Approaching Economic Spaces

METHODS AND INTERPRETATION IN ARCHAEOMETRIC CERAMIC ANALYSIS

Michael Meyer (ed.)

edition | topoi

BERLIN STUDIES OF THE ANCIENT WORLD

ARCHAEOMETRIC CERAMIC ANALYSIS has a long tradition. The work presented here by a research group of the Excellence Cluster *Topoi* focuses on the relationships between project design, methods utilized, and achieved results in focus. The concepts of the described projects were developed together in the group and are presented and discussed in a comparative way. Common to all of the projects was the question of economic spaces, which can be determined by means of ceramic analysis. Surprisingly often, the initial hypothesis of centralized production and broad distribution could not be verified – from the Neolithic to the Roman Empire, household production remains a prevalent model. It becomes consistently clearer that further results can only be realized via extensive intra-site analysis. An important methodological focus rests in the verification of the usefulness of portable x-ray fluorescence analysis. This method only makes sense from project to project; an ideal work flow for the application of pXRF technology is provided.

64 BERLIN STUDIES OF THE ANCIENT WORLD

BERLIN STUDIES OF THE ANCIENT WORLD · 64

EDITED BY TOPOI EXCELLENCE CLUSTER

Approaching Economic Spaces

METHODS AND INTERPRETATION IN ARCHAEOMETRIC CERAMIC ANALYSIS

Michael Meyer (ed.)

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliographie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

© 2021 Edition Topoi / Exzellenzcluster Topoi der Freien Universität Berlin und der Humboldt-Universität zu Berlin
Cover image: Wheel-thrown ceramics from Haarhausen, Ilm-Kreis, Landesamt für Denkmalpflege Thüringen (Photo: B. Stefan), superimposed with a plot of geochemical ceramic analyzes, Excellence Cluster Topoi by Małgorzata Daszkiewicz.

Typographic concept and cover design: Stephan Fiedler

Distributed by
Westarp Verlagsservicegesellschaft mbH

Printed by
Druckerei Kühne & Partner GmbH & Co. KG

ISBN 978-3-9819685-8-3
ISSN (Print) 2366-6641
ISSN (Online) 2366-665X
DOI 10.17171/3-64
URN urn:nbn:de:kobv:188-refubium-31150-8

First published 2021
Published under Creative Commons Licence CC BY-NC 3.0 DE.
For the terms of use of third party content, please see the reference lists.

www.edition-topoi.org

Dedicated to Gerwulf Schneider
for his 80th birthday

CONTENTS

1 Archaeometric Analysis of Ancient Ceramics: Approaching Economic Spaces – Introduction

Michael Meyer

The Cluster of Excellence 'Topoi – The Formation and Transformation of Space and Knowledge in Ancient Civilizations' approaches the interrelationship between space and knowledge in different fields of ancient societies. This book comprises results from a research group of the Cluster that uses archaeometric analysis of objects – mainly ceramics – to reconstruct production and distribution patterns in selected ancient societies. Its overall aim is to discuss the potential of archaeometric analysis for the identification of economic space.

Both categories, space and knowledge, are of great importance for this research. The distribution of ceramic products is a spatial one, it can be understood by reflecting the knowledge about the physical landscape, but also political and social space that might facilitate or obstruct the acceptance of the very objects. The technological knowledge of how to produce specific kinds of ceramic may have come from somewhere else in the course of innovation processes. It acquires the knowledge of where in the landscape the relevant resources can be found. These few aspects may show how the research of the group is connected with the overall research question of the cluster and how the cluster's research categories help to structure the research and yield new insights.

Economic activities and structures (not only) of ancient societies can be divided into those concerning production, distribution, consumption and dumping. The first two are in the specific focus of the group, whereas information about the last ones have to be taken into consideration to scrutinize whether the find spots of ceramics do reflect economic distribution or other processes. The group relies on a very broad concept of economy that integrates all sorts of motivations for production, as well as of motivations for the wish to own and use a certain ceramic vessel. It is, therefore, independent from aspects of profit-orientated production and distribution, and allows for the analysis of ritual objects, as well as for gifts and gift exchange and for household production, as well as for large-scale, specialized production and the trade networks connected to it.

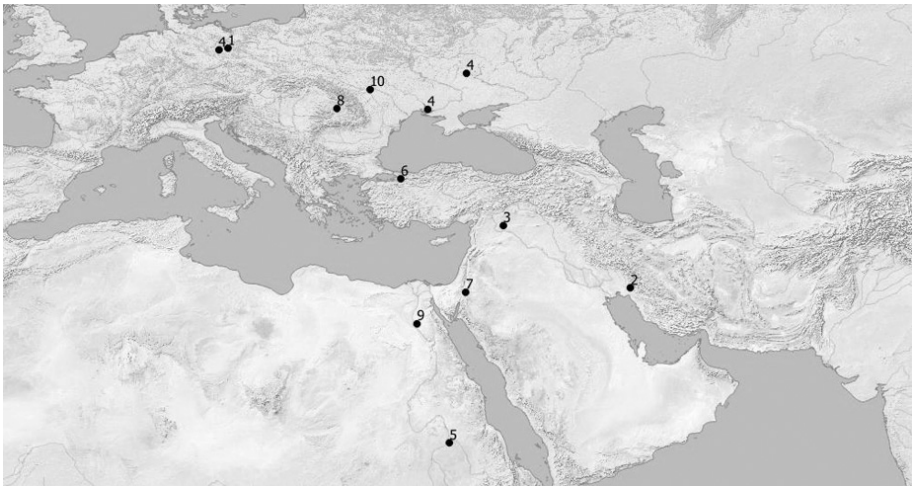


Fig. 1 Map of Topoi Projects A-6-1 to A-6-10: 1 Late Bronze Age *'Turbanrandschalen'* in and around the fortified site of Lossow; 2 The analysis of spheres of exchange in southern Iran; 3 Systems of pottery distribution from the Neolithic to the Islamic era along the Middle Euphrates Valley in Syria; 4 Wheel thrown pottery of the Roman imperial periods in northeastern Germany and the Ukraine; 5 Meroitic fine pottery: production, distribution, use (project 6 not mentioned in this volume); 7 Distribution and production locations of Nabataean ceramics; 8 Distribution of ceramics in the larger settlement of Cornești-Iarcuri and its settlement history; 9 Select pottery at Tell el-Amarna; 10 Glass working of the 3rd to 4th century AD in Komariv, Ukraine.

The research group assembles projects from different regions and periods within the old world (Fig. 1). It ranges from Neolithic Iran and Bronze Age Romania, Eastern Germany, El Amarna in Egypt, and the Syrian Euphrates Valley and integrates Nabataean and Meroitic ceramics as well as those of the Barbaricum in Roman Imperial times in East Germany and in the Ukraine. An additional project on glass analysis was used to test the methodology – especially pXRF – on another material and allowed for the comparison of the results on ceramics and glass.

Of course, this wide range of projects dealing with very different cultural and regional constellations cannot be compared with each other in a direct way – this is not the objective of the group. Instead, the comparative approach follows two different lines:

(1) Each of the projects requires a very specific sampling strategy to produce an optimal basis for the archaeometrical analysis. This is dependent on the archaeological site(s) and the specific conditions, on the one hand, and on the availability and applicability of different scientific methods, on the other hand. Sampling in a production site follows other requirements than a widely scattered settlement system; finds from large settlement layers will be sampled in a different way than finds from pits or from graves. It is important to note which structure and contexts the total of the ceramics have and

how this is related to an optimal sample. Is there the perfect – or objective – method to yield a representative sample?

The different scientific methods may vary according to the raw materials used, methods like portable XRF may appear to yield good results in one site, whereas no reliable results may emerge in another project.

The shared discussion of sampling strategies and their adaptation to the projects, as well as of the variety of methods applied, has emerged to be of great value. It allowed for a reciprocal profit of the experiences of the other projects and helped to sharpen the research approaches of the single projects. It was of particular value when enlarging projects, taking in new samples, and following specific and especially promising aspects of the preliminary results in the groups.

One focus of the methodology of the group was the recurrent application of portable XRF. The evaluation of the procedures and results led to a best practice guide for the application of pXRF in ceramic analysis.

(2) A simple one-to-one comparison of the results of the group does of course not make sense. The social, cultural, and economic structures underlying the different societies are too different, but it is in particular this great variety that makes a shared discussion of the structures of production and distribution very valuable. What does centralized production look like, and how can it be explained that a specialized production of wheel thrown pottery took place in every small village? Is there a difference between the production of settlement and grave ceramics, and how can it be explained? How can different distribution patterns of ritual vessels and of cooking and storage ware be identified and explained?

For the group, it was of great help to discuss the results that emerged from the different projects together and to be inspired by viewpoints that were developed in different social, economic, and cultural settings.

The book has five major parts. In Chapter two, the archaeometric methodology used in the projects is introduced and explained. Chapter three presents the categories that were developed in the discussions of the group and were applied to the projects and the interpretations of their results. Chapter four provides an overview of the projects and presents them according to their cultural and economic background and the research question, sampling strategy, and archaeometric methods applied and – as the case may be – their adjustment, along with the results achieved and the interpretation of the distribution patterns. Chapter five condenses the experiences collected in the research of the group for the conceptualization of a strategy for archaeometric ceramic projects and summarizes the results of the first comparative line provided above. Chapter six summarizes the experiences of the application of pXRF technique for ancient pottery analysis and presents important cautions that should be taken into account. Chapter seven discusses the methodology for interpretation and the identification of economic

space as made effective in the projects of the group, thus, it summarizes the results of the second comparative line.

The archaeometric analyses and their critical evaluation make up a large part of the volume. These are based on a long experience with analysis of ancient pottery at the FUB, starting in 1975 with the analysis of Roman terra sigillata. The studies later were extended to various groups of outstanding special pottery: Hellenistic to Late Roman black and red gloss fine wares in the Mediterranean, 3rd millennium North-Mesopotamian stone ware ('Metallic Ware'), Assyrian pottery and Brittle wares in Syria, and to pottery from the Neolithic to Meroitic periods in the Sudan. A database of nearly 40 000 analyses by WD-XRF has been generated and will be part of an Open Access databank. The experience with the classification by refiring (MGR-analysis) now is based on some 13 000 examples. An important experience of the various projects was that the methodology sometimes has to be changed during the course of the analyses. The results sometimes raised unforeseen new questions. This also means that the strategy in the lab cannot be fixed *a priori* and has to include control analyses using alternative independent methods. This is especially true for using more or less non-destructive chemical analysis like pXRF or LA-ICP-MS which are limited to very thin surface layers and, thus, do not represent the bulk composition of the body of a sherd as a powder produced after removing any surface layers does. Numerous archaeometric publications show that not all authors are aware of the significance of precision and accuracy, of the complexity of pottery composition, of the difficulties of interpreting chemical groups, and of the necessity of control analyses. The aim of our book is to demonstrate examples of combined laboratory methods used to solve archaeological questions.[1]

This book allows the reader to follow the setup and the development of archaeoceramological projects in diverse cultural, spatial, and temporal settings. Thus, the focus automatically shifts away from the individual projects and their results to a comparative evaluation of methods, results, and interpretations. This makes the volume unique. We hope that it offers an incentive to reconsider archaeometric ceramic approaches.

1 For an overview on the methodology see Hunt 2017.

2 Categorization Criteria for the Individual Projects of the Research Group A-6

Antonia Höhne (ehemals Hofmann)

The individual projects of the research group are all concerned with the superordinated subject of the analysis of economic structures, respectively, their reconstruction on the basis of archaeological, primarily ceramic find material. An essential link between the research projects is the approach to use archaeometric analysis methods.

In 2015, inspired by reading and discussing an article by Cathy Costin[1] and an additional article by Carla Sinopoli,[2] both published in 1991, a first attempt was made to link the methodological approach of the research group with common theoretical models for the analysis and interpretation of ceramics, in terms of the reconstruction of economic activities, and to present them schematically. The initially created scheme was regularly discussed in the research group and further developed. In this chapter, the result of this debate will be presented. In the sense of a middle-range theory,[3] this draft scheme should not be regarded as rigid, but merely provides a basis for discussion for the individual projects.

Figure 1 shows the simplified scheme, which can be considered as a kind of flowchart. It is mainly divided into three parts and a fourth column containing unanswered questions. The details of the columns can be studied in Figures 2, 3, 4, and 5.

Based on a research question that was developed on the basis of the available material, selected natural scientific analysis methods[4] are applied in order to yield results about production and distribution systems (see Fig. 2). The range of methods for characterizing ceramics, as described in detail in Chapter 3 of this volume,[5] can provide interpretable results in terms of raw materials and provenance, manufacturing technique,

1 Costin 1991.
2 Sinopoli 1991, 83–117.
3 A term introduced by Robert K. Merton in 1962 for theories that are intended to contrast with universal theories, that is, adaptable to new knowledge.
4 Within the research group, chemical analysis by pXRF and WD-XRF, MGR-analysis, determination of physical ceramic properties, and thin-section studies are mainly used.
5 See chapter 3.

physical ceramic properties, and functional properties. Statements about context and chronology are usually made using archaeological methods, such as classification (vessel shapes, decoration, and technological characteristics), analysis of excavation features or survey patterns (settlement archaeology, social archaeology), environmental archaeology research, and archaeological and scientific dating methods. Of course, hypotheses play an important role, which can be verified or falsified by the analytical process. Already at this point, scales of variability turn out to describe uniformity or diversity of the material, which can be captured by the quantitative recording and statistical analysis of the analysis data.

In order to be able to reach the interpretive level, certain aspects must be taken into account that complicate or influence both the evaluation of the results of the scientific and archaeological research methods and their interpretation; a source critical consideration of the material to be analyzed helps to avoid methodological pitfalls (see Fig. 3). This column, 'source filter' in the scheme, has been divided into three categories: first, general aspects of the sampling strategy; secondly, aspects concerning the research strategy and thirdly, methodological considerations. On the one hand, the sampling strategy includes the survey or excavation strategy at the site and, on the other, the strategy of selecting the samples for the analysis. Already while executing the survey or excavation, the selectivity of the selection of different site types, the quality of the documentation and the context information can affect a later analysis and the quality of the results.

Regarding the strategy of the sample selection for the analysis, factors such as subjective object selection, the representative fragment size (depending on the degree of fragmentation), concentrations and distribution of fragments, the total number of fragments, selection by shape and/or function, the dating of the fragments, the sampling location of the fragments and type, the representative number of samples, and whether there is clear evidence about typology, chronology, and context of the samples should be considered.

Aspects that can lead to problems within the research strategy include the question of how to deal with the lack of the above mentioned information, the research setting, or the available financial resources for analysis and the possibly insufficient state of research and material accessibility. Fundamental methodological considerations may concern the inaccuracy of the applied method itself, contamination caused by alteration during the deposition in the ground, the conservation status of the objects and the geological conditions of the study region, which could affect the composition of the raw material. In addition, wrong archaeological classifications, for example, due to taphonomical processes, could influence the interpretation of the data and even the sampling strategy itself.

Not only the state of the sources, but also more general aspects such as topographical conditions in the study area, individual outliers, spatial scale levels, and the possibility

that different forms of production and distribution systems may exist at the same time should be considered before applying the results on the basis of theoretical premises.

As already mentioned above, the theoretical part of the scheme for interpreting the knowledge gained through the study of the material is based on the work of Costin and Sinopoli, which in turn is based on a work of van der Leeuw from 1977.[6]

The theories elaborated by the authors mentioned are based primarily on empirical data, which is why a constant adaptation of the theory model is required. The research group has used the theory model of Costin as an opportunity to make a proposal based on their own experience from various research projects for the further differentiation and classification of the manifestation and organization of production in the theory model. It is inherent in the theoretical scheme for the reconstruction of economic organization that certain aspects of economic activity and even the organizational form of the respective society can be inferred from concrete results in the examined material. The considered categories are set according to their dependence on one another (see Fig. 4).

The main categories for the production and distribution of ceramic objects (technology, standardization, specialization, labor time, production system, and distribution as well as the socio-political and economic context of the producing society) discussed by Costin and expanded by the research group, were divided up unanimously into three interpretive levels. The first level includes concrete assumptions about the technology used in the manufacturing process of ceramics. This level is the most tangible archaeometrically (colored in violet in the column). As with the other categories of the various levels of interpretation, first of all, partial aspects, called 'attributes' by the research group, are shown (in this case ovens, firing temperature and hardness, manufacturing, and raw materials such as clay, temper, and fuel).

These are scaled in a further step, this means extremes are determined between which the material is to be classified. For example, poles for the firing temperature are set as low and high. These technological properties, which can be registered very well with the natural scientific investigation methods, can then be correlated with scalings of higher interpretation levels.

The next higher level 'interpretation' includes aspects such as standardization, specialization, labor time, production system (again divided into organization and system), and the aspect of the spatial distribution (including trade, redistribution, and donations[7]) of products.

Thus, ceramics fired at low temperature can both indicate, in the first category, 'technology', a specialized production for a certain function (e.g. cooking pots) and

6 Van der Leeuw 1977.

7 For further detailed aspects of distribution see Rice 2005, 193, and Renfrew 1984.

– depending on the material as well – a different level of firing technology. Further scientific analysis can be carried out to prove these assumptions.

Since, as already discussed above, not only the state of the sources per se can be regarded as uncertain, the conclusion on complex economic processes (named 'meta-level' in the scheme) based on the tangible technological characterizations of the material is all the more problematic.

The model seems to be rigid in itself, leaving little room for scenarios in which, for example, various forms of production can exist simultaneously within a settlement. Also, it is, e.g. not mandatory that a high population pressure leads to complex production processes or is the expression of it. It could be the opposite expressed by the repression of production activities. Thus, the individual projects of the research group (see Chapter 4) will illustrate whether the scheme is appropriate or not. It seems necessary to continue to develop the model and to examine, question, and adapt it with concrete examples.

As one example, it should be noted that for every project the term 'workshop' has to be defined individually. On the one hand, it could be understood, as proposed in chapter 5 of this volume, as where the materiality of labor is in focus. On the other hand, a more broadly ranged definition regarding the production settings could be accommodated in the term 'workshop'. The term 'workshop' was not explicitly discussed or considered by the above-mentioned authors, upon which the model is based. That is the reason why I recommend to add another category named 'location of production' with the attribute 'workshop' as used by Daszkiewicz[8] and the scaling poles 'flexible/mobile' and 'inflexible/immobile'. That means, the more complex production techniques for tools become, the more inflexible the producers are to move to another place and, therefore, could only transport their knowledge, but not necessarily their equipment. The question is, if the latter conclusion should be assumed only for a complex society.

Fortunately, there are many other questions as well (e.g. where to put categories like consumption, function of vessels, etc. that are not scalable?, see Fig. 5) that were raised during the discussion of the presented model, which demonstrate the generative and interested exchange within the research group A-6.

8 Daszkiewicz 2014, 184.

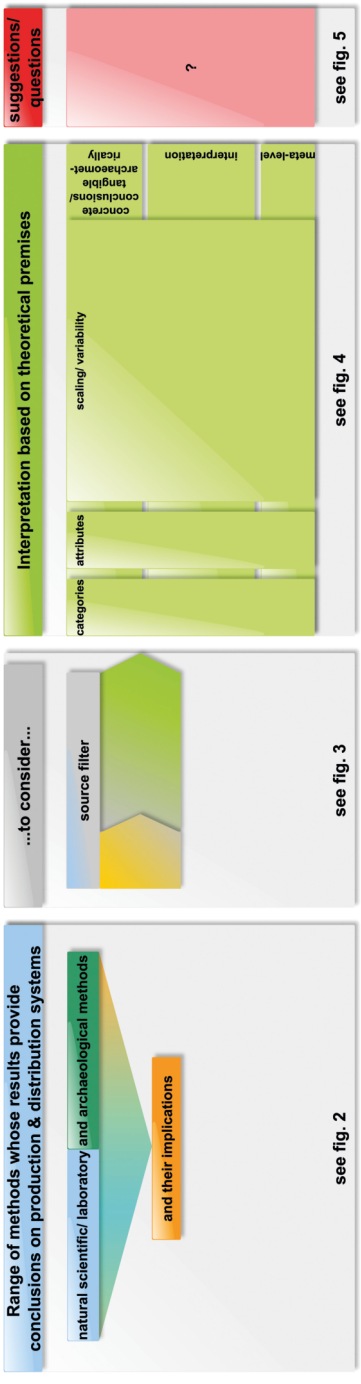


Fig. 1 Simplified representation of the scheme.

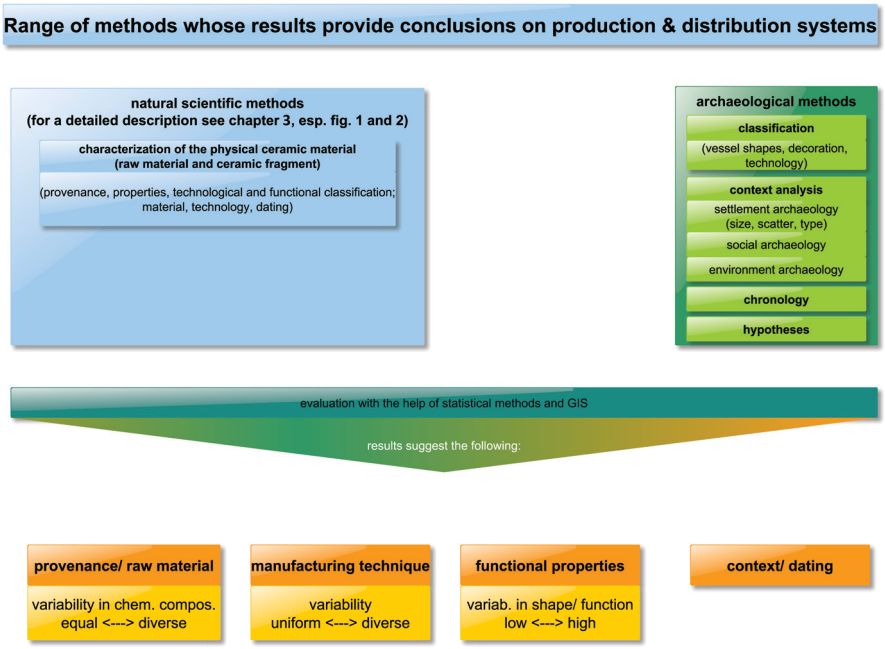


Fig. 2 Column 1: methods.

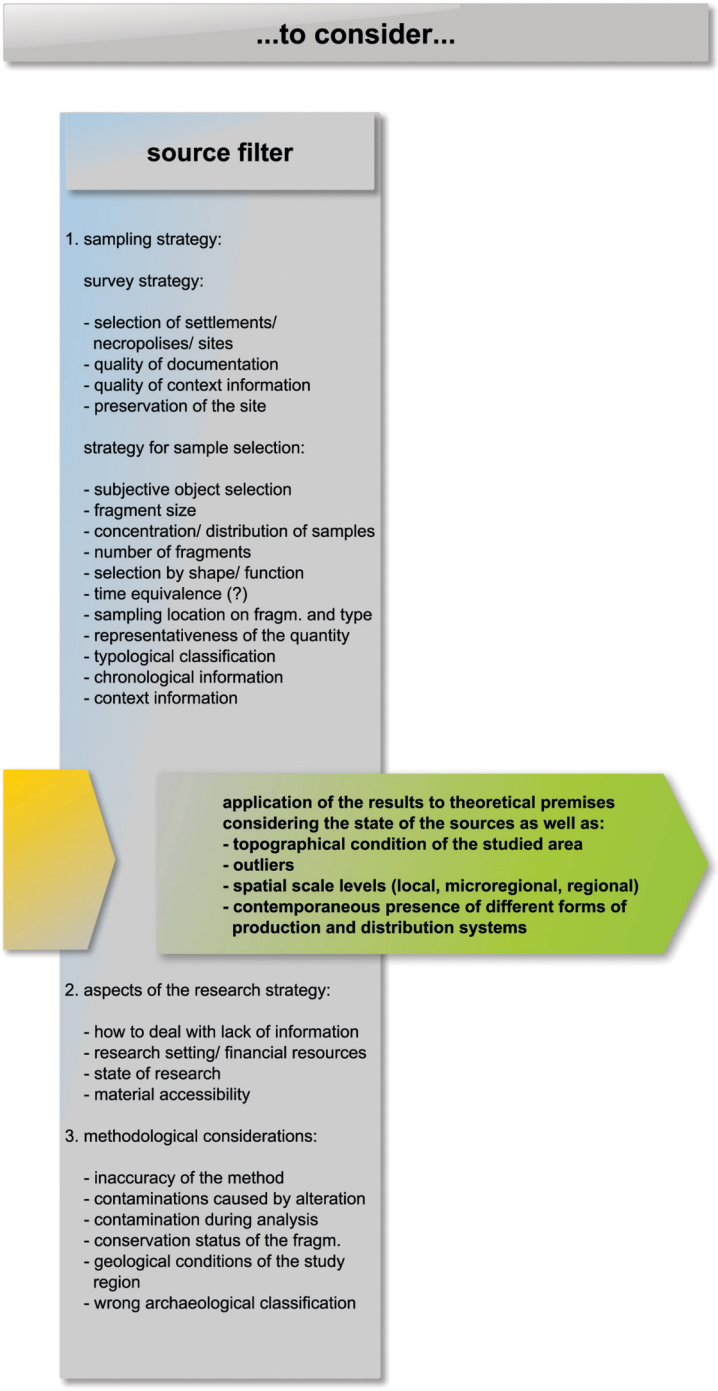


Fig. 3 Column 2: source filter.

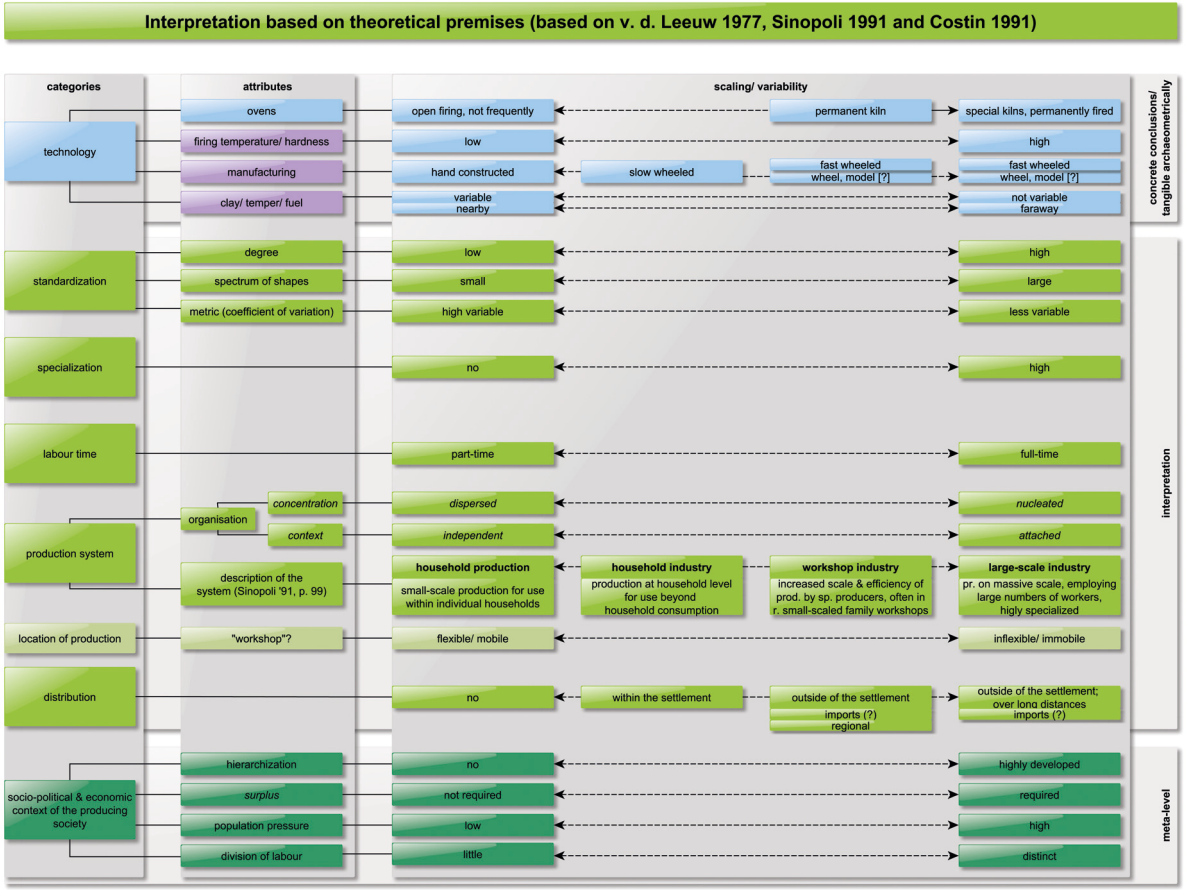


Fig. 4 Column 3: interpretation.

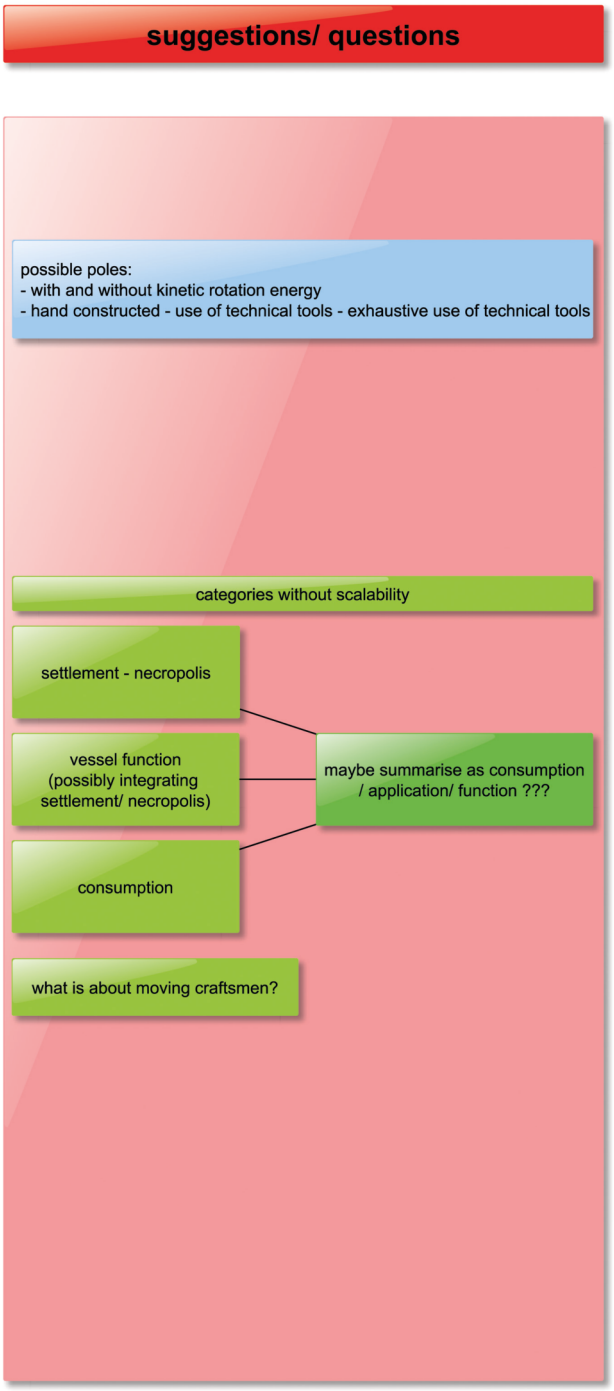


Fig. 5 Column 4: questions.

3 Analysis of Archaeological Ceramics

Małgorzata Daszkiewicz and Gerwulf Schneider
(in cooperation with Ewa Bobryk)

3.1. General information

Archaeological ceramic analysis, sometimes also referred to as archaeo-ceramology, is a narrow specialism within archaeometry[1] that deals with the comprehensive study of archaeological ceramics.[2] It includes analysis of the chemical, mineralogical, and petrographic composition of ceramics as well as assessments of their technological and functional properties. Until recently, there were only a limited number of research centers and researchers working in this discipline. A new book on archaeological ceramic analysis[3] summarizes papers covering the field discussed herein, including the history of such studies. Traditionally, archaeometric studies of pottery have focused on the chemical or mineralogical/petrographic composition and dating of sherds.

The first chemical analysis of archaeological pottery was carried out in 1932 by A. Levi.[4] He examined the differences in chemical composition between imported and local Greek pottery discovered in Apulia (Italy). In the late 1950s, E. Sayre and A. W.

1 Archaeometry is a scientific discipline focusing on the development and application of physico-chemical, as well as mathematical and natural scientific methods, to find answers to cultural and historical questions posed by archaeologists and historians. Archaeometric analysis is used to examine a wide variety of artefacts (manmade objects) and natural products recovered from excavation sites.

2 Ceramic material = inorganic non-metallic material formed from a raw material at room temperature and converted into a permanent solid mass by firing. Various materials are used to make contemporary ceramics. However, archaeological ceramics were made predominantly of aluminium-silicates and silicates, as well as raw materials with high levels of carbonates (clayey marls or marly clays). Only a small percentage of archaeological pottery consists of oxide ceramics (i.e. quartz ceramics). It must be remembered that in Anglo-Saxon terminology the word 'ceramics' can also encompass glass, enamel, and glass-ceramic, as well as inorganic cementitious materials (cement, plaster, and lime).

3 Hunt 2017.

4 Levi 1932.

Dodson (Brookhaven National Laboratory, USA),[5] and later I. Perlman and F. Asaro (Berkeley, USA)[6] began analyzing the chemical composition of ancient pottery using NAA (Neutron Activation Analysis). At the same time, M. Picon (Lyon, France)[7] first performed chemical analysis using the WD-XRF technique (wavelength-dispersive X-ray fluorescence). Meanwhile, in Oxford (England) analysis was being undertaken using OES (Optical Emission Spectroscopy), which was later replaced by AAS (Atomic Absorption Spectrometry and ICP-AES) by H. Thatcher. In 1975 the Arbeitsgruppe Archäometrie was set up in Berlin, where G. Schneider began analyzing archaeological ceramics using WD-XRF,[8] compiling what has now become one of the largest databases of archaeological ceramics in Europe. The data were checked to be fully comparable with those of M. Picon (Lyon, France) and those of the lab of M. Maggetti (Fribourg, Switzerland).[9] After joining forces with M. Daszkiewicz, their respective databases were merged in 1997 to create the joint Schneider-Daszkiewicz database, currently logging the analysis results for 36 000 samples – mostly of ceramic artefacts as well as clays, plasters, glazes, and glass finds. OES and AAS are no longer used these days, having been supplanted successfully by ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry) and ICP-MS (Inductively Coupled Plasma – Mass Spectrometry). For some years now, non-destructive analysis of chemical composition has been possible using portable equipment for ED-XRF (energy dispersive X-ray fluorescence), usually referred to in abbreviated form as pXRF, but there are severe limitations in the number of elements identified and the precision and accuracy of data yielded using this technique. In addition to numerous laboratories using NAA for ceramic analysis, at some centers chemical composition is determined by PIXE (Particle Induced X-ray Emission Spectrometry), TOF-LA-ICP-MS (Time-of-flight-laser ablation-inductively coupled plasma-mass spectrometry), or PGAA (Prompt Gamma Activation Analysis).

The optimum technique for analyzing chemical composition is one that identifies *all of the major elements*[10] in the ceramic sherd (Si, Ti, Al., Fe, Mn, Mg, Ca, Na, K, and P) and as many *trace elements*[11] as possible. WD-XRF and ICP-OES are the most suitable techniques to achieve these aims. ICP-MS is ineffectual when the content of elements

5 Sayre and Dodson 1957.

6 Perlman and Asaro 1969.

7 Picon, Vichy, and Meille 1971.

8 G. Schneider 1978.

9 Galetti 1994.

10 Major elements are elements that occur in a sample in concentrations exceeding 0.1%. In chemical analysis of pottery sherds, Mn is also considered a major element despite the fact that its concentration in such sherds is usually below 0.1%. Some classifications identify both major elements (those whose content is > 1.0%) and minor elements (elements that occur in concentrations of 0.1–1.0%).

11 Trace elements are elements that occur in a sample in concentrations below 0.1% = 1000ppm. In ceramic sherd analysis, trace elements also include elements that usually occur in the sherd in trace quantities and only occasionally in quantities of > 1000ppm, which is usually attributable to the alteration effect (e.g. high Ba content) or to the surface treatment of the sherd (e.g. higher Pb levels occur in samples of lead-glazed pottery).

exceeds 1%, while not all major elements can be determined using NAA, or can only be determined with poor precision. Table 1 provides details of the major elements (elements in bold in Tab. 1) normally identified in archaeological ceramics. The first column lists elements determined at the Arbeitsgruppe Archäometrie, FU Berlin, using the WD-XRF technique.[12] The second column details chemical analysis by NAA as usually carried out by H. Mommsen in Bonn, while the next two columns refer to chemical analysis by ICP-OES and ICP-MS, respectively. The latter data were taken from the report on analysis of a certified international ceramic reference material (SARM69 = ceramic 1).[13] The NAA technique is also used by laboratories for determining short-lived nuclides (e.g. SLOWPOKE, Toronto, or Atominstitut Vienna), thus, they were able to determine the content of a greater number of elements than H. Mommsen in Bonn.

As has already been stated, chemical analysis is also carried out to determine *trace element concentrations*. An example of trace elements determined by Schneider and Daszkiewicz and by Mommsen in archaeological ceramics[14] are given below (elements in parentheses are determined with poor precision).

WD-XRF (Schneider and Daszkiewicz, Berlin): Ba, Ce, (Co), Cr, (Cu), (Ga), (La), Nb, Ni, Pb, Rb, Sr, (Th), V, Y, Zn, and Zr (the concentration of further elements such as Sn, Cs, Hf, Nd, Sc, and W can also be determined in samples featuring high trace levels of these elements, which normally do not occur in archaeological ceramics). Measurements in Berlin are performed on molten discs of previously ignited powder samples.

NAA (Mommsen, Bonn): (As), Ba, Ce, Co, Cr, Cs, Eu, Ga, Hf, La, Lu, Nd, (Ni), Rb, Sb, Sc, Sm, (Sr), Ta, Tb, Th, U, W, Y, Zn, and (Zr). Measurements are of non-ignited powder samples removed using a sapphire drill. A comparison of the potential of the two methods was made using analyses of samples of Eastern Sigillata C from Pergamon and Čandarlı, Turkey.[15]

12 From 1975 to 2008 (Philips PW1212, PW1400). Since 2008 measurements have been carried out (using our own calibration) at the GeoForschungsZentrum (GFZ) in Potsdam using PANalytical AXIOS with the kind permission and support of A. Gottsche, R. Nauman, and A. Schleicher.

13 Marsland and Oosthuysen 2001. SARM69 was prepared and distributed by MINTEK (Council for Mineral Technology, Republic of South Africa). A quantity of 80 kg was prepared from Iron Age clay potsherds found at a site in Orange Free State (three mineral phases are present in SARM69: quartz, feldspar, and muscovite).

14 Archaeological ceramics made from natural clay or loam vary in their chemical composition only within certain limits and are not very different from the mean composition of the earth's crust.

15 G. Schneider and Mommsen 2009.

Element	WD-XRF FU-Berlin	NAA Mommsen	ICP-OES SARM69	ICP-MS SARM69
Li			(x)	(x)
Be			(x)	(x)
B			(x)	
C				
Na	x	x	x	
Mg	x		x	
Al	x		x	
Si	x		x	
P	x		x	
S	(x)		x	
Cl	(x)			
K	x	x	x	
Ca	x	x	x	
Sc	(x)	x	(x)	(x)
Ti	x	(x)	x	
V	x		x	(x)
Cr	x	x	x	(x)
Mn	x		x	
Fe	x	x	x	
Co	(x)	x	x	x
Ni	x	(x)	x	x
Cu	x		x	x
Zn	x	x	x	x
Ga	(x)	x	x	x
Ge				(x)
As	(x)	x	(x)	x
Se				(x)
Br				
Rb	x	x		x
Sr	x		x	x
Y	x		x	x
Zr	x	(x)	x	x
Nb	x		x	x
Mo				x
Ru				(x)
Rh				
Pd				(x)

Element	WD-XRF FU-Berlin	NAA Mommsen	ICP-OES SARM69	ICP-MS SARM69
Ag			(x)	
Cd			(x)	(x)
In				
Sn	(x)		(x)	x
Sb		x	(x)	x
Te				(x)
Cs		x		x
Ba	x	x	x	x
La	(x)	x	x	x
Ce	x	x	x	x
Pr				x
Nd	(x)	x		x
Sm		x		x
Eu		x		x
Gd				x
Tb		x		x
Dy				x
Ho				(x)
Er				(x)
Tm				x
Yb		x		x
Lu		x		x
Hf		x		x
Ta		x		(x)
W		x		x
Re				
Os				
Ir				
Pt				(x)
Au				(x)
Hg				
Tl				
Pb	x		x	x
Bi				(x)
Th	(x)	x		x
U		x		x

Tab. 1 Techniques of chemical analysis used for archaeological pottery.

As well as being capable of determining a large number of elements, chemical analysis should be carried out with high precision and accuracy. Comparing the coefficients of variation between various laboratories and techniques indicates that WD-XRF is the best technique for determining all major elements, with the possible exception of low concentrations of sodium (data from the SARM69 report). It is also easy to store prepared samples after measurement and to perform repeat measurements years later.

When analyzing archaeological ceramics, it is essential to compare new results with those obtained from samples analyzed many years earlier, thus, not only is measurement precision critical (as acknowledged by all analysts), but it is also vital that laboratories check their long-term precision. If long-term precision is assured, this guarantees that newly analyzed samples will not be erroneously classified.

For example, the chemical composition of terra sigillata produced in Lezoux was determined in 1976–1978 by G. Schneider from 15 sherds found in Heidelberg.[16] It was compared to the mean of sherds found at several other sites – sherds deemed to have come from workshops at Lezoux based on their chemical composition. The comparison examined seven sherds analyzed between 1995 and 2005 and 13 sherds analyzed between 2011 and 2016 using the same analytical procedure. The results turned out to be entirely consistent with the Lezoux reference group established in 1978, except for sodium, strontium, and zirconium (some trace elements were not determined in 1976–1978) (Tab. 2). This demonstrates that it is possible to draw direct comparisons between the results of pottery samples analyzed over a period of 40 years (!) despite the fact that measurements were performed using three different spectrometers (see footnote 12). This is due to very good long-term precision resulting from the use of the same sample preparation procedure[17] and thanks to repeated calibrations based on more than 30 CRMs (Certified Reference Materials) for geochemical analysis, covering the whole range of possible concentrations in archaeological ceramics.

Another technique increasingly used in chemical analysis of pottery is pXRF. As with all analytical techniques, it has its pros and cons. The limited depth of information (below 0.1 mm) of the long-wave X-rays means that the irradiated surface area does not represent the bulk composition of the ceramic body and, generally, energy-dispersive XRF is not especially appropriate for the analysis of the light elements that occur in ceramics, as opposed to the heavy elements that occur in metals. Precision and accuracy of data is worse than with other techniques. The possible measurement of the bulk composition of sherds without taking representative powdered samples causes additional

16 G. Schneider 1978.

17 Samples for measurement are currently prepared for analysis by ARCHEA (Warsaw) using the same procedure that has been used since the 1970s by the Arbeitsgruppe Archäometrie, FU Berlin (a similar procedure is used at most geochemical laboratories).

problems. Although due to these limitations chemical analysis by pXRF is not particularly useful in provenance studies of pottery, it can be used to great effect to rapidly classify large pottery assemblages and to analyze ceramic vessel surfaces. The application of pXRF analysis can yield results that reveal details about intentional pottery surface treatments and also about any alteration processes on surfaces. Furthermore, model tests have shown that pXRF results can detect the use of gypsum molds[18] or the use of vessels to produce or transport salt.[19] It is worth remembering that, as some analysts have observed, when analyzing ceramics the results of pXRF measurements should be treated solely as qualitative and not quantitative. Daszkiewicz and Schneider partially agree with this view. Based on their own experience gained from several years of using pXRF in the analysis of archaeological ceramics, they have concluded that identified elements can be divided into three groups: elements identified solely qualitatively, elements that can be identified quantitatively (depending on the type of pottery),[20] and elements identified by chance, i.e. either qualitatively or not at all despite occurring in a given sample, even at high concentrations (e.g. Mg).

Analysis by LA-ICP-MS is also becoming increasingly popular because of the sampling method involved (laser ablation). However, given that only a very a small area of the sample is analyzed, the use of this technique in ceramic provenance studies is limited, like when identifying chemical composition by pXRF, despite the lower detection limit.

18 Daszkiewicz and Bobryk 2013.

19 Daszkiewicz and Bobryk 2014 and chapter 4.4 in this volume.

20 Most often: Fe, K, Rb, Nb, and Zr – see Chapter 6 in this volume.

averages, standard deviation	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	Ce	Pb
	per cent by weight										ppm												
2011-2016 (n=13)	57.47	0.784	21.25	5.48	0.070	1.19	10.05	0.13	3.49	0.359	90	85	37	22	141	295	337	26	185	21	494	92	50
std±	1.73	0.021	0.56	0.25	0.013	0.08	1.79	0.03	0.26	0.174	6	5	3	6	13	14	28	5	14	2	52	14	15
1995-2005 (n=7)	56.18	0.756	21.48	5.45	0.078	1.26	10.77	0.26	3.45	0.324	94	90	40	25	128	270	303	28	144	27	463	93	40
std±	1.24	0.021	0.50	0.16	0.009	0.17	1.30	0.07	0.20	0.079	7	5	5	4	12	10	18	2	13	3	78	7	5
1976-1978 (n=18)	**56.70**	**0.780**	**21.40**	**5.33**	**0.074**	**1.13**	**10.60**	**0.34**	**3.40**	**0.280**	**-**	**82**	**35**	**26**	**144**	**284**	**307**	**-**	**150**	**-**	**506**	**-**	**-**
std±	2.04	0.043	0.68	0.33	0.016	0.14	1.80	0.07	0.19	0.218	-	5	3	4	25	17	40	-	20	-	86	-	-

Tab. 2 Chemical analysis of sigillata reference group Lezoux (means and standard deviations) by Arbeitsgruppe Archaeometrie 2016 compared to analysis results from 1978.

A few points should be made about the special case of chemical analysis of archaeological pottery as it is used in our lab. The first concerns sampling of a representative powder. The precision of sampling depends on the grain size and on the inhomogeneity of the material. Therefore, the sample size required does not depend on the analytical method used and it should be tested by analyzing different parts of a ceramic vessel. Alteration effects can have a significant impact, therefore, the layer to be removed before powdering a ceramic fragment should not be too thin.[21] Sample sizes and alteration effects must also be taken into consideration when powder samples are taken by drilling. The advantage of having analyzed all major elements (calculated as oxides) is that the sum should be 100% if sulphur is negligible and iron is oxidized, as it will be in samples ignited in an oxidizing atmosphere. Normalizing the sum to a constant 100% improves the precision of major elements (in our analysis results the original total is indicated) and it reduces differences between samples that are due to different losses on ignition (thus, analyses of non-ignited samples and of raw clay can be compared directly). Due to the less precise analysis of trace elements, these differences are normally not taken into account.[22]

Chemical analysis is an important part of archaeo-ceramological research; however, it has to be remembered that ceramic fabrics are not homogeneous. Pottery is made by forming and firing a ceramic body. This ceramic body consists of two basic components: a plastic component (clay minerals, carbonates, and other minerals represented by particles less than 10µm in size) and a non-plastic one (all clastic ingredients with a particle size of more than 10µm – mineral grains (e.g. grains of quartz, feldspars), fragments of crushed minerals or rock and microorganisms, phytogenic substances, dung, chaff, grog). The plastic ingredients bind the ceramic body and make it pliable. The non-plastic ingredients can be divided into tempers (which reduce shrinkage of the ceramic body during drying and firing) and, rarely, fluxes (which lower the sintering/melting temperature).[23] The non-plastic constituents can be authigenic or allogenic in the plas-

21 G. Schneider 2017.

22 Statistical interpretation of analyses done by NAA mostly consider the discussed effects by regarding losses on ignition and different amounts of quartz or calcite temper, like dilution effects. A factor is subsequently calculated for a best fitting of the analysis results to the average of the respective group (see, for example, chapter 4.2.1 by Nehls, Seyfried, and Mommsen in this volume).

23 Substances used as fluxes in contemporary commercial or studio ceramics should not be confused with the fluxes that were available to ancient potters. Neolithic potters, for example, could not have been expected to use fluxes consisting of chemical substances produced in the laboratory. Ancient potters used naturally occurring materials. It must also be remembered that fluxes act as fluxes within specific temperature ranges (for a given flux) and when they are of the appropriate grain size fraction. Feldspars, for example, which are widely recognized as fluxes, behave like temper during the initial stage of firing a plastic mass, and it is only at higher temperatures (temperature as high as the softening temperature) that they act as a fluxes (Płoński 1963, 213) – and ancient pottery was seldom fired at temperatures that exceeded the softening point. Furthermore, the size of grains seen in most ancient ceramics would have merely resulted in a so-called "fly effect". Prudence

tic raw material (so-called natural temper) or else they may have been intentionally added as a temper to improve the ceramic body's workability or the vessel's functional properties. During the firing process, the plastic part of the body hardens resulting in the non-plastic ingredients becoming embedded in a non-plastic matrix. Thus, analysis of ceramic artefacts must examine both the composition of the matrix (which will provide information about the plastic raw material used) and the non-plastic ingredients. It is important to analyze both of these components of the ceramic body because of the range of potential variations when using plastic and non-plastic ingredients; for example, the same clay can be used with different intentionally added tempers, or different clays can be used with the same temper.

The composition of a ceramic matrix includes phases produced by the thermal decomposition of clay minerals. This can pose certain problems when analyzing the matrix. Clay minerals that have not undergone thermal processes are analyzed using methods such as X-ray diffraction (XRD) and thermal analyses (TG, DTA, DTG) or electron microscopy. In the case of archaeological ceramics, these methods are usually of little use in determining matrix types given the most commonly used range of firing temperatures. Figure 1 shows diffractograms of ceramic raw material specimens[24] and of briquettes made from these materials and fired at various temperatures ranging from 400 to 1200°C. In this instance, the principal clay mineral is kaolinite. After firing at a temperature higher than the temperature at which the dehydroxylation of kaolinite takes place,[25] its reflections disappear. This is why lines associated with kaolinite do not appear in diffractograms of sherds fired at the most commonly encountered temperature range (Fig. 1). New phases such as mullite and crystoballite only appear at higher temperatures.[26] In this situation, analysis of the matrix and classification of archaeological ceramic sherds by the type of clay minerals present within the ceramic body must be based on a different type of analysis – one which enables the type and quantity of clay minerals to be estimated indirectly. The optimal solution appears to be to combine

M. Rice (Rice 1987, 94) wrote: "Besides feldspars, many naturally occurring materials or impurities in clays can act as fluxes in the body or slip if they have extremely small particles". A more common substance that can act as a flux at low temperatures (i.e. between 800 and 900°C) is iron (Searle and Grimshaw 1960), and iron compounds occur naturally in suitably small particles in clays. However, it must be remembered that the temperature level also depends on the firing atmosphere, both the atmosphere outside and inside the fired ceramic object (the latter is associated with the phase composition of the ceramic body). However, even this temperature range is higher than the original firing temperature of many archaeological pottery fragments. This is also true for calcia (CaO, after calcite decomposition) which is only working as a flux for stone wares or for glazes.

24 Unfired production debris found in Musawwarat (see chapter 4.3 by Näser et al. in this volume).

25 Briquettes fired below the dehydroxylation temperature of kaolinite disintegrated immediately after being immersed in water. This means that this temperature could not have been used to transform the clay into pottery.

26 After thermal decomposition at c. 550°C kaolinite is transformed into an amorphous phase metakaolinite and therefore the reflexes originating from this mineral 'disappear' from the diffractogram.

MGR-analysis (see below) with rational analysis,[27] i.e. analysis of the rational composition or, in other words, the hypothetical minerals that make up a given raw material determined on the basis of its chemical composition presented in the form of oxides.

A standard package of basic analyses used by the team of M. Daszkiewicz, G. Schneider, and E. Bobryk to investigate both the plastic and non-plastic components of ceramic bodies and the chemical composition of the two in combination encompasses: MGR-analysis (abridged or full),[28] chemical analysis by WD-XRF, and thin-section studies. This suite of analyses has also been used to study samples for the TOPOI projects.

Each of these analyses is carried out for a different purpose:

– MGR-analysis (Matrix Group by Refiring[29]) is used to determine the type of ceramic matrix. Matrix types can be identified using this analytical method because of the fact that the thermal behavior of the plastic components during firing is governed by their chemical and phase composition.[30] This analysis involves refiring ceramic fragments in controlled, standardized conditions[31] at a higher temperature than that of the original firing process, and then examining the appearance of each sample. The thermal behavior of ceramic sherds refired at a temperature exceeding their original firing temperature is entirely

27 The concept of rational composition was introduced by the German chemist Herman Bollenbach.

28 Since 1993, MGR-analysis has been carried out on ca. 12 000 ceramic sherds.

29 'Refiring' denotes the secondary firing of previously fired ceramics. Refiring is a laboratory procedure conducted in controlled conditions at a defined temperature. Laboratory firing can be carried out at temperatures both below and above the original firing temperature, despite the fact that laboratory firing at a higher temperature than that of the original firing represents a continuation and not a repetition of this process and, thus, it is in reality the original firing. The term 'original firing temperature' (To) is used solely in reference to the temperature at which a ceramic object was fired by the potter who made it. Meanwhile, the term 'refiring temperature' (Tr) denotes the temperature at which a previously fired product is fired in the laboratory. Analysis consisting of macroscopic observations of the thermal behavior of samples after refiring is regarded as one of the thermal methods of ceramic analysis. The name MGR-analysis was introduced by M. Daszkiewicz in 2001 at the European Meeting on Ancient Ceramics (EMAC'01 in Fribourg); it is an abbreviation of Matrix Groups by Refiring. Like other types of scientific analysis, accuracy, precision, repeatability, and reproducibility of results are critical in the MGR technique. Accuracy, the proximity of the analytical results to the true value – in this case the original firing temperature, is verified by analyzing test materials and/or pottery from ethnographic collections. Measurement of accuracy depends on the parameters of the refiring process, namely the heating rate, soaking time at the peak temperature, and atmosphere. Analysis of model briquettes revealed that in a fully oxidizing atmosphere, the same result is achieved with a heating rate of 200°C/h as with one of 300°C/h, and after a soaking time of 1h, 2h, or 3h. Thus, only temperature affects the results. The precision of refiring analysis of model briquettes depends entirely upon the operational precision of the laboratory kiln. However, analytical precision for archaeological samples is potentially affected by the heterogeneity of the ceramic body (precision of sampling).

30 Daszkiewicz and G. Schneider 2001b; Daszkiewicz 2014; Daszkiewicz and Maritan 2016.

31 Refiring should always be carried out in static air, with a strictly defined heating rate and soaking time at the peak temperature.

dependent on the composition of the ceramic body. As a consequence, samples can be classified by their matrix type and, hence, (given that the matrix constitutes the previously plastic part of the ceramic body) by the type of clay used. After refiring, the type and number of non-plastic particles in the ceramic body can also be assessed more reliably. To classify raw materials, it is sufficient to perform abridged MGR-analysis, which consists of refiring at only three temperatures.[32] So-called MGR-groups represent groups of greatest similarity, i.e. those samples in which the plastic part of the ceramic body has the same chemical and phase composition. MGR-groups can be merged into major MGR-groups (these groups consist of samples that have the same categories of matrix).[33]

– Chemical analysis is applied to sherds in order to determine the chemical composition of both the plastic and non-plastic components of the ceramic fabric. The results of this analysis reveal the quantity of major and trace elements in the body and show the geochemical characteristics of the raw materials used, although the phases in which individual elements occur cannot be determined[34] (giving the major elements as oxides is standard procedure in geochemistry when presenting the results of chemical analysis and does not reveal anything about the real mineralogical phases).

– Thin sections are examined to distinguish fabrics (an excellent overview is given by I.K. Whitbread)[35] and to identify the kind of non-plastic (clastic) components within the ceramic body, including their mineralogical-petrographic identification. They also show the shapes of inclusions and pores (texture), their relative amounts, grain size distributions, roundness, and degrees of sorting. Thin-section studies also make it possible to determine the ceramic body recipe used by the potter. The amount of information that thin-section studies can yield about the matrix, however, is limited by the resolution of the microscope used (and the thickness of the thin section), by the small size of the clay minerals making up the plastic part of the body and by the fact that transformation of these minerals occurs during the firing process. The term micro-fabric

32 Full MGR-analysis (refiring at nine temperatures) allows for an estimate of the original firing temperature range (indicated by a change in color of the refired sample in relation to the color of the original sample).

33 Categories of matrix identified by MGR-analysis correspond to groups of clay types (these groups are made up of samples with similar concentrations of major elements; an exact appraisal of the type of clay minerals is seldom possible due to the fact that they undergo thermal decomposition in the course of the firing process). Three fundamental categories of matrix can be identified: calcareous, non-calcareous, and mixed.

34 For example, Ca content identified by chemical analysis may be attributable to, for example, inclusions of calcite or dolomite or anorthite, or may occur exclusively in the clay fraction of the matrix.

35 Whitbread 2017.

also includes the stage of isotropy of the matrix (optical activity), which depends on firing temperature.

These three analytical methods (MGR-analysis, chemical analysis, and thin-section studies) are used in provenance studies to sort pottery into groups. Each method results in a different type of classification (matrix groups, geochemical groups, and clastic material groups, respectively). Provenance groups can be determined based on the collective findings from all three types of classification, highlighting not only differences in chemical composition but also revealing what these differences are associated with (e.g. ceramic vessels representing two different groups, such as tableware and kitchenware, may be local products made using the same clay, but with the addition of different tempers depending on the intended function of the vessel).

It is important to bear in mind that if sherds exhibit the same thermal behavior (appearance and shade of color) after refiring at 1200°C (and hence belong to the same MGR-group) this indicates that they were made using the same plastic raw material; however, it is very possible that they differ from one another in their chemical composition, given that the results of chemical analysis carried out on these sherds also encompass the chemical composition of the ceramic body's non-plastic ingredients. To establish that sherds were made from the same body (the same plastic and non-plastic material and in the same proportion) and have the same chemical composition, they must belong both to the same MGR-group and the same non-plastic material group. This means that two sherds made of the same clay will only be attributed to two different chemical groups if an intentionally added temper is present in one of them. For this reason, both the matrix group and the macroscopically visible non-plastic particles of the sherds are taken into consideration when selecting samples for chemical composition analysis.

Attention must be drawn to the fact that MGR-analysis cannot replace chemical analysis in provenance studies. Individual MGR-groups/major MGR-groups can only be sorted into groups of the same geochemically important parameters **on the basis of chemical analysis**. The results of chemical analysis are used to determine the chemical composition of the ceramic body and, hence, the 'fingerprint' of a given pottery workshop. A group of samples with the same chemical composition is referred to as a reference group. In order to attribute individual reference groups to a geographical region, the reference group must include ceramic finds from workshops or kilns (not all ceramic wasters are evidence of local production)[36] and/or ceramic raw materials available near archaeological sites must be analyzed (this is why fieldwork should include clay sampling for comparative studies). Once MGR-analysis has been completed, the

36 Daszkiewicz and Bobryk 1998.

results will facilitate the correct interpretation of chemical clusters deriving from multivariate statistics (multivariate cluster analysis is based on the content of elements within a given sample regardless of what phase they occur in).[37]

Geographic or geological factors might dictate that different pottery production centers use similar clay and the same non-plastic ingredients to make ceramic bodies. In these circumstances, only technological analysis can potentially identify individual production centers or workshops.

When studies are undertaken to recreate the technology used in making ancient ceramics, archaeologists usually want to establish what the original firing temperature was. Analyses can also be carried out to determine the techniques used in processing and decorating ceramic vessel surfaces to ascertain what forming techniques were used to make the pottery and to identify grog temper. Laboratory analyses also allow conclusions to be drawn about the methods used for de-airing ceramic bodies and about the type of make-up water used. The functional and mechanical properties of ceramic wares can also be examined.[38]

The original firing temperature[39] of archaeological pottery can be determined using static and dynamic methods.[40] Static methods focus on analyzing specific characteristics from which the firing temperature is then estimated. The presence or absence of clay minerals and calcite, gehlenite or diopside, or the degree of vitrification can be used to gauge firing temperatures.[41] Dynamic methods involve refiring ceramic sherds and evaluating at which temperature changes occur to a specific characteristic.[42] No significant changes should be observed in a sherd when it is fired at a temperature below that of its original firing temperature. Various parameters can be taken into consideration in dynamic analyses.[43] Bearing in mind the temperature distribution within a pottery kiln, analysis that allows estimates of original firing temperature accurate to 50–100°C can be regarded as sufficiently accurate.

37 For example, if calcium is a major constituent of the non-plastic inclusions (e.g. calcite), then, in spite of the chemical similarity of the bulk composition, the sample must be attributed to a different group because of its different matrix.

38 Tite, Kilikoglou, and Vekinis 2001; Daszkiewicz, Krogulska, and Bobryk 2000; Daszkiewicz and Bobryk 2001.

39 The term 'original firing temperature' refers to the highest temperature at which the ceramic object was fired, regardless of how many times the fragment was fired (e.g. twice fired glazed pottery).

40 Daszkiewicz and Bobryk 2011; Daszkiewicz 2014.

41 Tite 1972; Daszkiewicz and Maritan 2016.

42 The temperature at which changes take place in the individual sherd during the use of dynamic methods is related to the refiring conditions, therefore, the results of this analysis should be referred to as the 'equivalent original firing temperature.' Refiring should be carried out in standardized conditions; refiring in static air at a heating rate of 200°C/h and a soaking time of 1h at the peak temperature is considered optimal.

43 During the course of firing, the color of a sherd changes, its open porosity and water absorption decrease, its apparent density increases, its pores change shape, linear changes take place (shrinkage, expansion), and changes are also noted in mechanical and functional properties, as well as in phase composition (thermal decomposition of some minerals and building of new minerals). Changes also occur in chemical composition.

Optical, spectroscopic, thermal, mechanical, and physical methods are used in analyzing archaeological ceramics (Fig. 2). These methods enable us to investigate the provenance and properties of raw materials, the provenance and properties of ceramic sherds, technological advances in pottery production, and also allow for raw material, technological, and functional classifications (Fig. 3). Dating will not be discussed in this chapter.

Not all methods have been used for studying the samples discussed in this volume. In addition to being examined using the standard package of three analytical techniques (MGR, WD-XRF, and thin sections), an estimation was also made of the physical ceramic properties (apparent density, open porosity, and water absorption) of sherds analyzed as part of Topoi-2 projects.

If objects are made of the same ceramic body, formed using the same technique, and thoroughly dried and fired at the same temperature, their porosity will depend on the degree to which the body was de-aired. The more poorly the body was de-aired, the greater the porosity and associated water absorption of the end product and the lower its apparent density. However, if the only difference between the ceramics is their firing temperature, then their open porosity, water absorption, apparent density, and bulk density will be the same when sherds are refired at the same temperature that is higher than that of the original firing. In order to determine the degree of de-airing in pottery made from the same ceramic body, estimates must be made of open porosity, water absorption, apparent density, and bulk density after refiring at the temperature attained at the end of sintering.

The study of changes in open porosity, water absorption, and apparent density during refiring in standardized conditions is known as K-H analysis (this name, commemorating Dr. L. Kilb and Prof. H. W. Hennike, was suggested by M. Daszkiewicz at an archaeometry conference.)[44] This analysis makes it possible to determine the original firing temperature. Structural-textural MGR-analysis, full MGR-analysis, and X-ray diffraction analysis (both static and dynamic) were also used for estimating original firing temperature.

Technological analysis of forming techniques and surface treatment was carried out on selected samples (Petra and Musawwarat projects) using an SEM (scanning electron microscope) fitted with EDS (energy dispersive X-ray fluorescence spectrometer). The same method was used to examine fracture surfaces of graphite ceramics found in Cornești-Iarcuri. In the case of three ceramic sherds examined as part of the Vojtenki project, forming techniques were assessed by analyzing pore texture.

Macroscopic descriptions of ceramic fabrics were limited to defining the grain size of non-plastic particles and estimating the percentage of particular grain sizes. Macro-

44 Daszkiewicz and Bobryk 2001.

scopic analysis was performed in order to correlate grain size with the precision of chemical composition determined by pXRF (the results of studies by O. Mecking show that ceramic fabrics featuring temper with a grain size of >1.6 mm should on no account be analyzed using pXRF due to poor precision and accuracy).[45]

In addition, as part of the Musawwarat project, comprehensive model tests were carried out to assess the impact of temper on the mechanical and functional properties of pottery.[46] The practical use of ceramic materials classed as 'brittle,' i.e. those that crack under relatively low stresses without prior plastic deformation, is very often determined by their mechanical properties. Formerly, attempts to calculate the mechanical strength of brittle materials were based on knowledge of intermolecular forces and surface energy. A material subjected to tensile stress will become deformed with a concomitant increase in interatomic spacing. Elastic energy is stored in the material as a result of the force applied to cause the deformation. At the point of fracture, this energy turns into surface energy corresponding to newly formed surfaces. Hooke's Law states that just prior to the fracture characteristic of brittle materials:

$$\sigma = \sqrt{\frac{2\gamma E}{a}}$$

where: σ = fracture stress, γ = specific surface energy, E = Young's modulus, a = space between adjacent atomic surfaces. With known values of a and γ, an approximate formula is obtained: σ=E/10, from which it follows that the strength of the material should amount to around 1/10 of its modulus of elasticity. However, experience has shown that in practice the strength of the material amounts to barely 1/1000 of its elastic modulus. This discrepancy was explained in the 1920s by Griffith, who stated that all brittle materials contain large numbers of submicron cracks and that stresses in the material to which a load is applied concentrate around these cracks. If the cracks are sufficiently large, the stresses will exceed the strength of the material and may trigger its catastrophic failure. Critical cracks can be initiated by internal or surface defects associated with the manner in which the specimen or product was formed and fired. These include pores resulting from incomplete densification of the material during sintering, foreign inclusions, delamination and cracks, surface roughness, and recrystallization on the surface.

The mechanical strength values of ceramics are affected by how a load is applied. We distinguish between compressive, flexural, and tensile strength. When normalized with respect to tensile strength, flexural strength is 1.5 to 3 times greater and compressive strength is 3 to 15 times greater. Each type of strength test requires specimens of a

45 Behrendt, Mielke, and Mecking 2012.

46 This analysis was funded by ARCHEA and the Warsaw University of Technology.

specific geometric form – bars are used for testing flexural strength, cylinders for compressive strength, and rods with shouldered ends for tensile strength.

A convenient method in laboratory practice is the so-called Brazilian test, which assesses tensile strength by applying compressive stress to a disc-shaped specimen placed between the crossheads of the testing machine on the disc's generating line (Fig. 4). The advantage of using this method for testing tensile strength is the ease with which specimens can be prepared for analysis – specimens of 20mm in diameter and of a given height can be molded from a plastic mass or shaped in a hydraulic press, or can even be cut from a ceramic sherd. Tensile strength (σ_r) is calculated using the formula: $\sigma_r=2F/\pi dh$, where F is the maximum force that results in the failure of the specimen, d is the diameter, and h is the height of the analyzed specimen. The mechanical strength of ceramics is of a statistical nature, therefore, measurements must be performed on 3 to 5 specimens. It is also important to maintain a constant specimen loading rate. This is usually determined by the crosshead speed of the testing machine, which is set to 0.2mm/min.

Archaeological ceramic analysis also makes use of climatic chambers. A Memmert HPP110 constant climate chamber is useful for conducting climatic and climatic tests that require temperatures to be very accurately controlled within a range of 0°C to + 70°C and air humidity to be maintained at 10–90% rh (relative humidity). The chamber is made of acid-resistant stainless steel and is fitted with double doors (an inner glass door and an outer stainless steel door). The heating system ensures even temperature distribution throughout the chamber, and the digital timer can be set from 1 minute to 99 days. The control system allows for the following options: setting a desired temperature, switching off heating after a set process time, switching on heating after a set time delay, counting down process time once a set temperature has been reached, and switching off the appliance after a set process time, cyclical operation, switching on ventilation and setting run time, programming operation of fan and air flaps, and programming multi-phase temperature change profiles. A microprocessor humidity sensor ensures that the desired humidity level is consistently maintained. Ceramic samples can be subjected to aging processes inside the chamber, allowing for an assessment of the impact of elevated temperatures and high humidity and, indirectly, of environmental conditions (e.g. deposition in soil or a layer of ash – see model test carried out as part of the Musawwarat project, chapter 4.3 in this volume). The size and shape of ceramic specimens required for use in the climate chamber depends on what aspect of the material is being tested – changes in chemical composition, internal or external structural changes, or strength properties.

3.2 Description of principal analytical procedures used in the Topoi projects

The procedure of NAA involved in chemical analysis are not described below. For this technique, see the description in chapter 4.2.1 about pottery from Tell Amarna.

3.2.1 MGR-analysis

Thin slices were removed from each sample (four slices in the case of abridged MGR-analysis and ten for full MGR-analysis) in a plane at right angles to the vessel's main axis (Fig. 5a). One slice was left as a point of reference for the appearance of the original sample, while the remaining fragments were fired in a Carbolite electric laboratory resistance furnace using the standard procedure. The samples were fired in static air (i.e. without air flow), at a heating rate of 200°C/h and a soaking time of 1h at the peak temperature, and cooled at a cooling rate of 5°C/min to 500°C (Fig. 5b), followed by cooling with the kiln for 1 hour. They were subsequently removed from the kiln (Fig. 5c) and left to continue cooling until they reached room temperature. The fragments were then glued onto paper and a macro photograph was taken of each slice (Fig. 5d).

Abridged MGR-analysis: refiring was carried out at the following temperatures: 1100, 1150, and 1200°C. Full MGR-analysis: refiring was carried out at the following temperatures: 400, 600, 700, 800, 900, 1000, 1100, 1150, and 1200°C.

3.2.2 Structural-textural MGR-analysis

Structural MGR-analysis is one of the dynamic methods used to estimate the original firing temperature of ancient pottery.[47] It involves using an optical microscope to examine changes in the structure of ceramic sherds before and after refiring. A briquette removed from a sherd is repeatedly refired at 600 to 1200°C in increments of 100°C or 50°C. A photograph is taken of the same spot after each refiring (the refiring process follows the procedure outlined for MGR-analysis, see 2.2.1). An example is shown in Chapter 5, Fig. 11 in this volume.

3.2.3 Chemical analysis by WD-XRF

Sample preparation began by mechanically removing all old surfaces of the fragment using a corundum-tipped drill bit (Fig. 6a) and then cleaning the remaining fragments

47 Daszkiewicz 2014.

with distilled water in an ultrasonic device (Fig. 6b). After having been rinsed, the fragments were dried in a drying oven at 105°C. The dried samples were cooled to room temperature and then pulverized using an agate ball mill[48] (Fig. 6c–e). The resulting powders were dried for 24 hours in a drying oven at 105°C (Fig. 6f). Next, loss on ignition was calculated: having been weighed on a laboratory balance (Fig. 6g), the samples were ignited at 900°C in an electric furnace (Fig. 6h) (heating rate 200°C/h, soaking time 1h), after which they were transferred to a desiccator, cooled to room temperature, and then reweighed on a laboratory balance (Fig. 6i). One gram of the ignited powder was mixed with 4 grams of a flux,[49] put into a Pt/Au crucible (Fig. 6j), melted in an electric kiln, and cast in a Pt/Au mold to form thin discs of 32mm in diameter (Fig. 6k).[50] These discs (Fig. 6l and 6m) then underwent chemical analysis by WD-XRF (wavelength-dispersive X-ray fluorescence). This technique was used to determine the content of major elements including phosphorus[51] and a series of up to fifteen trace elements.[52] The same procedure is used by most laboratories for routine geochemical analysis of various silicate materials because such glass discs are optimal for precisely measuring X-ray fluorescence irrespective of the grain sizes or inhomogeneities of pressed powders consisting of a mixture of very different minerals.

Major elements are calculated as oxides. Total iron is calculated as Fe_2O_3. The element concentrations determined are valid for ignited samples but, with the losses on ignition given, may be recalculated to a basis of samples dried at 105°C. For easier comparison, the major elements are normalized to a sum of 100%; however, the totals of the original measurements are always given.

The long-term precision (coefficient of variation) for major elements is better than 2% (6% for Na). Levels of the trace elements V, Cr, Ni, Zn, Rb, Sr, Y, Zr, and Ba were determined by WD-XRF with long-term precision (measurement and preparation) ranging up to 3%, and up to 6% for Nb, Cu, and Ce (for trace elements at very low concentrations this may rise to 15–20%). Accuracy was tested by analyzing more than fifty certified international standard reference samples (CRMs) and by repeated exchange of samples with other laboratories. For major elements in CRMs, the maximum deviations are mostly below 5%, and for sodium and trace elements below 10% (except for

48 Fritsch Pulverisette Null Vibratory Micro Mill.

49 A mixture of lithium tetraborate and lithium metaborate (Merck Spectromelt A12).

50 Existing automates ro prepare glass discs from powder samples were not used by us up to now.

51 Si = silicon, calculated as SiO2; Al = aluminium, calculated as Al2O3; Ti = titanium, calculated as TiO2; Fe = iron, total iron calculated as Fe2O3; Mn = manganese, calculated as MnO; Mg = magnesium calculated as MgO; Ca = calcium calculated as CaO; Na = sodium calculated as Na2O; K = potassium calculated as K2O; and P = phosphorus calculated as P2O5. The total iron is calculated as Fe2O3, therefore, losses on ignition of not fully oxidized sherds could be negative.

52 V = vanadium; Cr = chromium; Ni = nickel; Cu = copper; Zn = zinc; Rb = rubidium; Sr = strontium; Y = yttrium; Zr = zirconium; Nb = niobium; Ba = barium; La = lanthanum; Ce = cerium; Pb = lead; Th = thorium.

low concentrations of Cu, Nb, Ba, La, Ce, Pb, and Th). Preparation of samples for analysis was carried out in the ARCHEA laboratory, and measurements were performed using the calibration by G. Schneider and measurements using a PANalytical AXIOS XRF-spectrometer.[53]

3.2.4 Chemical analysis by pXRF

Readings were taken with a Niton XRF analyzer (XL3t900S GOLDD RF-Analyzer, 50 kV, Ag anode, MINING software). The instrument was calibrated on twelve fine-grained ceramic reference samples analyzed by WD-XRF that were prepared by G. Schneider and M. Daszkiewicz in the form of round discs (e.g. cut from sherds or made of very fine clay fired at 900°C) (Fig. 7a). Measurements were performed without helium in a sample chamber (Fig. 7b and 7c), with an 8 mm measuring spot and a measurement time of 120 seconds (30 seconds per filter). The measurement surface of each of the pottery fragments was prepared by creating a fresh break using pliers with a cutting surface made of tungsten carbide. Subsequently, three measurements were taken at three different points on the prepared fracture of each sample. As pXRF analysis is performed on original (non-ignited) samples, this must be taken into account when comparing its results to those of WD-XRF analysis of ignited samples. As certain elements are missing (Na, Mg) and elements that occur in high concentrations (Al, Si) are determined with poor precision, there is no point in normalizing the sum of major elements.

3.2.5 Determining physical ceramic properties

These parameters were determined by hydrostatic weighing. Before this took place, samples were boiled in distilled water for two hours so that all open pores were fully saturated with water (Fig. 8a). The samples were then cooled to room temperature and weighed twice: in the first instance, the samples were weighed immersed in water (Fig. 8b) and, in the second, the wet samples were weighed in air (Fig. 8c–d). After having been dried to a constant mass in a dryer at 105°C and cooled to room temperature in a desiccator (Fig. 8e–f), the samples were then weighed for a third time in air (Fig. 8g). This process yielded three values: m_s – mass of dry sample; m_w – mass of wet sample weighed in air; and m_{ww} – mass of sample weighed in water (with pores saturated by boiling in water). The values of physical ceramic properties were then calculated.

Open porosity reflects the size and amount of open pores, hence pores which can take up new liquid (in this case, water), expressed as a percentage of the amount of

53 Courtesy of Anja Schleicher, Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum GFZ, Sektion 4.2, Anorganische und Isotopengeochemie.

water absorbed by a given volume of sample. This parameter was calculated using the following formula:

$$P_{\circ} = \frac{m_{\mathrm{w}} - m_{\mathrm{s}}}{m_{\mathrm{w}} - m_{\mathrm{ww}}} \cdot 100$$

Water absorption reflects the ability of the sample to absorb water; it represents the mass gain of the sample soaked in water in relation to the mass of the dry sample expressed as a percentage. Water absorption was calculated using the following formula:

$$N = \frac{m_{\mathrm{w}} - m_{\mathrm{s}}}{m_{\mathrm{s}}} \cdot 100$$

Apparent density reflects the mass of the sample in relation to its volume; the term 'apparent' refers to the fact that the volume of closed pores is taken into consideration in the sample volume. Apparent density was calculated using the following formula:

$$d_{\mathrm{v}} = \frac{m_{\mathrm{s}}}{m_{\mathrm{w}} - m_{\mathrm{ww}}} \cdot \rho_{\mathrm{H2O}}$$

and expressed in g/cm³. This formula takes into account $\rho_{\mathrm{H_2}}$, i.e. the specific density of water at the measurement temperature, which in this instance was room temperature (at 20°C ρ_{H2O} = 1g/cm³).

For the determination of original firing temperatures using K-H-analysis (Kilb-Henicke Analysis), apparent density, open porosity, and water absorption values were determined before and after refiring a fragment weighing 2–3 grams in controlled conditions at incremental temperatures. This was done in accordance with the procedure described in section 3.2.1. Up to the original firing temperature, the values should[54] remain constant. The first changes appear above a temperature higher than the original firing temperature.

3.2.6 Studying thin sections in a polarizing microscope

The study of thin sections of 0.03 mm thickness allows for a description of ceramic micro-fabrics. The thin sections are cut perpendicular to the wall of a sherd and to the rim of a vessel. Photomicrographs document images at different magnifications. Characteristic minerals or rock fragments can be determined using crossed polarizers (XPL) and can be used as indications of provenance. Grain sizes, amount, degree of roundness and of sorting of the inclusions (and pores), and the character of the ground mass are important features. Changes to inclusions and to the matrix during firing can be used for a rough estimation of the original firing temperature. Changes by later alteration (e.g. secondary calcite) can also be identified.

54 Changes may occur at low temperatures: e.g. a rise in open porosity may be observed after refiring at 400°C if not all organic matter was burned out during the original firing, or if the pores were sealed by secondary deposition in open pores during the use of the artefact, or as a result of the alteration effect.

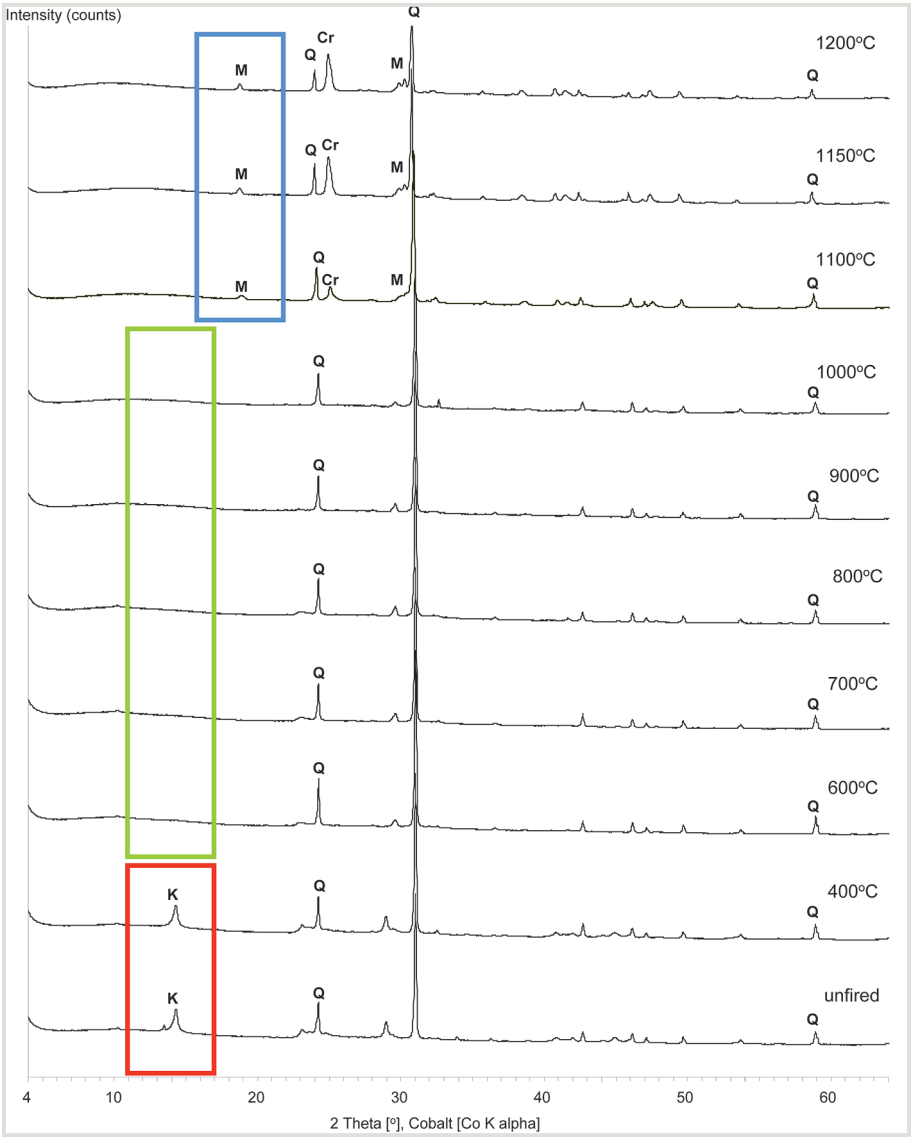


Fig. 1 X-ray diffraction of clay fired at various temperatures (K = kaolinite, M = mullite, Q = quartz, Cr = cristobalite).

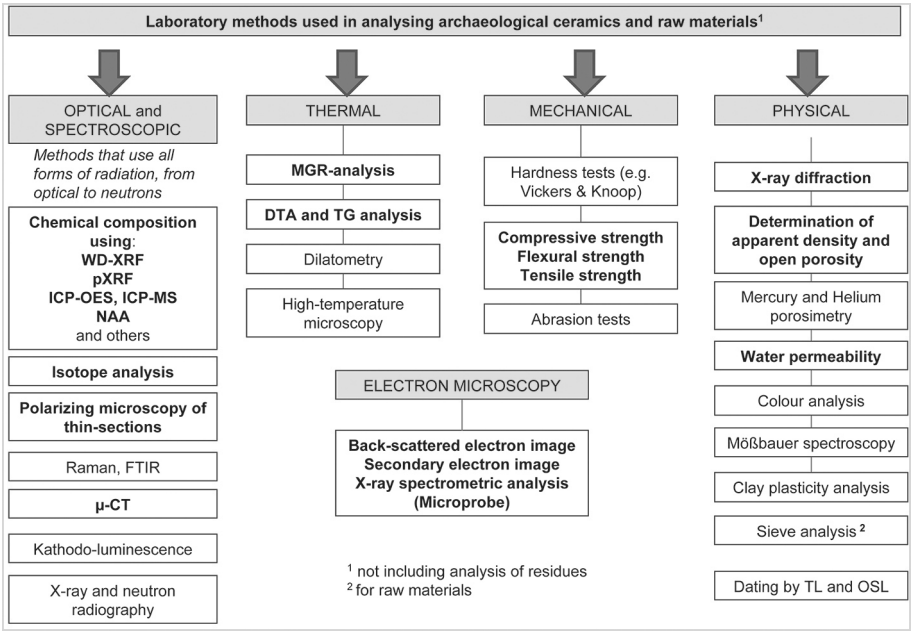


Fig. 2 Archaeometric methods used in analyzing archaeological ceramics and raw materials.

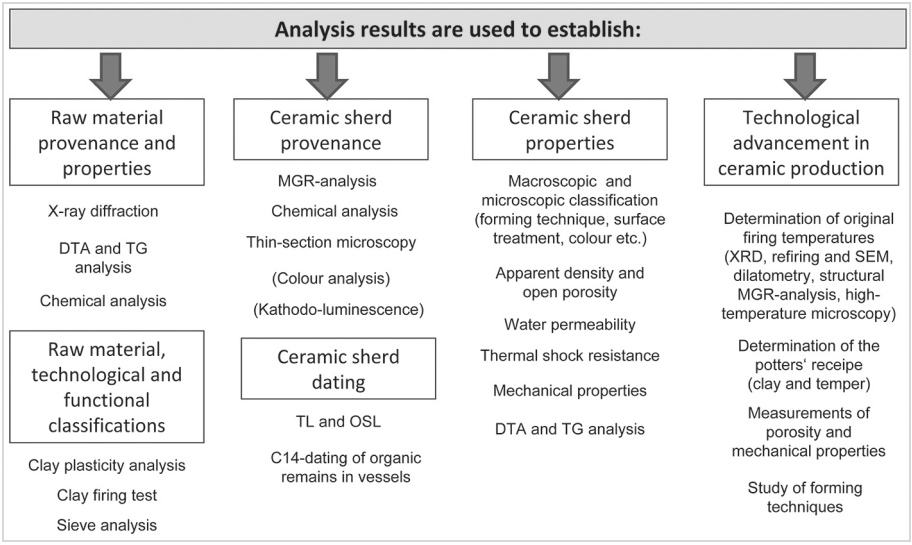


Fig. 3 Questions which can be answered by scientific analysis.

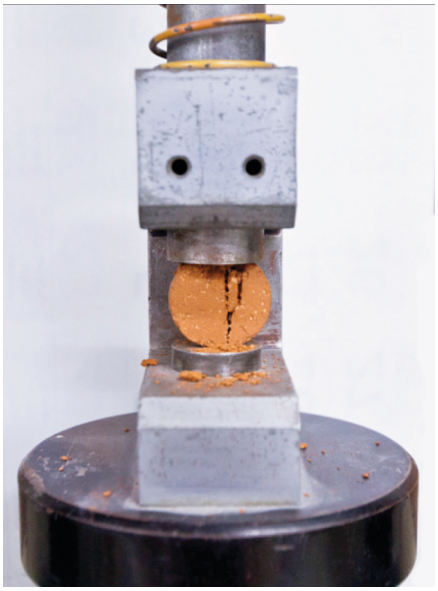
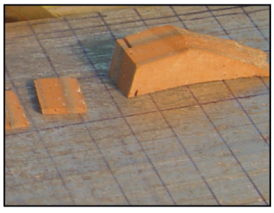
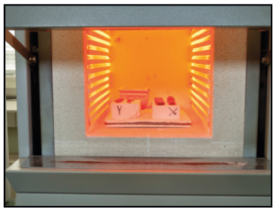
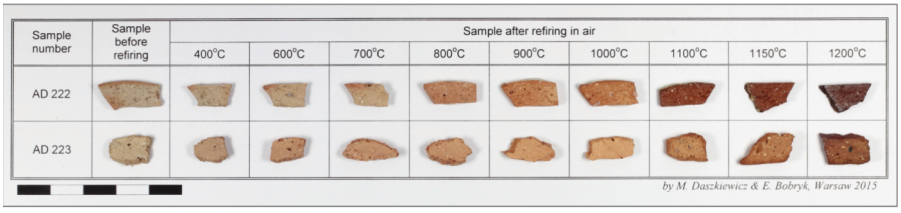


Fig. 4 Measurement of tensile strength (Brazilian test)


a


b


c



d

Fig. 5 MGR-analysis used in the ARCHEA laboratory.

Fig. 6 Preparation of samples for WD-XRF analysis in the ARCHEA laboratory.

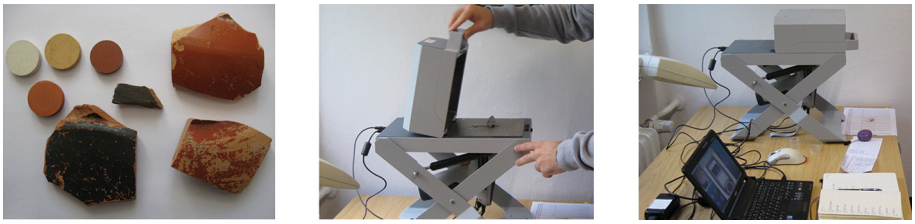


Fig. 7 Standard samples and measurements by pXRF in the TOPOI building in Berlin (Dahlem).

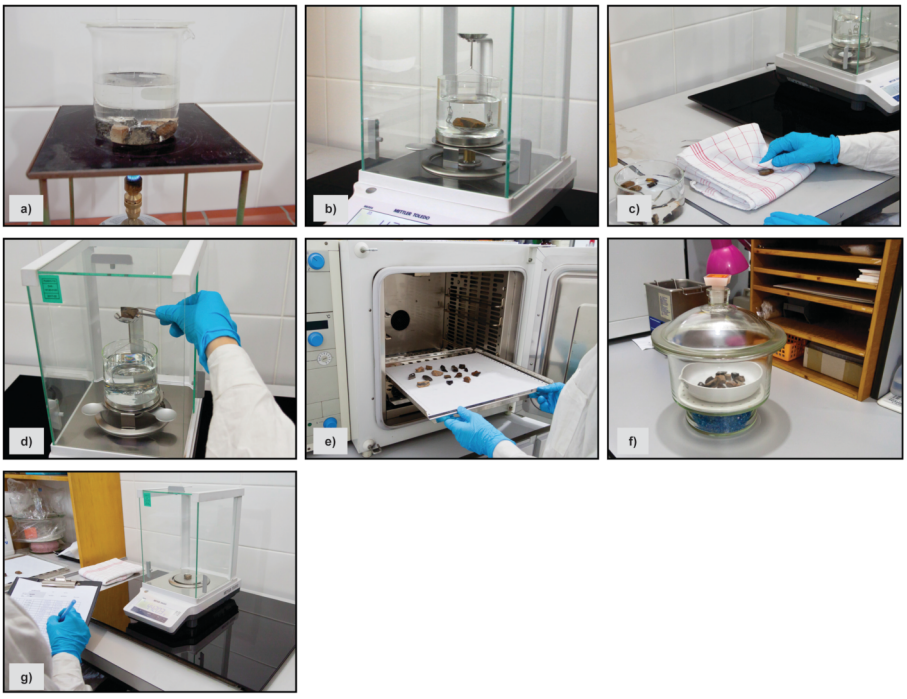


Fig. 8 Determination of physical ceramic properties by hydrostatic weighing in the ARCHEA laboratory.

4 Short Descriptions of the Aims and Results of the Individual Projects

Michael Meyer

This chapter offers compiled descriptions of the work done in different regions and epochs to give an overview on the projects of the research group. The projects are presented according to their cultural and economic background, the research question, the sampling strategy and the archaeometric methods applied, and – as the case may be – their adjustment, the results achieved, and the interpretation of the distribution patterns.

Most of the projects deal with ceramics. To test the pXRF-methodology also on ancient glass, the Komariv-project (chapter 4.10) was included in the group's work. In the case of Tell el-Amarna, where a current project on the important question of domestic manufacture of vitreous materials in the Late Bronze Age is on its way, the interesting results on the organization of production are included here in a short paper.

4.1 Locally Connected – Archaeometric Analysis of Pottery from 5th Millennium BCE Tepe Sohz

Reinhard Bernbeck, Małgorzata Daszkiewicz, Gerwulf Schneider

4.1 Introduction: the fifth millennium in Greater Mesopotamia

The fifth millennium BCE in Mesopotamia and Iran is known as a crucial period of development, from earlier Neolithic societies to the strongly hierarchized states and empires that appeared later. In terms of culture history, the period is known as 'Ubaid' in Mesopotamia, the 'Susiana' sequence in the southwestern Iranian lowlands, and the 'Bakun' period in the Iranian Zagros. Across these regions, we find a largely simultaneous change in pottery technology in the transition from the mid- to late sixth millennium BCE. While Neolithic pottery is generally vegetal-tempered, low-fired, and thick-walled, the onset of the Early Chalcolithic is accompanied by a change to a thin-walled, high fired ware that is mostly painted in a monochrome Black-on-Buff style. The painted patterns of this new kind of pottery show regional particularities.

This geographically wide-ranging technological change co-occurs with social, economic, and political developments of a more regional nature. I limit myself to the most general outline for the purposes of this paper: in the mid-fifth millennium BCE Mesopotamia sees the advent of hierarchical differences in households within one and the same village, most clearly manifest in Tell Abada's levels I and II. Among the usual multi-roomed Ubaid houses, we now find a special household with the traditional T-shaped unit at its center but with a separately walled-off courtyard, a different arrangement of rooms, and a set of decorative niches on its outside; a precursor to later temple façade decoration.[1] In the same period, at the southern Mesopotamian site of Eridu a slow development of a new public type of building occurs, starting in the lowest levels with a mere hut with an altar-like table and changing through various stages to a complex

1 Jasim 1985.

multi-roomed building with external niche decoration set on a platform. Traditionally, this building is considered to be a temple. At Susa in southwestern Iran, at least one public building was also identified by the excavators.[2] However, at Tall-e Bakun, the only large-scale exposure of a fifth millennium site in the Zagros Mountains, no such internal hierarchy of structures is apparent. The traditional interpretation of the situation in the Zagros region is, therefore, a continuation of non-hierarchical village structures in the 5th millennium BCE.[3]

In a series of articles and books, Abbas Alizadeh has challenged this traditional view of the Zagros Mountains as a sort of 'backwater' in the development towards early states in ancient Western Asia.[4] He suggests that the Zagros was a region with a separate and unique path towards state-level societies. Using ethnographic and historical analogies, he claims that mobile groups that left scant archaeological traces were the dominant political and economic force in the mountains. Sedentary village populations lived under their rule and that of settled nomadic 'khans'. This idea is based mainly on the historically known structures and ways of life of today's nomadic pastoralists in the region and, particularly, the Bakhtiyari and Qashqai tribes.[5] Until recently, these groups spent their winter months in the warm lowlands and the summer months in the high Zagros valleys, some of them migrating over hundreds of kilometers between these two areas.

Alizadeh's 'nomadism model' of state development has dominated discourse on the fifth millennium in Iran.[6] However, there is no lack of criticism, formulated most prominently and sharply by Daniel T. Potts, who argues that positive evidentiary support for Alizadeh's model is entirely lacking.[7] We're not going to venture into the details of this dispute, except to note that Potts positions himself equally extremely by implicitly assuming that people would be sedentary unless external conditions forced them out of such a way of life.[8]

This discussion underlies the current analysis of data from the excavations at Tepe Sohz, just outside the modern town of Behbehan in southwestern Iran (Fig. 1). Excavations at Tepe Sohz and a survey of the surrounding region were carried out in 1970 by Hans J. Nissen and Charles Redman.[9] While the survey results were analyzed a long time ago,[10] the excavation data have remained unpublished. A good share of these materials, particularly pottery, was shipped to the Freie Universität Berlin for final analysis in 1970. This work is now undertaken by Susan Pollock, who argues that Tepe Sohz is an appropriate site for an empirical reconsideration of Alizadeh's nomadism thesis.

2 Pollock 1989.
3 Hole 1987; Sumner 1972; Sumner 1994.
4 Alizadeh 1988; Alizadeh 2006; Alizadeh 2010.
5 E.g. Barth 1961.
6 E.g. Abdi 2003; Mashkour 2004.
7 Potts 2011; Potts 2014.
8 See Bernbeck 2008; J. C. Scott 2017.
9 Nissen 1973; Nissen 1976; Nissen and Redman 1971.
10 Dittmann 1984.

First, it is located in an area that is the region of winter pastures (*garmsir*) for today's vertically migrating nomads. Second, the site is by far the largest fifth millennium site in the Bhebehan region and would have attracted nomadic elites according to Alizadeh's direct historical analogy. If his thesis is valid, we should see close parallels to highland regions in the Tepe Sohz materials; high value items should be present and these should not be regularly distributed across the whole site. Following the ideas of the excavators, a different explanation for the centrality of Tepe Sohz is also possible. Hans Nissen originally suggested that the site may have been placed on a trade route between the Susiana lowlands (including the major site of Susa itself) and the highlands with the type site Tall-e Bakun.[11] In such a case, we would also expect regional links to the highlands, but not exclusively, as trade is mostly a matter of contacts in many different directions. Furthermore, rhythms of mobility can be expected to be less regular and geared towards the transport of highly specific goods. The movement of pottery would only be expected for vessels that have a function in such exchanges – because of their contents – or that were themselves traded for their particular value.

4.2 Specific research questions

Can pottery from Tepe Sohz be mobilized to test the above-mentioned different hypotheses about regional mobility, and if so, how? The archaeology of non-sedentary groups, and pastoral nomads in particular, has vexed archaeologists for a long time. Nomads, so the conventional wisdom goes, did not and do not possess breakable objects such as pottery. However, numerous ethnographic accounts have rendered this contention doubtful, even though it is unlikely that such mobile groups carried large amounts of goods with them.[12] Therefore, if nomads were a force dominating the populations in the 5th millennium Zagros Mountains, we should expect at least some traces of materials moving or other signs of close contact between lowland and highland regions. These are indeed present at Tepe Sohz in the form of the decoration styles of the pottery. Among the painted sherds located in Berlin, there is an elevated proportion with motifs that are clearly related to those known from the excavations at Tall-e Bakun, Tall-e Gap, and other sites in the Marv Dasht Plain. On the other hand, and perhaps speaking in favor of regional contacts towards the Susiana lowlands further west, there are also motifs closely resembling those from Susa and related sites. Finally, there is a substantial part of the pottery collection with no apparent stylistic similarities in the highlands or the western lowlands, presumably a more local production.

11 Nissen 1976.

12 Cribb 1991.

It was clear from the outset that not all materials with a style reminiscent of Bakun pottery would have been imported. This would simply have been too large an amount, considering that pack animals such as donkeys had not yet made their appearance and that domesticated cattle are not ideal for transporting bulk goods over long distances. Therefore, it would seem that the Tepe Sohz pottery with stylistic similarities in other regions could be composed of both imports and local imitations. The cultural impact of nomads would then show itself in the proportion of externally produced material brought to the site in the course of their vertical migrations. Under the conditions described, an archaeometric analysis of pottery clays contributes in crucial ways to a clarification of the potential impact of mobile elements of the population of ancient Tepe Sohz. This analysis starts from stylistic considerations to examine whether these match indications of clay sources.

4.3 Analysis of the material

Sampling and analytical procedures

With a total of more than 25 000 sherds from Tepe Sohz, a huge sample was at our disposal for potential analysis. This was reduced significantly since the three kinds of archaeometric analyses carried out (pXRF, WD-XRF, and MGR-analyses) are all destructive. We therefore tried to focus on pottery sherds that were either small fragments of vessels but still with clearly recognizable motifs or pieces so large that a small fragment removed for analysis would not impinge on archaeological and culture historical insights. From an overview of the available materials, we selected a total of 216 sherds from Tepe Sohz for potential analysis. These were then inspected more closely and a sub-sample of 113 extracted sherds were analyzed with WD-XRF (Tab. 1). In addition, a small collection of the survey sherds from the Behbehan-Zohreh survey are housed in Berlin, of which 21 were selected for analysis (Tab. 1). Of these, one third (seven sherds) are from two sites in the Behbehan Plain near Tepe Sohz (sites BZ 6 = Do Tulune and BZ 34 = Tepe Millak).[13] Another 14 sherds are from three sites in the neighboring Zohreh Plain, with the majority from the largest site in that region, Chogha Sofla[14], and a smaller number from the two nearby sites of Hajeriye (BZ 83) and BZ 97, for which no name was recorded (Tab.1).[15]

13 Cf. Dittmann 1984, 103, 106.

14 From the time of writing this paper to its publication, Moghaddam's research at Chogha Sofla has added extremely important new insights. They could no longer be included in detail (however, see Moghaddam 2021).

