lead isotope data gleaned from Turkish ore deposits. The lead isotope diagram (Fig. 5) allows us to recognize that the objects excavated at the Çukuriçi Höyük (grey diamonds) can be located within the "Anatolian orefield", whereas the great ore deposits of Laurion in Attica or Cyprus[5] can be excluded as a source for the copper. The copper mines in Middle and Eastern Turkey[6], which provided copper for, e.g., Hassek Höyük, Arlsantepe or Norşuntepe can also generally be excluded due to their differing lead isotope and

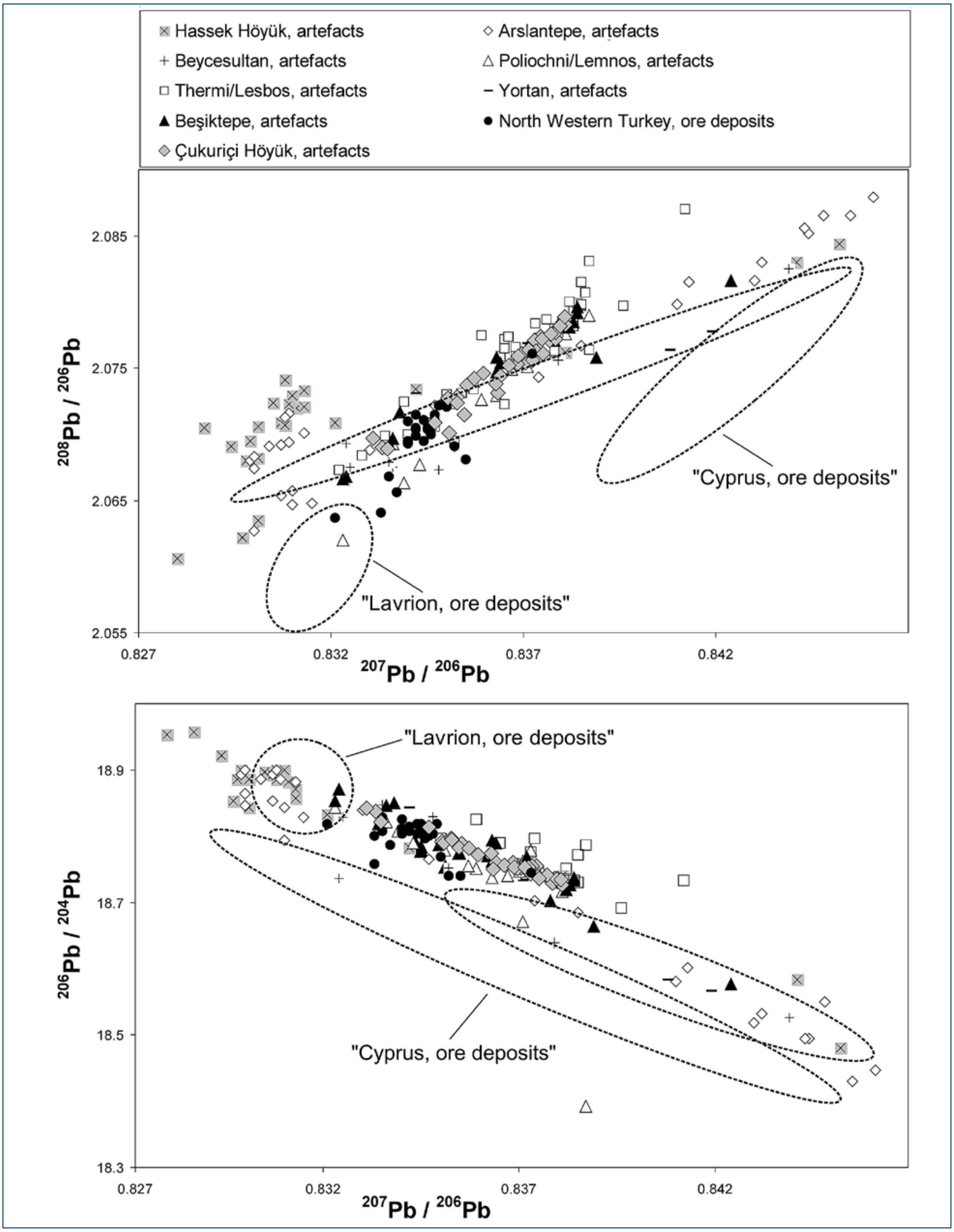


Fig. 5: The diagram presents the lead isotope ratios of the objects under study compared to published lead isotope ratios of copper and lead ores from Cyprus and Lavrion (outlined by ellipses). It illustrates that the objects found at the Çukuriçi Höyük (grey diamonds) plot with objects found at Beşiktepe (black triangles) as well as objects found in Poliochni and Thermi (open triangles and open squares). It further suggests a partial overlap with Northwest anatolian ore deposits (black dots). Meanwhile they do not coincide with Middle and East Anatolian objects (open diamonds, grey squares with cross) like e.g. those found in the “palace hoard” and “royal tomb” of Arslantepe. Data: Gale et al. 1985: 157, table 3, 161, table 5, 167, table 6, Seeliger et al. 1985: 641, Tab. 1; Pernicka et al. 1990: 269, table 4; Yener 1991: 560, Table 2; Pernicka 1984: 579, Tab. 4 ; Schmitt-Strecker et al. 1992: 112, Tab. 2; Stos-Gale 1992: 174, Table 1; Begemann et al. 1994: 214, Tab. 3; Hauptmann et al. 2002: 49, table 6; Begemann et al. 2003: 193, table 4 (© Mehofer, VIAS).

Table 1: Area analyses (SEM-EDS) of sulphidic inclusions in section 2 of sample no. 07/368/6/501, measurements in weight%, n.d.= not detected, normalised to 100%

nr. 07/368/6/501	O	S	Fe	Cu	As	total
area analyses	3.8	19.8	3.7	68.5	4.2	100

Table 2: Spot-analyses (SEM-EDS) of iron arsenide inclusions in sample no. 07/368/6/501, in weight %, n.d.= not detected, normalised to 100%

	O	S	Fe	Cu	As	total
spot analyses	n.d.	0.5	41.3	1.2	57	100

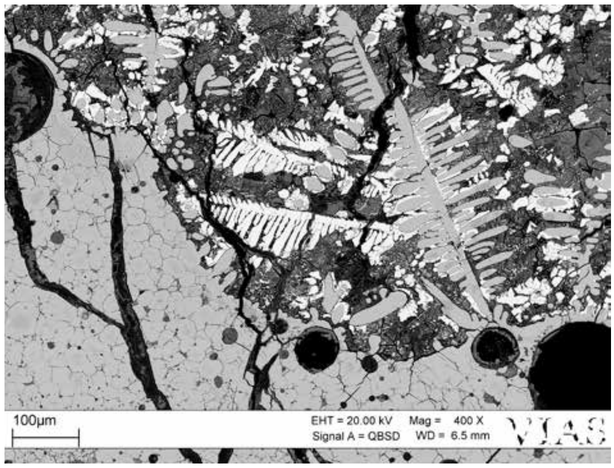


Fig. 6: The microstructure of the slag is composed of different phases, in the lower left part globular copper sulphides (grey) are visible, meanwhile iron arsenides (white) in dendritic form can be observed in the upper left section, they are embedded in matrix dominated by iron, arsenic and other elements (© Mehofer, VIAS).

trace element contents (Seeliger et al. 1985, 642 Tab. 2, Schmitt-Strecker et al. 1992, 112 Tab. 2; Hauptmann et al. 2002, 49 tab. 6; 56 tab. 9, 62). The data indicates a partial overlap with the lead isotope data gathered from ore deposits found in North-West Anatolia[7] but they do not correspond very well. Based on these observations it seems reasonable to look for the ore deposits in Western Anatolia, especially in the wider area around the site itself, as this was postulated by E. Pernicka and F. Begemann for Beşiktepe or by B. Marsh and U. Schoop for the site of Çamlibel Tarlası near Hattuša (Pernicka et al. 2003, 162; Begemann et al. 2003, 173). Geological mapping of the surrounding areas of the Çukuriçi Höyük allowed us to observe different metallic mineral deposits such as lead-, silver-, gold- and copper ores (Kaptan 2008, 249 Fig. 2; Lengeranlı 2008, 366 Fig. 1). This suggests that various ore deposits have been present in the wider neighbourhood of the site and might have provided the metal in prehistoric times. During the last years geological surveys have been carried out in co-operation with Danilo Wolf and Gregor Borg, University Halle to clarify whether the ore deposits were in fact exploited and mined (Wolf et al. 2012; Borg & Wolf 2012; Horejs 2013: 8).