15 Dittmann 1984, 111, 113.

	Behbehan Plain			Zohreh Plain			
Type of Analysis	Tepe Sohz	Do Tulune	Tepe Millak	Chogha Sofla	Tell Hajeriye	BZ 97 (Anonymous)	Sum
WD-XRF	41	3		4		4	51
MGR				1			1
WD-XRF & MGR	19	3	1	2	1	2	28
WD-XRF & pXRF	10						10
WD-XRF & MGR & pXRF	43						43
Sum	**113**	**6**	**1**	**7**	**1**	**6**	**134**

Tab. 1 Sites and regions of origin for sherds on which various archaeometric analyses were carried out.

	Stylistic classification				
Type of Analysis	highland	Susiana	local	unknown	Sum
WD-XRF	4	7	5	25	**41**
WD-XRF & MGR		18	1		**19**
WD-XRF & pXRF				10	**10**
WD-XRF & MGR & pXRF	12	5	23	3	**43**
Sum	16	30	29	38	**113**
Proportion/Style	14.2	26.5	25.7	33.6	**100.0**

Tab. 2 Stylistic attributions of the Tepe Sohz samples, and kinds of archaeometric analyses carried out.

With a few exceptions, the sample of 113 sherds from Tepe Sohz itself consisted of painted sherds. They were then further classified into four stylistic groups based on their similarities with excavated pottery from other regions or the absence of such similarities (Tab. 2). This classification was done with the assumption that the styles would potentially reveal the regional contacts of the ancient inhabitants of Tepe Sohz (Tab. 2). Among these stylistic groups were sherds with (1) motifs showing connections to the higher Zagros valley plains, and in particular to the Marv Dasht with its well known pottery from Tall-e Bakun and Tall-Gap;[16] (2) sherds that would potentially reveal the intensity of trade or other with contacts to the western lowlands of the Susiana Plain, including sites such as Jowi, Bendebal, Jaffarabad, Chogha Bonut and Chogha Mish, and of course Susa itself;[17] and (3) sherds that lack such parallels and would, thus, have been most likely of local origin. A final analyzed group are sherds that after further inspection did not seem to belong to any of the stylistic groups mentioned above. Relations to other regions remain unclear, so they were kept in a separate category (Tab. 2).

16 Langsdorff 1942; Egami and Sono 1962. Brun 1971; cf. Pollock 1983.

17 Dollfus 1978; Alizadeh 2003; Alizadeh 2008; Le

The regional dimension of pottery production: the evidence from WD-XRF

The Zagros Mountain Range is a geologically diverse region, so the chemical composition of pottery clays varies much more than in lowland Mesopotamia. This general insight is borne out by the WD-XRF and, to some extent, by the pXRF analyses of sherds from the above-mentioned six sites in the Behbehan and Zohreh plains. As Figure 2 shows clearly, each site constitutes a distinct cluster when all elements are considered in a discriminant analysis. For WD-XRF, 24 elements were measured. Since site-specific groupings also show up in cross plots of only two elements, such as zirconium and potassium (Fig. 3), we can be fairly sure that pottery production in the fifth millennium in the southern Zagros Mountain Range was largely a local affair. If pottery was traded, this happened rarely.

A closer inspection of Figures 2 and 3 leads to a number of further conclusions:

– At each site, pottery was produced for local use; however, a few vessels were traded. Among the 113 analyzed sherds from Tepe Sohz, 8 specimens (or 7% of the analyzed material) seem to be either non-local or derived from a different local clay source than the bulk of the material.

– Building materials at Tepe Sohz show significant differences in their make-up from sherds, both forming a tight group distinct from the other.

– Sites in close regional proximity, such as Tepe Sohz, Do Tulune, and Tepe Millak (all from the Behbehan plain), do not form a coherent sub-regional cluster, nor do the three sites located in the Zohreh Plain. Instead, material from Tell Hajeriye and BZ 97 (Zohreh Plain) seem to be chemically closer to the Tepe Sohz materials from the Behbehan Plain than Do Tulune and Millak. Only the sherds from Chogha Sofla show a lower similarity to the materials from Tepe Sohz.[18]

– Among the six sherds from Chogha Sofla, there is one similar enough to the Do Tulune cluster to potentially be an import from that site. The eight sherds that could be identified as 'imports' to Tepe Sohz do form a cluster, but one that is not close to any of the sherds from other sites in the region. Nor is this cluster particularly tight. This could suggest one locus of origin of these sherds, unfortunately from an unknown location. Alternatively, these sherds could be the product of a local manufacturer of pottery who provided her- or himself with clay from a source different

18 Recent excavations at Chogha Sofla by Dr. Abbas Moghaddam revealed an area with the remains of kilns at the western edge of the site (Pollock and Moghaddam 2018, 11, Fig. 24).

than the other potters. The sherds with this signature do not display any stylistic particularities.

Local relations of production

While the locally produced sherds from Tepe Sohz cluster tightly, there is one element, rubidium, that can serve to distinguish two large groups of 56 and 42 sherds each (in this sample, imported sherds and bricks are excluded). While samples of specific painted motifs are in almost all cases too small to interpret (Tab. 3), there are three interesting exceptions. Lock rims[19] are clearly related to pottery from the Susiana Plain and occur only with high rubidium pastes. On the other hand, two highland-related motifs, the 'Bakun bug' and a motif with rectangular, box-like entities and sloppily carried out vertical strokes at their inner are in 8 of 10 cases associated with low rubidium pastes (Tab. 3). This points towards two clay sources in the immediate vicinity of Tepe Sohz that were used by two groups of potters; the high rubidium source was preferred by those who had a penchant towards western lowland pottery designs, while the other with lower rubidium content was used by a group that produced pottery in a more highland-associated style.

It also seems that inclusions in sherds are somewhat related to levels of rubidium (Tab. 4). This is particularly clear for those sherds with limestone temper, as they tend to exhibit low levels of rubidium; the same is true for a reddish material that could be a soft stone or grog. Limestone does not need to be an intentional tempering agent and could be naturally present in the low rubidium clay source. However, this is unlikely for the red stone/grog, which is too dense and regular to be a natural occurrence. The latter finding suggests that several aspects of pottery production, from the extraction of clay from a specific source, to the preparation of the clay with particular kinds of temper, to the preference for specific painted motifs, are all related. If this can be confirmed by further research, it would mean that the chain of tasks in pottery production was not specialized, with one workshop acquiring the clay, another shaping the vessels, and a third decorating them; rather, each producing entity carried out all of these tasks itself and followed idiosyncratic practices that clearly distinguished such a unit from others in some of these tasks.

4.4 Analytical results in a larger framework

At a size of approximately 13 ha and an assumed population between 1300 and 2600 inhabitants, Tepe Sohz was large enough to include a number of pottery workshops.

19 Pollock and Moghaddam 2018, Fig. 17.

	High Rubidium		Low Rubidium	
Painted Motif	**n**	**%**	**n**	**%**
sigmas	1	2.4		
large animals	1	2.4		
unpainted	1	2.4		
thin zigzag between lines	1	2.4		
stripes (bowl, inside)	1	2.4		
fine dots	1	2.4	1	2.1
dots between lines	2	4.9	1	2.1
comb-like motif	1	2.4	1	2.1
concentric circles	1	2.4	1	2.1
triangle row	1	2.4	1	2.1
labrys motif	1	2.4	1	2.1
turned V's	2	4.9	4	8.5
lock rim	**4**	**9.8**		
X-hatched diamonds	3	7.3		
animal & dots	3	7.3	1	2.1
sun motif	13	31.7	6	12.8
"Bakun bug"	1	2.4	*5*	*10.6*
large arrow with inner dashes	1	2.4	*3*	*6.4*
Xs			3	6.4
X-hatch triangles (inside)	1	2.4	*4*	*8.5*
blob row /tear drop row	1	2.4	*7*	*14.9*
zigzag ladder			3	6.4
vertical hatch			1	2.1
triangular comb			1	2.1
box-like motif			1	2.1
wavy-hatched			1	2.1
checkerboard			1	2.1

Tab. 3 Painted motifs on Tepe Sohz pottery associated with high vs. low rubidium sherds (bold face = lowland Susiana-related; italics = highland Fars-related motifs).

	High Rubidium		Low Rubidium	
Type of Temper	**n**	**%**	**n**	**%**
sandy	22	52.4	40	71.1
limestone	4	9.5	1	1.8
dark mineral and limestone	1	2.4	0	0
red "mineral"	5	11.9	3	5.4
red "mineral" and limestone	4	9.5	2	3.6
dark mineral	6	14.3	10	17.9
sum	**42**	**100.0**	**56**	**100.1**
limestone all	9		3	
red "mineral" all	9		5	
dark mineral all	7		10	

Tab. 4 Temper of sherds with high vs. low rubidium.

Astonishingly, Tepe Sohz did not provide surrounding villages and hamlets with its products. Even the smallest sites such as BZ 97, and potentially Tepe Millak and Tell Hajeriye, seem to have produced their own pottery. Apparently, in fifth millennium BCE southern and southwestern Iran, pottery making was a ubiquitous craft. However, the precondition for such findings is a cultural particularity for which we have yet to find an adequate explanation: societies in the Bakun- and Susiana-orbit of the fifth millennium BCE must have given painted ceramic vessels a symbolic weight that surpasses our current imagination. The findings from Tepe Sohz and surroundings are corroborated by research in the Darreh-ye Bolaghi Valley of the Zagros Mountains. For example, soundings at several small sites have revealed an astonishingly dense network of kilns and other pottery production remains, while settlements that could have used these vessels are largely absent; when they are found, they also contain evidence for pottery production.[20] Why all this effort, which must also have had deleterious consequences for the local vegetation? After all, kilns use up a lot of fuel, whether in the form of wood or charcoal, and produce annoying fumes. A different issue, however, is underscored by these results, namely, the unexpectedly local character of pottery manufacture even in later fourth millennium BCE Mesopotamia.[21]

What do these analytical results imply for Alizadeh's nomadism thesis and its alternatives of locally sedentary farmers or traders? Alizadeh's scenario of vertically migrating nomads does not seem to fit the evidence particularly well. First, contacts had apparently been established by different households to separate regions, some leaning more

20 Bernbeck, Fazeli, and Pollock 2006; Helwing 2010. **21** Emberling and Minc 2016.

towards the western lowlands and Khuzistan, others towards the Marv Dasht and, thus, the highlands. The relations to the highlands (as opposed to other regions) are not as pronounced and one-sided as one might expect if local Qashqai and Bakhtiyari nomads serve as a model. On the other hand, if nomads from the upper Zagros ranges were just showing up with a few non-local products, pottery included, the 'imports' identified with the WD-XRF could be the result of such movements. Their occurrence mainly at the center of the site supports such a view: five out of seven locatable imports come from the crossing of the two rows of trenches in the middle of the mound. Empirical evidence, i.e. the presence of Susiana-related materials as well as highland ones, fits with Hans Nissen's initial ideas of Tepe Sohz as a location on a lowland-highland trade and exchange route in a predominantly sedentary agricultural setting.

In light of the results presented here, it would be interesting to examine more closely the two modes of pottery production at the site itself. So far, it seems that at least two different groups produced the massive amount of pottery used in the ancient community. They tapped two different local clay sources with slightly different chemical compositions. The even distribution of the products of these workshops across the site of Tepe Sohz suggests that the producing entities were not tied to particular local households or other kinds of village subgroups. However, each of the workshops shows stylistic preferences that ties them into wider regional networks, one with lowland Susiana tendencies, the other with clear Bakun-related highland affinities. Taking all indications together, this might mean that pottery was produced by two groups of craftspeople with discernibly different regional ties. One could go so far as to imagine two groups of itinerant potters who produced these wares. Research on details of pottery making, including elements of the shaping and decoration process, is necessary to assess this hypothesis.

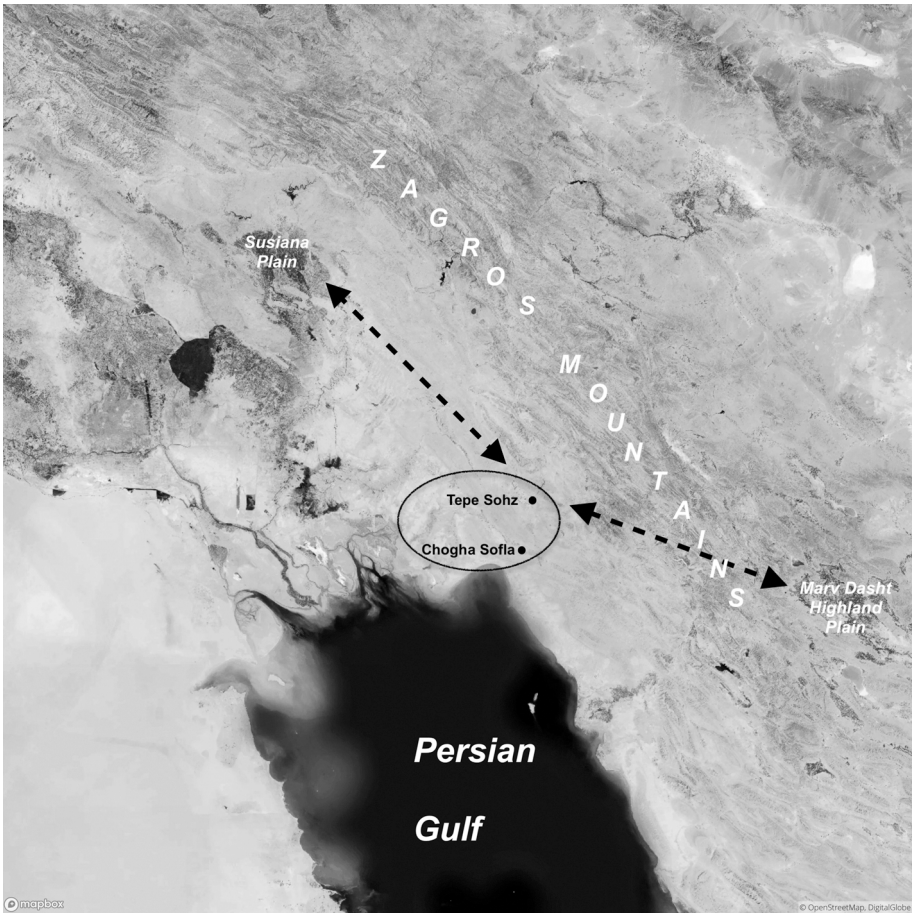


Fig. 1 Map of the regions and some sites mentioned in the text.

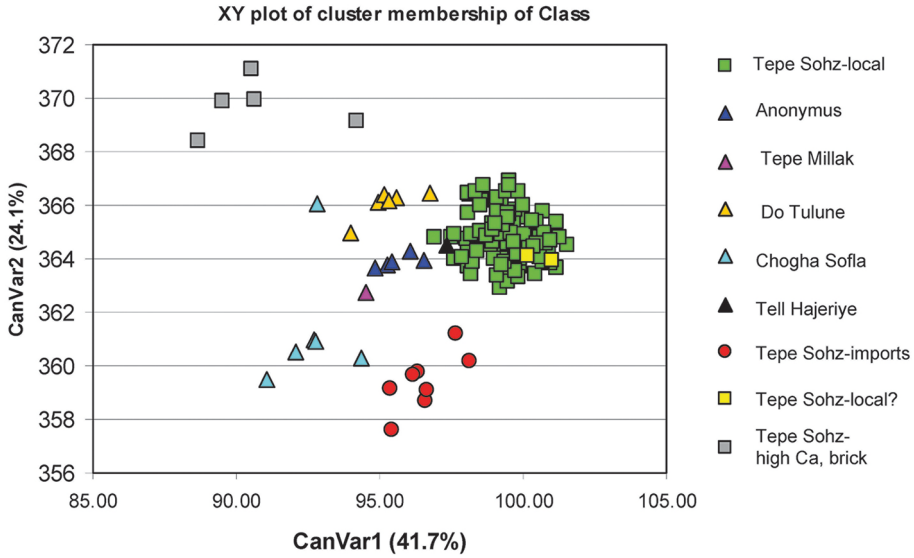


Fig. 2 Discriminant analysis of WD-XRF data for TepeSohz (sherds and building materials) and other sites (sherds only) on the Behbehan and Zohreh plains.

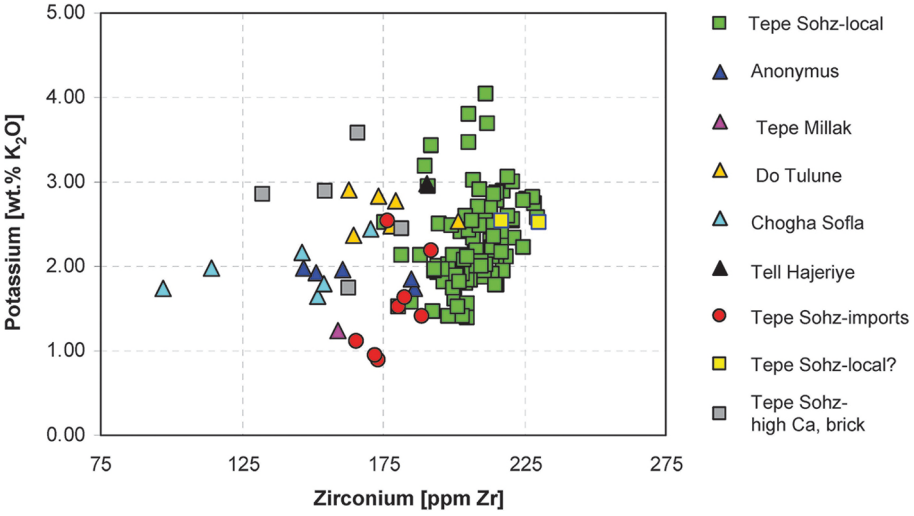


Fig. 3 Cross plot of zirconium and potassium using the same sherds as in Figure 1 (WD-XRF data).

4.2.1 Tell el-Amarna – Contribution to Research Group Publication

Saskia Nehls and Friederike Seyfried

Cultural and economic background

With respect to imported Mycenaean pottery, Tell el-Amarna holds a special place among the major cities of the New Kingdom of Egypt. Pharaoh Amenhotep IV (later Akhenaten) (reign ca. 1351–1334 BC) ordered the construction of the new city, Amarna, on the east bank of the Nile in central Egypt in the fifth year of his reign and the work was swiftly completed. After Amenophis' death in his 17th regnal year, ca. 1334 BC, the city was abandoned under the new pharaoh, Tutankhamun who chose Memphis, the old capital, as the new royal residence. Thus, the period over which Amarna was inhabited amounts to about 17 years. Amarna is the only city in Egypt known to have held imported Mycenean pottery of such high quality. A total of 1341 Mycenean objects[1] were found in Amarna during the earliest excavation there, led by F. Petrie in 1891/1892. Subsequent excavations by the Egypt Exploration Society (EES),[2] the Deutsche Orient-Gesellschaft (DOG),[3] and, starting in 1979, also those Prof. B. Kemp[4] have added to that total, bringing it to what is now estimated to be 1500–1550 objects. What is remarkable, in this respect, is not only the quality of these vessels, but also the precise timeframe of the period of occupancy of the city, during which they were brought there as imports, which point to close exchange relations with Mycenaean Greece.

1 Petrie 1894, 15–17.

2 Peet and Woolley 1923; Frankfort and Pendlebury 1933; Pendlebury 1951a; Pendlebury 1951b.

3 Borchardt 1907; Borchardt 1911; Borchardt 1912; Borchardt 1913; Borchardt 1914; Borchardt 1917; Borchardt and Ricke 1980.

4 See preliminary reports and excavation reports starting from 1979 in the *Journal of Egyptian Archaeology*, Amarna Reports I-VI and Kemp and Stevens 2010a.

> There is evidence for the existence of early relations between the two cultures even before the reign of Amenhotep IV. The earliest indications appear during the reign of Thutmose III (AD 1479–1425), as a passage in his Annals makes clear.[5] The Annals report that the pharaoh's court was visited by gift-bearing messengers from *Tnj* (*Tanaju*), today the region of the Greek mainland, while the pharaoh was on a campaign in Syria during his 42nd regnal year. Diplomatic 'gifts' served to develop and strengthen the conditions for trade and exchange. That these messengers must have come from the Aegean is evident from the nature of the gifts they offered (primarily vessels of precious metals with Aegean decorative elements).[6]

A later text, dating to the regency of Amenhotep III (1382–1344 BC), confirms that *Tanaju* is indeed situated in the Aegean region. The text in question, consisting of a list of countries and regions, is incised on the base of a colossal statue of Amenhotep III at his mortuary temple in Kom el-Hetan.[7] Based on the sequence of words and the fact that the reference to *Tnj* appears right after the word *Keftiu* (Crete), *Tanaju* is assumed to be located in the vicinity of *Keftiu* and should probably be associated with mainland Greece.[8] The Amarna letters also testify to an increasingly intensive exchange of gifts and goods of various kinds during reign of the pharaoh (Amenhotep III),[9] but the largest quantities of Mycenaean pottery in all of Egypt do not appear in the archaeological record until the time of Pharaoh Amenhotep IV (1351–1334 BC), in Amarna. This finding constitutes evidence, based on archaeological material, for direct and intensive contacts with Mycenaean Greece. There is also evidence for continuing, though declining, trade and exchange relations with Mycenaean Greece after the death of Amenhotep IV and the ordered withdrawal from the city after his 17th regnal year. These continue up to the reign of Pharaoh Ramses II (ca. 1303–1213 BC). Ultimately, the collapse of the Mycenaean civilization and the extensive destruction of the palace centers at around 1200 BC put an end to such relations, which is evident in the clear end to the appearance of Mycenaean finds in the archaeological record for Egypt from this period.

Research question

Of particular interest here, is the question of where the Mycenaean pottery from Amarna was originally produced (provenance), and to what extent this location can be precisely

5 Endesfelder and Priese 1984, especially 221–223.

6 Grave of Men-Cheper-Ra-Seneb, Thebes TT 86 see Davies 1933 and Guksch et al. 1995.

7 Bennet 2011.

8 See, for instance, Vandersleyen 2002.

9 Cf. particularly Knudtzon 1964a; Knudtzon 1964b; Moran 1992.

determined. An approximate origin of the objects can be determined using the established archaeological methods, but methods drawn from the natural sciences offer the possibility of a more precise determination of the original place of production. Specifically, archaeometric ceramic analysis can make it possible to identify among the objects, products originating in the same workshop. To date, nearly all of the comparative data available to researchers stem from neutron activation analyses (below: NAA),[10] a technique that has long been used in archaeological research.[11]

Source material and sampling strategy

A total of 18 sherds of Mycenaean pottery from the Egyptian Museum and Papyrus Collection in Berlin were selected for analysis. These consist of 10 finds from an excavation of the Exploration Fund (EEF) led by F Petrie 1891–1892,[12] and another 8 objects from excavations of the Deutsche Orient-Gesellschaft (DOG) in Amarna, led by L. Borchardt 1911–1914.[13] The actual selection of the objects that would be sampled was made in collaboration with the ceramics restoration expert N. Loschwitz of the Egyptian Museum, Berlin. Not all Mycenaean ceramic objects could be subjected to analysis because some of them are too small and/or have walls that are too thin to allow a sample to be taken without an unacceptable degree of damage. The sherds to be analyzed were selected with a view to form a series that came as close as possible to a representative cross section of the various vessel forms.

Method used

The selected method, neutron activation analysis, offered numerous advantages with respect to the research question set out above, relating to where the vessels were produced.

The Mycenaean ceramic objects from the collection of the Egyptian Museum, Berlin, were analyzed in collaboration with the physicist H. Mommsen of Bonn's

10 Cf. Manchesater archaeometric (NAA) database: http://archaeometry.missouri.edu/datasets/uman/index.html (last visited on 04/20/2020) ; Berkeley NAA database see Cf. Boulanger 2014; Catling, Richards, and Blin-Stoyle 1963; Mommsen, Beier, Diehl, et al. 1992; Mommsen, Beier, Hein, et al. 1994; Hankey 1997; Mountjoy and Mommsen 2001; Mountjoy 2008; Mühlenbruch and Mommsen 2011.

11 For around 50 years now, the method was first used by Sayre and Dodson, see Sayre and Dodson 1957; first used in its present form by Perlman and Asaro, see Perlman and Asaro 1969.

12 Inventory numbers: ÄM 12078, ÄM 12084, ÄM 12089, ÄM 12098, ÄM 12102, ÄM 12106, ÄM 12110, ÄM 12111, ÄM 12112, ÄM 12120.

13 Inventory numbers: ÄM 12126, ÄM 29424, ÄM 37088, ÄM 37093, ÄM 37097, ÄM 37109, ÄM 37125, ÄM 37129.

Fig. 1 Cleaning and extraction of sample by drilling.

Helmholtz Institute for Radiation and Nuclear Physics (HISKP), as he had the relevant reference data.[14]

In a first step, the internal surface of the sherds was cleaned with a scraper to remove impurities (Fig. 1).

In a further step, powder samples, of approximately 80 mg each, were taken from the inner side the sherds. The sample was extracted by means of a pointed sapphire (aluminium oxide) drill, 10 mm in diameter. This procedure proved very difficult due to the thinness of the walls of some of the pottery sherds, as it was imperative to avoid serious damage to these objects. Another challenge associated with some objects was the extreme hardness of the ceramic material, which made extracting a sample more difficult and required a great deal of time. Damage resulting to the sherds takes the form of a shallow depression, approx. 1–2 mm deep, on the internal surface. The relatively minor degree of destruction involved in this procedure was a key aspect, although the objects were from the museum. The powder obtained with the drill was then mixed with a cellulose powder serving as a binding agent and subsequently compressed to form a small pellet (diameter: 10 mm, thickness: 1.0 mm). In the next step of the procedure, the compressed samples, together with several Bonn pottery standard samples,[15] were irradiated with neutrons in a nuclear research reactor. After the transport of the now activated samples to the Bonn laboratory, the elemental content of the ceramic samples was measured, including the content of trace elements, which is why this method is often referred to in the literature as *chemical fingerprinting*.[16]

> The advantages of this procedure include high sensitivity[17] and precision, as well as the great versatility, which allows it to be used to measure the concentration of many elements at once in a single run.

The underlying assumption in this form of ceramic provenance determination is that vessels that exhibit the same elemental composition originate from the same place of production. The elemental content of the ceramics is determined largely by the geochemical composition of the clay deposits exploited and is, thus, an indication of place of production. This presupposes that raw clays were not being traded, which is probably a safe assumption due to lack of profitability. The raw clay is processed by the potter, who creates the clay paste from it through elutriation, the admixture of other clay and the addition of amounts of temper. As V. Hankey (†) aptly put it, "Potters, however, are rather like cooks in choosing ingredients".[18] One can assume that the clay paste is prepared on basis of a fixed 'recipe' characterized by a nearly constant quality and homogeneity; this would have prevented the misfiring of the formed vessels in the kiln and, thus, avoided economic losses. Thus, the clay pastes made by the potter determine the elemental composition of the ceramic vessels that were subsequently fired. It should be noted that the proportion of non-plastic inclusions can vary. In order to eliminate this variation in the measured values, the proportions of these values in relation to one another are considered, rather than their absolute concentrations. The focus here is on the 'relative composition' of the clay, which points to a certain place of origin. Thus, in principle, one can assume that the vessels that come from one specific workshop all exhibit the same elemental composition, within a very narrow margin. When the analysis results indicate that the elemental composition of two or more samples has the same or a very similar pattern, the samples in question are assumed to be associated with the same place of production.[19] The concentrations determined for the 29 individual elements measured indicate, with high probability, provenance in a specific geographic region, because the element pattern they present is characteristic and considered to be specific to one particular place. The greater the number of (trace) element concentrations that are measured and the more additional measurement values are obtained, such as isotope ratios, the more precisely this place of production can be defined. By comparing the measurement results acquired with the available reference data exhibiting the same or a similar element pattern, the provenance of a sample can be determined.

Once the measurement data were obtained, they were statistically evaluated with the Bonn statistical filter procedure[20] and prepared in a table format. The definite results demonstrate that with this natural scientific (archaeometric) method, the production

14 The NAA procedure used in Bonn has already been described multiple times in research literature, see, for instance, Mommsen, Lewandowski, et al. 1988; Mommsen, Kreuser, and Weber 1988; Mommsen, Beier, Hein, et al. 1994; Mommsen 2007.

15 Composition given in Mommsen and Sjöberg 2007.

16 Cf. for instance, Mommsen, Kreuser, and Weber 1988, 47; Mommsen 2007, 179–180.

17 Even chemical elements with concentrations below 1ppm (µ/g) can be measured.

18 Hankey 1979, 144.

19 See also Mommsen 2007, 181.

20 Beier and Mommsen 1994.

region of the 18 Mycenaean pottery objects of the Egyptian Museum Berlin could be identified.

Results

The results of the analyses of the objects indicate that all of the pottery vessels under study come from the northeastern part of the Peloponnese (Argolid) and form a homogenous group of clays. Thus, it was possible to assign the 18 objects analyzed to two very similar groups of clays: the groups MYBE (corresponding with Mycenae/Berbati) and MBKR (also Mycenae/Berbati, differing in the concentrations of K and Rb). H. Mommsen noted back in 2001 that the subgroup MBKR, referred to above, does not really represent an independent group, but could quite justifiably be counted as part of the core group MYBE. Minor differences detectable in this group relative to the core group of MYBE consist only in slightly different concentrations of potassium (K) and rubidium (Rb),[21] which, in Mommsen's view, do not on their own justify the assignment to a separate group. Thus, group MBKR should be classified as also belonging to the main group MYBE and the relevant samples ascribed to the same production location. All 18 ceramic sherds from the Egyptian Museum that were sampled, therefore, correspond to group MYBE. They can be classified as Late Helladic IIIA2 (ca. 1400–1200 BC), denoting a clearly defined geographic territory. The core MYBE group identifies a chemical group made up of numerous vessels from the Argolid,[22] which can now be associated with the well known Mycenaean pottery workshop in Berbati itself or other workshops in this region that used a chemically identical paste.[23] Thus far, MYBE is the core group predominating in the Mycenaean pottery that is represented throughout Egypt during the New Kingdom period.[24]

21 Mommsen, Beier, Hein, et al. 1994, 170: "A second small group of 5 sherds with pattern MBKR reveals a close similarity to the MB pattern, but can be separated statistically by its smaller K and Rb and its higher Na values. As already observed by Asaro (1977), these elements are similar chemically and can replace each other. Asaro mentioned a possible clay modification. The sum of the percentage of Na and K (expresses in atomic relative abundance dividing the weight percentages by the atomic weight) are about the same for groups MB and MBKR. The 5 sherds of this subgroup of MB, therefore, surely are also of Greek origin". Mountjoy and Mommsen 2001, 125–138.

22 Mommsen, Lewandowski, et al. 1988.

23 Mountjoy 2008, 138. "[...] it agrees statistically with the composition of the Bonn group called MYBE (Mycenae/Berbati), defined by wasters from the Mycenaean pottery workshop at Berbati".

24 See Chapter 6.

Statement of the problem – limitations of the method used

While NAA allowed the identification of a certain limited region, it did not make it possible to determine an origin in a specific workshop. The archaeological record for the geographic region of Mastos, Berbati Valley (in the immediate vicinity of Mycenae), for instance, reveals many larger and smaller-scale pottery production sites, whose numbers rose over the course of Late Helladic (LH IIIA–LH IIIB, ca. 1400–1200 BC).[25] These are generally assumed to have been largely under the control of the palace administration acting from Mycenae, and were quite probably associated with a very high degree of specialization and division of labor. To some extent, the workshops produced vessels for the local market,[26] but there must also have been larger-scale production sites in this immediate area that made pottery vessels destined for external trade.[27] Unfortunately, most of the pottery from the early excavations at Mastos was destroyed during World War II, has been lost, or can no longer be associated with a particular excavation.[28] Group MYBE is assigned to one or multiple workshops located within in the Mycenae/Berbati region.[29] Moreover, it has been shown that nearly all workshops in the Argolid produced a variety of pottery goods and types, ranging from coarse ware to the finest, richly decorated pottery forms.[30]

Mommsen and Mountjoy[31] have already described the problem presented by the larger geographic region represented by group MYBE, without a proper geographic 'delimitation'. This illustrates the limits of the capacities of archaeological and natural science analysis for determining the provenance of pottery for some cases.

25 In particular, see Åkerstrom 1967; Schallin 1997; Schallin 2002.

26 Schallin 2002, 150, 152–153.

27 Schallin 1997, 80; Schallin 2002, 153.

28 The excavation material was stored in the basement level of the Leonardo in Naplion, see Schallin 1997, 78; Schallin 2002, 151.

29 Mommsen, Beier, and Hein 2002, 620–621: "It (MYBE) was previously assigned to a workshop in the region of Mycenae /Berbati (Mommsen1988) with high probability. This is now ascertained by the analysis of several wasters from the workshop of Berbati ..." Mountjoy 2008, 138: "The wide geographical distribution of the many samples belonging to group MYBE suggests the group represents not only the Berbati workshop, but also several workshops in the Argolid and the north-eastern Peloponnese, which all have a similar geochemical clay deposit".

30 Mommsen, Beier, and Hein 2002, 627: "In apparently all workshops, the production comprised many different types of ware, including coarse products up to pottery of the highest quality like pictorial jars".

31 Mommsen, Beier, Diehl, et al. 1992, 301: "Although the supposed two Mycenaean pottery workshops in the Argolid both used geochemically closely related and probably neighbouring clay deposits with very similar composition, NAA analyses are able to ascribe the Mycenaean sherds found in Amarna to the northern production place in the Argolid, in the region around Mycenae-Berbati". Mommsen 2007, 188: "Die mykenische Keramik (hier aus Ägypten), die dem Elementmuster MYBE zugeordnet wurde, stammen mit hoher Wahrscheinlichkeit aus nur einer Werkstatt oder aus einem Produktionszentrum mit mehreren konkurrierenden Töpfereien, die alle eine ähnliche Tonmasse verwendeten". Mountjoy 2008, 138: "The wide geographical distribution of many samples belonging to group MYBE suggests the group represents not only the Berbati workshop, but also several workshops in the Argolid and the north-eastern Peloponnese, which all have a similar geochemical clay deposit".

Interpretation of the distribution images

The Mycenaean pottery from Egypt that is dated to the Late Helladic IIIA2–IIIB appears to come almost entirely from the northeastern Peloponnese, specifically, from areas in the Argolid such as Mycenae/Berbati and Tiryns/Asine. They provide an example of Egypt's increasingly intense trade and exchange relations with Greek territory and, specifically, with populations in the geographic region of the Argolid, during the 18th dynasty, particularly from the period of the reign of Amenhotep III (ca. 1388–1351 BC), until the collapse that brought the Mycenaean palatial period to a close (at around 1200 BC) brought them to a fairly abrupt end. Thus, one is left with a fixed window of time for the international trade and exchange of all kinds of products, including Mycenean pottery that was, naturally, of primary significance. The quantity of the Mycenaean pottery that has been assigned to the MYBE group, which has been shown to have been widespread in the western and eastern Mediterranean regions and in Egypt from the LH II to the end of LH III, is noteworthy and underlines the significant role that these forms of pottery played within an extensive network of trade and exchange in this period.[32] This also illustrates the long duration and continuity of production, of trade, and of the exchange of goods, which can be read in the distribution pattern of these vessels in Egypt and elsewhere.

32 Cf. Mommsen, Beier, and Hein 2002, 622: "The result collaborates the important role of the MB/MBP pottery workshop in long-range trade. [...] its sherds have been found in Asia Minor, Cyprus, Palestine, Egypt and even in Spain".

4.2.2 The Domestic Manufacture of Vitreous Materials in Late Bronze Age Egyptian and Ancient Near Eastern Settlements: Tell El-Amarna as a Case Study

Anna K. Hodgkinson

Cultural and economic context

The overall aim of the author's Marie Skłodowska-Curie project (2015–2017) was to establish an in-depth understanding of the administration and control of high-temperature industries on an urban level and the socio-economic relationship between the elite and the non-elite members of society in Late Bronze Age Egypt and the Ancient Near East (ca. 1650–1050 BC).[1] The focal site of this project is Amarna in Middle Egypt, in addition to Malqata (Upper Egypt), and Gurob (Faiyum) (Fig. 1). For purposes of comparison, an interdisciplinary examination of contemporary Egyptian and Ancient Near Eastern settlements was carried out.

The working of raw glass into finished objects and the production of faience goods were frequently, but not exclusively, found in connection with each other in the urban settlements of the Egyptian New Kingdom, which has been proved in a number of studies, both modern and early.[2] Small household bread ovens, as well as open firing, have been found to be capable of achieving temperatures sufficient for the processing of glass and the firing of faience.[3] Indicative objects such as glass rods and faience molds

1 This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 653188 (GLASS: Glass, Faience and Food in Late Bronze Age Societies: An Analysis of the Socio-Economics of Urban Industries in Egyptian and Mesopotamian Settlements).

2 Friedman 1998, 17; Shortland 2000; Shortland, Nicholson, and Jackson 2001; Nicholson 2007.

3 Eccleston 2008, 33–35; Miller 2009, 121–128. See also Wiesenberg 2016 for some experimental work in Roman glass ovens that reached temperatures sufficient for the manufacture of glass beads.

have been found in domestic buildings, and it may be postulated that these materials were processed in those locations by a non-elite population. The primary purpose of household, or bread ovens, however, was the production of foodstuffs, mainly bread, and the frequent discovery of pottery bread molds and querns for the grinding of grain emphasizes this.[4]

At a first glance, the working of raw glass into finished objects in Late Bronze Age Egypt and the Ancient Near East therefore appears to have been elite controlled and either household-based or institutionalized.[5] The glass industry has generally been considered high-status throughout Late Bronze Age Egypt, with the production of raw glass from primary materials being a royal monopoly, particularly since colorants were precious and high temperatures were required to melt the raw materials, necessitating large amounts of fuel and a specialized workforce.[6] While the manufacture of core-formed, polychrome glass vessels requires a greater set of skills,[7] the archaeological record provides evidence for the manufacture of small objects such as amulets and beads in domestic buildings. Since such items could be produced with a relatively low level of technological skill, the author believes that glass and faience were also produced in some households, with a lesser degree of elite control. A similar scenario can be reconstructed for the manufacture of faience goods, in which the manufacture of small items of jewelry or inlays is easily managed by means of molds[8], while the production of core-formed vessels or polychrome tiles required a more specialized workforce.[9]

No great level of skill appears to have been required for the production of bread or beer. However, as is the case with the manufacture of small glass and faience objects, this also appears to have been both institutionalized and household-based, with a degree of elite control.[10] At Amarna, for instance, large, industrial bakeries, which also yielded evidence of the production of glass and faience objects, were located throughout the Central City, while many more grain storage and baking facilities have been discovered in the larger houses throughout the urban areas of the settlement (Fig. 2).[11]

Most glass working and faience manufacturing remains are easily distinguishable in the archaeological record in the form of glass rods, ingots, cylindrical vessels,[12] faience molds, and unfinished products (Fig. 3). The evidence of beer and bread production,

4 Kemp, Samuel, and Luff 1994, 135, 140, 147–149.

5 Oppenheim 1970, 2–104; Shortland, Nicholson, and Jackson 2001; Nicholson 2007; Pusch and Rehren 2007; Henderson 2013.

6 Hodgkinson 2017, 38–45. See also Smirniou and Rehren 2011 for a discussion of the evidence from Amarna.

7 Nicholson 2011.

8 These (usually round or oval) clay molds are indicative of raw faience being shaped into the final product before firing: Nicholson 2009.

9 Hodgkinson 2010; Hodgkinson 2017, 45–48; Nicholson 2008; Nicholson 2009.

10 Moreno García 2012.

11 Kemp and Garfi 1993; Kemp, Samuel, and Luff 1994, 140, 147–149.

12 These vessels have been interpreted as molds for glass ingots. See Smirniou and Rehren 2016; Nicholson, Jackson, and Trott 1997.

by contrast, occurs mainly in the form of ceramic beer jars and bread molds, querns for the preparation of flour, granaries for storage, and ovens.

Objectives and methods

The main objective of the project was to establish the spatial relationship between the production of glass artefacts and that of faience goods and foodstuffs. This has been done by defining the archaeological contexts in which evidence of glass working, faience manufacture, and food production can be found, and by determining whether they are mainly private and domestic, or institutional, such as royal bakeries or magazines. As a second objective, the organization of workshops and areas of industrial activity throughout the urban sites and the infrastructures of these cities have been examined. Subsequently, the third objective was to determine how industrial activities within ancient Egyptian settlements can be compared to those taking place in contemporary Ancient Near Eastern settlement and palace sites. The fourth, and final objective was to identify export and trade facilities and networks in order to achieve an understanding of self-sufficiency on an urban level, as well as supply networks between settlements.

The analysis of the spatial relationship between the production of glass artefacts and that of faience and foodstuffs was carried out using Geographical Information Systems (GIS) technology. A GIS model encompasses the whole of the excavated settlement of Amarna and a spatial database of artefactual and archaeological evidence of the production and working of glass and the manufacture of faience objects alongside other industries.

The use of GIS in archaeology has become increasingly common in the last decades. It has become recognized as a modern and efficient tool capable of analyzing object distribution patterns and, thus, efficiently extracting knowledge of the function of various areas of archaeological sites and their infrastructure and organization.[13] The GIS model of Amarna mentioned above has already been used for a spatial analysis of the evidence of production and identification of areas of concentrated industrial activity throughout Amarna, which has led to the recognition of control patterns with regard to raw materials and finished objects, as well as patterns in the consumption of finished objects.[14] The present analysis of the organization of workshops and areas of industrial activity throughout the other urban sites and their infrastructures, within both Late Bronze Age Egypt and the Ancient Near East is also being carried out using GIS. A theoretical

13 Hodder and Orton 1976; Connoly and Lake 2006; Verhagen and Gazenbeek 2006.

14 Hodgkinson 2017.

approach to the identification of industrial activities and craft specialization across archaeological sites has been produced by C. Costin, and is used as a theoretical basis for the analysis of the evidence.[15] Other theories on Late Bronze Age urban industries are also being taken into account.[16]

Data: sources and collection methods

A detailed database has been produced containing information on all bread ovens, kilns, and other firing structures, together with silos and querns found at Amarna. This information has been extracted from publications,[17] archive material, and base maps.[18] The existing dataset for Amarna has been enhanced by unpublished resources, including large quantities of raw and unfinished glass objects in the collection of the Ägyptisches Museum und Papyrussammlung der Staatlichen Museen zu Berlin, Stiftung Preußischer Kulturbesitz (Egyptian Museum and Papyrus Collection = ÄMP) from the early 20th-century excavations at Amarna. Additional information has been acquired through visits to the archives of the Egypt Exploration Society and the Petrie Museum of Egyptian Archaeology, London, which house the excavation records from early British missions to Amarna. In addition, the objects from more recent excavation work at Amarna have been integrated.[19] For comparison, the primary survey and excavation archive of the current mission to Gurob have been consulted.[20] Further information on the nature of industrial activities at Malqata has been gained through a detailed study of the relevant materials and the archive in the Metropolitan Museum, New York, as well as a bibliographic study of the Ancient Near Eastern material. Based on the precise plotting of all relevant material raster (heat-)maps have been developed, which in turn have enabled the identification of areas of concentrated industrial activity and overlaps in object categories, i.e. the occurrence of objects related to glass and faience industries, together with ovens, indicating the production of foodstuffs.

15 Costin 1991.

16 See, for example, Kemp 1977; Yoffee 2005.

17 See, for instance, Nicholson 1989; Nicholson 2010. Data from early excavations has been extracted from Borchardt and Ricke 1980; Petrie 1894; Peet and Woolley 1923; Frankfort and Pendlebury 1933; Pendlebury 1951a. The object cards from the early excavations of the Egypt Exploration Society have been digitized and can be found on the website of the Amarna Project (Stevens 2007) as a spreadsheet and on the Flickr page of the Egypt Exploration Society (https://www.flickr.com/photos/egyptexplorationsociety/albums. Last accessed 06/14/2021).

18 Kemp and Garfi 1993. A visual inspection of the surface at Amarna is in preparation.

19 See, for instance, Nicholson 2007; Kemp and Stevens 2010a; Kemp and Stevens 2010b; Kemp 2012; Hodgkinson 2015 for excavations in the Main City South. The discrepancy in amounts of data from modern and from early excavation discernible in the GIS has been taken into account.

20 The author has also carried out the excavation of a workshop area at Gurob: Hodgkinson 2012, although it is not certain whether glass or faience were manufactured or worked in this area.

Results and relevance

The results from this analysis highlight how elite control influenced these domestic industries in an urban setting, and to what extent this influenced the role of the members of a non-elite population and the urban infrastructure.

The organization of glass working and production in the Late Bronze Age Egyptian settlements, including Amarna and Malqata, appears to have been less strict than those found in the Ancient Near East. The range of workshop types in the Egyptian settlements is larger, including both institutional and domestic working. While small workshops were found dispersed throughout Egyptian settlements, there is evidence of specialization in large, individual workshops or factories, or in spatial clusters of smaller workshops, alongside pottery, metal and food production.[21] Integrated crafts where various types of craft activity occurred together in the same workshop, sometimes linked by specialization or technology, were frequent at Amarna. The dispersal of large numbers of workshops throughout the city was necessary in order to serve the need for attractive vitreous materials for the large groups of people that came to Amarna. The production of large quantities of vitreous materials at Malqata was possible through the concentration of manufacture in various areas of settlement throughout the site.[22]

Firing structures found at domestic workshops were usually small and sometimes ephemeral. It can be assumed that some glass working and faience production took place in household ovens or even in rudimentary fire pits.[23] The absence of ovens in a cluster of small houses within Amarna's Main City (Fig. 4) can be interpreted in two ways: 1) open firing or small fire pits were used for production, resulting in voids in the archaeological record and 2) any ovens or more substantial firing structures have been lost due to the poor nature of preservation of archaeological material in this area. Large and specialized firing structures were found in the northern and southern parts of the Main City, where site O45.1 in particular appears to have served the royal court, manufacturing raw glass from its base materials.[24] It is even possible that Amarna produced the blue glass ingots found on the Late Bronze Age Uluburun shipwreck, since the chemical fingerprint of these is similar to that of blue glass objects from Amarna,[25] and

21 A tripartite hierarchy in types of workshop across Amarna has already been recognized by Kemp 1989, although it is believed that the boundaries of this were a great deal more fluent.

22 Hodgkinson 2017, 227–229.

23 See Krzyżanowska and Frankiewicz 2015 for the description of an experiment using a fire pit to produce glass beads. A series of archaeological experiments took place at Amarna between 2017 and 2019, where more than 1000°C were reached in a fire pit, and glass beads were produced (Hodgkinson and Bertram 2020).

24 See Nicholson and Jackson 2007. Cf. Smirniou and Rehren 2011.

25 See Jackson and Nicholson 2010 and Hodgkinson 2015.

due to the discovery in 2014 of a similar glass ingot at Amarna site M50.14–16 (Figs. 2 and 3).[26]

By contrast, the manufacture of vitreous materials at the Near Eastern sites of Tell Brak, Ugarit, and Alalalakh appears to have been under royal (and elite) control.[27] The two former sites yielded evidence of vitreous materials manufacture even within the palace walls, while recent excavations at the latter site unearthed an urban glass workshop with specialized kilns, not unlike workshop O45.1 at Amarna in character and layout.[28]

A degree of royal and elite control can be assumed for the processing of materials of high value probably in specialized Egyptian workshops, since some of the raw materials, particularly colorants, had to be brought in from expeditions to, for instance, the western oases.[29] The presence of copper colorant indicates that it was brought to the glass workshops as a by-product from nearby metal workshops by means of an internal network of exchange, unless, of course, it was integrated in the same workshop setting.[30]

In conclusion, it can be stated that the spatial analysis of industrial evidence of vitreous materials' manufacture and processing, together with the occurrence of firing structures in the domestic and institutional workshops of the Late Bronze Age settlements, has been successful in identifying areas of industrial activity. It has been possible to examine the industrial landscape and to classify workshop types and to learn more about the organization of production at these sites. It can be said that the Egyptian cities appear to have had a much more diverse industrial landscape than those found in the Ancient Near East.

The potential of chemical analysis

The chemical analysis of the glass and faience objects from Amarna by means of portable X-Ray Fluorescence (pXRF) was the focus of a post-doctoral project conducted by the author in 2017-2018 and funded by Topoi.[31] Chemical analysis was carried out in order to identify compositional groups, with a particular focus on colorants and trace elements. This work made possible the identification of raw materials in finished objects among

26 Hodgkinson 2015.

27 For Tell Brak: Matoïan 1997. For Ugarit: Matoïan 2000; Matoïan and Bouquillon 2003. For Alalakh: Dardeniz 2017.

28 See, for example, Hodgkinson, Anna K. "The Urban Vitreous Materials Workshops of the Late Bronze Age: Using GIS to Analyse the Evidence of Glass-Working and Faience Manufacture in Domestic and Institutional Buildings in Egypt and Mesopotamia". In *Innovations in the Technologies of Glass, Proceedings of the Workshop "Innovations in the Technologies of Glass", Berlin, July 2016.* Ed. by Klimscha, F. (in preparation); Henderson 2013, 139, 142–143; Nicholson 2007; Dardeniz 2017.

29 Shortland, Tite, and Ewart 2006, 163.

30 Mass, Wypyski, and Stone 2002; Hodgkinson 2020.

31 https://www.topoi.org/project/plus-8/ (last accessed 14.06.2021).

the various workshops at Amarna and the reconstruction of industrial exchange networks, both within and outside the city.[32] The focus of this project is the distribution and use of cobalt as a raw material. The on-site analysis of archaeological material carried out as part of this project is of particular value on account of a strict export ban of antiquities from Egypt,[33] which makes detailed chemical analysis of this material very difficult.

A pilot study was carried out on material from Amarna in 2015–2016 using a NITON XL3t GOLDD+ ED (energy dispersive)-XRF analyzer.[34] The instrument was calibrated using a total of 11 standard reference materials, and each object was measured several times, with a measurement time of 120 seconds at 53 KeV using both the 3 mm and 8 mm sample spot sizes. After every 20 measurements, the Corning A reference standard, which best reflects the average composition of the glasses studied, was measured in order to monitor the consistency. The study was carried out on 68 glass objects from Amarna in the ÄMP, including glass rods, flattened strips, an unfinished glass bead, fragments of raw glass ingots, and one ceramic shard with raw glass adhering to it, as well as some fragments of glass vessels with polychrome decoration and some items of glass jewelry (Fig. 5). Both the raw spectra and the automatically generated output from the instrument, which gives the measurement results in weight percent, were evaluated and normalized.

The two-part pilot study has demonstrated the possibility of identifying colorants used in the production of glass and faience by means of semi-quantitative analysis. These include cobalt and copper, which are responsible for dark and light blue or turquoise glass objects, in addition to lead, for yellow glass, or green, together with copper. Antimony, which was commonly used as an opacifier, can also be detected using pXRF, although only by means of qualitative, analysis, while most major and minor elements cannot be detected with confidence.[35]

The detection of cobalt and copper, together with relevant elements, has a special significance in the analysis of the industrial landscape of Amarna, in particular with regard to the organization of workshops and the use and exchange of raw materials. Cobalt (Co), for instance, was used in the production of pigments for the decoration of ceramics or architecture as well as glass and faience, and it could be combined with

32 See Hodgkinson 2016 for the results of a preliminary study carried out in 2015 using pXRF on glass objects from Amarna in the Egyptian collection in Berlin.

33 See Egypt – Ministry of Culture – Supreme Council of Antiquities n.d.

34 The author wishes to express her gratitude to Phillip Hoelzmann and Frank Kutz (Institute of Geographical Sciences, Freie Universität Berlin); Gerwulf Schneider, Małgorzata Daszkiewicz (Excellence Cluster *Topoi*), Friederike Seyfried, and Nina Loschwitz (Ägyptisches Museum und Papyrussammlung der Staatlichen Museen zu Berlin, Stiftung Preußischer Kulturbesitz).

35 Kaiser and Shugar 2012.

copper (Cu) to produce a variety of shades of dark blue.[36] Hence, the presence of elevated aluminium (Al) and magnesia (Mg) values (not obtainable by pXRF), together with the transition metals, nickel (Ni), zinc (Zn), and manganese (Mn) (correlating with cobalt, and all three obtainable by pXRF) can be considered characteristic of raw material brought into Egypt from the Western Desert (Fig. 6).[37] Simultaneously, a different pattern of transitional metals may point to a different geological cobalt source.[38]

Copper (Cu) was commonly used as a raw material for the production of bronze, usually as a copper-tin alloy, the copper being imported from a variety of sources such as the Egyptian Eastern Desert, Timna, and Cyprus.[39] Since copper was used for the light blue or turquoise color of glass and faience, scraps from metal workshops were often used for the coloring of vitreous materials.[40] Due to this, the presence and levels of tin in vitreous objects of a light blue color indicates the use of scrap metal in the workshops, and possibly the exchange of such materials between various workshops.[41]

It is important to note that pXRF is a surface analysis method that requires no sample preparation and can therefore be used in a non-destructive manner.[42] However, due to glass corrosion and weathering, the chemical composition of the glass objects, in particular the surface composition, may alter due to oxygen leaching and alkali depletion.[43] The pilot study included the partial polishing of a sample set of glass objects from Amarna in the Berlin collection (ÄM 36902, ÄM 36900, ÄM 39937, and ÄM 30848: see Fig. 5), the results being compared and taken into account for the analyses of the unpolished glass objects. While the readings for calcium oxide (CaO) and silicon dioxide (SiO_2) changed significantly, only minor changes were detected in nickel (Ni), zinc (Zn), manganese (Mn), iron oxide (Fe_2O_3), and potassium oxide (K_2O) values. Since the limits of detection are relatively low for some elements in the pXRF machine used, the four polished glass objects were analyzed using a scanning electron microscope FEI Quanta 400, equipped with an X-ray spectrometer (SEM-EDX) at the Rathgen-Forschungslabor in Berlin (Staatliche Museen zu Berlin, Stiftung Preußischer Kulturbesitz).[44] Differences between the minor elements detected by SEM-EDX and the pXRF were noted, although the SEM-EDX is generally more suitable for the detection of main elements. The detection of trace elements, such as zirconium (Zr) and titanium (Ti), which are indicative of an Egyptian or Mesopotamian origin of the glass

36 See Tite and Shortland 2003; Shortland, Tite, and Ewart 2006; see also Smirniou and Rehren 2013.

37 Kaczmarczyk 1986; cf. Tite and Shortland 2003, 294. Abe et al. 2012 achieved a distinction of cobalt colourant from various geological sources by means of transition metal analysis by pXRF.

38 See Walton et al. 2012.

39 Rademakers, Rehren, and Pusch 2018.

40 Shortland 2009, 2.

41 See, for instance, Rademakers, Rehren, and Pusch 2018; Smirniou and Rehren 2013; cf. Rehren, Pusch, and Herold 1998.

42 Kaiser and Shugar 2012, 449.

43 Kaiser and Shugar 2012, 458, 464–466.

44 The author would like to express her thanks to Ina Reiche and Stefan Röhrs for facilitating and carrying out the SEM-EDX analyses at the Rathgen-Forschungslabor.

objects, and which is routinely done by LA-ICP-MS,[45] is not possible by pXRF. In early 2018, a pXRF device by the company ELIO / XGLabs (owned by the Staatliche Museen zu Berlin, Stiftung Preußischer Kulturbesitz) was taken to Amarna, and a large number of blue glass and faience objects were analyzed. It was possible to detect and to obtain semi-quantitative measurements for transition metals (Ni, Zn, Mn). Most workshops at Amarna appear to have used a cobalt ore from the same source, although there were some differences.[46] In order to verify the results obtained for the transition metals in the cobalt-coloured objects, LA-ICP-MS analyses were carried out on the glass objects from Amarna at the Geoforschungszentrum / Helmholtz.[47]

In order to verify the detection of trace elements, such as zirconium (Zr) and titanium (Ti) by pXRF, it is planned to carry out LA-ICP-MS analyses on the glass objects from Amarna.

The majority of the ca. 175 glass ingots found on the Uluburun shipwreck was colored with either cobalt or copper, or with a combination of the two, while their overall chemical fingerprint adheres to an overall Egyptian chemical pattern with regard to trace elements. In order to gain information on the exact origin and manufacture of these ingots, the comparison of their trace elemental composition with that of glass objects from Amarna is of great importance. This has already been done to an extent,[48] although only the minority of the comparable objects from Amarna were from secured archaeological contexts. Since workshop site M50.14–16 yielded an Uluburun-sized ingot fragment, it would be of great importance to continue this comparison on the contextualized material at Amarna in the future. In addition, the analysis of trace elements associated with the copper colorant in glass from Amarna and the copper ingots from the Uluburun shipwreck, as well as the comparison of Egyptian glass with glass adhering to a Mesopotamian chemical fingerprint, would provide useful information on the contemporary trade in copper.

In summary, the determination of colorants and associated trace elements and transition metals by means of chemical analysis employing pXRF, it is possible for us to draw conclusions concerning the organization of individual workshops within a settlement site such as Amarna with regard to such aspects as multifunctionality, specialization, scale, and raw materials exchange. The analysis of raw materials, in addition to glass, metals, and pigments from various origins throughout the Mediterranean and the Ancient Near East during the Late Bronze Age will provide a thorough insight into the value of glass and copper during this time.

45 See, for instance, Shortland, Rogers, and Eremin 2007.

46 See Hodgkinson, Röhrs, et al. 2019b and Hodgkinson, Röhrs, et al. 2019a for the data publication.

47 See Hodgkinson and Frick 2020b and Hodgkinson and Frick 2020a for the data publication.

48 Jackson and Nicholson 2010.

Fig. 1 Sites discussed in this paper.

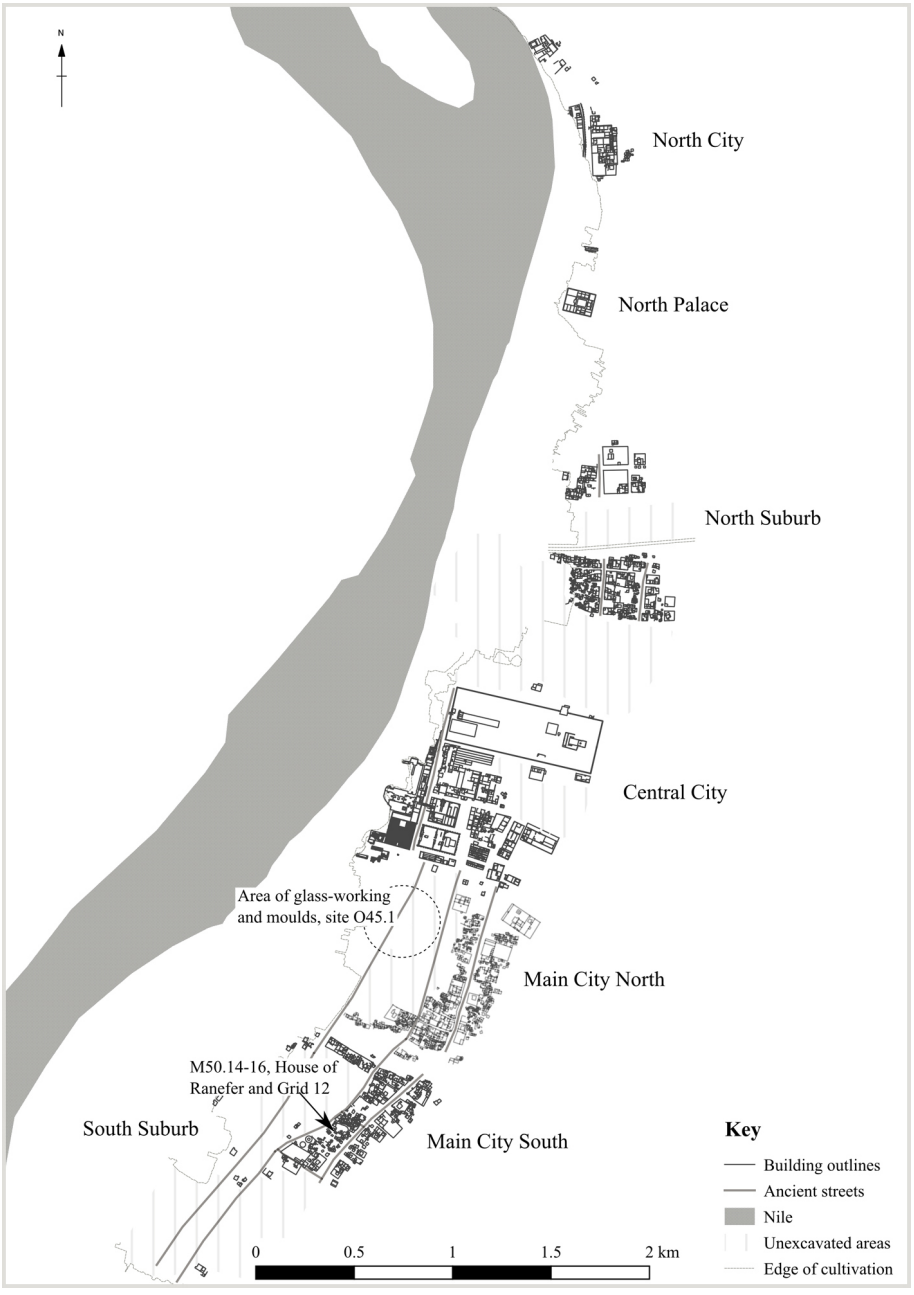


Fig. 2 Map of Amarna showing the locations discussed in this chapter.

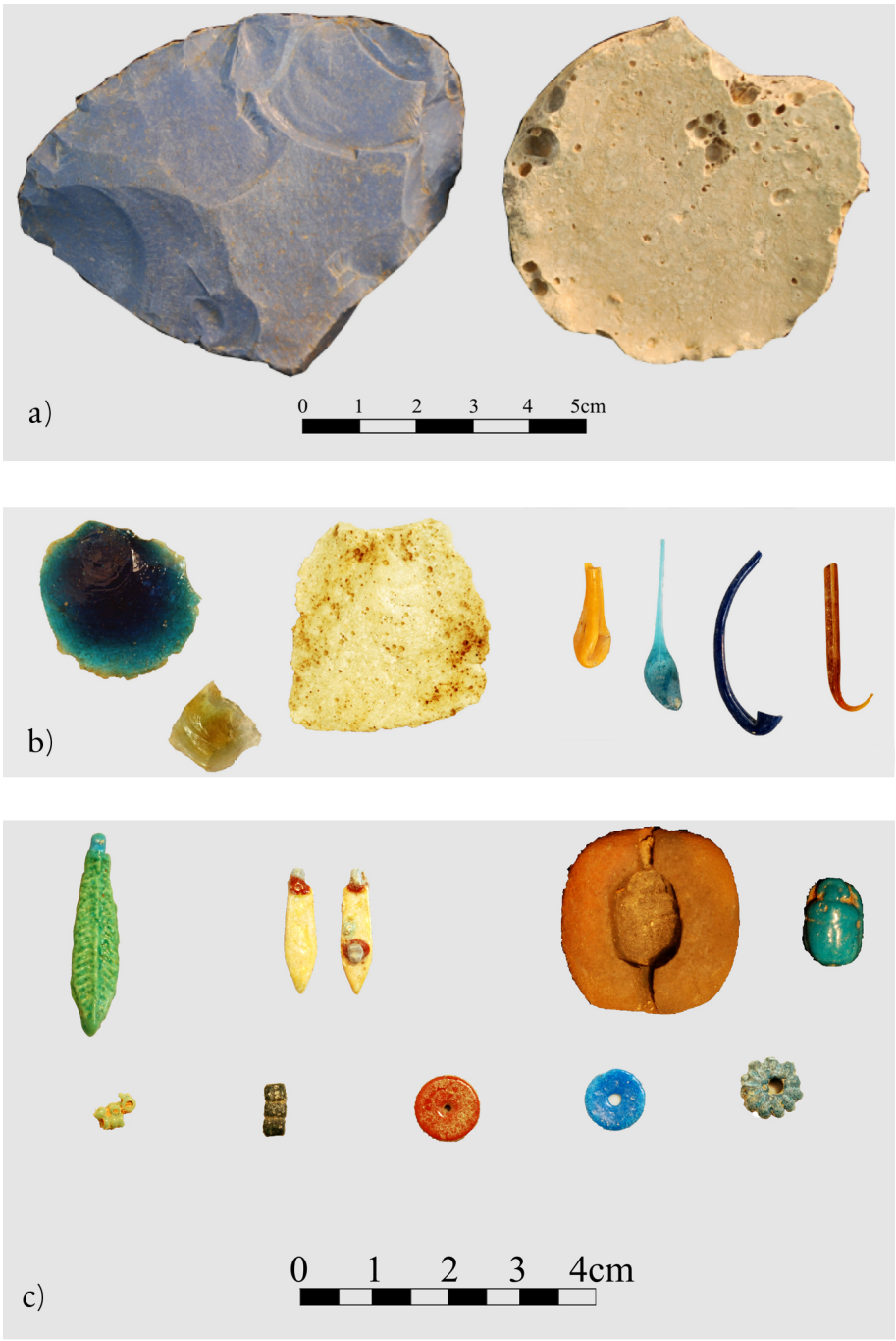


Fig. 3 Glass working and faience-production objects from Amarna site M50.14–16, excavated in 2014.

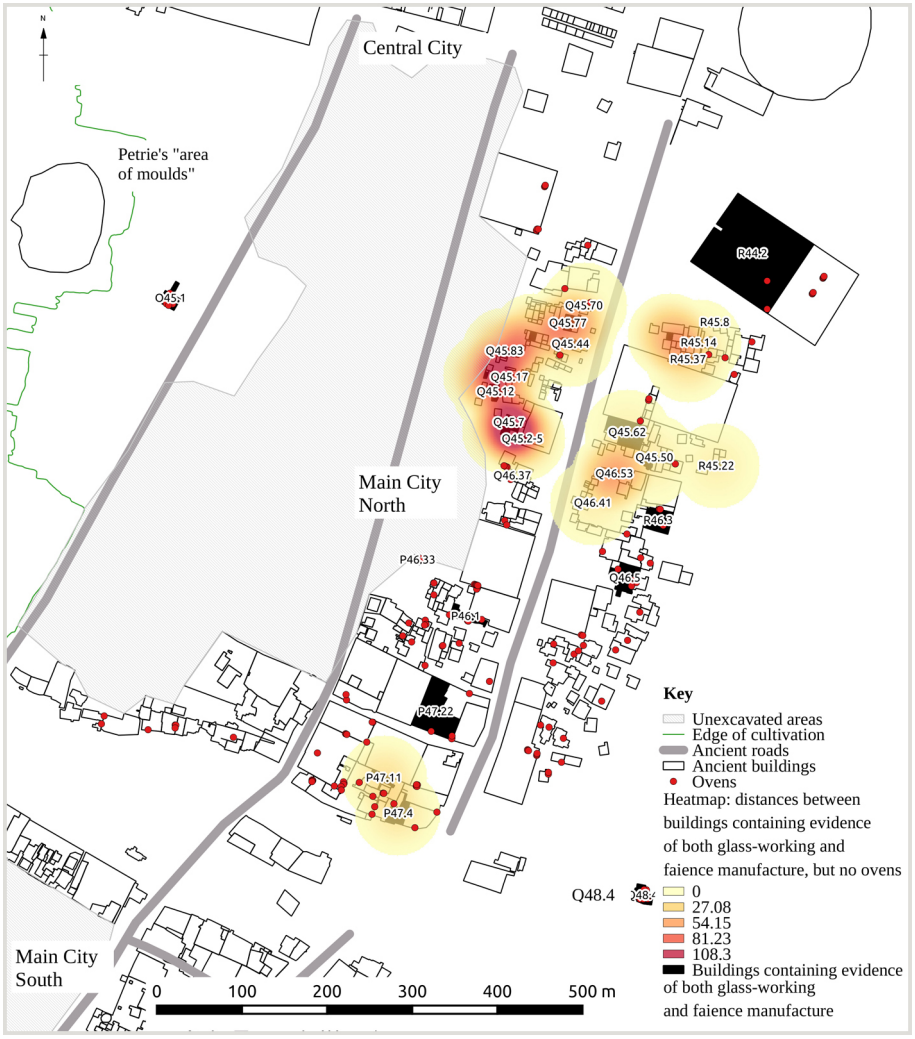


Fig. 4 The houses in the Main City North at Amarna containing evidence of glass working and faience manufacture. The heat map shows the distance between the houses without an oven to the nearest oven.

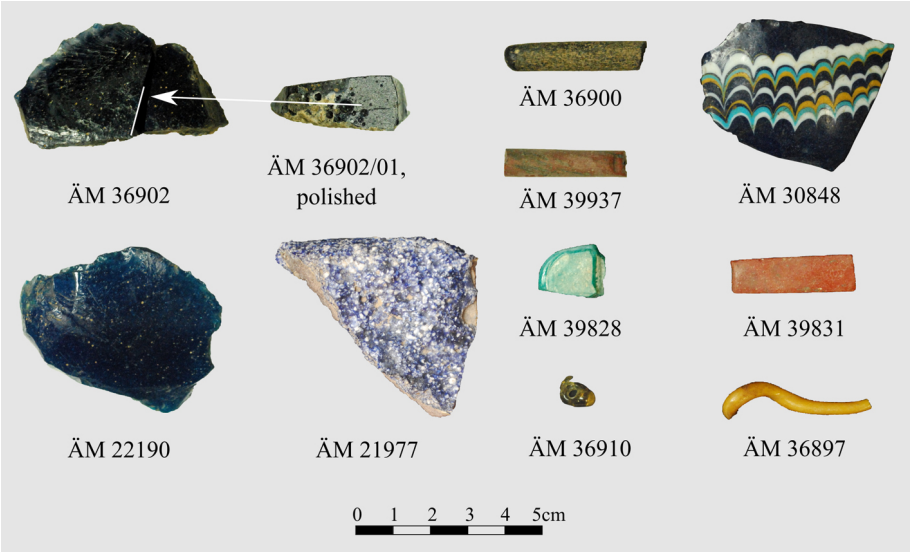


Fig. 5 A selection of glass objects from Amarna analyzed with pXRF in 2015 and 2016 in the collection of the Egyptian Museum Berlin.

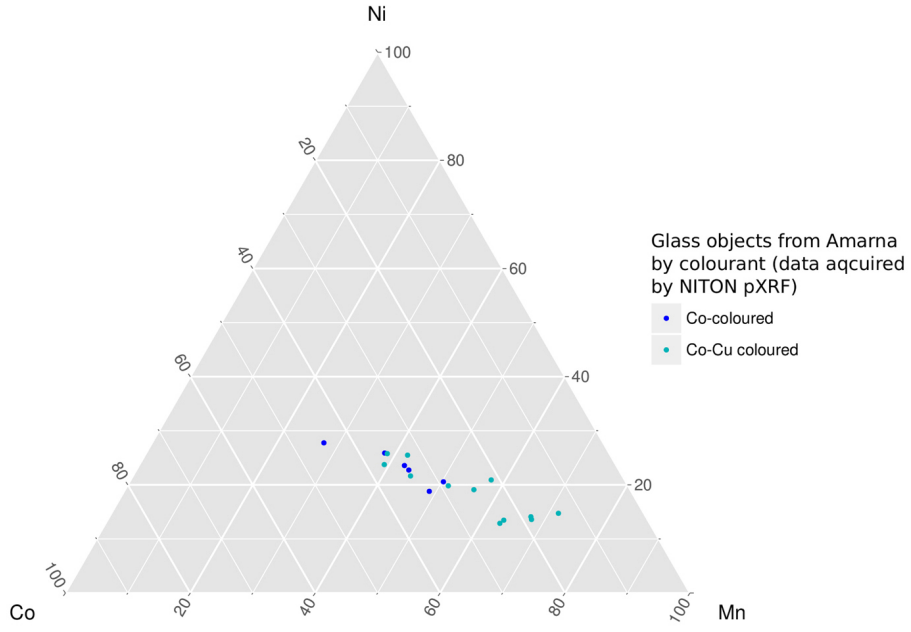


Fig. 6 The normalized values for Co, Ni and Mn as obtained by pXRF plotted in a ternary diagram, showing the clustering of Co- and Co-Cu colored objects. This highlights the correlation of cobalt with the transitional metals characteristic of raw material from the Egyptian western desert.

4.3 Understanding Meroitic Pottery and Its Production – Research Design and Methodology of an Interdisciplinary Research Project

Claudia Näser, Manja Wetendorf, Małgorzata Daszkiewicz, Gerwulf Schneider
(with contributions by Ewa Bobryk)

The study site

Musawwarat es-Sufra is located about 180 km northeast of the modern Sudanese capital Khartoum and 25 km away from the Nile in the semiarid landscape of the Keraba. Its main archaeological remains are distributed over a core zone of ca. 1 x 3.5 km within a wide wadi bordered by escarpments of Cretaceous sandstone plateaus. The site was a major sacral center of the Meroitic period (ca. 300 BC–AD 350) and the earliest evidence of the will of the Meroitic rulers to integrate the regions away from the Nile Valley into their socio-political sphere of influence. As Musawwarat shows, one of the means to realize this ambition was to turn these regions into an arena of religious life by equipping them with temples and making them part of the Empire's religious topography.[1]

The main monument of Musawwarat is the so-called Great Enclosure (Fig. 1), an architecturally unique assemblage that covers an area of ca. 43 000 m² and comprises several building complexes that are partly erected on artificial terraces; connected by ramps, corridors, and passages; and surrounded by huge walled courtyards. The function as well as the exact chronological attribution of the Great Enclosure are still widely debated, not least because it almost completely lacks formal decoration i.e., reliefs and related inscriptions, which could aid interpretation. Its first excavator suggested it was a religious site and pilgrimage center, whose central Temple 100 was dedicated to Amun-Ra, while the courtyards may have served as gathering and sheltering places for the large

1 Bebermeier et al. 2016, 21.

crowds coming from the Nile Valley during religious festivals.[2] Later researchers saw it as the Meroitic 'National Shrine', as the main place of worship of the Meroitic lion god Apedemak, or as a palace and a place of investiture of the Meroitic kings.[3] Today, it is widely accepted that the three main building complexes represent temples and that many of the ancillary rooms were related to cult activities and the presence of the king during religious ceremonies.[4] Recent 14-C dates confirm older investigations that suggest that most of the extant parts of the Great Enclosure belong to the early Meroitic period, i.e. the 3rd to 2nd centuries BC.[5]

In 1997, excavations in one of the courtyards of the Great Enclosure revealed a substantial deposit of a loose ashy material that was of up to 0.8 m thick and contained a substantial amount of potsherds. Its interpretation as the dump of a pottery workshop[6] was supported by the finding of potter's tools, including stamps for impressed decoration, pigments, and production debris within the debris. In addition, parts of a potter's wheel had already come to light in the excavations of the 1960s in a room (Room 225, 225.3 in Fig. 2) adjacent to the courtyard.[7] Due to the amount of finds – in all 25 000 sherds from a 25 m² trench – the investigation of the deposit was suspended after one season. The ceramic material was subjected to a first analysis by David Edwards,[8] who also outlined a preliminary fabric series based on earlier work by Anne Seiler on another pottery corpus from Musawwarat.[9] Edwards identified fabric groups A (Nile silt), B (mixed clay), and C (kaolin), and introduced fabric group H, which according to him represents pottery "manufactured from locally-dug wadi silts".[10] He also noted the "unusual nature of the assemblage as a whole, which includes a relatively limited number of different wares or fabric types, while being quantitatively dominated by a single (local) range of products".[11]

Work in the 'pottery courtyard' was resumed in 2013, with the aim to exploit the unique potential of the assemblage more fully and to study the production and consumption of ceramics at the site using a combination of archaeological, ceramological, geophysical, and ethnoarchaeological research components.[12] This multi-perspective

2 F. Hintze and U. Hintze 1970, 50; F. Hintze 1984, 337–338.
3 For a synopsis of the history of these interpretations see Wolf 2001.
4 Eigner 1999; Eigner 2010; Wolf 2001.
5 Scheibner 2011; Näser 2016.
6 Wenig and Wolf 1998, 29–33; Edwards 1998; Edwards 1999.
7 Edwards 1999, 42, Fig. 5, pls. 6.32–34; Näser and Wetendorf 2015, 56, 63.
8 Edwards 1998; Edwards 1999.
9 Seiler 1998; Seiler 1999.
10 Edwards 1999, 18, 27.
11 Edwards 1999, 16.
12 This project was conducted under the auspices of the Qatar–Sudan Archaeological Project (2013–2015) and the Berlin Topoi Excellence Cluster (2013–2018), see http://www.topoi.org/project/a-6-5/ (last visited on 04/20/2020). Parts of the analysis were funded by the Warsaw University of Technology. The support of these institutions is gratefully acknowledged. The authors also thank the colleagues of the National Corporation for Antiquities and Museums of Sudan, particularly its director general, Dr Abdelrahman Ali, for their support and the permission to export samples for analysis.

approach should also allow researchers to gain a firmer ground for placing the results of the investigation at Musawwarat into the wider patterns of distribution and use of pottery in the Meroitic period and to use this group of materials to study how Musawwarat was integrated into the wider social, cultural, economic, and political contexts of the Meroitic Empire. Fieldwork at the site was undertaken from 2014 to 2015 (Fig. 2);[13] the study of the find material is ongoing.[14]

Research strategy and implementation

The following chapter describes the trajectory of the 'Musawwarat Pottery Project' from its start in 2013 up to its current state in mid-2017, discussing the starting points of the analyses, data recovery, and sampling strategies; the integration of the individual strands of the investigation; and how results – expected and unexpected – informed the subsequent steps and progress of the overall research strategy.

Kick-off analysis

Prior to starting new excavations and generating new finds, the first step of the project was to analyze a first series of samples (n=39) from the 1997 excavations, in order to build a preliminary classification that would facilitate and inform the processing of the new finds by providing a prior knowledge of the range of fabric groups that were to be expected. This step proved to be crucial, as it saved valuable time when dealing with the first bulk of newly excavated material. The first series of samples was chosen in a systematic re-examination of the diagnostic material of the 1997 excavation. The series should encompass both fine ware and coarse ware sherds representing a spectrum of macroscopically differentiable fabrics, as well as different form and decoration types.[15] All samples were subjected to abridged MGR-analysis and chemical analysis by WD-XRF. A seminal corpus of reference for this material is the 'Sudan Database' (SDB) containing the results of analyses on archaeological pottery and raw materials from Sudan conducted by Małgorzata Daszkiewicz since 1991. Currently, the SDB comprises 1235 entries deriving from ceramic fragments dating from the Mesolithic to the Medieval period and 120 entries relating to chemically analyzed raw materials.

13 Näser and Wetendorf 2014, Näser and Wetendorf 2015.

14 Näser and Daszkiewicz 2013; Daszkiewicz and Wetendorf 2014; Daszkiewicz, G. Schneider, Wetendorf, et al. 2015; Daszkiewicz, Bobryk, and Wetendorf 2016; Daszkiewicz, Wetendorf, et al. 2016; Daszkiewicz and Wetendorf 2017; Näser and Wetendorf 2014, Näser and Wetendorf 2015.

15 Due to the small amount of handmade wares, as well as the general assumption that handmade pottery should represent household production, the focus of selected samples was on wheel made coarse wares and fine ware pottery.

The results of the archaeometric analysis indicated:[16]

– that all analyzed samples were made of raw materials sourced from the same region,

– that they represent a raw material group which was not documented from any other site in the Middle Nile Valley so far, and

– this group also includes sherds from Musawwarat analyzed in a previous study.[17]

In sum, this kick-off analysis from 'old' material strongly suggested that all sampled pottery was produced from local raw material in Musawwarat in a workshop whose existence is evidenced by the dump in Courtyard 224. The analysis further revealed that 19 coarse ware samples from this series (MGR-groups 101, 102, 102.1, and 102.2) were made from wadi clays – thus, corresponding to fabric group H in Edward's classification – with low contents of potassium and tempered with varying amounts of conglomerates of quartz with a white firing matrix. These samples were lumped as reference group Mus4 in the SDB. In contrast, the fine wares of the sample group were made from ceramic bodies featuring a variety of recipes based on kaolinitic clays colored by iron compounds. They were preliminarily divided into three groups (reference groups Mus1–3 in the SDB). Together, these groups seemed to represent the bulk of the local pottery production present in the dump of Courtyard 224.

Generation of find material and first series of refinement analyses

After the results of the first analyses had been obtained, archaeological investigations were resumed with a new trench in the dump, next to the 1997 excavation. Stratigraphic findings of the earlier seasons could be refined and complemented with the first 14C-dates.[18] They indicated that pottery production at the site may have started in the 1st century BC and continued into the 1st and possibly 2nd centuries AD.

In this first season, ca. 9000 sherds with a total weight of 365 kg were recovered. Of these, ca. 2000 pieces (equaling 42 kg) were diagnostic and ca. 7000 pieces (equaling 323 kg) were non-diagnostic. All sherds were macroscopically classed by fabric in the field, based on the groups identified in the laboratory kick-off analysis. While this was partly successful, the process also showed that macroscopic identification was difficult, and that also shapes, surface treatments, and types of decoration did not provide safe

16 Näser and Daszkiewicz 2013.
17 Gerullat 2001; Daszkiewicz and G. Schneider 2001a, chemical group GI.
18 Näser and Wetendorf 2014.

criteria for distinction.[19] It also became clear that more attention should be given to the handmade wares, a group that had been neglected in the first series of samples. Despite the fact that they represented less than 1% of the overall corpus, it was obvious from the macroscopic analysis that their fabrics differed significantly from the range established for the wheelmade wares. They were provisionally classified into four main groups and three sub-groups.

To evaluate and refine the results of this first round of macroscopic analysis in the field, a second series of archaeometric analyses was initiated, focusing on the wheelmade coarse wares and the handmade wares (n=35). Again, all these samples were subjected to abridged MGR-analysis and chemical analysis by WD-XRF.

This second series confirmed the identification of the group of wheelmade coarse wares (Mus4) that were made from ceramic bodies of similar chemical and mineralogical composition and represent a local production. Adding to the results of the first analysis, it also emerged more clearly that wheelmade fine ware and coarse ware were made from wadi clays with similar geochemical parameters. In addition, several samples represented pottery made from other wadi clays of probably local or regional origin. The handmade coarse ware specimens (with the exception of two sherds) were not locally produced, but came from elsewhere and include vessels made from various Nile alluvial clays and other clays of different unidentified origins (Fig. 3).[20]

Generation of further find material and second series of refinement analyses

In 2015, excavations continued and produced another 18 000 sherds with a weight of 673 kg. Of these, 2000 were diagnostic (equaling 75 kg), while 16 000 were non-diagnostic (equaling 598 kg). On top of that, numerous tools and gadgets used in pottery production, such as stamps for decorating fine ware pottery, polishing stones, and a turning device were registered among the finds from the deposit.[21]

Macroscopic fabric identification still proved to be difficult.[22] A new series of coarse ware samples was submitted for analysis in order to confirm attributions within the system and to place 'uncertain' sherds (n=26).

Next to the well-known group of locally produced fine wares (Mus1–3) and coarse ware pottery (Mus4), a new group of locally manufactured pottery was differentiated (Mus5). This group included, among other specimens, a series of cooking pots from Room 225 and is particularly significant in respect to chronology, since these vessels derive from older contexts.

19 Näser and Wetendorf 2014, 82; cf. Näser and Wetendorf 2015, 50.

20 Daszkiewicz and Wetendorf 2014.

21 Näser and Wetendorf 2015.

22 Näser and Wetendorf 2015, 50.

Re-classifications and a third series of refinement analyses

In the third season, ceramological work continued with a re-classification of the complete corpus – 27 000 sherds with a weight of ca. 1000 kg – to match the current state of the fabric system after its last refinement. In this process, another series of samples (n=70) was extracted for a final round of analyses to evaluate the correctness of the attributions and clarify 'uncertain' cases.

This season's reinvestigation showed that the 'spiraling' design of integrating field and laboratory ceramological analyses had been a necessary and successful measure to counter the problems that the corpus presented in the macroscopic analysis.

Repeated refinement and control through a successive series of archaeometric analyses was the only means to master this challenge. The process had resulted in a development of a clear and concise sampling strategy that is to:

- constantly evaluate the correctness of attributions of the analyzed pottery to specific fabric groups during the macroscopic analyses in the field,

- archaeometrically document and integrate new fabric types in the emerging fabric system, and

- generate representative reference samples for all fabric groups.

The results of the last series of laboratory analyses generally confirm the outcomes of previous series, but enlarge the number of reference groups of locally produced fine ware and coarse ware pottery (Mus1–12), as well as the number of imports (Fig. 4). One group of handmade pottery has a very characteristic fabric with a large amount of mineral temper in the sand fraction. In the light of current research, this group must be understood as an import from an unknown location from a great distance.[23]

The raw material survey

Already the 2013 kick-off analysis indicated that the majority of the pottery in the investigated corpus was made from raw materials sourced from the same region. The refinement analyses showed that they represent groups that are not known from other sites in the Middle Nile Valley and that they are composed of kaolinite-bearing wadi clays, which were used for the production of both wheelmade coarse wares and fine wares.

23 SDB: clay type O, reference group O1. Pottery fragments belonging to this group were found in Hamadab, Muweis, and Abu Erteila; see Daszkiewicz and Malykh 2017.

Taken together, this suggested that enquiries should be made into suitable raw material sources in the vicinity of Musawwarat. This strand of the research was implemented in an exhaustive raw material survey in the second project year. The coverage of the survey and the selection of samples followed three main objectives:

– to identify raw materials from the wadis in the immediate vicinity of the site that match the materials identified in the analysis of the ancient pottery (reference groups Mus1–12), including the identification of materials that could have been added as temper to the ceramic body (appearing in the pottery as white aggregates);

– to identify raw materials in the immediate and wider vicinity of the site that match the materials identified as 'potentially locally' produced in the analysis of the ancient pottery; and

– to identify raw materials that match the materials identified as produced from alluvial clays in the analysis of the ancient pottery (Fig. 5).[24]

A special category of locales sampled were ancient, i.e. Meroitic, and modern hafayir (sing. hafir). These are partly monumental water harvesting and storage installations, which constitute a common type of monument in the region of Muswwarat. Hafayir consist of catchment and inlet installations and roughly circular reservoir basins that are excavated in the ground and reach depths of more than 15 m and diameters of up to 230 m.[25] In the raw material survey, samples were obtained from the recent bottom deposits of one ancient hafir (Great Hafir) and four modern specimens, which had been dug by the local nomadic population to collect water during the annual rainy season (Hafir Khalifa, Hafir Said, Hafir Hamad, and one unnamed).

In all, 43 geological samples including clays and sandstones were taken and archaeometrically analyzed. On the one hand, the results allowed for the matching of the fabrics of the archaeological samples with local raw material sources in the vicinity of the site. On the other hand, none of the sampled raw materials matched any of the pottery samples that had been identified as being made of Nile alluvium.

Analyzing materials involved in the production process

Another strand of the investigation started from questions related to the production process of the pottery. Next to the deposit in Courtyard 224, which was obviously composed of production debris, Room 225 was identified as a locale where (part of) the

24 Daszkiewicz, Wetendorf, et al. 2016, 184–191.

25 Näser 2010; Näser and Scheibner 2012.

production may have taken place.[26] Kilns, however, were still missing. A geophysical investigation proved unsuccessful in identifying anomalies that might have indicated their existence.[27] Thus, the question to be investigated was whether the pottery could have been fired in a bonfire – a scenario that had so far been deemed implausible, particularly for the Meroitic fine wares.[28] Other sites, such as Hamadab[29] and Muweis,[30] had produced kilns that were directly associated with pottery production.[31]

Several findings from Courtyard 224 indicate repeated heat exposure. They include decolored areas in the surrounding sandstone walls and ancient floor surfaces with signs of burning (Fig. 6). While some of the earlier excavators assumed that the decolored walls derive from kilns that once stood in these locations,[32] this has been doubted by others.[33] The composition of the deposit itself, which consists of an extremely loose grey material mixed sandstone rubble and finds (Fig. 6), seemed to support the hypothesis of an open fire.[34]

In order to learn more about the firing process, two types of samples were investigated: pottery and the grey material that constituted the main component of the deposit. The pottery fragments were analyzed to estimate the original firing temperature (Teq).[35] K-H analysis and X-ray diffraction undertaken on samples of local wheelmade coarse wares showed that they had been fired at temperatures above 1000°C.[36] Mullite[37] detected in these samples through the X-ray diffraction analysis confirms their exposure to temperatures in this range.[38]

Analyses of the grey material from the deposit gave a surprising result: X-ray diffraction showed that what had previously been described as 'ash' consists of quartz, mullite,

26 Näser and Wetendorf 2015.
27 Näser and Wetendorf 2015, 67.
28 Previous research produced the impression that Meroitic wheel made pottery was kiln-fired throughout, see e.g. Adams 1986, 13, 31–33; Robertson and Hill 2004, 115–117.
29 Wolf, Nowotnick, and Hof 2014, 730–733, pls. 8–9.
30 Baud 2008, 53–54, Fig.1.
31 In Hamadab, fine ware pottery was found together with other ceramics and rubbish in the kilns; Wolf, Nowotnick, and Hof 2014, 729–730. For pottery kilns in Meroe, see Török 1997, 173–174, pls. 140–142.
32 Wolf 1997, 27; Wenig in Edwards 1999, 6.
33 Edwards 1999, 41; Onasch 2004, 67–69.
34 Näser and Wetendorf 2014, 73–76, 91–92; Näser and Wetendorf 2015, 35–40, 68–71; cf. Edwards and Onasch in Edwards 1999, 11, Fig. 9.
35 In the case of additional contact with fire (besides the original firing), "Teq" shows the highest temperature to which the analyzed pottery fragment had been exposed; see Chapter 5 in this volume; cf. Daszkiewicz and Maritan 2016.
36 Daszkiewicz, Bobryk, and Wetendorf 2016, 213.
37 Mullite is a high-temperature phase formed in ceramics, especially those made from kaolinitic clays. Mullitization temperature is dependent on the parameters of the starting material. In the case of Musawwarat wadi clays, mullite was not formed during firing up to 1000°C (see Fig. 1 in Chapter 3 in this volume). In contrast to its presence in ceramics, natural mullite is not a common mineral. For detailed information about phases (mullite, anorthite, hematite, and chrystoballite) mentioned in the text see e.g. Searle and Grimshaw 1960.
38 Daszkiewicz, Bobryk, and Wetendorf 2016, 213. Similar firing temperatures have already been established for Meroitic wares that were found in the area of the Fourth Cataract, but were identified as imports to the region; Daszkiewicz, Bobryk, and G. Schneider 2003.

anorthite, and hematite. On the basis of the data obtained so far, it is difficult to define from which material mullite was formed in this context. An analytical setup to follow up on this issue is currently being developed.

Alteration effect (in cooperation with Ewa Bobryk)

Model analyses were used to assess whether the exposure of pottery to a firing environment of a bonfire – namely the deposition of the vessels in the fuel and the resulting ashes – would have caused alterations in the ceramics.[39] Of particular interest was to explore whether the ashes of different fuels penetrate into the pores of the fired pottery and, if so, how they change the chemical composition and the physical properties of the ceramics, which could lead to changes in the results of the chemical analysis and the MGR-analysis of the sherds. Furthermore, this analysis was to elucidate whether potential residues in the pottery would allow researchers to determine which fuel had actually been used in the firing of the pottery.

This investigation was conducted as a simulation of alteration effects in a climatic chamber using samples of cow and donkey dung, as well as samples of several acacia species present in the study region today. The selection of samples followed the assumption that roughly similar climatic conditions in the Meroitic period would have supported a similar dry savannah flora, which would have provided similar options for obtaining fuels.[40] The results of the analyses showed that:

– Depositing a sherd in a layer of Zayal tree ash had no impact on the sherd's degree of vitrification; only a minimal change of shade was noted in the sherd's color.

– Depositing a sherd in a layer of Zamur tree ash affected the sherd's properties because glass-forming compounds migrated into the sherd. As a consequence, a ceramic sample classified as having a slightly over-melted matrix type developed an over-melted matrix type after the simulation.

– Deposition in a layer of Zelam tree ash as well as in a layer of ash from cow dung and donkey dung does not affect the thermal behavior of the samples in the subsequent MGR-analysis.

– Depositing a sherd in the grey material, which constituted the main component of the deposit in Courtyard 224, had no effect on its chemical composition and

39 Bebermeier et al. 2016, 21; cf. Eide, Hägg, and Török in Eide et al. 1998, nos. 187, 195, 202, 203, 206.

40 These analyses were partly funded by Warsaw University of Technology.

thermal behavior.

In all cases, identical results of the chemical analysis and the MGR-analysis were obtained for samples before and after the simulation. This indicates that deposition effects, i.e. alterations associated with the deposition of samples in ash (dung and acacia) and in the grey material that constituted the main component of the deposit in Courtyard 224, are negligible in provenance studies based on these methods.

Fuels and experimental firing

Assuming, that a range of locally available materials could have been used as fuels in the firing of the pottery from Courtyard 224, the next step was to test these materials for their suitability, focused on the question of whether pottery could be produced in bonfires reaching temperatures of minimum 1000°C with these fuels. The ethnoarchaeological studies that accompanied this investigation (see below, 2.11) showed that in current production contexts dried cow dung is used as fuel, whereas dry donkey dung is applied as temper to the ceramic body (Fig. 7).

Firing experiments were conducted on 81 vessels, which were produced for this purpose using four plastic raw material sources (three wadi clays [AD 236, AD 237, and AD 880] and one hafir clay [AD 291]) and three different tempers (cow dung, donkey dung, and white-firing kaolinitic sandstone), as well as combinations of the latter. One series of vessels was left free of intentional temper.[41] To obtain maximum information, further firing experiments were conducted using straw and charcoal as additional fuels, next to those discussed in the previous section (cow and donkey dung, acacia specimens). The experiments showed that in a bonfire fuelled by cow dung, a temperature of 1050°C can be reached in 30 minutes – mullite was detected by X-ray diffraction in vessels fired this way (Fig. 8).[42] With all other fuels, only significantly lower temperatures between 600 and 800°C were reached. This result is consistent with the observations in ethnoceramological studies that indicate that traditional potters in Sudan use cow dung as fuel and donkey dung as temper added to ceramic bodies.[43]

41 See also Daszkiewicz, G. Schneider, Wetendorf, et al. 2015, 89–91; Daszkiewicz, Wetendorf, et al. 2016, 140–143; Daszkiewicz, Bobryk, and Wetendorf 2016, 208–214.

42 For more details see Daszkiewicz and Wetendorf 2017.

43 See e.g. Daszkiewicz, Wetendorf, et al. 2016, 143; Daszkiewicz and Malykh 2017.

Model studies concerning the influence of tempering materials on the properties of the finished pottery products (in cooperation with Ewa Bobryk)

Another strand of the investigation concerned the impact of tempering on the properties of the ceramics. First, the nature of the white-firing aggregates, which are present in all Musawwarat fabrics, had to be established. Occurring in various amounts, they do not necessarily represent intentional additions, but could also be natural inclusions. Results of the MGR-analysis and thin-section studies of pottery fragments, as well as the results of firing tests of raw materials, suggest two potential identifications: crushed fragments of kaolinitic sandstone or aggregates of a kaolinitic-clayey material.[44]

In order to learn more about the impact of different tempers, mechanical properties (tensile strengths) as well as physical ceramic properties (apparent density, open porosity, and water absorption) were assessed on small test briquettes that were produced using different samples from the raw material survey, namely wadi clay (AD 236), hafir clay (AD 291), and Nile alluvial clay sampled in the vicinity of Shendi (AD 261).[45] The briquettes of 20 mm in diameter and ca. 5 mm in height were prepared by adding a variety of tempers, namely crushed kaolinitic sandstone and pore-forming agents (crushed dry cow and donkey dung).[46] One series remained free of intentional temper.

The analysis showed that the mechanical properties of ceramics made from wadi clay (AD 236) tempered with kaolinitic sandstone fragments and fired at high temperatures (about 1100°C) are improved in comparison to the dung-tempered and untempered wadi clay samples (Fig. 9, left).[47] In contrast, ceramics made from hafir clay (AD 291) or Nile alluvial clay (AD 261) tempered with dung display a similar resistance to mechanical stress when fired at lower temperatures (700–800°C) (Fig. 9, right). These results indicate that mechanical properties depend on the firing temperature, the clay, and the temper used. The mechanical properties of Nile clay are improved through the addition of dung. In contrast, wadi clay has better properties when tempered with fragments of kaolinitic sandstone than with dung (Fig. 9).

The stratigraphic sequence of the deposit in Courtyard 224 revealed several lenses of clay raw material (AD 676) as well as numerous chunks of ceramic bodies, i.e. prepared material (AD 223), some of which clearly derive from throwing the vessel on the wheel.[48] Due to their position in the archaeological context, these raw materials and ceramic bodies can be directly associated with the ancient production processes. They were identified as wadi clays equal to group Mus4. Samples of these materials were used to

44 Cf. Daszkiewicz, Bobryk, and Wetendorf 2016, 192–208; Daszkiewicz, Wetendorf, et al. 2016, 140–143; contra Edwards 1999, 18; Seiler 1999, 60–61; Seiler 1998, 57.

45 All tests were funded by Warsaw University of Technology.

46 Daszkiewicz, Wetendorf, et al. 2016, 140–143.

47 Daszkiewicz, Bobryk, and Wetendorf 2016, 208–214.

48 Näser and Wetendorf 2014, 76, figs. 6–7; Näser and Wetendorf 2015, 36, 52, figs. 2–3, 15.

produce a series of small vessels. These vessels as well as a number of the samples from the raw material survey in the shape of briquettes (see previous paragraph) were used to test functional properties, namely water permeability (Fig. 10). This model analysis showed that all samples, i.e. those made from wadi clays and hafir clays, as well as Nile alluvial clays, are permeable to water. Investigations also confirmed that to obtain water-impermeable vessels, the surface has to be compacted through polishing or burnishing or the application of a slip or wash.[49]

In a next step, 26 selected coarse and fine ware sherds from the 'pottery courtyard' that had been identified as slipped or washed in the macroscopic analysis were investigated with regard to their surface treatment. Due to the partial erosion of vessel surfaces, it was not always possible to distinguish between slipped and washed surfaces, or even to identify a coating in general. Several of the fine wares seemed to have no coating at all, but only polished surfaces. Thus, the aims of the analyses were:

– to ascertain whether the macroscopic evaluation was correct,

– to ascertain whether the individual specimens had a slip or a wash, and

– to identify colorants used in the coatings.

Previous researchers had suggested that Meroitic pottery from Musawwarat and elsewhere were coated with a wash.[50] The current series of samples were subjected to p-XRF, SEM-EDX, and RTI (Reflectance Transformation Imaging)[51] screening in order to establish their surface treatments. Preliminary results indicate that some of them had a slip (e.g. red slipped fine ware pottery AD 716 and white slipped coarse ware pottery AD 717). Final results of these investigations are not yet available, as the analyses are ongoing.[52]

49 Daszkiewicz, Wetendorf, et al. 2016, 140–143; Daszkiewicz, Bobryk, and Wetendorf 2016, 208–214. For a general definition of slip (mixture of clay, pigment, and liquid) and wash (pigment and liquid) see e.g. Arnold 1993, 86; Rice 1987, 147–152.

50 Based on her analysis of the pottery from the Small Enclosure in Musawwarat, Seiler had used the term 'wash' in connection with the wheel made coarse ware pottery (Gebrauchskeramik); Seiler 1999, 62. Gerullat 2001, 72–77, also speaks of 'wash' in her descriptions of wheel made coarse ware pottery from Musawwarat. Dittrich 2003, 87, observed "eine helle oder gewaschene Oberfläche der cremefarbenen Feinware" in Hamadab.

51 These analyses were funded by ARCHEA, Warsaw.

52 Malgorzata Daszkiewicz and Manja Wetendorf. "Surface Treatments of Meroitic Pottery from Musawwarat es-Sufra". *Novensia* 28 (in preparation).