Smelting debris

In addition to the rich metallurgical assemblage, the finds also included a small number of slag fragments and smelting debris from the Early Bronze Age layers. These stood out because they were heavier than other vitrified objects and had a brown colour. Comparable pieces in size and shape are known e.g. from Çamlibel Tarlası, Norşuntepe and were also mentioned for Liman Tepe and Bakla Tepe (Zwicker 1980: 17; Yalçin 2000; Kaptan 2008: 246, 250, Photo 5-8; Rehren & Radivojevic 2010: 208, Fig. 63a). The first analytical step involved examining polished cross-sections of these objects with an optical microscope and the scanning electron microscope[8]. The analyses of sample no. 07/368/6/501 showed, that three sections could be identified in the smelting debris. In the first section copper, arsenic, iron and sulphur were present as major elements, in the second section copper was the dominant element (Tab. 1-2) and in the third section arsenic had a higher concentration than copper or sulphur (Mehofer (in print)). The micrograph, taken at the junction between the second and the third section showed that copper sulphides in globular form were present, which can be identified as "matte". White dendritic inclusions were visible, which turned out to be iron arsenide (mainly as FeAs) or a so-called "speiss" (Fig. 6). They were embedded in a matrix in which arsenic and iron are the dominant elements (Mehofer (in print)).

Production of arsenical copper

The excavation at the Çukuriçi Höyük provided evidence that crucibles were heated in bowl- and "horse-shoe" shaped constructions (Fig. 3) in order to smelt and melt copper (crucible smelting). They were heated from above with the help of blow pipes. The initial archaeometallurgical analyses showed that remnants of copper sulphides and iron arsenides were present in the analysed smelting debris and in the vitrified sections of the crucibles. These results correspond very well with the results from the chemical analyses carried out on metal artefacts, where arsenical copper with sulphidic inclusions were detected. There is intense discussion on the production of arsenical copper and different scholars have argued for different methods (e.g., Heskel 1983; Rostoker et al. 1989; Lechtman & Klein 1999; Hauptmann et al. 2003: 211; Pigott 2008; Thornton et al. 2009: 314; Pernicka et. al. 2011, Rehren et al. 2012). The first option would be that an intentional or unintentional mixture of copper ores with arsenic-bearing minerals were smelted together. This particular smelting process, the so called "co-smelting", would produce arsenical copper in a single step. It is discussed for the Late Chalcolithic/Early Bronze Age sites of Tappeh Silak and other sites in Iran as well as it is postulated for the sites of e.g. Murgul, Eastern Turkey (Lutz et al. 1991). Archaeometallurgical research recently carried out on slags from Tepe Hissar, Iran or on slags from Arisman, Western Iran point to another option. These analyses provided evidence, that "speiss", an arsenic-bearing smelting product, was produced in a separate smelting process (Thornton et al. 2009, 311 Table 1, 313; Pernicka et al. 2011; Rehren et al. 2012) rather than within the copper smelting process. For the production of arsenical copper this arsenic-rich speiss then would have been melted together with copper or copper ore in a crucible.

The presence of copper sulphides and iron arsenides in separate zones in the afore mentioned smelting debris fits in with different interpretations. It is possible that during a "co-smelting" process the smelting conditions in the crucible were not suitable for oxidising the sulphur and therefore copper sulphides and other phases were formed. A different explanation might be that the copper ore or the separately produced speiss (deriving from an arsenopyritic ore) may still have contained a certain amount of sulphur[9] (Pernicka et al. 2011; Rehren et al. 2012), which then formed the copper sulphides during the smelting process. Both scenarios would produce the observed smelting debris but as the archaeometallurgical analyses on other slag fragments are still in progress no definitive assignments can be made (Mehofer (in print)). We may, nevertheless, state that arsenical copper was produced at the site itself.