Analysis of related find material

The study of the non-ceramic find material from the deposit in Courtyard 224, as well as the analysis of the findings from Room 225, which was tentatively identified as workshop locale, confirm the assumption that pottery was produced in the immediate vicinity of the excavated deposit. A range of items that include several objects directly identified as tools used in the production process – such as part of a potter's wheel and stamps for decorating fine ware pottery – throw additional light on local manufacturing techniques and conditions.[53] Analyses of this material and the integration of the insights derived from it are ongoing.[54]

Ethnoarchaeological studies

Investigations into recent contexts of pottery production were undertaken to supplement the archaeological and archaeometric analyses.[55] This branch of the research included visits to and interviews with potters in Musawwarat and the nearby market town of Shendi, as well as a visit to a pottery production center in Omdurman. Whereas pottery was fired in a wood-fuelled kiln in the larger facility at Omdurman, the traditional potters in Shendi and Musawwarat fired their vessels in bonfires, using dried cow dung as fuel (see also 2.7).[56]

As a next step, a test excavation was conducted at the firing place of the potter's workshop in Shendi. Its aim was to collect data that would help to evaluate the deposit in Musawwarat and to test the hypothesis that it represents the gradual build-up of an open firing place. While the two features, i.e. the firing place in Shendi and the deposit in Musawwarat, shared several elements, they differed significantly in their stratigraphic composition and other aspects.[57] This finding underlined the need to understand the deposit internally, i.e. based on data extracted from the deposit itself.

Results

Despite it still being a work in progress, the 'Musawwarat Pottery Project' has already yielded a wealth of results. The following discussion will outline major insights, their integration into wider issues of socio-economic organization, and how they triggered advances and new approaches in the research design.

53 Näser and Wetendorf 2014, 2015.
54 See already Näser and Wetendorf 2015.
55 Näser and Wetendorf 2015, 68–71.
56 Similar observations were made by M. Daszkiewicz and G. Schneider in field studies between the Sixth and Fourth Cataracts in 2008.
57 Näser and Wetendorf 2015, 68, figs. 2–3, 45–46.

Understanding Meroitic pottery and its production

The closely integrated ceramological and archaeometric approach has greatly informed understanding of the pottery corpus recovered from Courtyard 224 in Musawwarat. First and foremost, it has allowed researchers to clearly characterize the local production of both fine wares and coarse wares. Analyses revealed that the majority of the ceramics was made of local wadi clays, which were used for both, wheelmade coarse ware and fine ware pottery.[58] The white to beige-white-firing inclusions that are characteristic of these fabrics were identified as either crushed fragments of kaolinitic sandstone or a kaolinitic-clayey material. Wheelmade coarse wares were fired over 1000°C, at such a high temperature that the formation of the mullite and even crystoballite[59] was possible. In contrast, fine wares were fired at a lower range of about 800–950°C.

As no kilns could be traced at the site, investigations advanced to the question of whether and how temperatures above 1000°C could be reached in open fires. Experimental firings of replicated vessels indicated that bonfires fuelled with cow dung produce temperatures in this range.

Further strands of the study looked into the functional properties of the pottery. In order to make vessels impermeable, regardless of the type of clay and temper used and the original firing temperature, surfaces had to be treated, e.g. coated with a slip or wash and/or polished or burnished.

The next step was to explore the mechanical properties of the pottery. Model analyses showed that in order to achieve a similar resistance to mechanical stress, pottery from wadi clay had to be fired at higher temperatures (ca. 1100°C) than pottery made from alluvial and hafir clays (ca. 700–800°C).

One particularly interesting group of material is the handmade wares. They make up less than 1% of the overall corpus, but display the widest variety in terms of fabrics. They include vessels produced from different wadi and hafir clays that are local or at least from the wider region of Musawwarat and pottery from several Nile alluvial clays, as well as a very distinct group of pottery made from clay of an unidentified source that is suspected comes from a more distant location (Group O).[60] Only few of the wadi clay fabrics are also present in wheelmade coarse wares specimens.[61] This pattern provokes the revision of some more general assumptions about the organization and dynamics of pottery production. Contrary to the widespread postulate that handmade wares represent local household productions, while fine wares testify to the existence of nucleated

58 A similar scenario has been suggested for Hamadab, where wadi clays were also used for some of the fine wares, whereas the actual eggshell ware is typically made from kaolinitic clays, pers. comm. Ulrike Nowotnick.

59 Chrystoballite is a high-temperature polymorphic variety of silica, see footnote 37.

60 See above, chapter 3. Cf. also Näser and Wetendorf 2015, 51.

61 Cf. Daszkiewicz and Wetendorf 2014, 102.

workshops[62], the corpus of handmade pottery from Musawwarat clearly comprises a variety of imports, while fine ware pottery was produced primarily for 'home requirements' (aside from a few exceptions).

The interplay between archaeological enquiries, macroscopic ceramological studies, and archaeometric analysis also added a chronological dimension to this observation. While the horizon of the pottery workshop in Courtyard 224 is almost devoid of imported wheelmade pottery, earlier contexts at the site produced a significant ratio of non-local pottery, made e.g. from Nile alluvial clays.[63] This finding does not only herald a fabric-based dating system for Meroitic pottery (which is notoriously difficult to date) at Musawwarat, but also indicates a development in the patterns of its production, distribution, and use – for which the corpus analyzed in the current project provides a uniquely detailed data set available for future extensions and comparisons.

Integrating the results

The pottery corpus analyzed in this study displays a clear distribution pattern. The majority of the material from Courtyard 224 represents local production. Only 2% of the whole material can be identified as imported to Musawwarat. Vessels made of Nile alluvium and various other clays of unknown sources derive from stratigraphically older contexts below the deposit and from adjacent units (e.g. Room 225, N227) – some also appear in irregular distribution in the deposit itself. The fabrics of the imports were compared with the SDB database, which currently comprises 1235 samples of ceramics and raw materials from 28 sites, representing 16 study regions in Sudan (Fig. 11).[64] Only for four samples, a provenance could be established: Two of them match a local group in es-Zuma, one sample matches a local group in Hamadab, while the fourth sample matches pottery found in Muweis and Hamadab.[65] Vice versa, no pottery associated with the local production in Musawwarat has been identified at any other site in the Middle Nile valley so far.[66] Thus, ceramics at Musawwarat were clearly not produced for wider distribution, but for on-site use. The workshop can thus be interpreted as a special purpose installation with a functionally specific, immediate relationship to the site where it is located – criteria that assign it to the 'attached specialized production' category of Earle and Costin, which is "defined as production on command for elites and the social and political institutions they control".[67] The use of the term 'command' substituting 'demand' already signals the characteristics of the organizational setting that

62 E.g. Costin 1991.
63 Näser 2016, 12.
64 For the SDB see above, chapter 3.
65 See Daszkiewicz, Wetendorf, et al. 2016, 215; see also Daszkiewicz and G. Schneider 2011, 247–265.
66 This statement is based on the data assembled in the SDB.
67 Earle 1981; Costin 1991. For the quote see Costin 1991, 7.

goes with this kind of production.[68] Control of the production, which Costin names as "a central concern in attached specialization" and sees manifested "archaeologically through architecture and spatial arrangements aimed at segregating production activities and restricting or monitoring the flow of personnel to the facilities",[69] may well have been a major consideration in establishing and maintaining the production at Musawwarat. Next to the close proximity of production and consumption areas, the spatial separation from other production, distribution, and consumption contexts may explain the unusual locale chosen for this workshop.

Investigations into the process of pottery production at Musawwarat revealed an unexpected divergence between the quality of the finished vessels and the relatively simple organization of production. It did not only solely rely on local raw materials that could be procured with little effort, but also technological investment was low. Fuel – most likely cow dung – and other necessary materials could also be obtained locally. The firing procedure was apparently managed without purpose-built kilns. The majority of the tools recovered from the excavation[70] were also made using easily available resources; e.g. the stamps used to decorate the fine ware pottery were themselves made from clay. The major point with regard to investment into the production would have been to establish and maintain the specialists producing the pottery at the site.[71] Topographically and ecologically, Musawwarat was a marginal locale, 25 km away from the Nile Valley and its infrastructural networks.[72] However, simultaneously, it was a central place – the first and most important sacral site of the Meroitic Empire outside the Nile Valley. Establishing a pottery production catering for the religious institutions and/or the needs of the site's elite occupants, can be seen as part of the political interest in the site. At the same time, the locale and the absence of evidence for inter-site distribution, indicate that the pottery workshop at Musawwarat was part of a 'dispersed' pattern of production.[73] However, it shows the problems inherent in this model when Costinmaintains that "most attached producers are nucleated to some extent because they will produce near their patrons, and wealth and power tend to be concentrated in central places"[74] – in this sense the production at Musawwarat would have to be classed as 'nucleated'.

Concerning scale and intensity of production,[75] estimates are difficult. The actual demand in pottery was probably not very high, not least since the site was not perma-

68 Brumfiel and Earle 1987, 5–6; Costin 1991, 7.

69 Costin 1991, 27.

70 Edwards 1999; Näser and Wetendorf 2014; Näser and Wetendorf 2015.

71 For the characterization of technological knowledge and the degree of specialization evidenced by the ceramics from Musawwarat see Wetendorf, Manja. "Die Keramikproduktion in Musawwarat es-Sufra/Sudan: Untersuchungen zu Herstellung, Gebrauch und Distribution". PhD diss., Humboldt University Berlin (in preparation).

72 Bebermeier et al. 2016, 9–10, 21–24, 28.

73 So far, evidence from other sacral sites is missing, but a workshop from the settlement of Hamadab seems to support this hypothesis; see Wolf, Nowotnick, and Hof 2014, 729–733, pls. 8–9.

74 Costin 1991, 14–15.

75 Costin 1991, 16.

nently occupied by any significant number of consumers. It has been argued that the Great Enclosure was used intermittently, mainly for religious festivals.[76] As a consequence, it seems very likely that the production of pottery was also not continuous but sporadic, or possibly even limited to one, perhaps extended, episode. From these assumptions, we can conclude that efficiency and labor intensity would not have been important criteria in the organization of production in this case.

Methodological considerations

This paper outlined the course that the 'Musawwarat Pottery Project' took in a framework that closely integrated archaeology, macroscopic ceramological analysis, archaeometry, experimental archaeology, and ethnoarchaeology. The questions asked and the analyses employed to answer them sprang consecutively from rather straightforward and conventional initial enquiries that focused on the identification of fabrics and the provenance of the associated raw materials. Further issues relating to closer descriptions of materials from the archaeological context, the production process, and the functionality of the recovered pottery eventually led to an incremental development of the overall research design.

The combination of classification by refiring (MGR-analysis), chemical analysis (by WD-XRF), and thin section studies proved particularly beneficial for the fabric description and provenance identification. Ethnoarchaeological enquiries informed the thinking about raw material procurement, production processes, particularly the tempering of the ceramic bodies and the firing. Experimental archaeology and model analysis supported the arguments, which had been formed through the observations made in the ethnoarchaeological studies with regard to the production process, particularly the firing.[77] In sum, the interaction of all methods and investigations proved to be very fruitful and makes Musawwarat one of the most extensively studied sites.

76 See the first paragraph of this paper for references.

77 An exhaustive evaluation and interpretation of the results is reserved for Wetendorf forthcoming, PhD project (A-6-5-1). Wetendorf, Manja. "Die Keramikproduktion in Musawwarat es-Sufra/Sudan: Untersuchungen zu Herstellung, Gebrauch und Distribution". PhD diss., Humboldt University Berlin (in preparation).

Fig. 1 Great Enclosure seen from the east.

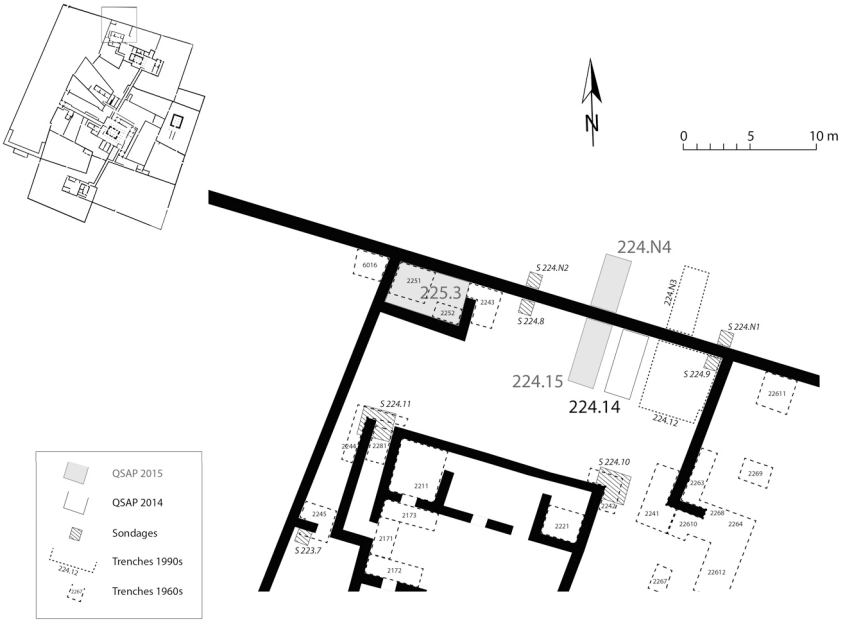


Fig. 2 Excavation plan of 'pottery courtyard' 224 and surroundings.

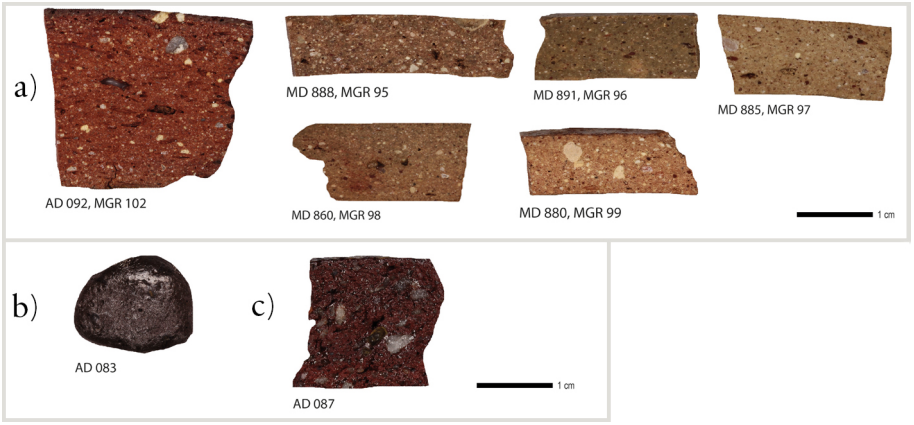


Fig. 3 Pottery fragments after re-firing at 1200°C. a) = pottery made in Musawwarat (MGR 102 coarse ware, MGR 95–99 fine ware samples), b) = import of Nile alluvial clay, and c) = import of clay of a different origin.

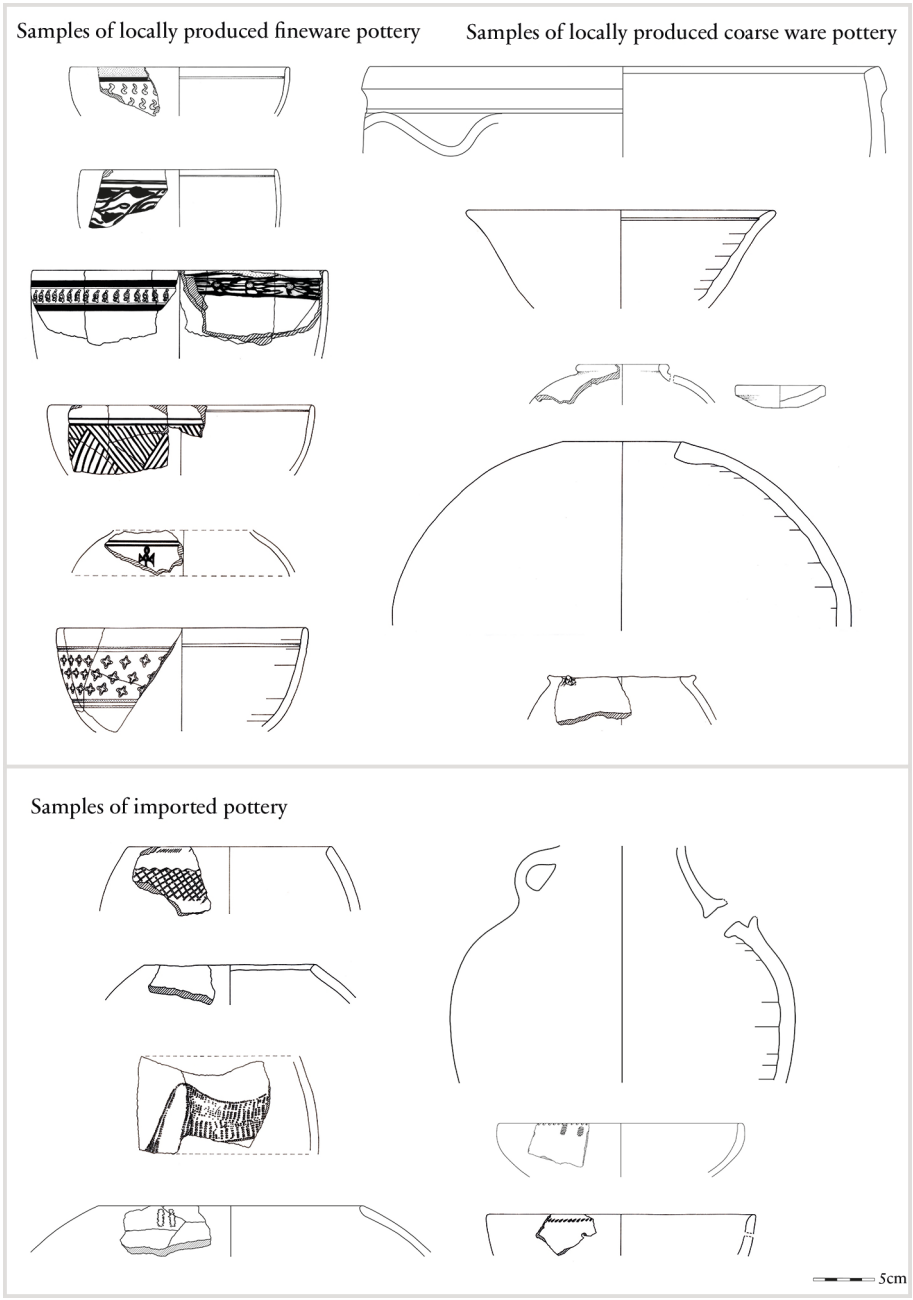


Fig. 4 Examples of pottery from 'pottery courtyard' 224.

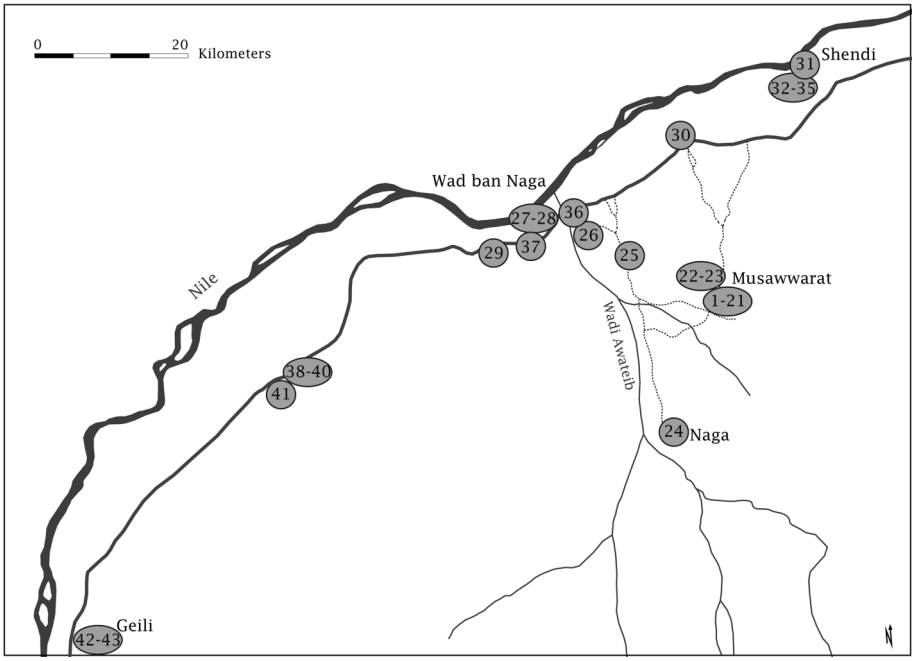


Fig. 5 Extraction points of raw material samples taken in 2014. Thick black line = modern tarmac road, dashed line = recent main tracks through the Keraba used by local communities, figures in circles = number of samples taken from each spot, and N = 43.

Fig. 6 Features connected with firing in Courtyard 224. Left = decolored area in a sandstone wall bordering the courtyard, center = signs of burning on an ancient floor surface, and right = the grey material of the ceramic deposit visible in a section of trench 224.15.

Fig. 7 Ethnoarchaeological observation. Above = dried donkey dung used as temper and below = dried cow dung used as fuel; both by a contemporary potter in Musawwarat.

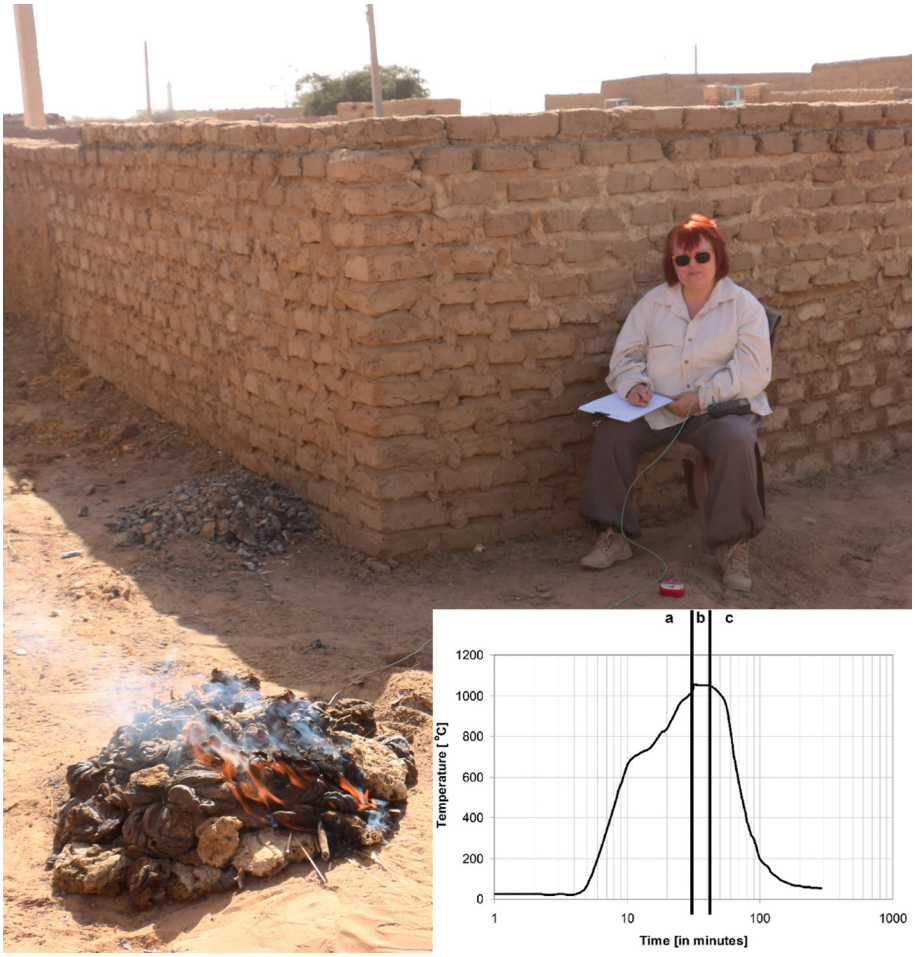


Fig. 8 Experimental firing. Left = a bonfire fueled by cow dung, reading of temperature using two thermocouples, and right = diagram showing that a temperature of 1050°C can be reached in 30 minutes in a bonfire fueled that way.

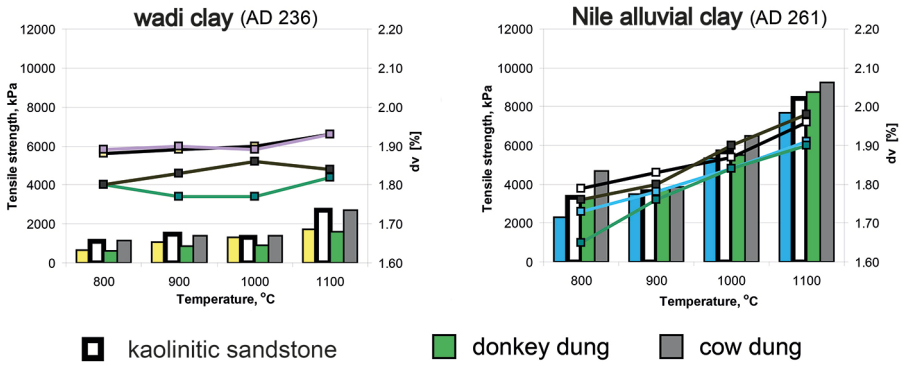


Fig. 9 Tensile strength of briquettes made from wadi clay (AD 236) on the left and Nile alluvial clay (AD 261) on the right side, tempered with either kaolinitic sandstone fragments, donkey dung, or cow dung fired at various temperatures; average values of tensile strength, cv < 15%.

Fig. 10 Vessels produced and used for the model analysis to assess functional properties (water permeability). Different tempers were added: C = cow dung, D = donkey dung, and K = kaolinitic sandstone.

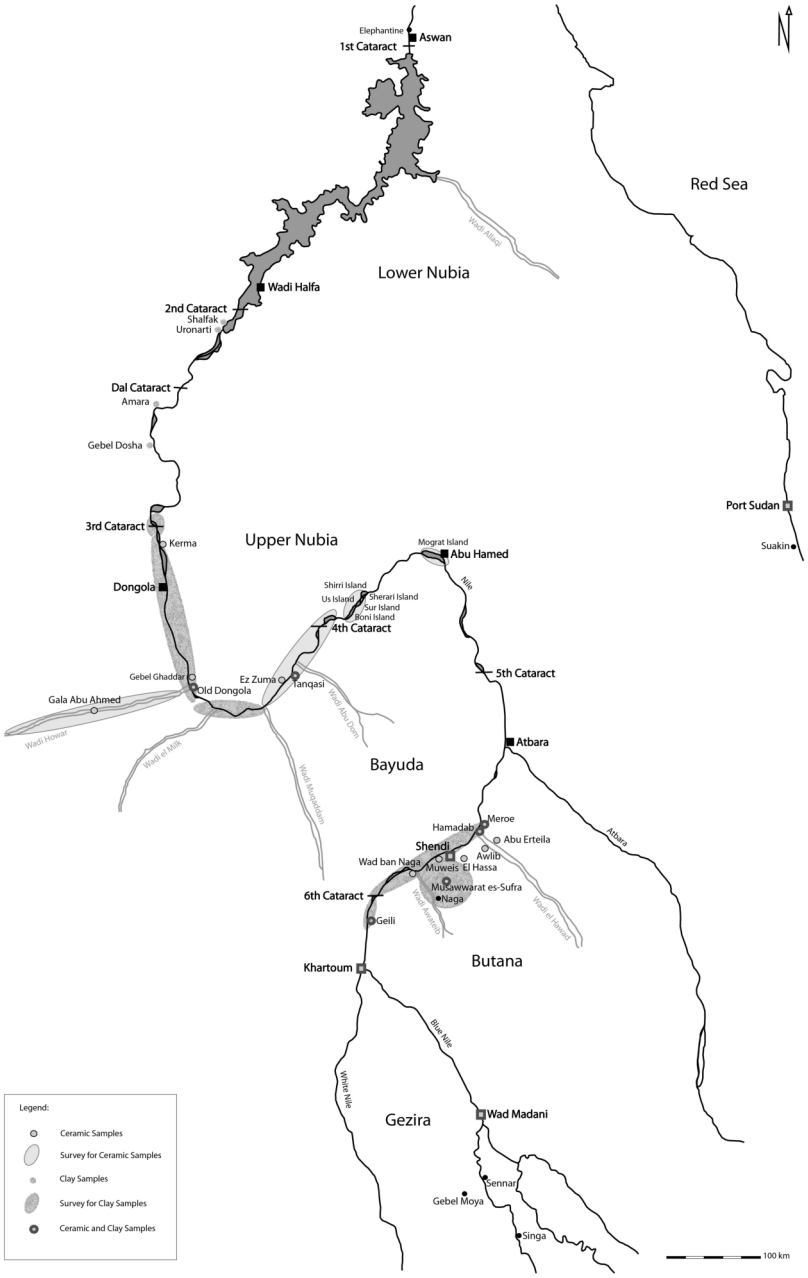


Fig. 11 Extraction points of raw material samples for the SDB taken in 2008, 2014, and 2017, and sites from which pottery was analyzed in 1997–2017.

4.4 Distribution and Places of Production of Nabataean Painted Fine Ware

Gerwulf Schneider, Małgorzata Daszkiewicz, Ewa Bobryk, Stefan G. Schmid

Introduction

Nabataean painted fine ware is a unique eggshell-thin ceramic ware with a thickness of barely one to four millimeters. It is found at Petra in Jordan and other Nabataean sites and dates from 2nd century BC to AD 4th century. It is one of the few cases where 'pots equal people'. Many articles have been published describing the historical and archaeological backgrounds of this fine ware, including archaeometric studies into mineralogical and chemical composition and into the techniques of manufacture.[1] Most of the products represent shallow open bowls, probably for drinking. Typically they have a characteristic interior painted decoration in styles that vary depending on the period they represent.[2]

Research questions (objectives and methods)

The aim of this study was to establish a reference group for this pottery produced at Petra, which then could be used to securely attribute finds from other places. This very characteristic pottery was found in all locations where a Nabataean presence could be verified. It did not disappear after the integration of the Nabataeans into the Roman Empire after AD 106, but the region was smaller where it was found. In the 2nd century AD it is detected in south Syria and in the Negev, but was detected in the region of Petra only in the 4th century AD. The question was, if all this pottery, excluding the few

1 E.g. 'Amr 1987; Gunneweg, Perlman, and Asaro 1988; Alawneh and Bala'awi 2012; 'Amr, Akasheh, and Na'es 2018.

2 Schmid 1995.

sherds that were clearly recognizable imitations, was made at the central Nabataean site Petra.

Sampling and analytical procedures

Thirty-two samples found at Petra, representing typical sherds of three chronological phases of production, were selected by Stefan G. Schmid (Fig. 1–2). Chemical analysis was conducted using WD-XRF for nine samples. Six sherds found at other sites (Fig. 3), five from Khirbet edh-Dharih in Jordan[3] and one from Tayma in Saudi Arabia,[4] were analyzed to find out if they had been made at Petra. Additionally, five thin-sections were studied and all 38 samples were classified using MGR-analysis and analyzed by pXRF, using measurements on the outer surface of sherds. Some sherds were also measured on inner surfaces, fresh breaks, and cut sections. For all sherds, physical ceramic properties were determined using hydrostatic weighing (the methods are described in chapter 3 of this volume).

Results of chemical analysis by WD-XRF, thin-section studies, and MGR-analysis

The results of chemical analyses of nine samples from Petra (Tab. 1) showed a more or less clear distinction between the phases. While in phases 1 and 2 similar raw material was used, a very clear change to more calcium rich raw materials characterizes phase 3. The sherds of phase 3 represent different clay with more calcium and less silicon. They also contain more iron, manganese, magnesium, sodium, (potassium), vanadium, zinc, strontium, and less titanium, chromium (but unusually related to more nickel), and zirconium. The high phosphorus content of 2.5% P_2O_5 of sample P23, certainly is an alteration effect from burial[5] that, however, did not significantly influence other elements besides strontium (this sherd will again be discussed later).

The difference of the composition between the sherds of phases 1 and 2, however, is not unequivocal. Based on the only the limited samples analyzed, it seems that iron and magnesium are lower and silicon (and zirconium) are higher in phase 1 than in phase 2. Sample P11 then should be attributed to phase 1. The high barium content in sample P15, together with a higher ratio of strontium to calcium and the highest loss on ignition, is probably due to alteration effects, even if phosphorus is not elevated. The

3 Given by G.S. Schmid: DH1 = AD398 (DH88.V10B.B119, Ph.1); DH2 = AD395 (DH87, V10.A44.4, Ph. 2b); DH3 = AD396 (DH87, V10.A44.6, Ph.3a); DH4 = AD394 (DH85, V10.A6.59, Ph.3b); and DH5= AD397 (DH87.V10.B103/B113-5/B112, Ph.3c).

4 Sample T1 given by Arnulf Hausleiter.

5 G. Schneider 2017.

values for strontium and barium in this instance, therefore, are not considered as the original chemical composition to be used for provenance determination. A significant distinction between phases 1 and 2 also cannot be seen in thin-sections (Fig. 4) nor by MGR-analysis, of which Figure 5 shows only one example of the whole series.

The compositional data now can be used to identify Nabataean painted fine painted pottery made in Petra. Comparing the samples Dh1 and Dh2 from Khirbet edh-Dharih (before analysis attributed to phase 1, respectively, phase 2), the similarity to the samples of phases 1 and 2 from Petra can be seen clearly in Table 1. Samples Dh3, Dh4, and Dh5 and the sample T1 from Tayma can securely be attributed to phase 3 of Petra. There may be a question mark for sample Dh5, with its much higher calcium and magnesium and lower aluminium and potassium contents. This, and the contents of other elements, however, does not exclude a provenance from Petra.

Comparison with published chemical analyses by NAA

Chemical analyses of Nabataean fine painted ware were already published in 1987 and 1988 using NAA and, thus, determining another series of elements.[6] The means of the contents of the up to six elements also determined by XRF are compared to our results in Table 2. For this purpose the NAA values of K, Na, Fe, Ca, and Ti are calculated to percent oxides (the trace elements are given in ppm).

The chemical composition of 211 samples of Nabataean fine painted wares was established as a homogeneous group by 'Amr in 1987, with coefficients of variation between 11 and 18% of the eleven elements analyzed.[7] She was able to securely attribute this group to local production at Petra. Gunneweg et al. distinguished two chemical groups corresponding to time periods.[8] For both groups, they found a good correlation to local Petra samples; for the latter group NAB-II, even with a series of wasters including three kiln wasters. The results for the few elements for which we can compare our XRF results are more or less matching our groups for Nabataean fine painted wares and may allow us to share the interpretation of the reference groups as local productions at Petra.

6 K, Na, Fe, Rb, Cs, Sc, La, Ce, Eu, Lu, Th, Cr, Co, and Sm by 'Amr 1987; Ca, Fe, Na, Ti, Ce, Co, Cr, Cs, Eu, Hf, La, Lu, Sc, Sm, Ta, Th, U, and Yb by Gunneweg, Perlman, and Asaro 1988.

7 'Amr 1987, 178

8 Gunneweg, Perlman, and Asaro 1988.

Results of pXRF

As part of tests described in this book, designed to check the possibilities of using non-destructive pXRF measurements in the analysis of ancient pottery, all thirty-eight samples were measured using the Niton RF-Analyzer of Topoi.[9] In order to remove any potential secondary calcite deposits on their surfaces before measurement, the sherds were cleaned with acetic acid for one hour in an ultrasonic device. Table 3 presents results of each measurement on the unpainted outer surfaces. This was done to compare only measurements under equal conditions for statistical evaluation. The analysis results of WD-XRF are included in this table, however, recalculated to the composition of non-ignited samples. The distinction of the calcium rich samples of phase 3 is evident when looking at the column of CaO (except the low calcium content of sample P23 as compared to the value from WD-XRF).

As a test, some samples were repeatedly measured, also on unpainted parts of inner surfaces, on fresh fractures surfaces or cut sections (Fig. 6). All 170 measurements of sherds from Petra are included as averages in a bivariate diagram of strontium and iron contents together with the WD-XRF results (Fig. 7). Regarding the data by WD-XRF (black symbols), the samples with the lowest iron contents (P1, P4, and P11) are separated from three samples of phase 2 with higher iron contents and, very clearly, from the three samples of phase 3 that show iron contents very similar to each other. The pXRF data show a much larger variation such as, e.g., the too high iron content of sample P11. The tendency towards higher iron contents seems to be a general feature of all pXRF measurements of the Petra samples,[10] but as a whole, phase 3 is distinguished. Sample P23 deviates with a higher strontium value in the WD-XRF results. This is confirmed in the pXRF results. In the diagram, the distinction is more obvious regarding strontium, which is generally measured more representative because of the larger depth of information than that of iron.[11]

Comparison of pXRF measurements on surfaces and cross sections

In the case of twelve samples, fresh fractures or cut cross sections were measured. Thanks to the software of the pXRF analyzer, this allows consistent values even if the cross sec-

9 Niton XL3t-900s GOLDD, 8-mm window, **Mining software**, calibration based on twelve ceramic standards analyzed by WD-XRF, measurements 120 seconds (30 seconds per filter) without helium in a sample chamber.

10 The significantly deviating iron content of sample P11 is one of the unexplained outliers of measurements by pXRF, e.g. the too high vanadium in sample P15 and too high barium in Dh4, maybe due to software problems. A software problem may also be that values shown as below the limit of detection for manganese always are correlated to values of magnesium shown as below the limit of detection.

11 See chapter 6 in this volume.

tions only cover a small part of the 8-mm spot (Fig. 6). Not all differences appearing in the measurements on the surfaces could be explained by the different geometries, e.g. when measuring strongly bended fragments. This would account, for example, for the differing values of the light elements aluminium and silicon (and magnesium, which was detected only in a few cases). Barium and chlorine, as well as manganese, were generally lower at the surfaces, and in many cases were below the limit of detection (l.o.d.). On the other hand, in some measurements, potassium, titanium, and chromium levels were higher on the surfaces. The red or dark brown painted decoration showed higher concentrations of iron, potassium, and less calcium, as expected for slurry used for painting made from finely levigated iron-rich clay. A white slip covering the rim of some vessels is composed of clay featuring higher levels of calcium and potassium, probably made of levigated clay with added lime and/or gypsum (S was slightly elevated).

For thirteen sherds, pXRF measurements were carried out on the outer and inner surfaces, yielding mostly significantly differing values. Measurements on the outsides compared to those on the insides were about 67% higher for calcium, and on 28 of the 32 samples (88%), elevated sulfur concentrations of up to about 1500ppm were detected on the outsides. On the insides sulfur was found in only 44% of the measurements. An example of the various measurements on sample P5 is shown in Table 3. While calcium on the insides (i), fractures (b), and cut cross sections (c) are similar, they mostly have higher values on the outsides (a) and sulfur was always detected. The differences in silicon and aluminium are probably due to geometric effects. Other differences are negligible regarding the large variation between measurements on different spots and at different times.

The significantly higher calcium and sulfur contents on the outsides of vessels lead to the idea that these vessels were formed on the wheel using concave molds made of gypsum. This would make it easier to thin the vessels by scraping before painting the insides. A model experiment with clay as a plastic mass pressed by finger into gypsum molds was carried out, which confirmed that after firing and thoroughly washing the experimental specimens showed elevated calcium and sulfur contents on the surfaces where they had been in contact with the gypsum mold.[12]

Physical ceramic properties

The physical ceramic properties (apparent density dv, water absorption N, and open porosity Po) of all analyzed samples are listed in Table 3 and are shown in a diagram of open porosity vs. apparent density (Fig. 8). The ceramic properties of the later phase 3

12 Daszkiewicz and Bobryk 2013; Daszkiewicz and Bobryk 2014.

differ significantly, with lower porosity values from those of the earlier phases. This is connected with different material and less thorough technology.

The density index dv/d (apparent density dv divided through the bulk density d, determined by helium pycnometer) is given for nine samples in Table 3 and seems to be somewhat lower for samples of phase 3. Comparison with various examples of Roman period pottery and model analyses show that the numbers of dv/d for the Nabataean pottery (63–69%) are too low for real wheel thrown pottery (generally above about 70%).[13] This may be another argument supporting the theory that on the wheel, gypsum molds were used in the manufacture of Nabataean painted bowls.

Conclusions

Nabataen painted fine ware has a characteristic composition of non-calcareous clay that changes in phase 3 to a more calcium rich composition, with calcium contents above about 5% CaO. This is also connected to a change of ceramic properties showing lower open porosity values. The now established chemical reference group, including all major elements, was used to attribute samples from another site in Jordan and from Tayma in Saudi Arabia to the production in Petra. The originally planned larger series of analyses to get information on the distribution of the Petra products was not possible because of lacking samples.

Non-destructive pXRF measurements after calibration, with standards analyzed by WD-XRF, were carried out at the unpainted parts of the outer vessel surfaces (after cleaning the sherds with acetic acid to remove any surface contamination of calcite), and the results agreed with the results of WD-XRF in clearly separating phase 3 from the earlier phases. The pXRF data cover fewer elements than analysis by WD-XRF and the variation of the pXRF data is much larger. Some unexplained outlying values must be deleted, but secondary alteration effects can be observed like with WD-XRF. The six analyzed samples from other sites could be attributed to a production in Petra. In spite of the very thin sherds, measurements on fresh fractures could be used due to the software of the Niton RF-analyzer and were comparable to measurements on the surfaces.

Normally a disadvantage of pXRF measurements is the low depth of information by the X-rays excited in the sample, which limits the analysis to a very thin layer of the surface.[14] In the case of the Nabataean pottery this, however, opened up a possibility to compare the composition of the inner and outer surfaces of the cross section, showing that on the outer surfaces calcium is always higher than on the inner surface. In most cases, this is connected with traces of up to 1000ppm sulfur. This is very probably due to

13 Daszkiewicz, Bobryk, and Wetendorf 2017.

14 See chapter 6 in this volume.

contamination by gypsum from the formation of shallow vessels in a concave mold on the wheel. Model analyses with clay pellets formed in gypsum molds, fired and cleaned in an autoclave with water, confirmed this idea.

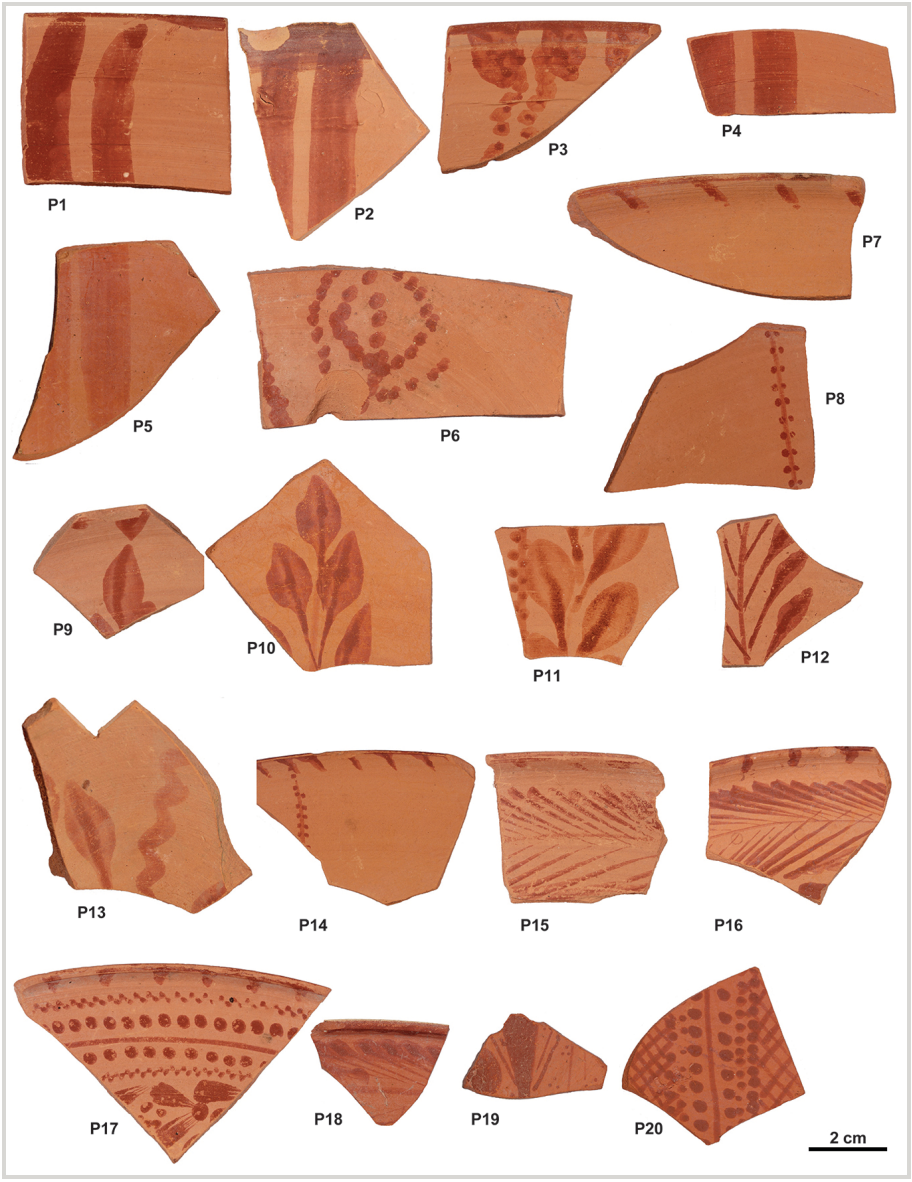


Fig. 1 Analyzed sherds from Petra, painted insides.

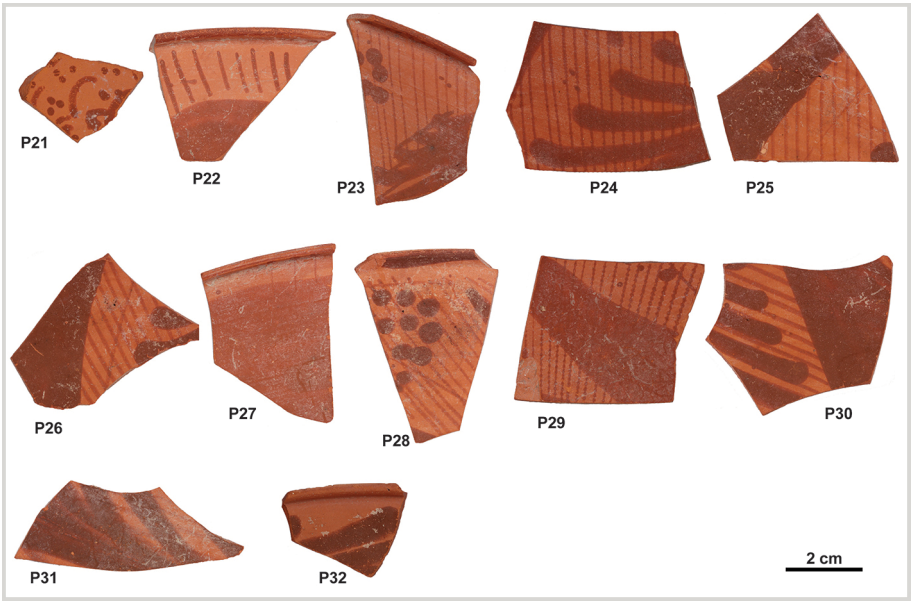


Fig. 2 Analyzed sherds from Petra, painted insides.

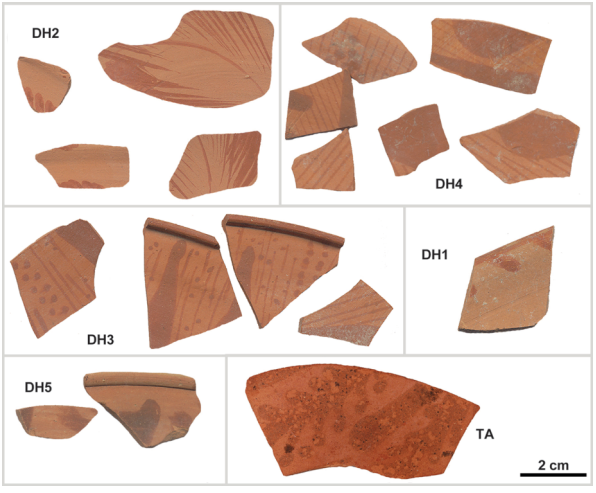


Fig. 3 Anlayzed sherds from Khirbet edh-Dharih and Tayma, painted insides.

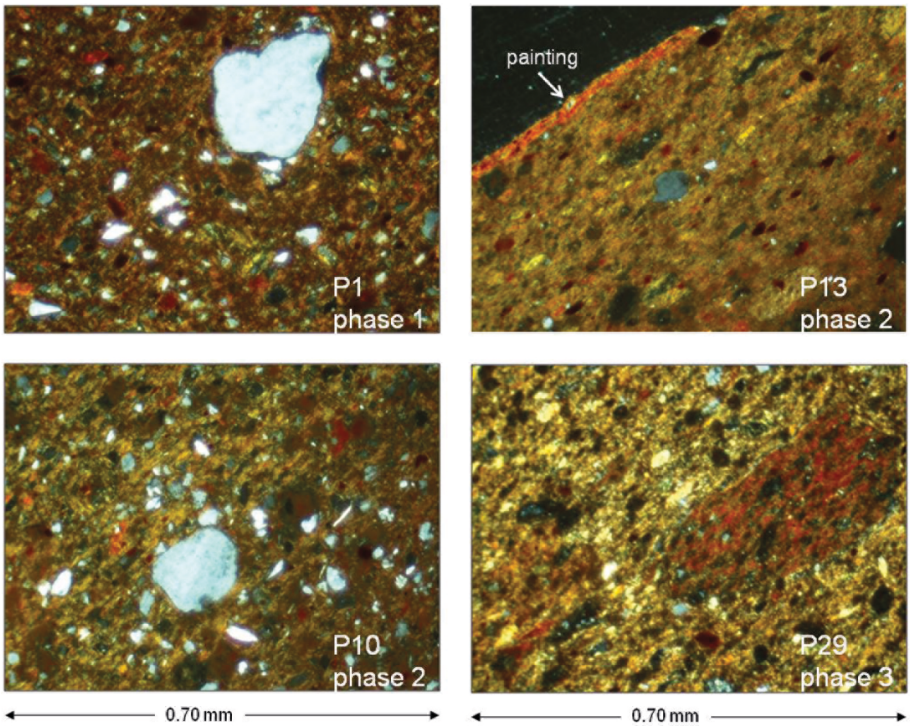


Fig. 4 Microphotograph of thin-sections representing sherds of different phases. The red paint layer of sample P13 is visible in the cross section (XPL, field of view 0.7mm).

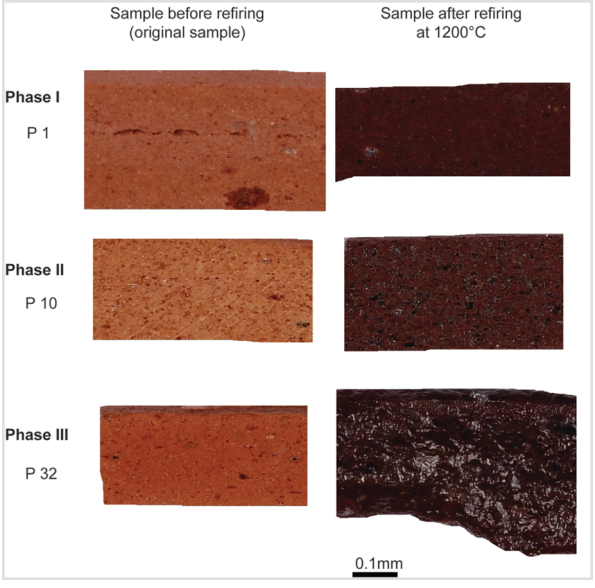


Fig. 5 MGR-analysis of three samples of Nabataean painted fine ware from Petra. Left column = fragments before refiring (original cross cut of samples) and right column = fragments after refiring at 1200°C.

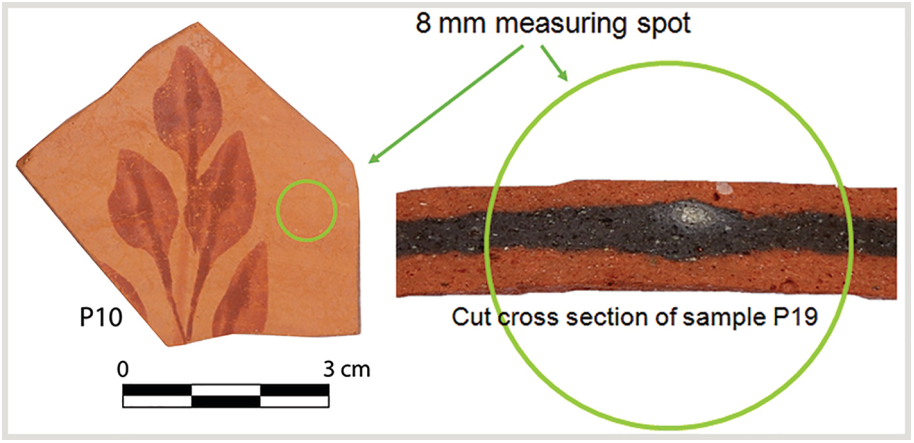


Fig. 6 Measuring by pXRF on unpainted part of sherds and on a cut cross section with indicated 8 mm spots of the pXRF-analyzer (sample P19, about 2.5 mm thick, is the only sherd with a black core).

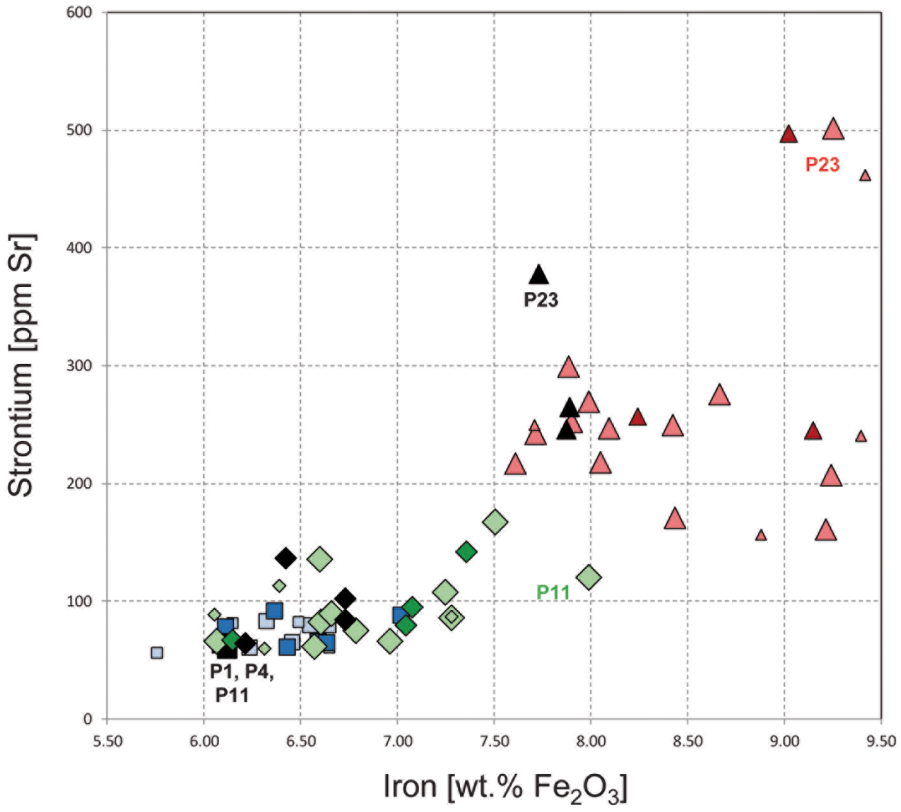


Fig. 7 Strontium and iron contents of sherds from Petra by WD-XRF (black symbols) and by pXRF (colored symbols). Phase 3 (red symbols) is clearly distinguished from phases 1 and 2 (respectively, blue and green symbols). Measurements by pXRF were done on the outsides of fragments (large symbols), on cut cross sections, on fresh fractures (smaller dark colored symbols), or on unpainted parts of the insides of fragments (smallest symbols); most points represent averages of several measurements.

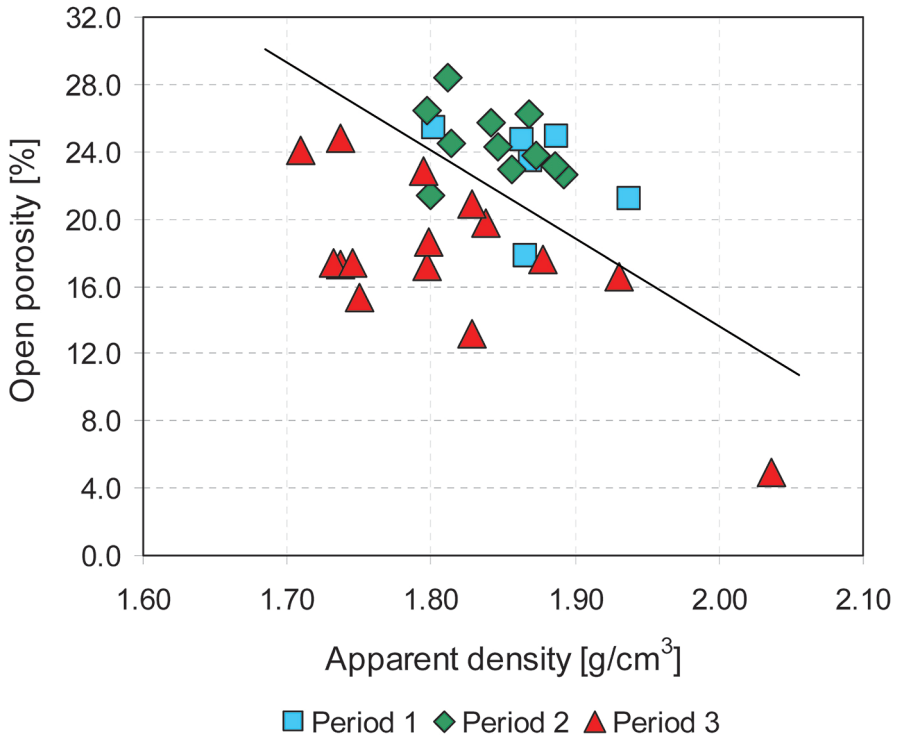


Fig. 8 Open porosity vs. apparent density of sherds from three phases in Petra.

Sample No.	Phase	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	(Cu)	Zn	Rb	Sr	Y	Zr	(Nb)	Ba	(Ce)	(Pb)	l.o.i.	total
			% by weight										ppm													%	%
P 1	1	MD528	66.79	1.44	20.27	6.12	0.020	1.35	0.87	0.06	2.96	0.116	85	144	44	5	52	80	63	18	315	14	172	39	12	1.13	99.90
P 4	1	MD529	66.77	1.45	20.31	6.09	0.020	1.36	0.85	0.08	2.97	0.110	83	148	43	5	52	80	63	21	317	15	171	54	14	1.18	100.04
P 10	2	MD530	63.61	1.37	20.81	6.73	0.027	2.11	2.31	0.08	2.80	0.143	71	143	40	5	39	81	84	23	306	16	157	63	15	1.06	99.79
P 11	2	MD531	66.69	1.45	20.18	6.21	0.019	1.64	0.76	0.08	2.86	0.112	81	150	40	5	40	79	64	22	330	17	171	39	14	0.92	100.02
P 13	2	MD532	63.66	1.36	21.60	6.73	0.024	1.56	1.79	0.05	3.02	0.208	86	145	44	32	43	84	102	18	300	14	166	66	14	1.59	100.00
P 15	2	MD533	65.75	1.43	20.80	6.42	0.021	1.38	1.15	0.08	2.85	0.119	91	148	42	15	42	72	136	19	310	16	484	55	24	2.28	99.23
Dh 1	1	AD398	64.63	1.42	20.30	6.14	0.022	1.56	1.67	0.12	2.86	0.187	80	142	39	15	51	79	164	19	308	16	286	42	24	1.80	98.90
Dh 2	2	AD395	63.70	1.41	21.57	6.56	0.022	1.87	1.14	0.11	2.79	0.120	98	143	44	5	45	81	85	21	295	16	144	42	13	1.21	99.28
P 23	3	MD534	53.44	1.02	21.81	7.73	0.059	2.32	7.85	0.20	3.02	2.545	121	131	50	12	90	80	378	20	196	11	194	36	16	1.83	100.07
P 24	3	MD535	54.50	0.95	23.25	7.87	0.038	2.14	7.92	0.06	3.07	0.189	142	139	57	12	102	76	246	14	164	9	126	39	13	0.97	100.33
P 29	3	MD536	55.81	1.00	21.61	7.89	0.046	2.25	7.78	0.23	3.19	0.195	116	115	47	11	95	70	265	15	182	11	182	53	12	2.02	98.83
Dh 3	3a	AD396	54.11	1.00	22.38	7.98	0.069	3.37	7.26	0.22	3.00	0.163	125	127	48	21	69	87	165	19	172	10	99	44	11	0.78	99.55
Dh 4	3b	AD394	57.93	1.06	21.32	7.58	0.061	2.66	4.73	0.22	2.98	0.348	139	118	45	42	59	86	137	26	219	12	119	72	11	1.68	98.89
Dh 5	3c	AD397	56.06	1.09	17.27	6.43	0.080	4.32	12.02	0.28	2.43	0.317	107	107	41	24	63	78	237	27	311	16	232	59	11	0.68	100.30
T 1	3a	MD992	56.29	0.99	21.86	7.62	0.050	2.52	6.95	0.38	3.09	0.252	118	120	47	18	79	80	197	16	187	11	111	37	14	1.95	99.51

Tab. 1 Results of analysis by WD-XRF of samples from Petra (P), from Khirbet edh-Dharih (Dh), and from Tayma (T); samples ignited at 900°C, l.o.i. = loss on ignition, major elements normalized to a constant sum of 100%.

Method	samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	(Cu)	Zn	Rb	Sr	Y	Zr	(Nb)	Ba	(Ce)	(Pb)	l.o.i.
		% by weight										ppm													%
Phase I and Phase II																									
WD-XRF	n=8	65.2	1.42	20.7	6.37	0.02	1.60	1.32	0.08	2.89	0.14	84	145	42	11	45	79	95	20	310	16	219	50	16	1.40
		1.5	0.04	0.6	0.27	0.00	0.27	0.55	0.02	0.09	0.04	8	3	2	10	5	3	37	2	11	1	116	11	5	0.46
pXRF	n=18	62.1	1.50	22.6	6.75	*nd*	*0.93*	1.8	*na*	3.10	0.15	146	158	*nd*	*40*	54	80	96	26	307	18	*na*	*na*	*11*	*na*
		3.3	0.08	2.5	0.48	*nd*	*nd*	0.8	*na*	0.45	0.09	55	14	*nd*	*29*	13	6	41	2	19	2	*na*	*na*	*6*	*na*
NAA (2)	n=16	*na*	1.25	*na*	6.49	*na*	*na*	2.0	0.31	*na*	*na*	*na*	154	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	60	*na*	*na*
		na	0.12	*na*	0.40	*na*	*na*	0.8	0.11	*na*	*na*	*na*	4	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	4	*na*	*na*
one phase																									
NAA (1)	n=211	*na*	*na*	*na*	6.74	*na*	*na*	*na*	*nd*	2.82	*na*	*na*	128	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*68*	*na*	*na*
		na	*na*	*na*	0.84	*na*	*na*	*na*	*nd*	0.42	*na*	*na*	20	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	12	*na*	*na*
Phase III																									
WD-XRF	n=5	55.2	1.01	22.1	7.81	0.05	2.55	7.11	0.19	3.05	*0.22*	129	126	49	20	83	80	238	19	186	11	144	49	13	1.46
		1.8	0.04	0.8	0.16	0.01	0.50	1.36	0.07	0.09	*0.08*	11	10	4	13	18	7	95	5	22	1	41	15	2	0.55
pXRF	n=17	56.1	1.11	22.5	8.37	*0.03*	*2.10*	7.1	*na*	2.91	0.46	161	164	*nd*	*25*	102	76	251	26	170	13	*na*	*na*	*13*	*na*
		4.7	0.16	3.8	0.64	*0.02*	*0.56*	2.2	*na*	0.46	0.58	44	27	*nd*	*nd*	28	7	82	5	23	2	*na*	*na*	*7*	*na*
NAA (2)	n=89	*na*	0.90	*na*	7.66	*na*	*na*	7.8	0.30	*na*	*na*	*na*	134	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	59	*na*	*na*
		na	0.08	*na*	0.73	*na*	*na*	2.5	0.08	*na*	*na*	*na*	11	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	5	*na*	*na*

Tab. 2 Comparison of means and standard deviations of chemical analysis by WD-XRF, pXRF, and NAA (1 = 'Amr 1987, 178, and 2 = Gunneweg, Perlman, and Asaro 1988, 324). Analyses by WD-XRF are given for ignited samples (1.4% average ignition loss), elements only determined by NAA are not included: n = number of analyses, na = not analyzed, and nd = not detected or unreliable values.

Date/time	Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	P_2O_5	S	Cl	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba
		% by weight							ppm										
2013-03-12 17:16	P5 a	61.8	1.39	21.6	6.43	1.98	2.89	0.16	580	126	104	152	49	78	59	27	292	19	-
2013-05-15 13:28	P5 a	59.0	1.38	19.5	6.45	2.05	2.83	0.18	557	128	110	135	44	80	60	24	300	17	71
2013-05-15 13:31	P5 a	58.9	1.40	19.7	6.41	2.04	2.88	0.16	501	130	98	151	46	77	61	26	298	16	-
2014-06-01 16:08	P5 a	59.8	1.37	20.4	6.43	2.02	2.91	0.18	494	118	106	133	46	79	63	21	291	17	68
	mean a	**59.9**	**1.39**	**20.3**	**6.43**	**2.02**	**2.88**	**0.17**	**533**	**125**	**105**	**143**	**46**	**78**	**61**	**25**	**295**	**17**	**70**
2013-05-15 13:33	P5 i	51.3	1.33	16.4	6.73	1.27	2.90	0.17	-	80	92	167	37	77	60	24	289	17	-
2013-05-15 13:36	P5 i	50.1	1.33	15.5	6.60	1.29	2.81	0.12	-	72	97	147	41	79	61	25	281	18	-
2013-05-15 13:38	P5 i	46.2	1.29	13.4	6.61	1.44	2.78	0.08	-	74	99	156	34	80	62	23	280	17	-
	mean i	**49.2**	**1.32**	**15.1**	**6.65**	**1.33**	**2.83**	**0.12**	-	**75**	**96**	**157**	**37**	**79**	**61**	**24**	**283**	**17**	-
2013-05-15 13:51	P5 b	51.4	1.34	15.3	6.48	1.46	2.86	0.04	-	92	111	156	41	76	59	26	286	15	102
2013-05-15 13:53	P5 b	49.1	1.31	13.9	6.43	1.44	2.77	0.04	-	95	103	140	39	80	60	23	272	15	-
2013-05-15 13:56	P5 b	50.0	1.28	15.1	6.82	1.58	2.76	0.08	-	75	85	129	35	87	64	28	291	19	187
2014-06-01 16:26	P5 b	57.7	1.15	20.7	6.57	1.15	2.58	--	-	47	83	95	51	87	66	22	307	19	262
2014-06-01 16:29	P5 b	57.3	1.19	19.8	6.81	1.20	2.68	--	-	55	98	114	52	90	67	26	307	20	205
	mean b	**53.1**	**1.25**	**16.9**	**6.62**	**1.37**	**2.73**	**0.05**	-	**73**	**96**	**127**	**44**	**84**	**63**	**25**	**292**	**18**	**189**
2013-05-15 13:42	P5 c	50.1	1.23	13.7	6.44	1.34	2.63	--	-	89	101	134	36	81	59	20	272	19	148
2013-05-15 13:45	P5 c	53.4	1.17	14.1	5.98	1.13	2.45	--	-	101	95	123	38	84	59	24	288	17	189
2013-05-15 13:48	P5 c	50.6	1.05	13.3	6.43	1.06	2.26	--	-	88	85	95	44	90	60	22	297	18	281
2014-06-01 16:31	P5 c	63.1	1.38	19.6	6.39	1.33	3.02	0.05	-	56	113	150	40	79	60	25	275	19	217
2014-06-01 16:34	P5 c	63.4	1.36	19.0	6.20	1.26	2.97	0.07	-	64	103	130	35	79	60	22	285	17	200
2014-06-01 16:36	P5 c	65.7	1.39	20.9	6.22	1.30	2.96	0.09	-	63	104	134	39	75	58	23	285	18	167
2014-06-01 16:42	P5 c	58.8	1.21	16.9	6.70	1.22	2.67	--	-	78	92	83	44	84	64	23	292	20	229
	mean c	**57.9**	**1.25**	**16.8**	**6.34**	**1.23**	**2.71**	**0.07**	-	**77**	**99**	**121**	**39**	**82**	**60**	**23**	**285**	**19**	**204**

Tab. 3 Measurements by pXRF of sample P5 (a = outer surface; i = inner surface; b = fresh fracture surface, and c = cut cross section), single measurements of 120 sec on different spots and at different times.

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	Cl	V	Cr	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	dv	N	Po	dv/d
	% by weight										ppm													g/cm$_3$	vol.%	vol.%	%
P1 #	**66.0**	**1.42**	**20.0**	**6.04**	**0.020**	**1.3**	**0.86**	**0.06**	**2.93**	**0.11**	**-**	**-**	**84**	**142**	**5**	**51**	**79**	**62**	**18**	**311**	**14**	**169**	**12**				
P1	61.1	1.51	21.2	6.26	-	-	2.25	-	2.94	0.18	910	159	159	139	-	60	82	64	24	320	19	-	5	1.86	11.7	24.7	68.3
P2	64.2	1.51	23.4	6.64	-	-	1.12	-	3.14	0.09	--	76	138	157	-	55	81	80	28	301	18	-	6	1.87	8.7	17.8	
P3	57.1	1.46	18.7	6.46	-	-	2.22	-	3.27	0.14	618	141	183	146	-	69	77	83	25	297	19	76	8	1.80	12.4	25.4	
P4 #	**66.0**	**1.43**	**20.1**	**6.02**	**0.020**	**1.3**	**0.84**	**0.08**	**2.93**	**0.11**	**-**	**-**	**82**	**147**	**-**	**51**	**79**	**62**	**20**	**314**	**15**	**169**	**13**				
P4	63.8	1.51	24.1	6.48	-	-	1.89	-	3.13	0.14	597	112	111	149	-	51	82	67	26	313	18	55	8	1.89	11.6	24.9	68.8
P5	61.8	1.39	21.6	6.43	-	-	1.98	-	2.89	0.16	580	126	104	152	-	49	78	59	27	292	19	-	6	1.87	11.2	23.5	
P6	61.7	1.41	24.5	6.49	-	-	1.32	-	2.96	0.13	--	55	124	175	-	36	81	79	26	264	18	87	--	1.94	9.9	21.2	
P7	65.2	1.43	24.8	6.57	-	-	0.73	-	2.92	0.06	--	90	85	131	-	36	92	61	22	307	22	69	10	1.87	11.2	23.7	
P8	63.6	1.53	23.3	6.70	-	-	1.59	-	2.88	0.13	497	91	134	170	-	49	83	85	24	336	20	-	9	1.80	10.6	21.4	
P9	64.9	1.56	23.3	6.66	-	-	1.92	-	3.07	0.13	509	75	142	169	15	52	77	89	28	345	17	-	7	1.89	10.7	22.7	
P10 #	**62.8**	**1.35**	**20.5**	**6.65**	**0.027**	**2.1**	**2.29**	**0.08**	**2.76**	**0.14**	**-**	**-**	**70**	**141**	**-**	**38**	**80**	**82**	**22**	**302**	**16**	**155**	**15**				
P10	63.2	1.48	24.9	7.36	--	0.9	3.94	-	2.58	0.19	575	86	123	153	-	46	80	90	28	324	17	-	-	1.81	11.9	24.5	65.8
P11 #	**66.1**	**1.44**	**20.0**	**6.15**	**0.019**	**1.6**	**0.75**	**0.08**	**2.83**	**0.11**	**-**	**-**	**81**	**148**	**-**	**39**	**78**	**64**	**22**	**327**	**17**	**169**	**14**				
P11	68.7	1.68	27.8	7.99	-	-	1.62	-	3.46	0.12	599	61	166	174	-	75	91	120	27	317	21	-	8	1.85	11.6	24.3	66.9
P12	61.7	1.50	22.2	7.25	-	-	2.37	-	2.97	0.17	532	87	168	138	72	62	83	107	26	290	21	-	11	1.86	11.0	23.0	
P13 #	**62.6**	**1.34**	**21.3**	**6.62**	**0.024**	**1.5**	**1.76**	**0.05**	**2.97**	**0.20**	**-**	**-**	**84**	**142**	**31**	**43**	**83**	**100**	**18**	**295**	**14**	**164**	**14**				
P13	60.0	1.40	20.7	5.99	-	-	2.05	-	2.68	0.14	698	118	105	153	-	39	77	65	22	317	18	178	-	1.84	12.3	25.8	66.5
P14	64.0	1.56	24.3	6.96	-	-	0.77	-	3.01	0.09	--	65	132	169	-	50	83	66	26	319	16	-	10	1.89	10.9	23.1	
P15 #	**63.7**	**1.38**	**20.2**	**6.22**	**0.021**	**1.3**	**1.11**	**0.08**	**2.76**	**0.12**	**-**	**-**	**89**	**144**	**15**	**41**	**70**	**132**	**18**	**300**	**16**	**469**	**23**				
P15	62.7	1.67	22.6	6.89	-	-	0.96	-	3.59	0.17	505	61	317	164	33	72	69	187	24	299	17	299	24	1.81	13.5	28.4	66.0
P16	59.5	1.48	21.6	6.78	-	-	1.48	-	2.87	0.10	--	105	104	174	-	45	75	75	27	301	18	-	-	1.87	12.3	26.3	
P17	60.9	1.54	20.8	7.23	-	-	1.47	-	4.61	0.14	537	62	231	168	-	75	78	165	27	286	17	157	24	1.80	12.8	26.4	
DH1 #	**64.6**	**1.42**	**20.3**	**6.14**	**0.022**	**1.6**	**1.67**	**-**	**2.86**	**0.19**	**--**	**--**	**80**	**142**	**15**	**51**	**79**	**164**	**19**	**308**	**16**	**286**	**24**				
DH1	54.0	1.42	17.2	6.31	-	-	3.38	-	2.77	0.49	654	17	108	153	-	45	72	182	27	290	15	77	12	1.79	14.5	26.0	
P18	52.3	1.13	21.9	7.88	0.034	2.2	9.79	-	2.83	0.88	614	113	213	171	-	124	72	299	30	173	11	-	15	1.74	12.5	24.8	
P19	54.4	1.27	25.3	8.79	0.014	-	4.20	-	2.59	0.21	482	70	172	187	-	111	76	154	23	157	13	-	8	2.04	2.4	4.9	
P20	60.1	1.14	24.4	8.43	0.029	1.2	5.03	-	3.22	0.21	600	167	130	166	-	70	78	171	38	224	12	-	-	1.79	11.3	22.9	
P21	55.0	1.15	23.1	7.61	0.025	2.1	6.50	-	3.98	0.35	637	84	167	154	-	87	81	217	26	208	13	-	-	1.83	10.2	20.9	
P22	60.0	1.30	26.8	9.24	-	1.6	4.82	-	3.29	0.19	527	66	202	198	-	117	72	207	26	158	12	-	-	1.93	7.9	16.5	
P23 #	**52.5**	**1.00**	**21.4**	**7.60**	**0.058**	**2.3**	**7.72**	**0.20**	**2.96**	**2.50**	**-**	**-**	**119**	**129**	**12**	**89**	**78**	**371**	**19**	**193**	**11**	**190**	**15**	1.83	6.7	13.1	
P23	60.7	1.44	15.9	9.45	0.017	--	3.81	-	3.22	2.54	506	119	158	184	-	138	73	508	30	174	9	-	21	1.83	6.7	13.1	
P24 #	**54.2**	**0.94**	**23.1**	**7.82**	**0.038**	**2.1**	**7.87**	**0.06**	**3.05**	**0.19**	**-**	**-**	**141**	**138**	**12**	**101**	**76**	**245**	**14**	**163**	**9**	**125**	**13**				
P24	58.8	1.06	25.9	8.56	-	1.3	8.27	-	2.98	0.24	697	94	131	184	-	102	72	256	22	146	13	-	9	1.80	8.7	17.1	66.4
P25	58.7	1.10	24.6	8.21	0.021	2.6	10.13	-	2.59	0.48	880	119	227	174	-	104	72	277	22	151	14	-	30	1.73	9.1	17.4	
P26	56.8	1.04	24.2	7.77	0.019	2.8	9.51	-	2.70	0.27	717	80	159	150	-	86	74	258	19	144	14	-	6	1.75	9.1	17.4	
P27	58.3	1.20	23.1	9.20	0.046	2.5	6.21	-	2.24	0.26	605	86	143	182	-	70	83	163	32	194	15	-	6	1.88	8.6	17.6	
P28	58.3	1.03	24.8	8.20	0.009	3.1	10.50	-	2.75	0.29	621	100	129	158	-	88	67	252	26	151	8	-	19	1.74	9.1	17.3	62.9
P29 #	54.0	0.97	20.9	7.63	0.044	2.2	7.53	**0.23**	3.09	0.19	--	--	112	111	11	91	68	256	15	176	11	176	12	1.71	12.4	24.1	
P29	58.5	1.07	22.0	8.20	0.015	2.3	7.35	-	3.36	0.44	597	91	127	175	-	112	66	281	26	170	13	-	18	1.71	12.4	24.1	
P30	57.6	1.03	22.1	7.70	0.014	1.8	9.17	-	2.74	0.28	757	162	207	139	-	93	69	260	23	148	11	88	8	1.75	8.0	15.3	63.4
P31	57.5	1.06	24.3	8.05	0.017	1.7	7.77	-	3.11	0.23	563	118	116	175	-	162	81	218	26	168	13	-	12	1.84	9.7	19.7	
P32	57.0	1.24	24.3	8.67	0.050	2.3	7.45	-	3.16	0.34	527	82	247	185	-	136	88	276	24	169	16	-	15	1.80	9.4	18.6	
DH3 #	**54.1**	**1.00**	**22.4**	**7.98**	**0.069**	**3.4**	**7.26**	**0.22**	**3.00**	**0.16**	**-**	**-**	**125**	**127**	**21**	**69**	**87**	**165**	**19**	**172**	**10**	**99**	**11**				
DH3	46.2	0.81	16.7	9.08	0.061	-	6.23	-	2.55	0.12	1677	230	99	112	25	85	90	169	23	160	13	117	7	1.93	8.1	15.7	
DH4 #	**57.9**	**1.06**	**21.3**	**7.58**	**0.061**	**2.7**	**4.73**	**0.22**	**2.98**	**0.35**	**-**	**-**	**139**	**118**	**42**	**59**	**86**	**137**	**26**	**219**	**12**	**119**	**11**				
DH4	44.0	0.79	12.9	7.20	0.069	-	4.51	-	2.10	-	-	81	111	100	-	55	74	307	32	187	17	524	7	1.99	4.7	9.2	
T1 #	**54.9**	**0.97**	**21.3**	**7.44**	**0.049**	**2.5**	**6.78**	**0.37**	**3.02**	**0.25**	**-**	**-**	**115**	**117**	**18**	**77**	**78**	**193**	**16**	**183**	**10**	**108**	**14**				
T1	47.8	0.93	16.8	7.69	0.058	-	5.40	-	3.98	0.21	1432	369	120	129	-	81	76	176	22	167	10	157	9				

Tab. 4 Results of measurements by pXRF on the unpainted outer surfaces of sherds compared to results of analysis by WD-XRF (#), calculated for non-ignited samples. PXRF measurements for Mn, Mg, S, Cl, Cu, Ba, and Pb were many times below the detection limit (-). In the final columns the physical ceramic properties are given: dv = apparent density, N = water absorption, Po = open porosity, and dv/d = density index.

4.5 Household Production and Wider Connections – Analysis of Bronze Age Pottery Found in the Romanian Banat

Bernhard Heeb, Małgorzata Daszkiewicz, Gerwulf Schneider, Andrei Bălărie, Alexandru Szentnmiklosi (†)

Introduction

During the 2nd half of the 2nd millennium BC, fortified settlements of immense size appeared in the historical landscape of Banat (today's Serbia, Romania, and Hungary), at the southeast periphery of the Pannonian Plain.[1] Some of them cover nearly 100 ha or even more (e.g. Sântana-Cetatea Veche, Munar, and Czanádpalota-Földvár[2]). By far the largest is Corneşti-Iarcuri, located around 18 km to the north of the modern-day city of Timişoara. The site features four earth-filled wooden ramparts with a total length of more than 33 km. They encompass an area of 1765 ha.[3] After a first unfortified settlement phase in the Middle Bronze Age (Vattina culture), Iarcuri grew to its full size during the Late Bronze Age (Cruceni-Belegiş culture), and then seems to have vanished by the beginning of the Early Iron Age. The main phase of occupation dates to between 1500 and 1000 BC. A lot of small and unfortified hamlet-like settlements seem to have existed parallel to the huge fortified settlements. Some of these have been excavated, but most of them are still unpublished.[4]

Since 2007, the Muzeul Naţional al Banatului in Timisoara has been conducting research in Iarcuri. In cooperation with the Museum für Vor- und Frühgeschichte Berlin, the Johann Wolfgang Goethe-Universität Frankfurt/Main, and the University of Exeter,

1 Czukor et al. 2017.

2 Gogâltan and Sava 2010.

3 Lehmphul et al. 2018; Balarie et al. 2016; Heeb, Szentmiklosi, and Krause 2015; Heeb, Jahn, and Szentmiklosi 2014; Heeb, Szentmiklosi, Harding, et al. 2012; Szentmiklosi, Heeb, et al. 2011.

4 Sava, Hurezan, and Mărginean 2011; Szentmiklosi 2016; Szentmiklosi and Medeleţ 2016.

different research methods have been applied.[5] With the support of Topoi II (RG A-6), it has been possible since 2013 to analyze Late Bronze Age (LBA), Middle Bronze Age (MBA), and Copper Age pottery sherds from Iarcuri (recovered from excavation and mostly from fieldwalking). Additional LBA and MBA material from eight other settlements and necropolises has also been analyzed.

Chronological framework and description of the study material

Only the later phase of the Vattina culture (Reinecke Bz B2) is evidenced at Iarcuri. As mentioned, it was followed by the Cruceni-Belegiš culture.[6] The typical vessels of the Cruceni-Belegiš culture are spherical and biconical amphoras with straight neck, bowls, cups without handles, twin vessels, and pyraunois. Colors range from various shades of brown and grey to black;[7] this is probably also a chronological indicator. The Cruceni-Belegiš culture is defined by three main phases (I–III). The first phase is characterized by ornamentation techniques such as grooves, pseudo-cord impressions, and in some cases vertical and oblique cannelures on the body. Phase I covers the period from Bz B2 and Bz C.

In Phase II, cannelures become characteristic and bowl rims start being curved inwards. The color is now mostly greyish-blackish, which points to non-oxidizing firing conditions. The second phase covers the period from Bz D to the first half of Ha A1.

Biconical amphoras with low bodies, cannelure garlands on the neck, and turban motifs on the body are typical elements of the third phase. Bowls with incurved rims, mostly faceted, are also typical. Phase III dates to the second half of Ha A1 to Ha A2.[8]

Questions

The starting point for the project was to identify and map pottery sherd distribution inside the settlement area in Rings I and II based on the possible different raw materials or technology used in their manufacture. Identifying potential clay sources was another of the project's aims.

It was hoped that the results of this research might help us to identify a spot or an area where the pottery for Iarcuri was produced. In the next step of the project, the focus was widened to include contemporary sites within the examined landscape to determine whether they featured pottery made using the same raw materials and technology as the

5 The project has been funded by the Deutsche Forschungsgemeinschaft since 2013.

6 Bóna 1975; Gogâltan 2004.

7 Vranić 2002, 187; Szentmiklosi 2009, 167.

8 Gumă 1993, 180; Szentmiklosi 2009, 80.

ceramics from Iarcuri, and to see if it could be demonstrated that Iarcuri was a central production site for pottery distributed on a regional scale.

The third step involved examining Copper Age and Middle Bronze Age ceramics to compare them with the Late Bronze Age material. Finally, inspired by results from the Lossow-Project,[9] pottery from Late Bronze Age necropolises was also included in the analyses.

Sites and choice of samples

In all, 592 samples from nine different sites were analyzed (Giroc-Mezcal, Voiteni-Voiteg, Timişoara-Fratelia, Peciu-Nou, Deta-Dudarie, Cruceni, Hodoni-Pusta, Corneşti-Iarcuri, und Corneşti-Cornet). All are located in the West-Romanian Judeţ Timiş (Fig. 1). Late Bronze Age material was sampled and analyzed from all sites except Corneşti-Cornet. Middle Bronze Age pottery was taken from two sites (Corneşti-Iarcuri and Corneşti-Cornet) and Copper Age material from one (Corneşti-Iarcuri). Analysis was also carried out on pottery from necropolises associated with the following sites: Timişoara-Fratelia, Peciu-Nou, Voiteni-Voiteg, and Cruceni (Tab. 1).

Samples were only taken from material that could be securely dated, in the best case scenario, to one of the phases of the Cruceni-Belegiş culture. Settlement pottery included sherds recovered from cultural layers, pits, or (especially in Iarcuri) from the site surface. Samples from burial contexts consisted of material from broken but complete vessels. Due to the small size of the fragments of settlement pottery, very few vessel types were identifiable. Dating was instead based on the typical ornamentation of the ceramic sherds. In Iarcuri, samples were chosen from a lot of different areas because of the immense size of the site.

Further fieldwork was carried out in order to take 44 samples of clays that were analyzed to assess their suitability as raw materials for making pottery and to determine whether there was any correlation between these clays and the raw materials used by potters during the LBA, MBA, and Copper Age.

Results and perspectives for future research

Settlements

A first spatial mapping based on the results of MGR-analysis, analysis of chemical composition, and physical ceramic properties of samples found in Iarcuri did not show any

9 See chapter 4.6 in this volume.

Site	MBA settlement	LBA settlement	LBA cemetery	Copper A. settlement
	number of samples			
Cornești Iarcuri 18				18
Cornești Iarcuri; Ring I		69		
Cornești Iarcuri; Ring II		66		
Cornești Iarcuri; Ring I	23			
Cornești Iarcuri; Ring II	30			
Cornești Cornet	64			
Cruceni		12		
Cruceni			12	
Deta-Dudarie		20		
Giroc-Mezcal		60		
Hodoni Pusta		30		
Peciu-Nou		42		
Peciu-Nou			14	
Timişoara Fratelia		50		
Timişoara Fratelia			10	
Voiteni		50		
Voiteni			11	
Cornești Iarcuri daub		9		
Peciu-Nou daub		1		
Total	117	409	47	18

Tab. 1 Number of analysed samples.

clear patterns inside the settlement. It would appear that in both Ring I and Ring II, the same approach was taken in local pottery production: there was no preference in the choice of raw material (reflected in the large number of MGR-groups) and similar technology was used. Notably, both in the MBA and the LBA assemblages there were only solitary examples of sherds made from the same clays in Ring I and in Ring II (three clay types are represented in each ring). Aside from ceramics made from locally sourced raw materials, pottery made from non-local clays was also noted in the MBA and LBA assemblages from Iarcuri. Only five of the MBA sherds represented non-local pottery (9% of all MBA sherds). In contrast, 28 of the LBA sherds came from non-local ceramics (21% of all LBA sherds). These included: twenty sherds attributable to pottery with a regional distribution (its production site has not been identified; this pottery was present at all of the analyzed LBA sites), two fragments of pottery made within the region, and six fragments representing supra-regional wares (imports). As already stated, Ring I does not differ from Ring II in terms of local pottery; however, among the LBA assemblages, there is far more regional pottery in Ring I (20 sherds) than in Ring II (2 sherds). The opposite tendency was observed in the MBA assemblages. Assuming that

the pottery selected for analysis is a representative sample, of what significance is the fact that the ceramic assemblage from Ring I presents a far greater number of sherds that had a regional distribution?

The most remarkable result of laboratory analyses so far is that a regional group of pottery was attested at all of the studied Late Bronze Age settlements (Fig. 2). This points to a central place of production from which the pottery was distributed, at least on a regional level. The place of origin is not Iarcuri, and has not been identified thus far. Why and how distribution was carried out also remain unresolved issues.

Most of the analyzed sherds from Iarcuri had been tempered with grog of the same composition as the ceramic body to which it was added. Intentional mineral and organic temper were not noted. Non-standardized firing conditions and the large number of different local clay sources make household production very likely. Comparison of Copper Age and Middle Bronze Age material from Iarcuri showed that although other local clay sources had been used, the technical aspects of production had remained virtually unchanged and were indeed comparable to those seen in the Late Bronze Age. The technical aspects of local Late Bronze Age ceramics in Iarcuri are also comparable to the other settlement sites examined as part of this project. At all of these sites, people mostly used ceramics made from locally sourced clay, and it is very probable that households produced pottery predominantly for their own use. Grog temper is also observed at all sites, though mineral temper is only seen in solitary sherds recovered from Giroc Mezcal (these sherds are not from pottery local to the site).

Burials

The analyzed pottery from four of the sites involved in this project (Cruceni, Timosoara Fratelia, Peciu-Nou, and Voiteni-Voiteg) included sherds recovered from burial contexts, as well as from the associated settlements. No relevant differences were observed between these two contexts in the pattern of ceramics. In each case, local pottery and sherds representing the so-called regional group occurred both at cemeteries and at settlements (though fewer sherds were recorded at cemeteries). Imported pottery was noted at the necropolises of Voiteni-Voiteg and Peciu-Nou (no pottery of this type was recovered from settlement contexts). Regionally produced pottery was found at both the settlement and cemetery sites in Cuceni and Voiteni-Voiteg.

No graves have been discovered at Iarcuri, which makes comparing analyses impossible. If future research were to uncover necropolises linked to the Late Bronze Age settlement, this would certainly be worth investigating. It would also make sense to widen the circle of Late Bronze Age sites involved in this study to include ones beyond the borders of the Judeţ Timiş. The analyses carried out so far have only provided a rough picture and give a preliminary insight into what is potentially possible with more

material from a greater number of sites and a greater number of areas. The results raise new questions which can only be answered by comparison with more data.

General remarks

1. Iarcuri: the only significant difference between Ring I and Ring II is that there is a much greater number of sherds representing the regional group in Ring I (Fig. 3).

2. The percentage of individual groups of pottery represented at Iarcuri Ring II and Voiteni-Voiteg are very similar.

3. There is a preponderance of pottery attributable to the regional group at Peciu Nou – does this bear any relation to this pottery's place of production?

4. Very few sherds attributable to the regional group were noted at Timisoara-Fratelia and Iarcuri Ring II.

Fig. 1 Map of the analyzed settlements and necropolises (Doris Schäffler, Cornești-Projekt, Museum für Vor- und Frühgeschichte der Staatlichen Museen zu Berlin).

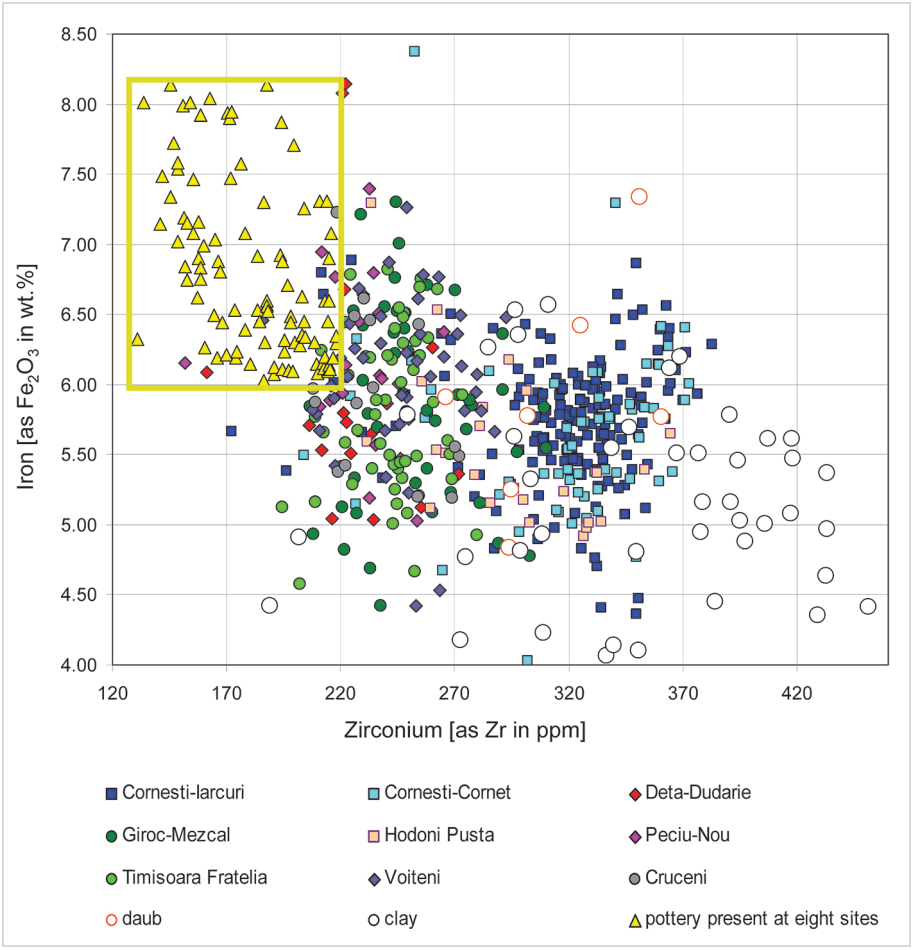


Fig. 2 Diagram of iron vs. zirconium contents of pXRF measurements of sherds from various sites.

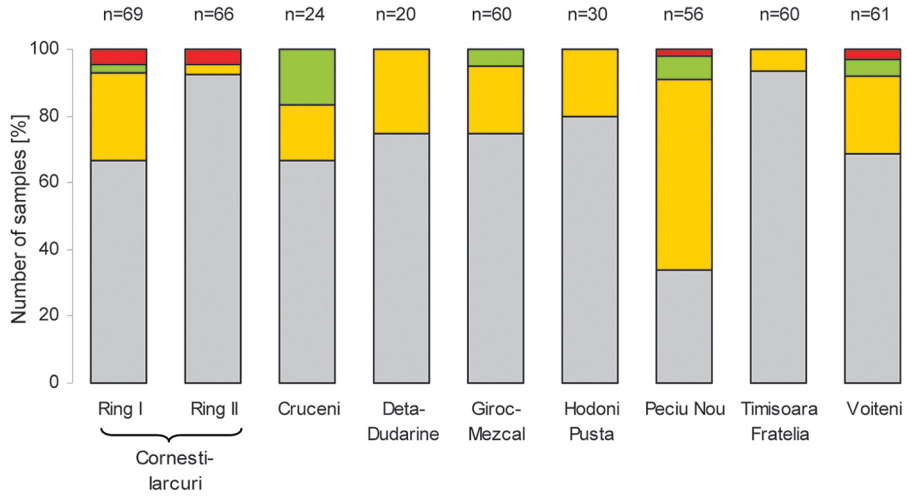


Fig. 3 Number of samples of various groups found in Ring I and Ring II of Cornești-Iaurcuri and other sites (grey = local at this site, yellow = regional group occurring at all sites, green = individual regional group only occurring at this site, red = imports from outside the region).

4.6 Economic Archaeological and Archaeometric Studies on Bronze Age Turban-Edged Pottery in Brandenburg – A Case Study of Lossow

Ines Beilke-Voigt and Małgorzata Daszkiewicz

Cultural and economic background

The 'hillfort' or 'Burgwall' of Lossow was a fortified settlement built on a prominent high bank of the river Oder at the transition from the Middle to Late Bronze Age (15th/14th century BCE). The site was continually inhabited until the start of the Early Iron Age, 9th century BCE (Fig. 1).

During this early phase of its use, the hillfort fulfilled central-place functions that the Topoi 1.0 research group 'Central Places' was able to map out. In the second phase of use, there was a change in function, and the fortified settlement was used as a place for ceremonial gatherings in the early Iron Age. The results of recent settlement and landscape archaeology investigations, in combination with natural science analytical techniques, have provided further evidence in support of the assertion that the hillfort exhibited the characteristic aspects of a central place – of defense, rule/administration, and trade and craft production – confirming the influential status of Lossow as a fortified center in its region.[1]

From a strategic viewpoint, the site selected by the builders of this fortified settlement, an attractive natural elevation by the course of the river Oder, provided excellent views over the terrain, specifically over the Oder to the north and south, and, thus, over the lines of approach by water from upriver and downriver, with the natural protection of an elevated position, offering optimal defensive advantages. Moreover, the transport advantages provided by the site's convenient access to the Oder satisfied the

1 Beilke-Voigt 2010, 41–54; for a detailed discussion, see Beilke-Voigt 2014b, 174–185.

basic requirements for ideal integration into the long-distance trade network. One of the fortified settlement's essential functions was undoubtedly to take charge of controlling transport and trade at this specific point along the river. The hillfort represented a transportation hub, not only for the bi-directional north-south waterway but also for the east-west overland route. Even today, Lossow is situated near a ford-like crossing point in the river, which is only approx. 150 m across at that point. Thus, one can assume that it would already have been an important river crossing and place for the unloading/reloading of goods in earlier periods. Trade goods could easily be transferred here from water to overland routes and vice versa. A *position of economic power*, would have been one result of these topographic advantageous, and this was undoubtedly coupled with a *ruling/administrative function*. The representative character of the fortified settlement, prominently situated on a natural elevation, emphasized this function. It seems logical that the 'ruling class' based at the hillfort would have been charged with administrative duties – like the organization, administration, and/or production and distribution of trade goods – and have profited from them.

The numerous finds in Lossow testifying to regional and long-distance contacts, thus, constitute evidence that the fortified settlement held a well-established position within a supra-regional trade network. This evidence is embodied archaeologically in numerous imports and high-quality individual finds.[2] Finds of vessels used in salt extraction (briquetage) and the archaeometric analysis of two samples have shown that salt, perhaps from the area around Halle (Saale) made its way through trade to Lossow.[3] The hillfort also had contacts with the Silesian region, as various finds, including graphitic ware, make clear. Similarly, metal finds, such as a bronze armband and a bronze pin with a profiled head and ribbed neck (Mostkovice variant), corroborate contacts with Silesian territory. A small vase-headed pin (*Vasenkopfnadel*) decorated with oblique notching at the transition from its decorative to functional section, points to the Moravian cultural space (*Kulturraum*). Contacts with the Nordic cultural sphere (*Nordischer Kreis*) are manifest in the early find of a five-part bronze disc neck collar (*Plattenhalskragen*) with ribbing and of a bronze double button. A single-edged Lháň/Hrušov-type razor points to its main area of dissemination, which is in the Central Elbe-Saale area, extending as far as the river Morava.[4] Beyond a doubt, the most significant imported object among the finds is the small bronze ram figure. This figure is evidence for supra-regional ties to Greek cultural space, whose large sanctuaries, especially in Olympia, contained similar figures.[5] **This particular find permits remarkable conclusions to be drawn about the geographic reach of the influence and degree of prominence that Lossow must have enjoyed, emphasizing its importance as a central place.**

2 For a detailed discussion, cf. Beilke-Voigt 2014a, 133–144.

3 Bönisch, Daszkiewicz, and G. Schneider 2012, 206.

4 On the blade, cf. Mehner 2010, 85–86.

5 Beilke-Voigt 2016, 87–120; Beilke-Voigt 2018, 51–68.

Moreover, finds of equipment used to produce bronze objects show that intensive bronze production took place – another economic aspect emphasizing Lossow's role as a central place. The inventory of finds – including eight casting molds, the associated shells, and technical ceramics, such as a fragment from a smelting pot and seven clay nozzle fragments – provides evidence of repeated activity by specialized metalworkers at the hillfort. Hence, persons with specific technical knowledge worked here over a longer period. By contrast, no evidence at all for bronze production has been found at the contemporaneous settlement outside the fortified enclosure thus far. Based on the research to date, one must assume that this 'extramural' settlement was largely agriculture-oriented, and that its function was to supply the inhabitants of the 'hillfort', the fortified settlement. The hillfort for its part, would have served as the place of production and distribution of various goods, and there is good reason to suppose that some of the sought-after bronze objects produced there were intended for trade rather than settlement use.

This trading orientation sheds an interesting light on the quite striking quantity of finds – over 200 objects – of 'turban-edged' pottery (*Turbanrandkeramik*, sometimes 'turban rim' pottery) from the hillfort alone. In addition to being noteworthy in itself, this sets this find assemblage apart from the corpus of finds from other contemporaneous settlements.

Turban-edged ware bowls are handmade vessels exhibiting a characteristically twisted edge (Fig. 2).[6]

'Twisted' should be understood here in the proper sense of the word, meaning that the eponymous decoration is created by *twisting* the rim of the bowl (similar to a turban). This twisting was executed through uniform stroking of the rim into the soft clay. Depending on degree of smoothing, the twisting left a smoothly or sharply contoured ridge, though as a rule, it is rendered flat through stroking. The twisted edge, which can vary in width but is always oblique in relation to the diameter of the vessel opening, runs around the entire opening; in most cases the 'twist' starts at the outer vessel walls and runs at an angle over the rim.

The area of distribution of these twisted, or 'turban-edged' bowls is quite large, and two variants of the ware have been defined: a North Bavarian/Bohemian variant and a Danubian/southeastern European variant.[7] Schneider determined relatively early that the turban-edged bowl finds in Brandenburg represent a "markedly eastern form".[8] Though the earliest of these vessels date to the end of the Early Bronze Age/transition

6 For a detailed discussion, see Beilke-Voigt 2014b, 44–45.

7 For a detailed discussion, cf. Schopper 1995; Rind 1999, 131–135; Rind and Schopper 2002, 100–118.

8 J. Schneider 1958, 21.

to the Late Bronze Age (period IV/V or HaA2/B1), they are characteristic in the Late Bronze Age period (period V or HaB2/3).[9]

In the case of Lossow, one can assume that the large number of finds of this specific *Turbanrand* ware should be interpreted as another indication of craft production specific to the hillfort, and that it is probable that Lossow functioned as the production site of these vessels. Further, one should assume that the pottery was produced not only to meet its producers' immediate demands, but that surplus vessels were also intentionally produced and were sold in stationary trading, in the sense of a market place. In this context, use of the road network and/or waterways which had long been familiar was possible. Finally, one can assume that this high-quality pottery was specifically associated with the hillfort, not only with respect to its production and distribution but also with respect to its user group. This assumption is supported by the current corpus of archaeological finds for the contemporaneous extramural settlement, which, as is the case with bronze production, does not include any indication of turban-edged ware.

Research questions

Turban-edged ware constitutes the starting point for the economic archaeological and archaeometric investigations presented here. This pottery can be described as a prestige/exclusive ware, which unlike the otherwise common household pottery, was not the product of large-scale production. The strikingly high concentration of sherds from turban-edged ware among the Lossow find material, therefore, raises several questions.

Turban-edged ware: Lossow as the place of production and distribution?

Thus, the first question is where the turban-edged ware was produced, which given Lossow's status as an economic center, may well have been at the hillfort itself. If one assumes that this was so, it seems very probable that Lossow served not only as the place of production of the pottery but also as a distribution point, i.e. that the pottery was sold/traded from there.

This made it necessary to compare the turban-edged pottery with a sufficiently large pool of reference material made up of 'normal' settlement pottery and everyday pottery, in order to identify products from the same workshop through archaeoceramic analyses to clarify the question of whether the pottery was produced locally or represented imported goods. Depending on the findings from this investigation, this question was coupled with economic archaeological questions relating to the reconstruction of trade

9 For a detailed discussion, see Beilke-Voigt 2014b, 44–45.

routes and networks encompassing large areas, with the aim of revealing some of the web of economic relationships surrounding the hillfort center in the Bronze Age. Thus, the distribution of the postulated 'export goods' could form a basis for conclusions about the framework of economic trade of the Lossow hillfort and provide answers to questions relating to its infrastructure – How did the traders travel: on foot, overland? Was the network of waterways used? – and the structuring of trade relations.

Exploitation of clay deposits

Assuming that there were clay deposits in the immediate vicinity of the settlement and that these were exploited, locally produced ceramic material should exhibit the same thermal behavior and chemical composition as the raw materials at the source deposit. If the turban-edged ceramic material could be shown to match a local source, this would be interpreted as an indication of local production. Thus, one investigation objective was to determine whether there were suitable clay deposits in the vicinity of Lossow that could be shown to have been exploited by Bronze Age inhabitants.

Turban-edged ware – luxury ware?

Irrespective of the question of raw material sourcing, the presence of the turban-edged ware in both settlement and cemetery contexts gives rise to questions relating to the function and demonstrable use of these specific ceramic vessels and to the persons who used them.

As noted above, the hillfort of Lossow is still the only settlement site in Brandenburg associated with such a large quantity of this specific pottery. The sherds of turban-edged pottery are noteworthy, not only due to their large number but also because there is no record of a single sherd of this pottery being found in the contemporaneous extramural settlement at Lossow. This observation was at the root of the question of whether the turban-edged bowls may have been something more than 'normal' settlement pottery, but might instead be viewed as having been a sort of prestige/luxury ware, i.e. one associated with a 'social' message in the sense of an 'identity marking' pottery.

The turban-edged bowls that have a pair of holes near the edge are sometimes interpreted as decorations that could be hung up on a wall, causing researchers to describe these bowls as prestige dishes, for instance. Ganslmeier disputes this interpretation though, suggesting that the bowls were used as lids and that these pairs of holes,[10] which are sometimes situated on opposite sides of the vessel, allowed the corresponding vessels to be tied shut, thus, protecting the food inside from vermin. This profane use

10 Ganslmeier 2008.

of the bowls, to cover storage containers, has been considered by other researchers as well.[11]

The use of turban-edged bowls as lids (*Deckschalen*) has been documented in the context of cemeteries. For example, the terrine used as the burial vessel in urn burial no. 12 of the Lossow cremation cemetery was covered with two turban-edged bowls: one smaller (rim diam. 18cm, vessel 5) the other, larger but incomplete (rim diam. 46cm, vessel 1). Isolated sherds of this vessel type were also found occasionally in the fill of some of the other graves.[12] Turban-edged dishes was also used as a cover for burial vessels in burials in the cemetery at Müllrose, in the Märkisch-Oderland District. Analogously to Lossow, there is evidence in a small number of cases that the burial urn in question was covered by two dishes, or – and in the majority of cases this is so – fragments of this pottery were found in the fill of graves.[13] There is evidence that turban-edged pottery functioned as a lid at the Late Bronze Age cemetery at Einsenhüttenstadt as well.[14]

In view of this information, a range of vessels large enough encompass vessel types like pots, bowls, cups, etc., to use the standard archaeological designations, was compiled for the purpose of comparison. The aim was to analyze the ceramic properties of the material, such as apparent porosity and bulk density, use the resulting data to compare turban-edged ware from both settlement and cemetery contexts across sites, and to identify a possible function on that basis.

Sampling strategy

The first consideration in compiling the range of samples was the objective of determining the location of production of turban-edged ware in this period, which it was proposed might be Lossow, and of obtaining insight into the distribution of this specific class of vessels from that production location. Thus, as a first step, it was necessary to analyze the composition of the clay used and investigate the techniques used to process the clay in the production of the pottery.

To this end, a total of 83 sherds of turban-edged ware from Lossow were subjected to ceramic analysis. Of these, 77 sherds were from the hillfort and six sherds were from the cemetery.

11 Hummel and Soeters 1999, 70.

12 Data on the pottery come from the list attached to the analyses on the cemetery at Lossow, still under preparation, which is the subject of a Master thesis: Girgard 2017, 12–13. With regard to the cemetery in general cf. Beilke-Voigt 2012.

13 I wish to thank Ms. Verena Tiedtke, M.A. for this information from the still ongoing additional work on the cemetery (e-mail communication, 19.06.2017)

14 Rücker 2007, 60.

In a subsequent step, the broadest possible corpus of comparative material in the form of sherds of turban-edged pottery found at other sites was analyzed. Ultimately, 23 of the circa 40 sites in Berlin/Brandenburg that are associated with turban-edged ware finds were selected for an analytical series, with both settlement and cemetery sites represented (Fig. 3).

A total of 90 sherds of turban-edged pottery from these 23 sites were collected for sampling. The number of sherds from each individual site varied from one to a maximum of 18. The total number of turban-edged sherds analyzed, including this material and the Lossow material, was 173. The sherds were examined individually and selected with a view to performing a pXRF analysis at three spots on a fresh fracture surface of each sherd.[15]

In addition to the samples of turban-edged pottery under study, samples were also taken from other sherds representing various classes of vessels. The purpose of this was to obtain reference material for the intra-site archaeometric comparison. In the case of Lossow, 291 sherds of non-turban-edged pottery were sampled and another 50 sherds found at the other sites in Brandenburg were also sampled. In this way, a representative selection of samples of other classes of vessels (non-turban-edged vessels) was compiled, consisting of samples from a total of 341 sherds.

Another objective was to ensure that the analysis encompassed the greatest possible range of vessels representing the Lossow complex so that archaeometric analysis could be used to ascertain whether the vessel-type designations commonly used in archaeology could be verified against the presumed function of the vessel in question. The selection of reference ceramics was designed to constitute a representative cross section of the various vessel forms as possible, and ultimately incorporated 13 vessel types.[16] Both technical pottery[17] and clay daub were also sampled for inclusion in the analysis. In the end, the reference material from Lossow consisted of 151 ceramic objects from the hillfort (BW), 50 from the extramural settlement (VB), and 91 from the cemetery.

The total material for ceramic analyses from all sites amounted to 529 ceramic objects (turban-edged ceramic objects (TR) and reference ceramic objects) (Tab. 1).

While the pottery sherds were being sampled, investigations in the surrounding area were conducted to identify potential sources of raw material, i.e. clay deposits. In the end, nine clay deposits (alluvial clay) from the immediate and more remote surroundings of Lossow were included in the archaeometric analyses, represented by a total of 12 samples. A match between geological clay samples and the sherds would confirm the

15 See chapter 2.2 and chapter 6 in this volume for a description of the pXRF procedure.

16 The vessel types in question are baking plates, double-cone vessels, pots, cups, jugs, terrines, various types of bowls, saucers, omphalos bowls, a tub, miniature barrels, plates, and spoons. Both fine and coarse ware were included in the analysis.

17 At issue are four ceramic casting molds and molding clay, nozzle and briquetage fragments (two each).

Site	all	varia	TR	Analysis					
	Number of samples			pXRF	a MGR	WD-XRF	pCP	macr-gr	t-s
				Number of samples					
Lossow Burgwall	**228**	150	77	228	104	95	67	105	11
Lossow Vorburgsiedlung	**50**	50			50	5			
Lossow Gräberfeld	**97**	91	6	97	12	12	8	12	
Lossow Burgwall Briquetage	**14**			8		14			
Altgaul	**8**	1	7	8	3	7	3	3	1
Angermünde	**1**		1	1		1			
Berlin-Buch	**24**	7	17	24	13	13		13	
Buckow	**6**	4	2	5	6	3	6	6	1
Cottbus	**2**	1	1	2		2			
Dolgelin	**5**	3	2	5	3	5	3	3	
Garzau	**2**	1	1	2		2			
Groß Gastrose	**1**		1	1		1			
Großbahren	**1**		1	1		1			
Lebus	**3**	2	1	3	3	3	3	3	1
Lichterfelde	**1**		1	1		1			
Müllrose Gräbefeld	**32**	14	18	32	32	8	30	32	3
Neumeichow	**4**	1	3	4	1	4	1	1	
Oderberg	**3**		3	3	1	3	1	1	
Rathsdorf	**14**		14	14	3	14	3	3	1
Rathsdorf Gräberfeld	**7**	7			7	7			
Reichenbach	**3**	2	1	3		3			
Schmellwitz Cottbus	**5**	2	3	5		5			
Templin	**1**		1	1		1			
Vogelsang	**3**	1	2	3		3			
Wegendorf	**4**	1	3	4	1	4	1	1	1
Wriezen	**6**	2	4	6	2	6	2	2	1
Wustermark	**4**	1	3	4		4			
Total	**529**	**341**	**173**	**465**	**241**	**227**	**128**	**185**	**20**

Tab. 1 Number of samples analyzed of turban-edged and reference pottery for Lossow and comparison sites (TR = turban-edged pottery, a MGR = abridged MGR-analysis, pCP = physical ceramic properties, macr-gr = macroscopic grouping, and t-s = thin-sections).

hypothesis of local exploitation, thus, making a determination as to the specific place of production possible.[18]

Methods used

Ceramic sherds are characterized by the natural clay used and by the processing it undergoes, and consist of the matrix and inclusions. Archaeometric techniques make it

18 I would like to express my sincere gratitude here once again to Mr Pöhnack, archaeological monument conservation volunteer (Eisenhüttenstadt), for his helpful local knowledge and skilled guidance during the search for clay deposits of this kind. Samples were taken on 18 Nov. 2013. See Tab. 2 for details.

possible to analyze this information in order to identify clay deposits used by potters in the past, and by this means to determine the provenance of pottery, or rather its place of production. To this end, a broad range of ceramic analytical techniques were employed (see chapter 2 in this volume). A combination of mutually independent analytical methods was used to assess the robustness of the results of these analyses (cf. Tab. 1).

As a first step, a total of 457 sherds from this project were selected for measurement with a portable energy-dispersive analyzer (pXRF). Each sherd was measured at three different spots on a fresh fracture surface, and the standard deviations for the means of the three measurements were calculated (on precision of analysis, see chapter 6). The maximal values should be below 20%. The results for most elements, other than Si, Ti, Fe, K, Rb, and Zr, came in far above this limit, even reaching as high as 80% for Mn and Ca (Fig. 4). The accuracy of the pXRF results was checked by comparison with the results obtained by WD-XRF (n = 201). The maximal deviations for all elements determined turned out to be between 35 and 136% (Fig. 4).

The first chemical data obtained through pXRF and WD-XRF were used to check groupings using multivariate tests (scattergrams, cluster analysis, principal component analysis, and discriminant analysis). Figure 5 shows one of the many tests performed, as an example. The objective was to determine whether samples of turban-edged ceramics found at different sites were form only one group, thus, indicating a central production. Therefore, a discriminant analysis was performed on the analysis results of the samples from five individual sites as groups (only elements estimated with acceptable accuracy were used). The discriminant analysis shows that pXRF measurement results (triangles) are shifted towards the upper left corner relative to the WD-XRF results (squares), but groups are nonetheless clearly recognizable, e.g. when comparing samples from Altgaul (black) to samples from Müllrose (red) or to samples from Schmellwitz and Cottbus (turquoise). These latter are the sites most distant to each other, which clearly used different raw materials. They produced their own turban-edged ceramics. The grouping of samples from Berlin-Buch and Neumeichow overlapping in composition with samples from Müllrose is somewhat problematic. In this case, it is clear that other analyses are indispensable (e.g. MGR).

Another method of ceramic classification, and one independent of the chemical analysis, was also employed: 241 samples (166 were from finds at Lossow) were subjected to MGR-analysis. The results from these analyses could then be compared to those of the WD-XRF chemical analysis on 227 samples (113 from Lossow). This is necessary to distinguish among different clays used by the potters and to ensure a reliable interpretation of chemical groups (see chapter 2). In some cases, fragments refired at 1200°C showed very different thermal behavior (Fig. 6). In the first row are samples from Lossow BW (hillfort), in the second samples are from Lossow VB (extramural set-

tlement), and in third row are typical samples from the Lossow cemetery. Each of the matrix groups characterize specific raw clays (e.g. the matrix group Lss 12 characterizes pottery found in Lossow VB and some pottery fragments found in Lossow BW, similar to daub but not including any TR (turban-edged pottery). More or less calcium-rich raw materials in the groups Lss 20 and Lss 22 are only found on BW; these groups do not include any TR. Lss 50 is the group containing the most pottery from the VB, whereas Lss 53 only represents two samples , which differ from all other material used in Lossow. The raw material used for the cemetery is mostly Lss 51, a group that was not detected at other sites within the Lossow complex. With the exception of one sherd, the matrix groups Lss 50 and 52 were not represented at BW and VB (Tab. 2).

To obtain information on the kind of inclusions (natural or intentional) and other properties relating to production technology, 20 thin-sections were prepared: eleven from pottery from Lossow (11 thin-sections) and nine from pottery from other sites. Some examples of TR thin-sections are shown in Figures 7 and 8. The intention was not to apply a third method of classification, but to gain some understanding of the potters' recipes/use of tempering materials from analysis of the thin-sections. It is highly probable that the geological origin of the temper material used in the samples from all sites (in this project) is a glacial deposit driving from Scandinavia, which would mean that the temper material in the pottery fragments analyzed should exhibit some degree of similarity. Indeed, petrographic analysis of the thin-sections revealed that the temper material in the different samples is generally similar, consisting of more or less rounded quartz and mostly sharp-edged pieces of feldspars. The matrix of the sherds shows characteristic differences, as was expected on the basis of the MGR-analyses (included as a third column in Figs. 7 and 8). A very small number of microfossils (foraminifera) (sample BV0066, Fig. 7, right upper corner) were observed in the sample of calcareous clay at high magnification (second column in Figs. 7 and 8). Sample BV0125, with its finer temper consisting mainly of rounded quartz, indicates the use of a different recipe for the clay paste.

To supplement these results, the physical ceramic properties of the sherds were determined and macroscopic descriptions of the size and distribution of the aplastic particles were prepared, as this is significant for the interpretation of the pXRF measurements.[19]

19 A total of 88 of the 181 samples had inclusions larger than 1.6mm in diameter.

Site	Clay type				
	NC	NCcc	NC Fe-	CC	MIX
	MGR - groups				
Altgaul	Atg 3 Atg2	Atg1			
Berlin-Buch	BB 3, 4,8 BB 5,6,7-9	BB 2, BB10		BB 1	
Buckow	Bck 1				
Dolgelin	Dlg 2 Dlg 3	Dlg 1			
Lebus	Lbs 1,3 Lbs 2				
Lossow (Burgwall)	Lss 3, Lss 4-8, 11, 24-26, 28-34 Lss 12-19, 21, 23, 35, 36, 38, 42, 43, 45-49, 64, 65	Lss 1, 2 Lss 9, 27, 31 Lss 19.1, 20, 32, 37, 40, 44		Lss 22, 39, 39.1, 41	Lss 40, Lss 10
Lossow (Vorburgsiedlung)	Lss 12, 21, 43, 50, 54-63, 66		Lss 53		
Lossow (cemetery)	Lss 50-52	Lss 2			
Müllrose	Mir 1-3, 7, 8, 11 Mir 4, 6, 10 Mir 5, 9, 12				
Neumeichow	Neum 1				
Oderberg	Odl 1				
Rathsdorf	Rts 1,2				
Wegendorf	Wgd 1				
Wriezen	Wrz 1,2				

Tab. 2 Distribution of MGR-groups (red = only TR, blue = all kinds of pottery including TR, and black = all kinds of pottery; clay types NC = non-calcareous, NCcc = non-calcareous with calcitic inclusions, NC Fe- = non-calcareous iron-poor, and CC = calcareous).

Results

Turban-edged ware: Lossow as the place of production and distribution?

One question that arose at the start of the research was whether the reason for the strikingly high number of turban-edged ware finds at the fortified settlement was that it functioned as the place of production and/or distribution center of this specific ware. The hypothesis: the potters who resided here produced objects both for local use and for the larger (supra-)regional market and were connected to a larger network of trade. To

test this hypothesis, a group of reference pottery from sites in the surrounding region, at distances ranging from nearby to just over 100km away[20] (cf. Fig. 3), was compiled.

With respect to the place of production of the Lossow turban-edged pottery, the analyses were able to show that the turban-edged vessels were all produced locally, i.e. in Lossow, and yielded no indication of non-local connections in the sense of 'imports' from other locations. MGR and chemical analysis of the ceramics indicated that the sherds belong to the same matrix group and were, therefore, produced from the same clay/clay mixtures.

Like the turban-edged ware, most of the other pottery from the fortified settlement at Lossow was produced locally. Only a small number of vessels from the hillfort analyzed point to non-local production and, therefore, can be considered imported goods. This includes a small barrel-shaped vessel (BV0253 / MD674) (Fig. 9);[21] two roughened wall sherds that have a flat groove (BV0476 and BV0479, the former can be described as coarse ceramic); a third wall sherd of a light color (BV0135 / MD661); and a miniature bowl (BV0292) (Fig. 9).[22]

The results of the archaeometric analyses of the everyday pottery associated with the extramural settlement at Lossow and their comparison with the results for the everyday pottery for the hillfort revealed that both the clay deposit and the production technology used for each group are essentially the same (cf. Tab. 2), meaning that the pottery from the extramural settlement was also produced locally. Some objects from the two sites even fall into the same matrix groups. We can therefore assume an exploitation of local clay deposits and local production of pottery for both settlement forms, whereby the pottery was produced in the context of manual domestic work.

Similarly, the archaeometric analyses of the ceramic objects from the Brandenburg reference sites revealed a relative high degree of uniformity among the objects found within each site context. Thus, we can state that both the everyday and the turban-edged pottery were locally produced in the case of these sites as well and, thus, does not correspond with the pottery from Lossow. There was no indication of regional trade of turban-edged pottery produced in Lossow, of the kind it was suggested may have occurred. All of the (sampled) ceramic objects were either produced in the settlements they were found in or are of non-local origin, but did not come from Lossow. Thus, both

20 The sites Wustermark, Havelland District, and Neumeichow, Uckermark District, at a distance of ca. 130 and ca. 150km, respectively, are the furthest away.

21 Two fragments of the small barrel-shaped vessel from feature 56 are present (inv. no. BLDAM: 2008-600:53/6/1-[1]). This vessel is characterized by a preserved, pierced lug handle with three circumferential grooves running through it. Grooves, known as crow's feet, run diagonally out from below the handle's attachment point. The barrel-shaped vessel is 8.5cm in diameter.

22 The miniature bowl has a diameter of 6cm and a maximum height of 2cm (inv. no. BLDAM: 2008-600:117/5/1-[1]). It was found in a two-layer potsherd pavement (feature 136).

the clay deposits used for and the production sites of the pottery from the reference sites must be sought in or near to the settlement in question, as is the case for the pottery from Lossow. The question of whether there was a broadly based distribution network that organized and engaged in the trading of turban-edged bowls must, unfortunately, be answered in the negative, with one exception.

This exception relates to the settlement of Altgaul, situated 59km north of Lossow in the Märkisch-Oderland District. It was possible to confirm that the chemical composition of a fragment of turban-edged ware from this site matches that of ceramic material from Lossow. The results of both the chemical WD-XRF analysis and the MGR-analysis indicate a shared affiliation with one group, and the physical properties of the ceramics also match. This sherd of turban-edged pottery represents the sole evidence for a Lossow-based production and subsequent distribution of this ware.

Another ceramic object from the settlement at Dolgelin in the Märkisch-Oderland District also shows similarities with the ceramics from Lossow, both with respect to the MGR-analysis and in its chemical composition; these too can be assessed as an indication of production in Lossow. This is not a turban-edged sherd, however, but a light grey, lightly tempered sherd from a non-turban-edged vessel wall (BV0218 / MD794). Dolgelin also lies to the north of Lossow, at a distance of around 30km.

Exploitation of clay deposits

To learn more about the raw material and locate its source, a total of nine different clay deposits in the vicinity of Lossow were identified and samples taken (cf. Fig. 3). After homogenization and gauging the water content at which the clay becomes workable (make-up water content) samples of 2cm in diameter were prepared for firing at three different temperatures (Fig. 10).[23]

The results showed that the clay pit designated 'Alte Ziegelei' (the name means 'old brickyard' and a brickyard did operate here into the last century), which is situated only 800 m from the hillfort, was known and exploited in the Bronze Age (clay 2a, MD634). Clay taken from this deposit was used both in the hillfort and in the extramural settlement to coat (as daub) the earthfast-post buildings and log buildings of the time. The chemical composition of the technical pottery employed in the context of bronze production (casting molds, mold shells, and clay nozzles) is also similar to that of this clay, though these objects did not fall into the same MGR-group. An object thought to be a fragment of briquetage (BV0295) also falls into this group.

23 The sites in question: Lossow 'Steile Wand' (BV0348); Lossow 'Alte Ziegelei' (BV0349-350); Pohlitz, site 2 (old clay pit: BV0351, field: BV0352-353); Fürstenberger Niederung (BV0354); Vogelsang, site Larsfeld (BV0355); and Ziltendorf (field: BV0356-357, burials/Wiesenauer Groddisch: BV0358) Wiesenau (BV0359).

The clays used for pottery production, above all in the extramural settlement, are also very similar to the clays from this clay pit.[24] The calcareous clay from the deposit designated 'Steile Wand' (clay 1, MD633 in Fig. 10) could also be shown to have been one of the raw materials used for pottery production in the hillfort. Thus, at least these two separate clay deposits were exploited for the local pottery production.

Briquetage fragments

Samples of briquetage from multiple sites were analyzed in 2012 for another project, including two samples from Lossow (MD4618 and, without chemical analysis, MD4619).[25] These results were compared to those for a new series of 13 briquetage fragments found in the hillfort (see table in Fig. 11). Regarding the refired samples, sample MD 4618 from Lossow (Fig. 11) is of the same clay type as two briquetage fragments from Bad Lauchstädt, a site known as a salt-brewing center with many finds of briquetage, but it does not fall into the same MGR-group and its temper is not identical.[26] One could interpret this as arguing for a joint provenance region. Sample MD 4618 has the same chemical composition as another sample found in the hillfort (BV0523/AD 704). However, in spite of its similar thermal behavior to samples from Bad Lauchstädt, it differs chemically from sample MD4620, which was analyzed as a reference (e.g. in contents of TiO_2 and Zr). However, two other briquetage fragments found in Lossow (BV0528/AD709 and BV0526/AD707) are chemically similar to the sample from Bad Lauchstädt. One can, therefore, assume that these two samples came from there.

The other analyzed eleven briquetage fragments found in Lossow were determined to belong to multiple different chemical groups (Table in Fig. 11). It might be possible to ascribe a common origin to ten of these samples that have calcium contents above 4.5 wt.%, but no reference material of comparable composition is available at this time and a non-local origin is assumed. The greater silicon content of sample BV0295/MD689 sets this sample apart from all of the other briquetage samples analyzed. As mentioned above, it falls into the same group as the daub and clay from the clay pit 'Alte Ziegelei'.

The MGR-analysis (Fig. 11) results include results for another briquetage sample from Lossow, for which no results from chemical analysis are available (MD 4619). This sample was produced from calcareous clay used to make one sample from Öchlitz (but these two samples do not fall into the same MGR-group).

24 Sample nos.: BV0295/MD689 from hillfort feature 143.

25 Bönisch, Daszkiewicz, and G. Schneider 2012, 206–207

26 Bönisch, Daszkiewicz, and G. Schneider 2012, 206–207.

Turban-edged ware – luxury ware? Cemetery pottery versus settlement pottery

The chemical compositions of the settlement pottery (BW and VB) were also compared to those of the vessels from the cemetery (urns, associated vessels, and *Turbanrand* ware objects). This comparison revealed surprising results depicting a fundamental differentiation between the two complex contexts.

This differentiation could be detected early in the research in the context of the pXRF analyses, as the measurements obtained for settlement and cemetery fall into two clearly separated groups. This separation emerges more clearly in the diagram from the discriminant analysis (Fig. 12, lower diagram) than it does in that of the principal component analysis (Fig. 12, upper diagram). The measurements attest to separate groups for each complex context and indicate that the ceramic grave goods were produced at a potter's workshop other than that which produced the pottery for the settlement (BW and VB).

Additional archaeometric analyses (MGR and WD-XRF) were performed in order to verify the robustness of the grouping observed. Their results showed significant differences between the two find contexts: not only was a different clay deposit (another clay pit) exploited for the vessels used in all burial contexts, but the manual processing of the clay used to produce the burial ceramics was considerably different from that used to produce the settlement pottery. It emerged that less effort was invested in the preparation of the clay for the burial vessels and that less care was taken in processing the clay paste, i.e. kneading and elutriation. As a result of this perfunctory approach, the cemetery pottery is of inferior quality, expressed in a high apparent porosity and high hydraulic permeability of the sherds (Fig 13). This finding indicates that the cemetery pottery was not – as had been assumed up to this point – taken from the existing stock of settlement and household ware, but was instead produced separately for the burial ritual as burial vessels or grave goods.

Another observation should also be noted here as well; an analysis of cremation remains from the Lossow cemetery revealed that the bodies of the deceased were, as a rule, cremated at temperatures of between 650° and 700°C, or, in the case of feature 17, at only 550°C.[27] Might it be possible that the vessels used for the burials were still unfired when placed on the funeral pyre and that their firing took place there with the corpses? At this point it appears unlikely because preliminary results of ongoing analyses to determine the original firing temperature ($T_{eq,}$ using the K-H analytical method – see chapter 2) are showing the same firing temperature ranges for the pottery from cemetery

27 The anthropological analyses and the analyses relating to the cremation temperatures were carried out by the anthropologist Barbara Teßmann, M.A. (Berlin, Apr. 2017). I would like to express by sincere gratitude to her for allowing us to use her results.

and settlement, and it appears that this range does not extend below 700°C (but work is still in progress).[28]

In order to determine whether the surprising difference in the raw material and quality of the cemetery and settlement pottery was specific to Lossow, analyses were performed on the turban-edged pottery from the Müllrose cemetery in the Oder-Spree District to allow for a comparison. It emerged that the ceramics of the cemeteries at Lossow and Müllrose both showed a higher open porosity and lower apparent density than the pottery from the Lossow settlements (Fig. 13). This means that in Müllrose too, the processing of the clay used to produce the burial pottery was of inferior quality.

These results were compared with the results of the analyses of pottery from the Rathsdorf cemetery in the Märkisch-Oderland, as well as with those for the settlement pottery from Rathsdorf. Here, again, it was possible to show that the burial pottery formed a distinct group whose clear separation from the settlement pottery could be confirmed (Fig. 14). The analyses revealed that in the case of Rathsdorf too, the raw material used to produce the burial pottery was significantly different from that used to produce the settlement pottery and the processing of the raw material was also inferior. The differences in composition are also evident with respect to elemental concentrations, as the bivariate diagrams, for instance, make clear (Fig. 15).

Summing up the archaeometric results, therefore, we can rule out a secondary use of pottery previously used in the settlement as burial pottery for all three sites. In the case of all three cemeteries, special funerary pottery was produced, pottery that differs significantly from the settlement pottery both with respect to the chemical composition of the clay and with respect to how the clay was processed. This applies to the turban-edged ware and to the other burial pottery.

Interpretation

Access to suitable clays, water, and fuel constitute the basic prerequisites for making pottery. Lossow satisfied all of these requirements for the establishment of intensive production, perhaps one able to meet more than local demands. Clay/loam deposits were available in sufficient quantities here, as is evident from the exploitation of the 'Steile Wand' and of the clay pit 'Alte Ziegelei', which is in the immediate vicinity of the hillfort. This latter deposit was still being exploited at the beginning of the 20th century. Water, a basic prerequisite for processing clay, was also available in sufficient quantities, whether from the nearby Oder or from any of the four sources located in

28 A new research project of the TOPOI Excellence Cluster is attempting to clarify the differences between settlement and cemetery pottery.

the immediate vicinity of the hillfort. Moreover, wood charcoal and archaeobotanical analyses have indicated that the area around Lossow would have had extensive mixed forest-like vegetation during the Bronze Age and Early Iron Age. It has been established that this vegetation was made up of coniferous (pines) and deciduous trees (alder, oak, hazel, willow, and poplar) and woody plants (black elder).[29] Thus, sufficient quantities of fuel material for the pottery-making process were also available.

A variety of finds testifying to regional and long-distance trading contacts prove that Lossow also had a far-reaching radius of action, the geographical range of its finds cover a vast area from the Nordic cultural sphere and the Silesian and Bohemian-Moravian region, extending as far away as the Aegean by way of the Balkans. For this reason and based on the remarkably large number of finds of turban-edged ware at the hillfort, in one line of inquiry by the research group, the hypothesis was put forth that Lossow functioned as the place of both production and distribution of this specific class of vessels.

Through archaeometric analyses, it was possible to show that the turban-edged pottery from the hillfort was made from clay from local deposits and, thus, was produced locally; i.e. we can confirm that Lossow was the place of production of these vessels. The identity of the producers of this pottery cannot be established on the basis of archaeological sources alone, and there are no relevant written sources. One can assume, though, that pottery-makers from the village *community* were entrusted with the production of this pottery. It is also possible that there were *individual*[30] potters who engaged specifically in the production of turban-edged ware, although this would not have entailed any specialized knowledge. On the other hand, ensuring that the characteristic 'turban edge' was uniformly shaped would have required dexterity and, certainly, some level of experience too. In this respect, we note here the interesting fact that the twisting of the edge was nearly always executed from the right to the left over the vessel edge. Only one edge fragment revealed a rightwards twisting. The different direction of the twisting in this case might suggest that the potter in question was left-handed.[31]

Furthermore, one can assume that the turban-edged ware was produced at production sites, or potters' kilns that would have been present in the settlement regardless for the purpose of producing normal household pottery. The possibility that kilns were built solely for the production of the turban-edged ware appears to be ruled out, as they would have justified neither the investment of work nor the capacity. The geographical distribution and numbers of finds of turban-edged ware in Berlin/Brandenburg makes it clear that this was not a good produced in bulk that was used in every household, hence it is quite conceivable that it was only 'made to order'. This would assume an *attached production*, which was tied to a *corresponding demand*.

29 For a detailed discussion see Beilke-Voigt 2014b, 170–173.

30 On the terminology see Costin 1991.

31 Beilke-Voigt 2014b, Taf. 87,5.

Unfortunately, it was not possible to substantiate the hypothesis regarding a large-scale Lossow-centered distribution of turban-edged ware as an 'export good'. This would have provided an explanation for the high percentage of turban-edged finds at the fortified settlement in Lossow. However, the archaeometric comparison with reference ceramics from 23 other sites near Lossow and within a wider region showed that, with the exception of one sherd of turban-edged pottery from the site Altgaul in the Märkisch-Oderland District, all of the reference ceramics were the products of local production, thus, eliminating the possibility of a large-scale Lossow-centered distribution of this pottery.

A second line of inquiry was aimed at the question of whether the turban-edged vessels represented a luxury ware with respect to their use and the group of persons who acquired them. This proposition was based on the fact that an extraordinarily large number of turban-edged ware finds had been reported for the fortified settlement, one that significantly differs from the numbers of finds associated with other non-fortified settlements (in most cases less than a dozen). Moreover, as has already been emphasized, no turban-edged ware at all has been found at the contemporaneous extramural settlement. It is possible that this is an expression of a hierarchical order between the two settlement forms – fortified and unfortified – and answers the question of who had access to the pottery.

A look at the cemeteries from this perspective reveals that the presence of turban-edged ware is far more frequent there. It was possible to document a "staggering number of 339 specimens" of turban-edged bowls, corresponding to 55% of the total number of bowls, in the Late Bronze Age cemetery at Eisenhüttenstadt.[32] In the cemetery at Müllrose too, turban-edged bowls were found in around 47% of the graves. The current, albeit not yet completed, study of this cemetery has revealed no indication that the deposition of turban-edged ware in a burial is correlated with specific groups of persons or the quantity or selection of grave goods. Turban-edged ware is found in both individual burials and multiple burials, and no spatial concentration or incongruities have been detected in relation to its distribution at the cemetery.[33] Thus, an interpretation of turban-edged ware as a 'prestige/luxury ware' could not be confirmed on the basis of this specific example. This statement can, on the basis of the research on Lossow to date, be confirmed for Lossow as well. Urn burial 12 from the cremation burial cemetery at Lossow, mentioned in the context of the research questions, in which the burial vessel was covered with two turban-edged bowls, contained only a single fragment of bronze that could not be identified more specifically as its sole grave good,[34] and no unusual

32 Rücker 2007, 60.

33 I wish to express my sincere gratitude once again here to Mrs. Verena Tiedtke for this information and the use of these not yet published statements (e-mail communication of 19 Jun. 2017).

34 Girgard 2017, 13.

features or incongruities set this burial apart from the others. Thus, one can probably assume that turban-edged ware represented a common class of vessels in the burial context. However, what one should make of the disparity between the disproportionately high quantity of turban-edged pottery among burial pottery in relation to the extremely small (by comparison) share of such finds within the Bronze Age settlements, or why the hillfort of Lossow is the only site where this disparity is significantly reduced, cannot be explained at this time.

In a related aspect though, surprising and highly intriguing results were obtained with respect to differences in the physical ceramic properties between cemetery and settlement pottery, of a kind which could not have been anticipated.

The ceramic analyses for Lossow showed that all ceramic objects from burials that were sampled (including the turban-edged bowls) were produced specifically for the burial process and that their deposition does not represent a secondary use of pottery taken from the settlement. The vessels were the products of a pottery production process that was solely responsible for the production of sepulchral pottery. Furthermore, both the inferior processing of the clay and the selection of the clay itself, testify to a conscious differentiation from settlement pottery. The clay used for the burial vessels came neither from the 'Alte Ziegelei' clay pit nor from the 'Steile Wand'. At least a third clay deposit in the immediate surroundings of Lossow must have been exploited specifically for the funerary pottery. The analyses of reference ceramics carried out for comparative purposes were able to show that this surprising finding is not unique to Lossow but applies to the cemeteries at Müllrose and Rathsdorf as well.

Thus, based on the findings thus far, we can state that a strict division was maintained between profane domestic pottery and funerary pottery. The differentiation starts with the source of raw material exploited; there was a strict, intentional division between the clay deposits used for sepulchral pottery and those used for the settlement pottery. This means that there must have been separate clay pits associated with the specific purpose/context. One might go so far as to suppose that some kind of *taboo* was at work, one which explicitly ruled out using a clay deposit exploited for one production context for the other production context. Whether this deliberate separation can really be interpreted as having this ritual character or should be understood rather as reflecting the activity of specialized potters who produced either only burial pottery or only settlement pottery, is a question that calls for further research. Another such question is, whether it was acceptable for the sepulchral pottery to be produced in the settlement and in the same pottery production setting, including the same kiln/firing pit, or whether one should assume that a strict separation applied here too. Parallels in ethnographic sources could help clarify these questions and offer approaches to interpretation.

Fig. 1 View of the Burgwall of Lossow on a steep bank of the Oder (from the northeast).

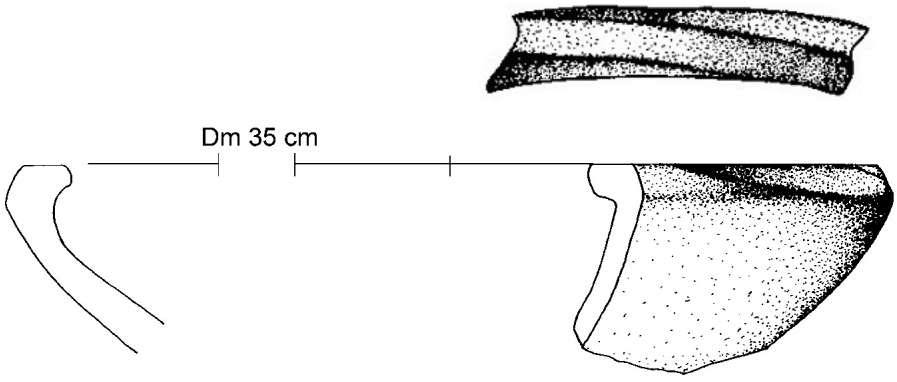


Fig. 2 Twisted-edged bowl from the Lossow Hillfort.

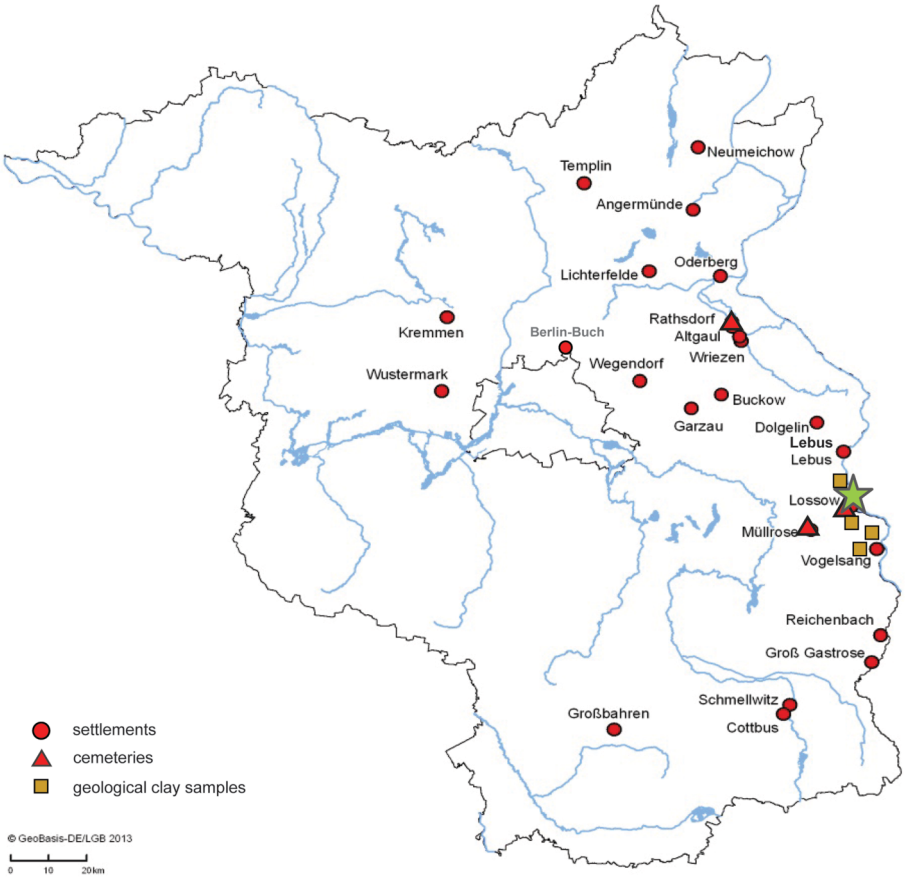
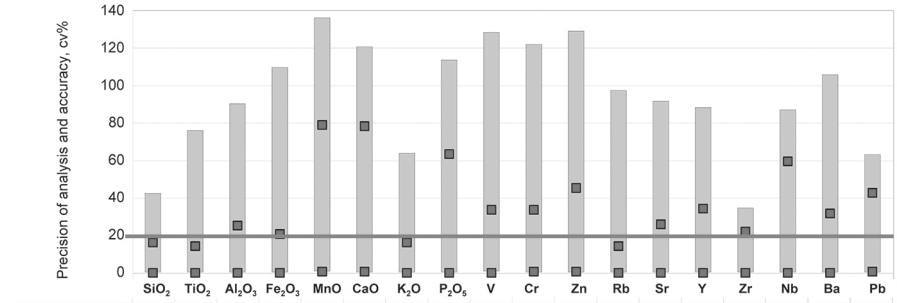


Fig. 3 Sites in Berlin/Brandenburg from which turban-edged and reference pottery was sampled for ceramic analysis.



	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O_5	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb
max precision	15.9	14.0	25.2	20.5	78.8	78.1	16.2	63.2	33.6	33.4	45.1	14.3	25.8	34.2	22.0	59.4	31.5	42.7
min precision	0.11	0.07	0.06	0.22	0.67	0.51	0.12	0.07	0.16	0.37	0.57	0.12	0.13	0.28	0.20	0.19	0.24	0.74
max accuracy	42.8	75.9	90.5	109.5	136.3	120.4	63.9	113.5	128.6	122.0	128.9	97.1	91.9	88.3	34.9	86.8	105.6	63.4
min accuracy	0.17	0.01	0.10	0.01	0.45	0.02	0.05	0.22	0.69	0.06	0.19	0.01	0.11	0.06	0.11	0.01	0.06	0.23

Fig. 4 Precision and accuracy of analysis using pXRF for samples from Lossow.

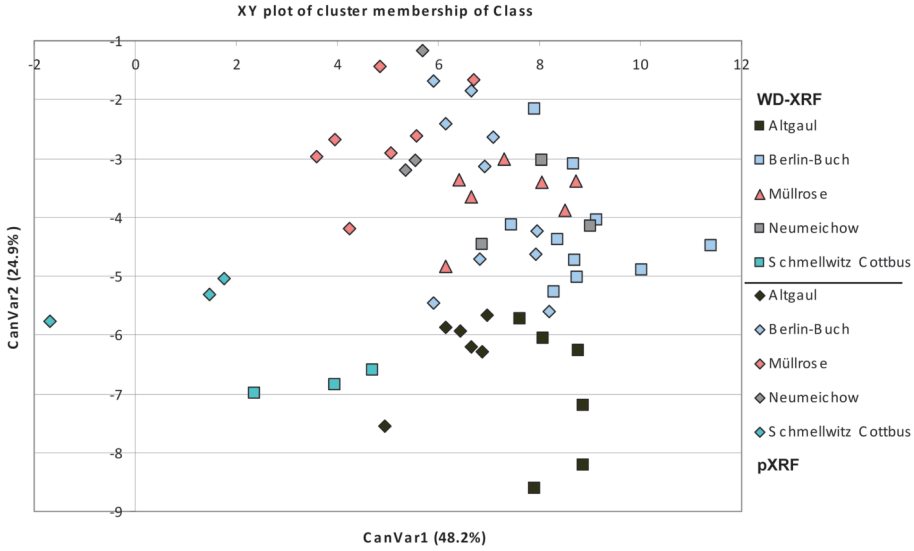


Fig. 5 Discriminant analysis of results by pXRF and WD-XRF for sherds of turban-edged pottery found at different sites in Brandenburg (elements used: Ti, Fe, Ca, K, Cr, Rb, Sr, Y, Zr, and Nb).

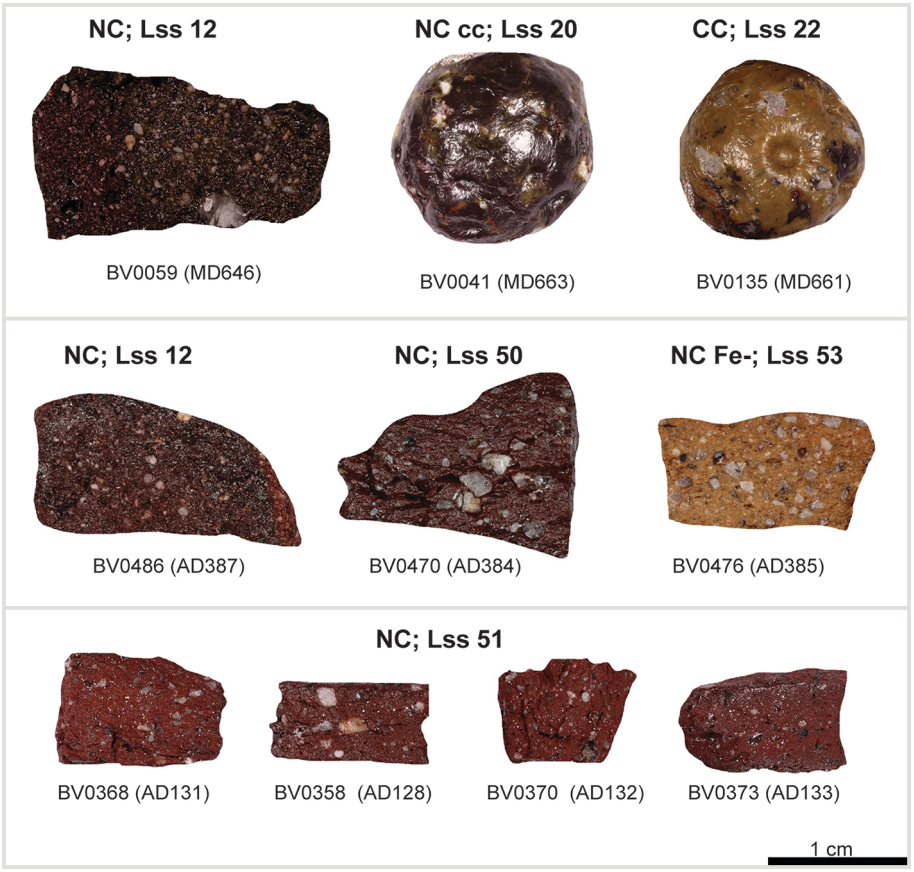


Fig. 6 MGR-analysis: typical thermal behavior of ceramics from Lossow after refiring at 1200°C; upper row = samples from the hillfort (BW), second row = samples from the extramural settlement (VB), and third row = samples from Lossow cemetery.

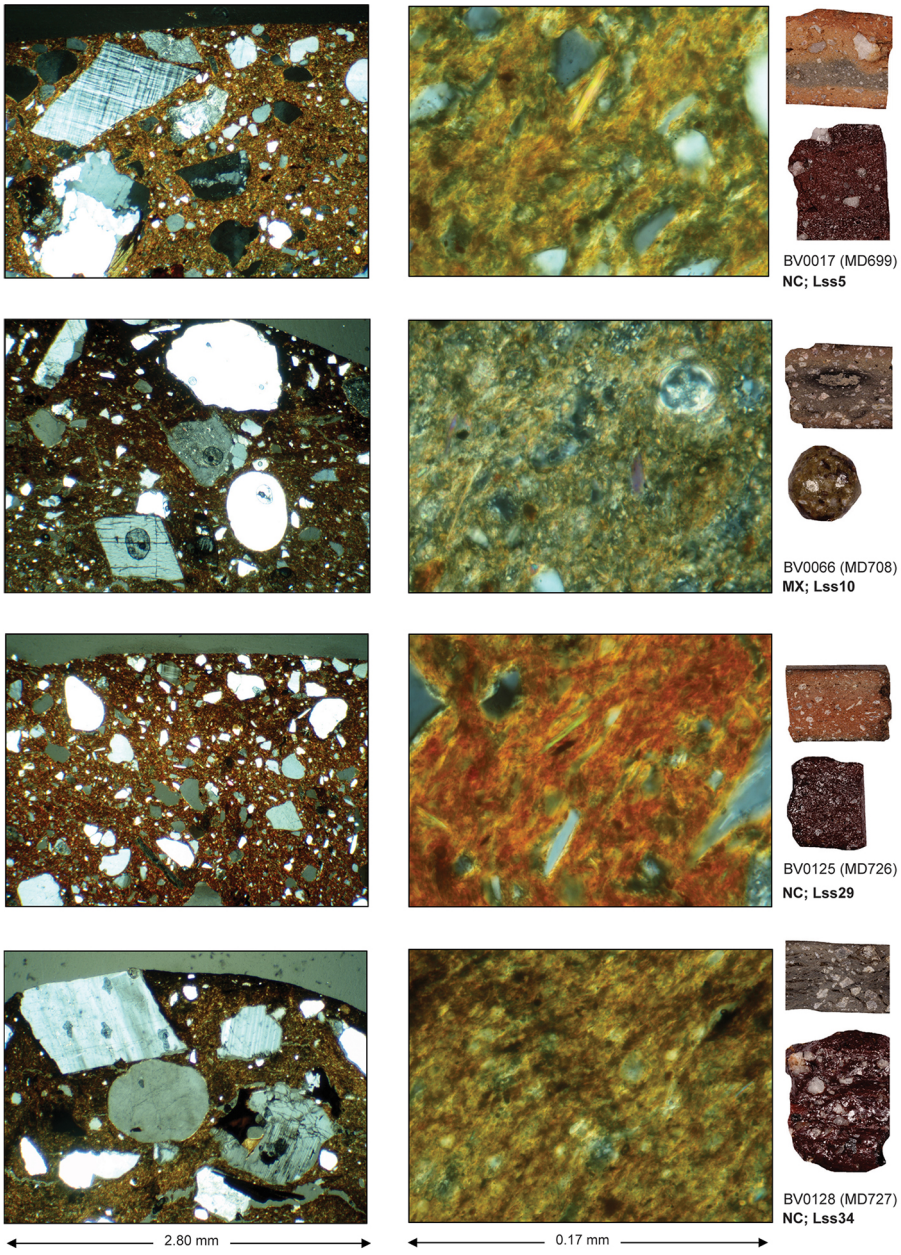


Fig. 7 Photomicrographs of thin-sections of pottery from Lossow and in last column photographs with macro lens of original fragments (up) and of fragments refired at 1200°C (down).

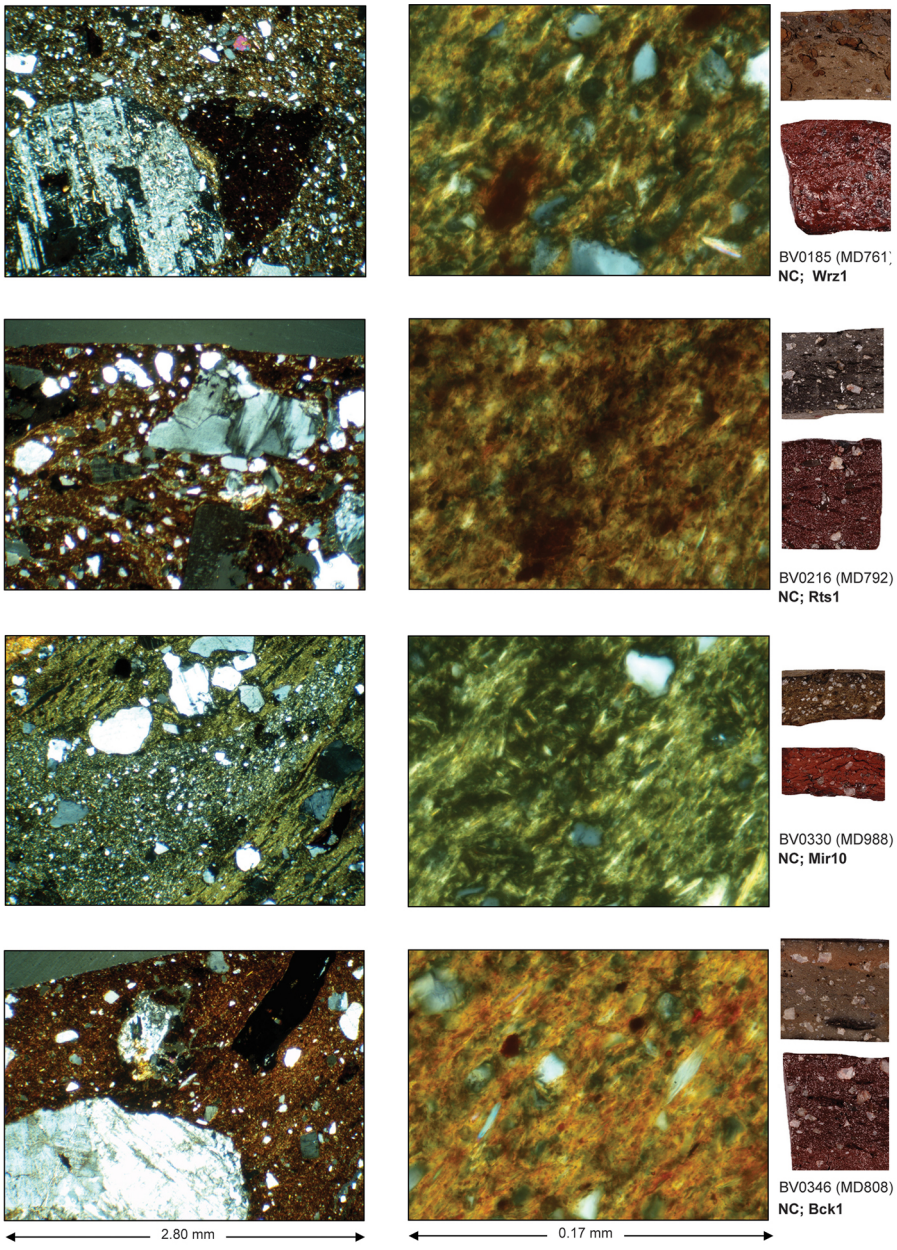


Fig. 8 Photomicrographs of thin-sections of pottery from other sites in Brandenburg and in last column photographs with macro lens of original fragments (up) and of fragments refired at 1200°C (down).

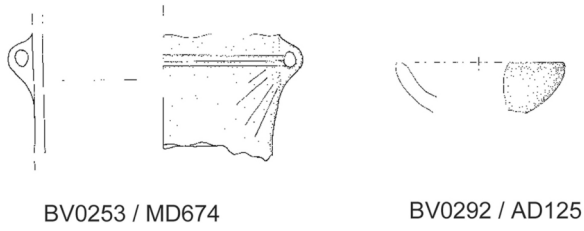


Fig. 9 Small barrel-shaped vessel (BV0253) and miniature bowl (BV0292), from Beilke-Voigt 2014b, Taf. 50.10 and 93.9.

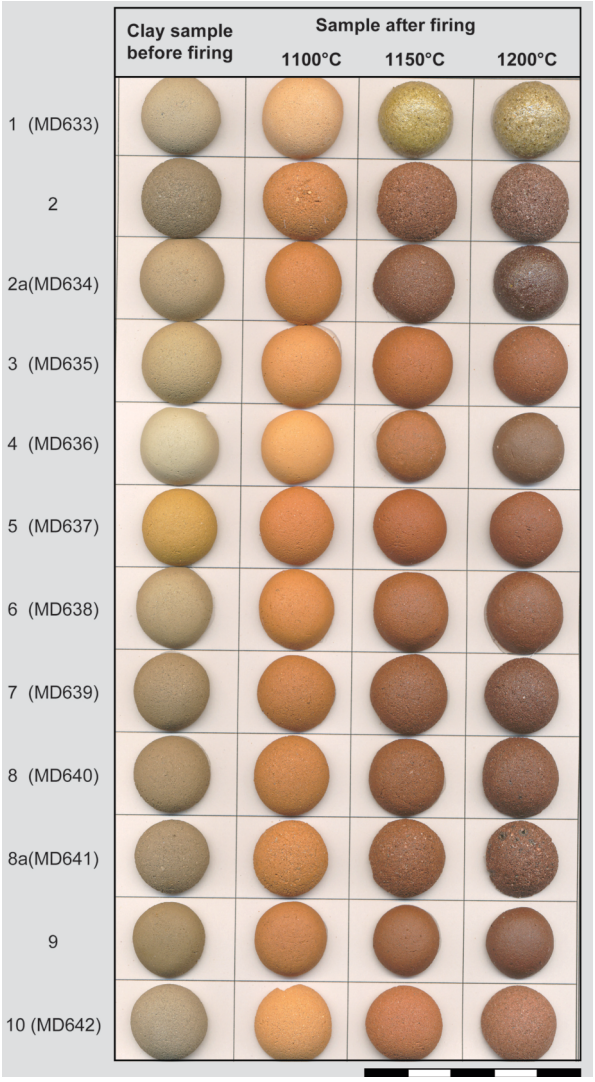
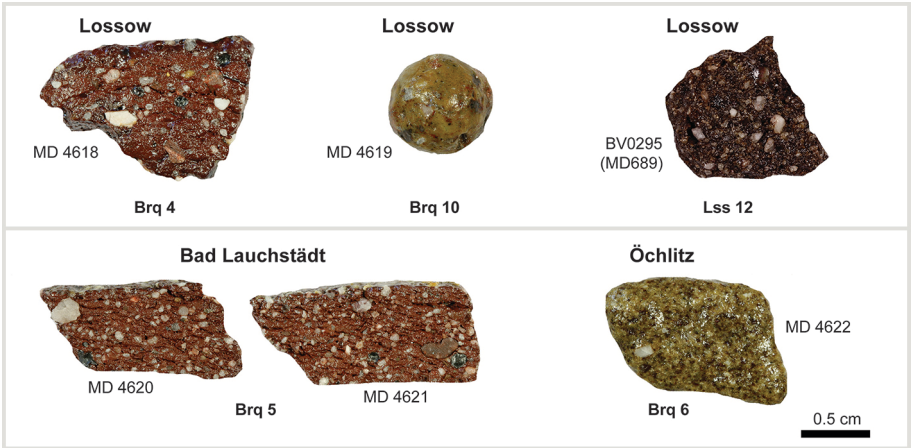


Fig. 10 Scan of firing tests of clays from Lossow and surrounding.



Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	l.o.i.
		per cent by weight										ppm														%
Briquetage found in Lossow Burgwall (MD4618 - MGR group Brg 4)																										
	MD4618	71.49	0.667	13.81	5.53	0.157	1.19	2.15	0.48	2.64	1.88	82	80	45	15	110	154	308	39	227	14	736	23	66	21	3.11
BV0523	AD704	72.99	0.639	12.72	4.85	0.131	1.25	2.33	0.67	2.91	1.52	77	75	45	16	176	169	249	32	249	14	1051	40	73	21	3.16
Briquetage found in Bad Lauchstädt (MD4620 - MGR group Brg 5)																										
	MD4620	75.27	0.564	13.47	5.01	0.132	1.11	1.09	0.56	2.71	0.08	75	76	52	21	84	132	185	23	165	12	676	21	65	20	2.53
Briquetage found in Lossow Burgwall (MGR was not done)																										
BV0528	AD709	74.92	0.595	12.54	4.07	0.049	1.37	1.97	0.78	3.20	0.51	87	65	32	5	64	161	152	21	165	15	622	18	49	20	2.11
BV0526	AD707	77.95	0.517	11.04	3.86	0.051	0.93	1.95	0.39	2.52	0.80	79	56	31	9	75	122	162	19	131	13	567	13	49	18	2.60
Briquetage found in Lossow Burgwwall - groups high in Ca (MGR not done)																										
BV0527	AD708	74.85	0.499	10.84	3.92	0.049	1.15	4.59	0.47	2.59	1.05	66	63	35	17	84	142	178	22	191	13	623	32	53	17	4.82
BV0529	AD710	74.50	0.508	11.00	3.88	0.060	1.19	4.69	0.54	2.68	0.94	66	64	37	11	87	137	176	22	181	13	610	24	52	17	4.90
BV0521	AD702	78.01	0.469	8.81	2.88	0.041	1.10	5.35	0.43	2.31	0.60	55	54	26	<5	108	122	176	21	159	11	631	8	46	10	5.33
BV0522	AD703	78.87	0.458	8.53	2.84	0.033	1.03	4.76	0.50	2.28	0.70	52	48	25	11	117	126	171	19	160	12	654	14	39	10	4.73
BV0519	AD700	78.10	0.487	8.98	2.90	0.072	0.99	4.79	0.48	2.57	0.64	56	51	25	<5	78	99	176	18	178	14	685	25	18	13	2.41
BV0525	AD706	77.74	0.440	9.00	2.85	0.063	1.05	4.88	0.56	2.69	0.73	57	48	27	<5	83	117	205	18	150	14	635	30	25	18	4.03
BV0530	AD711	78.55	0.425	8.76	3.06	0.043	0.95	5.03	0.49	2.17	0.52	55	47	25	<5	48	93	164	20	135	13	458	25	29	10	3.85
BV0531	AD712	77.56	0.437	8.87	3.16	0.062	1.07	5.67	0.63	2.22	0.32	51	48	25	<5	70	90	155	21	151	12	459	14	37	13	3.09
BV0520	AD701	78.66	0.438	8.14	2.79	0.053	1.15	5.72	0.52	2.25	0.29	49	45	21	<5	47	87	161	23	172	10	410	18	59	12	3.44
BV0524	AD705	78.52	0.426	7.83	2.52	0.051	0.91	6.56	0.44	2.12	0.62	47	40	22	<5	68	100	191	19	166	12	491	15	45	11	5.62
Briquetage from Lossow (MGR group Lss12, the same group includes daub and clay from old brick factory)																										
BV0295	MD689	84.43	0.469	6.60	1.97	0.057	0.52	2.84	0.37	1.81	0.94	34	40	19	<5	62	66	164	13	273	9	552	14	32	11	1.64

Fig. 11 Results of MGR-analyses and chemical analyses by WD-XRF of samples of briquetage from Lossow (MD 4618, MD4619), compared to samples from Bad Lauchstädt und Öchlitz (MD 4620, MD4621, resp. MD4622). Table with results of chemical analyses by WD-XRF (MD4619, MD4621, and MD4622 have not been analyzed).

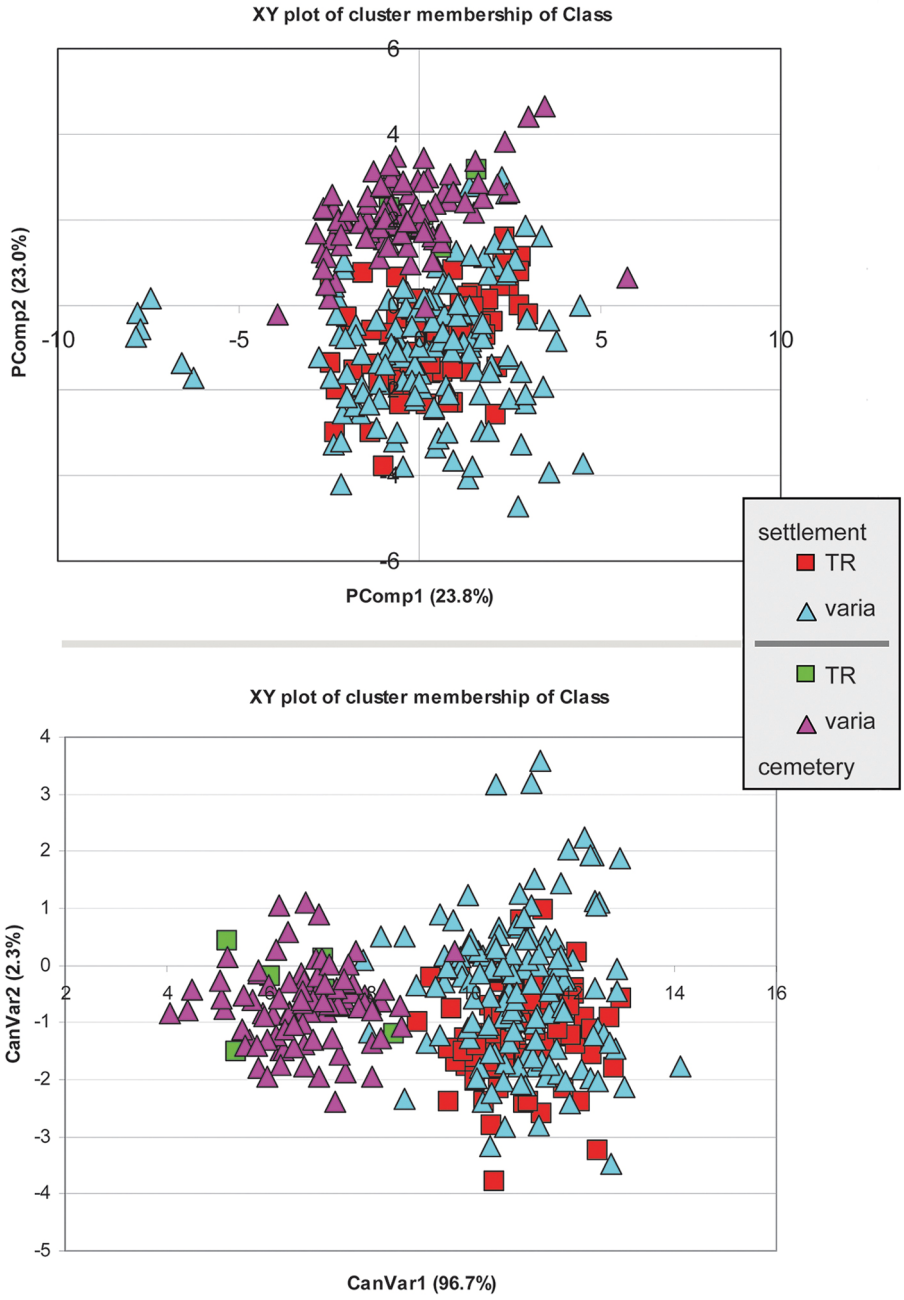


Fig. 12 Principal Component Analysis (upper diagram) and discriminant analysis (lower diagram) of chemical analyses results of pXRF of pottery found in Lossow (TR = turban-edged and varia = all other kinds of pottery).

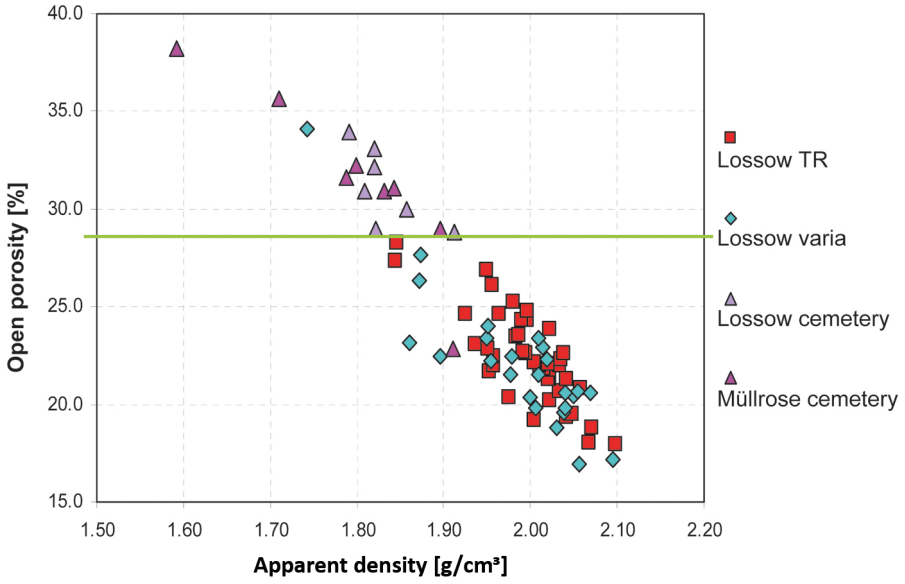


Fig. 13 Open porosity vs. apparent density of pottery found in Lossow BW and VB (squares) and found in cemeteries of Lossow and Müllrose (triangles).

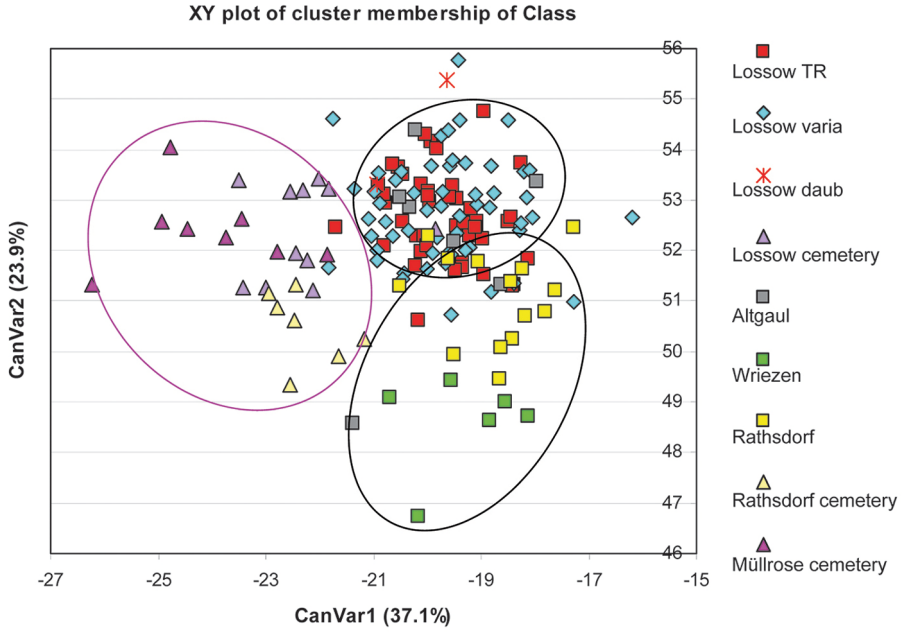


Fig. 14 Discriminant analyses of WD-XRF analysis results of pottery from various settlements (squares) and cemeteries (triangles).

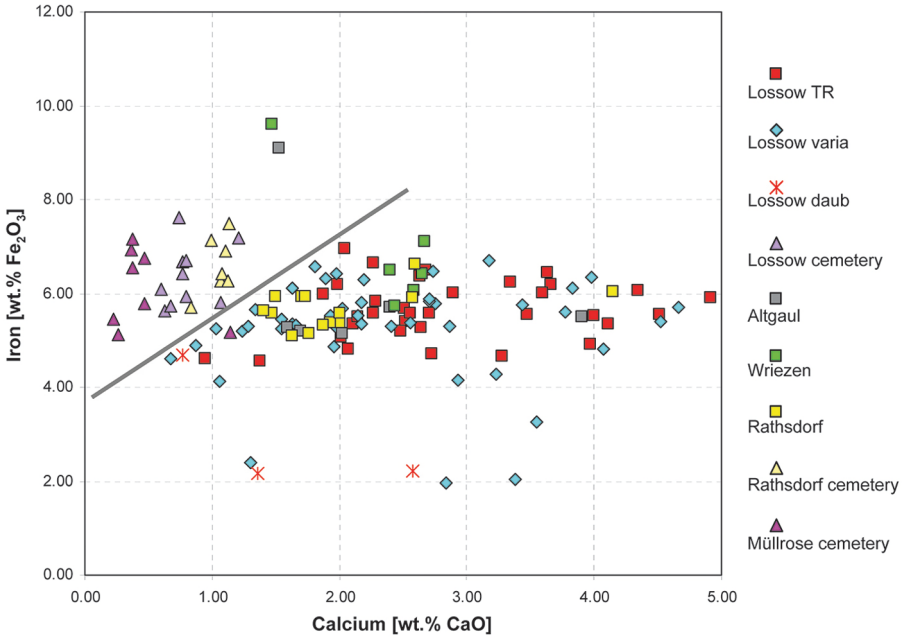


Fig. 15 Iron vs. calcium contents of the samples used in Fig. 14.

4.7 Imperial Period Wheel Made Pottery between the Elbe and Oder

Fleur Schweigart, Morten Hegewisch, Michael Meyer

Object of investigation and the research area

The project "Imperial Period Wheel-Thrown Pottery between Elbe and Oder – Production, Distribution and Consumption"[1] aims at the investigation of Imperial period wheel thrown pottery in Eastern Germany, with a focus on Brandenburg and Eastern Saxony (Fig. 1). In this area wheel thrown pottery first appears at the end of the second century AD and lasts until the beginning of the Migration period in the second half of the 4th century AD.

The rural societies of that time were mainly based on a subsistence economy. Central places were missing; settlements consisted of very few houses at one time and can be best regarded as hamlets. In addition, extraordinary rich graves, so called *Prunkbestattungen*, are missing in Brandenburg and Eastern Saxony. Such graves are known in some numbers in Central Germany and other parts of the Barbaricum, and might indicate differences in societal organization. Knowledge about economic networks is limited. The discussion is often restricted to objects that were produced in the Roman Empire and found in the Barbaricum. Such finds are often labeled with the economic term 'import' and seen as the result of a regular trade.[2] Both Roman objects and the transmission of Roman ideas and technologies are mainly restricted to aspects of status and prestige; metal (and certainly also glass) objects were also important as recycling material. Little is known about distribution networks within the Barbaricum. Clear evidence from

1 Small-scale preparatory project (Hegewisch and Meyer 2011) and the PhD-project by Fleur Schweigart (Schweigart 2018b).

2 See e.g. Lund Hansen 1987; Kunow 1983. For a different point of view see e.g. Meyer 2015; Schreiber 2018.

the so-called 'princely graves' indicate that the elite was entangled with each other and shared the same general concept of material expression of status.

Consequently, the archaeometrical study of ceramics is of great interest. As there is no recycling of raw materials that might lead to secondary distribution phenomena – like with metal objects – clear distribution patterns can be expected. Wheel made pottery was chosen because specific skills are needed to sufficiently produce these vessels, so a certain exchange could be expected.

The western part of the area under study belongs to the archaeological culture of the *Elbgermanen*, whereas in the East and especially in the Lausitz parts in southeastern Brandenburg and eastern Saxony clear influences of the Przeworsk culture and the Wielbark culture[3] appear. These areas were deserted from the 4th century BCE onwards, and the eastern influences that show up from the second half of the 2nd century onwards are discussed as being the result of migration into these abandoned landscapes.[4]

With the latest phase of the Imperial period at the beginning of the Migration period, findings, which are typically associated with the 'Niemberger Group' are also adding to the mix in Eastern Germany.[5]

Inhumation graves that are well known from Central Germany[6] are very few in the Late Imperial period and start to become more common only in the early Migration period. Cremation graves (such as *Brandschichtengräber, Brandgrubengräber,* and to a lesser extend urn graves) were the preferred grave forms in the Late Imperial period – similar to the eastern Przeworsk culture. In particular, *Brandschichtengräberfelder* are obviously an adaptation from the eastern Przeworsk culture (namely the Dobrzenień-group).[7] This specific grave form consists of the residues of funeral pyres that could have been used for one or more cremations. Consequently, the identification of individual graves and their equipment is a major challenge.

The wheel thrown pottery of the research area differs clearly from the current one in Central Germany. Pots produced in workshops like the one from Haarhausen[8] clearly imitate Roman forms. In contrast to that, the pottery from the study area shows no similarities to Roman forms, but unites local forms with influences mainly from Przeworsk culture and – to some extent – even from the Czernjachov culture. There are also clear differences in the frequency of wheel made pottery: whereas the average of this pottery in Thuringian, as well as in Przeworsk settlements, is mostly between 10% and 20% and in the Czernjachov culture it is even about 90%, this pottery covers only 2–3% of the inventory of average settlements in the study area.

3 Due to the heterogeneity of the whole area and the lack of clear *Leitfunde*, the concept of 'Luboszyce culture' (Domański 1982) has been widely criticized (Schuster 2005, 91–92, 97–98; Schweigart 2018b).

4 Schuster 2005.

5 Bemmann 2001, 77–79.

6 Bemmann 2008.

7 Brather 2010, 162; Schulz 2008.

8 Dušek 1992.

The technology of forming pots on a potter's wheel is new in the study area and has no endogenous roots. In Central Germany, this technology was well known and applied in the late Iron Age, but was lost in early Imperial times. It is most probable that the new technology was transferred from the Roman world, but also a transfer via the Dacian culture and the Przeworsk culture is possible. The differences in the shape of the vessels – Roman imitations in Thuringia, local and eastern forms further north and east – might reflect different influence areas. The formal differences might also reflect the structure of production. As in Haarhausen elements of Roman pottery, kilns were used. It also seems likely that the centralization of the workshop was adopted by the potters in this production center. This might be different in our study area.

Part of the PhD project[9] was the (new) classification of the investigated wheel thrown pottery. It could be shown that there are vessels, which can be found in similar appearance throughout the whole research area, as well as those that are strictly regional in their distribution. According to their main features, generally the vessel form, 16 vessel classes could be defined (Fig. 2). They were further divided in subgroups according to different décor features. This enabled to identify more distinct, recurring types than initially expected.

Aim of the investigation and the methods used

The initial, preliminary study of the project was based on a restricted number of archaeometrical analyses.[10] A surprising result was the identification of distribution spaces of identical wares that covered ca. 80 km in diameter. This led to the hypothesis of a specialized production of wheel made pottery in central workshops and a broad distribution network.[11] One main task of the PhD project – which was based on a sample more than 20 times bigger than the first study – was to test this hypothesis and yield reliable insights into economic structures of imperial times and the early Migration period.

Therefore, for the second phase of the study it seemed promising to evaluate a bigger sample and increase the research area. The following analyzation methods were used for this purpose:

1. Portable energy-dispersive X-Ray fluorescence technique (pXRF) with Niton XL3t900S GOLDD RF-Analyzer. All measurements by F. Schweigart; mining mode, 8-mm spot, without helium, calibration on 12 ceramic standards by G. Schneider/M. Daszkiewicz.

9 Schweigart 2018b.

10 Results published in: Hegewisch and Meyer 2011; G. Schneider and Daszkiewicz 2011.

11 Hegewisch 2011, 35.

The pXRF-measurements were mostly conducted for a first overview/impression of the chemical data. The results were – after initial clarification of their reliability (see chapter results) – used to make the decision of which sherds should be further investigated and the suitability of the sherds provided.

2. Wavelength-dispersive X-ray fluorescence technique (WD-XRF) (sample preparation by ARCHEA (Warsaw) and measurement by G. Schneider/A. Schleicher in GFZ Potsdam).[12]

3. Matrix-group by Refiring (MGR) executed by M. Daszkiewicz.

Sampling Strategy

For the study, more than 2000 sherds were sighted and collected.[13] As would be expected, not all these samples were suitable for analysis. In the end, samples from 45 sites[14] were selected for analysis (Fig. 3). Of course, this selection was not random, but was based on the suitability and availability of samples for the analysis.

First, finds from excavated sites were in general preferred to surface finds,[15] as they generally showed a better state of preservation (strongly weathered sherds are not suitable for the analysis) and had clear contexts. Second, sherds with vessel forms that could be reconstructed were preferred. Unfortunately, these were a minority of the collected sherds. By analyzing only these kind of sherds, the results would have been clearly limited as finds were often highly fractured, especially in burial context. Therefore, it was often inevitable to add non-classifiable sherds (assumedly from different vessels) to gain more detailed results by increasing the number of analyzed sherds and, therefore, having more samples to compare in general between sites and also within sites.

After this selection, pXRF measurements were executed first. After the evaluation of the pXRF results, the decision was made about which samples should be analyzed further with WD-XRF and MGR. Of course, within a site, ideally samples from all appearing different clay types should be analyzed. In reality, selection was again strongly limited by the characteristics of the individual sherds (e.g. size and weight of the sherd)

12 GFZ = Helmholtz-Zentrum Potsdam, Deutsches Geo-Forschungs Zentrum GFZ, Sektion 4.2, Anorganische und Isotopengeochemie.

13 We gratefully acknowledge the support of the following institutions that enabled the sighting and examination of the sherds and usage of archival material: Brandenburger Landesdenkmalamt für Denkmalpflege (Wünsdorf), Landesamt für Denkmalpflege Sachsen (Dresden), and Stadtmuseum Bautzen (Bautzen).

14 This number includes different site nos., e.g. Briesnig 4, Briesnig 33, and Briesnig 51.

15 Most of the sites with wheel thrown pottery in Eastern Germany are still only known from surface finds.

and the limitations of the pXRF technique. The pXRF analysis could not be regarded as accurate enough to clearly distinguish different clays with similar chemical compositions. The pXRF results were, therefore, used only as preliminary test.

Final conclusions were arrived at after the comparison and evaluation of all the methods that were used (pXRF, WD-XRF, and MGR). Only with additional MGR-analysis could the clay type and specific group be determined.[16]

Overall, this strategy has proven to be the right strategy. The more analyses, the clearer the picture, even without the knowledge of the specific vessel form in every case.

Very late in the evaluation of results some hints emerged that sometimes different clays were used for different body parts (namely the bottom and the rim) of a vessel (see chapter 5 in this volume). For future analyses, it should be considered preferable to analyze samples of the same vessel parts (if possible).

Results

An important step regarding chemical data was to clarify the accuracy and precision of the pXRF data by comparing it with the WD-XRF data (for the reasons and necessity of this comparison, see chapter 6 in this volume). In general, it answers the purpose of determining or confirming the reliability of the pXRF data.

The pXRF results were mostly quite satisfying (Fig. 4). A lot of elements showed an average variation below 5% – Titanoxide (TiO_2), Iron(III)oxide (Fe_2O_3), Potassiumoxide (K_2O), Rubidium (Rb), Zirkonium (Zr), Niob (Nb) – when comparing the results of the pXRF and WD-XRF data.

Regardless, by chemical analysis alone, the distinction of different clays would not have been possible, as the clays in the investigated area in general did not differ distinctly enough in their chemical composition to tell them apart. The only exception was the caolinitic clays from Eastern Saxony, which could be identified as a separate group by chemical analysis alone (Fig. 5). However, this was only due to the special chemical characteristics of the Eastern Saxonian caolinitic clay deposits, which are enriched with Titan associated with Niob (which is the geochemical correlate of Titan[17]). These high Titan and Niob values are otherwise not typical *per se* for caolinitic clay.

The distinction of different clay types was provided by MGR-analysis. Altogether, 97 main clays with a further 60 MGR-subgroups (for more on the definition of method and

16 In the end, more than 2700 pXRF-measurements (this number includes measurements of ceramic standards and excludes double- and control measurements), more than 170 WD-XRF, and more than 320 MGR-analyses were executed.

17 Schmitz 2008, 91.

grouping see chapter 2 in this volume) were identified by M. Daszkiewicz throughout the whole investigated area.

A surprising result, and in contrast to the initial hypothesis, the majority of clays were only found locally. There are not more than 17 MGR-(sub)groups that directly link together different sites (Table 1).

An interesting result was provided by samples Glie001 and Glie003, a vessel of type C I from Glienick 14, Lkr. Teltow-Fläming (Fig. 3, no. 12). These two matching sherds from an identical vessel show the usage of different clays, both chemically and by MGR (Fig. 6).[18] This came to the researchers' notice only because the shared affiliation of both sherds was beyond question (identical matching breaks). It became clear that the different results were due to different spots within the vessel of the sampling. Glie003 was taken directly from the rim-area, whereas sample Glie001 originated from the upper body of the vessel. After that, the investigation of the whole length of the sherd Glie001 was ordered. The result (chapter 5, Fig. 5 in this volume) showed that, indeed, two different clays were used during the manufacturing of the vessel.

A second example within this project (see also chapter 5 in this volume) – this time from a bottom sherd – showed, that indeed this was no single occurrence.

Consequently, in regards to sampling strategy, researchers should consider taking samples from the same part of all the vessels. However, this will often not be possible due to the fracturation grade of sherds, the lack of sherds from the same vessel parts, and problems in the identification of the position of the sherds.

Interpretation of distribution patterns

In general, the numerous variation of identified clays is not indicative for the initially expected, widespread distribution network within the research area of wheel thrown pottery by single, specialized workshops.[19] In addition, the identified interaction patterns of Brandenburg and Eastern Saxony differed quite obviously.

In Brandenburg, an 'area of interaction' about 120 km in diameter could be identified due to vessels with matching results. However, the number of matches was few and did not allow for a clear conclusion about the distribution mechanism at work (trade, exchange, prestige exchange, gift, dowry, etc.). However, it showed that Brandenburg in the Imperial period seemed to be a well-connected area with wheel thrown pottery as a not common good, but a prestige good. In contrast to Brandenburg, in Eastern

18 Schweigart 2018a, 608.

19 For a discussion of the term 'workshop' see chapter 2 in this volume.

Saxony the investigated samples appeared to be mostly local. Only on rare occasions could connections between different sites by vessels made of the same clay be detected.

However, this does not completely disregard production by skilled potters. It just does not seem likely that this kind of local production – especially in light of the general low percentage of wheel thrown pottery within settlements – allowed people to earn a livelihood by solely producing wheel thrown pottery and, therefore, this was not likely potters' main occupation. This is true based upon the assumption that potters worked only in their own hamlet. Therefore, another possible explanation might be the existence of itinerant craftsmanship. Identical twin vessels, made of different local clays indicate that this possibility should be strongly considered.

Summing up, there is not enough evidence in the study area for centralized, specialized workshops for wheel made pottery. The distribution networks appear to be too weak and random to postulate organized trade. Other mechanisms of distribution like gift exchange and marriage relations have to be taken into consideration and could explain most of the evidence. The concept of itinerant craftsmanship is interesting to explain cross area distributions on a medium-scale. While a potter's tools (including the potter's wheel) could easily be transported, the potter would have had to be ready to use different raw materials from the vicinity of the respective sites of production.

A completely unexpected new insight was provided by the comparison of pottery from a single settlement, which allowed a direct comparison of wheel thrown pottery with the contemporary one from a cemetery clearly connected to the site. The analysis demonstrated that different clay sources where used for the production of domestic and funerary pottery. Obviously, the funerary pots where specifically manufactured for burial and were not part of the 'living culture'. Pottery that was only produced to be part of the burial ritual does not necessarily have the same quality standards as pots that were used in daily life, e.g. water density or fire proofness. It is, therefore, possible that the production of wheel thrown pottery for settlement and burial use were produced in different settings and by different people. A household production of the burial wares would guarantee production directly for the burial.

As this phenomenon was also observed in the Lossow project (see chapter 4.6 in this volume), further investigations shall analyze whether this is a rare exception or a regular division of production in different epochs and cultures.

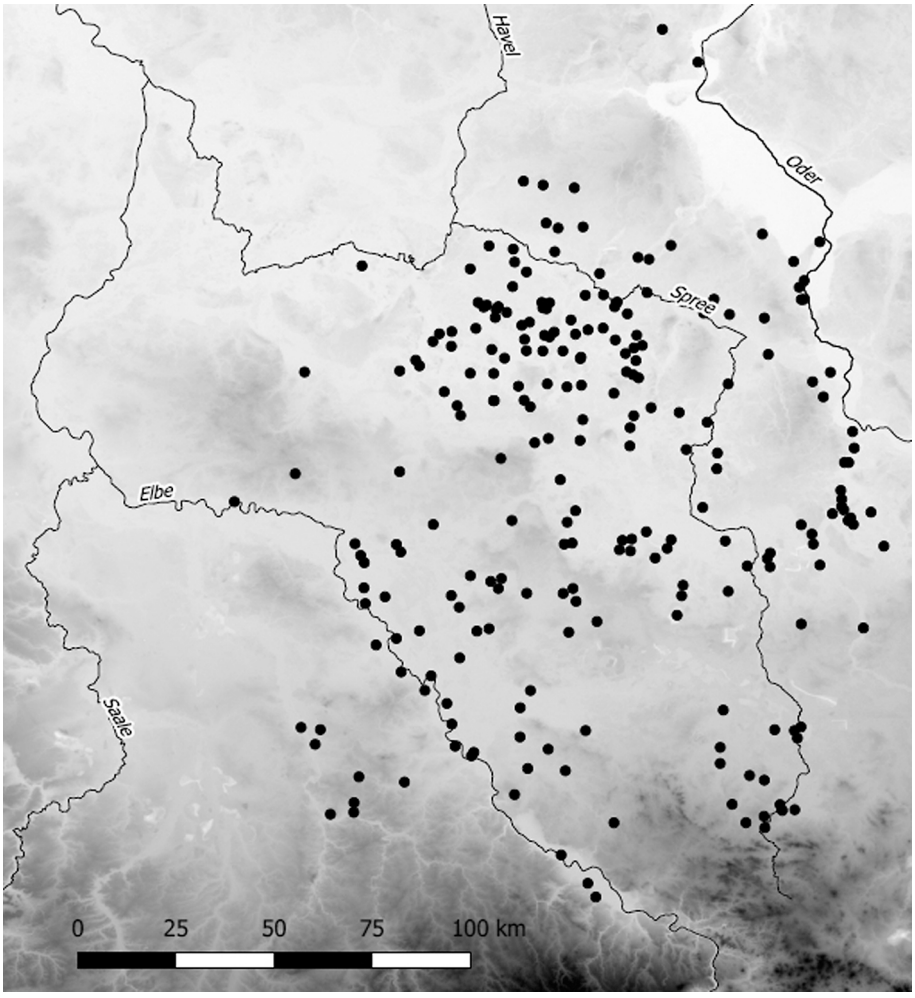


Fig. 1 Sites with wheel thrown pottery of the Imperial and Early Migration period within the investigated area.

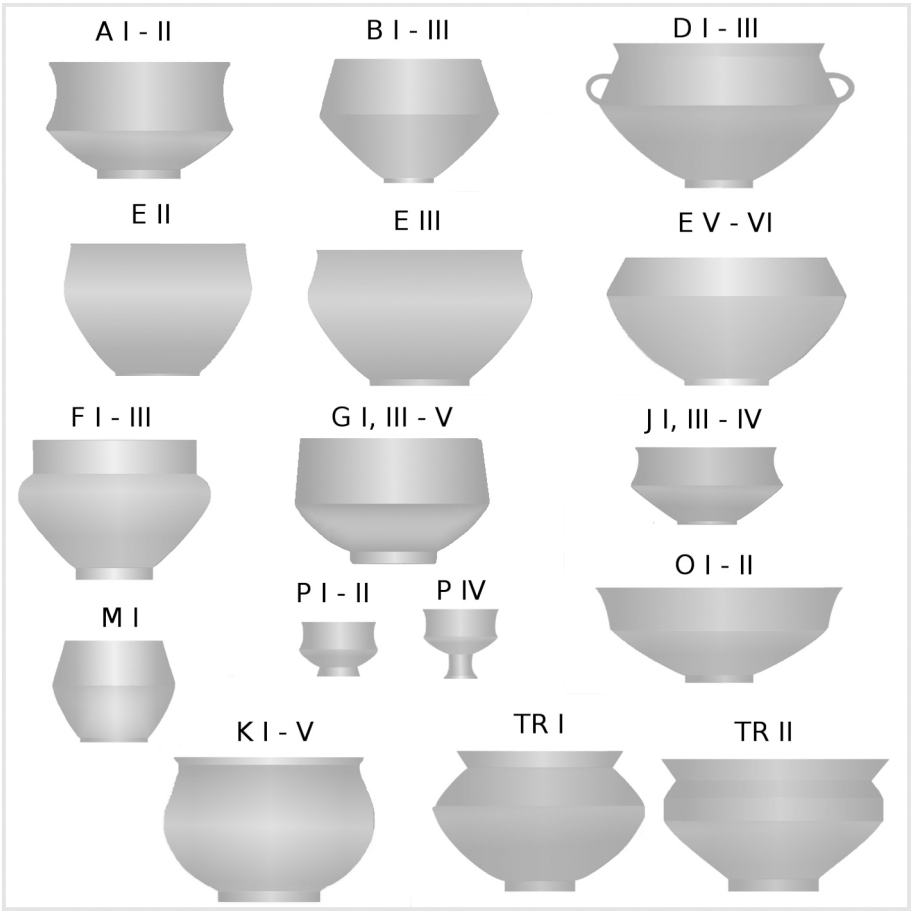


Fig. 2 Selection of the most important general vessel forms from the wheel thrown pottery of Brandenburg and Eastern Saxony.

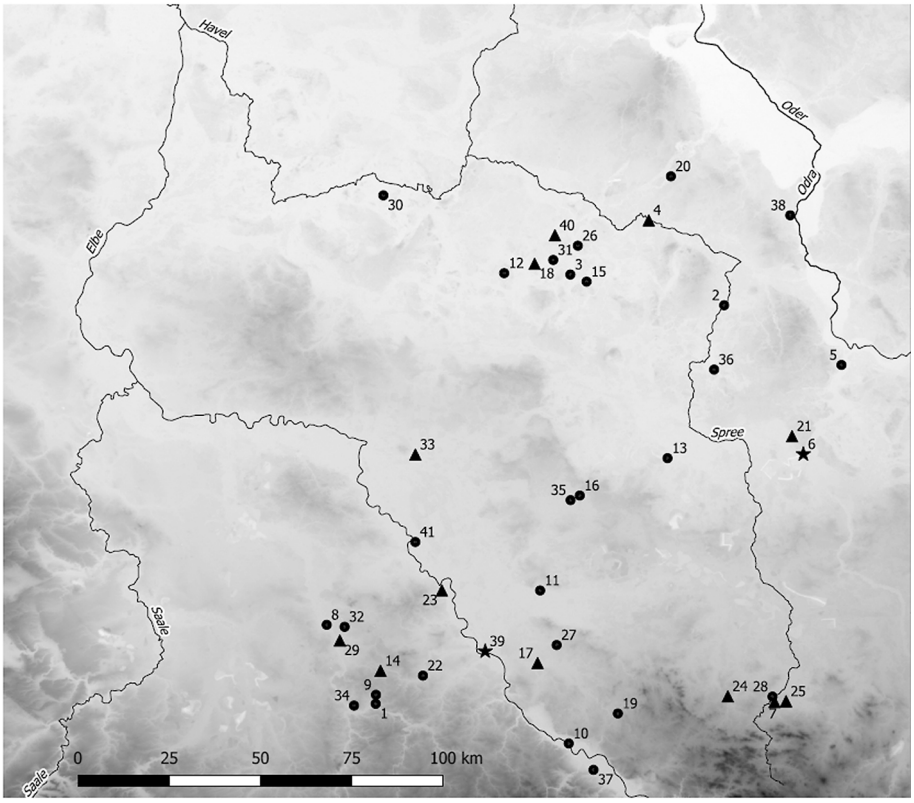
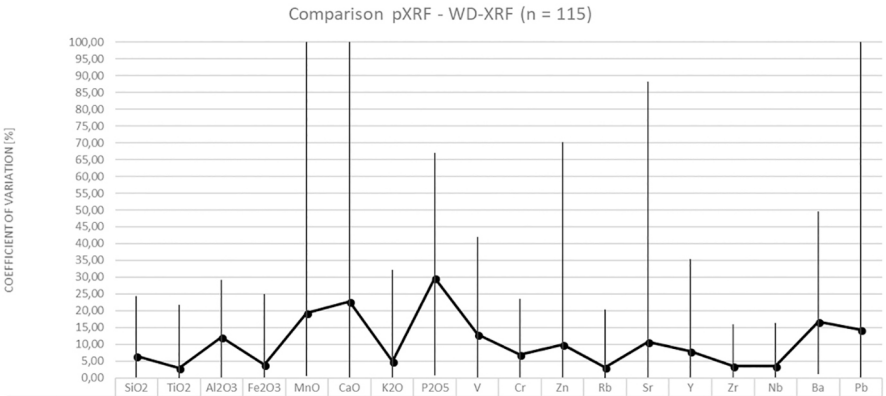


Fig. 3 Investigated sites. Numbers in alphabetical order of sites. Meaning of symbols: triangles = samples from grave/graveyard; dots = samples from settlements; stars = samples from settlement and grave/graveyard. 1 – Arras, Lkr. Mittelsachsen; 2 – Beeskow 35, Lkr. Oder-Spree; 3 – Bestensee 4, Lkr. Dahme-Spreewald; 4 – Braunsdorf, Lkr. Oder-Spree; 5 – Breslack, Lkr. Oder-Spree; 6 – Briesnig 4, 30, 33, 38, 51, Lkr. Spree-Neiße; 7 – Burk, Lkr. Bautzen; 8 – Deuben, Lkr. Leipzig; 9 – Doberquitz, Lkr. Mittelsachsen; 10 – Dresden-Kaditz, Lkr. Dresden-Stadt; 11 – Elsterwerda-Ost 28, Lkr. Elbe-Elster; 12 – Glienick 14, Lkr. Teltow-Fläming; 13 – Göritz 4, Lkr. Oberspreewald-Lausitz; 14 – Göttwitz – Lkr. Leipzig; 15 – Gräbendorf 12, Lkr. Dahme-Spreewald; 16 – Großbahren 8, Lkr. Elbe-Elster; 17 – Großenhain, Lkr. Meißen; 18 – Groß Machnow 6, Lkr. Teltow-Fläming; 19 – Grünberg, Lkr. Bautzen; 20 – Hoppegarten 3, Lkr. Märkisch-Oderland; 21 – Jänschwalde 9, Lkr. Spree-Neiße; 22 – Leuben, Lkr. Nordsachsen; 23 – Liebersee, Lkr. Nordsachsen; 24 – Liebon, Lkr. Bautzen; 25 – Litten, Lkr. Bautzen; 26 – Niederlehme, Lkr. Teltow-Fläming; 27 – Niegeroda, Lkr. Meißen; 28 – Nimschütz, Lkr. Bautzen; 29 – Ölschütz, Lkr. Muldentalkreis; 30 – Phöben, Lkr. Potsdam-Mittelmark; 31 – Ragow 5, Lkr. Dahme-Spreewald; 32 – Roitzsch, Lkr. Leipzig; 33 – Schweinitz, Lkr. Wittenberg; 34 – Seidewitz-Thümmlitzwald (Forstrevier), Lkr. Leipzig; 35 – Sonnewalde, Lkr. Elbe-Elster; 36 – Speichrow, Lkr. Oder-Spree; 37 – Strehlen, Lkr. Dresden; 38 – Wüste Kunersdorf 2, Lkr. Märkisch-Oderland; 39 – Zeithain, Lkr. Meißen; 40 – Zeutzen-Miersdorf 8, Lkr. Dahme-Spreewald; 41 – Zwethau, Lkr. Nordsachsen.

MGR-group	Connected sites	Max. approx. distance
1.02	Göritz Wüste Kunersdorf	75 km
1.03	Briesnig 4 Briesnig 33	
1.04	Göritz Ragow Speichrow	63 km
1.06	Breslack Göritz	55 km
1.07	Briesnig 4 Briesnig 51	
3.03	Braunsdorf Jänschwalde	71 km
4.01	Briesnig 4 Briesnig 30 Göritz Ragow	85 km
4.011	Briesnig 4 Göritz Sonnewalde	65 km
4.02/4	Briesnig 38 Briesnig 51	
4.08	Braunsdorf Schweinitz Elsterwerda	105 km
4.09	Göritz Großbahren	26 km
4.1	Doberquitz Zeithain	33 km
8.01	Briesnig 33 Jänschwalde	5 km
27.01	Göritz Beeskow Glienick Speichrow	67 km
31.01	Braunsdorf Göritz Beeskow Niederlehme	65 km
85.01	Grünberg Liebersee	59 km
85.02	Leuben Elsterwerda	40 km

Tab. 1 Verified connections between sites per corresponding identical MGR-subgroup. Approximate distance as the crow flies.