Conclusions

The excavations of Early Bronze Age remains at Çukuriçi Höyük revealed two settlement phases with building complexes used as living quarters as well as workshops indicated by many bowl- and horse-shoe shaped furnaces and fireplaces and a large amount of equipment associated with the production of metal as well as characteristic domestic finds assemblages. Both settlement phases were dated by relative means to EBA 1 based on pottery typology, which was confirmed independently by radiocarbon dates ranging between 2900 and 2750 cal BC. It is also worth noting that these metal workshops were located in the presumed former centre of the tell, whereas similar workshops at contemporary Anatolian sites such as Norşuntepe, Tepecik, Arslantepe or Troy were situated on the periphery of their settlements (Müller-Karpe 1994, 30 Abb. 14; 34 Abb. 17; 37; 44 Abb. 24). The archaeometallurgical results not only helped to reconstruct the metallurgical innovations in Western Turkey during the first half of the 3rd millennium BC but also gave an interesting insight into the interaction and communication networks throughout that particular period (Mehofer (in print)). To date this site is the only place on the West Anatolian coast, where it could be proved by means of archaeometallurgical analyses that arsenical copper[10] was produced as early as EBA 1. Whether this smelting/production processes were carried out with an unintentional mixture of different ores or whether separetly smelted speiss was added to the copper will be in the focus of further research (Mehofer (in print)). The numerous moulds for rod ingots demonstrate that metal was collected and cast into different standard sizes on the tell, which then were possibly used for further exchange. In combination with the exceptionally large amount of tools and metal objects found, this allows us to postulate that the production of metal was not just carried out at a domestic level at this site. The immediate proximity of the tell not only to the sea but also to the Küçük Menderes River estuary underlines the possible function of this tell as a place for communication and exchange at the beginning of the Early Bronze Age 1. Finally, these results allow us to draw the conclusion, particularly in terms of the object made of the copper-silver alloy, that EBA Çukuriçi Höyük was firmly embedded in an interregional wide ranging social and technological network at the beginning of the 3rd millenium BC.

Acknowledgements

The authors want to thank E. Pernicka, CEZ Mannheim, T. Rehren and Loic Boscher, UCL Quatar for the useful hints and discussions.

Footnotes

1 Funded by the Austrian Science Fund from 2007-2011 (FWF-Project no. P 19859-G02;START Project Y 528-G19) and is currently financed by ERC (Project no. 263339) since 2011.

2 For topographical maps and digital models s. Horejs et al. (2011, 38-39 Fig. 4-5); Stock et al. 2011, 58 Fig. 1.

3 Concerning the botanical and zoological results see U. Thanheiser & A. Galik (2011), in Horejs et al. (2011, 50-60).

4 Former reports described 24 ovens; recently conducted follow-up excavations in 2011 could clear an uncertain context as the 25th oven in this area. We decided to use here the term oven instead of furnace, because we are convinced that these fireplaces were not only used for metallurgical operations, but also for other purposes.

5 While the ore deposits of Laurion are particularly interesting due to the lead and silver that took place there production (this is also mentioned for other deposits in the Aegean), researchers have repeatedly suggested that they were also used for copper mining. Concering the discussion of the copper mining potential in Lavrion see e.g. Gale et al. 1985; Pernicka 1987, 671, 702; Stos Gale 1992, 165; Pernicka 1995; Gale et al. 2004; Muhly 2005.

6 The ore deposits of Alihoca, Bakir Daği, Derealan-Bakır Çay, Ergani Maden, Eseli Maden, Gümüş, Gümüşhane-Hazıne Mağara, Helva Maden, Işık Dağ-Maden Boğazı, Karadağ, Karoli, Keban-Fırat Batı1, Keban-Bamaş, Keban-Kalhane, Keban-Keban Dere, Keban-Sirt, Kedak, Kısabekır, Kürtün Çayirçukur, Küre, Mamlis, Menteşe, Siirt-Madenköy, Sizma-

Bakırlık, Ortabaraka, Piraziz-Madenköy, Pirajman, Tekmezar, Tirebolu-Haşit Köprüibaşi, Yakadere-Tepeyurt Kıltençik Dere, Zankar. Seeliger et al. 1985, 641 Tab. 1.

7 This comprises the ore deposits of Avcilar, Balya, Camyurt, Doğancılar, Gümüşköy Kozcağiz, Serçeören Köy and Tahtaköprü. Begemann et al. 2003, 193 Tab. 4.

8 Optical microscope: Olympus BX 51; SEM–EDS: Zeiss EVO 60 XVP with an EDS system produced by Oxford Instruments (INCA 400). Accelerating voltage: 20kV, working distance of 9.5 mm, beam current 100µA, dead time between 30 and 40%. The stability of the beam current was verified by cyclical measurements of a cobalt standard. All results were normalized to 100% and are given as mass percentage. Mehofer & Kucera 2005; Bietak et al. 2007.

10 Other sites with of more or less contemporary dating are Almirzaraque (Spain); Arisman (Iran); Los Millares (Spain); Poros Katsambas (Crete); Shar-i Sokhta (Iran); Teppeh Hissar (Iran); Thornton et al. (2009, 309-310); Rehren et al. (2012).

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