	SiO2	TiO2	Al2O3	Fe2O3	MnO	CaO	K2O	P2O5	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb
Min	0,09	0,02	0,11	0,08	0,55	0,03	0,10	0,78	0,04	0,21	0,09	0,00	0,09	0,11	0,06	0,07	1,08	0,11
Max	24,35	21,82	29,14	24,96	100,00	100,00	32,13	66,93	42,04	23,55	70,27	20,29	88,30	35,45	16,02	16,27	49,52	100,00
Arithm. mean	6,46	2,88	12,12	3,93	19,32	22,77	4,83	29,77	12,95	6,85	10,00	3,23	10,80	7,84	3,53	3,54	16,79	14,30

Fig. 4 Comparison of pXRF and analogue WD-XRF data with coefficient of variation (cv).

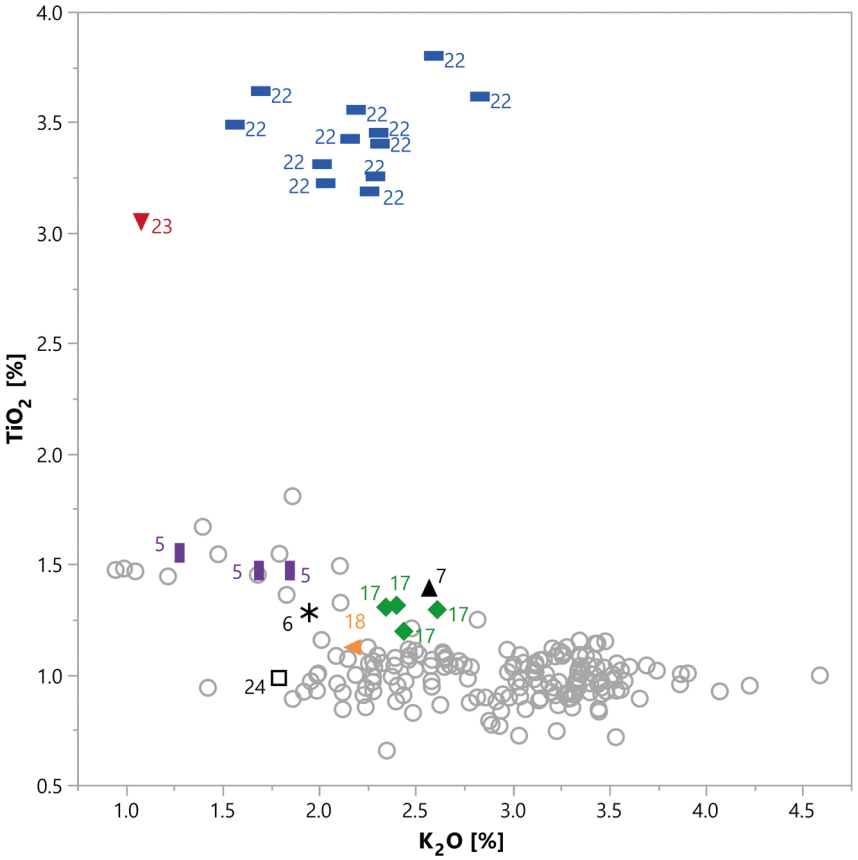


Fig. 5 WDXRF-diagram of potassium oxide and titanium dioxide in percent by weight [Empty dots: all measurements. Blue squares: kaolinitic clay samples (MGR 22) from the Muldental and Elbe region. Inverted red triangle: kaolinitic clay sample (MGR 23) from the Oberlausitz area. Black empty square: kaolinitic clay sample (MGR 24) from the Oberlausitz area. Purple upright squares: kaolinitic clay samples (MGR 5) from the Niederlausitz area. Black star: kaolinitic clay sample (MGR 6) from the Niederlausitz area. Black triangle: kaolinitic clay sample (MGR 7) from the Niederlausitz area. Green rhombs: kaolinitic clay samples (MGR 17) from the Oberlausitz and Niederlausitz area. Orange triangle: kaolinitic clay sample (MGR 18) from the Elbe-Elster area.

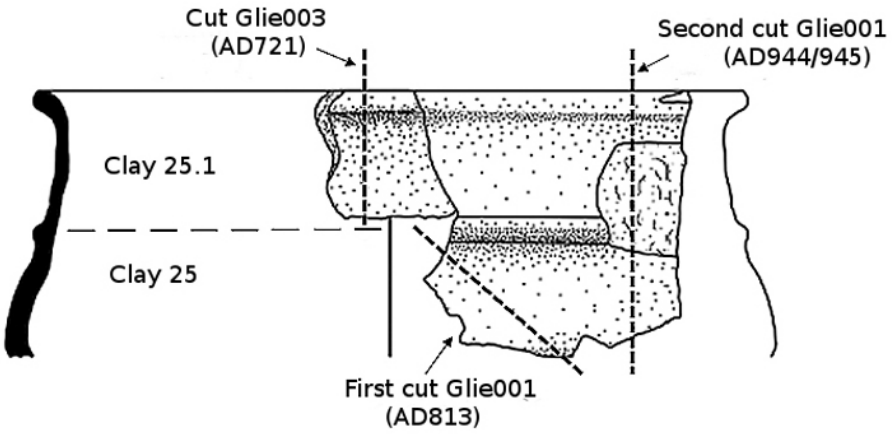


Fig. 6 Vessel of type C I from Glienick 14 (samples Glie001 and Glie003). The sherds of this vessel shows the usage of two slightly different clays.

4.8 Wheel Thrown Pottery in Olbia and Chernyakhov Culture

Erdmute Schultze, Fleur Schweigart, Małgorzata Daszkiewicz

Introduction

The material associated with the region around the lower reaches of the Bug (Ukraine), and specifically the pottery from Olbia, has been a frequent topic of study. One such study, conducted some years ago, investigated the gray-colored pottery of the first centuries AD from this region, focusing specifically on the finds from the *chora*, or the area surrounding the *polis*. The authors of this study were able to distinguish two ranges of gray ware.[1] Subsequently, in 2010 the Eurasian Department of the DAI (German Archaeological Institute) and the National Academy of Sciences of Ukraine began a joint project, also investigating the ware from Olbia, with the intent of building on that earlier work. This joint project was originally the idea of Valentina V. Krapivina, who headed up the expedition for many years and was the leading expert on Roman-period material from Olbia. Regrettably, illness prevented her from seeing the project through to its completion, though the archaeological institute in Kiev continued to support the research after her death in 2013. We wish to express our particular thanks to Alla Bujskich, who is currently leading the expedition in Olbia.

History of culture and economic background

The *polis* of Olbia at the mouth of the Bug was founded as a Greek colony in the 6th century BC. The *polis* came to hold considerable influence within this region based on economic exchange between it and the surrounding area (Fig. 1).

1 Schultze, Magomedov, and Bujskich 2006.

The history of the Olbia and its *chora* is an eventful one.[2] Over the period from the late 1st century BC to the mid-3rd century AD, the *polis* of Olbia became a sort of outpost of the Roman Empire. There was even a Roman garrison in Olbia from the sixth decade of the 2nd century until the mid-3rd century AD. The *polis*' influence on the Sarmatian tribes living in the surrounding area was at times great in this period as well. In the first centuries AD, the *chora* extended out from both sides of the estuary. While internally structured in economic/administrative terms in the form of settlements with urban structures, the *chora* was militarily secured against threats, including external threats, through strong fortifications. The *polis* and its surroundings were destroyed during the so-called Scythian or Gothic Wars, AD 232–235 and AD 269–270. Olbia remained uninhabited for some years after that. Its resettlement took place at the end of the third century. The *polis* of that time, then considerably smaller, was again characterized by classical building structures and production sites. The results of excavations to date indicate that Olbia continued to exist into the 3rd quarter of the 4th century; they also reveal a high probability that it was not fortified. The interpretation of this final period is under debate. V. V. Krapivina always assumed that the earlier settlers had returned from the Roman provinces.[3] She was able to show that the *polis* continued to reveal planning and building techniques of classical antiquity right up until it ceased to exist, although its long-distance trading activities clearly declined. B. Magomedov and others disagree, believing that Olbia was part of the zone of influence of the Chernyakhov culture from the final decades of the late third century. [4] The representatives of this culture, who are associated with the Gothic tribes mentioned in written sources, settled near the *polis* in the second half of the third century, in some cases on what had once been the fortifications within the *chora*. These settlers were of great importance for Olbia economically, because its *chora* now extended only 5–10 km out from the *polis*.

Culturally, the *polis* of Olbia and its surroundings were influenced by Greek traditions and provincial Roman culture. Minting of Olbian coins recommenced in the first half of the first century and did not stop until 235. There is evidence of local production of gray wheel made pottery in the mode of classical antiquity extending back without interruption to the pre-Roman period. Finds of potter's kilns are evidence that the production of pottery, and probably brick as well, were economic activities of the *polis* in the first centuries AD as well (Fig. 2). Throughout the period under study, the economic and cultural development of the *polis* was based to a considerable extent on trade with the 'barbarian' region surrounding the *chora*.

2 For the facts referenced below cf. Буйских 1991; Krapivina 2007; Krapivina and Schultze 2011.

3 Krapivina and Schultze 2011.

4 Магомедов 2007.

Research questions

Gray ware is a stable element in the pottery repertoire in Olbia, but gray ware also represents a characteristic element of the Chernyakhov culture. An earlier project succeeded in identifying archaeologically two distinct ceramic ranges for the settlements in the area surrounding Olbia. One of these clearly conforms to Graeco-Roman traditions; the other is in line with Chernyakhov traditions. The Graeco-Roman range is comprised solely of tableware (Fig. 3). This tableware includes jugs of various forms and cup-like pitchers, in addition to bowls, whose rims usually slant inwards. Some of the pottery was decorated with grooves and smoothing patterns.

The pottery range of the Chernyakhov culture, for its part, included both tableware and kitchenware (Fig. 4). The latter consists primarily of pots and storage vessels, both exhibiting minor degrees of surface treatment. By contrast, the surface of the tableware was smoothed or polished and, in some cases, decorated with bulges, incised lines, or smoothing patterns. The tableware is represented by bowls of various forms: vases, some of which had three broad handles; pitchers; jugs; and beakers. Thus, while it is possible to distinguish between the two pottery ranges on the basis of vessel forms, the two ranges are very similar with respect to their other characteristics. Macroscopic analyses of the hardness, structure of vessel fractures, the temper components, and other technical characteristics of the vessels revealed great similarities in the materials used in the two ranges. Only a greater temper content in the kitchenware of the Chernyakhov pottery forms a clear differentiating factor. This greater temper content was primarily added for technical reasons; the pots of the Chernyakhov pottery were used to prepare and cook food. This explains why it is not seen in the Graeco-Roman vessel repertoire, which is restricted to tableware.

In addition to an explanation of the technical similarities, it was also unclear whether the gray ware was produced locally or was the product of specific workshops. On the basis of the known historical situation, V. V. Krapivina, who led the excavations in Olbia for many years, even put forward the hypothesis that some share of the output of gray ware production in Olbia was produced for the Chernyakhov settlements in the surrounding area. Given this initial situation, the following questions arose for the pottery analyses:

- Which ceramic groups can be distinguished within the pottery from Olbia, and can they be correlated with the results for pottery in the surrounding region?

- Is it possible to identify groups of products that point to an origin in different workshops?

– What indications are there for the exchange of pottery within the region of the Lower Bug?

– What significance did pottery production in Olbia have for the surrounding area?

Sampling strategy

The sampling strategy was adjusted as the work proceeded. An initial project carried out in the mid-2000s, which looked only at the material from the area surrounding Olbia, had the objective of capturing all of the fragments of gray ware from settlement complexes that had been dated to the first centuries AD, as well as selected materials from the occupation layers.[5] This encompassed 235 vessel fragments from seven of the fortified settlements within the *chora*. Another 31 fragments of gray ware from two 4th century settlements of the Chernyakhov culture were analyzed to provide a basis for comparison (Fig. 1.2). One of these settlements was in Adzhigolska Kosa, which lies directly west of the Bug Estuary and about 12 km southwest of Olbia within the bounds of the earlier *chora* of the 1st through 3rd centuries. The other Chernyakhov settlement in Novokondakovo lay east of the Bug, far outside the *chora*, about 75 km (as the crow flies) from the *polis*. A total of 162 of the samples come from this first project; of those, 83 came from settlement complexes like pits, structures, ovens, etc., and the others were from occupation layers. As the earlier project was not able to use these samples, the first analysis performed on them occurred within the framework of the Topoi cluster. A second project, begun in 2010, specifically addressed the gray ware from Olbia. However, this project was unable to even come close to recording all of gray ware from the first centuries AD, let alone assessing it all. The focus in this project was on the last phases of the *polis* of Olbia. The primary objective was to compare the Graeco-Roman and Chernyakhov material of this period. To that end, the excavator, V. V. Krapivina, drew together a selection of interesting pottery from the complexes and occupation layers that had been dated by other finds to the late third and fourth centuries AD. A total of 119 vessel remains were recorded, and samples were taken from 116 of them. In the course of the assessment by the Topoi cluster working group, it became clear that the addition of more samples from Olbia could further increase the quality of the results. However, due to the death of the excavator in 2013 and a lack of specialists for this period in Olbia among those who came after her, it has not been possible to expand the source base. In total, thus, 278 ceramic samples are now available.

5 Schultze, Magomedov, and Bujskich 2006.

Samples of clay from the area of the *polis* are also available. According to the researchers at Olbia, potters still use this material today due to its high quality.

Analyses

The following analytical techniques were employed: chemical analysis by portable energy-dispersive X-ray fluorescence (pXRF), chemical analysis by wavelength-dispersive X-ray fluorescence (WD-XRF), and abridged MGR-analysis (Matrix Group by Refiring) (Tab. 1).[6]

PXRF measurement was the first procedure undertaken. This analysis was carried out on all 285 samples. After samples with pXRF outlier values were excluded, 255 samples were available for the statistical cluster analysis. The chemical data determined by pXRF measurements were statistically analyzed using the Ward method of hierarchical cluster analysis. This analysis revealed a 4-cluster solution (see Fig. 5). Particularly in the case of the Fe_2O_3/CaO matrix, the separation of groups became quite visible. The conclusions based on the chemical data, however, were initially limited.

217 samples were selected for abridged MGR-analysis (refiring at 1100°, 1150°, and 1200°C); examples are shown in Figure 6. Three fundamental categories of matrix can be identified on the basis of the color of samples after refiring.[7] Different colors and shades can be distinguished within each category of matrix. Various calcareous clays were identified (CC), as well as a range of non-calcareous clays variously enriched with carbonates in the matrix (NC cc), non-calcareous clays slightly colored by iron compounds (NC Fe-), and various non-calcareous clays colored by iron compounds (NC).

Of the 217 samples examined through MGR-analysis, 42 were also subjected to chemical composition analysis using WD-XRF.

Unlike the 4-cluster solution arrived at using the pXRF data, the Ward´s clustering of the WD-XRF data resulted in a 5-cluster solution. Similar to the pXRF clusters, the separation of the WD-XRF clusters was determined in part by the relative Ca content (Fig. 7 a and b). Direct correlation of pXRF and WD-XRF clusters is not possible, as the numbers of clusters derived from the two sets of data differ. MGR-grouping correlates very well with the results of WD-XRF analysis, and there are clear differences in chemical composition among the individual MGR-groups. It was possible to connect the same MGR-groups to the same clusters with the pXRF data as well.

6 For details concerning the methods see Daszkiewicz and Schneider, chapter 3 in this volume; results for Olbia cf. Schweigart.

7 Examples see Fig. 5–14, Daszkiewicz and Schneider, chapter 5 in this volume.

The comparison of the Ward clusters to clay types and the pottery range (Graeco-Roman as well as Chernyakhov) made it apparent that calcareous clay (CC) is mainly associated with Cluster 4 and is mainly associated with the Graeco-Roman range, whereas Chernyakhov pottery is found in all four clusters (mostly Clusters 1–3) and mainly made of calcium-pure clay (NC/NC cc/NC Fe-) (Fig. 8).

The MGR-analysis not only yielded different clay types, but also specific MGR-groups within those clay types. Within the samples made of calcareous clay, the MGR-analysis yielded one major group, CC1, and five groups formed by just a few samples (CC1.1 – C4). Graeco-Roman pottery is mainly made up of the group CC 1, whereas CC 2 and CC 4 are mainly associated with Chernyakhov pottery (see Fig. 8). Since calcareous clay itself was more often than not associated with Ward Cluster 4, most of the MGR CC groups appear in Cluster 4 as well. Cluster 2 only contains samples of MGR-group CC 2, which was made up mostly of samples from the Chernyakhov range.

In contrast to calcareous clays, which were associated with only a few MGR-groups, quite a few non-calcareous MGR-groups were identified, each consisting of just a few samples (in general 1–3 samples per non-calcareous MGR-group). The non-calcareous MGR-groups were spread out over all four clusters.

Results and their interpretation

Some interesting conclusions relating to the economic region emerged from comparing the results of the different analyses for the two pottery ranges.

With regard to the Graeco-Roman range, it is striking that the clay type CC1 predominated among the calcareous clays used most frequently. The results of the analyses indicate that the clay type CC1.1 was probably used by one production site, primarily for the production of bowls. These have been found at almost all of the sites within the *chora* of Olbia that have been investigated.[8] The clay type CC1.1 appears in the individual settlements with varying frequency; however, these differences result primarily from the number of fragments taken from each settlement. Vessels made of this clay type are probably ceramic products from a single production site (nucleated workshop). The pottery was transferred by way of exchange and trade from this workshop to the other settlements within the *chora* (Fig. 9.1).

The finds from the *chora* of this clay type come from complexes associated with the 1st through the 3rd century; in Olbia, 4th century pottery of this type was also found. The place of production of the pottery made of the clay type CC1.1 is unknown. There

8 Outside Olbia in Kozyrka, Zolotyi Mys, Radsad, and Stara Bogdanivka. Finds of this clay type from Stanislav and Petukhivka are among the fragments from the Chernyakhov range.

is evidence that gray ware was being produced in Olbia itself as early as the last centuries BC. Eleven kilns dating to the 1st through 4th centuries AD are also known; with respect to their structure, they would also have been suited to the production of gray ware. These kilns stood in multiple sites within the upper part of the city (Fig. 2.1) in the 1st and 2nd centuries, starting in the 2nd century there were kilns in the city's lower section (Fig. 2.2).

In the 4th century, a kiln was situated at the edge of the citadel. Thus, there is evidence for the local production of pottery over the entire period, but there was no single, continually used center of pottery production. Excavators did not find the remains of the last batch of pottery fired in any of the kilns, nor have finds of misfired pottery in the area of the kilns been reported. Potter workshops may also have existed in or near the other fortified settlements of the *chora*, but the areas investigated thus far, which are quite small in most cases, have yielded no evidence of this.[9] Only in Kozyrka has an indication been found: the remains of a metal processing or pottery production workshop were found in this fortified settlement of the 1st to 3rd century.[10]

Thus, production of the material group CC1.1 and other material groups represented in the Graeco-Roman range may have taken place in Olbia or at one of the other settlements within the *chora* during the first three centuries, at least until the destruction and temporary abandonment of Olbia. During these centuries, the individual settlements within this area were in constant contact with one another, according to the infrastructure analysis performed by S. Bujskich.[11] They formed a single economic and administrative unit. Thus, the pottery of material group CC1.1 produced at one location in the *chora* was conveyed to the other settlements via overland or water routes as part of a continuing internal exchange. The number of samples associated with the other calcareous material groups represented in the Graeco-Roman range is too small to permit conclusions of this kind to be drawn. Overall though, pottery production in the first centuries AD points to the existence of one economic space with distribution principles.

One surprising result of the natural science materials analyses was that there is practically no indication of the importation of gray ware from the Roman provinces in the entire range of Graeco-Roman pottery. Only one vessel from Zolotoyi Mys (ZjM-7) differs so greatly from the others in the composition of its material as to rule out an origin in Olbia or the surrounding area. The vessel in question is the upper part of a jug, which does not differ from the other gray ware jugs in form or macroscopically observable qualities.[12] The explanation for the small share of pottery imports may lie

9 Буйских 1991.

10 Бураков 1976, 132.

11 Буйских 1991, 127–140.

12 Schultze, Magomedov, and Bujskich 2006, Abb. 13.7; 31.5.

in the research context, however. The material acquired from the main settlement, Olbia, which was the economic center and surely enjoyed the most extensive interregional contacts, dates primarily to a time after the *polis*' period of greatest prosperity in the first through third century. This selection during the compilation of the material could have resulted in the early exclusion of existing finds of imported pottery.

Another question that the analyses leave unanswered is to what extent the production of pottery in the Graeco-Roman range recommenced after the resettlement of Olbia in the late third century. In the case of the settlements in the *chora*, this can be ruled out on the basis of earlier investigations. The materials from Olbia that were analyzed were those of finds from layers containing older admixtures, so no conclusions on this issue can be drawn at this time.

Unlike the Graeco-Roman range, gray ware in the Chernyakhov range tended to be made from non-calcareous clays (Fig. 8). Numerous material groups were identified using MGR and pXRF analysis. Each of these is specific to the individual finding place; material groups of this kind were also identified in Olbia (Fig. 9.2). An exchange of these products occurred only in exceptional cases, such as that of the clay type NC/MGR-group 40. Two fragments of this type were found in Olbia and Novokondakove (Fig. 9.2). Rather than testifying to a genuine exchange of pottery, the vessels may have made their way to the different settlements as packing material, gifts, or in some other way.

To date, no kilns have been found at the settlements investigated here or, for that matter, at any of the Chernyakhov settlements in the Lower Bug region. Since finds of kilns are not uncommon elsewhere within the area of distribution of this culture,[13] their absence was considered suggestive of decentralized ceramic production.[14] The analyses have now confirmed that this is the case for the Lower Bug region. Each of the settlements under study here produced gray ware for its own use. This refutes V. V. Krapivina's hypothesis that pottery was produced in Olbia for the surrounding settlements of the Chernyakhov culture. Conversely, the identification of non-calcareous clay types that are specific to Olbia in pottery of the Chernyakhov range shows that Chernyakhov pottery was produced within the *polis*. Presumably, this would have supplied the pottery demand of a population group that had apparently settled there.

A smaller number of sherds associated with the Chernyakhov range were made of calcareous material (Fig. 8b). These fragments came from multiple locations. Two fragments were identified as clay type CC4 (O-09, Zjm-53). The vessel from Zolotoyi Mys differs from the normal Chernyakhov range, in that the fragment in question was once part of a bucket (Fig. 3.13). Like the difference in material composition, this suggests that this vessel was not produced in Zolotoyi Mys, and perhaps not even in the region under study. The CC4 sample from Olbia does come from a pot typical for the

13 Бобринский 1991; Schultze and Ljubičev 2007.

14 See section 4.9 in this volume.

Chernyakhov culture. Another five fragments of the clay type CC2 (O-18, O-44, Pt-6, Koz-79, Nk-8) differ only in their calcareous material from vessels in the Chernyakhov range. As the material identified in this small number of samples does not match the other, non-calcareous raw materials used, one can suspect that these vessels were not produced in the places they were found, but rather in other settlements or neighboring regions. Whether they represent one or multiple places of production cannot be determined at this time. However, the small number of finds involved cannot support the conclusion that a real exchange of pottery existed.

The archaeological analyses of the gray ware from Olbia and the surrounding area yielded archaeologically identified ranges of pottery but did not permit any statements to be made about the production sites or distribution of the pottery. Only through the use of a range of natural science analytical techniques and the comparison of their results was it possible to obtain new insight into these questions. This assessment yields different pictures over the course of the first centuries AD. The gray ware associated with the Graeco-Roman range from the 1st through 3rd centuries was produced in larger quantities in certain workshops. Its distribution occurred via overland and water routes within the entire *chora*, which represented one functioning economic space until the time of the warlike events in the mid-third century.

The period from the late third to mid-fourth centuries presents a different picture; the economic space had been fundamentally altered by the arrival and settlement of representatives of the Chernyakhov culture. In the Chernyakhov settlements, which were founded on the former settlements of the *chora* or at new sites, the gray ware served as both tableware and kitchenware. The pottery demand of individual settlements was met by local production sites. The material composition of the samples, which is specific to the individual settlements, points to the existence of sites of production of Chernyakhov range pottery in each of the settlements, as well as in Olbia itself. In each place, this pottery production served the local demand. Only a small proportion of finds were associated with non-local production. No exchange specifically of pottery existed. Gray ware was no longer involved in the economic ties between the *polis* and the surrounding area, though such ties undoubtedly existed in this period too.

Site	No. of samples	Spectrum	pXRF	WD-XRF	MGR
Olbia (O)	116 Graeco-Roman (29) Chernyakhov (80) Unknown (7)	116 (1)*	14	87	
Kozyrka (Koz)	76	Graeco-Roman (19) Chernyakhov (50) Unknown (7)	76 (51)*	5	51 (2)*
Zolotoyi Mys (ZjM)	42	Graeco-Roman (27) Chernyakhov (13) Unknown (2)	37	6	34
Petukhivka (Pt)	20	Graeco-Roman (3) Chernyakhov (13) Unknown (4)	20	5	14
Novokondakove (Nk)	10	Chernyakhov	10 (1)*	5	8
Stanislav (Stv)	9	Chernyakhov	9	3	7
Adzhigolska Kosa (AK)	9	Chernyakhov	9	1	8
Stara Bogdanivka (StB)	4	Graeco-Roman (3) Chernyakhov (1)	4 (4)*	1	3 (1)*
Radsad (Rd)	3	Graceo-Roman	3 (3)*	1	3
Skelka (Slk)	1	Graeco-Roman	1 (1)*	1	1
Total	**290**		**285 (61)***	**42**	**217 (2)***

Tab. 1 Sites and analysed samples (the numbers in brackets are double measurements).

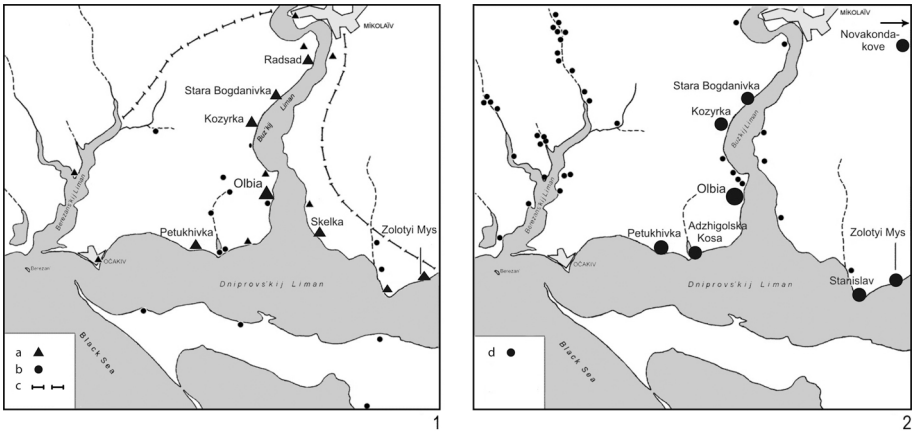


Fig. 1 Settlements on the lower Bug River: 1 (on the left) from the 1st–3rd century AD; 2 (on the right) from the end of the 3rd to 4th century AD. a = hill forts and the *polis* of Olbia; b = rural settlements; c = border of the *chora* of Olbia up to the middle of the 3rd century AD; d = sites with evidences of the Chernyakhov culture. The named sites display settlements whose ceramics were analyzed.

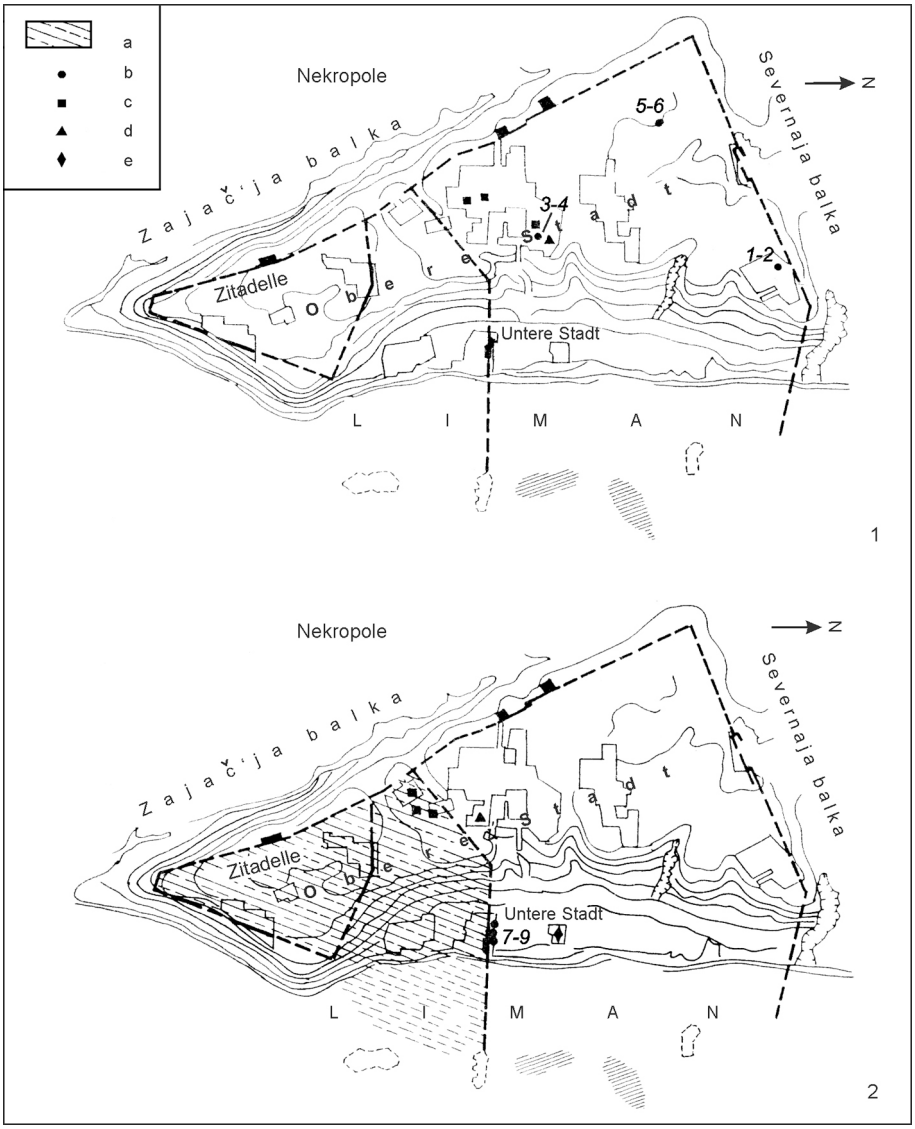


Fig. 2 Olbia. Map of the *polis* with kilns: 1 (top) position of the kilns during the 1st–2nd centuries AD; 2 (bottom) position of the kilns during the 2nd–3rd centuries AD. a = territory of the polis during the 2nd–3rd centuries AD; b = kilns (no. 11 not on the map); c = production of vine; d = granary; e = storeroom.

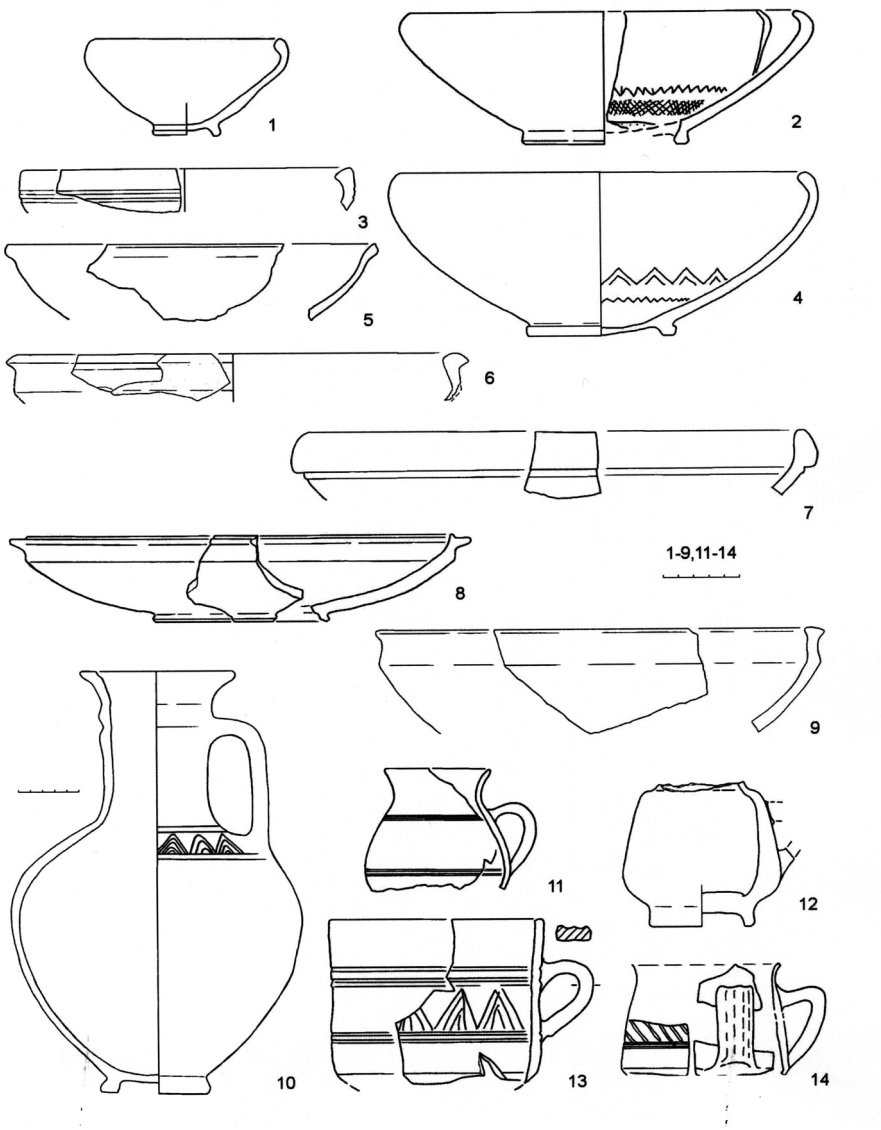


Fig. 3 Ranges of pottery, examples from the vicinity of Olbia. Graeco-Roman range.

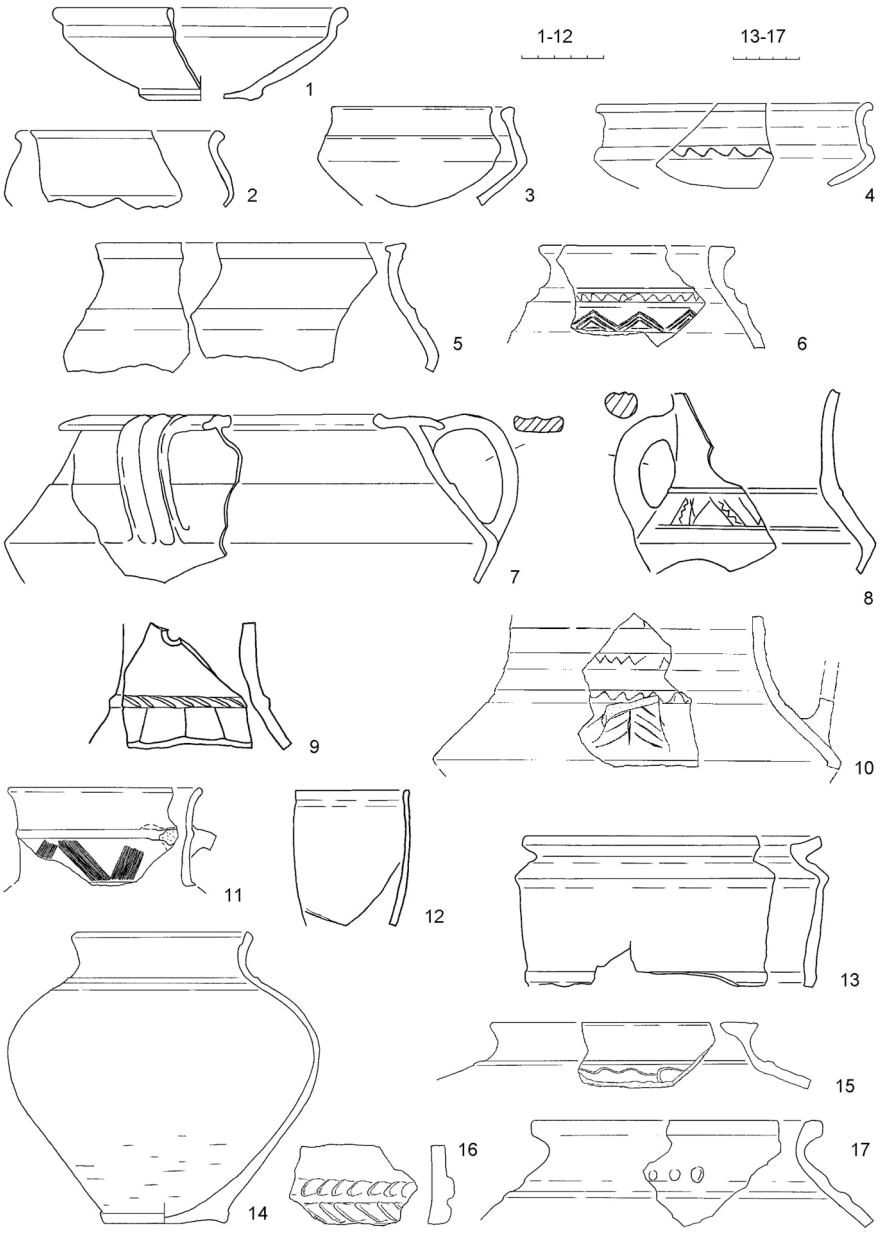


Fig. 4 Ranges of pottery, examples from the vicinity of Olbia. Chernyakhov range.

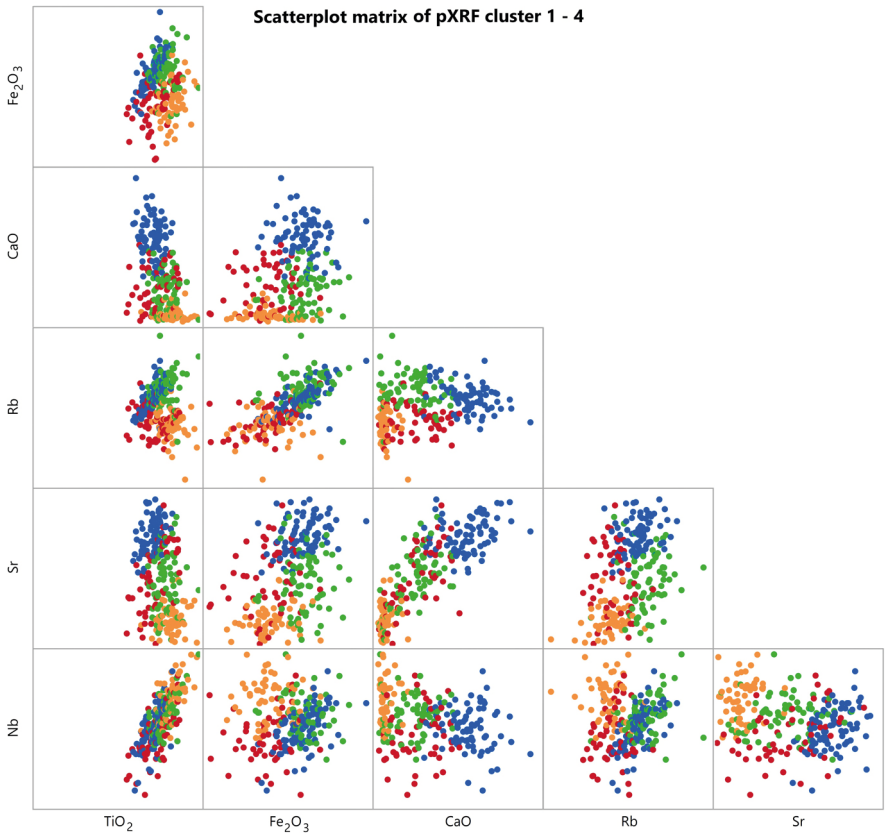


Fig. 5 Cluster analysis of pXRF data (Ward method). Distribution of Cluster 1 to 4 according to Fe2O3 (% by weight) and CaO (% by weight).

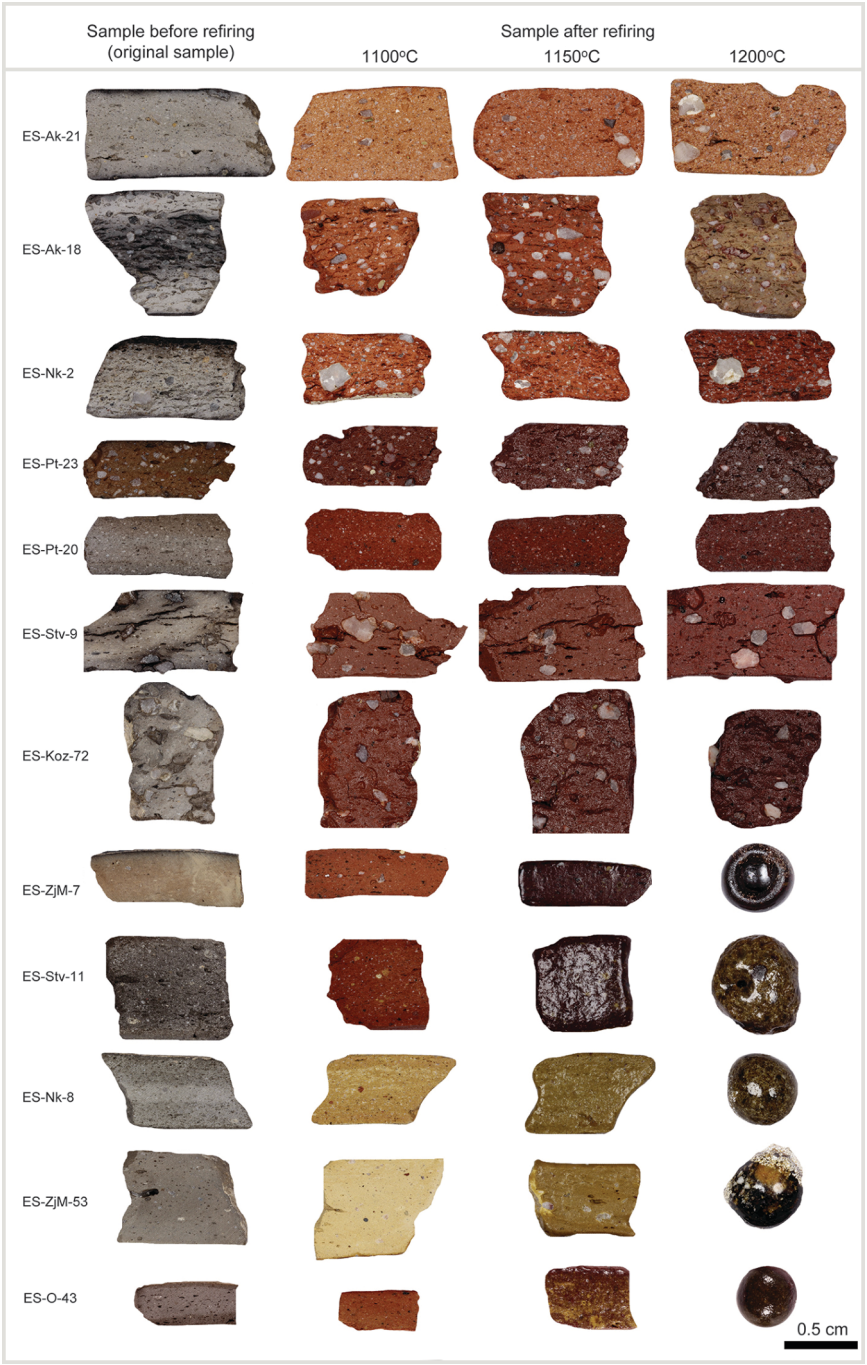


Fig. 6 Examples of MGR-groups: Matrix types NC (row 1–6), NCcc (row 7 and 8), CC (row 9 and 10), and MX (row 11).

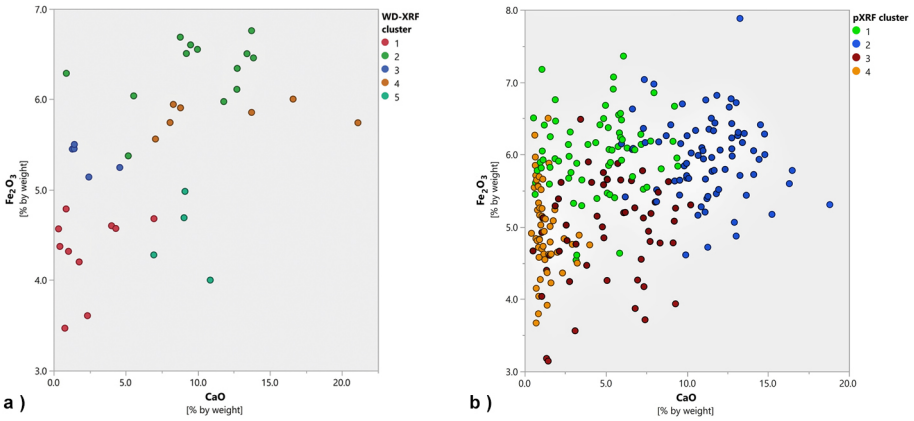


Fig. 7 Diagram of Fe vs. Ca of WD-XRF (a) and pXRF (b).

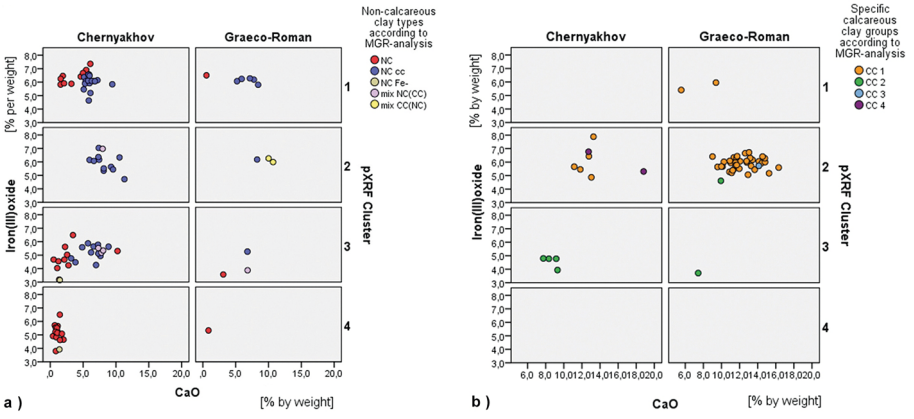


Fig. 8 Distribution of clay types according to clusters and pottery range: a = non-calcareous clay types and b = calcareous clay types.

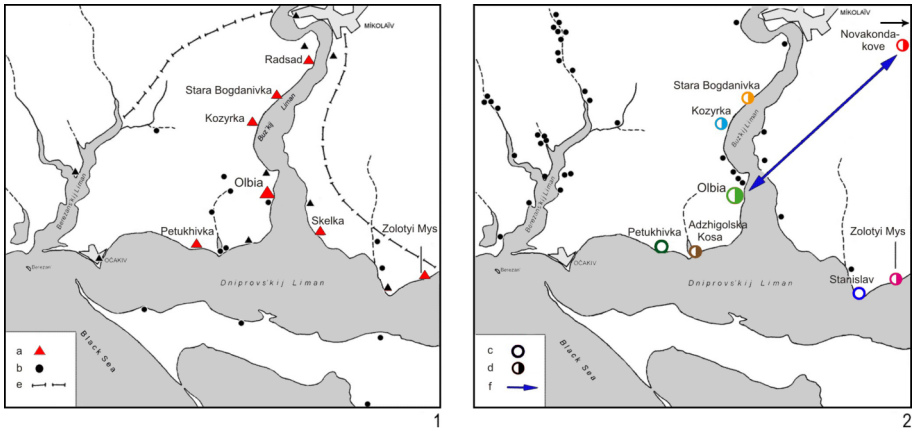


Fig. 9 Grey wheelmade ceramics, groups of composition and its distribution. 1 = Graeco-Roman range, calcareous clay CC1, distribution of samples from the 1st to 3rd century AD, marked with red triangles. a = hill forts and the polis of Olbia; b = rural settlements; e = border of the chora of Olbia. 2 = Chernyakhov range from the end of the 3rd to 4th century AD: black spots = settlements of Chernyakhov culture. c = sites with specific local compositions of noncalcareous clay, marked with several colors; d = sites with additionally calcareous samples; f = relation between the sites according to distribution of clay type NC cc MGR-group 40.

4.9 Production and Distribution of Wheelmade Pottery in the Chernyakhov Culture: The Example of the Region around Voitenki

Erdmute Schultze, Małgorzata Daszkiewicz,
Gerwulf Schneider, Fleur Schweigart

Introduction

The Voitenki settlement and burial grounds lie in the eastern part of the area of distribution of the Chernyakhov culture (Fig. 1.1), in territory now part of the oblast of Kharkiv in Eastern Ukraine. The settlement is strongly associated with pottery production. The Germanic-Slavonic Archaeological Expedition of the V. N. Karazin Kharkiv National University has been investigating the site since 2004, under the leadership of M. V. Liubichev. Four pottery kilns have been excavated in this context (Fig. 2). A partnership between the School of History of Karazin University and the Eurasian Department of the German Archaeological Institute, first established in 2005, forms the basis for multiple joint Ukrainian-German research projects.[1] Thanks are due to the expedition for the excavation results used in this paper; the archaeological analyses of the pottery were conducted jointly with M. V. Liubichev.

Cultural and economic background

The area of distribution of the Chernyakhov culture reached its maximum expanse in the 4th century AD, when it was widespread within the territory of the realm of the Gothic

1 For the project results of greatest significance with respect to pottery making, Schultze and Ljubičev 2007; Schultze, Liubichev, et al. 2010; Ljubičev and Schultze 2011; Шультце et al. 2013.

King Ermanaric, which is mentioned in written sources. Modern scholars interpret this archaeological culture as having been multi-ethnic, involving late Scythian-Sarmatian population groups and others, in addition to the Germanic population groups.[2] The culture is associated with a dense settlement pattern, which correlated closely with the presence of chernozem soils, indicating an advanced form of agriculture. The settlements and bi-ritual burial grounds have yielded artifacts that originally came from the ancient centers in the northern Black Sea region and the Roman Empire, including fragments of amphorae and glass vessels, evidence of various kinds of engagement in exchange and trade relations. Settlements varied in size and were not fortified. Identification of the centers of individual regions can be made only on the basis of the position and size of a settlement and/or the structure of the associated find material. While the inventories of cremation and inhumation burials provide some indication of evolving social structures, there are no burials with elaborate grave construction and/or rich grave goods that might be attributed to an upper class of regional or even supra-regional significance.[3]

One of the characteristic elements of the Chernyakhov culture is grey wheelmade pottery, which in specific designs, were widespread and can account for nearly 100 percent of the local pottery. This pottery was produced in many places, as evidenced by the potter's kilns uncovered in numerous settlements. One of the larger sites of the Chernyakhov culture is the settlement of Voitenki (Fig. 2.1). This settlement site extends over 18 ha, although whether this entire area was ever in use at one time has not been established. The special status of the settlement, evidenced in the rich find material associated with it, resulted from its position near the Dnieper-Seversky Donets watershed, which constituted an overland route northward from the Black Sea. Moreover, the Voitenki settlement was probably connected over water routes all the way to the Dnieper via the course of the river Merchik, which flows not far to the north.

Research questions

The wheelmade pottery of the Chernyakhov culture can be divided into kitchenware and tableware (Fig. 3). The former includes pots, storage vessels and some crudely worked bowls, while the tableware is made up of bowls, vases, jugs, pitchers, and beakers.

The pottery reveals a certain degree of standardization: the basic forms and decorative elements of the vessels are quite similar throughout the culture's extensive area of distribution; regionally specific characteristics appear only on a limited scale. For this

2 Магомедов 2001.

3 Магомедов 2001, 25–44.

reason, scholars have long been interested in the organization of production and distribution of this wheelmade pottery.[4] Concentrations of kilns, like those identified for the Przeworsk culture in Igołomia[5] (in southeastern Poland), have not been detected, but there have been multiple kilns found at some Chernyakhov culture settlements. Voitenki is one of these, four kilns having been discovered there. Since the kilns are separated by distances of between 40 and 500 m, it would appear that they represent individual workshops, rather than a single production center (Fig. 2). Archaeological analysis has revealed quality variations in the pottery, which includes both vessels of high quality and pieces whose workmanship clearly points to a limited expertise of their makers.[6]

The pottery assemblages from the settlement and from the burial ground are very similar in composition (Fig. 4), though there are no storage vessels or larger pots in the grave inventories. A small number of the vessels found in the graves were very instable; these may have been made as funerary pottery. Thus, with respect to Voitenki, the following questions are the focus of the investigation:

– Was all of the pottery found here also produced locally?

– Where did the raw material used in pottery production come from?

– Was Voitenki a place where pottery was produced to supply the demand of neighboring settlements, or even of an entire region?

Research into these questions, in the form of macroscopic analyses of the sherds as well as natural science analyses, was well underway even before the Topoi Group A-6 took up its work.[7] At the time, the pool of material available for analysis consisted of 179 samples from the 2004–2007 excavations at Voitenki, 150 of which were found in the settlement (Areas A and C) and 29 of which came from graves (Gr. 1–70). For the most part, the samples were from wheelmade pottery; only 12 samples came from handmade vessels. A sample of loam from the casing of a kiln and four samples of clay from near the finding site (Fig. 2.1) were also analyzed. A further 44 samples were obtained from six neighboring settlements of the Chernyakhov culture, known from smaller excavations and surveying, to serve as comparison material. In an initial step, all of the samples underwent MGR-analysis, after which 35 samples were selected for XRF analysis, and 15 samples were selected for thin-section study. The analyses resulted in the identification of a large number of material groups. The source materials of the pottery vessels were

4 Круг 1965; Бобринский 1991; Магомедов 2001, 45–61; Schultze 2009.

5 Dobrzańska 1990.

6 Ljubičev and Schultze 2011.

7 Schultze, Liubichev, et al. 2010.

non-calcareous, while the kiln was made from a calcareous material.[8] In general, the chemical composition of the clay materials was very similar, which probably has to do with the source material found in the area.

However, it was possible to identify iron-rich and iron-poor groups within the non-calcareous clay of the ceramics. Most of the material groups were found only in pottery from a single location: groups A–C (iron-rich) were found only in Voitenki, for instance. All of the samples falling into group B were from handmade pottery, while group A was made up only of bowls of form 1; the other groups included samples from vessels of multiple different forms. However, the pottery in material group D (iron-rich) was found in settlements in Khalimonovka and Vysokopole as well as in Voitenki, while representatives of material group E (iron-poor) were also found in Khalimonovka and Baranovo. Within these last two groups (D and E), the ceramics matched so closely that the vessels in question must be assumed to come from the same source material; in the case of material group D, the suspicion even arose that the vessels originated in the same workshop.

These earlier analyses clearly indicated that each settlement primarily owned its own specific pottery; thus, one can assume that pottery was locally produced for the most part. As matches were sometimes detected in materials from multiple settlements, some exchange must also have taken place, probably on a rather limited scale. The materials used in pottery production were evidently put to multiple uses rather than one material being associated with a specific type of vessel. However, the number of samples limited the significance of the results of the analyses, and thus the research questions could not yet be adequately answered.

Sampling strategy

In order to acquire a more extensive pool of materials for analysis within the framework of the working group of the Topoi Excellence Cluster, another 149 samples were taken of pottery from Voitenki (2008–2014 excavations). The selection of vessels for sampling was modified in a few ways as a result of experiences with earlier research. An attempt was made to better capture the full range of vessel types; almost no samples could be extracted from the, usually heavily decorated, beakers, but they were the exception in this regard. More samples were taken from pottery found in graves. In addition, more samples were taken from archaeologically non-standard vessels, e.g. the jugs of light-colored clay.[9] Another focus lay on the environs of the kilns discovered in recent years,

8 Schultze, Liubichev, et al. 2010; Ljubičev and Schultze 2011; Daszkiewicz and G. Schneider n.d.

9 As the vessels in question are intact, this required drilling.

Site	Number of analysed samples	Analysis			
		a MGR	WD-XRF	p-XRF	t-s
		number of samples			
	49			49	
	48		48		
Voitenki	11	11			
	195	193	32	195	4
	28	28	28		6
Baranovo	4	4	1	4	1
Khalimonovka	19	19	8	17	3
Khvorostovo	3	3		3	
Gvozdevo	7	7	7	7	
Lozovaya	6	6	1	5	
Ogul´tsy	12	12	2	12	
Shlyakh 2	6	6	1	1	
Shlyakhove	3	3	1	3	
Trofimovka	4	4	1	4	
Vysokopole	9	9	6	8	1
Total	**404**	**305**	**136**	**308**	**15**
clays	**14**	**14**	**14**		

Tab. 1 Overview of analyses and number of analysed samples (a MGR = abridged MGR-analysis, t-s = thin-section).

where one expects firing debris to be found and where actual misfired pottery has been found. Another 29 additional samples were found through surveys at the sites of the neighboring settlements. A total of 73 samples from 10 settlements in the area around Voitenki were taken. Overall, the total number of samples is now 404.

Methods used

As the Topoi Excellence Cluster offered the possibility of portable XRF (pXRF) analysis, pXRF measurements were taken on all of the samples from Voitenki and the surrounding area, including the older samples. MGR-analyses also were performed, and the results were added to those of the existing MGR-analyses. Additionally, chemical analysis by WD-XRF for nearly half of the samples was carried out and for some samples thin-sections were done. Table 1 provides an overview of the analyses conducted.[10]

10 For a detailed description of the scientific methods and their combination, see Daszkiewicz and Schneider, chapter 3 in this volume.

Results

In the cases of 13% of the samples, the pXRF data did not correspond well with the WD-XRF data. As this high percentage of anomalous results could not be satisfactorily explained, none of the results used below are based solely on pXRF measurements. On the basis of the comparison of the results of MGR, WD-XRF, and pXRF analyses and the thin-section studies with the archaeological data, the following statements can be made:

Multiple material groups were detected in Voitenki and the surrounding area (Fig. 5) – one being a group of non-calcareous clays. This group contains clays containing various contents of iron compounds (clay types A–F).[11] It also consists of non-calcareous and iron-poor clays (clay type G1–G3). The second group is made up of calcareous clays (clay type H). There are also a number of samples that do not fall into either of these groups; these are imports that may come from the region (X1–X3) or from someplace quite far away (clay type Y1). Specific characteristics in the chemical composition of these samples clearly distinguish them from the rest of the samples. These clay types are quite distinct, both with respect to discriminant analysis and with respect to principal components analysis (Fig. 6).

Almost all of the subgroups within an entire range of clay types identified were represented in the samples from Voitenki (Fig. 7). The bulk of the materials from Voitenki fell into one of only a small number of clay types though: clay types A1, C1, and A4 account for 59% of all samples. Some clay types were found only in Voitenki. Among these are types A2, B1, C6, and E1, each of which is represented by more than three samples and all of which were found at the settlement. Conversely, clay type A3 was found only in the burial ground. Other clay types restricted to Voitenki, such as H1–3, were detected in only one or only a small number of samples.

Samples were taken at clay exposures in the area surrounding the settlement. Of these, the samples from sources 1 and 4 proved to be suitable for clay analyses (Fig. 2.1). A sample from source 1, which is an exposure in the more immediate environs of the settlement, was identified as clay type H1. This calcareous clay type was also found in a wheelmade bowl from grave 101. Clay type H3, as mentioned above, was found in a handmade pot from grave 43, and clay type H was found in a sample from the casing of Kiln 1 and in a lump of clay from the settlement. Thus, calcareous clay, despite being readily available, was not used to any great extent for pottery production. Instead, it was used as the raw material for the kiln, and probably for other building projects at the settlement as well. Sample 1 from source 4, an exposure approximately 2 km from the settlement, was identified as clay type A3, a non-calcareous clay which was also found in 16 samples of vessels, all of which came from grave inventories (see below). The material

11 Daszkiewicz and G. Schneider n.d.

of two clay samples obtained in 2012 in Area B of the Voitenki settlement also belong to clay type A3. One of these samples came from an unusual pit, almost 2 m deep, which may have been dug for the purpose of preparing clay for pottery production. Thus, this non-calcareous clay type, A3, was probably also acquired near the settlement. No other clay types identified through the analyses of the pottery have been detected in the form of raw material, however the opportunities for obtaining further samples in the area are limited, as the terrain is covered with plants and does not contain any larger exposures.

The composition of clay types A–C, E, and H corresponds to that which one would expect to find in clay material from this geographic region. Clay type E is also characterized by a high percentage of titanium. Clay types F and G, for their part, have high percentages of aluminium. This, combined with a very low calcium content (less than 1 wt.%), suggests kaolinitic clays, of which there is no known evidence in this area. Kaolinitic clays can be associated with higher quality with respect to the functional properties of vessels and, thus, might have been specifically selected for use in pottery production.[12] However, it was not possible to obtain more detailed information about the deposit sites of the specific clay type G within the scope of the analyses presented here. Thus, the question of whether material from undetected local deposits was used to make the pottery of this clay type must remain unanswered for the present. Variants of this clay type are found both in samples from Voitenki and in samples from eight other settlements. While it is possible the pottery in question was imported from other regions, clay type G2 was found in multiple samples from the working pit of Kiln 4 in Voitenki (see below, Fig. 9).

The largest group of samples from vessels from Voitenki can be classed as non-calcareous, ferruginous clay of types A1 and C1; clay type A4 appears somewhat less frequently. Of the iron-poor non-calcareous clays, clay type G2 was found most often.

With a few exceptions, the pottery found in Voitenki was made on a potter's wheel. Most (7 of 13 samples)[13] of the exceptions (the freehand formed vessels from which samples were taken) are of clay type B1, which was also used in the production of wheelmade pottery.[14] The hand formed vessels of this clay type come from Area A and were assigned archaeologically to the Boromlya horizon, which is dated to the second half of the third century BC, and did not yet belong to the Chernyakhov culture. The samples of wheelmade vessels of this clay type are also largely from Area A; only one (sample 34), taken from the lower section of a vessel, was found in Area C. Thus, the use of this clay type is associated with Area A of the settlement and, at least to some extent, with an older phase of the area's use. This assumption is supported by the absence of clay type B1 among

12 This has been demonstrated for the pottery in the Chernyakhov settlement of Zhuravka (middle Dnieper region) (Кругликова 1965).

13 Samples 16, 17, 18, 19, 20, 75, and 76.

14 Samples 10, 28, 29, 34, 49, 53, 73, 86, 132, 157, 158, and 159.

the clay types represented at the burial ground containing only Chernyakhov culture graves.

Of the other six hand formed vessel samples, two were classified as clay type A1 and two as A7; clay types A4 and H3 each accounted for one sample. The samples associated with the first two clay types, A1 and A7, also came from Area A of the settlement. Clay type A4 was found in a hand formed pot from grave 140 (Voj 281); this material, as stated above, is frequently found in wheel worked pottery. The hand formed vessel from grave 43 (Voj 106) differs greatly from the other samples in its form and is also the only sample of clay type H3. We, therefore, assume that this pot was not made locally.

As was stated earlier, the range of pottery found in the settlement is very similar to that found in the burial ground (Fig. 4). However, all 16 of the vessel samples of clay type A3 came from the burial ground. This clay type was detected as a raw material near the settlement (see above), and hence would have been readily available. It seems reasonable, therefore, to ask whether the pottery in question is funerary pottery. The 16 samples of clay type A3 came from vessels deposited in 8 inhumations, including two double burials. Most of them are tableware (9 bowls of various types, 2 vases, 4 jugs, and 1 pot). Only in one case, grave 64, was a vessel (a jug) of this clay type the sole vessel deposited in the grave; the other graves in question contained as many as 16 other vessels. Not all the other vessels were of clay type A3. For instance, clay type A3 accounted for only one vessel out of 6 in grave 198 (Voj 298); 3 of 12 in grave 196 (Voj 292, 294, and 299); and, as the highest proportion, 5 of 10 vessels in grave 206 (Voj 303–306 and 310). This suggests that the vessels of clay type A3 were not an essential element of the grave goods and, therefore, that this clay type was not necessarily used specifically for the production of funerary pottery. However, it should be noted that the inventory of burial 1 in grave 183 contains (in addition to a jug, four bowls, and a pot) a vase of clay type A3 that stands out due to the instable structure of the material. The vase in question is one of the vessels found at Voitenki that were only lightly fired and would, therefore, not have been of practical utility. This suggests that this vase, at least, was made specifically for deposit in grave 183.[15]

Other vessels, found both in graves and at the settlement, were fairly brittle, and their broken edges crumbled when samples were taken.[16] The explanation for this probably lies with the temper, but pots were not the only vessels that yielded samples of this kind, tableware vessels of various forms did as well.

Comparing the types of wheelmade pottery vessel with the types of clay used to make them did not reveal more than tendencies: pots of clay type C1 predominate,

15 Since Voj 285 is the only sample from a lightly fired vessel, the question of whether other clay types were also used to produce such vessels remains unanswered.

16 Samples 295 (F1), 297 (C13), 314 (G2), 315 (G2), 317 (E1), and 319 (E1).

though many other types of clay are also represented among the samples in smaller numbers. Bowls were made primarily of clay type A1, A3, or A4, but here again, other clay types were also represented in smaller numbers. Similarly, while most vases were found to be of clay types A1 and A4, not all of them were. The jugs and storage containers sampled are spread over clay types A-E and A-C1, respectively.

On the whole, the notion that specific materials, i.e. clay types, were required to make the specific vessel forms could only be substantiated to a limited degree. Kitchenware (pots and storage vessels) and tableware (bowls, vases, jugs, etc.) differ primarily with respect to temper, treatment of the material, and/or decoration and less with respect to the clay type used. The analyses did not bear out the supposition that the material composition of jugs in particular, requiring as they did more elaborate production methods and, in some cases, displaying very meticulous workmanship and different hues, would differ from that of simpler forms of vessels. On the contrary, the results suggest that they, like the other pottery, were produced locally.

An assumption of non-local origin can only be made in the case of a few samples. The hand formed pot from grave 43 has already been mentioned. Other samples clearly stand out with regard to the MGR-analyses and their chemical composition (Fig. 8). The sample Voj 284 clearly deviates from the standard with respect to the composition of the material, primarily because of its high chromium content. The hemispherical vessel was probably used as a bowl in grave 183. However, it was originally the lower part of a jug, one that was certainly already missing its upper part when it was deposited, since the grave had not been disturbed. Whether the upper part of this jug exhibited any special form characteristics is, therefore, unknown. The lower part of the vessel is not of a particularly noteworthy quality and does not have the character of a prestige good or a luxury object.

Other 'imports' which could, based on their chemical composition, come from the region, include an open bowl (Voj 79), which differs from the other vessels of this type only in having a somewhat heavier rim, and a pot (Voj 143) that has a relatively narrow mouth. Neither fragment would have stood out from the other pottery in the absence of the material characterization based on natural science methods.[17]

Among the settlement pottery, the material from the kilns is of particular interest. While the inner chambers of the kilns were filled with settlement debris, the working pits may have preserved remnants from loading or emptying the kilns. Here again, the principal groups of clay types are represented in the samples from the kilns and their immediate area. Beyond this, some tendencies could be identified (Fig. 9): kiln 1 contains primarily clay type A1 and kilns 2 and 3 contain chiefly clay types A1 and C1, though kiln 2 also contains type A4. By contrast, the samples from kiln 4 were

17 Another sample whose material suggested an import from the region came from Vysokopol´e (X37).

almost all of clay types E1 and G2, which are nearly completely absent in the content of the other kilns. This distribution is interpreted as an indication that the different materials were used in the kilns. To what extent chronological differences play a role in this context, i.e. whether the use of individual kilns was associated with different phases of the settlement, is a question that must remain unanswered at present: the kilns have all been dated to the 4th century AD, but it has not been possible to obtain a more precise date than that.

No clear picture emerged from comparing clay types to vessel forms for the content of individual kilns. It is clear that individual forms of vessels predominated in individual kilns – bowls in kiln 1, for instance, or pots in kiln 4. In kilns 1–3, pots and storage vessels tend to be made of clay type C, vases and bowls of clay type A. However, each of these kilns also contained pots and bowls falling into different material groups as well. Thus, one cannot conclude that the vessel types were linked to certain clay types on the basis of the composition of the range of samples from the four kilns. The concentration of individual vessel forms in the kilns can probably be better put down to the composition of the last batch of pottery fired in each kiln.

As mentioned above, the tableware differs from the kitchenware, not only with regard to the more meticulous workmanship and in terms of surface treatment, but also with respect to a lower percentage of temper. In Voitenki pottery, the temper consists largely of quartz sand with round grains and grain sizes within a certain range (Fig. 5).[18]

No evidence for the systematic addition of grog was detected, although coarse clay aggregates (non-homogenous ceramic bodies) were detected in at least 15 of the samples from Voitenki (Fig. 10). The rounded form of this clay aggregates does not necessary support its characterization as grog though (could be so-called 'green grog'?). Two samples (Fig. 10, sample Voj 200 and 252) particularly stand out due to the presence of very pure, non-calcareous, iron-poor clay. Both samples came from pots with high proportions of evenly distributed temper. This indication that the material was well mixed notwithstanding, it is possible that the admixture was the result of a non-uniform processing of the raw clay, since both the clay of the vessel and the clay of the admixture consist of non-calcareous and iron-poor material.

Several MGR-groups are made up of samples that match one another very closely not only with respect to characteristics in the context of refiring, but also in their WD-XRF values and the physical ceramic properties. These are, therefore, considered to be products of the same workshop.[19] Some of these MGR-groups appear only in Voitenki,

18 Measurement with a magnifying lens (7x magnification) yielded predominantly grain sizes of 0.1–0.5mm, in some cases as large as 1.0mm, but seldom larger.

19 Pottery of matching material (batch) and of matching production process (run) is assumed to come from one workshop. Theoretically, quite a number of such 'workshops', as defined by the material, could come from one and the same place of production.

	A1	A4	A6	A8	C1	C4	C9	C11	D1	F1	F2	F3	G1	G2	G3	Y1
Baranovo (n = 4)				o	x									x		
Khalimonovka (n = 19)	x			o		x	o		+				x	x		
Khvorostovo (n = 3)				o			o							x		
Gvozdevo (n = 7)	x		+		x					x	+					
Lozovaya (n = 6)	x			o			o							x		
Ogul´tsy (n = 12)		x			x			o		x						
Shlyakh 2 (n = 6)				o	x											
Shlyakhove (n = 3)		x						o		x						
Trofimovka (n = 4)		x			x			o		x						
Vysokopol´e (n = 9)	x	x			x							x			x	+

Tab. 2 Clay types in other sites of the region. + = marked clay types found once; o = marked clay types not found in Voitenki; n = number of samples.

but there they are quite common. As examples, we will cite MGR-group 18 (clay type A1), MGR-group 57–57.3 (clay type A4), and MGR-group 15.83 (clay type C1), each made up of more than five samples. The commonly occurring groups should certainly be viewed as representing the products of local pottery production.

Several clay types, including those found most frequently in Voitenki, also appear at settlements in the surrounding region. There is no settlement in the area for which all samples were classified into only one of the groups A–G; some degree of diversity of material is exhibited in the samples from each of them, even though these settlements were represented by a smaller number of samples than Voitenki was (Tab. 2). Clay types not found in Voitenki were identified for some of the settlements – sometimes in multiple samples (clay types A8, C9, C11), sometimes just in a single sample (clay types A6, D1, F2, Y1). It seems clear that none of these vessels were produced in Voitenki; they must come from other settlements. As some clay types were found in more than one sample, one has to wonder whether these might represent local production in other settlements. However, comparing the results of the MGR-analyses with the WD-XRF counts and the physical ceramic properties revealed only a small number of samples whose values match to a degree that indicates a high likelihood that they came from one workshop: three samples from Khalimonovka in MGR-group 60.2 (clay type A1), two samples from Ogul´tsy in MGR-group 77 (clay type C11), and two samples from Lozovaya in MGR-group 95 (clay type G2). These examples should be considered a preliminary indication of local workshops in other settlements in the Voitenki region.

Some of the samples falling into MGR-groups that are found both in Voitenki and in the surrounding region can also be attributed to a single workshop on the basis of a high degree of correspondence in results. This is the case for three samples in the MGR-group 60.2 (clay type C1) from Khalimonovka (X10, X12, X13) and two samples in the

MGR-group 95 (clay type G2) from Lozovaya (X22, X26). In these cases too, the vessels are likely to originate in the local workshops at those settlements.

Two samples associated with MGR-group 2–2.2 (clay type C1) from Shlyakh 2 (X16, X17) and ten samples from Voitenki (settlement and burial ground) also exhibit such a high degree of similarity that one can assume them to be the products of a single workshop. For the most part, the samples in question came from pots, although one of the samples from Shlyakh was from a vase. In this case, one can probably assume that the vessels were produced in Voitenki. Their presence in Shlyakh testifies to a relationship with the settlement there (Fig. 11), but one cannot speak in terms of the exchange of ceramics on the basis of two pieces alone.

The values for two samples in MGR-group 35 (clay type C4) also match to an extent associated with a high probability that they came from the same workshop; one of these samples came from Voitenki (Voj 69), the other from Khalimonovka (X41). Again, this is evidence of relations between the two settlements, but is not sufficient to support a conclusion that they engaged in the exchange of pottery. The vessels might also have served as packaging material.

Upon conclusion of the earlier analyses, described at the start of this paper, a common origin in a single workshop was also assumed in the case of certain samples from Voitenki, Khalimonovka, and Vysokopl′e, which were assigned to pottery group D.[20] The results from the more recent research, which also includes analyses of physical ceramic properties, show a lesser degree of correspondence, thus, we now assume that these samples represent the products of more than one workshop.

Summary

Taken together, the results from the archaeological and natural science analyses clearly point to the predominance of locally organized pottery production, in which locally available clays were used. These clays were not uniform, and preference was always given to non-calcareous material. The further processing of the ceramics, vessel shaping, and firing did not take place at one central location within the settlement, but was decentralized, determined by the location of the kiln. In this respect, one could expect changes in both the clays used and the firing locations to have occurred over the course of the existence of the settlement.

Locally produced pottery was routinely used in daily life, but it was also used, in a very similar manner, to furnish graves. Estimating the scale of pottery production is difficult at present, because there is as yet insufficient basis for reliable conclusions about

20 Schultze, Liubichev, et al. 2010.

the simultaneous existence of farms, farmsteads at the settlement. The fact that there were four kilns in a settlement that existed for about a century suggests seasonal pottery production rather than continuous year-round production.

When one examines the pottery found in Voitenki, in addition to the differences associated with the various functions of kitchenware and tableware, one finds differences in the quality of the individual forms of vessels that can be ascribed to differences in the levels of diligence, experience, and/or professionalism of their producers.[21]

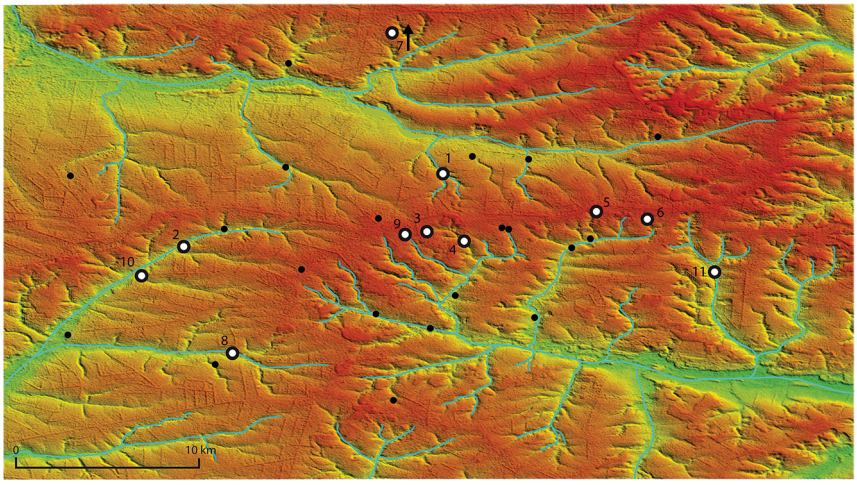
Moreover, some of the vessels found in graves were only lightly fired and, thus, would not have been of much practical utility.[22] These vessels may have been produced specifically as funerary pottery. The presence of fragile vessels has also been documented at other necropolises of the Chernyakhov culture; these are usually assumed to have been produced especially for burials. In the context of local pottery production, funerary pottery of this kind does not necessarily differ in material from the other pottery vessels produced. Sample 285, which was lightly fired, is associated with clay type A3. This was the only clay type that was found solely in vessels from the burial field. The other vessels made from this clay type had undergone the normal firing process.

As stated above, as a group, the pottery in Voitenki displays varying degrees of production quality. In all vessel categories there are vessels that were uniformly worked, well turned, and perfectly fired, but also vessels that were poorly shaped or whose overly thick walls in the lower section had had to be cut down to size, or vessels that emerged misshapen from firing under poor firing conditions or had been too thick or betray other errors in production. This reveals the existence of differing quality standards for the vessels and, above all, that the producers were skilled to differing degrees. On the other hand, the range of forms of Chernyakhov pottery reflects a high degree of standardization. The forms of the bowls and vase types, in particular, display a high degree of similarity both within the region under study here and beyond it, in other parts of the culture's area of distribution. These standards for forms must have been somehow communicated. If, as the analyses have shown is the case for the region under study, this communication did not occur through the exchange of pottery, one has to wonder whether the producers themselves were mobile. For instance, specialists may have visited a given place on a seasonal or temporary basis, producing the pottery that was needed from the local raw materials there; at other times settlement inhabitants themselves may have made their own pottery on a smaller-scale. Neither this model nor another model for the organization of pottery production within the economic region under study can be confirmed on the basis of the analyses conducted; further research is required before any such model can be verified.

21 See Ljubičev and Schultze 2011, 390–392.

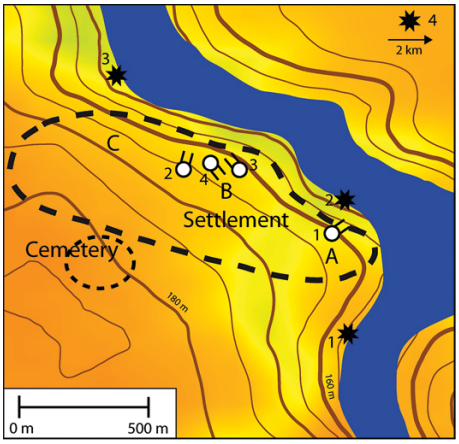
22 Samples 270, 271, and 285.

1



2

Fig. 1 Study area: 1 = Location of Voitenki within the distribution area of Chernyakhovculture and 2 = Study area. Settlements where ceramic samples were taken: 1 = Voitenki; 2 = Vysokopol′e; 3 = Khalimonovka; 4 = Baranovo 3; 5 = Khvorostovo; 6 = Shlyakh 2; 7 = Lozovaya; 8 = Shlyakhove; 9 = Trofimovka; 10 = Gvozdevo, and 11 = Ogul′tsy.



1

2

3

Fig. 2 Voitenki. 1 = settlements with pottery kilns (white dots, with orientation of the firing tunnel) and places where clay samples were taken (black stars), and 2–3 = pottery kiln 2.

Fig. 3 Voitenki. Examples of wheelmade pottery: 1 and 4 = jugs; 2 = bowl form 2; 3 = bowl form 1; 5 and 8 = vases; 6 = beaker; 7 and 9 = pots.

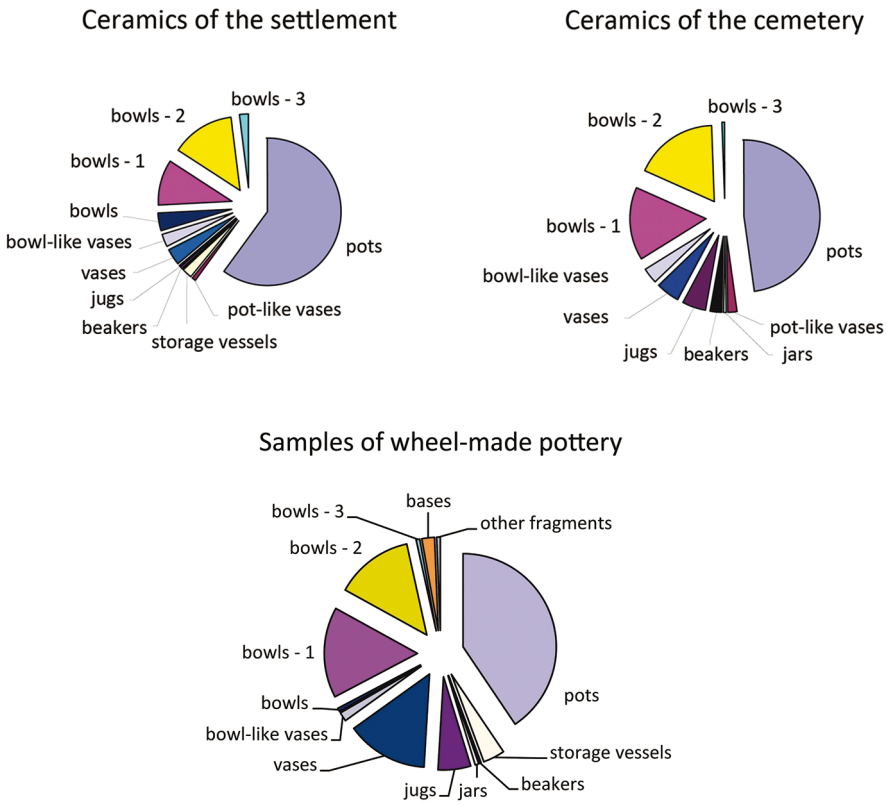


Fig. 4 Voitenki. 1–2 = Occurrence of vessel types on the settlement and cemetery (after the excavations 2004–2009) and 3 = samples of wheelmade pottery.

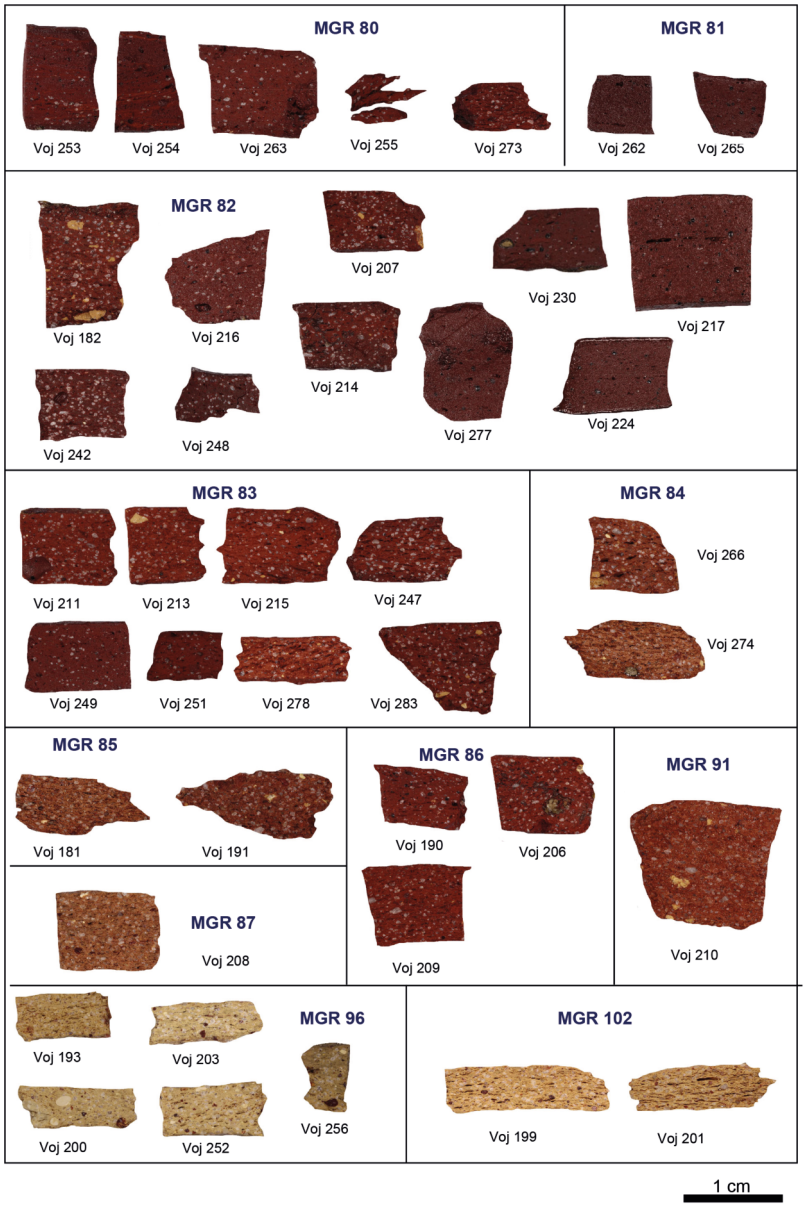


Fig. 5 Pottery fragments refired at 1200° C. Examples of clay types in Voitenki: clay type A1 = MGR 81 and 82, clay type C1 = MGR 80, 83, 85, 86 and 91; clay type C1 mx = MGR 84; clay type C10 = MGR 87; clay type G2 = MGR 96 and clay type G3 = MGR 102. After comparing MGR-analysis, WD-XRF and pCP for the samples, each of the following MGR groups represents a single workshop: MGR 80, 81, 83, 84, 85, 86, 102.

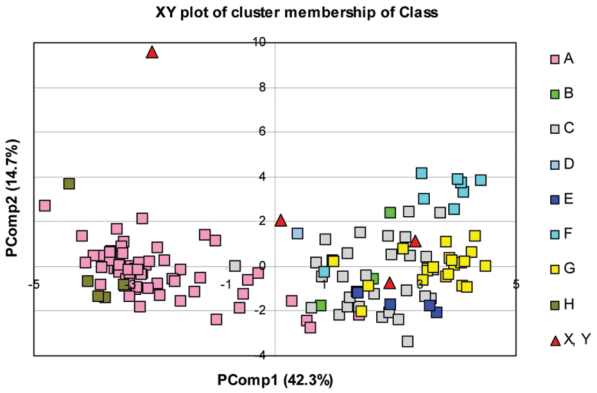


Fig. 6 Principle component analysis of the chemical analysis of the clay type results from Voitenki and the Freiggi. 07n. Occurrence of the clay types in the samples from Voitenki.

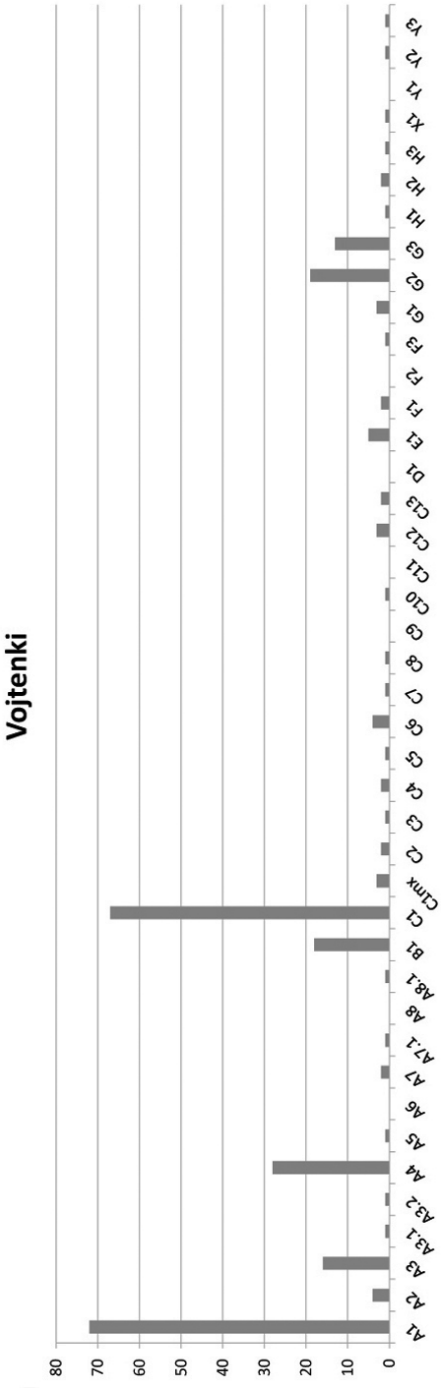


Fig. 7 Voitenki. Occurrence of the clay types in the samples from Voitenki.

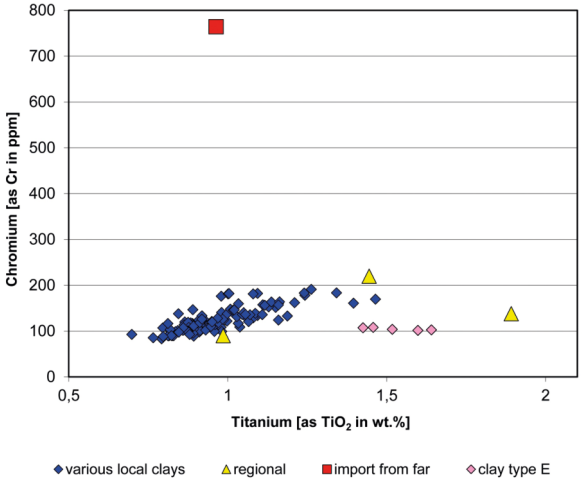


Fig. 8 Bi-plot for chromium vs. titanium for samples from Voitenki and the region.

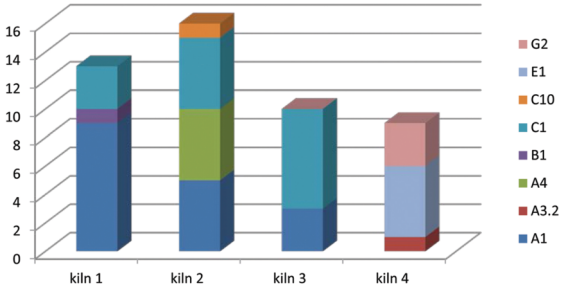


Fig. 9 Occurrence of clay types in the pottery kilns of Voitenki.

Fig. 10 Voitenki. Non-homogeneous ceramic bodies.

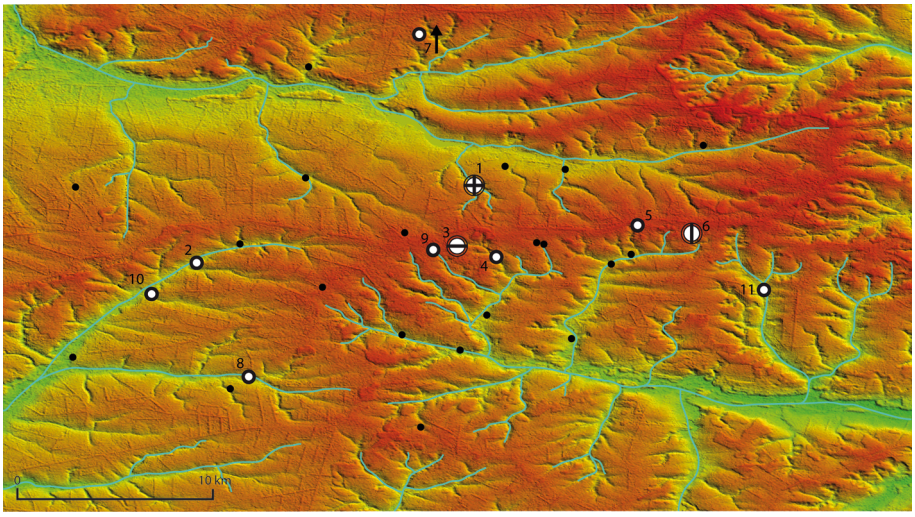


Fig. 11 Map of occurrence of some groups of materials originating from a workshops proved to have been not only in Voitenki, but also in other settlements in the region: vertical bars = MGR-group 2–2.2 (Clay type C1) and horizontal bars = MGR-group 35 (Clay type C4). 1 = Voitenki; 2 = Vysokopol´e; 3 = Khalimonovka, 4 = Baranovo 3; 5 = Khvorostovo; 6 = Shlyakh 2; 7 = Lozovaya; 8 = Shlyakhove; 9 = Trofimovka; 10 = Gvozdevo, and 11 = Ogul´tsy.

4.10 Glass Production of the 3rd and 4th Century AD in Komariv, Ukraine

Hans-Jörg Karlsen and Małgorzata Daszkiewicz

Introduction

The fact that glass finds constitute a group of materials that is very well represented in Barbaricum of the Imperial period notwithstanding, the state of research on them can be described as thoroughly insufficient and is characterized by controversial views. Even glass beads, which make up an extremely extensive material base, encompassing tens of thousands of objects,[1] are the subject of debate: indeed, there is little sign of an emerging consensus even on the question of whether (and if so which) beads arrived in Barbaricum as a popular export item from the Roman Empire, or whether we can assume that 'barbarians' engaged in their own bead production on a greater or lesser scale.[2] However, the indications that glass was in fact processed outside the borders of the Roman Empire, and that this may even have been fairly common,[3] are accumulating rapidly, inevitably raising a whole range of other questions relating to the acquisition of raw materials, the structure and organization of the workshops in question, and the mechanisms involved in the distribution of both the materials used and the products themselves. In addition, questions relating to specific aspects of a possible transfer of technology from the Roman Empire into Barbaricum also need answering. Hence, this project ties in extremely well with the research questions and methods of the 'Economic Space' research group, which focuses on ceramics. The use of a specific formula to make glass means that the material 'glass' holds out extra potential as a source of information that is useful for the localization of production sites and the analysis of distribution

1 As early as in 1985, Tempelmann-Mączyńska 1985, 1, make reference to 35 000 beads.

2 As representative of the diverging views of researchers, see: CRFB D I, 7; Laser 1982, 480; Lund Hansen 2009, 98.

3 Gustavs 1989; Vogt 2002; Bock 2013, 213–214, Fig. 5.

paths, this in comparison to clay deposits, which are, in principle, more readily available and more variable with respect to their chemical composition. On the other hand, glass is recyclable, which means that researchers must always take the issue of further economic circulation into account.

The present project focuses on Komariv (Ukraine), the most well known site in European Barbaricum associated with convincing evidence of autonomous glass production. In the late 3rd century AD (i.e., after the relinquishment of the province of *Dacia*), the settlement lay about 350km (!) from the border of the Roman Empire, but the immediate proximity of the river Tyras (Dniester) offered a connection to the Black Sea that may, hypothetically, have been used (Fig. 1). The excavations conducted back in the 1950s, 1960s, and 1970s yielded sherds of excellently preserved glass and production waste, over 3000 pieces in total, leading the excavators to conclude that there was a glass production site at the settlement. The excavators also uncovered a circular oven made of bricks, which was convincingly interpreted as a glass melting furnace. Specific tools and clay forms used in glass blowing supported the proposition that Komariv was an important center of glass production at a technically advanced level.

Unfortunately, a complete scientific analysis of the site was never published; only the preliminary reports from the excavations were ever released.[4] In many cases, individual finds can no longer be identified with specific find contexts, and even ascertaining the precise location of the old excavation areas has proved something of a challenge. Relaunching investigations at the site, therefore, appeared to be a high priority. The Topoi project has supported the recent excavations,[5] initiated by O. Petrauskas, since 2014, and its researchers have resolutely applied themselves to the analysis of the recent glass finds.

While the earlier excavations conducted in various parts of the settlement area provided glimpses into the site on a small-scale, they yielded no insight into the scope and internal structure of the settlement as a whole. The enormous number of glass finds they discovered provided only initial clues as to the scale of glass processing that went on there. An initial priority was, therefore, to obtain a better understanding of the settlement area as a whole and, in particular, to identify areas where glass production work may have taken place. Given the excellent state of preservation encountered during the earlier excavations, there was reason to expect to find very good preservation conditions at the site again and, thus, to expect correspondingly good results from geomagnetic prospection.

In 2014, it was possible to complete a magnetic survey of the entire part of the settlement lying to the north of the valley of a stream that runs through the site (Fig. 2).

4 Smischko 1964; Schapova 1978.

5 Most recently, Petrauskas 2014.

The survey data represent an area of approximately 9 ha, which appears to be characterized by numerous structures extending into the subsoil and multiple different ovens; the anomalies associated with the latter emerge particularly clearly. The anomalies indicating ovens, which may have been associated with possible glass workshops, are concentrated primarily in the eastern part of the settlement, but these are not particularly great in number. The new surface finds reveal an abundance of glass material, particularly in the area south of the road; it seems very probable that the early excavations with the remnants at issue were located to the north of the road. On the basis of these observations, one can conclude that the glass making was apparently concentrated in this part of the settlement.

Based on these data and the geophysical survey results, initial trial excavations were carried out to uncover the complexes associated with particularly striking anomalies. In addition to investigating the anomalies directly associated with glass production, the recovery of glass samples from these complexes was a major focus of the fieldwork. The intent was to obtain objects from clearly identified and, ideally, datable features, which could then be subjected to chemical analysis. Unfortunately, however, none of the archaeological structures uncovered could be identified as the remains of a manufacturing operation. The complexes yielded numerous glass sherds. However, these were only the fill material of (building) pits associated with the domestic sphere – and hence the finds do not reflect primary usage. Although the multiplicity of finds supports the conclusion that glass processing did take place nearby, the precise location of this processing could not be determined on the basis of the geomagnetic map. Moreover, the trial excavations revealed that the striking geomagnetic anomalies might just as well be potter's kilns – one trail excavation uncovered a well preserved complex including a vent-holed floor. The excellent preservation of the complexes, though, is another indication that conditions will turn out to have been equally good for preservation of the work sites of the glassmakers.

Research questions (objectives and methods)

Unlike the production of pearls, the production of hollow glass required craftsmanship and knowledge that would seem inconceivable without knowledge of Roman glass production. Unlike the western part of European Barbaricum, which has so far yielded evidence only for the production of glass beads from recycled Roman glass,[6] there were clearly glassmakers at work in Komariv whose technical expertise was very advanced. While beads are relatively simple to make, the hollow glassware of the kind produced in

6 Stawiarska 1984, 156; Vogt 2002, 103–104, Tab. 1.

Komariv requires a level of expertise and craftsmanship of its makers that would seem inconceivable in the absence of a correspondingly expert knowledge of Roman glass production. This raises several interesting questions, particularly with regard to the type of knowledge transfer that was involved and the category of people who carried out the glass processing in Komariv. The present project focuses on the following questions and aims, some of which are for the longer term:

1. Did direct personal contacts with the Roman Empire exist, or was a multistage process of knowledge transfer at work? The workshops themselves may be the primary source of answers to this question if, once the relevant complexes have been uncovered, it is possible to determine the degree to which they replicated Roman glass workshop characteristics and work processes.[7] Might perhaps (enslaved) glassmakers from the Mediterranean region have worked there?

2. Another issue of central importance is the procurement of raw materials. As a first step, then, the aim was to determine whether glass production in Komariv relied on raw glass (primary glass)[8] of Roman origin and/or recycled material, or whether the raw glass itself was produced locally or in the region.[9] This determination will also serve as a starting point for the identification of possible 'fingerprints' specific to glass from Komariv. The chemical analysis (WD-XRF) of an initial series of samples has been performed to ascertain the basic potential for future measurements. In addition, the same series was measured using a portable XRF analyzer, to test the suitability of this device for analysis of the chemical composition of glass objects.

3. On the basis of the future analysis of a larger series of samples, the project will seek to identify an assortment of products typical for Komariv. This range will be defined by correlating any chemical groups identified with the results of the typochronological analysis of the glass finds. Ideally, given well dated contexts, it will be possible to differentiate within the production range along the temporal dimension over the period from the 3rd century on into the 5th century. It may even be possible to trace the further distribution paths of the glass products through the interior of Barbaricum through the identification of characteristic products, possibly even at the level of individual batches. This path ultimately leads all the way to the cut-glass glassware preserved in Scandinavian burials.

7 Cf., for instance, Roman glass workshops in Fischer and Peter 2009; Brüggler and Berke 2009.

8 The term primary glass, as used by R. B. Scott and Degryse 2014, 17, seems far more appropriate. Primary glass = raw materials technologically processed into glass that was then transported throughout the Roman Empire to workshops where it was melted and shaped.

9 Rau 1972, 169, refers to all workshops in the eastern part of Barbaricum as "forest huts, other raw material base".

Sampling and analytical procedures

For this reason, surface finds from the current excavations were chosen for the first sample series. The selection was carried out after the finds had been individually examined, with priority given to including the greatest possible range of colors (Fig. 3). The series included some pieces of production debris, as well as sherds from vessels. In total, 23 glass fragments were selected for laboratory analyses by WD-XRF. Subsequently, 17 of these, plus an additional 19 fragments, were measured using pXRF.

When selecting samples for analysis, the condition of the glass fragments was also taken into account and, wherever possible, well preserved specimens were chosen, hence fragments of glass that were not weathered or only slightly weathered. It was decided to forego technological analyses[10] on the first series of samples, and only chemical analysis was carried out. All of the samples underwent chemical composition analysis by WD-XRF. The samples were cleaned mechanically and their outer layers were removed in order to obtain samples of the original glass that were suitable for provenance analysis.[11] Samples were prepared for measurement using the procedure described in chapter 3.2 of this volume, though omitting the estimation of loss on ignition, as this is not relevant to glass material. Glass standards Corning A, B, and D;[12] Schott 1; DGG 2; CRM126B; and VS-N were available for comparison.[13] Measurements by pXRF (**Niton** XRF analyzer, see Daszkiewicz and Schneider chapter 3.2 in this volume) were made on the outer and inner surfaces of each of the 36 samples and on fresh fracture surfaces of seven samples.

10 Technological analysis provides insights into glass quality; for example, the absence of melting defects (e.g. contamination by solid substances) and the lack of gas bubbles indicates that the raw materials were carefully selected, the batch was thoroughly mixed, an appropriate melting temperature was used, and that the glass was melted in a crucible made from suitable materials. Characteristic temperatures can be defined by employing high-temperature microscope analysis, which makes it possible to determine whether the glass had a long or a short working range and whether it was a hard or a soft glass. The range required for forming glass products by hand can be considered. For example, it is possible to determine whether the analyzed glass is a soft glass with a very long working range, meaning that it is suitable for forming glass products by hand at a wide range of temperatures; at the same time, the range of temperatures at which the glass could be worked is low. It was planned to carry out technological analysis during the second phase of this study, which did not go ahead for reasons beyond the authors' control. It would also have been interesting to analyze the glasses' mechanical, thermal and optical properties as well as their chemical resistance, e.g. testing how resistant glass vessels were to the effects of water, weak acids and alkalis (test of functional properties of glass vessels).

11 Cleaning a heavily weathered fragment of glass can result in there being no glass left in it (e.g. Daszkiewicz 2006).

12 Changes to the recommended concentration (Adlington 2017) were taken into account.

13 These are international reference materials representing various types of glass (lead, soda, soda-lime, potassium, and barium glass). In order to choose suitable reference materials, the content of individual elements in them is checked so that calibration is conducted for the full range of predicted concentrations, meaning that if the aim is to analyze samples in which, for example, K content is < 0.5wt.% in one sample and > 20wt.% in another, several reference materials must be used for calibration.

It proved possible to carry out standard preparation and chemical composition analysis by WD-XRF on 15 samples, revealing the concentrations of 24 elements in these samples (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, V, Cr, Ni, Cu, Zn, Rb,[14] Sr, Y, Zr, Sn, Ba, Pb, Co, and Sb). These elements cover all of the main ingredients of a glass batch, i.e. network formers and network modifiers as well as colorants, opacifiers, etc. Eight of the glass samples were so small that they required special preparation;[15] concentrations of Sn, Co, and Sb were not determined for these samples. Table 1 presents the results of chemical composition analysis in percent by weight or ppm for all of the elements determined by WD-XRF or by pXRF.[16] The main components as oxides were subsequently recalculated to 100% (without P_2O_5 content) in order to calculate characteristic chemical coefficients that would allow conclusions to be drawn about the original composition and recipes of the glass batch (Tab. 2). In the next step, concentrations of Na, Mg, Ca, and K (as oxides) were normalized to 100% so that these results could be integrated with the results given in Wedepohl's rhombic diagram.[17]

Results of analysis

The obtained results showed that all of the analyzed samples are soda glasses with a Na_2O concentration of 15–20wt.% (Tab. 1). The potassium and phosphorous contents (K_2O < 0.7wt.%; P_2O_5 < 0.19wt.%), as well as the sodium/potassium ratio (Na_2O/K_2O > 18), clearly indicate that these glasses were melted with natural soda and not with plant ash, and that all of the analyzed glass samples represent one of two varieties of soda glass, i.e. a variety in which K_2O < 1.3wt.% and the Na_2O/K_2O ratio is > 13:1[18] (Tab. 1 and 2). Individual glass varieties can be further subdivided into chemical types of glasses, identified based on concentrations of Al_2O_3, MgO, and CaO. Chemically, glasses from Komariv can be classified as sodium-calcium-aluminium-silica type glasses (Al_2O_3 > 2wt.%, CaO > 3wt.%) and sodium-calcium-silica type glasses (Al_2O_3 < 2wt.%, CaO > 3wt.%). One sample (MD5169) contains 2.8wt.% Pb; however, this does not affect the classification of this glass because the content of lead oxide is much lower than that of sodium oxide.

14 Rb values determined by WD-XRF are around the detection limit, therefore, the results of pXRF are also included in Table1 even if they appear to be systematically too high.

15 Samples of 100mg were melted with lithium tetraborate (Merck Spektromelt A10).

16 Elements not determined by WD-XRF are given pXRF values (in cursive, in red).

17 Wedepohl 2003.

18 The second variety is soda glass in which $K_2O \geq$ 1.3wt.% with a Na_2O/K_2O ratio of < 13:1.

Sources of glass sand

The quartz constituting the dominant component in ancient glass comes from quartz sands of varying purity, which introduced not only SiO_2 into the glass batch but also accessory components. They are evident in chemical composition primarily in the form of Al_2O_3, the content of which can exceed 2wt.%. In concentrations above 0.1wt.%, the following may be present: TiO_2, Fe_2O_3, MgO, and K_2O, as well as MnO and traces of V, Cr, Ni, Rb, Y, Zr, and Ba. Strontium in soda-lime glasses is mainly associated with the lime source (see the following paragraph), but CaO and Sr can occur in sands containing shell (e.g. Belus sand contains 8% CaO).[19] However, optimization of the technological process, which can be achieved by (among other things) maintaining the specific chemical composition of the batch, in the case of soda-lime glasses should involve the use of a three-component batch recipe (quartz-sand + natural soda + calcium) using the purest ingredients possible.

The analyzed glasses were characterized by a varied zirconium (Zr) content (Tab. 1). The concentration of this element in soda-lime glasses made of natural soda is indicative of the source of the quartz sand, hence, it enables the identification of glass from various points of origin (regions or workshops within a particular region). Figure 4 shows Zr content versus Al. The content of these two elements is not correlated in one particular way with the content of Zr in the glasses from Komariv (the same is true of Si and Zr); for example, glasses with the highest Zr content (over 120ppm) also have the highest concentration of Al.[20] Comparing Zr content versus Al_2O_3/SiO_2 ratio yields the same groups of glasses, which also shows that the quartz sand was of various origins. This is additionally indicated by the fact that these were quartz sands contaminated to varying degrees by Al_2O_3 and TiO_2 (Fig. 5). The results allow us to conclude that the analyzed glass fragments from Komariv were made from several different glass sands (groups: KOM 1 to KOM 7).

Sources of soda

Sources of natural soda include the mineral natron ($Na_2CO_3 \cdot 10H_2O$) and the mineral trona ($Na_3H(CO_3)_2 \cdot 2H_2O$). Deposits also contain various amounts of burkeite ($Na_6CO_3.2SO_4$) and halite (NaCl).[21] Natural soda, which is largely associated with deposits in the Wadi Natrun depression (Western Desert, Egypt), was known in ancient

19 Average content in seven samples analyzed by R. H. Brill (Wedepohl 2003).

20 In contrast to, for example, Celtic glasses analyzed by O. Mecking, in which the lower concentrations of Al are correlated with a higher Zr content (Mecking and Seidel 2018).

21 From the perspective of glass technology, the contamination of natural soda with halite has a positive effect: it accelerates the decomposition of carbonates, accelerates melting, reduces viscosity, and makes glass clarification easier (see e.g. Andrusieczko 1972).

Egypt as a cleaning agent and was used in the process of mummification, and later, up until the early medieval period, as a raw material in glass making. How many deposits of natural soda were used in Roman Period? V. Devulder and P. Degryse made the following observation about sources of natural soda for ancient glass production: "Despite geochemical analysis, until now, no scientific evidence existed for the use of either one or multiple sources of natron in ancient glass making".[22] They also stated that:

> The fact that all natron sources from north Africa analysed so far are very similar (to identical) in isotopic composition, and consistent with ancient natron glass, makes placing the source of all flux for natron glass making in this wider area very tempting. The recent discovery of natron deposits in Fezzan, shows that there may be many such sources yet undiscovered in this part of the Roman world. The high potassium content of this particular deposit could also be a promising feature to distinguish possible sources of natron in glass. [23]

One thing is certain in terms of the glass from Komariv: the source of natural soda could not have been deposits rich in potassium (Tab. 1). The variable concentrations of burkeite and halite in natural soda point to the identity of the soda deposit. Bearing in mind the potassium content in natural soda deposits referred to by Devulder and Degryse, the ratio of Na_2O to K_2O content within the glass batch can also be an indicator of the deposit (assuming that K is not a contaminant in the glass sand). Figure 6 shows S/Cl ratio versus Na_2O and P_2O_5 content; groups KOM 2–KOM 6 are characterized by the same S/Cl ratio.[24] One sample of glass (KOM-7) stands out from the remainder. The remaining glass groups do not show a correlation between concentrations of sodium as well as phosphorus and S and Cl. Could it be concluded from this that the natural soda came from various different sources?

Sources of lime

The high ratio of CaO/MgO (Tab. 2) coupled with an MgO content of only up to 1.03wt.% points to a relatively pure source of lime. At the same time, there is a fairly high concentration of Sr in all of the samples (Tab. 1, Fig. 7a). Given that Sr is geochemically correlated with calcium and that the $Sr/CaCO_3$ ratio is an indicator of the origin of limestone, the Sr content for all samples was calculated as the content in pure $CaCO_3$ (Fig. 7b). These values can be compared to the Sr contents of recent carbonates from the

22 Devulder and Degryse 2014, 89.
23 Devulder and Degryse 2014, 89.
24 It was assumed that the entire Cl content is related to the natural soda source; the intentional addition of NaCl seems very unlikely (Cl content is less than 0.12wt.%).

River Belus/Na'amat in Israel, which corresponds to the average value calculated for 373 analyzed Roman glasses (0.38% Sr in 100% $CaCO_3$).[25] Thus, the glasses from Komariv were all made using recent carbonates given that Pleistocene and older limestones have Sr contents below 0.25% (Fig. 7b). The varied Sr/$CaCO_3$ ratio and the varied theoretically calculated Sr content in 100% $CaCO_3$, point to the use of limestone skeletons from a diverse range of organisms.

Sr and Zr contents (Fig. 7b) suggest that for the various groups of Komariv glasses, different (recent) carbonate sources and different sources of sand were used.

Glass color

Glass color depends not only on the type of colorant dissolved in it, which causes the selective absorption of light rays, but also on the type of incident or transmitted light to which it is exposed. In determining the color of the analyzed glass, samples were examined in daylight, at midday, and in sunless conditions.[26] Most of the fragments (13 specimens) are of transparent glass, which is perceived as pale and colorless (white). The following groups were defined optically: colorless, warm white, and whitish-greyish glass (with one greyish fragment). Glass is rendered colorless through a process known as decolorization. Decolorizing glass is part of a technological process aimed at eliminating the color associated with the natural contaminants that occur in raw materials used in glass production. Colorlessness can be achieved by adding a complementary colorant to the batch (this is known as physical decolorization). In cases such as this, decolorization actually involves coloring the glass batch with complementary colorants[27] (complementary colors neutralize one another and cease being perceptible to the human eye). Glass can also be decolorized by adding an oxidizing agent (which is known as chemical decolorization). Natural contaminants in quartz sand used as a raw material for making glass also include colorants such as iron and titanium.[28] In theory, these compounds should be completely eliminated from any glass batch. For example, iron compounds should not be allowed to exceed 0.01%,[29] so that the shade of color is not visible,[30] which in practice, using the natural ingredients that were available to ancient glassmakers, is virtually impossible to achieve. In white glass from Komariv, the iron content, calculated as Fe_2O_3, ranges from 0.42wt.% to 1.39wt.%. Iron is present in the glass batch in the form of ions of both Fe2+ (greenish-blue glass) and Fe3+ (yellow

25 Wedepohl 2003, 15.

26 This roughly corresponds to the light emitted by a black body at 4500°K.

27 For example, for a predominantly yellow batch, the complementary colorant would be navy blue.

28 Titanium gives glass a pale yellow tint but its presence enhances the colorizing effect of iron ions; however, it also enhances the decolorizing effect of manganese.

29 Nowotny 1969.

30 Varieties or shades of color are distinguished within individual color groups (corresponding to specific light wavelength ranges).

glass). This mixture results in a green glass, with the Fe^{2+}/Fe^{3+} ratio affecting the shade of green. Manganese is one of the agents that can be added as a complementary color to counterbalance the color produced by iron ions. Figure 8 shows the relationship between the atomic ratio of Mn/Fe and the concentration of Fe_2O_3. Nine fragments of glass were decolorized by adding Mn compounds to the batch (denoted by yellow circles in Fig. 8).

Two samples have a much lower Mn/Fe atomic ratio, placing them within the range for colored glass. One of the fragments in question is a whitish-greyish glass in which the Fe_2O_3 content is the same as that noted in the aforementioned group of eight samples; however, the concentration of MnO is much lower (Tab. 1), though Cu is present (260ppm) as is a small amount of Pb (341ppm).The second glass fragment (warm white) is characterized by a high concentration of Fe_2O_3 and only a slightly higher concentration of MnO. This glass was also found to contain Cu (282ppm) and Pb (292ppm). The decolorization effect is attributable to the presence of Cu.

Only one fragment of glass has a lower concentration of Mn than of iron (Tab. 1, sample MD5180,105). This is a piece of colorless glass that was decolorized not as a result of adding a complementary colorant, but through the addition of an oxidizing agent. This is the only one of all of the colorless analyzed fragments that has a chemical composition featuring 0.5wt.% of Sb and traces of As (antimony oxides and arsenic oxides are used as oxidizing agents).[31]

Turquoise-blue glass (probably a piece of primary glass) was colored by copper compounds.[32] The color intensity of all greenish/turquoise glasses increases as iron content decreases; the color is related to the concentration of copper. Only one glass features trace amounts of cobalt (Co) and antimony.

Recycling

Glass recycling is the glass technology that converts glass objects and cullet into new objects. Two types of recycling can be taken into account:

- SGT recycling – glass objects are formed from a glass batch of molten glass cullet derived from one type of primary glass (Single-Glass-Type recycling) and

- MGT recycling – glass objects are formed from a glass batch of molten glass cullet derived from various types of primary glass (Multi-Glass-Type recycling).

31 Andrusieczko 1972, 196.

32 Soda glass is bluer because of the presence of copper compounds, while potassium glass is greener.

Generally, recycling of glass will affect the trace element content of a glass batch and can, as such, be detected,[33] but to confirm SGT recycling we need archeological evidence, as the chemical composition of recycled glasses should be the same as that of the primary glass (with the exception of accidental impurities, e.g. of crucibles material). In the case of MGT recycling, which changes in trace element contents are really significant?

According the results of chemical analysis, MGT recycling consisting of mixing SLG[34] glasses with SAG[35] can be excluded for all analyzed glass fragments from Komariv.

For KOM-1 glasses, MGT recycling of primary glasses from Syro-Palestine and Egypt can be excluded, unless such a glass can be found that could be added to the primary glasses to obtain a glass with Al_2O_3 contents < 2wt.%.

To recognize recycling technology, the criteria described by I. C. Freestone[36] were taken into consideration. First of all, no glass fragment analyzed by WD-XRF has a cobalt concentration exceeding the level of cobalt in the Earth's continental crust (24ppm).[37] Only one glass fragment has such high Co contents, the levels in the rest of the samples are < 7ppm (Tab. 1). A significant loss of sodium what could be an indication of reheating was not observed. Contamination by iron (from the equipment used in the workshop) or by potassium, magnesium, and phosphorus from ashes are excluded, except for two samples belonging to KOM-2 group (Tab. 1).

An important indicator of recycling is the joint presence of two decolorization agents (Mn and Sb) in one glass fragment,[38] This is not the case of glass found in Komariv, colorless glass were decolorized either by physical or chemical decolorization but not by both. Only one glass fragment decolorized by Sb belongs to a different glass group (KOM-4) than glasses with Mn or Cu.

Glasses of group KOM-5 have a high Mn content and low Ba contents (less psilomelane than pyrolusite). Glasses of KOM-1 show no correlation of Mn and Ba (ratio Ba/Mn varying from 167 to 500), but this is probably connected to the source of Mn and not to recycling.

One pale green and one pale turquoises glass may be regarded as recycled glasses due to higher Cu and Sb or Pb content (> 100ppm but < 300ppm). However, macroscopically these are homogeneous melted glasses in contrast to the heterogeneous stained glass 650-MD5171 with no indication of recycling in their chemical composition. Pale turquoises glass could be intentionally colored by pieces of glass 332-MD5169, to achieve a pale color; 1g of Cu for 100kg of glass is sufficient.[39]

33 R. B. Scott and Degryse 2014, 24.
34 SLG = soda-lime-glass.
35 SAG = soda-ash-glass.
36 Freestone 2015.
37 Wedepohl, Simon, and Kronz 2011.
38 Freestone 2015.
39 Nowotny 1969. This is only 10ppm of Cu for 100% of glass batch.

Measurements by pXRF

Measurements using pXRF were made on the surface and fresh fractures of samples, in each instance readings were taken from three different spots (see Daszkiewicz and Schneider, chapter 3.2 in this volume). The results of these measurements are subject to limitations arising from the fact that we are dealing with energy-dispersive X-ray fluorescence and from the sampling error associated with the geometry of the samples (quite apart from the problems caused by the weathering of the glass surface).[40] Sodium content cannot be determined by pXRF and magnesium can only be determined generally semi-quantitatively. As a consequence, the rhombic diagram of concentrations of Na, K, Mg, and Ca, which is widely used in the classification of glasses,[41] cannot be applied to the results of pXRF analysis.

Measurements by pXRF were also performed on fresh fractures of seven samples of glass. Figure 9 shows the results of these measurements, as well as the results of WD-XRF analysis (the WD-XRF results have been recalculated to 1). The only significant differences between measurements taken on the surface and on a fresh fracture are observed in the case of Al and K (and P) content.

The pXRF analysis of the glass fragments from Komariv was found to be surprisingly good in terms of sampling precision in the case of SiO_2, CaO, and Sr. The concentration of these elements was determined by pXRF analysis with an average precision (precision of average value) of less than 1%; this means that the analysis precision was good (Fig. 10). Concentrations of Fe_2O_3, MnO (very wide variation in sampling precision), CaO, and Sr were determined with acceptable analysis accuracy (Fig. 10).[42] Unfortunately, the Zr content and Al content, which are important in establishing the provenance of quartz sand, were determined with poor accuracy. Examples of regression curves for Si, Al, Fe, and Ca are shown in Figure 11 using measurements by pXRF and results from WD-XRF analysis.

Although the grouping of the Komariv glasses can be observed in the results of pXRF (Fig. 12), the groups are shifted towards lower Zr contents and the distinctions are much less clear than in the results by WD-XRF (Fig.4). One sample of KOM-7 is a distinct outlier because of its very high Al content (maybe a gross error).

Bearing in mind its limitations, the non-destructive pXRF technique can be used as a pre-classification tool that will help reduce the number of samples selected for more reliable destructive analyses. This technique is particularly useful for classifying glass,

40 See e.g. Hodgkinson 2016; Nagel, Paz, and Behrendt 2018.

41 E.g. Kronz, Simon, and Dodt 2018; Wedepohl 2003.

42 See, for example, Hodgkinson 2016, who used the same equipment for glass analysis. As with pottery analysis (Daszkiewicz and Schneider, chapter 6 of this volume), differences are noted in the accuracy with which specific elements are determined depending on the particular glass analyzed. For example, aluminium and potassium were determined with poor accuracy in the glasses from Komariv.

given the technology involved in coloring and decolorizing glass (see Daszkiewicz and Schneider, chapter 5 of this volume). Additionally, using pXRF in combination with chemical analysis by WD-XRF to analyze the glasses found in Komariv made it possible to determine a greater number of elements (particularly in the case of WD-XRF analysis carried out on samples of 100mg, in which some elements are not determined).

Conclusions

The recipe used for the glass batch from which all 23 analyzed samples were made was a soda recipe, characteristic of ancient glass, in which the batch is prepared using an alkaline raw material (natural soda), pure lime, and quartz sand. In the glass fragments found in Komariv, the ratio of sand content to that of soda is greater than 3:1, which is also typical of ancient glasses.

The analyzed glass fragments represent a variety in which $K_2O < 1.3$wt.% and the Na_2O/K_2O ratio is > 13. The ratios of principal glass forming components (columns 8 and 10 in Tab. 2) in this variety of Roman glasses are mostly between 3.4 and 4.5. [43] All of the analyzed glasses from Komariv conform to these criteria except sample 426 from KOM-2 (see Tab. 2). Figure 13 presents the analyzed samples divided into seven groups of glasses made using various sources of quartz: values showing the ratio of silica content to the sum of components making up the glass batch together with quartz sand[44] are shown on the X axis, and zirconium concentration is shown on the Y axis. Recipe ratios are not correlated with groups of glass sands (except KOM-6). Principal component analysis (Fig. 14; elements used: Si, Ti, Al, Fe, Mg, Ca, Na, K, Sr, and Zr) shows the same relations for the glass sand groups KOM-1–KOM-7.

Glasses made from the same source of quartz sand (and the same recipe) can be further subdivided into groups of glasses featuring various concentrations of strontium (Sr). In this instance, this points to different batches,[45] which can be indicative of different glassworks operating within the same region or of a single glassworks and various glassmakers (i.e. various glass workshops in one production center).

Natural soda is needed to make this type of glass. It is highly unlikely that soda would have been imported to Komariv from North Africa.[46] Is it possible to source natural soda (in quantities sufficient for glass making) somewhere near Komariv? Until this

43 Dekówna 1980.

44 This ratio was calculated for concentrations of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O normalized to 100% (Tab. 2 column 11).

45 Adlington and Freestone 2017 also take into account the concentration of rubidium; in the glasses from Komariv, Rb contents are around the detection limit of routine WD-XRF and values determined by pXRF are probably too imprecise.

46 Transport of natural soda from the mining in North Africa to primary factories in Italy can be taken into account (Devulder and Degryse 2014, 95).

possibility is confirmed, or it is proven that natural soda could have been sourced from somewhere other than North African deposits,[47] we have to assume that production at the glass workshops in Komariv was reliant on imported primary glass products made using several deposits of natural soda.

The results of analysis show that the examined samples of glass were made from seven different glass sands. Does this point to the import of primary glass (raw glasses) from seven different primary glass factories? Or does it illustrate the use of recycling technology?

Regarding the relations of Ca-Na-K-Mg, there is no doubt that the analysis results clearly demonstrate that the glass fragments found in Komariv represent typical Roman soda-lime glasses (Fig. 15). These are glasses of the SLG (LMLK) types.[48]

The diagram in Figure 16 shows a full classification of the 23 fragments of glass found in Komariv.

Final conclusions

The results of this analysis of glasses from Komariv are entirely consistent with the analysis carried out by Biezborodov in the 1960s.[49] We can echo Biezborodov's assertion that the discovery of the glassworks in Komariv shows that glassware that was made during the Roman period in Eastern Europe (i.e. beyond the Roman Empire) using the Roman recipe was produced at local glassworks and not imported. If we accept a model of production[50] in which primary glass was made in a limited number of glassworks and then distributed over long distances in the form of lumps of primary glass (raw glass), the glassware made in Komariv should have the same chemical composition as that of the glass from the primary factory.

This analysis has demonstrated that primary glass of the high iron, manganese, and titanium glass (HIMT) type and Levantine I type[51] was melted and modeled into various shapes at one of the Komariv workshops. This means that Komariv lay within the trade network of the Barbaricum and the Roman Empire.

Figure 17 shows a model of glassware production at the workshops of Komariv.[52] Factories 2–7 denote sources of primary glass from Syro-Palestina or Egypt. In contrary,

47 When looking at sources of natron and trona, we can find the information about the sources e.g. in Czech Republic (see www.mindat.org).

48 LMLK stands for low-magnesia, low-potash glass.

49 Only the content of major elements can be compared as Bezborodow 1965 did not determine the content of trace elements.

50 Freestone, Hughes, and Stapleton 2008.

51 Kom-2 type glass (Levantine I), according to the terminology proposed by Phelps et al. 2016.

52 Modified schema given by Freestone, Hughes, and Stapleton 2008, 31.

factory 1 denotes unknown sources of primary glass[53] or, as some would prefer to see it, local melting of raw materials (similar in composition to Roman glasses found in Colchester).[54]

The writings of ancient authors suggest that primary workshops (factories producing raw glass) probably operated in Syro-Palestine, Egypt, Italy, Gaul, and Spain.[55] Perhaps such workshops also existed in Komariv? The authors of this article hope to be able to answer this question, but to do so requires further archaeological work, as well as isotope analysis (of glassware from Komariv as well as of natural soda sources, for example from the Czech Republic).

53 Group (KOM-1) is characterized by Al_2O_3 < 2wt.%, which excludes a primary origin of these glasses from known Syro-Palestinian or Egypt factories.

54 Baxter, Crummy, and Heyworth 1981.

55 R. B. Scott and Degryse 2014, 17.

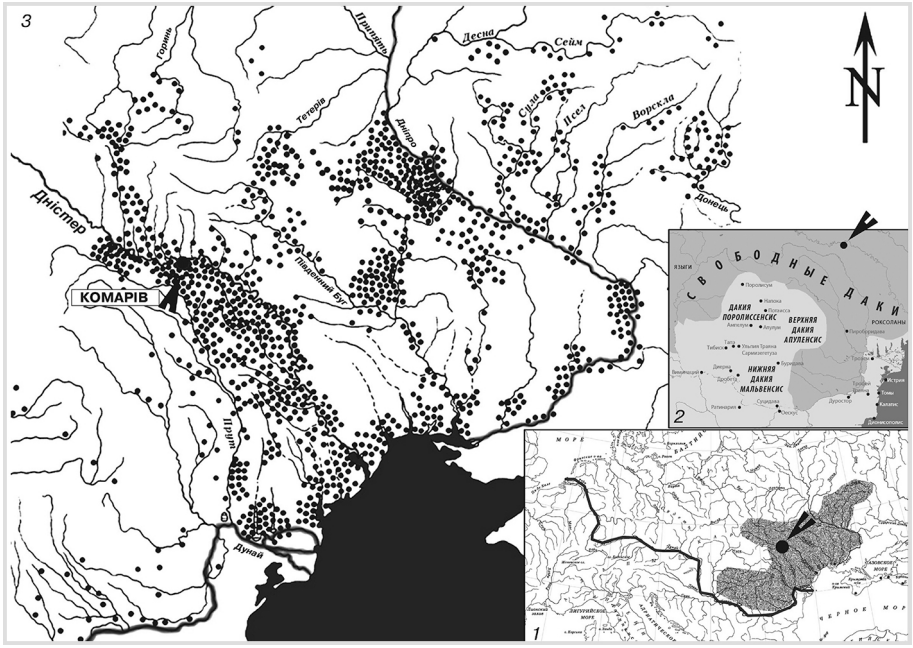


Fig. 1 Localization of Komariv.

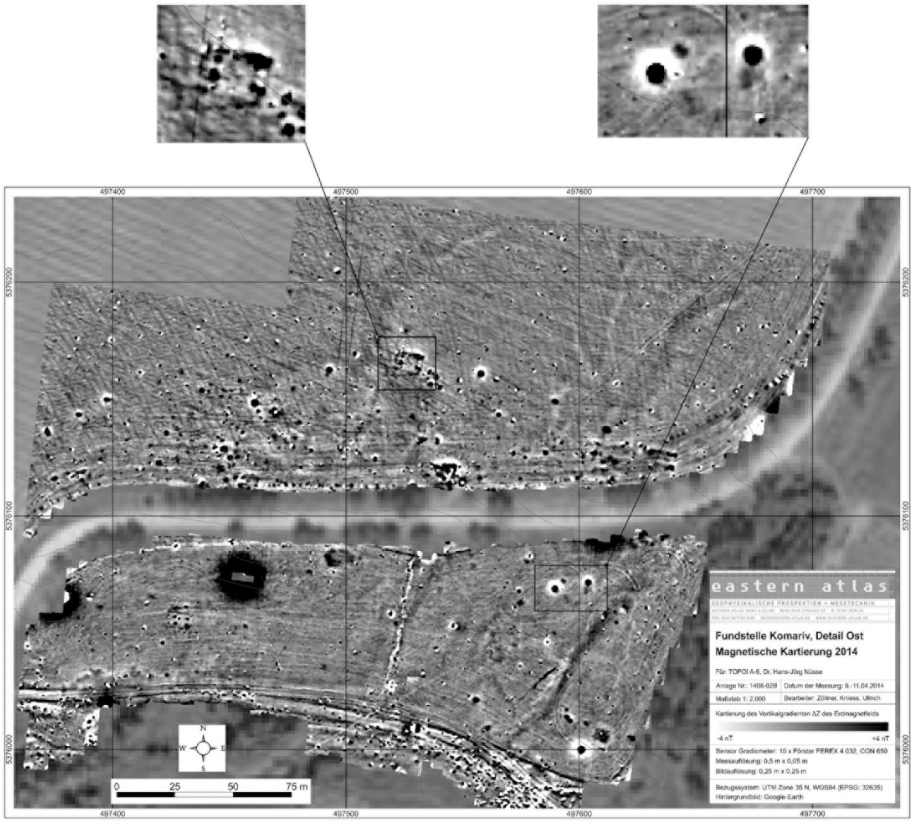


Fig. 2 Magnetic survey of the Komariv site. In larger scale: ovens and a rectangular building.

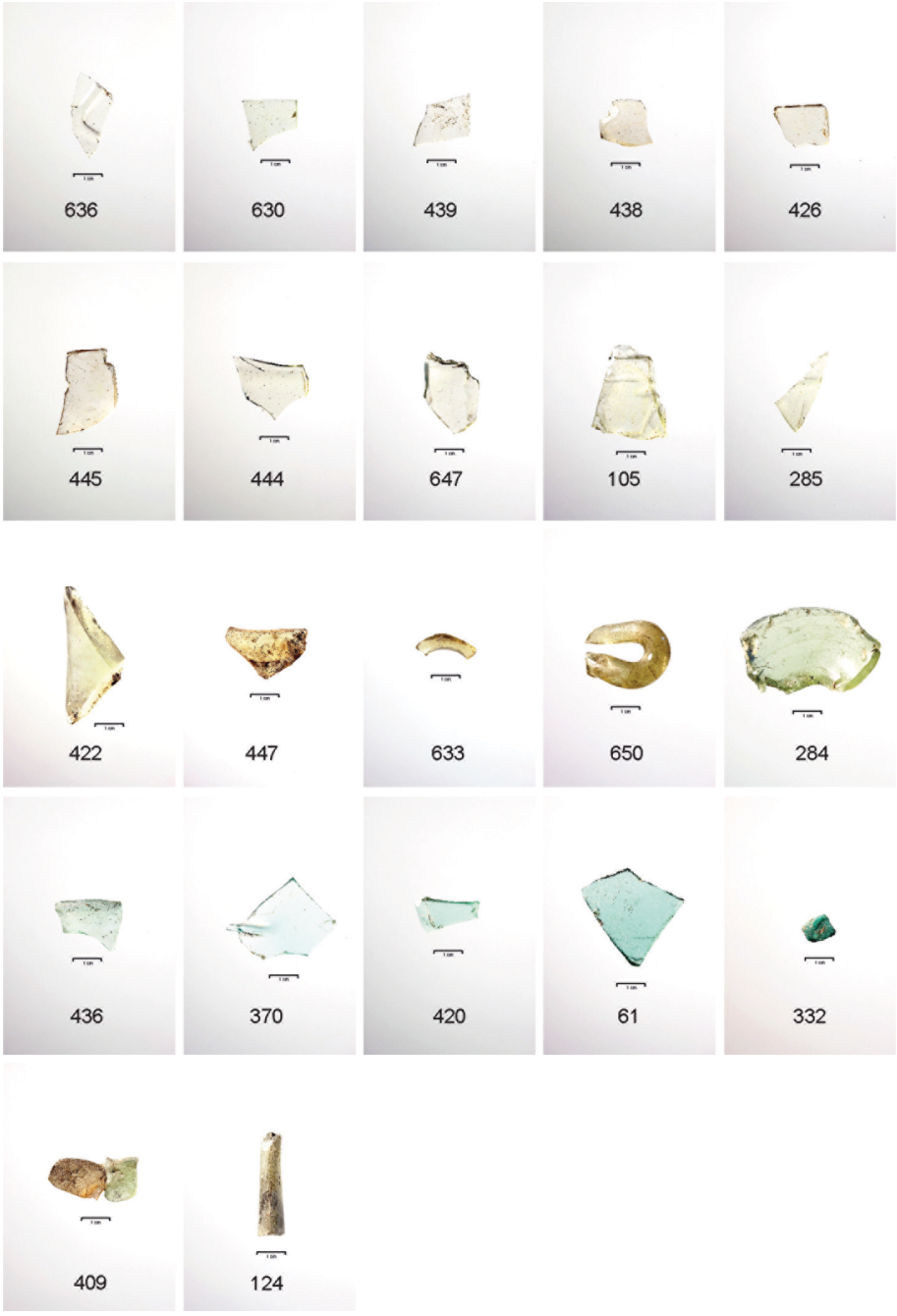


Fig. 3 Analyzed glass fragments.

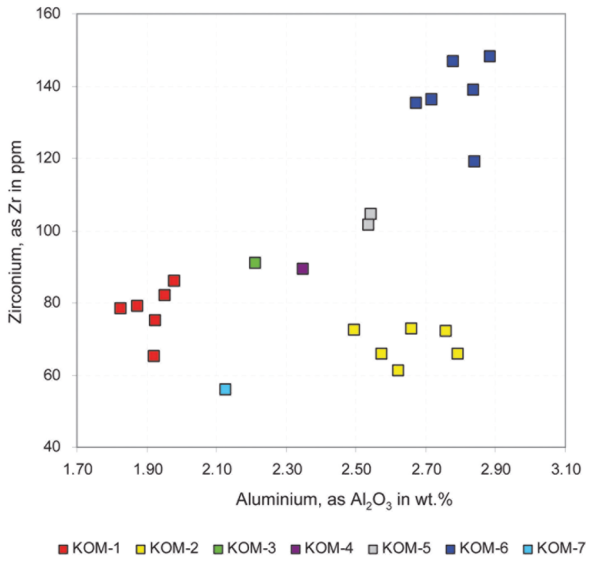


Fig. 4 Zr vs. Al_2O_3 contents of the analyzed glass samples from Komariv, showing seven groups.

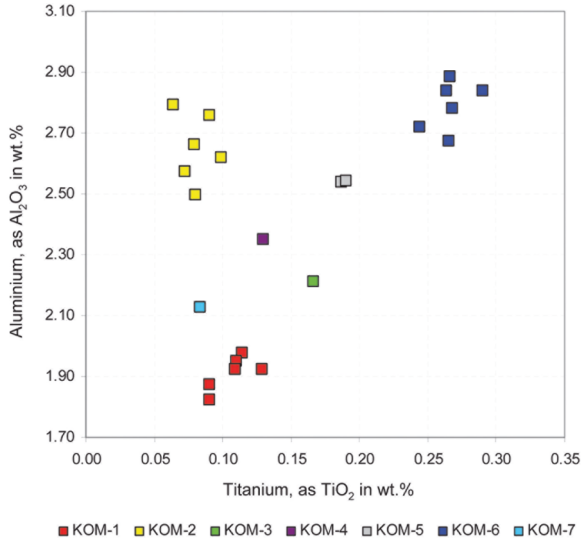


Fig. 5 Al_2O_3 vs. TiO_2 contents of the analyzed glass samples from Komariv, showing seven groups.

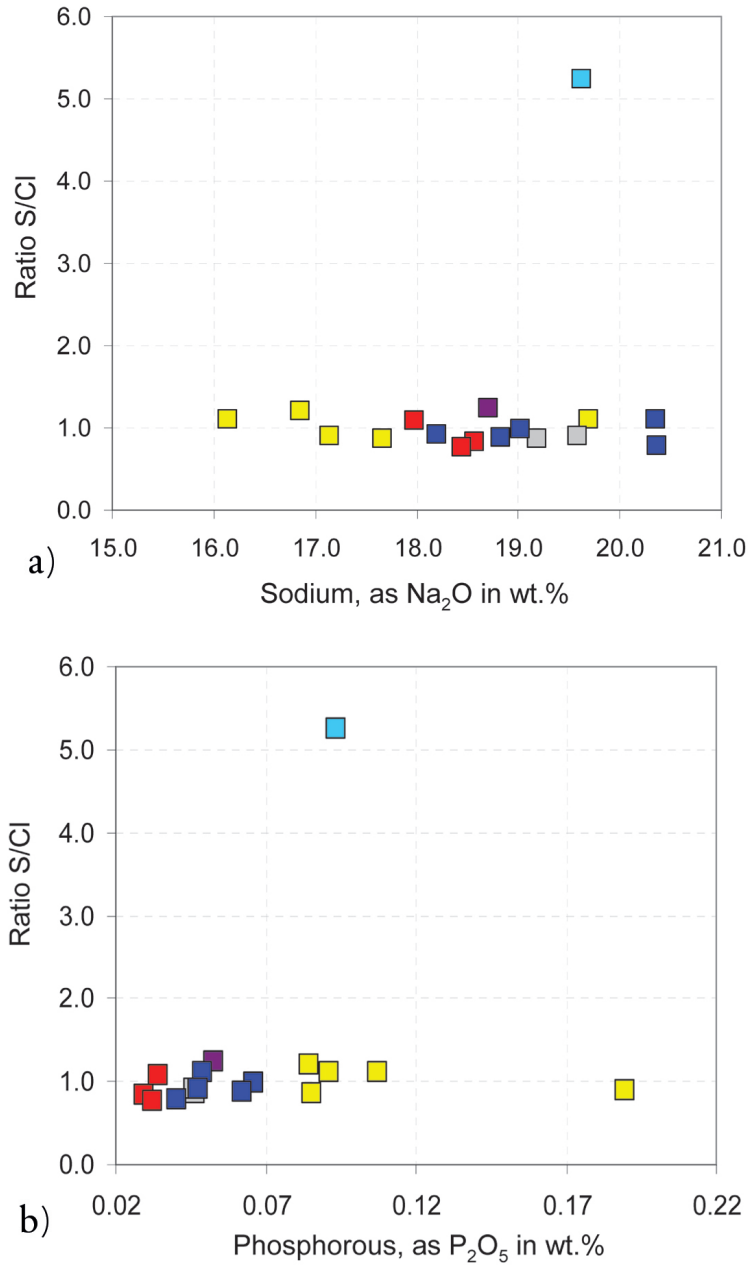


Fig. 6 Ratio S/Cl vs. Na_2O contents (a) and P_2O_5 vs. ratio S/Cl (b) of the analyzed glass samples from Komariv, showing the outstanding value of KOM-7.

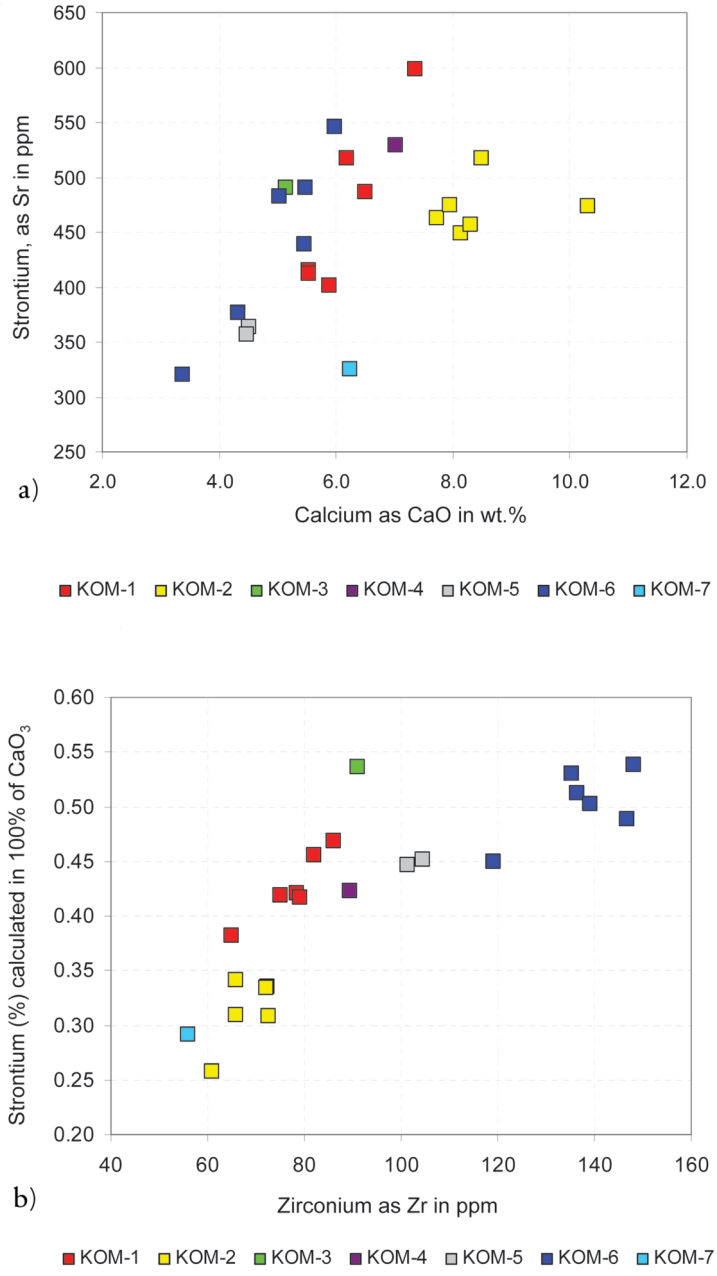


Fig. 7 Sr vs. CaO contents, original values (a); Sr in % calculated for 100% $CaCO_3$ vs. Zr (b). For recent limestones from the Belus River and for 373 Roman Soda-lime glass samples, the average values are 0.38% Sr (Wedepohl 2003, 15), for Pleistocene and older limestones the values are below 0.2%.

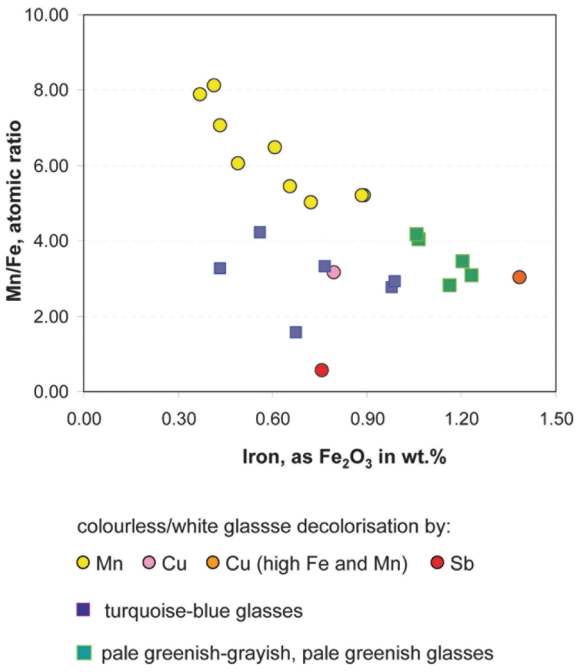


Fig. 8 Atomic ratio Mn/Fe vs.wt % Fe_2O_3. Glass samples of group KOM-2 (yellow circles) are decolorized by Mn.

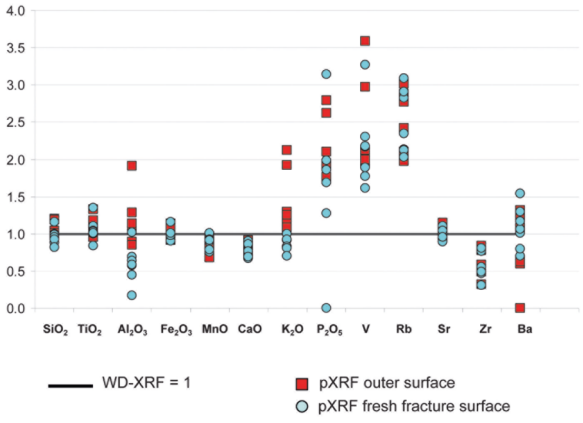
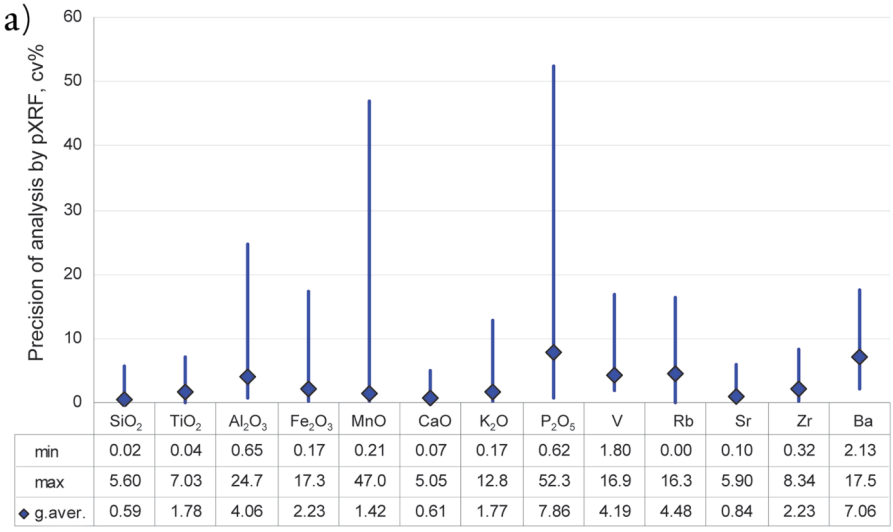
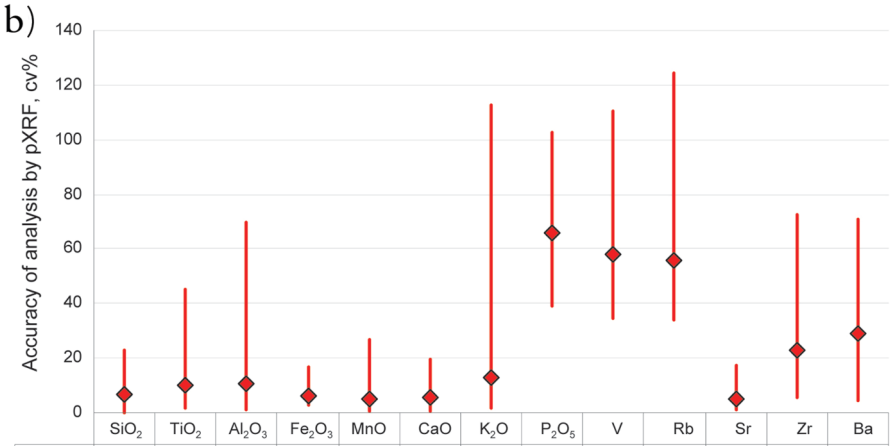


Fig. 9 Results of analysis by pXRF of seven glass samples measured on outer surfaces and on fresh fracture surfaces. Ratios to results by WD-XRF.



	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O_5	V	Rb	Sr	Zr	Ba
min	0.02	0.04	0.65	0.17	0.21	0.07	0.17	0.62	1.80	0.00	0.10	0.32	2.13
max	5.60	7.03	24.7	17.3	47.0	5.05	12.8	52.3	16.9	16.3	5.90	8.34	17.5
◆ g.aver.	0.59	1.78	4.06	2.23	1.42	0.61	1.77	7.86	4.19	4.48	0.84	2.23	7.06



	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O_5	V	Rb	Sr	Zr	Ba
min	0.23	1.64	0.96	2.59	0.53	0.36	1.83	39.1	34.8	34.2	1.39	5.78	4.74
max	23.0	45.4	69.9	16.6	26.6	19.6	112.7	102.4	110.4	124.4	17.4	72.4	71.0
◆ g.aver.	6.44	10.1	10.6	6.16	4.84	5.75	12.6	66.1	57.9	56.0	5.12	23.0	29.2

Fig. 10 a) Precision of analyses by pXRF calculated from repeated measurements of the same sample (n = 36); b) accuracy calculated as differences to WD-XRF results (n = 23). Minimal and maximal cv% and geometric average of cv%.

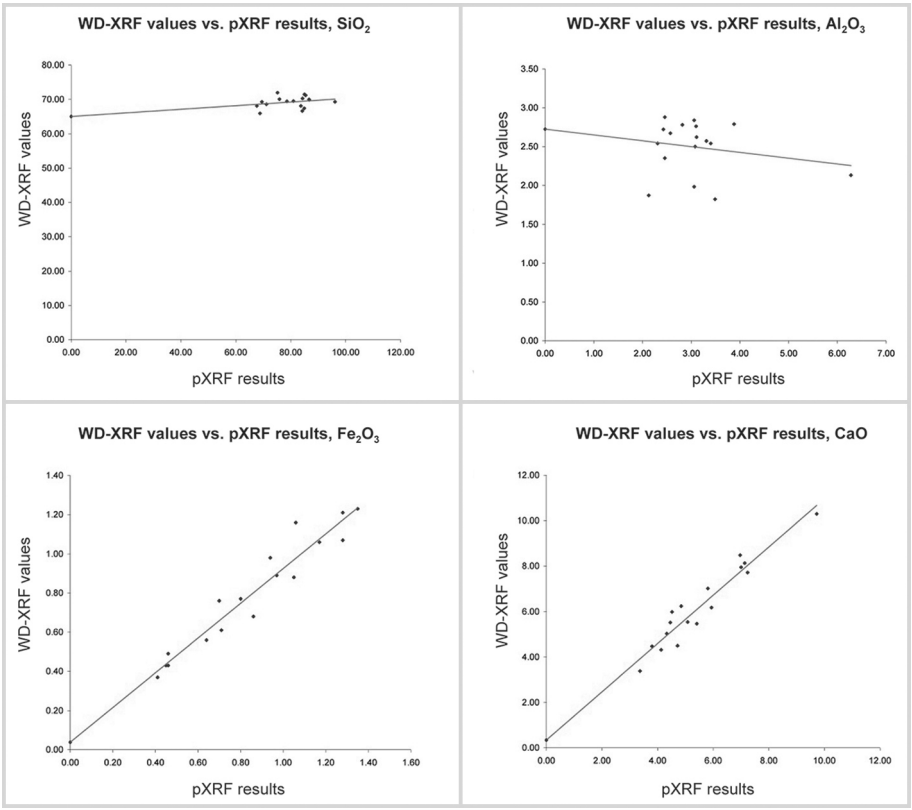


Fig. 11 Diagrams of results by WD-XRF vs. results by pXRF for SiO_2 (R2=0.0639), Al_2O_3 (R2=0.0423), Fe_2O_3 (R2=0.9258), and CaO (R2=0.9149).

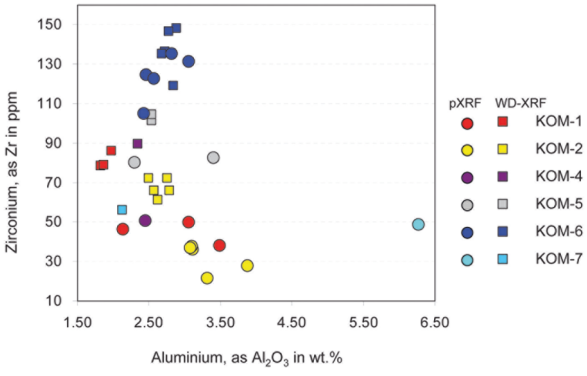


Fig. 12 Zr vs. Al_2O_3 contents measured by pXRF compared to results by WD-XRF (see also Fig. 4).

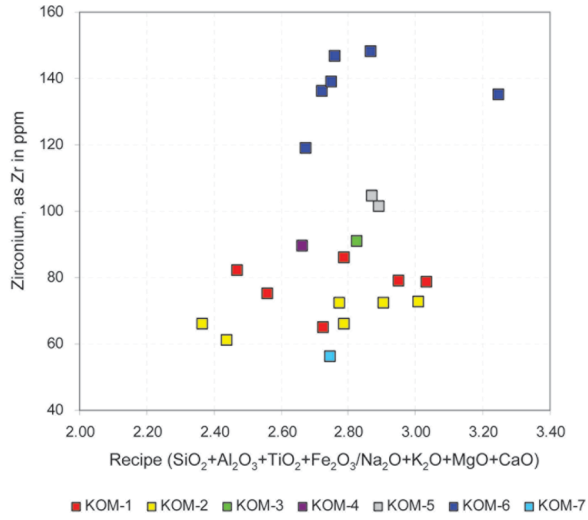


Fig. 13 Zr contents vs. ratio $SiO_2+Al_2O_3+TiO_2+Fe_2O_3 / Na_2O+K_2O+MgO+CaO$ to demonstrate the relation of recipe and sand type.

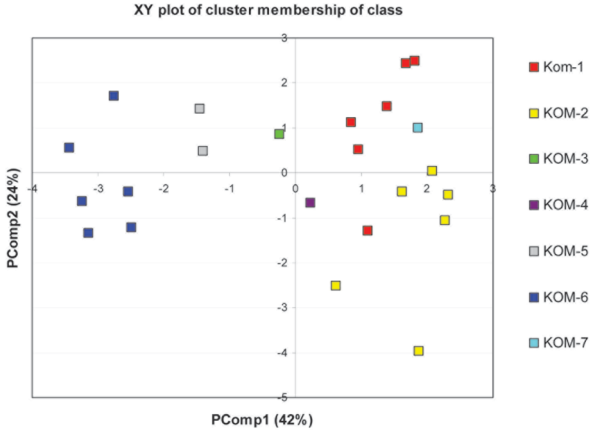


Fig. 14 Principal component analysis of the results of WD-XRF analysis (Si, Ti, Al, Fe, Mg, Ca, Na, K, Sr, and Zr) of glass samples from Komariv.

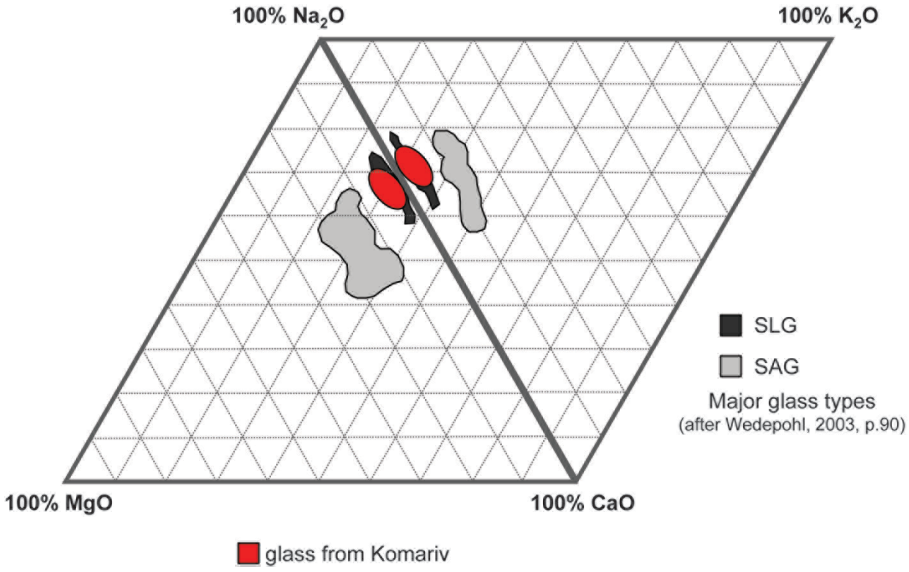


Fig. 15 Chemical composition of the analyzed glasses in the three-component systems Na_2O-K_2O-CaO and Na_2O-CaO-MgO (sum of concentrations calculated to 100%).

Glass type	Glass varaiety	Source of natural soda	chemical characteristic	Source of glass sand	Type of lime Sr-Ca Ca-Mg relations	Recepie	Lab. No.	Decolourisation/ /colour	
soda-lime-glass (SLG)	Al_2O_3 < 2 wt.% sodium-calcium-silica glasses	1	TiO_2 ≤0.13 wt.% Fe_2O_3 0.43-0.79 wt.%	KOM-1	1	1	MD5177	physical decolourisation	Mn
							MD5184		
							MD5182		
					2	2	MD5188		
							MD5191		
							MD5190		Cu, Pb
	Al_2O_3 > 2 wt.% sodium-calcium-aluminium-silica glasses	2	TiO_2 ≤0.10 wt.% Fe_2O_3 0.37-0.98 wt.%	KOM-2	3	3	MD5174	physical decolorisation	Mn
						2	MD5178	turquoise-blue	Fe, Mn,Cu
					4	4	MD5179		
					3	5	MD5181		
							MD5185		
						6	MD5189		
LMLK glasses (natural soda) Na_2O/K_2O > 18:1 K_2O < 1.0 wt.% P_2O_5 < 0.2 wt.% CaO > 3.4 wt.% MgO ≤ 1.0 wt.%		3	TiO_2 ≤0.17 wt.% Fe_2O_3 0.99 wt.%	KOM-3	5	2	MD5187	very pale greenish	Fe. Mn, Cu
			TiO_2 ≤0.13 wt.% Fe_2O_3 0.76 wt.%	KOM-4	6	7	MD5180	chemical decolourisation	Sb, As
			TiO_2 ≤0.19 wt.% Fe_2O_3 0.89 wt.%	KOM-5	7	2	MD5176	physical decolourisation	Mn
							MD5186		
			Fe >1 wt.% Mn > 1 wt.%	KOM-6	8	7	MD5170	pale greenish	Cu, Co, Sb
							MD5171	pale greenish-grayish	Fe, Mn
						1	MD5172		
							MD5173		
						2	MD5175		
							MD5183	physical decolourisation	Cu, Pb
		4	Cu 1.8 wt.%	KOM-7	9	2	MD5169	dark turquoise-blue	Cu, Zn, Pb

Fig. 16 Classification of glasses from Komariv.

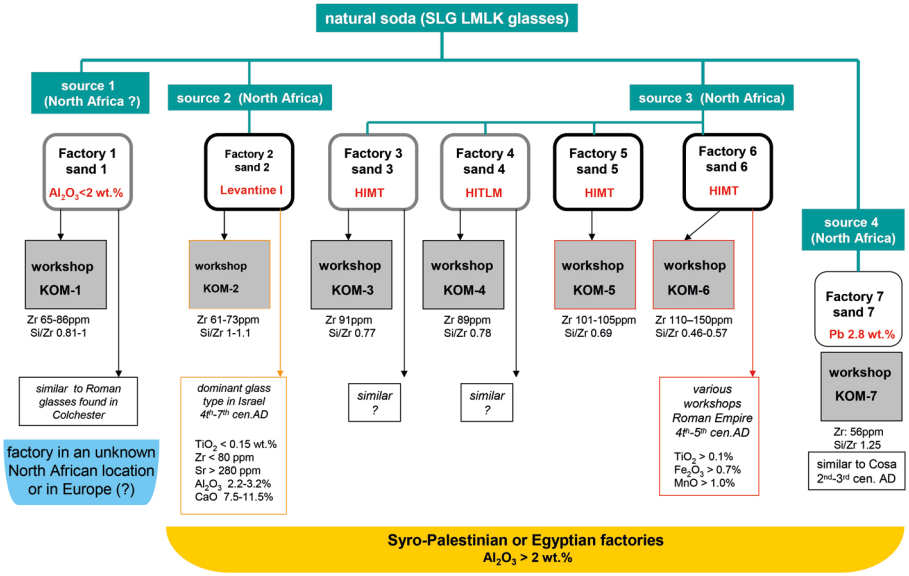


Fig. 17 Provenance of glasses found in Komariv.

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Sn	Ba	Pb	Co	Nb	La	Ce	Mo	Nd	Sb	S	Cl	As	Ag	Cd	Hg	U
		per cent by weight										ppm																		ppm (pXRF)						
KOM-1																																				
422	MD5177	71.99	0.09	1.82	0.49	1.05	0.67	5.52	17.98	0.34	0.03	11	5	14	9	8	6	416	<5	79	23	295	5	<5	nd	<5	9	21	25	20	*553*	*512*	*nd*	*nd*	*nd*	*nd*	*nd*
647	MD5182	69.85	0.11	1.98	0.61	1.40	0.94	6.18	18.57	0.32	0.03	20	8	14	8	9	5	518	<5	86	31	701	<5	<5	<5	<5	12	20	7	16	*873*	*1044*	*nd*	*nd*	*47*	*nd*	*31*
445	MD5184	71.46	0.09	1.87	0.43	1.09	0.71	5.54	18.45	0.32	0.03	16	<5	10	<5	<5	6	412	<5	79	<5	182	6	<5	<5	<5	<5	17	42	<5	*746*	*973*	*nd*	*nd*	*13*	*nd*	*nd*
636	MD5188	68.19	0.13	1.92	0.72	1.29	0.48	6.51	20.40	0.33	0.04	5	14	22	15	6	<5	487	12	75	*na*	337	13	*na*	<5	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
439	MD5190	67.64	0.11	1.95	0.79	0.89	0.40	7.36	20.25	0.54	0.07	12	21	19	260	22	<5	599	14	82	*na*	339	341	*na*	5	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
438	MD5191	69.52	0.11	1.92	0.66	1.27	0.44	5.88	19.82	0.34	0.03	12	<5	23	28	8	<5	401	8	65	*na*	326	20	*na*	5	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
KOM-3																																				
630	MD5187	69.71	0.17	2.21	0.99	1.03	0.52	5.13	19.85	0.36	0.03	11	21	26	59	13	<5	491	18	91	*na*	338	44	*na*	<5	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
kOM-4																														%						
105	MD5180	69.31	0.13	2.35	0.76	0.15	0.93	7.02	18.71	0.59	0.05	10	12	11	18	22	8	529	nd	89	7 / 68	126	21	<5	<5	<5	20	14	11	**0.5**	*712*	*574*	*256*	*nd*	*19*	*nd*	*nd*
KOM-5																																				
447	MD5176	69.43	0.19	2.54	0.89	1.64	0.93	4.48	19.19	0.67	0.05	28	14	16	13	9	7	357	<5	101	36	191	<5	7	<5	6	24	21	27	18	*849*	*983*	*nd*	*nd*	*15*	*nd*	*nd*
444	MD5186	69.29	0.19	2.54	0.88	1.63	0.94	4.50	19.59	0.38	0.05	33	23	14	16	8	6	363	<5	105	<5	193	<5	6	<5	<5	6	17	40	42	*1043*	*1154*	*nd*	*nd*	*22*	*nd*	*42*
KOM-2																																				
124	MD5174	69.55	0.06	2.79	0.37	1.04	0.52	8.13	16.86	0.59	0.08	12	7	11	5	11	9	450	<5	66	<5	304	9	<5	<5	<5	<5	20	12	10	*837*	*700*	*nd*	*nd*	*37*	*nd*	*nd*
61	MD5178	65.91	0.07	2.57	0.98	0.96	0.65	8.48	19.69	0.58	0.11	23	12	16	54	11	8	517	5	66	6	324	<5	<5	<5	<5	21	17	16	<5	*805*	*729*	*5*	*nd*	*7*	*nd*	*nd*
420	MD5179	66.67	0.10	2.62	0.77	0.90	0.39	10.30	17.14	0.92	0.19	8	20	22	60	22	<5	474	7	61	*na/nd*	574	169	*na/nd*	<5	na	na	na	na	*238*	*545*	*605*	*nd*	*nd*	*57*	*79*	*24*
436	MD5181	70.30	0.09	2.76	0.56	0.84	0.80	7.95	16.14	0.46	0.09	27	7	11	10	9	7	474	<5	72	<5	548	7	6	<5	<5	15	15	28	<5	*936*	*844*	*nd*	*nd*	*nd*	*nd*	*nd*
370	MD5185	70.05	0.08	2.50	0.43	0.50	0.53	7.72	17.67	0.42	0.09	9	21	10	39	<5	6	463	<5	72	7	333	8	<5	<5	<5	6	15	7	24	*832*	*964*	*nd*	*nd*	*14*	*nd*	*nd*
426	MD5189	70.93	0.08	2.66	0.42	1.20	0.74	8.29	15.01	0.56	0.11	11	13	15	<5	9	8	457	<5	73	<5	291	8	<5	<5	<5	<5	18	21	<5	*na*	*na*	*na*	*na*	*na*	*na*	*na*
KOM-6																																				
284	MD5170	68.11	0.24	2.72	1.16	1.16	0.97	5.98	19.03	0.56	0.07	26	25	19	102	20	6	547	6	136	<5	380	39	24	<5	<5	17	20	19	163	*701*	*718*	*5*	*nd*	*nd*	*nd*	*nd*
409 a	MD5172	71.23	0.27	2.67	1.06	1.57	1.01	3.38	18.20	0.57	0.05	31	31	17	9	13	8	320	<5	135	<5	301	5	5	<5	<5	8	22	23	44	*921*	*1005*	*nd*	*nd*	*26*	*nd*	*nd*
409 b	MD5173	68.14	0.27	2.78	1.07	1.52	1.01	4.32	20.37	0.48	0.04	32	30	17	9	13	7	377	<5	147	<5	306	<5	6	<5	<5	13	24	27	<5	*898*	*1148*	*<5*	*nd*	*36*	*nd*	*nd*
650	MD5171	68.64	0.27	2.88	1.21	1.47	1.03	5.03	18.84	0.57	0.06	29	30	17	17	26	6	483	5	148	19	318	6	6	<5	<5	24	21	29	<5	*660*	*750*	*5*	*nd*	*nd*	*nd*	*nd*
633	MD5175	67.42	0.26	2.84	1.23	1.35	0.62	5.46	20.35	0.40	0.05	18	33	20	34	14	<5	439	10	119	*na*	315	19	*na*	7	*na*	*na*	*na*	*na*	*na*	*1261*	*1143*	*nd*	*nd*	*19*	*nd*	*72*
285	MD5183	67.69	0.29	2.84	1.39	1.49	0.67	5.48	19.52	0.59	0.06	27	44	35	282	34	<5	491	11	139	*na*	452	292	*na*	7	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
KOM-7															%								%						%	%						
332	MD5169	70.07	0.08	2.13	0.68	0.38	0.19	6.24	19.62	0.51	0.09	14	<5	41	**1,8**	332	<5	325	159	56	*135*	278	**2,8**	*na/nd*	17	*na*	*na*	*na*	*na*	***0.7***	***0.4***	*730*	*nd*	*24*	*6*	*28*	*nd*

Tab. 1 Results of chemical analysis by WD-XRF (powdered, melted samples). nd = not detected, na = not analyzed, and na/nd = not analyzed by WD-XRF and not detected by pXRF. Trace elements contents below 50ppm were measured with poor precision. Elements Co, Sn, Sb, and the elements measured using only pXRF (S, Cl, As, Ag, Cd, Hg, and U) may be regarded as semiquantitative. Preparation of samples for analysis carried out in ARCHEA, Warsaw, measurements using a PANnalytical AXIOS XRF-spectrometer and the calibration of ArbeitsgruppeArchaeometrie by G. Schneider (measurements courtesy of A. Schleicher in Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum GFZ, Sektion 4.2, Anorganische und Isotopengeochemie).

Sample No.	Lab. No.	Ratio														Al_2O_3
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	wt.%
KOM-1																
422	MD5177	52.74	18.32	8.22	6.20	18.72	13.70	74.42	4.06	4.06	4.39	3.03	0.47	0.92	0.043	1.83
647	MD5182	57.18	18.90	6.61	7.12	19.57	12.23	72.57	3.83	3.84	4.21	2.79	0.44	0.81	0.031	1.98
445	MD5184	57.25	18.78	7.75	6.26	19.23	13.62	73.88	3.93	3.94	4.26	2.95	0.40	0.90	0.028	1.87
636	MD5188	61.74	20.73	13.59	6.99	20.93	10.96	70.99	3.42	3.42	3.75	2.56	0.56	0.91	0.144	1.93
439	MD5190	37.83	20.80	18.40	7.76	20.74	9.59	70.54	3.39	3.39	3.76	2.47	0.89	0.83	0.066	1.95
438	MD5191	57.68	20.17	13.37	6.32	20.33	12.26	72.23	3.57	3.58	3.89	2.73	0.52	1.07	0.055	1.92
KOM-2																
124	MD5174	28.44	17.46	15.56	8.66	17.47	9.08	72.84	4.17	4.17	4.66	2.79	0.36	1.06	0.032	2.80
61	MD5178	34.23	20.29	13.13	9.14	20.43	8.42	69.61	3.43	3.43	3.88	2.37	1.02	1.00	0.042	2.58
420	MD5179	18.62	18.10	26.67	10.71	17.65	6.86	70.29	3.88	3.88	4.47	2.44	0.85	1.10	0.096	2.63
436	MD5181	34.98	16.61	9.91	8.76	17.01	9.64	73.78	4.44	4.44	4.96	2.91	0.67	0.97	0.021	2.76
370	MD5185	41.79	18.11	14.47	8.26	18.27	9.61	73.13	4.03	4.04	4.49	2.77	0.86	0.97	0.047	2.50
426	MD5189	26.89	15.59	11.19	9.04	15.84	9.29	74.16	4.75	4.76	5.33	3.01	0.35	0.98	0.037	2.66
KOM-3																
630	MD5187	55.07	20.21	9.88	5.65	20.44	14.10	73.10	3.61	3.62	3.89	2.83	0.96	0.77	0.090	2.21
KOM-4																
105	MD5180	31.86	19.30	7.53	7.95	19.73	10.81	72.59	3.75	3.76	4.17	2.66	4.97	0.78	0.080	2.35
KOM-5																
447	MD5176	28.76	19.87	4.82	5.41	20.28	16.43	73.08	3.67	3.68	3.94	2.89	0.54	0.69	0.032	2.54
444	MD5186	51.26	19.98	4.82	5.44	20.61	16.32	72.95	3.64	3.65	3.91	2.87	0.54	0.66	0.027	2.54
KOM-6																
284	MD5170	33.88	19.60	6.14	6.96	20.11	12.37	72.28	3.67	3.69	4.03	2.72	1.00	0.50	0.045	2.72
650	MD5171	32.88	19.42	4.90	6.05	19.99	14.68	73.05	3.75	3.76	4.06	2.87	0.82	0.46	0.042	2.89
409 a	MD5172	32.16	18.77	3.36	4.39	19.38	22.06	75.27	4.00	4.01	4.23	3.25	0.68	0.53	0.034	2.68
409 b	MD5173	42.72	20.86	4.26	5.34	21.50	16.78	72.28	3.45	3.47	3.71	2.76	0.70	0.46	0.034	2.78
633	MD5175	50.98	20.76	8.77	6.09	21.06	12.97	71.80	3.45	3.46	3.74	2.67	0.91	0.57	0.069	2.84
285	MD5183	33.30	20.12	8.22	6.15	20.31	13.03	72.24	3.58	3.59	3.88	2.75	0.93	0.49	0.051	2.84
KOM-7																
332	MD5169	38.21	20.16	32.98	6.44	19.92	11.41	73.03	3.62	3.62	3.94	2.75	1.79	1.25	0.048	2.13

1 = Na_2O/K_2O
2 = Na_2O+K_2O
3 = CaO/MgO
4 = CaO + MgO
5 = $Na_2O+K_2O/CaO+MgO$
6 = $SiO_2/CaO+MgO$
7 = $SiO_2+Al_2O_3+Fe_2O_3+TiO_2$
8 = $SiO_2+Al_2O_3+Fe_2O_3/Na_2O+K_2O$
9 = $SiO_2+Al_2O_3+Fe_2O_3+TiO_2/Na_2O+K_2O$
10 = $SiO_2+Al_2O_3+CaO+MgO+Fe_2O_3/Na_2O+K_2O$
11 = $SiO_2+Al_2O_3+Fe_2O_3+TiO_2/Na_2O+K_2O+CaO+MgO$
12 = Fe_2O_3/MnO
13 = SiO_2/Zr
14 = Fe_2O_3/V

Tab. 2 Characteristic glass components and ratios (can be calculated from WD-XRF, but not from pXRF values), all components recalculated to a sum of 100%.

5 Analysis and Strategies

Małgorzata Daszkiewicz, Gerwulf Schneider

The majority of laboratory studies conducted for Topoi 2 projects were MGR-analysis, measurement by pXRF, and chemical analysis by WD-XRF (see chapter 3 of this volume). MGR-analysis was carried out on 1795 pottery samples.[1] This included abridged MGR-analysis (a-MGR), full MGR-analysis (f-MGR), and structural-textural MGR-analysis (st-MGR).[2] Abridged MGR-analysis is usually used to determine matrix type, and refiring should be carried out at three temperatures. In the case of the various Topoi 2 projects, this analysis was prompted by matrix classification, and its results yielded additional, unexpected information about the technological process.

Structural-textural MGR-analysis[3] was performed on two sherds as part of the Vojtenki project and four sherds from the Corneşti-Iarcuri project. Both f-MGR and st-MGR-analysis was undertaken in order to determine original firing temperatures (Teq). pXRF measurements were made of 2729 samples. Chemical analysis by WD-XRF was performed altogether on 1366 samples, including raw materials and glass samples (all analyses results are given in the table in the appendix). Estimation of physical ceramic properties (open porosity, water absorption, and apparent density) was carried out for 354 sherds. Other analyses were performed on only a small number of samples (Table 1). The conclusions drawn from these analysis results are presented individually for each project (chapter 4 of this volume). Some of the analyses (e.g. analysis of mechanical and functional properties), in particular the model tests, were funded as part of a collaboration with the Warsaw University of Technology.[4]

1 Additionally, firing tests for clay samples were done (the number of specimens is listed in Table 1 under aMGR-specimens).

2 The sum total of samples includes 230 ceramic samples from the NORD-SYRIEN project that were examined using a-MGR-analysis funded by the Hochschule für Technik und Wirtschaft Berlin (University of Applied Sciences) Berlin.

3 As part of a collaboration with Warsaw University of Technology, st-MGR-analysis was carried out on four samples recovered from Corneşti-Iarcuri.

4 Cooperation with Ewa Bobryk of the Advanced Ceramic Team (Warsaw University of Technology Faculty of Chemistry).

Chapter	Name of project	Number of samples measured by pXRF	Analysis												
			a MGR		WD-XRF	pCP	TG-DTA	XRD	f MGR	t-s	SEM	st-MGR	KH	macro	FTR
			samples	specimens	number of samples										
4.1	**Iran (Tepe Sohz)**	53	72	263	133										
	Nord-Syrien	64	304	1211	142										
4.3	**Musawwarat**	36	285	930	267	64		41	14		5		32		
	Musawwarat clay			841	79			68							
4.4	**Petra**	38	32	128	17	39				5	2				
4.5	**Corneşti**	496	312	1062	135	111	10	10	16	15	1	4		69	
	Corneşti clay	44	44	606	7										
4.6	**Lossow**	465	241	964	227	128				20				185	
	Lossow clay	5	15	60	14										
4.7	**Brandenburg**	661	320	1116	172				1				31		
4.8	**Olbia**	285	217	638	42										
	Olbia clay	3	3	12	3						3				
4.9	**Vojtenki**	308	305	1220	136					15		2			3
	Vojtenki clay		14	64	14										
4.10	**Komariv**	22			22			2							
	SUM	**1819**	**2166**	**9097**	**1413**	**342**	**10**	**121**	**31**	**55**	**11**	**6**	**63**	**254**	**3**

Tab. 1 Types and numbers of analyses of the different projects.

Workshops, batches, and runs

Performing three types of analysis (MGR and WD-XRF analysis, as well as an estimation of physical ceramic properties) has enabled us to bolster our interpretation of the term 'workshop'. Sherds attributed to the same MGR-group, the same clastic material group, and which also share the same chemical composition can be assumed to have come from the same workshop.[5] The same MGR-group means that the ceramic body was made using the same plastic material; the same clastic material group means that the ceramic body was made using the same non-plastic ingredients. Therefore, it seems indisputable that pottery made using a ceramic body composed of the same plastic material, the same non-plastic ingredients (type, amount, grain size, sorting, and roundness), and prepared in the same manner must have been produced at the same workshop.

This is a very narrow definition of workshop, as a place where one or several persons are working using the same raw material, recipe, and facilities. At the same place in the same or in another time there could have been another workshop, if we keep the definition of using a certain recipe (corresponding to a certain MGR-group). This follows the

5 An example from ethno-ceramic studies in Mexico conducted by M. Daszkiewicz and G. Schneider has shown that pottery in one village made at three different workshops by potters taking clay from the same outcrop, around 10 m apart from one another, differed significantly in chemical and phase composition, as well as in physical ceramic properties and functional properties. Within one workshop all parameters were constant, at least for the products of one year (project together with Sandra Lopez Varela).

idea that we can recognize an ancient workshop only in what we can see in our analysis results.

Some of the samples analyzed for the Topoi 2 A-6 project were made from the same batch of ceramic body if they share the same MGR-group and an identical chemical composition (within the frame of the analytical precision), which is unlikely to be random (Fig. 1, project: Brandenburg-Sachsen). In case the sherds also share the same firing temperature and the same ceramic properties they had been made in the same production run (or they must be fragments of the same vessel). Examples of this include the two sherds of MGR-3 and very probably the two sherds of MGR-14 in Figure 2, which must have been produced at two different workshops in Corneşti-Iarcuri. Figure 3 shows a series of five sherds produced in one workshop in Lossow (MGR-Lss 2) and five sherds that were produced in another workshop (MGR-Lss 51). The two groups not only differ significantly in composition but also in the ceramic properties.

Although we can say that sherds made from the same ceramic body were produced at the same workshop, it is far more difficult to determine how many types of clay were used in any single workshop. Thus, several workshops identified on the basis of MGR and WD-XRF analysis results and on the identification of physical ceramic properties, may in reality represent various ceramic bodies prepared at a single workshop. However, in these cases, there should be a correlation with vessel type/function. An example of various clays being used at the same workshop – and not to produce various types of vessels, but to make a single vessel – is provided by pottery analyzed as part of the Brandenburg-Sachsen project. Figure 4 shows a base sherd after refiring at 1200°C. Two different clay types are clearly visible: the basic raw material is a clay which is melted at 1200° (over-melted matrix type, part a on Fig. 4), while the underside of the base is reinforced with a strip of clay (part b on Fig. 4) that has an over-fired matrix type (it means a greater thermal resistance). Adding this strip of clay saved the base of the vessel from becoming deformed (preventing its collapse). However, this raises the question of why clay b wasn't used for the whole vessel. Perhaps this was a one-off vessel made from a different clay as part of raw material testing and this is why it is the only sherd representing MGR-group 57. There are no matches to either clay a or clay b among the remaining samples.

In terms of research methodology, another interesting example showing the use of two raw materials is provided by sample GLIE001 from the Brandenburg-Sachsen project (Fig. 5). The sample to be taken from this sherd before was marked with a strip of adhesive tape (AD813). As it seemed that this fragment was too small to make WD-XRF and MGR-analysis, a second sample of the same sherd (a part which matched with the part from where AD813 was taken) was analyzed, yielding different results in MGR-analysis. Refiring of the whole available cross section showed that the vessel was made by using coils of somewhat different clays (AD944 differs from AD945, which has the same

thermal behavior as AD813). The ceramic bodies from which these coils were made are characterized by varying thermal expansion – cracks are visible at the coil junctures. Given how the coils are stacked, it appears that this vessel was produced on a potter's wheel and that the coils were joined using kinetic rotation energy. However, a vessel made in this manner cannot be classified as wheel thrown.

Special experiences from various projects

The TEPE-SOHZ Project (see chapter 4.1)

After analysis of the first series of suspected local pottery showing a very limited variability, it was difficult to distinguish groups either by MGR or by WD-XRF. The local pottery came only to be clear after the analysis of pottery fragments found at other sites from the region, showing clear differences from the local pottery at Tepe Sohz (Fig. 6).

The NORTHERN SYRIA Project

This project is not included as a chapter in this book and will be published elsewhere.[6] The special experiences from this project, however, will be discussed here.

The generally very small chemical differences in chemical composition must be secured using MGR-analysis to establish groups representing different workshops. Even the quite clear differences of samples refired at 1050°C (first row in Fig. 7) or at 1200°C (second row) cannot easily be recognized in the chemical data from WD-XRF analysis. pXRF is not helpful in this case because of the small chemical differences, especially as magnesium and sodium are not determinable. This problem is common in calcareous pottery, as it is common in Mesopotamia.[7] If we compare the small chemical differences in calcareous pottery with the differences, e.g. in the non-calcareous pottery from Lossow (Fig. 3), it is clear that a general statement about the acceptable variation within one workshop (MGR-group) cannot be made.

An additional problem can influence the value of the important calcium content. This is an alteration effect of leaching calcite from the sherd during burial in the ground. Such alteration effects can only be seen in refired fragments (Fig. 8), which must be considered when taking samples and interpreting differences in calcium contents.

6 For short information see Höhne (ehemals Hofmann) 2021.

7 Daszkiewicz, van Ess, and G. Schneider 2012.

The Amarna Project (see chapter 4.2)

There is one note to make for this project: it is very important that analyses are made in a laboratory in which analyses of the ceramics to be compared for provenance determination have already made. This saves a lot of work and is more important than the analytical method used when precision and accuracy are comparable, as is the case with the analyses by NAA in Bonn (M. Mommsen).

The MUSAWWARAT Project (see chapter 4.3)

In the case of this project, the first step was a test of pXRF measurements done on 22 samples from 4th cataract in Sudan, representing various fabric types. It was supposed that pXRF measurements could be used to distinguish pottery made from alluvial and from wadi clay. This was possible to answer, but using existing reference groups to tell about provenances failed because of the low precision and accuracy of pXRF and the missing data of contents of magnesium and sodium. This can be seen in the data of WD-XRF analysis in Table 2, where the differences between questionable samples are too small to be significantly recognized by pXRF. Therefore, the whole project was later based on MGR-analysis and WD-XRF analysis.

The so-called Musawwarat fabric hypothetically was found at many sites, but this macroscopic identification does not in reality indicate imports from Musawwarat as can be highlighted in two examples: one sherd found in Abu Erteila and one found in Musawwarat could not be distinguished macroscopically, but they clearly differ in thermal behavior (Fig. 9) and chemical composition by WD-XRF. On the other hand, samples of imports in Musawwarat are recognized also at other sites both by MGR-analysis (Fig. 9) and chemical composition by WD-XRF.

The PETRA Project (see chapter 4.4)

The very thin-walled samples were measured by pXRF, mostly on the unpainted outer surfaces after cleaning in a 20% solution of acetic acid to remove calcite impurities. These data corresponded more or less to analysis by WD-XRF and distinguished two chronological phases. An unexpected result was that the outer surfaces showed elevated calcium and sulfur contents, probably due to forming the shallow bowls in gypsum molds (Fig. 10), which was an unexpected argument for the use of concave molds.

Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	(Cu)	Zn	Rb	Sr	Y	Zr	(Nb)	Ba	(La	Ce	Pb)	l.o.i.
	per cent by weight										parts per minute														%
AD216	65.86	1.463	15.10	8.09	0.119	2.38	3.17	1.51	1.91	0.40	152	136	58	46	86	46	290	30	326	21	504	32	58	9	4.00
AD621	66.99	1.578	14.48	8.56	0.12	2.26	3.24	1.13	1.36	0.27	148	140	69	49	84	40	304	36	302	25	647	29	63	9	2.77
AD218	67.30	1.403	16.77	8.31	0.088	1.49	2.14	0.94	1.31	0.27	142	107	54	42	65	30	206	54	286	13	364	45	97	7	2.91
AD505	66.59	1.429	16.67	8.57	0.097	1.45	3.00	0.84	1.12	0.24	139	114	52	44	61	24	294	56	263	20	629	48	100	5	3.36

Tab. 2 Examples of WD-XRF analyses from project Musawwarat: AD216 = sample found in Wad Ben Naga, AD621 = import in Musawwarat of the same provenance as AD216 (see Fig. 9); AD218 = sample found in Wad Ben Naga, and AD505 = sample found in Abu Erteila of the same provenance as AD218.

The CORNEŞTI Project (see chapter 4.5)

The chemical composition of 496 sherds recovered from eight sites in the Banat region was determined using pXRF as a first step. This was followed by step-by-step classification and the selection of samples for a-MGR-analysis (312 samples), chemical analysis by WD-XRF (135 samples), and other analyses. The original pXRF data, thus, could be critically evaluated. MGR-analysis revealed a discontinuation in the use of raw materials used for making pottery dated to the Middle Bronze Age (MBA) and Late Bronze Age (LBA). Apart from determining matrix type, MGR-analysis also allowed us to establish that the grog constituting the predominant ingredient of the tempering material came from ceramic vessels made of the same plastic raw material as the ceramic body to which it was added (Fig. 11). The fact that sherds contain coarse-grained grog of the same composition as the matrix, therefore, has no negative effect on the precision and accuracy of pXRF data.

The LOSSOW Project (see chapter 4.6)

The combined analyses revealed many varieties of non-calcareous clays, all representing different raw materials. Even only regarding *Turbanrandscherben*, there must have been many workshops producing this pottery. At Altgau and at Lossow there was even more than one workshop at one site (Fig. 12). The significant difference in composition of the pottery from settlement and from cemetery at Lossow is also recognizable in a different technology, as analyses of ceramic properties showed. All samples were been analyzed using pXRF. The data distinguished the same groups.

The BRANDENBURG-SACHSEN Project (see chapter 4.7)

In terms of MGR-analysis research methodology, one of the samples analyzed as part of this project (sample GLIE 001, see Fig. 5) demonstrates why it is important to adhere to a strictly defined procedure when carrying out MGR-analysis (the procedure in question is described in Chapter 3.2 in this volume). In keeping with this procedure, samples for

MGR-analysis must always be cut from a sherd in a plane at right angles to the vessel's main axis. If the samples are cut in different directions (i.e. not according to the procedure developed for this analysis) this can lead to problems with classification through comparison. The same is true of refiring at one or two temperatures instead of three. Figure 13 shows samples removed from the same sherd in perpendicular and parallel planes to the vessel's main axis. Differences in the texture and structure of these samples are clearly visible, as are minimal differences in their shade of color (it must be remembered that MGR-analysis is a low-tech but highly sensitive method). Classification into clastic material groups will also be different if the samples are fired, for example, only at 1200°C. Thus, if some samples submitted for MGR-analysis are very small (or only a small part of the sherd can be cut) interpreting the results of their refiring may be problematic.

The OLBIA Project (see chapter 4.8)

The chemical composition of 285 sherds recovered from Olbia and from nine sites in the region was first analyzed by pXRF. Subsequently, samples were selected for abridged MGR-analysis and for chemical composition analysis by WD-XRF, based on the results of the preceding MGR-analysis. MGR-analysis revealed several instances where the same levels of calcium contents were recorded by pXRF in sherds made of calcareous clays as in sherds made of non-calcareous clays in which the calcium content is not linked to the presence of carbonates in the matrix. These samples were attributed to the same chemical cluster of multivariate cluster analysis (Fig. 14). In order to investigate further, additional MGR-analysis was carried out on all ceramic sherds for which pXRF analysis revealed a CaO content of over 5wt.% (CaO levels below 5wt.% rule out calcareous clay). As a consequence, it proved necessary to carry out MGR-analysis on twice as many samples as originally planned. In this case, this analysis could be restricted to refiring at only one temperature because the main aim was to quickly ascertain whether we were dealing with a calcareous or a non-calcareous clay.

The VOITENKI Project (chapter 4.9)

There were numerous problems in interpreting the results of analysis carried out on samples for this project because of the big clay aggregates and/or grog. Figure 15 shows examples of sherds featuring this kind of temper, which has a significant impact on chemical composition. Generally speaking, if samples contain this type of temper it is worth considering selecting samples for chemical analysis after MGR-analysis. A detailed description should certainly be made of the non-plastic ingredients and this should be taken into consideration when interpreting the results of chemical analysis (both by WD-XRF

and pXRF). An additional problem when interpreting the chemical analysis data is the alteration effect, in this case, mainly concerning iron (and manganese?) contents. In refired samples (Fig. 16), the migration of iron compounds into the open pores of the sherd can be seen.

The KOMARIV Project (see chapter 4.10)

Big sampling errors can be connected to preservation of glass fragments (surfaces weathered or not) and/or geometry (fresh fracture surfaces mostly are not as flat as in the case of pottery). Additionally, there is a problem with sodium what cannot be determined (and the important element magnesium, which can only be determined with poor precision).[8] Therefore, the rhombic diagram of the concentrations of Na, K, Mg, and Ca commonly used for the classification of glasses[9] cannot be used when analyses were done by pXRF.

Collating the results of individual analyses done by WD-XRF and pXRF shows that, in the case of glass samples, measurement by pXRF does not provide (as had been expected) results with sufficient accuracy for network former and network modifier elements; however, pXRF is nonetheless useful in helping to identify major groups – which was a surprise. This technique was especially useful for the analysis of colorants, e.g. analysis of the blue decoration and the transparent colorless glass (Fig. 17).

Determining what material any given glass fragment was made of, however, requires additional destructive analyses. Non-archaeometrists should especially be made aware of the fact that the pXRF technique cannot be used for analyzing Na, and that determining Mg and Al is often problematic; hence, a quick pXRF measurement cannot be used to accurately distinguish all types of glass. Soda glasses may be identified based on the absence of lead, which can, however, result in mistakes.

Sampling strategy for laboratory-based studies of ancient pottery: experiences from various projects

Most important for any archaeometric project is the formulation of an exact question which should be answered, keeping in mind that the exact analyses can only decide if two sherds are sufficiently similar to be grouped together (same workshop, same provenance). In this way, we can test if an archaeologically predetermined group of pottery is different from a second group, e.g. one group accepted as local and the second group of another provenance. The minimum number of samples to be studied of one group

8 See e.g. Hodgkinson 2016, who used the same equipment for glass analysis.

9 E.g. Wedepohl 2003; Kronz, Simon, and Dodt 2018.

should not be less than five. Even if five samples will not be statistically significant, they can give some information about the variance. This is very important because groups only are distinguished if the variance within the groups is significantly smaller than the variance between the groups.

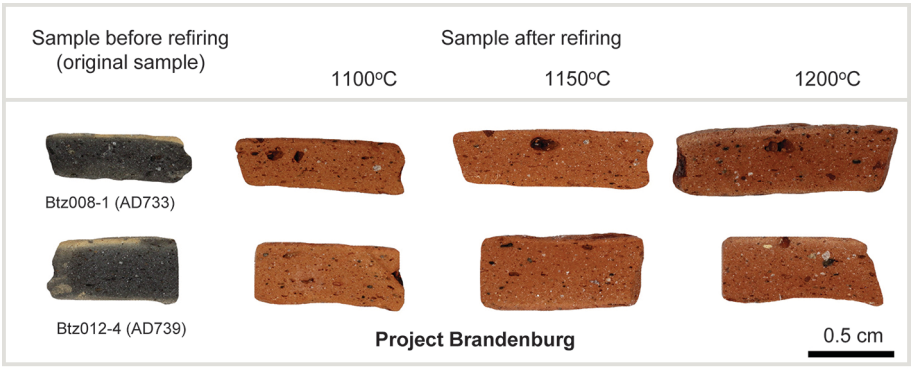
The first step should always be a macroscopic classification of wares, including archaeological criteria. For each of the classified groups, a minimum of five samples should be analyzed using pXRF and lab-methods such as MGR-analysis and WD-XRF. From this pilot series, it can be seen if the grouping into wares was successful and what will be the precision and accuracy of the pXRF measurements (from three times measurements on fresh fracture surfaces). After this, a decision can be made about which elements of the pXRF measurements can be used to classify a larger series of samples. The analysis results must be checked in a table and in two-element diagrams. This is indispensable, in addition to applying multivariate methods.[10]

When classifying bulk ceramic finds, in order to minimize analysis costs, a *down–up sampling classification* strategy is used. This procedure involves individual analyses being carried out consecutively and the number of samples selected for subsequent analyses being limited based on the results of the preceding analysis (*down*). The first method that is usually applied in our team is MGR-analysis carried out on all samples, after which only samples representing individual MGR-groups are selected for chemical analysis. On completion of chemical analysis, the samples are reclassified and subsequent selection of fragments for thin-section studies and technological studies is based on this new classification. Subsequently, it is possible to identify all of the analyzed potsherds (*up*) based on the correlation between macroscopically described fabrics, MGR-groups, and the results of chemical analysis and thin-section studies.

Using pXRF measurements enables a large number of measurements to be made relatively quickly at a low cost. Besides the necessity of a fresh fracture, these are non-destructive. In case that pXRF proves to be reliable in the pilot project, it could replace MGR-analysis as the first step. This means that classification using MGR-analysis may be preceded by classification based on the data of chemical composition analysis using the pXRF technique (Fig. 18), thus, increasing the number of analyzed samples, or even allowing the entire assemblage to be analyzed. However, when writing up the results of this analysis, it has to be taken into consideration that there are strong limitations associated with the use of this technique in provenance studies and especially in the analysis of coarse tempered pottery. The final interpretation has to be based on representative samples, on MGR-groups, and/or thin-section studies, and on true chemical

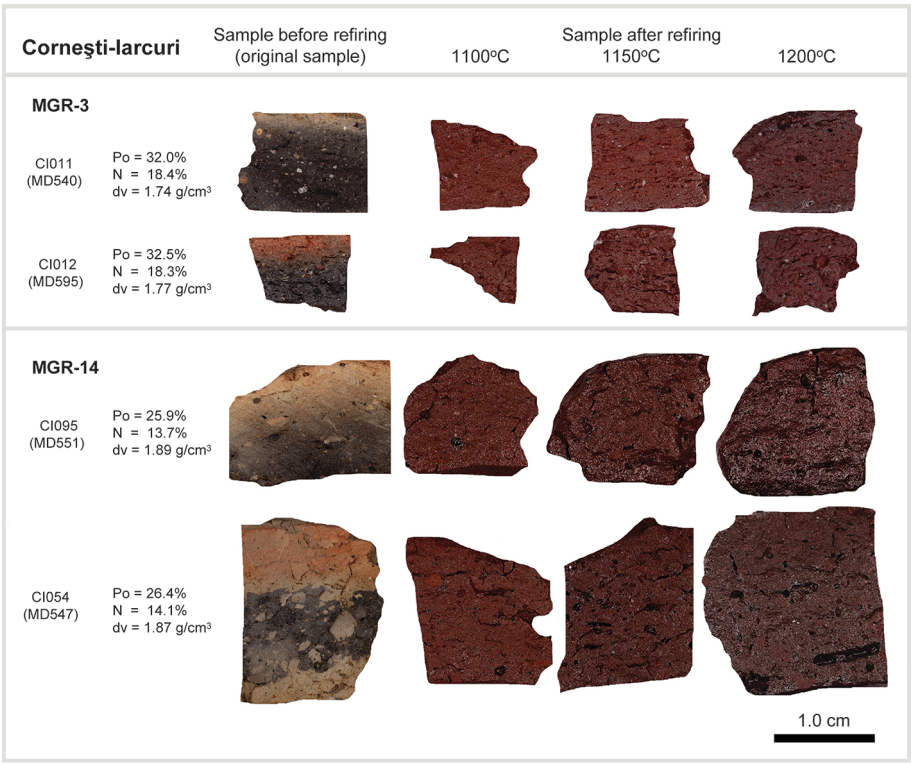
10 This is our experience from many projects, those within Topoi and others. An example of the possibility of false attributions of chemical data using multivariate methods is discussed by Daszkiewicz, G. Schneider, Baranowski, et al. 2018.

data of powder samples. The combination of different methods also provides a chance for unexpected insights into the material and technology of the studied pottery.



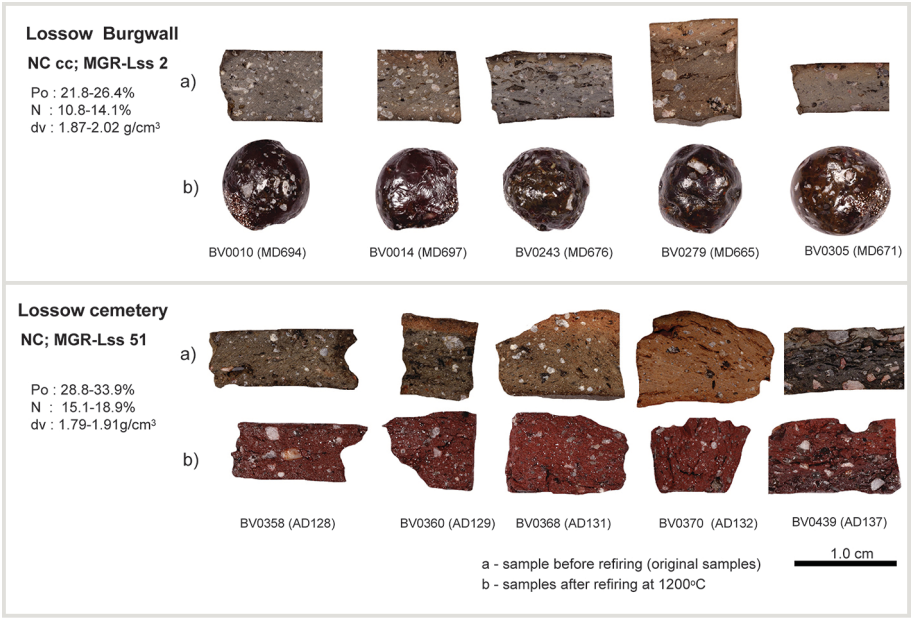
Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	(Nb)	Ba	l.o.i.	SUM
	per cent by weight										ppm										%	%
AD733	77.10	1.48	15.15	4.05	0.083	0.31	0.27	0.01	0.99	0.54	88	79	23	39	59	26	51	361	28	366	1.38	99.92
AD739	77.32	1.47	15.14	4.05	0.096	0.29	0.27	0.02	0.95	0.39	88	78	24	36	59	26	56	363	31	353	1.19	99.84

Fig. 1 Two samples with the same chemical composition and of the same MGR-group (project Brandenburg-Sachsen).



Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Ba	l.o.i.	SUM
	per cent by weight										ppm									%	%
MGR-3																					
MD540	58.58	0.96	21.64	8.34	0.076	1.86	1.20	0.87	2.82	3.66	163	139	74	135	139	151	35	202	1511	7.13	100.09
MD595	59.42	0.96	21.09	8.61	0.069	2.15	1.50	0.80	2.54	2.69	161	139	74	148	136	154	37	218	1446	3.17	100.97
MGR-14																					
MD551	68.93	0.99	15.94	6.02	0.080	1.45	1.82	0.52	2.40	1.84	106	116	59	87	116	152	35	371	1811	4.12	99.89
MD547	68.64	1.00	15.88	5.82	0.115	1.03	1.59	0.79	2.22	2.90	107	114	52	77	107	166	37	395	1544	4.33	99.89

Fig. 2 Example of MGR-analysis and WD-XRF of pottery of two different workshops in Cornești-Iarcuri. Besides the composition the two samples of MGR-3 share, they also share the same ceramic properties (open porosity = Po, water absorption = N, and apparent density = dv). The same may also count for the two samples of MGR-14.



Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	l.o.i.	TOTAL
	per cent by weight										ppm										%	%
Lossow Burgwall																						
MD665	64.39	0.66	15.06	5.04	0.076	1.86	7.13	1.18	3.35	1.26	93	81	41	155	179	260	28	225	13	1056	7.81	99.99
MD671	63.19	0.77	15.43	5.82	0.096	1.38	7.31	0.87	3.70	1.45	93	82	39	88	156	336	32	263	17	688	2.58	100.17
MD676	61.28	0.71	16.65	6.01	0.111	1.68	7.77	0.84	3.25	1.69	123	99	39	107	153	390	30	237	14	781	4.04	100.23
MD694	64.64	0.70	14.65	5.46	0.120	1.43	5.93	0.72	3.18	3.18	93	85	42	109	173	413	25	230	14	682	6.32	100.05
MD697	65.44	0.71	14.99	5.61	0.069	1.58	5.19	0.75	3.19	2.47	96	94	47	93	178	300	38	233	13	726	6.22	99.99
Lossow cemetery																						
AD128	72.18	0.74	14.84	5.74	0.075	1.34	0.68	0.68	3.25	0.48	88	82	46	67	136	112	20	295	14	574	4.34	99.21
AD129	72.48	0.68	15.00	5.64	0.054	1.10	0.63	0.73	3.09	0.60	94	83	41	57	129	103	15	241	14	528	4.49	99.24
AD130	68.86	0.65	16.39	5.81	0.125	1.01	1.07	1.35	3.06	1.67	80	75	34	59	116	197	25	223	13	737	5.20	100.13
AD131	68.61	0.81	16.61	7.19	0.049	1.30	1.21	0.97	2.56	0.69	111	94	26	62	125	152	9	297	14	575	4.56	100.23
AD132	69.93	0.81	16.16	6.41	0.042	1.00	0.76	0.82	3.13	0.94	86	88	34	72	125	150	17	321	15	656	3.58	100.03
AD137	68.09	0.85	17.18	6.09	0.035	0.97	0.60	1.08	3.48	1.64	114	114	45	78	186	122	27	258	28	423	4.58	100.30

Fig. 3 Comparison of five samples of pottery found in the settlement and of five samples found in the cemetery of Lossow (cross sections a = original fragment and b = fragment refired at 1200°C). Analysis by WD-XRF is also given.

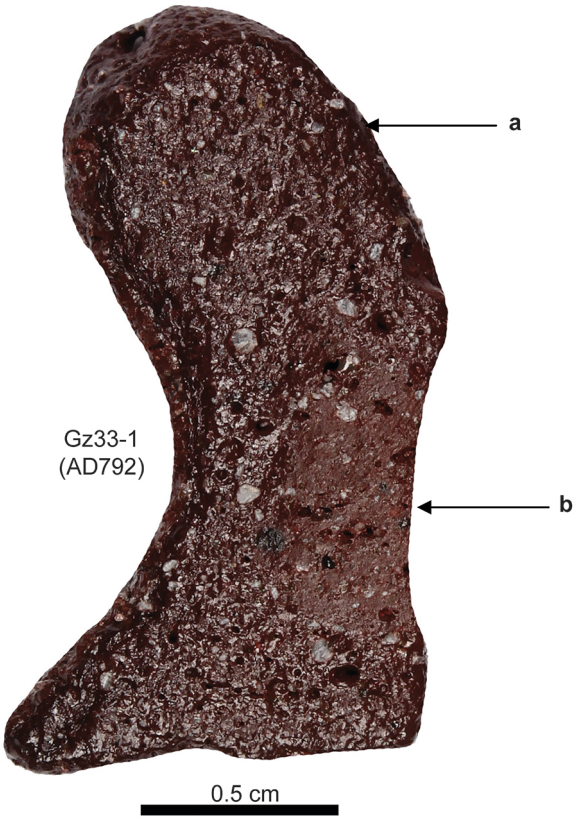
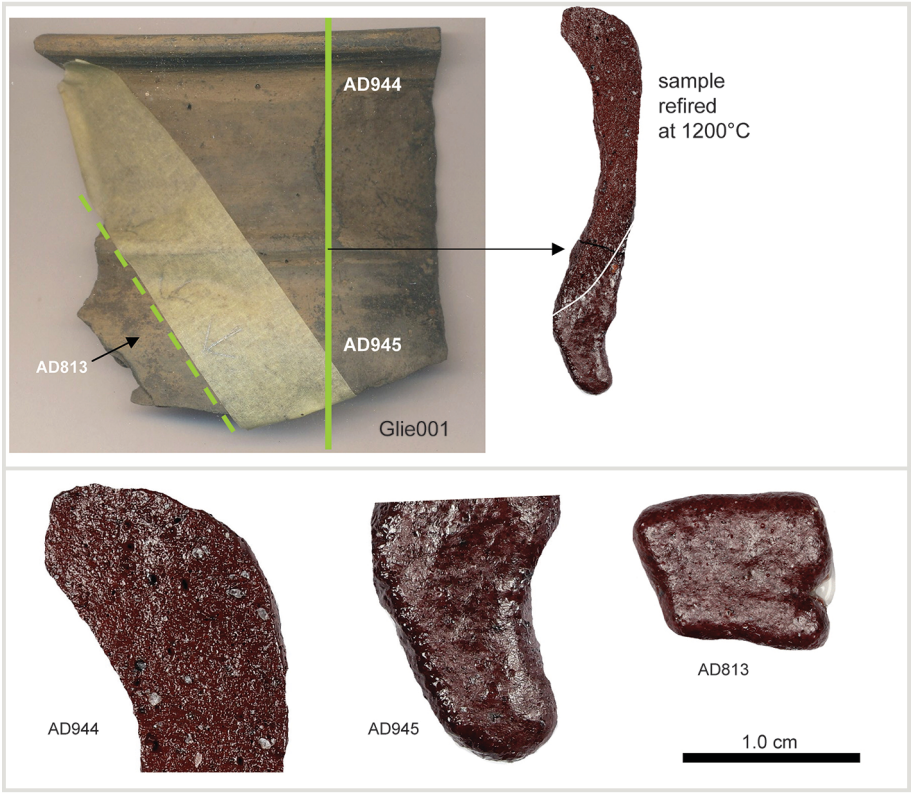


Fig. 4 Cross sections of a sherd made from two different clay raw materials, sample refired at 1200°C; clay b is more refractory than clay a (project Brandenburg-Sachsen).



SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	(Nb)	Ba	(La	Ce	Pb)
per cent by weight										ppm												
AD944																						
64.11	0.85	18.14	7.44	0.090	1.98	2.24	0.32	3.29	1.53	130	120	60	100	137	178	33	221	17	774	52	81	26
AD813																						
62.57	0.84	18.00	7.39	0.077	2.23	3.79	0.38	3.45	1.28	136	120	56	91	147	172	37	216	18	693	50	80	26

Fig. 5 Repeated analyses of a sherd Glie001 (project: Brandenburg-Sachsen) made by coiling, using coils made of different clay (AD944 and AD945/AD813).

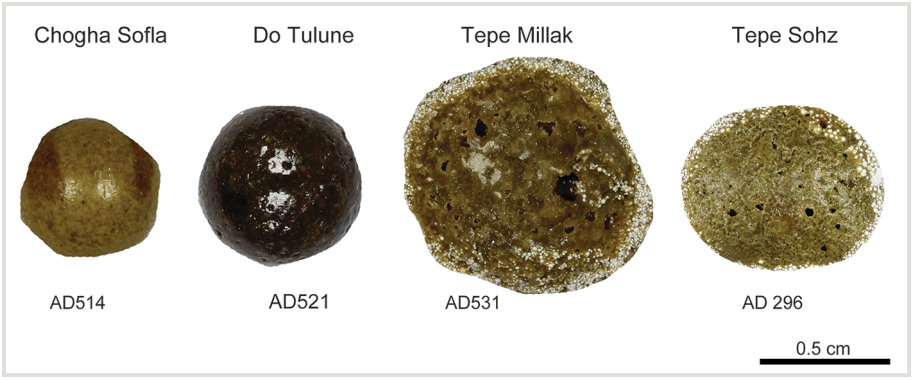
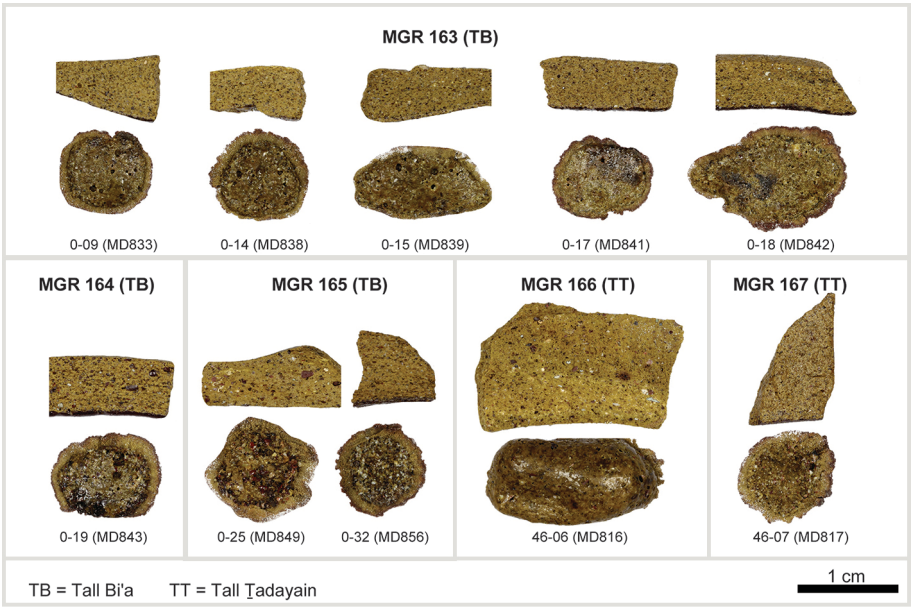


Fig. 6 Distinction of pottery from different sites by refiring at 1200°C (project: Tepe Sohz).



	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Ba	l.o.i.	SUM
		per cent by weight										ppm									%	%
	MGR-163																					
TB	MD833	51.72	0.854	14.61	8.09	0.141	6.23	14.77	1.22	2.12	0.25	129	398	289	81	67	586	22	188	387	2.21	100.00
TB	MD838	52.13	0.842	14.00	8.16	0.158	6.68	14.01	1.71	2.05	0.25	142	428	278	83	51	634	21	175	1161	3.63	100.33
TB	MD839	52.78	0.778	13.33	7.23	0.150	6.47	15.17	1.99	1.72	0.38	144	401	241	82	47	551	16	155	386	4.30	99.96
TB	MD841	52.12	0.864	14.00	8.17	0.149	6.50	14.14	1.81	2.03	0.24	146	476	267	76	46	581	20	173	505	2.68	100.17
TB	MD842	50.47	0.768	13.13	7.51	0.155	6.91	16.71	1.67	2.21	0.47	138	360	270	81	42	709	18	166	775	4.87	100.05
	MGR-164																					
TB	MD843	49.32	0.891	13.34	7.91	0.134	5.84	20.77	0.25	1.34	0.20	118	593	410	91	60	316	22	170	276	4.26	100.00
	MGR-165																					
TB	MD849	52.41	0.896	13.91	8.22	0.132	4.99	17.35	0.24	1.51	0.34	117	508	443	95	68	229	23	172	220	2.28	100.50
TB	MD856	51.22	0.844	14.70	7.69	0.133	4.76	17.69	0.81	1.89	0.27	111	489	387	84	75	350	23	175	299	4.39	100.02
	MGR-166																					
TT	MD816	52.07	0.840	14.74	7.70	0.117	4.77	16.49	1.06	2.05	0.17	110	518	393	79	71	307	21	175	245	4.95	100.01
	MGR-167																					
TT	MD817	50.68	0.846	14.38	7.72	0.115	4.62	18.60	0.75	2.01	0.29	116	511	395	89	73	380	19	175	227	6.98	99.67

Fig. 7 Examples of five MGR-groups from the Northern Syria project. The clearly visible differences in the refired fragments (at 1050°C upper row, at 1200°C lower row) are correlated to only minor chemical differences.

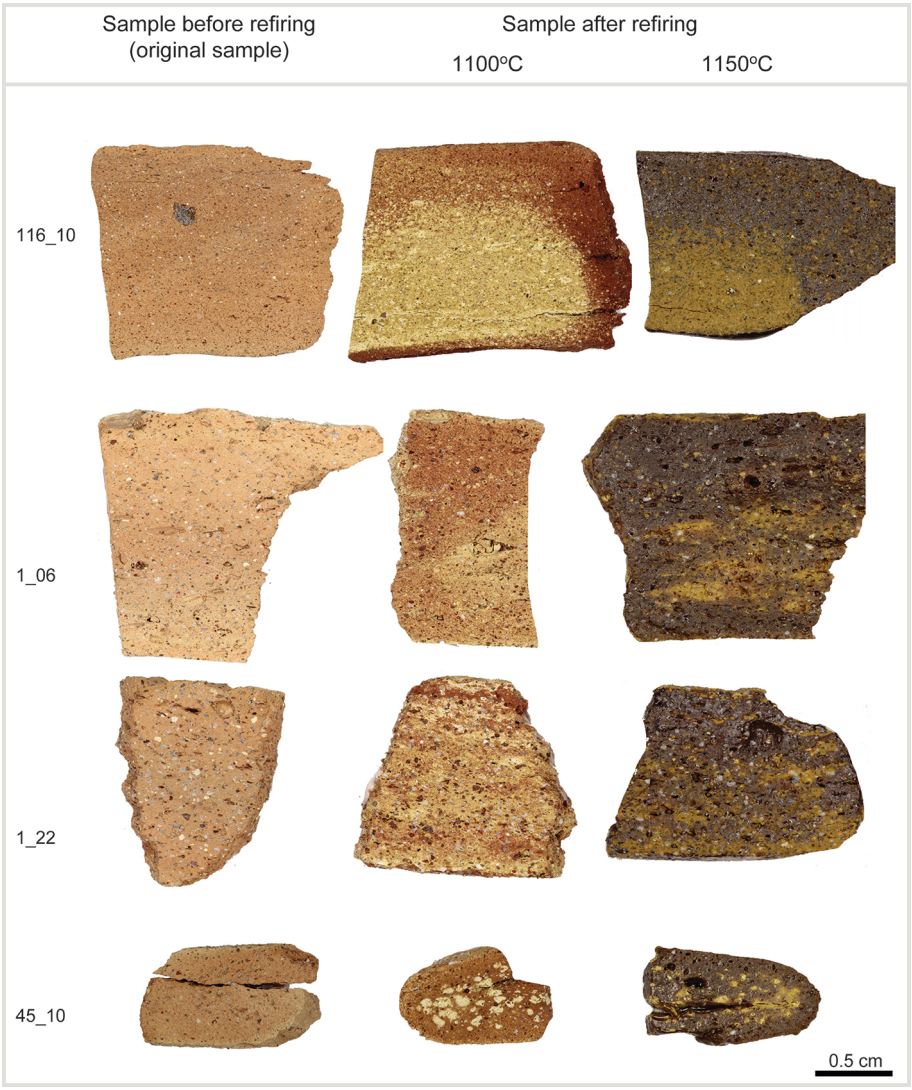


Fig. 8 Examples of alteration effects by leaching calcite (Northern Syria project). The leaching can only be seen in samples after refiring at 1100°C or 1150°C.

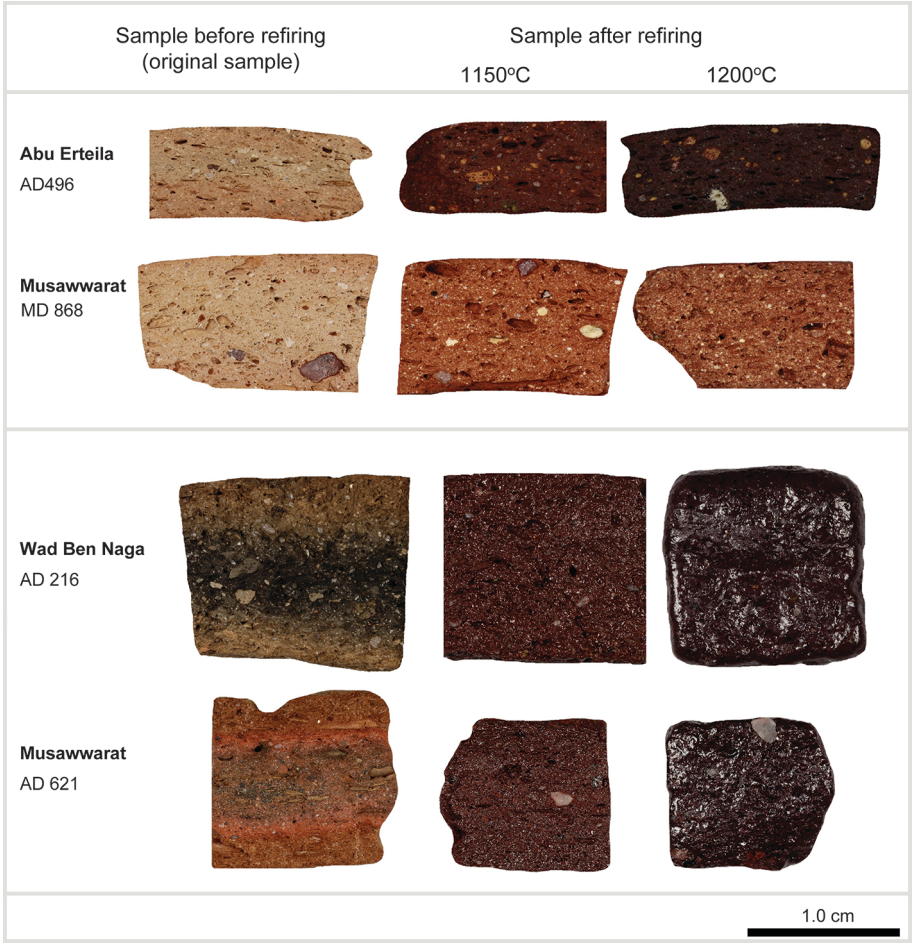
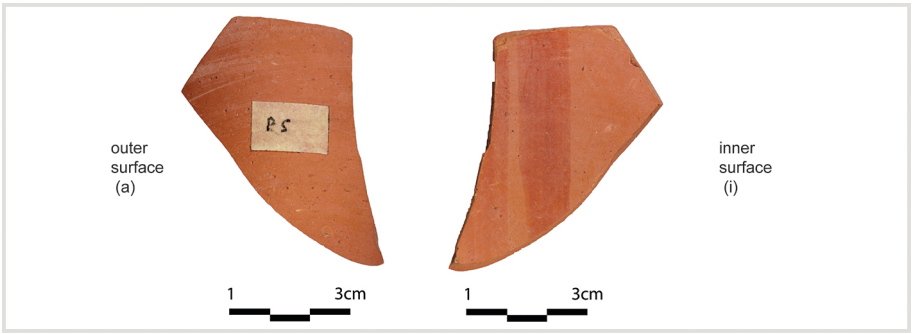


Fig. 9 Examples of MGR-analyses from project Musawwarat: AD496 = hypothetical Musawwarat fabric found in Abu Erteila, AD868 = real Musawwarat fabric from Musawwarat, AD216 = sample found in Wad Ben Naga, and AD621 = import into Musawwarat from the same workshop as of AD216.



Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	P_2O_5	S	Cl	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba
	per cent by weight							ppm										
P5 a	59,82	1,37	20,44	6,43	2,02	2,91	0,18	494	18	106	133	46	79	63	21	291	17	68
P5 a	58,97	1,38	19,50	6,45	2,05	2,83	0,18	557	28	110	135	44	80	60	24	300	17	71
P5 a	58,85	1,40	19,70	6,41	2,04	2,88	0,16	501	30	98	151	46	77	61	26	298	16	
P5 i	51,33	1,33	16,43	6,73	1,27	2,90	0,17		80	92	167	37	77	60	24	289	17	
P5 i	50,11	1,33	15,46	6,60	1,29	2,81	0,12		72	97	147	41	79	61	25	281	18	
P5 i	46,17	1,29	13,42	6,61	1,44	2,78	0,08		74	99	156	34	80	62	23	280	17	

Fig. 10 Analysis of outer (a) and inner (i) surface of sherd P5 of Nabataean pottery using pXRF showing elevated calcium and sulfur contents on the outer surface.

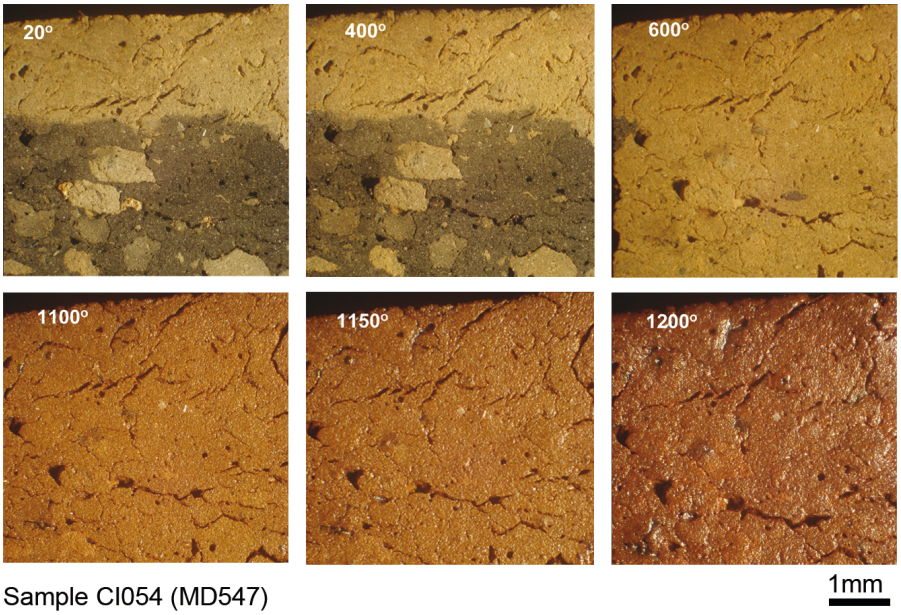


Fig. 11 Structural-textural MGR-analysis of a typical sample from Cornești-Iarcuri tempered with grog of the same composition as the matrix.

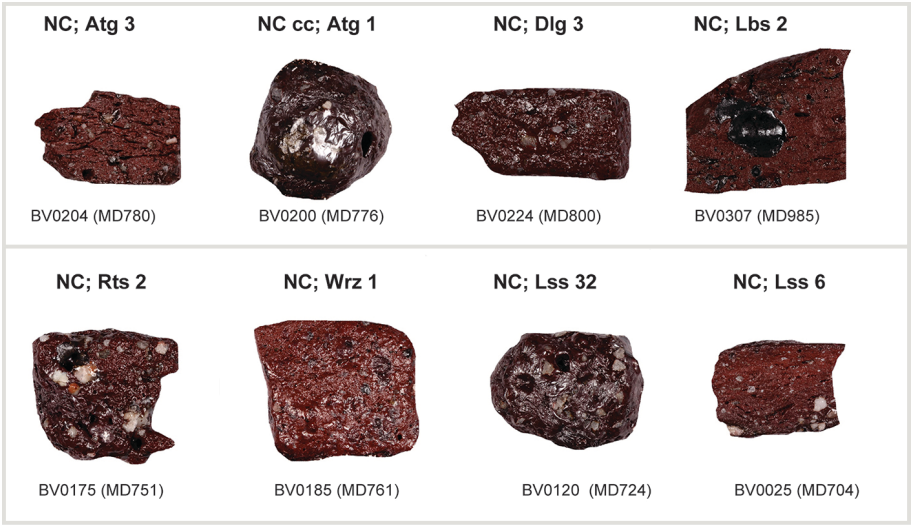


Fig. 12 Distinction of *Turbanrandscherben* found at various sites: Atg 3, Atg 1 = Altgau; Dlg 3 = Dolgelin; Lbs 2 = Lebus; Rts 2 = Rathsdorf; Wrz 1 = Wriezen; Lss 32, and Lss 6 = Lossow Burgwall (all fragments refired at 1200°C).

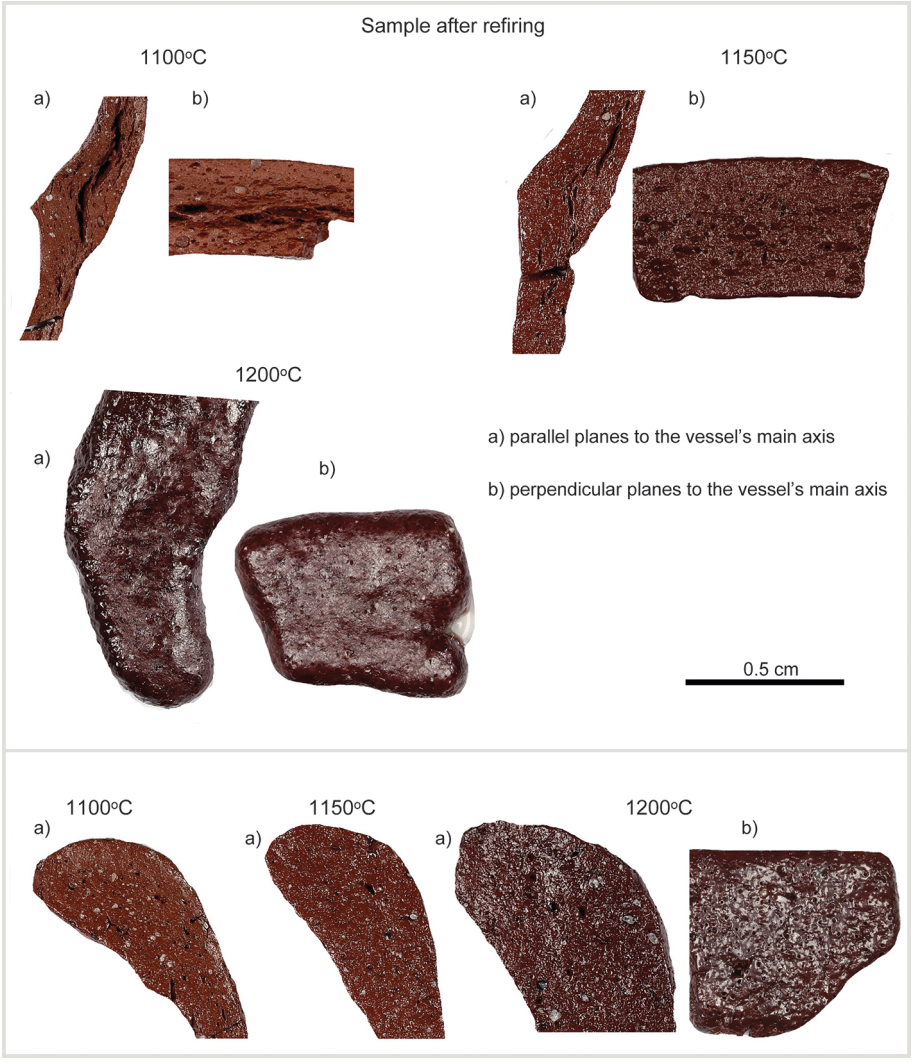


Fig. 13 Upper part: fragments of sherd GLIE 001 (project: Brandenburg-Sachsen) cut parallel (a) and perpendicular (b) to the vessels main axes and refired at three temperatures; lower part: a different fragment of the same sherd (rim) cut parallel (a) and refired at three temperatures, compared to a fragment perpendicular (b) refired only at 1200°C. Temper visible after refiring at 1100°C and is less visible after refiring at 1150°C and 1200°C.

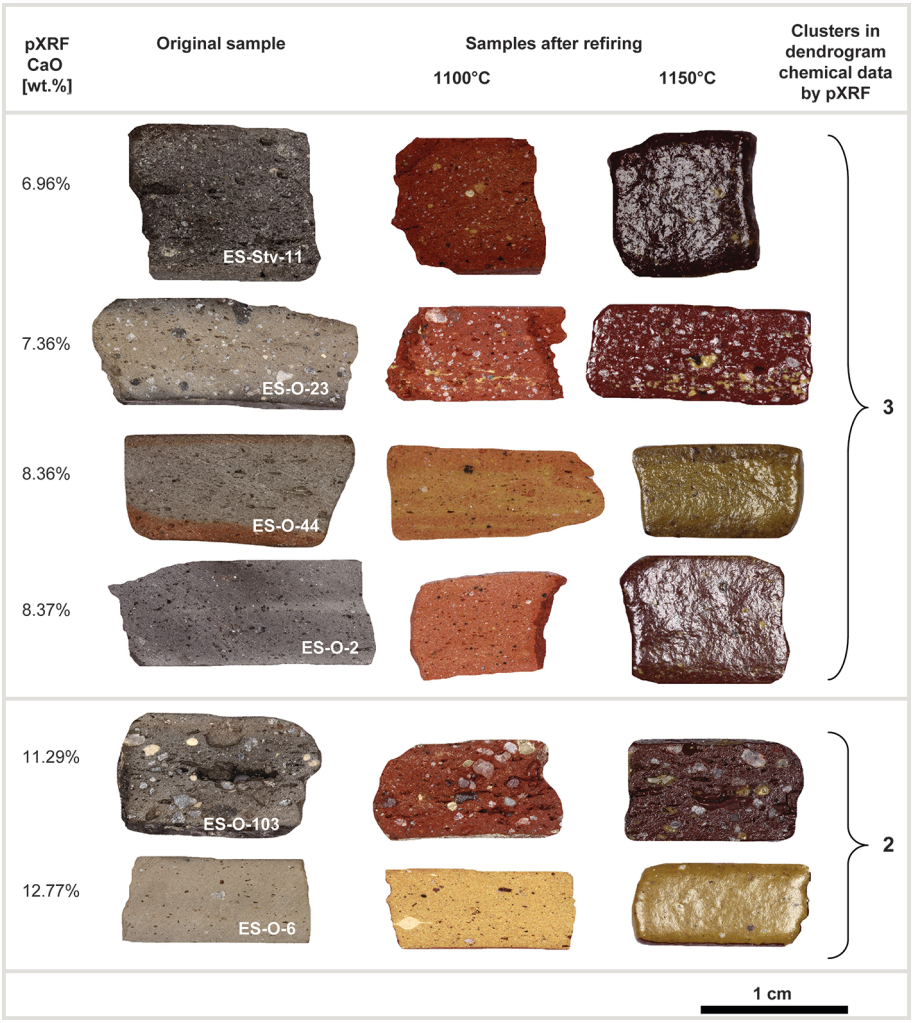


Fig. 14 Comparison of calcium contents with the respective refired samples showing that the chemical grouping using multivariate cluster analysis of the pXRF data is misleading. Similar calcium contents were detected e.g. in calcareous clay (ES-O-44, ES-O-6) and in non-calcareous clay with temper (ES-O-23, E-O-103) (project: Olbia).

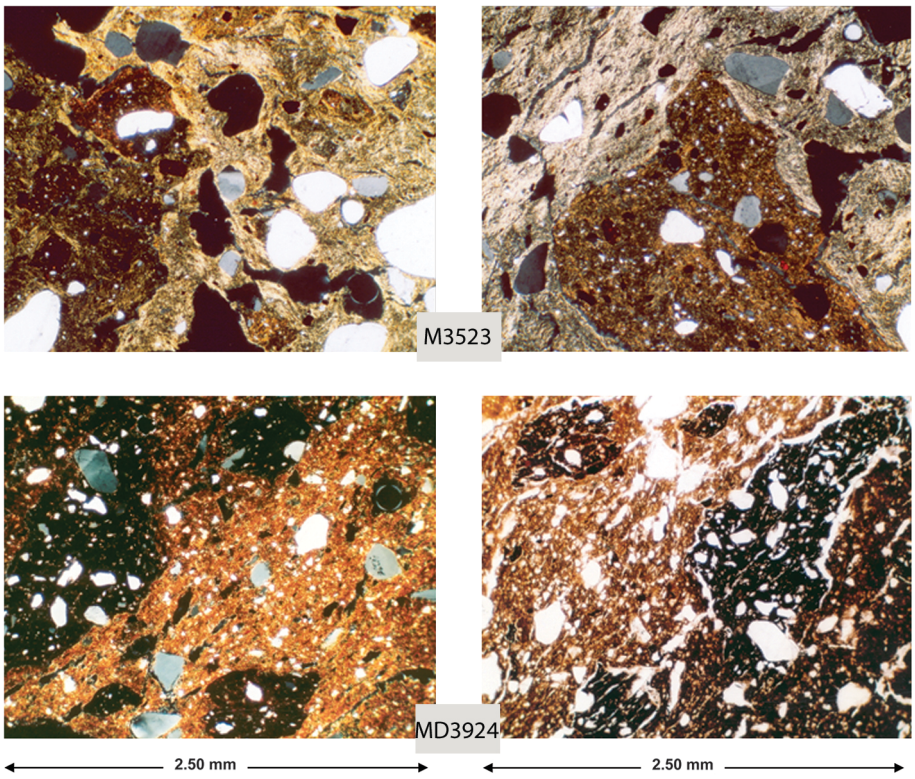


Fig. 15 Grog and/or clay aggregates in two sherds from Voitenki (Photomicrographs XPL, width of field 2.5mm).

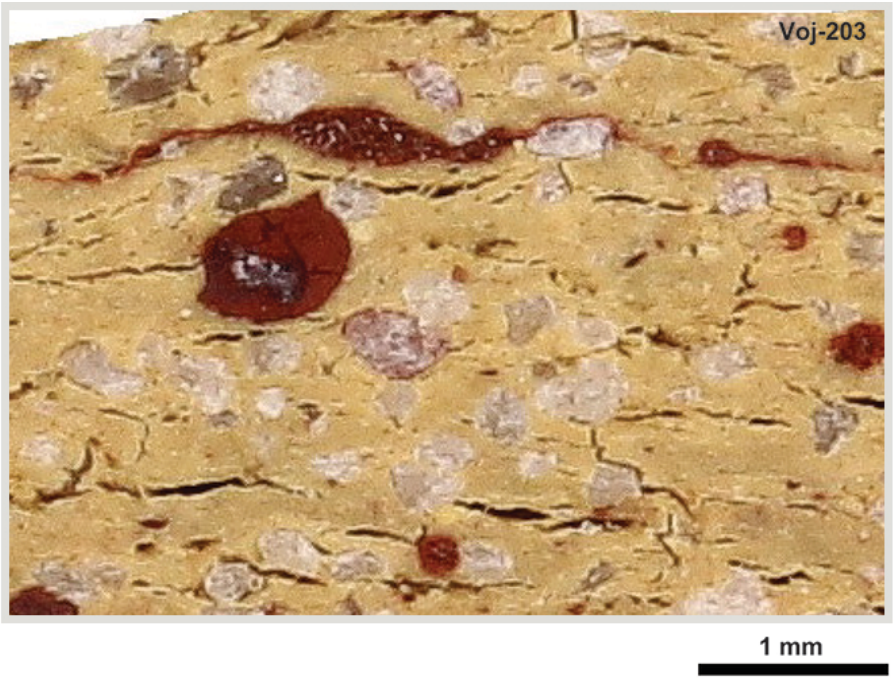
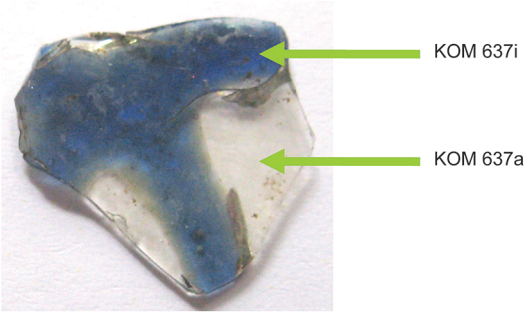


Fig. 16 Alteration effect through infiltration of iron-rich solutions into sherds clearly visible after refiring at 1150°C.



Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	NaO	K_2O	P_2O_5	Cl	V	Cr	Cu	Zn	Rb	Sr	Y	Zr	Sn	Ba	Pb	Co	Sb	As
	per cent by weight										ppm														
transparent colourless glass																									
KOM 637a	77.1	0.13	2.8	0.58	1.27	nd	5.4	na	0.77	0.16	926	50	21	nd	7	9	465	16	47	nd	nd	106	nd	nd	nd
blue decoration																									
KOM 637i	78.8	0.21	5.5	1.76	0.27	nd	6.0	na	0.62	0.76	624	53	32	1209	76	9	458	19	62	nd	nd	1539	848	nd	nd

Fig. 17 pXRF analysis of a colorless glass sample with blue decoration.

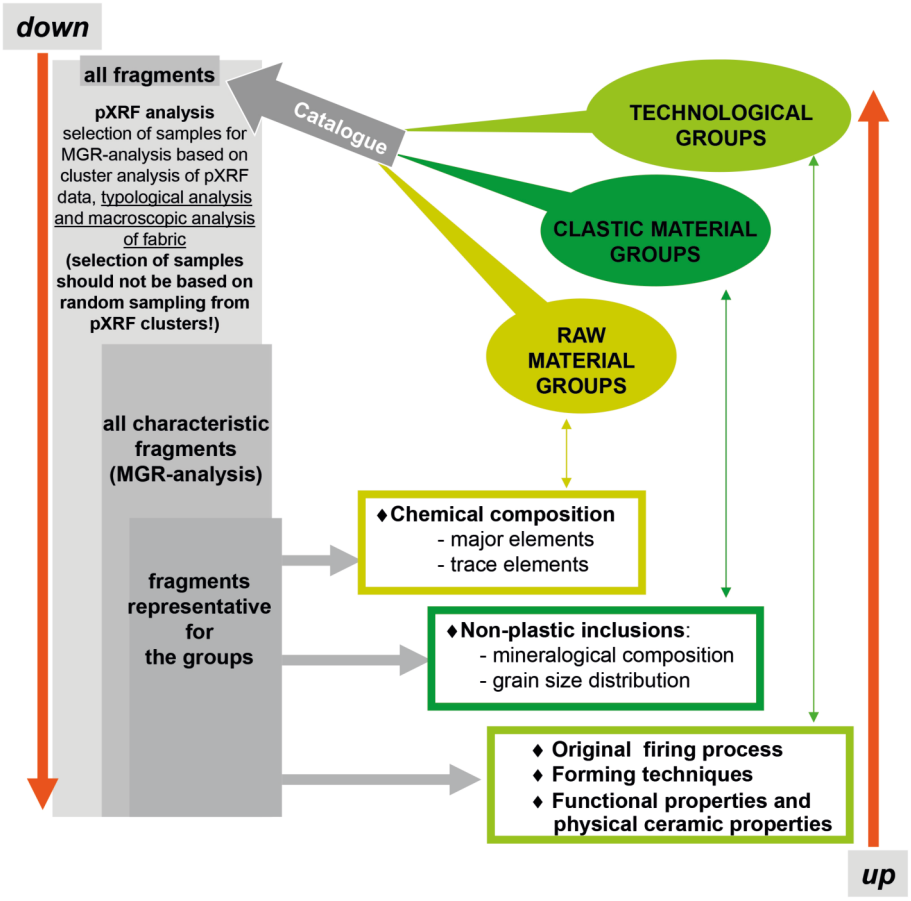


Fig. 18 Schema of a down-up sampling classification strategy.

6 Guide for Using pXRF for Chemical Analysis of Archaeological Pottery

Małgorzata Daszkiewicz, Gerwulf Schneider

Introduction

A portable XRF analyzer might seem like the answer to an archaeological pottery specialist's prayer, making it possible to obtain data on the chemical composition of ceramic wares without taking any samples and without being reliant on expensive help from scientists and limited laboratory capacities. However, it is must be remembered that this device was primarily designed to analyze metals (e.g. for use in the scrap metal trade), and it is marketed as the ideal tool for analyzing metal alloys, carrying out mining exploration and mapping, detecting soil contaminants, and testing electronics and consumer goods for prohibited substances. Using pXRF to analyze ceramics, in particular their provenance, is not quite as simple as it might seem from reading certain advertising brochures. Currently, two main trends can be seen in the approach to using pXRF for analyzing archaeological artifacts: one is rather too optimistic (and not critical enough), whilst the other is too pessimistic. Notwithstanding, like all analytical techniques, pXRF has its advantages and disadvantages. Chemical analysis by pXRF is of limited use in provenance studies, but using this technique opens up new possibilities for rapidly classifying large numbers of archaeological pottery sherds and analyzing the surfaces of ceramic vessels. The results of pXRF analyses can potentially not only provide information about layers intentionally applied to vessel surfaces, but also about the alteration process. Model tests also show that pXRF results can be useful in reconstructing vessel-forming techniques in gypsum molds and in assessing functional properties.[1]

There are three fundamental issues to bear in mind when embarking on the use of pXRF and interpreting the results:

1 Daszkiewicz and Wetendorf 2014.

(1) radiation safety rules apply to the use of handheld XRF devices just as they do to the use of all other equipment emitting X-radiation;
(2) the fact that the pXRF spectrometer is simple to use does not mean that the results of measurements made using this device should not be checked for precision and accuracy; and
(3) the exclusive use of pXRF for pottery analysis in a number of projects carried out by Behrendt, Mielke, and Mecking[2] resulted in the erroneous provenance classification of 10–45% of samples (in the case of fine wares, up to 20%). This is confirmed by own experiences with various projects.[3] This means that potentially as many as nearly half of samples analyzed by pXRF can be misclassified; so, in order to avoid erroneous interpretations, other procedures (analyses) must be carried out to verify the results obtained by pXRF.

This article presents a discussion of the issues outlined above, mainly based on measurements performed on samples of Bronze Age pottery found at the Corneşti-Iarcuri site in Romanian Banat (for a description of this project see chapter 4.5 in this volume).

Basic information

Each measurement, no matter how carefully made, will be subject to some degree of error. However, it should be minimized as far as possible so that the results of each analysis are as precise and accurate as the given device and technique used will allow. The precision and accuracy of results are particularly important when analyzing archaeological ceramics in order to determine their provenance. To do this, it must be possible to compare the results of analyses carried out years apart, with no additional samples of the reference artifact available to verify the analysis results. Regardless of whether we are dealing with analyses carried out in the laboratory using no portable equipment or with measurements made using a handheld XRF device, whether or not it will be possible to make a direct comparison of the results of chemical analysis obtained using whichever of these two approaches, the results will depend on the precision and accuracy of each individual element of the analysis, wherever and however it was carried out.

There are several errors that affect total precision (analysis precision); these are linked to:

– precision of sampling (sampling error);

2 Behrendt, Mielke, and Mecking 2012.

3 For example in Baranowski, Daszkiewicz, and G. Schneider 2021.

– precision of the individual preparing the sample for measurement (personal error);

– precision of the sample preparation method (in the case of pXRF, measurements may be done on fresh fracture surfaces, on cut surfaces, and on unprepared original surfaces or on scratched surfaces); and

– precision of measurement (this can vary if, for example, equipment is replaced or repaired).

Sampling errors will have the greatest impact on analysis precision; the error will be especially large when analyzing coarse tempered pottery and will depend on the sample size, in particular in those instances where the temper is poorly sorted and/or grains of temper are not homogeneously distributed within the matrix. It is not actually possible to minimize this error when analyzing ancient pottery. Another factor to bear in mind is that the smaller the sample taken for analysis, the larger the sampling error will be – this applies to samples prepared for measurement by powdering. For a representative sample with minimal sampling error, there is a minimum amount of powder needed depending on the grain size of the sherd. In the case of measurements made by pXRF on powdered ceramic samples, the sampling error may be much larger than in the case of melted samples for WD-XRF. This is due to the limited depth of information depending on the low energies of the X-rays of the elements in ceramics. Personal error can occur when using pXRF because of the way that the surface is prepared for measurement (preparation error) and the way that the sample is placed on the measurement window.

To improve the precision of measurement, a monitor sample must be measured (on each day when measurements are made) and then tested by performing repeat measurements on the same sample at specified periods. When using pXRF in Berlin, measurements of a monitor sample are taken at least twice (at the beginning and the end of each measurement session). On the whole, to evaluate the precision of analysis (total precision) it is better to analyze ten samples removed from the same ceramic sherd than to repeat analysis of the same specimen ten times. Naturally, we do not recommend that ten samples should be taken from an ancient potsherd, but precision of analysis can be assessed by analyzing ceramic sherds prepared in the laboratory (or by using contemporary ceramics).

The difference between precision and accuracy of measurements is shown schematically in Figure 1. **Precision of** measurement (repetitive accuracy)[4] is the convergence between the values obtained with repeated measurements. High precision in measurements is when the measured values are close to one another. High precision is marked

4 German: *Wiederholungsgenauigkeit*.

by a low coefficient of variation (hereafter, cv). Precision of measurement encompasses repeatability[5] and reproducibility[6] and is determined by random errors. Accuracy of measurement (comparability of data)[7] is the convergence between the value of the measured quantity and the true value of the quantity. This means that a measurement is accurate when the difference between the measured value and the true value (accepted as true) is very small. Accuracy of measurement is determined by systematic errors. An inaccurate measurement may be linked to a constant systematic error (an error independent of the concentration of the measured element) and a variable error (an error dependent on the concentration of the measured element).

Repeating a measurement can only provide information about precision. The only way to test measurement accuracy is by measuring international certified reference materials (CRM's, e.g. SARM69 reference material in the analysis of ancient pottery) and by exchanging samples between laboratories.

Caution 1: *The acceptance criteria for precision of measurement and accuracy of measurement are different for major and trace elements. For example, the acceptable precision of measurement for major elements is cv below 3%, whilst for trace elements it may be larger and up to 15%.*

It must be borne in mind that the so-called preparation error plus the measurement error should be less than ~ $\frac{1}{3}$ of the sampling error, as in this situation, precision of analysis is usually associated only with the non-homogeneity of the analyzed ceramic sherd.

$Sa^2 = Ss^2 + Sp^2 + Sm^2$

where: Sa = precision of analysis; Ss = sampling precision; Sp = preparation precision; Sm = measurement precision. If the preparation error plus the measurement error is greater than ~ $\frac{1}{3}$, it will not be possible to correctly identify ceramic groups nor to recognize ceramic sherds from various vessels because the preparation error and measurement error constitute too great a proportion of the analysis error. This means that, in the case of archaeological pottery, chemical analysis has to be carried out with high precision.

Other important issues to bear in mind when selecting an analytical technique and working up the analysis results are the measurement range, limit of detection (LOD) and limit of quantification (LOQ).

5 Repeatability is the precision of analyses carried out in a short space of time by the same person under the same conditions (same reagents, same equipment).

6 Reproducibility allows us to determine whether a given technique yields the same results in different laboratories (different analysts, different equipment, and measurement conditions). For example, in 2017 the reproducibility of two laboratories was examined – the agreement of the results from WD-XRF analysis of the same powder samples in two laboratories, one in Athens and one in Berlin, was acceptable.

7 German: *Treffgenauigkeit* or *Richtigkeit*.

The measurement range is the interval between the minimum and maximum concentration of a given element in the samples to be analyzed. For a given method/technique, this range has a specified degree of acceptable linearity,[8] precision, and accuracy (acceptance criteria). For example, pottery made of carbonate clays tempered with crushed calcite cannot be analyzed if the instrument has been calibrated to a calcium content not exceeding 6wt.% of CaO because in these circumstances the results obtained will not (cannot) be of acceptable accuracy.

The limit of detection is the lowest concentration of a given element that can be detected in an analyzed sample using a given instrument and technique (*can be detected* does not automatically mean that the concentration level will be determined with adequate accuracy). If, in the analyzed sample a given element is measured as having a concentration below LOD, this applies solely to that particular measurement; it cannot be assumed that the given element is not present in that sample, only that it is not present in detectable amounts using that particular measurement technique.

The limit of quantification is the smallest concentration of a given element in an analyzed sample that can be quantified with adequate precision and accuracy.

When defining LOD and LOQ values, the former is defined as 3-standard deviation of the measurements of the blank, and the latter as 10-standard deviation of the blank.

Caution 2: *In original downloaded values measured by pXRF, columns alternately show: content of the given element and measurement error (statistic) at one time (or two times) standard deviation, which at least gives an idea of the theoretical precision of measurements.*

pXRF as a source of X-rays

X-rays are dangerous radiation. Therefore, it is the law (in Germany §3 RöV) that the instrument must have the official permission of the Federal Office for Radiation Protection to be used and that somebody with special knowledge (Radiation Protection Officer) is responsible to prove that the use is always according to the rules. The advantage of X-rays compared to other ionizing radiation is that they stop the moment the instrument is switched off. The handheld Niton X-ray analyzer stops automatically (more or less suddenly) when no sample is in the beam path (but this can anyway be too long of an exposure).

Important is that radiation is not only registered in the direction of the sample to be measured (primary beam) but there is also scattered radiation backwards (secondary beam) that is more intensive when material with a light matrix is irradiated (Fig. 2).

8 Linearity is the possibility of obtaining measurement results directly proportional to the real concentration of a given element in a sample (within a specified range and after corrections of matrix effects). The dependence of both variables is characterized by a correlation coefficient, regression curves are created on the basis of analysis of certified reference samples (CRM's).

Element	Symbol	Atomic Number	Kα 1 [keV]	Kβ 1 [keV]	Lα 1 [keV]	Lβ 1 [keV]	depth mm
magnesium	Mg	12	1.25	1.3			<0.01
aluminium	Al	13	1.49	1.557			
silicon	Si	14	1.74	1.84			
phosphorus	P	15	2.02	2.14			
sulfur	S	16	2.31	2.46			<0.01
chlorine	Cl	17	2.62	2.82			
potassium	K	19	3.3	3.6			
calcium	Ca	20	3.7	4.0			0.01
titanium	Ti	22	4.5	4.9			
vanadium	V	23	4.9	5.4			
chromium	Cr	24	5.4	5.9			
manganese	Mn	25	5.9	6.5			
iron	Fe	26	6.4	7.1			0.05
nickel	Ni	28	7.5	8.3			
copper	Cu	29	8.0	8.9			
zinc	Zn	30	8.6	9.6			
rubidium	Rb	37	13.4	15.0			0.3
strontium	Sr	38	14.2	15.8			
yttrium	Y	39	15.0	16.7			
zirconium	Zr	40	15.8	17.7			
niobium	Nb	41	16.6	18.6			0.5
barium	Ba	56	32.2	36.4	4.5	4.8	
cerium	Ce	58	34.7	39.3	4.8	5.3	
lead	Pb	82	75.0	85.9	10.5	12.6	

Tab. 1 X-ray energies of elements analyzed in archaeological pottery. For pXRF the Ka and La lines with energies between 1 and 17 KeV are used. Some lines have nearly the same energy (e.g. Sr Kb and ZrKa and, therefore, must be corrected for overlapping). The increasing depths of information with energy are indicated.

This concerns all ceramics made of clay consisting mainly of the elements aluminium, silicon, and oxygen.[9] These are very light elements with, therefore, a strong scattering effect. This means, e.g. that at the trigger of the instrument, the radiation exposure could be more than 0.1 mSv/h. This is not negligible. Therefore, the distance of operators to the instrument should always be as large as possible and, generally, measuring should best be done in a sample chamber. If this is not possible, a shield against scattered radiation should be used. This is important in the case of all light materials (like ceramics, wood, and plastic), which is not convenient because the measuring point then cannot be seen easily (Fig. 3).

9 It also concerns analysis of glass samples (Adlington 2021).

Important for the analysis of inhomogeneous materials is the depth of information, which depends on the X-ray energy of the element to be analyzed (Tab. 1) and on the matrix of the sample. The primary beam of the Ag-tube is able to excite atoms as deep as more than 1mm, e.g. in a matrix of ceramics. Due to the strong absorption of the X-rays in the sample, 50% of the secondary radiation for major elements leaving the sample, however, comes from a depth of less than about 0.05mm (aluminium to iron) or for trace elements, e.g. rubidium, strontium, and zirconium from about 0.3 to 0.5mm. Together with the limited irradiation area of 8mm in diameter, only a small part of the sample is, therefore, analyzed, which in coarse pottery will not be representative for the bulk composition of the sherd.

Caution 3:

X-rays are dangerous and measurements should best be made in a sample chamber. Otherwise a radiation protection shield must be used when ceramics are analyzed (in contrast to metals). Due to the shallow depth of information of low energy X-rays, the irradiated part of a ceramic sample in many cases will not be representative for the composition of the sherd's body.

Comparison of precision of analysis by WD-XRF and pXRF

As a test for precision, sherds from different periods and regions were measured on four different spots of fresh fracture surfaces and cv % was calculated.[10] The values divided through the square root of the number of measurements (error of analysis) then can be compared to the long-term precision of analyses by WD-XRF. The results are shown as colored columns in the usual geochemical order for the major elements (Fig. 5). Using pXRF, sodium cannot be detected and the precision with which magnesium content is determined is too poor.

The trace elements normally detected by XRF are given in the order of atomic numbers (Fig. 6). The black columns show the long-term precision of analysis by WD-XRF (for major elements cv % always is below 2%). The empty columns show the precision of pXRF of repeatedly measuring a standard ceramic sample of very fine Roman pottery (not a pressed powder!).

10 The coefficient of variation cv % is the relative standard deviation in percent. It is a measure for the error of a single measurement. For the error of analysis when averages of several measurements are used, it has to be divided though the square root of the number of measurements. This was made only in Figs. 5, 6, and 10 to show the errors of analysis by pXRF.

G296	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	Ce	Pb
	% by weight									ppm												
pXRF: monitor sample (G296), 147 measurements from March 2013 to November 2015 (polished surface)																						
aver	**61.47**	**0.79**	**17.04**	**5.72**	**0.029**	**0.89**	**2.83**	**3.20**	**0.34**	**153**	**147**	**42**	**32**	**222**	**186**	**147**	**27**	**123**	**18**	**518**	**124**	**23**
STD	2.14	0.02	0.95	0.04	0.006	0.22	0.02	0.03	0.03	9	11	5	9	16	3	2	2	2	1	32	26	4
cv%	3.5	2.1	5.6	0.7	21.4	24.5	0.9	0.9	8.9	6.1	7.7	11.2	27.0	7.0	1.9	1.5	9.1	1.9	8.0	6.3	21.4	15.1
WD-XRF, data calculated to dry basis																						
G296	62.14	0.75	19.10	5.51	0.041	2.30	3.09	3.20	0.31	135	140	71	27	123	172	144	30	122	17	480	82	18

Tab. 2 Repeated measurements of the monitor sample and analysis results by WD-XRF.

Monitor sample

The monitor sample used for routine measurements is a very fine ware ceramic cylindrical briquette (diameter = 2cm, h = 0.5cm) with parallel flat bases. Measurements are performed on one of the cylinder's smooth base surfaces, positioning the sample centrally in the measurement window. A measurement is taken at the start and end of each measurement session, and additional measurements are made if the session lasts for several hours. The average of the results of 147 measurements performed on the monitor sample between March 2013 and November 2015 can be seen in Table 2. In the case of pXRF, measurement precision (repeatability) is too poor compared to the range considered acceptable by the authors for WD-XRF measurements, except for the estimation of Fe, Ca, K, Rb, Sr, and Zr levels, although the accuracy may be acceptable for most elements apart from Al, Mn, Mg, Ni, Zn, and Ce. The concentration of Mg was only determined in five of the 180 measurements (WD-XRF result is MgO = 2.3%), whilst Ni levels were determined in 33 instances (in WD-XRF Ni = 71ppm) and Ce levels in 22 instances (in WD-XRF Cr = 82ppm).

Further tests of precision

As part of a project on Bronze Age pottery found in Romanian Banat, pXRF was used to determine the chemical composition of 591 ceramic sherds recovered from the following sites: Corneşti-Iarcuri, Corneşti-Cornet, Timişoara-Fratelia, Deta-Dudarie, Giroc-Mezcal, Peciu Nou, and Voiteni-Voite. Samples of these sherds were analyzed using a Niton XRF (XL3t900S GOLDD RF-Analyzer, MINING software, 50 kV, Ag anoda). The instrument was calibrated against twelve ceramic reference samples analyzed by WD-XRF, which were prepared in the form of round discs from ancient very fine ceramic sherds (Terra Sigillata, Campana) or from fine clay fired at 900°C by G. Schneider and M. Daszkiewicz. Analysis was conducted without helium, in a sample chamber, with an 8mm measuring spot and a measurement time of 120 seconds (30 seconds per filter).

The measured surface of each of the 446 ceramic sherds was prepared by creating a fresh fracture using pliers with tungsten carbide cutting edges (Fig. 7). Once the samples had been prepared, three measurements were taken at three different spots on the prepared fresh fracture surface of each sample. Additional measurements were performed on a total of twelve samples, which were selected based on the size of the ceramic sherds they were removed from (unfortunately, most of the 447 sherds were not large enough to use for all test measurements).

Caution 4: *It is very important what type of pliers are used to create the fresh fracture. The authors recommend that only pliers with tungsten carbide cutting edges (mosaic pliers) be used. This type of cutting tool, unlike ordinary pliers, allows the ceramic sample to be cut rather than broken, thus providing a more even measurement surface, which in turn ensures a smaller measurement error.*

Both the total precision of analysis and accuracy of analysis were tested for ceramic samples recovered from Cornești-Iarcuri. The precision of sampling was tested by performing measurements on the same sample at three different spots on the same surfaces of fresh fractures or cut cross sections. The fresh fractures were created using pliers with tungsten carbide cutting edges or by cutting with a diamond-saw (precision of sample preparation). Personal error was tested by getting two people to each make measurements and create fresh fractures surfaces on the analysed sherds (both individuals using the same pliers).

Further tests were carried out to evaluate what impact the fact that pXRF analysis was performed on original ceramic sherds (i.e. air-dry samples) had on measurement results. These tests involved firing samples, prior to measurements, at 900°C in the same conditions as samples prepared for analysis by WD-XRF (the authors perform WD-XRF measurements on samples after determining loss on ignition at 900°C). All of these tests were carried out on samples taken from one ceramic sherd using the same removal method.

Accuracy of measurement was tested by measuring reference materials. In addition, accuracy of analysis was further tested by comparing the results of pXRF measurements with the results of WD-XRF measurements performed on the same ceramic sherd.

Figure 8 illustrates sampling precision, i.e. the minimum, maximum, and average value of the coefficient of variation (cv %) calculated from measurements taken on three different surface spots of fresh fractures of 591 sherds. The sampling precision depends on the inhomogeneity of the sample, which for every element is different in a certain material. No results are shown for Na and La because these elements were not measurable by pXRF and for Mg, S, Cl, Ni, Cu, Sn, and Ce because they were mostly undetected. These calculations concern 591 samples. One sample was disregarded because the small surface of the fresh fracture made on it meant that only two measurements could be performed. The average sampling precision is relatively good, and lower than could

be expected given the experiences of Behrendt et al.[11] with coarse tempered sherds. It is less than 5% for Si, Ti, Fe, Ca, K, V, Rb, Sr, and Zr. Average sampling precision above 10% was observed solely for Mn and Pb, hence, for elements which we know are non-homogenously distributed within the matrix and affected by alteration effects. Relatively large differences in sampling precision were noted in individual samples; for example, the precision of sampling for Ti ranges from less than 1% to 28.7% (average cv% = 2.9%); however, the number of samples in which sampling precision was greater than 10% is small (2.2% of all samples). Among the total number of 591 sherds, the percentage of samples in which sampling precision was greater than 10% for individual elements is small (up to 17%), with the exception of Al, Mn, P, Cr, Zn, Y, Nb, Ba, and Pb (Fig. 9).

Coarse tempered sherds, despite featuring non-homogeneously distributed inclusions, yielded surprisingly good sampling precision. Grains of coarse sand size and gravel size are readily visible macroscopically in these sherds (Fig. 10), and with an 8mm measurement spot, these should produce an increase in sampling precision. Thus, the observed correlation, or rather its absence, must be linked to the type of inclusions. The results of structural-textural MGR-analysis[12] showed that gravel-size grains represent a grog temper of crushed pottery made from the same plastic raw material as the vessel to which the grog was added. Grog fragments and clay lumps[13] exhibiting the same thermal behavior after firing at 1150°C as the matrix of the analyzed sherd can be seen in Figure 11 (in Figure 12 is shown an example of inclusions of different clay). Analysis of thin-sections also confirmed that the grog, the clay lumps, and the sherd represent the same ceramic body; clay aggregates are also visible in some samples. Figure 13 shows the precision of sampling for samples containing 30% non-plastic inclusions of various grain sizes.[14]

Samples in which only grains of 0.1–0.5mm or of 0.1–1.0mm were observed are denoted by yellow and green circles, respectively; other samples also featuring grains in very coarse sand fraction and gravel fraction are marked with squares. Gravel-size inclusions do not significantly change sampling precision for the worse (except when

11 Behrendt, Mielke, and Mecking 2012.

12 For a short description of this method see chapter 3 in this volume.

13 Clay lumps = particles of the same clay as that used to make the ceramic body, clay aggregates = particles of a different clay than that used to make the ceramic body. Clay lumps may represent insufficiently broken down clay or fragments of crushed but unfired vessels (i.e. clay rather than grog), for example, pots that became misshapen during the drying process. Experiments have shown that it is not always easy to differentiate between grog, clay lumps, and unfired 'grog,' hence the authors often use the term 'grog/lump.'

14 The percentage of non-plastic ingredients was estimated based on a visual examination of sherds under a binocular microscope at a maximum magnification of 10x and comparison with reference cards (AGI data sheets 1982).

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O_5	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb
MD599	% by weight								ppm									
(CI036)	**pXRF measurements on the same spot of cut surface (every 30 minutes)**																	
	65.34	0.95	13.01	5.73	0.055	1.44	1.93	0.58	181	104	71	102	175	43	366	18	857	14
	65.95	0.96	13.19	5.76	0.050	1.45	1.94	0.56	195	105	82	102	178	43	365	18	802	13
	65.77	0.95	13.17	5.76	0.063	1.48	1.91	0.57	187	121	74	100	177	44	371	17	889	13
	65.83	0.94	13.33	5.76	0.054	1.48	1.96	0.55	195	137	71	102	176	43	368	21	848	16
	66.08	0.96	13.01	5.72	0.056	1.46	1.99	0.57	181	111	73	104	176	40	368	20	897	12
	66.19	0.95	13.26	5.73	0.067	1.47	1.97	0.55	202	113	63	100	174	43	368	20	906	15
	66.18	0.96	13.38	5.70	0.064	1.46	1.96	0.57	184	123	66	101	174	46	369	16	805	15
	66.03	0.96	12.99	5.75	0.056	1.46	1.99	0.57	176	132	79	102	175	44	372	17	822	13
	65.58	0.96	13.04	5.71	0.055	1.47	1.97	0.53	182	104	70	105	178	43	361	19	836	15
	66.46	0.96	13.55	5.84	0.061	1.46	1.96	0.58	192	97	70	100	176	45	371	19	841	14
	66.29	0.97	13.22	5.78	0.053	1.47	1.97	0.57	181	126	76	102	181	41	368	19	880	15
	65.92	0.96	13.19	5.74	0.055	1.49	1.98	0.56	192	119	68	105	173	44	368	17	879	16
	66.14	0.95	13.20	5.73	0.056	1.49	1.97	0.57	181	134	70	99	173	44	370	20	838	16
	65.77	0.97	13.18	5.74	0.049	1.48	1.95	0.56	191	117	73	105	175	40	370	20	805	10
	66.11	0.96	13.26	5.74	0.056	1.45	1.99	0.55	175	111	72	97	178	41	371	18	841	17
	65.98	0.95	13.50	5.73	0.055	1.47	1.95	0.59	190	127	66	100	171	43	367	16	867	15
mean	65.98	0.96	13.22	5.75	0.057	1.47	1.96	0.56	187	118	71	101	176	43	368	19	851	14
std ±	0.28	0.01	0.16	0.03	0.005	0.01	0.02	0.01	8	12	5	2	2	2	3	2	33	2
cv%	**0.42**	**0.94**	**1.23**	**0.55**	**8.55**	**0.94**	**1.16**	**2.55**	**4.1**	**10.0**	**6.7**	**2.3**	**1.4**	**4.0**	**0.8**	**8.5**	**3.9**	**11.9**
	precision calculated from measurements on three different spots on fresh fracture of the same sample CI036																	
cv%	**1.08**	**1.07**	**1.36**	**0.66**	**4.20**	**3.27**	**0.88**	**11.83**	**6.3**	**3.1**	**4.2**	**0.6**	**2.7**	**8.0**	**2.0**	**3.2**	**6.4**	**9.9**
	precision calculated from measurements on three different spots on fresh fractures (n = 591)																	
cv% (aver.)	**4.30**	**3.91**	**7.12**	**4.41**	**21.22**	**7.01**	**4.10**	**10.60**	**5.9**	**10.4**	**7.6**	**3.8**	**4.2**	**9.0**	**3.6**	**8.3**	**6.9**	**18.3**

Tab. 3 Coefficients of variation cv % of repeated measurements of a monitor sample compared to the average cv % of measurements on three spots of 591 samples (differences are not significant only for V, Zn, Cr, and V).

determining Mn and P levels); in this instance, it is the type of inclusions rather than their size that has the greatest impact on sampling precision.

To counter these issues and further assess the precision of measurement, another test was employed. This involved measuring the same spot every 30 minutes over an 8-hour period and measuring on three different spots of the same sample (Tab. 3). The error of measurement noted for the 16 measurements, as expected, was significantly lower[15] than the error calculated from three measurements per sample (calculated for 591 samples), but not for all elements (V, Zn, Cr, and Nb, for which it seems that the sherds are more homogeneous). Similar results were received with other projects by other authors.[16]

Caution 5: *Elements determined with worse precision than the acceptance criterion for a given element should not be taken into account in the interpretation of analysis results. If only single results fail to meet the acceptance criterion, checks should be made for gross errors*[17] *and only those samples where an incorrect measurement has occurred should be discarded. Generally,*

15 Fisher F-Test for P = 95%

16 Behrendt, Mielke, and Mecking 2012.

17 Gross error is an unsystematic error. It occurs when the result of one of the measurements deviates significantly from the others and it can be assumed that this deviation is a random (unexplained) anomaly.

measurements must be made on different spots and the averages of at least three spots taken for interpretation.

Tests of accuracy

To test the accuracy of pXRF analysis, multivariate cluster analysis[18] (using the average value from three measurements) was the next procedure to be carried out. This determined the concentration of those elements that the authors usually investigate in this type of analysis (the routine procedure was the same as for the results obtained by WD-XRF: based on experience in the comparison of chemical data, two samples are identical (i.e. the differences are within the limits of precision) if they yield matching levels of all analyzed and significant elements (e.g. not including phosphorus).[19] In this case, cluster analysis was performed using Euclidean distance and average linkage **aggregative clustering of a distance matrix** and logarithmic transformation of data. The elements used were: Si, Ti, Al, Fe, Mg, Ca, K, V, Cr, Rb, Sr, Y, Zr, Nb, and Ba. The results of the multivariate analysis and analysis of original pXRF data using the finger method[20] formed the basis for selecting 170 samples for abridged MGR-analysis. Having completed this analysis, MGR-groups were compared with chemical clusters and then 103 samples were selected for chemical analysis by WD-XRF. Once the WD-XRF results had been obtained, a Student's t-test for paired data was performed for individual elements determined in 103 samples in order to verify at the 0.01 significance level the hypothesis that element concentrations determined by pXRF (on fresh fractures of air-dry samples) differ from those determined by WD-XRF.[21] The t-test results confirm that the type of analytical technique used has a major impact on determining the concentrations of individual elements, with the exception of Fe and Cr (these elements are also characterized by good sampling precision).

Caution 6: *The tests performed clearly demonstrate that the measured concentration of individual elements in the sample depends on the technique of analysis used. Concentrations of the same elements in the same sample will be different when the sample is analyzed by WD-XRF (the same applies to NAA, ICP-MS, etc.) than when it is analyzed by pXRF. This means that analysis results obtained by WD-XRF and by pXRF cannot be compared directly. Therefore, it is*

18 Multivariate cluster a*nalysis,* discriminant analysis, and principal components analysis *were all carried out using* the SYSTEM Package on license from the *Weierstrass Institute for Applied Analysis and Stochastics, Leibniz Institute in Forschungsverbund Berlin e.V.*

19 This is the basis of provenance studies and is done by WD-XRF, NAA, or ICP-MS yielding data on 25 to 30 elements with good precision (e.g. G. Schneider and Mommsen 2009). Multivariate cluster analysis based on fewer than about 15 elements may produce doubtful provenance groups.

20 Or 'by eye' as it is sometimes referred to.

21 The results of WD-XRF analysis for this comparison were recalculated to a dry (non-ignited) basis.

very important to avoid simply stating 'chemical analysis by XRF' in publications and presentations (a mistake which happens all too often). It should be made very clear whether elements were measured by WD-XRF or by pXRF.

The next test examined personal error. It was clear from the results of this test that this particular error had a profound effect on the total precision of analysis. Comparisons were made of the average values of a given element, calculated using three measurements taken from identically prepared fresh fracture surface measurement spots. The two individual operators performing these measurements made a fresh fracture surface using the same tool, and the measurements were carried out in the same conditions. The operators were not told that they were taking part in a test. The results reveal a great degree of variation in the concentrations of specific elements, up to two-fold differences being noted in some cases (Al and Ba). However, for Si, Ti, Fe, K, Rb, and Zr, the differences in results of the two persons were almost the same as the average sampling error calculated for 591 samples, whilst for all other elements, apart from Al and Ba, they were smaller than the average sampling error (Fig. 14). The differences in the average value of individual elements can be seen in Figure 15, where the pXRF results of the two persons as an example, for one sample were compared to the results obtained by WD-XRF (red line in Fig. 15). Both operators obtained similar results, matching the WD-XRF results only for Ti, Rb, and Sr levels. In a situation where two individuals perform measurements, personal error is not a systematic error that can be corrected by a specific factor.

Caution 7: *The test described above showed that personal error has a greater impact on pXRF measurements than, for example, on preparations carried out in the laboratory for WD-XRF. The optimal solution would be for only one operator to do all of the measurements for one project. Personal error results in quite significant differences in accuracy between individual measurements, though these are only statistically significant (P = 99%) in determining levels of Si and Al.*

Tests were also conducted to assess the precision and accuracy of different sample preparation methods. Therefore, pXRF analysis was carried out on:

- fresh fractures,
- fresh fractures of samples refired at 900°C (same firing conditions used as when determining loss on ignition at 900°C in the preparation of samples for WD-XRF analysis),
- fresh fractures of samples refired at 1000°C,
- cut surfaces,

– cut surfaces of samples refired at 900°C (same firing conditions used as when determining loss on ignition at 900°C in the preparation of samples for WD-XRF analysis), and

– cut surfaces of samples refired at 1000°C.

The results of these tests demonstrated that better precision was achieved by performing measurements on cut surfaces than on fresh fractures. An improvement in the precision of measurements on fresh fractures was noted when samples were ignited at 900°C before measurement; the difference was smaller for measurements on cut surfaces. The results of an assessment made to examine whether these differences were statistically significant can be seen in Figure 16.

The F-test revealed that there is a 99% probability that the difference in variances between measurements (performed on fresh fractures as well as on cut surfaces) on original samples and samples ignited at 900°C is not statistically significant in the ceramic sherds analyzed for this project.[22] In the case of samples ignited at 1000°C, there is a 99% probability that the difference for measurements performed on a fresh fracture surface is significant for Si, Al, Ca, and K levels (for Ti and Mn concentrations only at a 95% level). A different situation was observed comparing the results of measurements made on fresh fractures and cut surfaces of original samples (air-dry): there were statistically significant differences (P = 99%) in Si, Ca, and P concentrations (at levels of 95% also Ti, Al, Fe, and K). The results of tests carried out as part of the project examining pottery from the Banat region revealed that pXRF analysis can be limited to measurements made on the fresh fracture surfaces of air-dry samples. Laborious steps to improve precision and accuracy of analysis, such as the preparation of smooth cut surfaces and ignition of samples, only have a statistically significant impact on determining the concentrations of a very small number of elements.

Caution 8: *Different sample preparation methods result in* ***statistically significant differences in the*** *precision and accuracy of some major elements. It is recommended to make all measurements on fresh fracture surfaces of air-dry samples (see caution 4).*

The variable geometry of samples (e.g. of small bended sherds) may cause different results when taken on different spots. To counter these issues and further assess the precision of measurement, another test was employed on seven experimental hemispherical samples. Here, the bended upper side, the flat underside, and the fracture were measured (Fig. 17). The comparison to the WD-XRF results shows systematic differences.

22 N.B. These conclusions are only valid for the pottery analyzed as part of this project; they are not general conclusions applicable to all types of ceramics.

The raw material has lower concentrations because of its loss on ignition. Measurements on fired samples show large differences. The values of Si and Al are highest on the hemispherical surface because of geometry (it is nearest to the detector).

Caution 9: *The variable geometry of samples has a large impact on the precision with which levels of Ca, P, Si, and Zr are determined.*

Both, chemical analysis by WD-XRF and pXRF was carried out on 135 ceramic sherds, and the results of these analyses were used to test accuracy. The accuracy of pXRF analysis on fresh fracture surfaces (air-dry samples) was tested by comparing its results with those of WD-XRF analysis. The WD-XRF results, recalculated to a dry basis, were compared with the average from three pXRF measurements taken on various spots. Figure 18 shows the minimum and maximum accuracy of pXRF analysis (n = 135), as well as the minimum and maximum precision of the averages of always three measurements (n = 591). This collated data reveals that maximum values are below 30% for nine elements: Ti, Fe, K, Cr, Zn, Rb, Sr, Zr, and Nb.

The blue points in Figure 19 represent the number of samples for which the precision of analysis is worse than 10%. Only for four elements (Fe, K, Cr, and Rb) the number of samples with both errors larger than 10% does not exceed 20% of all samples. The number of samples with an accuracy (red points) worse than 10% was lowest for the determination of Fe and highest for Si, Al, P, V, and P (over 90% of all samples). The number of samples for which individual elements were determined with an accuracy worse than 10% ranges from 132 samples in the case of Al to five samples in the case of Fe. The deviating results for five samples in the case of Fe probably represent a gross error.

Caution 10: *After testing the accuracy of analysis by pXRF, it is possible to conclude which element concentrations have been determined in keeping with the acceptance criterion (using a particular sample preparation method). Subsequently, a list of these elements should be compared with the results of the precision of analysis tests (for the same method of preparation). Those elements whose concentrations were determined by pXRF with good accuracy and precision should be considered significant.* ***For pXRF measurements, the authors accepted average accuracy < 10% for major and trace elements, average precision better than 5% for major elements, and average precision of up to 10% for important trace elements and not lower than 20% for other trace elements.***[23]

23 In the case of the pottery analyzed from sites in Banat discussed herein, no element concentrations were determined with better than 2% precision (average coefficient of variation), which also holds true for WD-XRF analysis carried out by the authors for major elements (except Na). Levels of the trace elements V, Cr, Ni, Zn, Rb, Sr, Y, Zr, and Ba were determined by WD-XRF with long-term precision (measurement and preparation) ranging up to 3%, and up to 6% for Nb, Cu, and Ce (for trace elements at very low concentrations this may rise to 15–20).

Caution 11: *Given that it is not possible to determine the Na content (and mostly also the Mg content) of samples and because the original sum of the major elements in pXRF measurements is usually much less than 90%, after several tests the authors believe that the content of major elements should not be normalized to a constant sum of 100%.*

Examples of groupings based on analysis by pXRF and WD-XRF

Grouping of pXRF analysis results without knowing the outcome of tests verifying which elements were determined with precision and accuracy meeting the acceptance criteria

Following chemical composition analysis by pXRF, 447 ceramic sherds found at various sites in Romania Banat were grouped using multivariate cluster analysis featuring all of the elements determined by both techniques. The resultant groups had to be verified by chemical analysis using WD-XRF. To this end, samples were selected from every group: one sample from each small group and several from each larger group. The first assessment of pXRF results looked at a group of sherds that had distinctly higher levels of Y than the other samples. Figure 20 shows the pXRF (triangles) and WD-XRF (squares) results for Y versus Zr content and Y versus Rb content. In both cases, three groups emerge from the pXRF results: a so-called local group, a so-called regional group, and a group of samples with a higher concentration of Y. The third group, which was not produced by the WD-XRF results, is visible in bivariate diagrams and in PCA using all elements determined with sufficient precision and accuracy (Ti, Fe, K, Cr, Zn, Rb, Sr, Y, Zr, and Nb) (Fig. 21). The Y-group, however, only exists in the pXRF results.

WD-XRF analysis of the samples in this group yielded results that showed that their Y content does not deviate from the Y content of the remaining samples. Bivariate diagrams of Fe versus Cr, Ti, Zn, Rb, K, and Zr, respectively, are presented in Figure 22. In each diagram, only the local and regional groups are evident, both using the pXRF and the WD-XRF results.

Caution12: *Not all groups identified based on the results of chemical analysis by pXRF are real groups. It is important to verify each group, even if the grouping fits in with the assumptions made by the analyst (or archaeologist).*

If chemical composition determined by pXRF technique is used as the basis for classification in a down-up strategy (see chapter 3 in this volume), it is vital to bear in mind that the initial clusters must be verified in the 'up' part of the classification using only well determined elements (which do not have to be the same for each project, as evinced by the analyses carried out by the authors).

Multivariate cluster analysis of analyses by pXRF and WD-XRF

Multivariate cluster analysis was carried out on 60 samples found in Corneşti-Iarcuri (Banat), which had undergone chemical analysis by both pXRF and WD-XRF. All cluster analyses were performed using Euclidean distance and average linkage **aggregative clustering of a distance and** logarithmic transformation of data; the results of analysis by WD-XRF were recalculated to dry basis. Element concentrations determined using both techniques are shown in the form of a dendrogram in Figure 23 (elements used: Si, Ti, Al, Fe, Mn, Ca, K, V, Cr, Zn, Rb, Sr, Y, Zr, and Nb).

Further multivariate cluster analysis was performed using only those elements that tests indicated had been determined with good average accuracy and good average precision using the pXRF technique (Ti, Fe, K, Cr, Zn, Rb, Sr, and Nb), as well as Zr, which was determined with good average precision, but with poorer accuracy. Zr was included because of the significant differences in its content between the so-called regional group (pottery found at several sites) and other groups (groups comprising pottery identified as local at individual sites and pottery from beyond the region) – for a description of pottery groups see chapter 4.5 in this volume.

The difference in Zr content between these groups is much greater than two-sigma level. Figure 24 shows that when elements which were well determined by pXRF are used, this yields no obvious clusters associated with the analysis technique. Sherds representing local and regional wares form distinct large clusters, irrespective of which analytical technique was used, a division into results produced by pXRF and WD-XRF can be seen within the clusters. This means that if multivariate cluster analysis is applied to data obtained by pXRF using elements determined with good average accuracy and good average precision, major groups can be identified and samples that have a significantly different chemical composition can be very clearly distinguished. PCA carried out on pXRF results using the same well determined elements also yielded the same general divisions as WD-XRF (Fig. 25).[24] Examples of analysis results are given in Table 4 for sample MD541, which appears side-by-side in the dendrogram, and for sample MD573 placed by pXRF in the first cluster (yellow), whilst WD-XRF results place it in cluster 2 (green).

Precision and accuracy detected from different projects

Figure 26 presents details of the precision and accuracy of major and trace element analysis for five different projects.[25] This collated data shows that lists of elements deter-

24 The distinction of MGR-groups within the local groups 101–106 cannot be recognized in the chemical data (Figs. 23–24).

25 Samples from Horodysko for test measurements were provided by Dzieńkowski and P. Łuczkiewicz, from Nieszawa by M. Stasiak-Cyran.

Chemical analysis	Lab. No.	TiO_2	Fe_2O_3	K_2O	Cr	Zn	Rb	Sr	Zr	Nb
		wt.%			ppm					
pXRF	MD541	0.81	5.41	2.07	97	101	93	184	272	13
WD-XRF - l.o.i.	MD541	0.83	5.37	2.20	100	108	98	194	309	14
pXRF	MD573	0.80	5.22	2.30	98	86	114	157	246	17
WD-XRF - l.o.i.	MD573	0.89	5.55	2.66	106	100	128	186	295	14

Tab. 4 PXRF and WD-XRF results for two samples clustered in the same group (MD541) and in different groups (MD573).

mined with good precision and accuracy cannot be known *a priori*. The differences seen between individual projects mostly stem from sampling error (sampling precision), hence, they are linked to both the structural-textural characteristics of the analyzed ceramic sherds and to the size of the samples. The diverse structure and texture of samples results in different types of fresh fracture surfaces, which means that the geometry of the surfaces prepared for measurement will differ – this in turn affects the accuracy of analysis. The presence of various coarse non-plastic inclusions in the sherd will also have an impact on precision and accuracy; for example, coarse tempered pottery analyzed as part of the Lossow project is notable for featuring the greatest number of elements determined with unsatisfactory precision and accuracy.

Table 5 presents elements analyzed by authors by WD-XRF in ceramics and generalized information of the precision and accuracy of analysis by pXRF based on experiences that the authors have gained while working on six various projects (beyond those of this volume). Elements that are important in provenance studies of pottery are marked in bold.

General cautions

Portable XRF analyzers must be handled and used with care to minimize radiation risks. Samples should not be held in the hand during analysis. The use of a sample chamber, backscatter shields, or a test stand is recommended.

The following remarks are based on experiences that the authors have gained while working on various projects (beyond those of this volume).

(1) A pXRF spectrometer is a good tool to use for quick classification. Hitherto, the selection of samples for cost-intensive laboratory analyses was based on frequently unreliable macroscopic descriptions, whereas now decisions about

atomic number	Element name	symbol	pXRF precision and accuracy of analysis
11	sodium	Na	cannot be detected
12	**magnesium**	Mg	not useable
13	aluminium	Al	bad
14	silicon	Si	bad
15	phosphorus	P	bad
16	sulfur	S	bad
17	chlorine	Cl	bad
19	**potassium**	K	sufficient
20	**calcium**	Ca	moderate to sufficient
22	**titanium**	Ti	sufficient
23	**vanadium**	V	bad
24	**chromium**	Cr	bad to moderate
25	manganese	Mn	bad
26	**iron**	Fe	sufficient
28	**nickel**	Ni	bad / not usable
29	copper	Cu	bad
30	zinc	Zn	moderate
37	**rubidium**	Rb	good
38	**strontium**	Sr	good
39	**yttrium**	Y	sufficient
40	**zirconium**	Zr	sufficient
41	niobium	Nb	good
56	barium	Ba	moderate
57	lanthanum	La	cannot be detected
58	cerium	Ce	moderate
82	lead	Pb	bad / not usable
90	thorium	Th	cannot be detected

Tab. 5 Elements analyzed in ceramics by WD-XRF (Schneider and Daszkiewicz) and accuracy and precision of analysis by pXRF. Elements marked in bold are important in provenance studies.

which samples to select for further analyses can be based both on macroscopic studies and on the results of pXRF (down-up sampling classification strategy, see chapter 5 in this volume).

(2) Combining pXRF analysis with a *down-up* classification strategy produces very good results. Chemical composition analysis using the pXRF technique should be used to classify sherds before they undergo MGR-analysis. However, the first step to take is to carry out a small pilot series to ascertain which ele-

ments in the project have been determined with good precision and accuracy. In addition, checks should be made to evaluate whether the size, number, and type of non-plastic inclusions in the pottery will result in erroneous attributions.

(3) Determining the chemical composition of pottery using pXRF will allow the ceramic sherds to be grouped in the same major clusters as when using WD-XRF, though only elements determined with good precision and accuracy should be taken into consideration.

(4) Wrong data may produce statistically significant groups (e.g. the Y-group of Corneşti). Therefore, it is important to verify the groups received by pXRF using other methods (MGR-analysis, WD-XRF, and thin-section studies). Elements estimated with bad accuracy but good precision may yield reliable groups if differences are more systematic than random. It is important to stress that pXRF results cannot be used to establish chemical reference groups that form the basis of precise provenance determinations.

(5) It must be remembered that precision and accuracy for individual elements may be different in various projects. Therefore, a pilot series of analyses should be performed for each project.

(6) Tests demonstrate that there is no need for pXRF measurements to be made on cut surfaces or on ignited samples. It is equally acceptable to perform these measurements on the fresh fracture surface of an air-dry sample.

(7) Personal error may be an important factor to take into consideration. To limit its impact, the number of operators carrying out the measurements should be kept to a minimum.

(3) The results of chemical analysis by WD-XRF done on ignited samples must be calculated to a dry (non-ignited) basis before the comparison with the measurements done by pXRF. When analysis of raw materials is made for comparison it should be made after firing them at the same temperatures.

(4) pXRF may be a useful tool to analyze the composition of surfaces. Model analysis and analysis of ancient pottery have shown that pXRF can yield information about: the possible use of plaster molds, the possible use of vessels for salt brewing, alteration effects, and the composition of coatings.

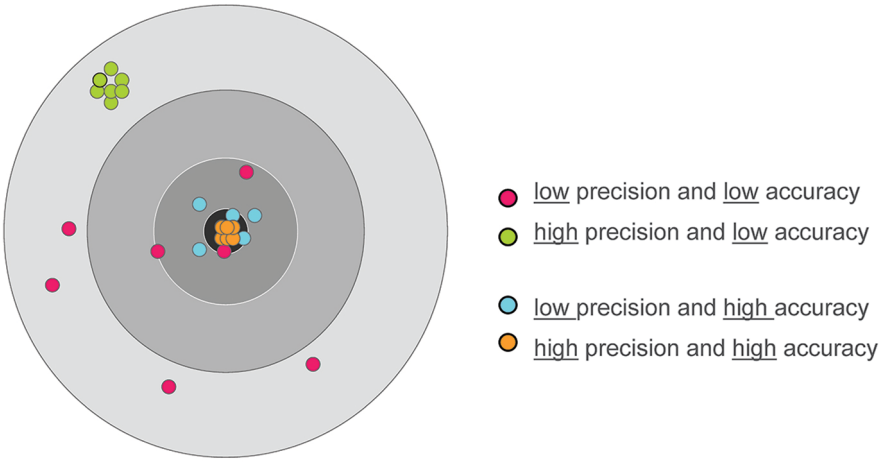


Fig. 1 Precision and accuracy.

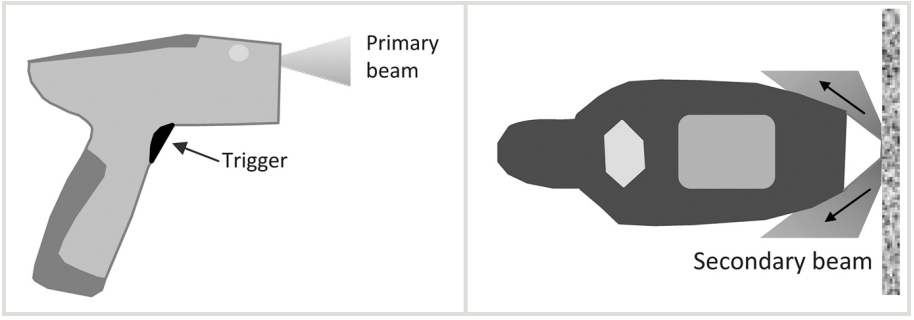


Fig. 2 PXRF: primary beam and back scattered x-rays.

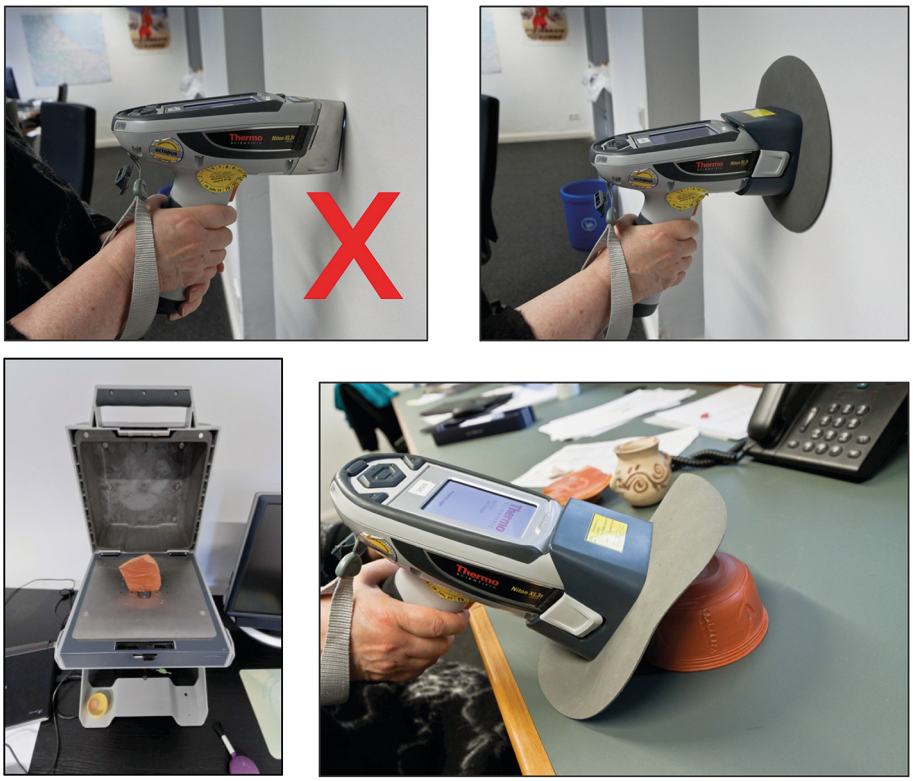


Fig. 3 Use of the handheld pXRF analyzer with protection shield and sample chamber.

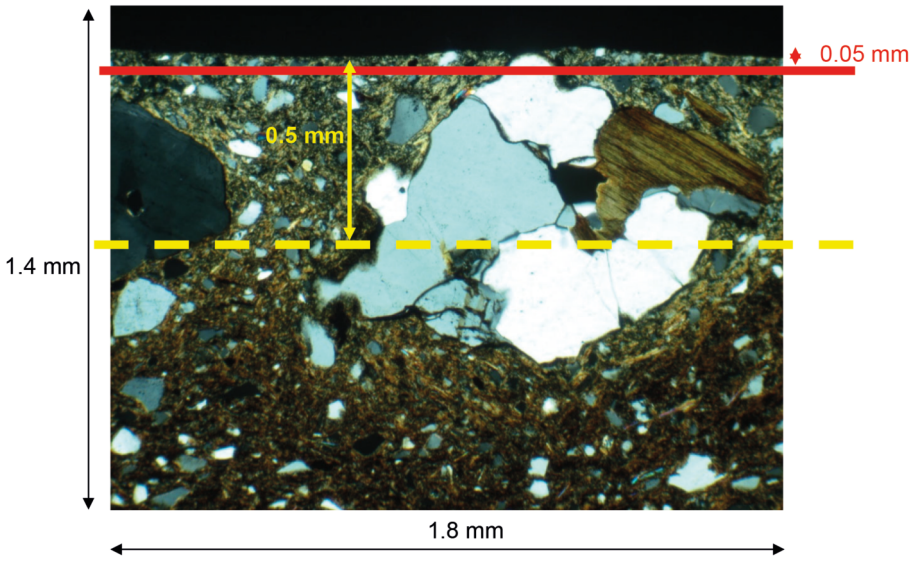


Fig. 4 Depth of information in coarse pottery (between < 0.05mm for major elements and about 0.5mm for rubidium, strontium, and zirconium).

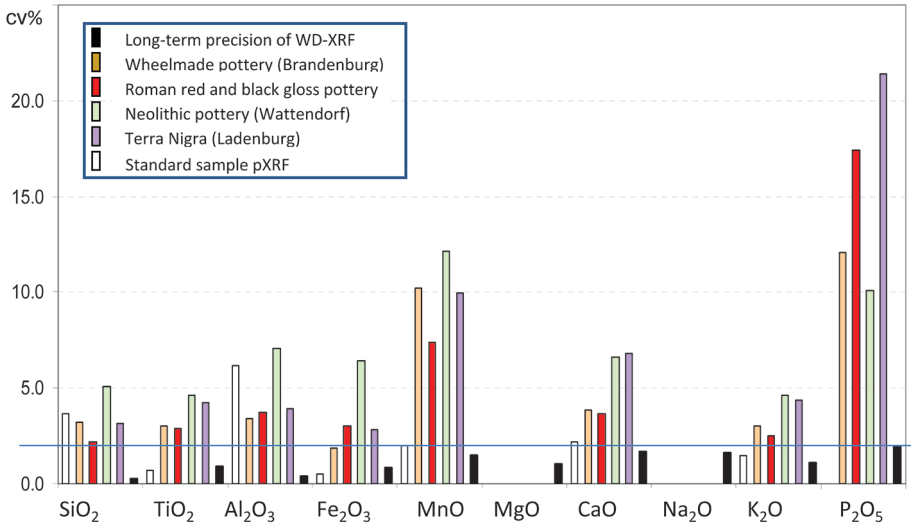


Fig. 5 Precision of pXRF analysis (error of the averages of four measurements) for major elements (colored columns are for different pottery examples) compared to long-term precision of single analysis by WD-XRF (black columns): major elements (the cv of the latter is generally below 2%).

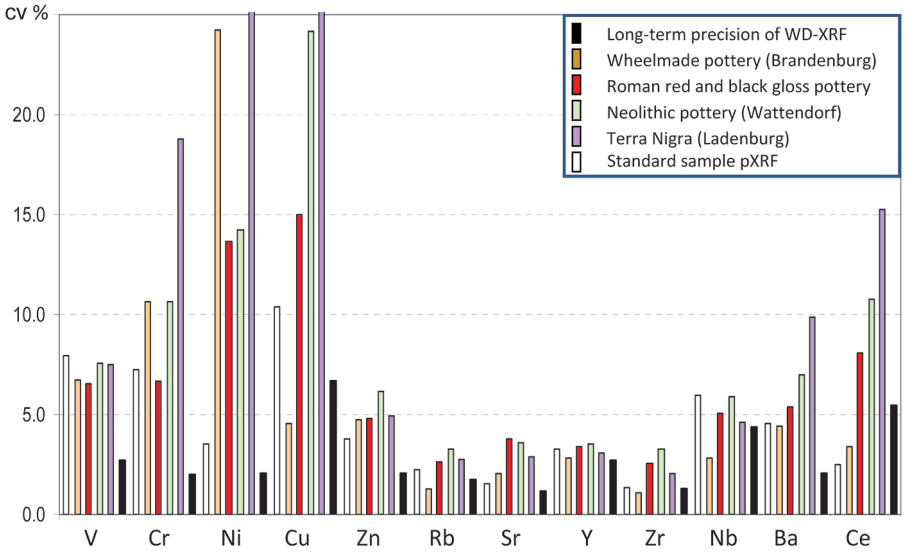
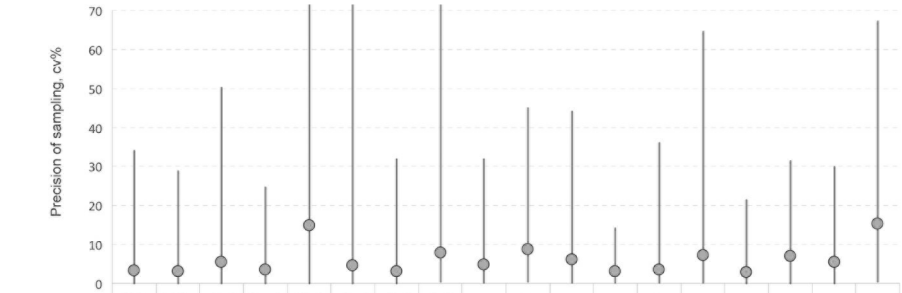


Fig. 6 Precision of pXRF analysis compared to long-term precision of WD-XRF for trace elements (as Fig. 5).

Fig. 7 Pliers with tungsten carbide cutting edges (used for mosaics) for optimal use in knapping pottery samples or producing fresh fracture surfaces for macroscopic description or pXRF measurements.



n = 591	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O_5	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb
max	34.0	28.7	50.2	24.6	175.1	85.5	31.8	76.7	31.8	44.9	44.1	14.2	35.9	64.4	21.5	31.3	29.9	67.2
min	0.02	0.07	0.11	0.11	0.00	0.07	0.02	0.51	0.16	0.40	0.25	0.16	0.19	0.15	0.10	0.06	0.10	0.47
geom.average	3.2	2.9	5.5	3.4	14.8	4.5	3.1	7.8	4.8	8.7	6.2	3.1	3.4	7.1	2.9	7.0	5.5	15.2

Fig. 8 Sampling precision cv % calculated for individual samples from measurements taken on three different surface spots of fresh fractures.

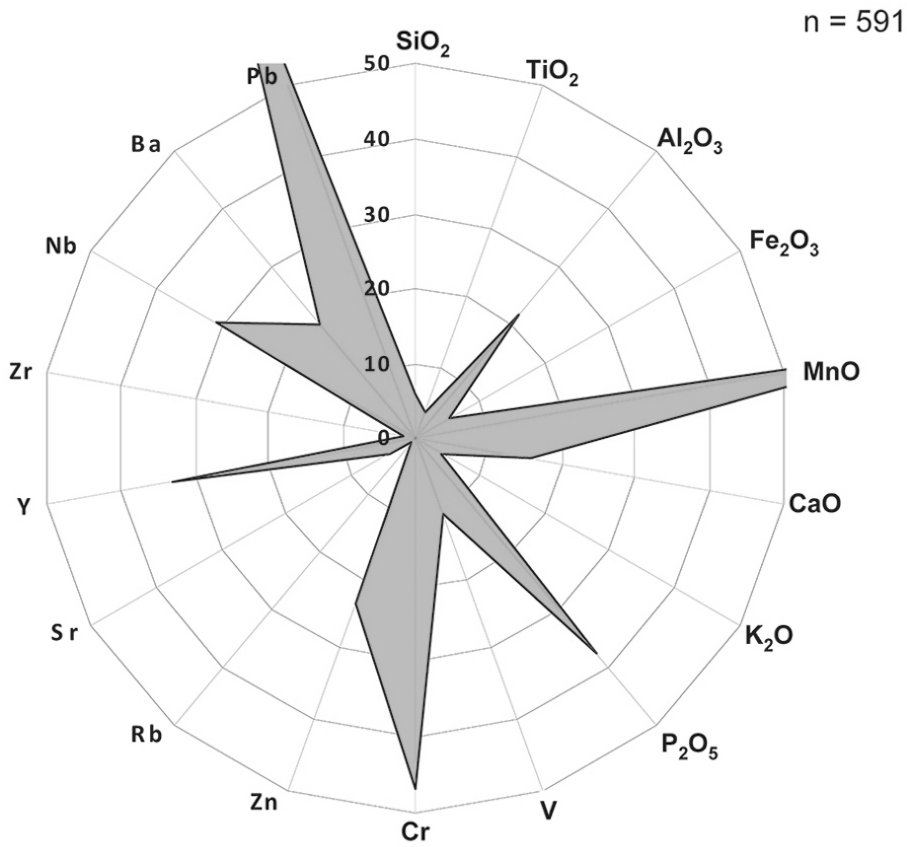


Fig. 9 Proportion of samples with a sampling precision cv exceeding 10%.

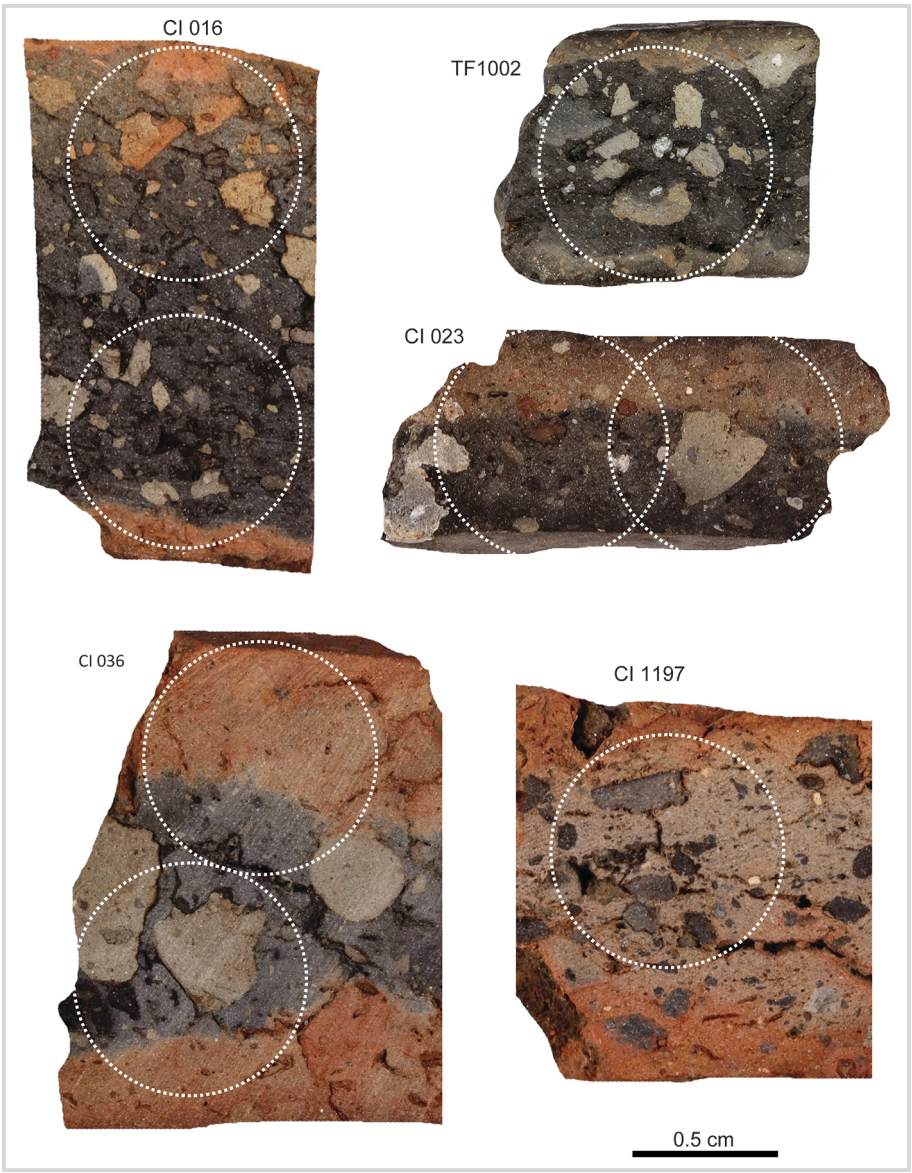


Fig. 10 Areas of 8mm measured by pXRF of coarse grog-tempered sherds from Cornești-Iarcuri.

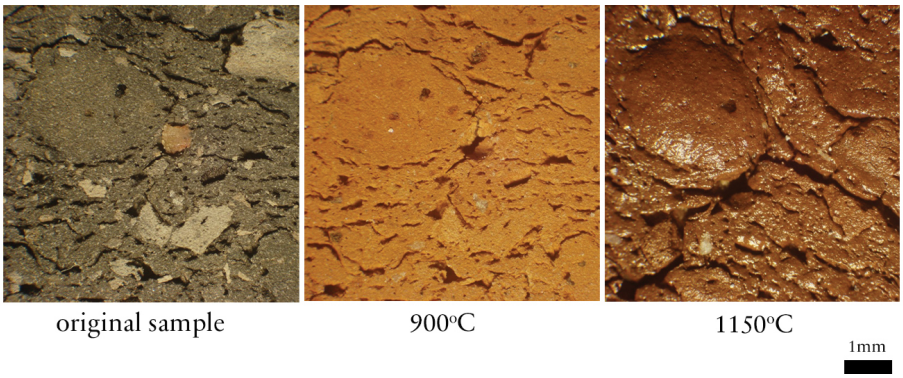


Fig. 11 Example of grog inclusion of the same composition as the matrix (refiring at 900°C and 1150°C, st MGR-analysis).

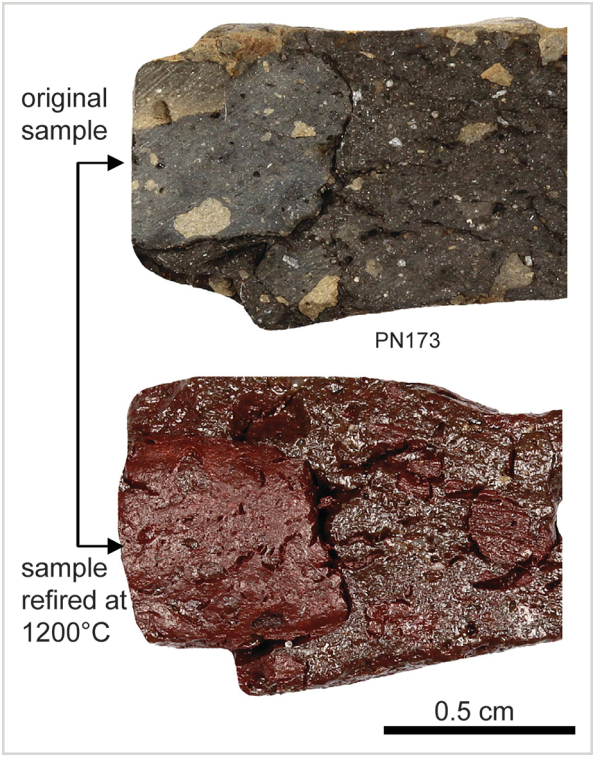


Fig. 12 Example of inclusions of clay with a composition different from the matrix (refiring at 1200°C, a MGR-analysis).

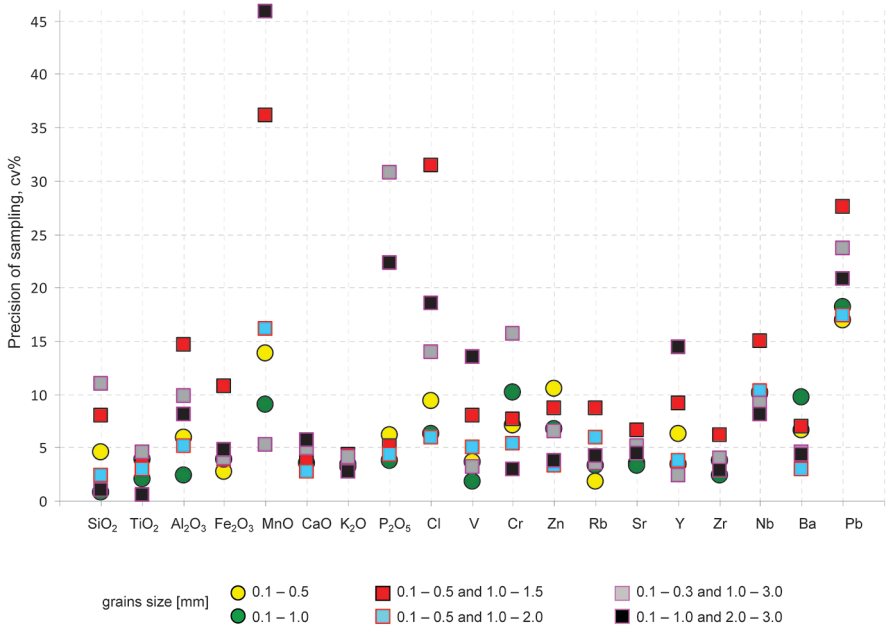


Fig. 13 Sampling precision cv % for samples containing 30% non-plastic inclusions of various grain sizes.

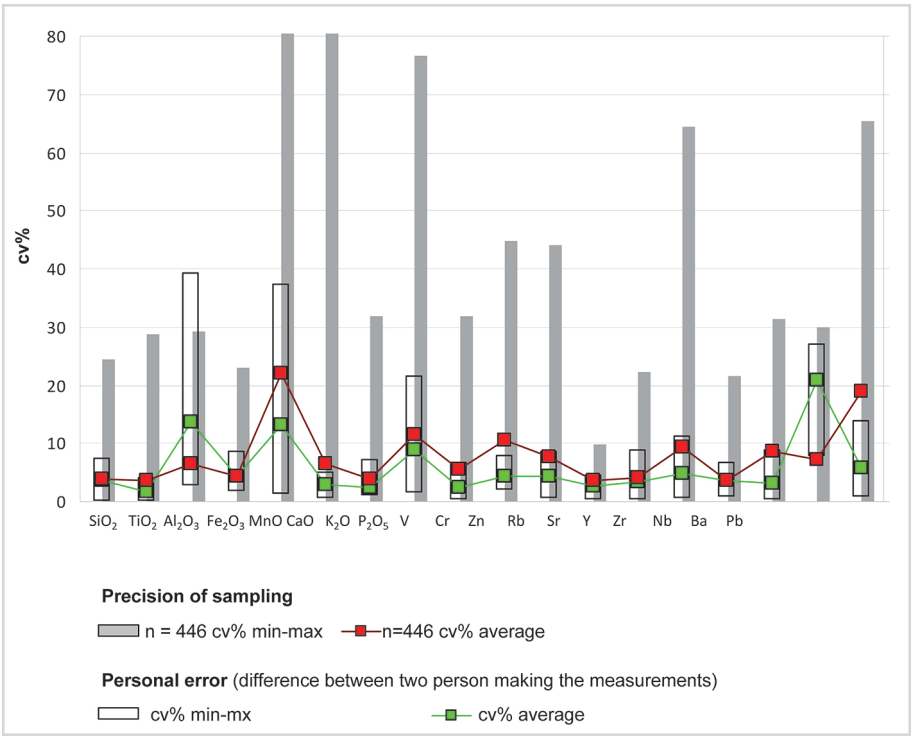


Fig. 14 Sampling precision compared to differences in the pXRF results, as measured by two persons.

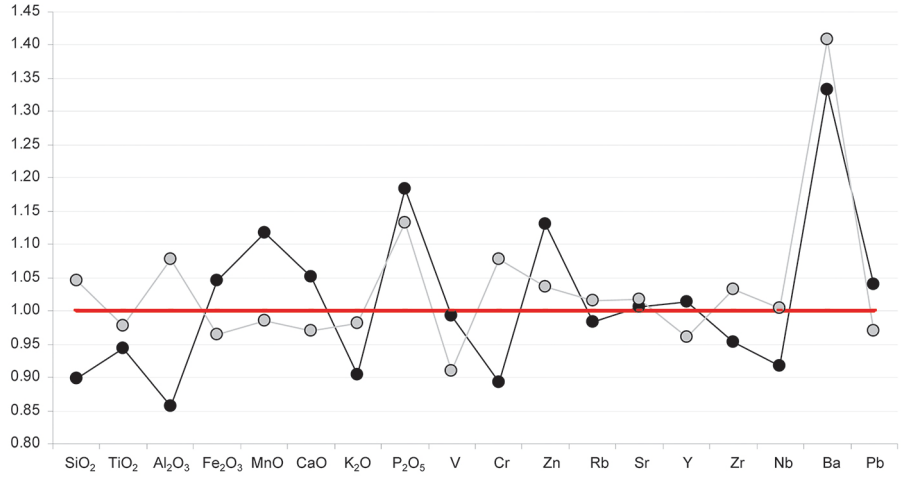


Fig. 15 Differences in results of the same sherd analyzed by WD-XRF (red line) and by two people using pXRF.

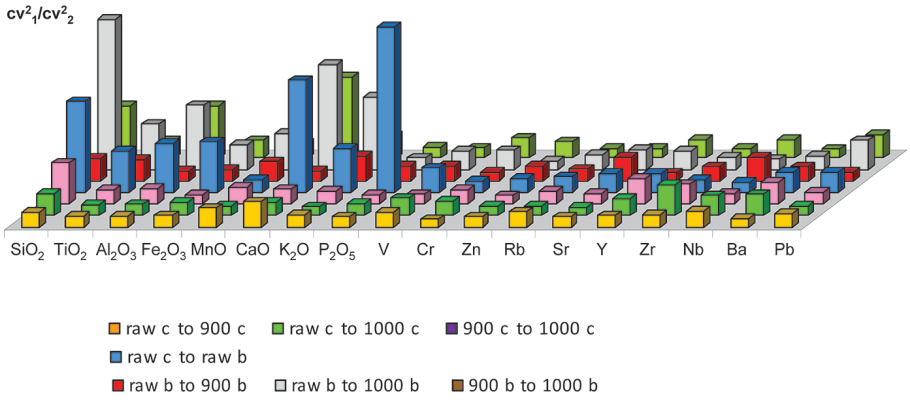


Fig. 16 Fisher-test proving the significance of differences in precision using different preparation methods: raw (original sample) vs. 900 or 1000 (samples refired at 900°C respectively 1000°C), measuring on fresh fracture surfaces (b) or cut sections (c).

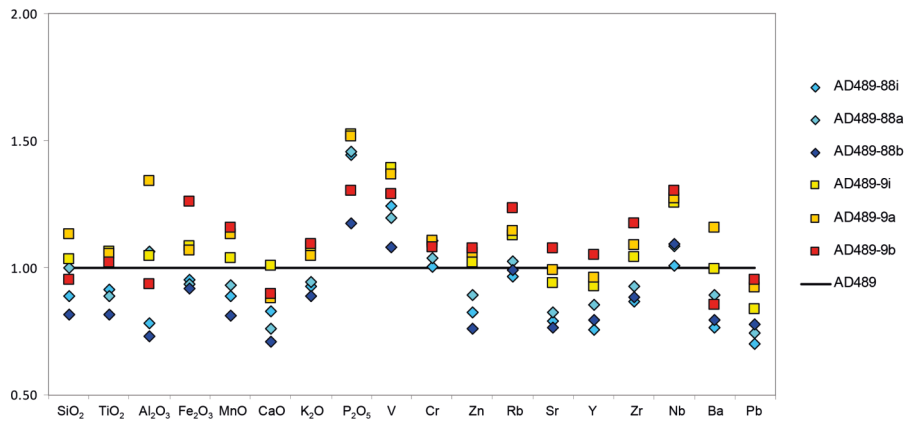
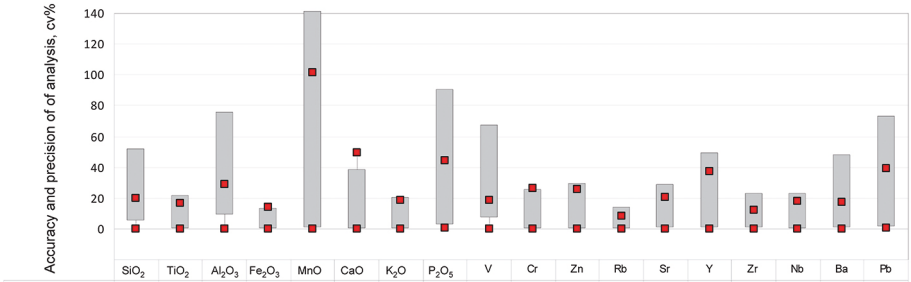


Fig. 17 Comparison of pXRF measurements and WD-XRF results for a clay sample prepared as a hemispherical specimen with the WD-XRF results: blue colors = samples from raw clay (AD489-88 (I = flat surface, a = hemispherical surface, and b = fracture surface) and yellow and red colors = specimens fired at 900°C.



	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	K_2O	P_2O_5	V	Cr	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb
min cv% accuracy	5.0	0.02	8.7	0.02	0.3	0.1	0.03	2.6	6.9	0.01	0.23	0.02	0.5	0.3	0.3	0.05	0.6	1.0
max cv% precision	19.7	16.6	29.0	14.2	101.2	49.4	18.4	44.3	18.4	26.0	25.5	8.2	20.8	37.3	12.4	18.1	17.3	38.9
min cv% precision	0.01	0.04	0.06	0.06	0.21	0.04	0.01	0.29	0.09	0.23	0.14	0.09	0.11	0.09	0.06	0.04	0.06	0.27
max cv% accuracy	52.2	22.0	75.5	13.1	141.4	38.5	20.3	90.3	67.3	25.4	29.2	13.9	28.8	49.1	23.3	22.9	48.1	73.1

Fig. 18 Precision and accuracy of analysis by pXRF using always averages of three measurements (for precision n = 591, for comparison with WD-XRF n = 135).

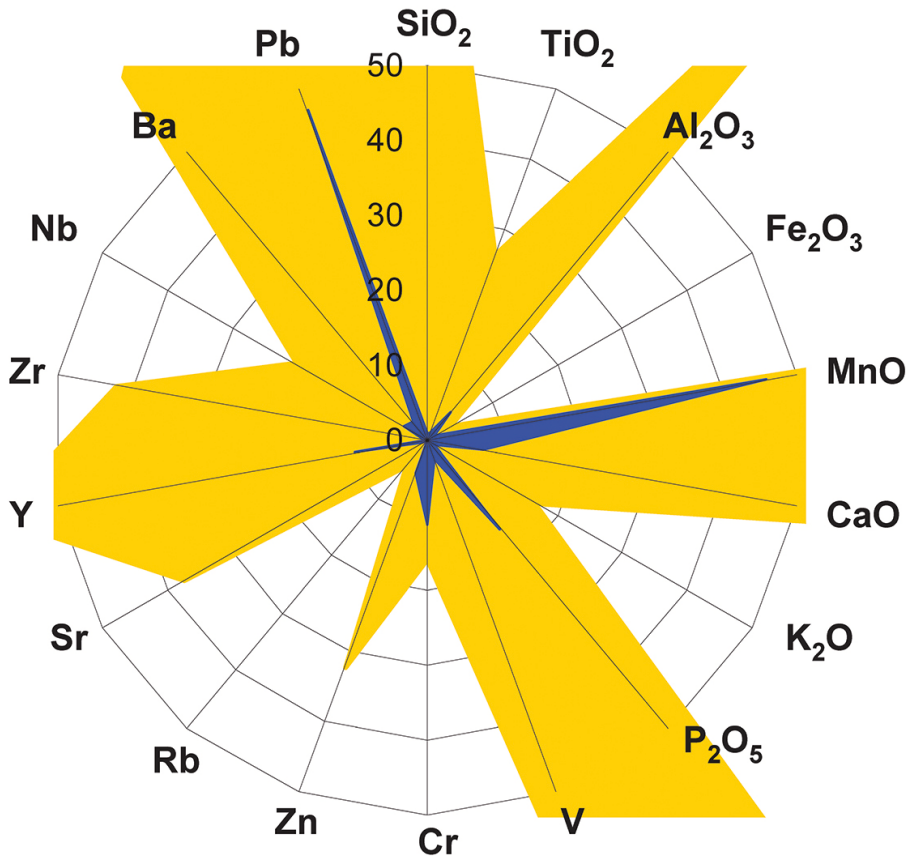


Fig. 19 Proportion of samples measured with a precision of worse than 10% (blue) and accurcay worse than 10% (yellow).

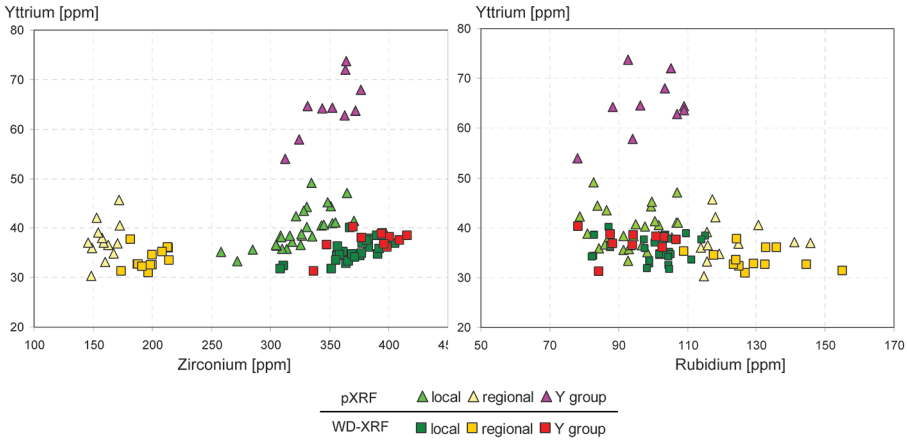


Fig. 20 Example Cornești-Iarcuri: scattergrams of WD-XRF and pXRF data, the latter showing a separated group with high Y contents.

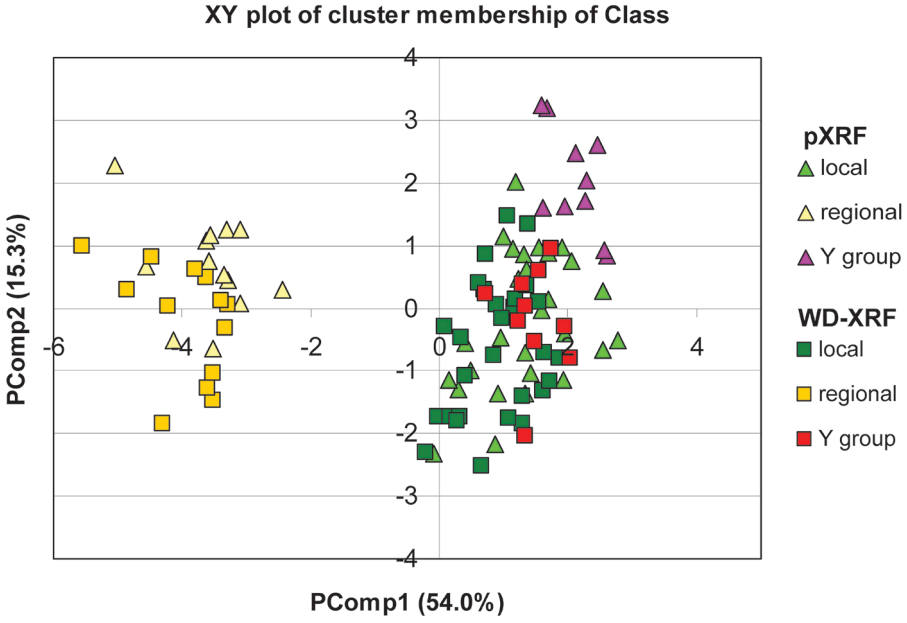


Fig. 21 Example Cornești-Iarcuri: principal component analysis of the analysis results of the same samples as in Fig. 20.

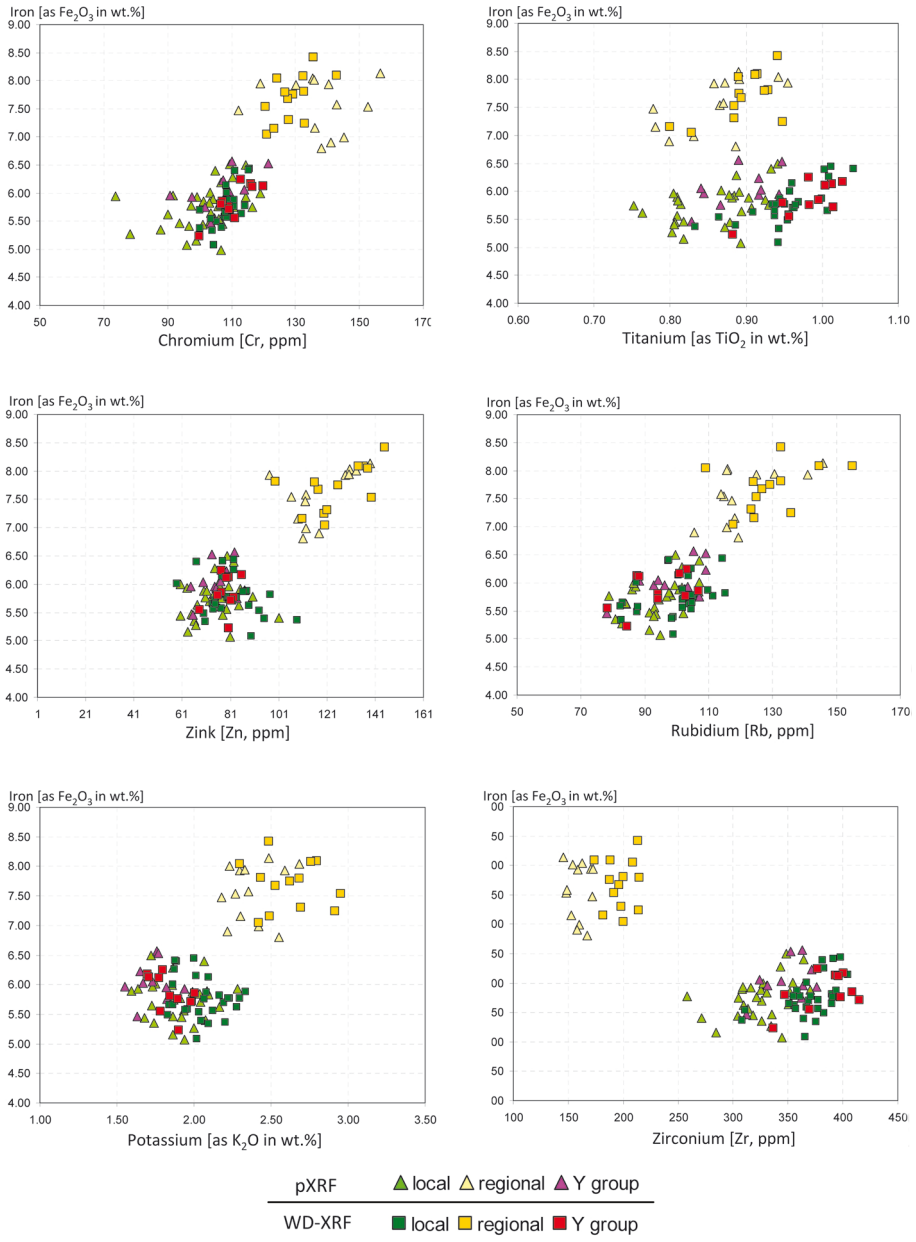


Fig. 22 Example Cornești-Iarcuri: scattergrams of iron vs. other elements, showing the clear separation of the regional group from the local group by WD-XRF, as well as by pXRF, however, without separating the Y-group.

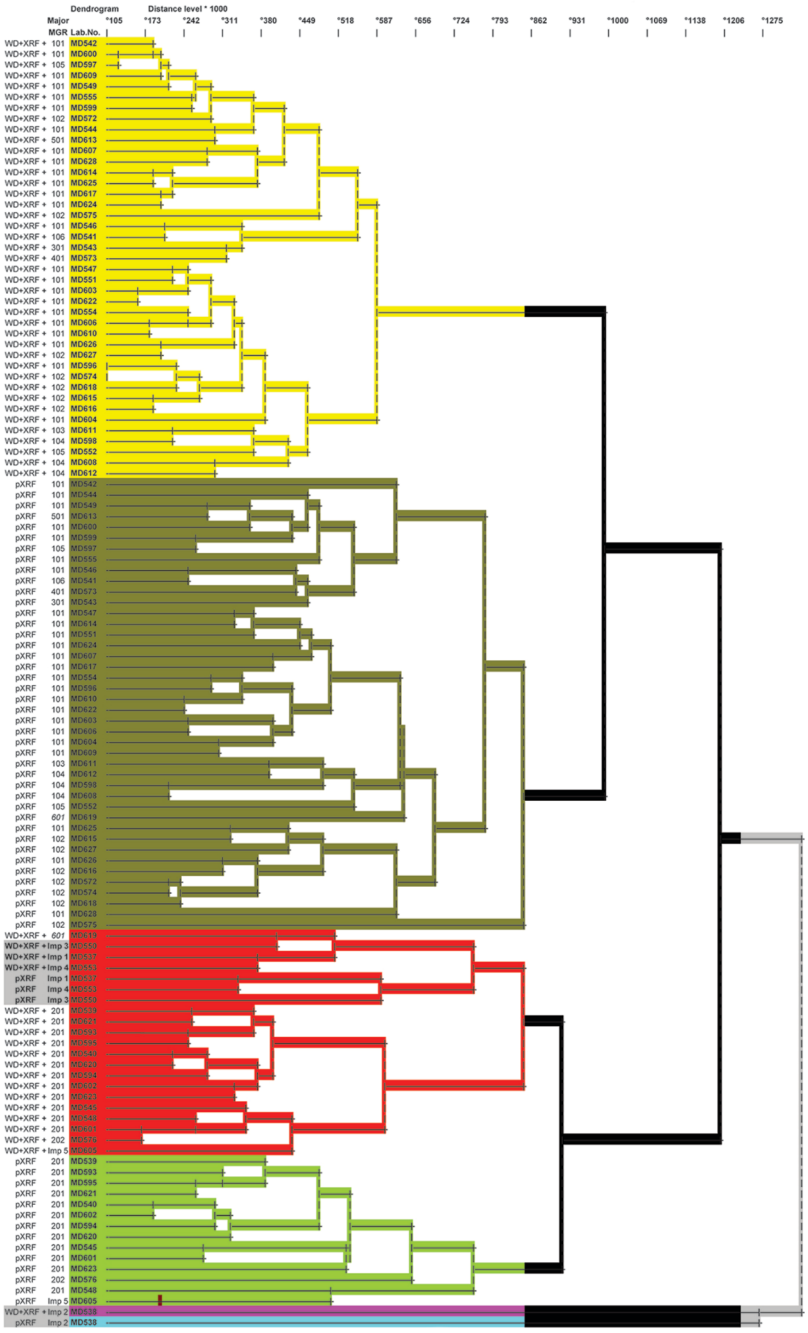


Fig. 23 Example Cornești-Iarcuri: dendrogram of a multivariate cluster analysis using both WD-XRF and pXRF results (same series of chemical elements). The pXRF results are clearly distinguished from the WD-XRF results.

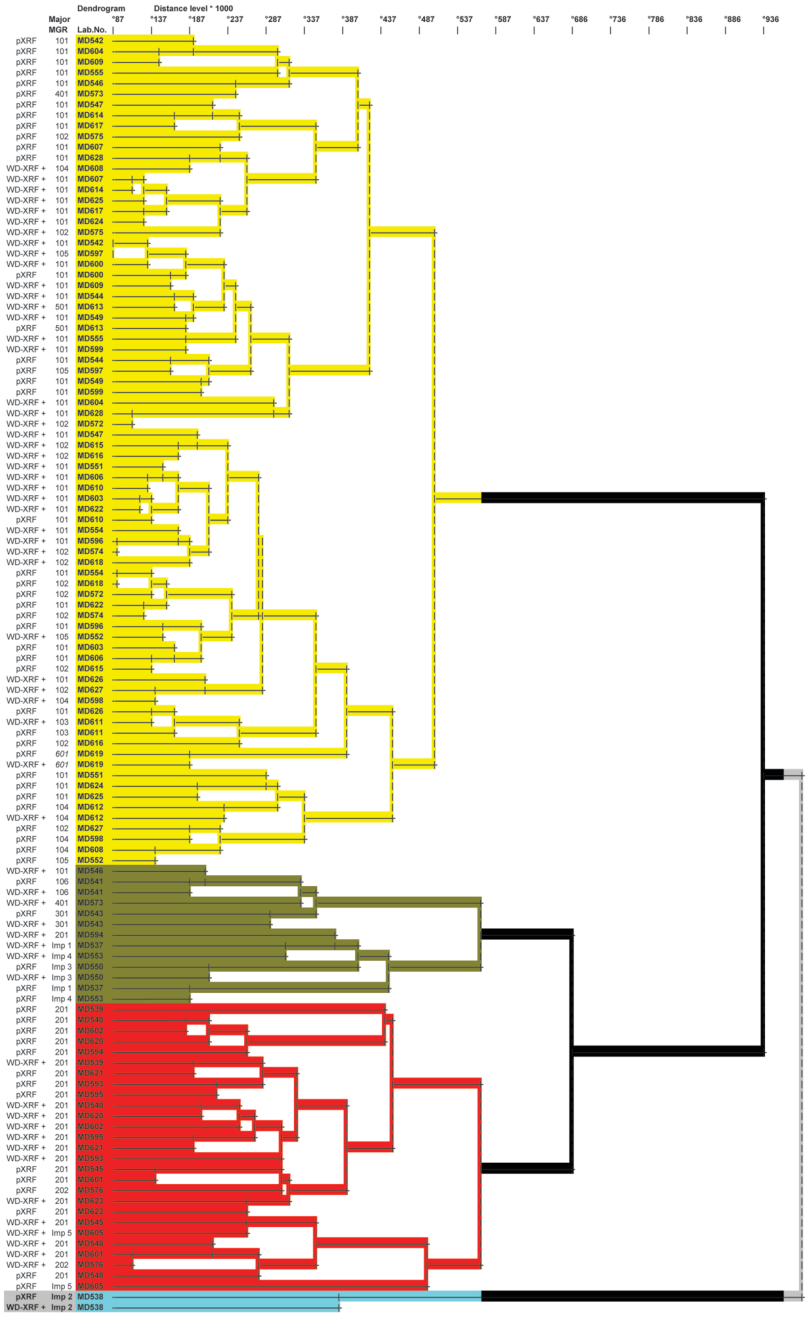


Fig. 24 Example Cornești-Iarcuri: dendrogram of a multivariate cluster analysis using both WD-XRF and pXRF results, but only using elements well determined also by pXRF. The groups by WD-XRF and pXRF fall together and the regional group 280 (MGR 201) is clearly distinguished by both methods from the other groups.

Fig. 25 Example Cornești-Iarcuri: principal component analysis of WD-XRF and pXRF analysis results.

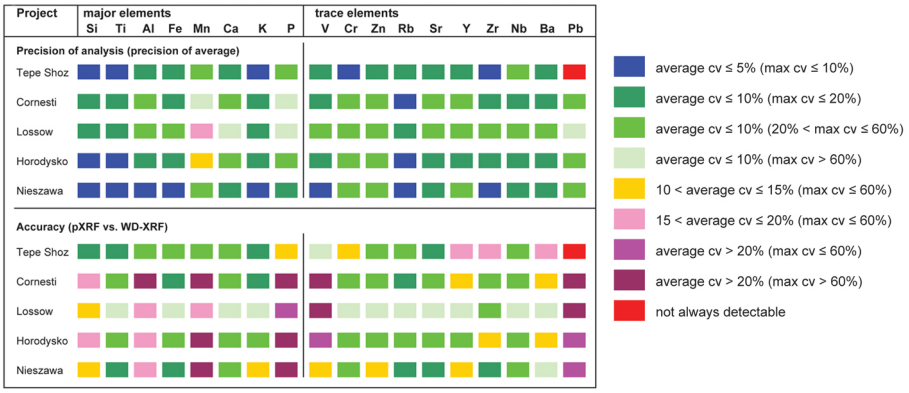


Fig. 26 Average precision and accuracy of analysis of major and trace elements. Analysis by pXRF in five different projects.

7 Discussion

Michael Meyer

Our research started out with a set of culturally, regionally, and temporally diverse projects from various regions of the old world, reaching from Iran to Syria, from Sudan to Rumania, and from the Ukraine and to Central Europe. Initial goals were formulated generally to reconstruct production and distribution patterns of pottery in ancient societies. It was hoped that through this, we would be able, at least to some extent, to generalize from these results towards a modeling of past economies.

Regional, temporal, and cultural particularities prevented any direct comparison between all projects from the start. Even projects of the same time period show significant differences: the three projects dealing with the Barbaricum of Roman Imperial times differ: wheel thrown pottery occurs only in low quantities in eastern Germany, whereas in Ukraine it is the everyday ware. The Bronze Age fortified sites of Corneşti in western Romania and in East German Lossow vary decisively in size and material culture, and the contemporary site of El Amarna is an Imperial City. However, we aimed for a comparative approach for all of the steps taken, from the hypothesis to the test arrangements to the results of our investigations.

Each of the projects of the research group yielded reliable and interpretable results. The analysis of the clay composition and matrix, often complemented by the analysis of temper, the treatment of the clay, and the forming and firing techniques used, allowed the identification of groups of products that must have been produced at one workshop or – if such clear conclusions were not possible – in a specific region. These results were the starting point for the interpretation of economic patterns of production and distribution – always keeping in mind the quantities of sherds analyzed in the projects and the restricted information that might be caused by too small samples.

Surprisingly enough, hypothesis and result matched only in a few projects. In the case of El Amarna (chapter 4.2) the broad pre-existing knowledge about the production and distribution of Mycenean ceramics made it more than probable that the fragments from El Amarna were produced in one of the well known pottery workshops in Greece. Current chronological sequencing and concepts of centralized production and distribu-

tion of the Nabataean pottery were confirmed by the archaeometrical results (chapter 4.4). However, in most cases the initial hypothesis could not be verified and had to be dropped or modified.

Due to the wide network reflected in all sorts of finds within the fortification of Lossow and its position directly on the major river Odra, the assumed centrality of the site was also expected to be apparent in a centralized production and widespread distribution of the *Turbanrandschalen* so typical for the site – but a distribution of the Lossow bowls could not be verified (chapter 4.6). Similarly, for the huge fortification of Corneşti centralized production and attendant distribution of pottery was assumed, but our results indicate a major role of local production for Corneşti itself and for the neighboring sites (chapter 4.5). The hypothesis of a centralized manufacture of wheel thrown pottery with broad distribution patterns in 3rd to 5th century East Germany (chapter 4.7) had been based on a test project with a small number of sherds and could only be confirmed in a few cases; such distributions turned out once again to be a clear exception. The hypothesis of a central production of ceramics in Olbia (chapter 4.9) could only be verified for the 2nd and 3rd century AD, while it was refuted for the 4th century CE with the resettlement of the area by the differently structured **Chernyakhov** culture. In addition, this finding was supported by the results of the Voitenki project (chapter 4.10). In the Tepe Sohz project, good arguments could be found against the hypothesis of ruling nomadic people that brought in their ceramics, again leading to a scenario of limited regional distribution of pottery (chapter 4.1). Additionally, analysis of the ceramics of the Meroitic site of Mussawarat (chapter 4.3) yielded the surprising result that the fine ware was locally produced and not found at other sites, whereas part of the coarse ware had been imported from quite a distance.

It is very interesting that throughout these heterogeneous projects the amount of imports of pots that were distributed and used at a distance from their production site is remarkably low. In the Corneşti project we see a small number of vessels from a regional group with a production site that remains unknown. The Roman Imperial period projects show only low quantities of pots distributed at a regional level; the 5th millennium ceramics from western Iran equally show low quantities of non-local products. There is a small number of imported coarse ware in Mussawarat. Even the imported Mycenaean ceramics from El Amarna are only a very small segment of the ceramic finds. Within this general pattern, there are two exceptions: the Nabataean ceramics and the Olbia products from the 2nd and 3rd centuries CE were clearly distributed and in high quantities.

How can these low quantities of distributed ceramics be interpreted? Of course, it is dependent on each specific cultural, political, and economic background. We learn about Mycenaean trade within the Mediterranean and have no reason to doubt that the El Amarna pots were part of that trade. However, in the other cases we must ask, have the

vessels that were found distant to their production sites been transported in trade or are they relics of other activities? Of course, ceramic vessels are containers for goods and can be used in trade that was mainly focused on other goods. In this case, we would expect non-local pottery occurrences. However, containers made from different materials not detectable in the archaeological record – such as leather or basketry – could have been the mainstay in ancient trade.

In general, however, other kinds of mobile activities should be reflected by this evidence. Ceramic containers could have functioned as gifts (the pots themselves or the content), maybe as part of gift exchange; they might be personal belongings of traveling persons, as would be the case for 'pilgrim flasks'; or could have belonged to individuals who moved to other places. Visits, meetings, and feasting ceremonies may all have involved ceramics being brought to the location of the venue from smaller or larger distances.

Compared to other well established pieces of evidence of ceramic trade – for instance terra sigillata or amphorae in the Roman world – the quantities of traded pottery identified in our research projects also appear to be much too small to guarantee any sustained profit from such a trade. Transport is cost-intensive and only makes sense if enough goods can be traded.

Market places that partly entice the customer to do the distribution work could be a model – but it would lead to large numbers of non-local wares. In addition, neither in the Bronze Age Banat (Corneşti project) or in Roman Imperial times in East Germany – to just take some examples – there is evidence for markets places.

Of course, our findings are not entirely new in each project. For example, Geoff Emberling and Leah Minc undertook a wide-ranging NAA analysis of fourth millennium BCE ceramic objects from Mesopotamia and the surrounding regions.[1] Their findings corroborate our own, since they found overwhelmingly local production patterns with few sites where a larger proportion was non-local. This picture changes when specific pottery of high quality is regarded. This involves painted pottery of specific styles or pottery of outstanding technological quality as was often the case for cooking pots. An example for the distribution of a special style of painted pottery is the Mycenaean pottery in the eastern Mediterranean. From more than 1500 samples analyzed by Hans Mommsen using NAA, it can be concluded that at many sites this pottery was made locally, but some workshops such as Berbati/Mykene on the Greek mainland had a large distribution area.[2] Gerwulf Schneider analyzed some 1000 samples of pottery from Neolithic Thessaly using WD-XRF, where the painted wares of characteristic styles showed a different distribution than coarse wares. Whereas the latter at the studied sites proved to be locally made, the fine ware vessels of diverse styles were made at several yet unknown

1 Emberling and Minc 2016.

2 Mountjoy and Mommsen 2015; Maran et al. 1997.

workshops and distributed throughout the whole of Thessaly. Sherds of an extraordinary style of grey-on-grey painted pottery found at many sites, mainly in the western Thessalian plain, could be attributed to only one production center in the northwest of the plain, with only a few exceptions found at more distant sites.[3]

An example of technologically extraordinary pottery from the Early Bronze Age in North Syria presents a stoneware-like pottery (North Syrian Metallic Ware), which was produced at only two unknown centers, very probably outside the area of major distribution. It is clearly distinguished from local products at many places where potters tried to obtain similar technological properties using local and very different raw materials.[4]

For the Hellenistic and Roman periods, we will not regard the case of amphorae for the transport of oil or wine that were produced mostly at the production sites of the items to be transported. Common wares used at home were still preferably made within the local region. On the other hand, all specialized pottery was generally produced in manufacturing centers for a larger distribution. Analyses of a special cooking ware found from early Roman to early Islamic periods in Syria and the Levant (so-called brittle ware) showed that only products from up to six manufacturing centers were detected (in Raqqa, brittle ware came from the main center for brittle wares, probably situated west of Aleppo) at nearly all sites studied in Syria, whereas in Palmyra this ware was locally produced and not distributed.[5]

Hellenistic and Roman black and red gloss pottery (e.g. Campana and Sigillata) were nearly exclusively produced in large centers, for which the workshops are mostly known. This is also true for some cooking wares, which must have had special properties. Using analysis by WD-XRF, imports at very distant sites can be securely connected to their production centers such as, e.g. Campana A from Naples found in Gadara (Jordan);[6] Sigillata from Lezoux (Central Gaule) found in legionary camps in Rumania;[7] and cooking pots from Phokaia (Asia Minor), e.g. in Gadara, in Austria[8] and Slovenia.[9] At Phokaia in other workshops using different clay, a Late Roman red gloss ware (LRC) was produced with many imports analyzed, e.g.in France.[10] For small items such as ceramic oil lamps, e.g. *Firmalampen* bearing stamps of the producer, it was not clear how the production was organized. Chemical analysis revealed that only one center at Modena supplied a very large area (e.g. the whole of northern Italy and Raetia) for at least 150 years, where at all sites imports from Modena were detected alongside locally made lamps with nothing more than a local distribution. For the easier supply of the military at more distant sites, e.g. along the Rhine, branch workshops of the firms known

3 G. Schneider, Knoll, et al. 1994.
4 G. Schneider and Daszkiewizc 2001.
5 G. Schneider, Vokaer, et al. 2007.
6 Daszkiewicz, Liesen, and G. Schneider 2014.
7 Daszkiewicz, G. Schneider, Baranowski, et al. 2018.
8 Auer and Daszkiewicz 2017.
9 Istenič and G. Schneider 2000.
10 Mayet and Picon 1986.

from Modena were established at Trierof.[11] Concluding, throughout the periods we always had local common pottery made regionally and imports of special ceramic wares manufactured at one or only a few centers. For high-quality products, the problem of transport seemed to play a secondary role, e.g. imports of 6th millennium DFBW (dark-faced burnished ware) in SabiAbyad in North Syria show, which according the analysis of the material from which they were made, must have been imported from more than 200km away from the region of ophiolitic rocks in the northwest of Syria.[12]

What do we learn about the production sites and workshops themselves? In some projects kilns have been documented. In Voitenki it could even be demonstrated that the clay used varied from kiln to kiln, providing a definitive fingerprint for each workshop. Olbia yielded several kilns, but no ceramics connected to them were available for analysis. Glass working at the site of Komariv itself is proven by one excavated furnace. In Tepe Sohz no kilns or other remains of workshops are known, but it became apparent that two slightly different clay sources were used for the production of vessels that each have their own stylistic preferences. The project revealed that a lot could be learned if a large-scale intra-site project could be organized. It would be very interesting to learn about the role the different workshops played in that process.

The pottery from Mussawarat that was analyzed within the project came exclusively from several workshops within one production center. The excavation of one workshop and ensuing experiments allowed the researchers to reconstruct the production procedure and the raw materials used. Even in the desert it was no problem to supply the potters with clay, fuel, and water.

Other projects can only reconstruct production sites from the distribution patterns of the samples analyzed. Within the two rings of the fortification of Corneşti, no area of production could be identified. In east German Roman Imperial times concentrations of vessels of specific clays in one site may indicate a production there or in its vicinity. Similarly, the production of the Mycenaean pottery found in El Amarna can only be limited to a region, not to a specific site.

In two projects, the high quality of the ceramics together with the lack of a central production led the researchers to the assumption of itinerant craftspeople. Indeed, the low amount of wheel thrown pottery in almost every settlement of the East German project region strongly argues for such a model, as does the Iranian evidence. Skillful ceramic production – be it wheel thrown or intensely decorated – requires experience and training. The implicit knowledge that is needed to make the pots might be lost if there would be production only every few years. Craftspeople who produce ceramics

11 G. Schneider 1993; Auer and Sitz 2014.

12 Daszkiewicz, Bobryk, and G. Schneider 2000.

several times a year in different hamlets or villages maintain that knowledge. The technical installations are not very sophisticated, as the potter's wheel can be brought along and the firing can be done in open fires or in simple kilns.

A surprising side effect of the projects was the clear distinction of the production of pottery for the use in settlements and for burials in three projects: the Bronze Age site of Lossow, different sites in Roman Imperial time in East Germany, and in the Ukraine. It is possible that the wheel thrown pots were not fired in a furnace, but together with the deceased person on the funeral pyre. A potter's skills must have been available in these sites within a short time frame.

Overall, our findings are sobering when considering the initial goal of reconstructing past regional economies. In antiquity in general, regional or even large-scale distribution patterns of pottery were the exception, not the rule. Containers were not often taken from one habitation, whether a village, town, or even city, to another one, even in times when means of transport such as ships and carts had become frequent. Pottery is not only a breakable product, but also a heavy one, preventing easy regional distribution. This also means that we have to abstain from generalizing the pottery production – plus – distribution systems we were able to identify. Other goods were produced at different rates with different ranges of regional distribution.

Still, it is worthwhile pursuing the kind of research we started here. The exceptions – almost all projects include such cases – to local production and use merit closer inspection. Why were these particular vessels transported over longer distances than others? Was this due to their morphology, aesthetics, particular abilities, or to their being used to transport some specific content? Some of the issues raised above (vessels as gifts, or as tribute, for example) could be integrated into such scenarios.

More important is another matter. Our search started on a geographic scale that can be characterized as 'misconstrued'. Pottery is distributed, albeit in most cases not at a regional level, but rather at a local one. It is in this realm that further work is required, whether on the level of a village or a huge site like Corneşti. Ceramic products were actively exchanged, and we can get closer to the reconstruction of not just spatially highly restricted patterns of distribution, but also to locally variable conditions of production.

8 Appendix: Table of WD-XRF Analysis Results

Małgorzata Daszkiewicz, Gerwulf Schneider

Preparation of samples for analysis carried out in ARCHEA by Dr. M. Daszkiewicz, Warsaw, measurements using a PANnalytical AXIOS XRF-spectrometer and the calibration of Arbeitsgruppe Archaeometrie by G. Schneider (measurements courtesy of A. Schleicher in Helmholtz-Zentrum Potsdam, Deutsches Geo-ForschungsZentrum GFZ, Sektion 4.2, Anorganische und Isotopengeochemie).

Major elements are calculated as oxides. The element concentrations determined are valid for samples ignited at 900°C but, with the losses on ignition given, may be recalculated to a basis of samples dried at 105°C. For easier comparison, the major elements are normalized to a sum of 100%.

Si = silicon, calculated as SiO_2; Al = aluminium, calculated as Al_2O_3; Ti = titanium, calculated as TiO_2; Fe = iron, total iron calculated as Fe_2O_3; Mn = manganese, calculated as MnO; Mg = magnesium calculated as MgO; Ca = calcium calculated as CaO; Na = sodium calculated as Na_2O; K = potassium calculated as K_2O; and P = phosphorus calculated as P_2O_5. Due to the fact that total iron is calculated as Fe_2O_3, losses on ignition of not fully oxidized sherds could be negative.

V = vanadium; Cr = chromium; Ni = nickel; Cu = copper; Zn = zinc; Rb = rubidium; Sr = strontium; Y = yttrium; Zr = zirconium; Nb = niobium; Ba = barium; La = lanthanum; Ce = cerium; Pb = lead; and Th = thorium.

Elements with low precision: Cu, La, Ce, Pb, and Th

Empty space = elements that have not been analyzed (values of analyzed elements below limit of detection are indicated as <5ppm)

First column = sample number within projects

Second column = laboratory numbers (as used in the Schneider-Daszkiewicz database)

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
rb1	AD015	50.59	0.758	13.35	6.53	0.105	4.06	20.58	1.59	2.14	0.30	114	271	162	32	67	20	720	18	188	11	121	<5	53	5	6	6.49
rb41	AD016	55.12	0.802	14.22	6.56	0.064	4.52	13.65	1.21	3.47	0.25	150	250	163	35	68	65	515	18	206	13	263	17	52	5	8	4.85
rb4	AD017	51.13	0.783	13.50	6.16	0.080	4.18	20.65	1.45	1.52	0.55	126	284	158	48	92	38	1014	19	202	10	1084	13	54	<5	<5	4.82
rb5	AD018	50.52	0.775	14.04	6.94	0.065	5.09	17.62	1.44	1.64	1.88	152	271	193	33	122	51	723	20	183	12	530	9	47	<5	6	2.30
rb6	AD019	54.71	0.843	14.06	5.81	0.058	5.15	15.56	1.46	2.12	0.23	133	321	164	26	88	60	500	18	205	14	265	11	34	<5	7	0.75
rb7	AD020	49.96	0.697	11.78	5.57	0.072	5.02	22.91	1.62	2.11	0.26	107	262	151	44	107	41	2029	17	205	11	635	14	47	5	<5	12.11
rb51	AD021	57.15	0.853	13.97	6.08	0.057	3.83	13.50	1.19	2.84	1.09	141	348	150	34	70	84	660	22	215	11	671	24	53	8	5	3.97
rb8	AD022	57.30	0.799	14.13	6.53	0.082	4.59	11.14	1.12	4.04	0.53	128	256	169	27	119	90	713	22	212	13	413	7	44	12	6	2.28
rb9	AD023	56.76	0.827	13.70	6.21	0.062	3.90	13.66	1.68	2.91	0.27	136	326	159	41	73	81	508	21	209	12	308	6	38	<5	8	5.65
rb26	AD024	52.81	0.792	13.52	5.88	0.069	4.48	18.23	1.81	1.96	0.34	121	284	153	33	66	24	741	20	196	14	411	6	35	<5	5	4.93
rb39	AD025	53.00	0.774	14.32	6.58	0.074	6.05	14.74	2.03	2.18	2.29	148	242	181	26	55	28	493	19	192	10	816	<5	41	<5	6	9.10
rb10	AD026	58.06	0.847	13.76	5.92	0.057	4.28	12.32	2.05	2.29	0.28	148	341	156	26	55	44	589	23	213	13	284	7	35	<5	9	2.15
rb14	AD027	57.08	0.852	13.71	6.98	0.061	4.44	12.59	1.52	2.56	0.42	141	364	165	20	74	73	496	23	221	13	273	15	44	10	9	2.46
rb15	AD028	56.30	0.830	13.34	6.65	0.058	4.70	14.09	1.57	2.22	0.20	144	352	160	34	79	66	461	25	213	13	459	23	41	<5	10	1.11
rb16	AD029	55.79	0.810	13.71	6.36	0.064	4.83	14.34	1.27	2.51	0.25	145	300	161	24	75	75	517	21	195	11	300	6	54	5	7	1.03
rb17	AD030	58.19	0.858	14.40	6.44	0.062	4.48	11.17	1.17	3.01	0.32	134	330	165	29	91	91	641	21	207	13	272	20	42	9	8	1.54
rb19	AD031	55.19	0.785	13.02	6.39	0.075	5.48	14.98	1.34	2.47	0.22	147	306	164	45	157	71	762	20	200	11	564	9	37	<5	<5	3.50
rb21	AD032	58.92	0.862	13.74	6.49	0.059	4.20	10.79	1.68	2.89	0.27	130	363	156	35	98	87	444	25	217	11	862	27	57	9	5	6.68
rb22	AD033	56.72	0.819	13.74	5.65	0.049	3.99	15.25	1.58	1.83	0.37	149	306	150	31	63	46	717	19	205	13	257	25	54	<5	7	4.28
rb37	AD034	50.37	0.739	14.73	6.89	0.069	6.44	17.48	2.06	0.94	0.21	146	222	186	16	64	47	618	18	172	11	620	5	47	<5	7	2.32
rb12	AD035	52.61	0.787	13.62	6.58	0.073	4.23	18.69	1.20	1.88	0.43	135	284	168	22	94	36	1205	21	201	11	187	19	61	6	<5	4.16
rb49	AD036	55.37	0.824	13.53	7.02	0.061	4.85	14.62	1.47	2.08	0.31	161	330	164	30	87	63	553	22	207	12	578	11	48	10	<5	4.45
rb23	AD037	59.60	0.879	13.55	6.39	0.062	4.00	10.98	1.42	2.73	0.38	105	393	144	22	86	86	476	24	229	13	1233	30	52	12	10	2.72
rb29	AD038	56.89	0.842	13.53	6.76	0.065	4.22	13.61	1.67	2.16	0.37	138	341	157	31	83	51	535	26	214	13	586	32	34	<5	6	1.36
rb31	AD039	57.14	0.858	13.66	6.14	0.062	4.29	14.02	1.21	2.36	0.26	128	357	149	27	84	81	495	22	217	12	365	22	62	<5	8	2.20
rb32	AD040	56.60	0.837	13.48	6.70	0.064	4.44	13.91	1.29	2.38	0.26	143	350	153	35	75	70	534	23	216	13	464	8	42	9	8	1.85
rb53	AD041	49.49	0.718	13.22	6.65	0.088	7.73	19.55	1.46	0.89	0.32	131	224	156	31	64	30	646	19	173	9	429	9	42	<5	5	1.88
rb24	AD042	44.82	0.723	13.49	6.57	0.081	3.95	25.24	1.32	1.51	0.28	132	208	169	30	104	18	1546	19	180	12	314	26	25	7	<5	2.26
rb36	AD043	58.38	0.861	13.71	6.24	0.063	4.03	11.94	1.36	3.01	0.30	113	353	140	34	86	85	805	20	221	11	646	10	27	7	5	2.47
rb48	AD044	51.86	0.825	13.78	5.98	0.073	4.56	19.08	1.86	1.74	0.20	123	295	150	19	85	36	847	21	200	13	442	20	31	5	6	1.36
rb40	AD045	53.19	0.792	13.99	6.24	0.062	5.23	16.05	0.99	2.79	0.40	131	290	169	28	82	77	2641	20	225	12	292	15	40	10	<5	2.80
rb44	AD046	51.07	0.741	12.40	6.08	0.077	3.69	22.34	1.56	1.82	0.21	105	305	139	32	77	21	1044	18	202	11	675	8	63	8	<5	7.32
rb47	AD047	55.56	0.840	13.77	6.10	0.051	4.52	15.25	2.00	1.61	0.35	126	306	152	21	73	38	455	18	201	12	267	24	41	6	8	0.59
rb3	AD048	54.63	0.855	14.70	6.11	0.062	5.00	14.78	1.69	1.82	0.39	138	295	161	33	100	51	469	22	197	12	319	18	57	9	<5	1.48
rb54	AD049	54.46	0.830	14.17	6.64	0.067	4.95	15.46	1.82	1.40	0.22	144	293	170	33	71	35	590	20	198	11	352	6	46	<5	7	2.16
rb27	AD050	52.98	0.795	13.25	6.45	0.067	4.82	18.35	1.60	1.38	0.17	120	322	156	28	88	32	790	21	205	12	336	12	50	<5	6	1.24
rb50	AD051	52.21	0.824	13.58	6.68	0.073	4.08	19.22	1.56	1.41	0.37	123	308	161	37	85	31	829	20	203	13	809	10	43	<5	5	3.14
rb42	AD052	52.41	0.775	13.82	6.15	0.061	5.21	17.25	0.70	2.54	0.66	134	268	163	43	110	81	2093	19	206	13	502	18	45	7	<5	3.72
rb52	AD053	58.26	0.872	13.92	6.38	0.063	4.01	12.09	1.32	2.87	0.21	118	365	139	32	79	92	497	19	215	14	308	20	42	9	12	3.43
rb13	AD054	49.87	0.759	14.26	7.52	0.104	6.64	17.88	1.54	1.12	0.24	139	259	222	33	94	32	613	20	165	12	197	12	51	8	7	2.51
rb45	AD055	55.32	0.850	13.68	6.92	0.066	4.76	14.47	1.23	2.49	0.29	125	339	160	32	82	84	511	22	214	12	218	26	56	9	8	1.64
rb55	AD056	55.66	0.827	14.86	6.98	0.076	4.62	12.15	0.86	3.69	0.28	104	261	167	40	104	96	560	15	212	12	569	20	47	8	10	1.70
rb56	AD057	51.35	0.763	13.03	6.36	0.072	4.58	20.12	1.39	1.96	0.37	117	277	154	37	133	30	1023	18	193	9	681	28	54	<5	<5	6.69
rb58	AD109	46.32	0.640	10.78	5.23	0.089	4.22	29.12	0.73	2.44	0.43	105	218	141	50	126	55	1212	17	182	10	646	20	43	13	8	19.63
rb59	AD110	58.77	0.865	13.54	6.51	0.060	3.82	11.81	1.33	2.58	0.70	129	376	144	39	97	89	500	21	230	13	481	15	46	10	9	2.23
rb60	AD111	53.88	0.783	13.84	6.39	0.080	4.11	15.06	1.82	3.80	0.24	123	239	159	59	101	80	630	16	205	11	281	15	41	<5	7	6.87
rb61	AD112	51.59	0.782	14.38	7.05	0.091	4.89	17.78	1.23	1.95	0.24	131	245	166	30	74	41	829	19	193	13	1026	6	46	<5	5	4.08
rb62	AD113	53.12	0.824	13.43	5.51	0.064	4.79	17.36	0.74	3.06	1.11	140	337	151	34	108	30	926	24	219	11	2942	38	46	<5	<5	5.19
rb63	AD114	51.49	0.763	14.30	6.73	0.069	6.47	16.95	1.59	1.41	0.22	144	243	174	31	68	48	640	17	189	11	614	25	40	<5	5	2.57
rb64	AD115	59.56	0.881	13.77	6.61	0.059	4.08	10.54	1.45	2.80	0.24	123	369	149	35	85	93	430	23	226	14	301	20	54	14	10	1.81
rb65	AD116	45.33	0.621	10.29	4.99	0.085	3.82	30.50	1.15	2.89	0.33	98	216	142	41	108	47	844	24	154	15	234	20	42	11	<5	21.28
rb66	AD117	43.50	0.622	11.18	5.48	0.071	4.97	30.23	0.65	2.85	0.45	132	195	164	44	130	65	730	23	132	14	307	29	42	6	<5	21.38
rb67	AD118	49.89	0.679	11.12	5.43	0.094	3.84	23.53	1.44	3.57	0.43	105	222	143	36	130	50	885	28	166	17	267	9	44	14	<5	17.63
wxrf1	AD151	55.61	0.845	13.97	5.83	0.061	4.46	15.20	2.01	1.79	0.24	128	320	155	32	66	27	495	20	204	13	209	9	41	<5	7	2.17
wxrf2	AD152	52.38	0.757	14.31	7.57	0.076	4.72	15.46	1.76	2.52	0.45	113	238	193	42	133	33	1055	17	175	12	601	11	43	6	<5	4.38
wxrf3	AD153	55.37	0.836	13.31	6.89	0.071	3.63	14.66	1.62	3.19	0.42	103	284	144	40	102	78	566	19	190	12	289	<5	40	10	14	3.44
wxrf4	AD154	57.69	0.855	13.70	6.52	0.064	4.05	13.05	1.69	2.12	0.27	137	356	153	25	84	53	583	22	219	13	532	17	43	6	8	1.85
wxrf5	AD155	56.19	0.801	13.46	5.82	0.064	4.96	14.61	1.95	1.88	0.26	138	358	146	32	72	29	678	17	208	11	254	17	35	<5	<5	2.43
wxrf6	AD156	53.10	0.894	13.19	7.21	0.070	4.77	16.90	1.64	2.01	0.23	136	313	148	30	70	38	457	17	195	11	327	17	47	<5	8	2.17
wxrf7	AD157	54.38	0.811	13.52	6.58	0.065	4.17	16.35	1.93	1.90	0.29	121	320	153	24	62	24	666	20	203	12	227	19	47	<5	7	3.95

Tab. 1 Project Tepe Sohz (chapter 4.1).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
wxrf8	AD158	54.51	0.809	14.46	6.44	0.067	4.80	14.67	2.02	1.99	0.22	136	258	150	33	88	30	443	17	207	11	219	16	25	10	6	1.35
wxrf9	AD159	54.40	0.815	14.49	6.61	0.072	4.99	14.48	1.98	1.90	0.26	129	263	178	45	72	28	696	21	214	12	216	15	24	<5	<5	1.69
wxrf10	AD160	53.76	0.803	13.66	6.42	0.068	3.70	16.91	1.87	2.02	0.78	121	307	154	36	75	22	627	24	198	12	190	8	50	<5	10	3.50
wxrf11	AD161	56.32	0.840	13.54	6.49	0.063	4.53	14.08	1.14	2.59	0.41	97	318	146	33	106	85	519	20	219	13	413	14	46	11	6	2.36
wxrf12	AD162	56.50	0.807	14.30	6.44	0.068	4.97	12.45	1.90	2.34	0.22	132	271	159	30	76	40	515	20	222	11	267	26	41	6	7	1.02
wxrf13	AD163	56.18	0.842	13.69	6.05	0.061	4.67	14.63	1.08	2.60	0.19	110	323	150	44	90	90	547	20	205	11	290	14	50	13	8	2.25
wxrf14	AD164	56.91	0.870	14.34	6.20	0.059	4.67	13.16	1.66	1.97	0.16	132	346	152	23	77	55	415	19	197	15	287	14	55	5	11	0.90
wxrf15	AD165	55.96	0.843	13.54	6.31	0.065	4.24	14.74	1.85	2.17	0.28	135	360	153	24	58	35	539	18	217	14	439	15	38	<5	9	2.13
wxrf16	AD166	58.71	0.860	13.40	6.50	0.058	4.03	11.80	1.57	2.54	0.52	125	384	135	35	87	78	434	22	221	11	312	5	55	10	8	1.24
wxrf17	AD167	49.74	0.781	15.19	7.13	0.072	4.08	18.53	2.03	2.13	0.32	149	227	182	29	61	17	1091	16	182	12	755	12	25	5	<5	4.38
wxrf18	AD168	49.62	0.794	15.42	7.30	0.061	3.84	19.65	1.30	1.57	0.44	162	240	180	28	70	32	1109	15	185	15	1525	15	57	<5	<5	5.69
wxrf19	AD169	54.72	0.817	13.38	6.47	0.059	4.99	16.03	1.23	2.10	0.20	134	319	149	25	91	63	511	21	201	11	273	29	50	5	8	1.16
wxrf20	AD170	53.25	0.791	13.84	6.53	0.071	4.15	17.00	1.48	2.12	0.75	139	280	169	29	70	26	1355	21	200	13	169	13	40	7	<5	3.10
wxrf21	AD171	50.06	0.733	13.46	6.25	0.082	4.77	20.06	0.92	3.43	0.22	98	239	150	36	78	71	999	15	192	10	400	24	17	10	5	8.84
wxrf22	AD172	56.78	0.786	12.49	5.90	0.072	4.24	14.47	2.00	2.71	0.56	107	348	143	39	113	74	1123	23	209	12	458	7	44	<5	<5	6.94
wxrf23	AD173	57.31	0.876	13.80	6.39	0.060	4.44	12.91	1.42	2.54	0.25	128	350	148	30	73	72	717	21	214	12	615	21	44	7	<5	1.56
wxrf25	AD174	55.61	0.825	13.24	6.64	0.063	4.84	14.77	1.49	2.17	0.36	134	341	152	28	73	47	538	22	208	12	268	11	43	12	6	2.11
wxrf26	AD175	55.36	0.818	14.72	6.62	0.069	4.28	13.20	1.87	2.41	0.66	140	245	160	31	89	38	512	19	202	12	259	16	34	6	7	1.67
wxrf27	AD176	56.65	0.829	13.40	5.74	0.063	4.57	14.92	1.41	2.17	0.25	121	337	149	30	71	47	622	21	209	12	314	12	50	9	<5	2.38
wxrf28	AD177	58.43	0.839	13.29	6.30	0.057	4.37	12.84	1.72	1.95	0.20	136	378	136	19	61	44	416	23	218	11	292	24	30	5	6	1.06
wxrf29	AD178	56.06	0.812	13.19	6.29	0.059	4.54	15.03	1.86	1.83	0.32	131	332	149	35	78	31	781	21	206	13	554	18	41	<5	6	2.88
wxrf30	AD179	52.33	0.741	13.99	6.50	0.084	6.34	15.65	1.55	2.53	0.29	132	253	154	32	66	35	412	22	177	9	172	23	41	<5	6	2.33
wxrf31	AD180	60.86	0.942	14.42	7.50	0.069	3.83	7.53	1.87	2.52	0.46	157	469	195	35	87	87	383	27	231	14	438	20	50	14	11	1.33
wxrf32	AD181	49.71	0.739	12.19	6.05	0.085	2.83	23.88	1.25	2.95	0.33	80	276	117	30	60	33	953	17	191	11	179	27	44	7	5	12.60
wxrf33	AD182	53.74	0.807	13.67	6.07	0.064	4.94	17.11	1.81	1.46	0.32	137	315	168	25	56	17	504	19	193	13	123	6	38	<5	8	2.23
wxrf34	AD183	54.81	0.830	13.42	6.52	0.071	4.01	15.89	1.94	2.03	0.48	131	353	156	30	73	28	592	19	212	13	341	28	41	<5	<5	3.16
wxrf35	AD184	57.50	0.845	14.16	5.44	0.044	4.22	13.91	1.36	2.33	0.19	132	334	164	38	67	59	518	19	207	13	302	9	46	7	6	1.31
wxrf36	AD185	57.54	0.869	13.86	6.39	0.059	3.92	13.17	1.91	2.11	0.16	136	402	146	34	65	55	420	22	216	12	366	26	34	5	7	1.21
wxrf37	AD186	59.67	0.901	14.50	6.76	0.050	4.33	9.61	1.49	2.53	0.15	134	411	170	29	80	102	359	24	217	12	550	11	42	8	10	0.68
wxrf38	AD187	55.08	0.832	13.12	6.49	0.066	4.33	15.75	2.14	1.95	0.25	116	353	150	16	69	17	853	27	211	17	398	<5	76	<5		3.35
wxrf39	AD188	51.82	0.770	13.06	6.36	0.058	4.46	19.52	2.16	1.53	0.27	134	289	146	29	80	16	680	19	181	11	385	13	32	<5	5	5.60
wxrf40	AD189	53.26	0.819	13.78	6.82	0.069	4.56	16.79	1.75	1.88	0.27	134	314	158	42	74	36	644	20	202	11	366	28	38	<5	8	3.56
wxrf41(rb054b)	AD190	55.28	0.838	13.61	6.74	0.065	4.68	14.81	1.24	2.48	0.26	142	343	157	33	83	80	512	22	209	11	359	25	55	12	8	2.42
wxrf42	AD191	53.29	0.813	13.52	6.55	0.067	4.48	17.37	1.83	1.55	0.52	135	329	167	49	70	24	569	21	205	12	319	13	44	9	8	2.77
rb068	AD294	56.37	0.823	14.45	6.52	0.062	4.40	12.55	1.77	2.69	0.37	126	253	161	41	98	49	375	18	213	13	265	17	50	<5	10	1.24
rb069	AD295	54.17	0.811	13.41	6.18	0.073	4.09	17.59	1.40	2.00	0.27	129	307	156	28	76	26	790	20	210	12	612	11	43	5	6	3.62
rb070	AD296	55.15	0.808	14.16	6.53	0.069	4.50	14.45	1.88	2.23	0.22	126	262	163	51	64	27	804	19	225	13	272	15	39	<5	<5	2.07
rb071	AD297	56.94	0.851	13.84	6.59	0.063	4.34	13.20	1.40	2.54	0.23	137	337	162	33	70	78	657	22	212	14	264	15	36	<5	<5	1.39
rb072	AD298	56.64	0.834	13.53	5.68	0.056	5.02	14.61	1.69	1.78	0.18	124	344	141	30	90	36	460	20	215	14	347	15	32	<5	6	0.85
rb073	AD299	56.36	0.842	13.51	6.50	0.059	4.63	13.89	1.72	2.11	0.39	141	348	151	33	79	47	439	21	214	14	302	19	46	<5	8	1.13
rb074	AD300	58.22	0.862	13.87	5.94	0.063	4.32	12.08	1.58	2.82	0.25	119	359	151	41	90	85	743	21	228	13	1063	19	50	<5	<5	3.06
rb075	AD301	56.13	0.848	13.01	6.28	0.058	4.99	14.54	1.36	2.43	0.35	107	341	157	37	91	83	569	21	206	14	454	17	40	9	8	2.40
rb076	AD302	58.19	0.887	14.08	6.34	0.059	4.32	11.70	1.41	2.78	0.22	123	368	149	35	80	95	458	21	215	13	310	18	54	6	10	1.44
rb077	AD303	55.75	0.838	13.68	5.81	0.064	3.86	16.04	1.75	1.78	0.44	119	351	152	43	84	43	718	22	215	12	825	22	47	6	8	3.06
rb078	AD304	54.35	0.781	14.01	6.47	0.068	5.59	14.84	1.74	1.87	0.28	128	262	173	46	104	43	586	18	210	12	390	8	41	11	9	1.72
rb079	AD305	56.43	0.753	12.33	5.84	0.065	4.16	16.74	1.33	2.06	0.29	131	396	146	32	88	41	648	20	210	11	772	15	35	8	5	4.86
rb080	AD306	55.08	0.844	13.46	6.30	0.062	4.75	15.36	1.70	1.83	0.62	141	343	165	38	84	34	610	21	205	14	527	19	72	<5	7	1.91
rb081	AD307	55.78	0.833	13.75	6.71	0.070	4.02	14.50	1.85	2.24	0.25	130	319	163	41	68	33	932	19	217	13	1987	25	31	38	<5	2.47
rb082	AD308	55.04	0.818	13.11	6.13	0.071	4.44	16.59	1.34	2.19	0.28	112	342	160	32	98	46	820	19	208	13	1002	13	59	26	<5	4.40
rb083	AD309	56.14	0.832	13.34	5.70	0.070	5.13	14.90	1.19	2.35	0.34	127	338	156	36	92	76	741	22	215	13	489	22	52	10	<5	0.98
rb084	AD310	51.44	0.811	13.55	5.62	0.055	3.95	20.42	1.68	2.08	0.38	121	333	122	47	94	29	769	20	204	12	466	20	52	<5	<5	7.38
rb085	AD311	58.13	0.869	13.85	6.57	0.063	4.52	11.68	1.32	2.80	0.21	132	351	156	39	114	90	461	21	214	13	273	32	39	49	11	1.77
rb086	AD312	34.93	0.468	7.39	3.67	0.064	3.25	46.87	1.06	1.74	0.55	87	199	96	64	105	31	1050	9	163	6	287	14	33	50	7	27.58
rb120	AD512	55.12	0.785	13.98	6.80	0.088	6.23	13.01	2.04	1.79	0.16	162	354	217	11	75	37	369	29	154	16	267	32	34	<5	<5	1.53
rb121	AD513	43.89	0.718	11.74	6.33	0.086	4.16	29.45	1.26	2.17	0.20	74	220	143	13	94	21	1051	21	146	16	140	<5	27	<5	<5	9.29
rb122	AD514	49.11	0.726	12.87	6.62	0.083	6.26	20.61	1.75	1.66	0.31	137	283	185	5	71	17	908	26	152	17	175	14	44	<5	<5	2.75
rb123	AD515	50.73	0.732	13.46	7.06	0.103	5.73	18.01	2.20	1.74	0.23	106	255	206	45	84	15	442	16	97	16	400	28	16	8		4.54
rb124	AD516	54.10	0.801	12.88	6.76	0.078	5.47	15.29	1.87	1.98	0.78	119	295	182	35	93	40	358	16	114	17	498	<5	14	13		1.31
rb125	AD517	51.97	0.759	13.46	6.65	0.104	5.40	16.65	2.14	2.44	0.43	112	326	179	10	94	23	617	27	171	16	191	19	48	<5	<5	5.77
rb126	AD518	61.32	0.910	14.45	5.67	0.051	4.60	8.82	1.54	2.47	0.17	129	350	152	23	90	86	272	29	178	17	249	38	62	11	<5	1.51
rb127	AD519	49.19	0.733	13.17	6.48	0.095	4.28	22.08	1.21	2.37	0.38	112	228	156	26	74	32	1195	27	165	17	678	18	51	<5	<5	9.94
rb128	AD520	58.15	1.084	14.10	7.12	0.063	4.66	10.28	1.52	2.82	0.20	112	318	141	17	82	79	265	28	173	17	203	33	39	7	<5	1.54
rb129	AD521	61.28	0.920	14.40	5.76	0.052	4.61	8.72	1.53	2.54	0.20	133	382	169	21	97	91	302	29	201	19	263	31	60	13	<5	1.41
rb130	AD522	57.45	1.134	14.07	7.76	0.068	4.69	10.27	1.49	2.91	0.16	107	299	137	5	74	76	238	27	163	16	195	25	28	10	<5	1.23
rb131	AD523	59.38	1.034	14.30	6.65	0.059	4.63	9.46	1.51	2.77	0.20	120	345	147	32	86	82	274	29	179	18	220	21	34	11	<5	1.15
rb132	AD524	55.75	0.867	13.42	6.82	0.062	4.71	14.29	1.86	1.93	0.29	153	355	156	16	68	36	574	30	195	19	345	33	41	<5	<5	1.41
rb133	AD525	55.77	0.842	13.41	6.66	0.063	4.74	14.41	1.87	1.98	0.26	126	330	165	51	85	38	388	20	147	19	565	27	<5	15		1.34
rb134	AD526	55.83	0.839	13.42	6.63	0.063	4.83	14.50	1.86	1.73	0.30	144	344	154	32	68	35	497	29	186	17	326	41	42	<5	<5	1.37
rb135	AD527	51.60	0.986	12.76	8.37	0.075	4.99	17.21	1.78	1.97	0.25	123	286	140	5	62	32	425	25	161	18	263	16	26	<5	<5	1.13
rb136	AD528	55.34	0.834	13.35	6.66	0.064	4.81	14.81	1.88	1.93	0.31	130	334	166	39	78	31	425	24	151	18	565	53	25	13		1.55
rb137	AD529	55.83	0.844	13.45	6.65	0.063	4.84	14.39	1.81	1.85	0.27	144	346	156	15	70	37	542	30	185	17	341	16	38	<5	<5	1.29
rb148	AD530	61.33	0.999	14.52	7.99	0.114	4.64	6.06	1.07	2.99	0.29	137	331	174	20	88	91	361	26	191	18	312	33	42	15	<5	1.85
rb149	AD531	50.14	0.856	12.76	7.40	0.084	5.03	20.58	1.51	1.23	0.40	116	263	147	7	45	13	1183	27	159	16	739	33	38	<5	<5	5.08

Tab. 1 (Contin.) Project Tepe Sohz (chapter 4.1).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
1	MD811	52.04	0.848	15.43	7.78	0.109	4.51	15.94	0.96	2.18	0.20	107	522	363	33	83	76	305	23	182	14	251	15	18	12	13	2.83
2	MD812	51.55	1.056	14.69	8.42	0.118	4.52	16.52	0.87	1.89	0.37	146	543	315	47	80	60	393	20	186	14	338	5	38	10	14	4.55
3	MD813	54.98	0.992	13.97	7.58	0.120	4.40	14.45	1.22	1.89	0.39	171	798	227	47	97	54	348	22	210	14	305	27	27	10	10	5.54
4	MD814	52.06	1.236	14.33	9.00	0.131	4.45	15.81	0.89	1.85	0.25	141	550	235	44	90	47	388	19	188	14	282	10	33	9	12	7.18
5	MD815	54.04	0.828	12.85	7.91	0.131	5.32	16.69	0.29	1.64	0.30	108	608	459	42	94	63	244	24	163	13	204	11	44	8	17	4.72
13	MD823	50.50	0.817	14.53	7.67	0.111	4.54	18.94	0.74	1.97	0.18	107	461	416	37	91	80	294	20	171	13	235	15	62	9	14	5.40
14	MD824	48.33	0.852	13.81	7.03	0.104	3.95	22.80	0.87	1.97	0.27	107	613	274	41	86	73	349	22	204	12	233	23	52	9	16	8.30
15	MD825	51.00	0.843	14.51	7.61	0.108	4.56	18.14	0.92	1.94	0.37	121	562	387	47	82	75	381	22	177	11	239	26	52	11	12	4.18
16	MD826	50.56	0.867	14.93	7.78	0.127	4.82	17.85	0.91	1.90	0.26	113	533	369	60	89	77	348	20	177	12	318	29	43	11	15	4.44
17	MD827	50.26	0.816	14.37	7.49	0.108	4.69	18.67	1.10	2.29	0.21	113	500	367	58	88	71	412	21	169	11	226	23	37	9	15	7.83
18	MD828	50.21	0.812	14.00	7.33	0.118	4.75	19.59	1.02	1.93	0.23	104	530	383	48	82	69	364	18	163	13	239	17	31	9	16	6.37
19	MD829	52.68	0.855	14.70	7.68	0.114	4.90	15.65	1.14	2.02	0.26	126	563	399	48	72	73	363	18	178	13	274	17	43	10	13	3.66
20	MD830	50.64	0.815	14.02	7.40	0.113	4.39	19.42	0.99	1.95	0.26	118	538	369	47	83	68	363	22	173	12	269	30	36	10	15	8.07
21	MD831	54.21	0.865	14.71	7.52	0.126	5.58	13.17	1.33	2.22	0.27	141	440	198	55	84	70	457	20	185	12	325	26	36	12	9	3.89
22	MD832	53.49	0.861	13.66	7.09	0.126	5.03	15.85	0.97	2.64	0.27	139	504	187	48	77	62	569	22	205	13	394	22	57	12	8	5.89
24	MD834	51.06	0.864	13.96	6.98	0.120	5.46	18.17	1.35	1.82	0.20	124	381	176	43	77	46	604	22	198	17	405	22	56	9	8	3.74
25	MD835	53.63	0.844	13.49	7.10	0.124	5.56	14.98	1.57	2.39	0.31	133	593	219	53	68	55	604	19	191	12	334	28	47	11	7	5.59
26	MD836	55.66	0.773	13.47	7.23	0.134	5.67	13.21	1.64	2.01	0.20	129	419	221	63	79	51	514	17	173	10	317	12	30	11	9	4.84
27	MD837	52.76	0.875	14.37	8.12	0.140	6.03	13.65	1.71	1.96	0.39	145	419	270	55	68	54	472	22	182	12	300	15	30	7	10	1.63
30	MD840	52.09	0.782	13.95	7.92	0.147	6.47	14.53	1.62	2.19	0.30	128	320	271	48	90	55	586	18	165	9	305	14	56	8	9	6.85
34	MD844	54.38	0.901	13.75	7.86	0.158	4.61	16.17	0.61	1.41	0.15	149	445	238	50	80	50	446	23	177	12	240	17	47	13	10	5.14
35	MD845	53.41	0.805	12.71	7.51	0.119	5.07	18.04	0.32	1.71	0.29	106	627	460	46	89	64	266	24	167	15	165	27	47	8	11	5.62
36	MD846	51.79	0.870	14.74	7.91	0.114	4.72	16.65	0.86	2.03	0.31	106	548	411	42	98	73	351	20	177	13	269	24	49	10	11	4.34
37	MD847	50.53	0.909	14.79	8.00	0.103	4.96	17.68	0.85	1.92	0.26	106	529	370	47	91	72	384	22	181	14	288	21	28	9	12	4.74
38	MD848	50.69	0.860	12.79	7.64	0.127	4.55	20.85	0.32	1.93	0.24	119	500	378	38	97	59	231	21	164	11	197	19	41	13	17	9.64
40	MD850	52.23	0.861	12.44	8.08	0.128	4.50	19.17	0.36	2.03	0.20	105	611	475	50	102	52	252	22	168	14	168	14	56	10	15	10.93
41	MD851	51.35	0.826	14.66	7.64	0.109	4.53	17.64	0.78	2.19	0.28	116	477	385	36	91	78	324	23	173	15	228	15	38	13	14	4.63
42	MD852	53.89	0.817	12.61	8.47	0.129	5.64	15.95	0.42	1.77	0.31	115	669	610	39	91	61	273	22	163	12	183	18	29	6	9	4.57
43	MD853	51.74	0.918	14.62	7.99	0.130	4.77	16.53	1.02	2.07	0.21	113	535	368	41	88	64	344	23	180	13	301	18	60	11	17	4.91
44	MD854	53.37	0.827	12.76	8.47	0.120	5.37	16.37	0.38	1.81	0.53	119	768	619	49	93	63	274	19	167	12	165	24	39	9	11	3.67
45	MD855	55.29	0.884	15.12	7.57	0.093	4.55	12.53	1.29	2.43	0.25	119	671	367	34	71	75	334	20	178	12	234	7	26	8	9	3.46
47	MD857	52.17	0.809	12.26	8.34	0.105	5.45	18.86	0.23	1.48	0.30	119	714	607	53	97	63	203	21	159	12	176	5	35	9	14	3.52
48	MD858	50.34	0.901	14.65	7.94	0.109	4.99	18.19	0.81	1.80	0.25	111	527	369	42	96	70	370	23	177	12	264	11	57	12	11	4.85
49	MD925	52.82	0.813	13.82	7.72	0.141	6.78	12.59	2.30	2.73	0.28	140	331	241	43	89	56	380	19	166	14	282	21	35	7	14	10.28
50	MD926	54.80	0.809	14.37	7.96	0.147	6.03	11.89	1.73	2.02	0.25	128	306	255	54	78	58	451	20	172	10	416	17	38	6	10	1.49
51	MD927	51.27	0.843	13.85	8.10	0.158	6.83	15.32	1.72	1.67	0.24	144	424	286	40	83	47	474	21	174	11	453	25	28	<5	9	1.13
52	MD928	53.63	1.000	14.55	7.55	0.178	5.03	14.26	0.89	2.48	0.43	145	347	180	54	92	79	627	28	255	17	497	29	67	10	9	3.37
53	MD929	55.74	0.773	14.17	7.62	0.144	5.75	11.65	1.71	2.09	0.36	128	332	260	51	76	60	423	20	164	12	522	<5	50	5	9	1.77
54	MD930	51.50	0.830	14.07	8.08	0.153	6.01	15.46	1.45	2.18	0.27	146	334	253	46	104	59	599	20	176	12	422	14	42	14	12	8.78
55	MD931	49.48	0.805	14.16	8.43	0.161	7.30	16.36	1.50	1.60	0.21	143	317	303	55	96	62	446	22	169	10	296	<5	35	5	13	0.78
56	MD932	52.04	0.804	14.56	8.09	0.145	6.45	14.75	1.36	1.59	0.22	134	358	263	54	95	57	446	22	167	12	581	15	32	5	8	1.45
57	MD933	53.41	0.791	14.30	8.12	0.153	6.74	12.93	1.63	1.68	0.24	138	399	280	59	94	52	430	19	162	11	618	19	46	10	12	3.15
58	MD934	53.87	0.799	14.18	6.87	0.112	5.75	14.80	0.98	2.20	0.43	111	279	165	37	88	68	474	23	178	17	345	15	34	38	11	1.39
59	MD935	53.55	0.817	14.10	7.20	0.130	5.49	14.89	1.10	2.17	0.56	124	350	198	56	89	66	603	23	184	15	354	34	49	13	10	3.59
60	MD936	50.36	0.920	13.29	7.01	0.124	4.74	20.29	0.97	1.99	0.31	132	500	160	38	93	65	923	22	215	16	809	24	57	13	6	8.55
61	MD937	53.50	0.863	14.01	7.85	0.141	6.51	12.58	2.07	1.99	0.48	140	482	255	70	83	53	480	19	173	12	301	7	32	<5	8	4.76
62	MD938	47.66	0.729	12.02	5.64	0.090	3.96	26.70	0.89	1.93	0.39	159	317	99	41	62	34	1017	16	160	6	1027	6	29	17	<5	13.40
63	MD939	52.09	0.844	14.40	7.23	0.121	5.22	16.36	1.44	1.88	0.40	151	283	173	29	77	36	621	22	200	16	381	17	42	<5	10	1.96
64	MD940	51.35	0.792	13.15	7.20	0.131	6.34	15.19	2.79	2.80	0.26	132	439	249	35	76	43	924	17	174	11	299	<5	29	6	<5	9.71
65	MD941	54.54	0.844	14.87	8.29	0.153	6.40	10.63	1.82	2.26	0.19	131	382	275	49	76	63	407	19	172	12	337	18	37	7	17	2.01
66	MD942	52.51	0.757	13.85	7.88	0.164	6.67	14.46	2.12	1.40	0.19	140	372	298	41	72	40	429	18	158	10	269	8	35	<5	11	0.63
67	MD943	52.12	0.801	13.61	7.06	0.137	5.75	16.18	1.47	2.63	0.24	109	401	211	51	71	55	1510	20	198	13	818	13	58	5	<5	7.13
68	MD944	52.55	0.897	14.01	7.33	0.130	6.13	14.46	1.55	2.64	0.30	125	387	193	33	83	52	550	24	192	14	316	13	63	12	8	5.54
69	MD945	50.91	0.833	13.95	7.87	0.144	6.49	16.31	1.41	1.81	0.28	128	370	252	42	80	43	576	21	184	11	333	24	53	<5	9	0.61
70	MD946	51.34	0.849	13.72	7.78	0.159	6.16	16.15	1.74	1.88	0.23	132	414	248	48	71	41	557	21	174	11	508	<5	48	5	8	3.11
71	MD947	51.40	0.783	13.27	7.45	0.130	5.67	16.73	1.77	2.54	0.24	134	341	236	43	88	40	525	17	166	12	268	22	30	<5	10	13.63
72	MD948	52.15	0.849	14.40	8.16	0.146	7.38	12.48	1.71	2.50	0.23	103	342	270	65	62	53	390	25	162	13	418	31	57	<5	15	3.26
73	MD949	51.15	0.863	14.72	8.39	0.156	6.37	14.60	1.76	1.76	0.24	147	353	261	48	84	32	489	22	188	12	371	22	45	<5	9	0.96
74	MD950	50.60	0.854	14.01	8.12	0.157	5.97	16.13	1.36	2.54	0.28	127	357	278	57	88	64	649	22	186	10	337	14	47	12	9	6.56
75	MD951	53.54	0.814	14.05	7.85	0.137	6.48	12.87	1.42	2.57	0.27	137	367	255	37	85	47	443	22	178	13	337	25	49	9	8	1.22

Tab. 2 Project Northern Syria.

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
76	MD952	54.32	0.814	14.43	7.92	0.144	6.06	12.46	1.70	1.94	0.22	129	389	256	51	87	59	423	19	170	9	364	20	44	9	9	0.77
77	MD953	55.83	0.821	14.24	7.65	0.138	5.58	11.72	1.83	1.95	0.24	143	463	234	51	90	58	466	19	175	9	345	17	25	11	9	4.25
78	MD954	54.06	0.789	13.92	7.49	0.141	6.34	12.35	2.48	2.20	0.23	128	364	249	43	77	48	434	16	163	10	299	10	40	<5	9	4.39
79	MD955	53.28	0.832	14.11	7.51	0.133	5.27	14.82	1.52	2.24	0.28	131	291	208	48	94	62	487	21	177	10	329	10	49	12	11	6.54
80	MD956	53.73	0.836	14.26	7.08	0.111	5.03	15.38	1.07	2.07	0.42	124	287	170	40	89	65	472	21	192	14	338	28	50	7	9	1.34
81	MD957	49.15	0.928	12.56	6.54	0.121	4.54	22.19	0.62	2.87	0.48	110	418	158	46	104	65	746	23	237	14	360	17	56	12	9	10.61
82	MD958	54.04	0.827	13.58	6.93	0.122	5.92	14.79	1.52	2.03	0.25	119	411	194	47	68	44	497	21	190	13	450	19	58	<5	8	1.65
83	MD959	53.21	0.828	13.66	7.60	0.132	6.02	13.99	1.66	2.52	0.38	124	548	278	60	92	57	662	17	188	12	338	15	36	9	11	4.90
84	MD960	53.73	0.876	14.37	7.39	0.126	5.97	13.42	1.29	2.42	0.41	120	376	199	42	70	61	482	24	195	13	474	25	53	6	10	1.44
85	MD961	54.72	0.837	13.69	7.19	0.132	5.32	14.15	1.60	2.07	0.28	125	425	189	48	79	57	569	21	181	14	455	12	45	10	9	6.11
86	MD962	46.98	0.865	13.06	6.98	0.123	4.71	23.91	1.03	2.09	0.26	135	334	148	50	87	67	947	22	211	14	436	26	55	12	6	12.49
87	MD963	51.26	0.871	14.02	8.00	0.152	6.28	15.32	1.20	2.48	0.40	123	386	242	67	103	64	581	22	191	12	807	14	46	14	7	6.96
88	MD964	52.50	0.843	13.46	7.43	0.135	5.78	15.20	1.77	2.59	0.29	130	522	241	59	98	56	847	20	191	9	313	10	43	10	<5	9.06
89	MD965	55.13	0.839	14.19	7.67	0.137	5.55	12.91	1.48	1.86	0.25	138	448	236	55	83	57	581	24	171	12	383	19	44	11	7	4.18
90	MD966	51.22	0.874	14.90	8.68	0.154	6.18	14.32	1.09	2.12	0.45	127	324	276	67	85	65	524	24	186	12	450	23	27	9	8	2.38
91	MD967	49.87	0.862	12.95	7.46	0.140	7.24	17.61	2.05	1.60	0.23	147	496	246	50	94	51	579	24	188	11	304	14	27	<5	<5	0.70
92	MD968	53.23	0.817	13.34	7.33	0.131	6.65	14.73	1.74	1.82	0.22	145	460	217	49	82	55	495	21	173	11	372	6	47	<5	6	0.99
93	MD969	51.66	0.773	13.31	7.27	0.125	7.23	15.29	1.57	2.44	0.33	139	383	227	56	91	60	654	18	166	10	401	7	46	12	10	8.66
94	MD970	52.85	1.395	14.61	8.71	0.157	4.68	13.81	1.07	2.35	0.37	157	319	178	44	84	64	458	26	242	18	348	24	58	<5	11	4.03
95	MD971	49.33	0.839	13.99	8.20	0.163	6.58	17.04	1.28	2.18	0.40	135	307	285	73	92	57	585	22	171	12	382	13	48	11	8	5.65
96	MD972	51.13	1.003	12.96	6.92	0.109	4.93	19.00	1.25	2.15	0.55	114	393	158	48	77	26	671	24	240	15	309	21	61	6	7	5.41
97	MD973	54.30	0.841	13.56	7.52	0.136	5.88	13.43	1.57	2.28	0.49	126	612	279	50	82	55	564	21	189	12	349	<5	43	5	5	3.38
98	MD974	50.45	0.795	13.10	7.41	0.138	6.35	17.73	1.57	2.19	0.27	134	517	284	60	73	53	632	19	170	11	721	10	28	12	8	8.26
99	MD975	52.39	0.817	13.94	7.70	0.143	8.14	12.39	1.81	2.36	0.32	135	394	250	68	82	54	627	22	168	13	376	14	44	6	5	4.01
100	MD976	52.12	0.841	14.15	8.06	0.176	6.59	13.47	1.80	2.50	0.29	146	344	261	50	116	57	646	21	182	10	345	<5	44	8	9	4.69
101	MD977	53.47	0.890	14.75	8.33	0.145	5.87	12.11	1.83	2.35	0.26	141	429	257	50	74	60	544	22	192	13	331	11	41	8	5	1.84
102	MD978	52.21	0.843	14.23	7.67	0.140	6.29	14.48	1.68	2.07	0.38	161	397	244	39	77	54	603	23	179	10	336	21	52	5	5	2.30
103	MD979	52.54	0.789	14.15	8.10	0.158	6.42	13.65	1.31	2.66	0.22	138	331	268	49	99	55	654	21	174	9	320	9	46	5	7	4.10
104	MD980	52.01	0.778	14.00	7.96	0.154	6.23	14.76	1.38	2.50	0.22	131	322	258	40	86	49	760	21	172	9	343	23	34	<5	<5	4.22
105	MD981	48.46	0.786	12.84	8.07	0.154	8.26	18.25	1.47	1.52	0.19	145	388	356	58	91	53	475	20	155	10	281	13	35	8	7	0.27
106	MD982	50.19	0.972	12.82	6.65	0.101	3.73	22.22	0.44	2.21	0.67	129	347	135	36	96	60	954	22	222	13	312	39	59	17	6	7.89
107	MD983	50.86	0.763	13.26	7.69	0.139	7.36	15.97	2.15	1.57	0.23	139	348	292	29	63	24	491	20	160	10	271	<5	57	<5	7	2.43
108	AD001	66.48	1.356	18.65	9.33	0.158	1.01	1.57	0.05	1.26	0.14	136	337	184	41	102	97	116	54	372	27	323	56	101	25	24	1.24
109	AD002	48.96	0.844	13.03	7.66	0.155	8.26	18.30	1.39	1.16	0.23	141	519	287	53	83	28	653	16	171	10	190	13	34	<5	7	2.74
110	AD003	64.86	1.298	18.22	9.12	0.176	1.46	2.25	1.01	1.46	0.16	121	324	181	38	80	92	180	44	353	26	392	48	114	10	22	2.71
111	AD004	64.16	1.324	18.74	9.14	0.161	1.37	3.77	0.12	1.09	0.12	128	327	175	39	88	95	350	48	355	27	472	45	100	22	20	2.66
112	AD005	66.04	1.318	17.64	8.68	0.158	1.48	3.20	0.12	1.19	0.17	139	317	163	36	94	87	253	48	358	24	556	58	101	18	19	1.06
113	AD006	43.42	0.596	8.90	5.29	0.129	6.18	32.69	0.87	1.50	0.43	113	424	214	61	112	26	1306	22	143	8	862	<5	31	5	<5	17.91
114	AD007	52.59	0.840	13.59	7.67	0.137	7.06	14.19	1.95	1.72	0.24	144	365	246	43	85	47	445	22	175	12	280	25	30	<5	10	1.26
115	AD008	49.56	0.776	13.17	7.57	0.151	7.01	17.67	1.64	2.06	0.38	127	320	272	72	93	51	612	19	162	11	301	18	23	9	7	7.08
116	AD009	49.64	0.787	12.92	6.67	0.117	5.11	21.13	1.27	2.10	0.27	124	398	157	61	69	54	1007	19	195	13	380	15	42	<5	<5	8.87
117	AD010	52.37	0.783	13.69	7.61	0.154	6.84	14.28	1.84	2.06	0.37	118	396	282	69	98	53	504	16	160	11	314	25	49	8	12	5.71
118	AD011	49.11	0.863	13.59	7.14	0.129	5.90	19.86	2.21	0.97	0.23	112	380	191	33	82	21	879	21	208	14	293	17	60	120	5	3.90
119	AD012	68.39	1.301	17.60	8.84	0.154	1.02	1.29	0.06	1.19	0.15	150	331	169	44	92	95	96	48	369	26	301	36	118	21	22	0.42
120	AD013	50.58	0.836	13.49	7.59	0.150	5.73	18.09	1.69	1.62	0.22	128	364	250	55	87	52	1378	22	187	11	825	28	50	12	<5	10.01
121	AD014	52.92	0.807	14.40	8.00	0.146	6.11	14.09	1.47	1.87	0.20	131	320	252	72	89	64	581	20	172	11	499	<5	25	6	9	2.13
122	AD 313	48.40	0.774	13.38	7.54	0.141	6.94	19.21	0.89	2.25	0.48	128	245	231	38	80	69	558	17	155	13	227	14	38	<5	12	3.48
123	AD 314	51.69	0.873	13.26	7.20	0.126	5.52	16.93	1.54	2.64	0.22	94	450	189	78	82	44	451	21	130	16	487	<5	29	15		4.79
124	AD 315	55.40	0.790	14.32	7.25	0.133	5.28	12.95	1.70	1.95	0.23	131	340	207	66	86	60	465	22	168	12	351	19	49	13	10	2.88
125	AD 316	52.12	0.834	13.46	6.98	0.127	6.28	16.74	1.14	2.09	0.23	133	410	187	190	104	70	517	-5	188	13	411	18	102	3394	54	4.45
126	AD 317	51.45	0.902	13.30	7.03	0.132	6.40	16.51	1.64	2.37	0.26	148	463	174	101	86	56	717	10	213	12	349	24	64	1107	21	5.90
127	AD 318	51.26	0.872	13.81	7.11	0.117	5.26	18.03	1.75	1.57	0.22	126	411	173	32	62	51	754	21	207	14	610	7	43	<5	6	3.24
128	AD 319	55.22	0.788	13.37	7.23	0.134	5.92	13.26	1.73	1.97	0.37	118	417	236	51	92	37	362	21	109	15	458	27	28	88		2.07
129	AD 320	51.85	0.834	15.03	8.22	0.160	5.99	14.06	1.44	2.17	0.25	127	322	262	68	103	68	465	22	173	12	369	28	29	29	14	3.85
130	AD 321	57.48	0.803	13.31	7.29	0.135	5.10	12.21	1.65	1.79	0.24	127	479	201	62	84	53	524	21	169	11	309	7	41	46	10	3.64
131	AD 322	51.98	0.809	13.74	7.82	0.155	6.71	14.71	1.97	1.86	0.24	131	446	281	43	86	40	602	19	170	12	318	<5	33	<5	<5	6.35
132	AD 323	43.60	0.554	8.88	4.93	0.134	4.75	34.25	0.84	1.66	0.41	92	354	196	43	101	28	1046	21	130	8	982	6	22	5	5	19.43
133	AD 324	51.99	0.813	14.17	7.04	0.105	6.83	15.41	1.11	2.23	0.30	111	262	157	53	73	65	1047	19	191	15	364	14	37	9	6	2.82
134	AD 325	52.87	0.786	13.63	6.43	0.109	4.96	16.04	2.50	2.10	0.57	115	268	153	26	103	55	688	21	189	14	356	<5	46	<5	<5	6.24
135	AD 326	52.51	0.714	11.96	6.51	0.120	8.41	16.14	1.88	1.45	0.31	86	302	230	1906	83	10	307	28	105	16	408	14	<5	215		2.76

Tab. 2 (Contin.) Project Northern Syria.

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
136	AD 327	40.48	0.538	8.96	5.20	0.150	5.06	37.41	0.56	1.32	0.33	106	339	209	46	107	26	1336	34	117	13	1932	29	38	8	<5	19.15
137	AD 328	51.84	0.768	13.41	6.36	0.112	4.98	17.11	2.68	2.02	0.72	111	262	150	29	78	52	723	17	191	12	354	28	47	<5	8	7.02
138	AD 329	51.75	0.792	13.76	7.33	0.132	6.02	16.65	1.49	1.90	0.18	141	374	209	52	87	62	578	23	174	12	319	19	47	12	10	9.10
139	AD 330	52.69	0.843	13.67	7.94	0.152	6.63	14.32	1.58	1.95	0.22	131	401	252	50	80	48	540	19	167	10	306	<5	33	14	10	3.98
140	AD 331	51.19	0.697	12.91	6.91	0.121	6.75	17.90	1.74	1.57	0.21	88	271	230	790	91	30	331	19	106	13	464	<5	12	55		1.61
142	AD 333	50.42	0.726	12.45	6.45	0.116	6.26	19.82	1.36	2.14	0.26	125	334	195	96	81	65	778	-27	168	10	343	15	136	5504	81	11.03
216	MD818	49.12	0.838	14.90	7.74	0.102	4.52	19.73	0.74	2.08	0.23	103	473	387	45	92	83	400	21	179	12	220	31	30	12	10	6.12
217	MD819	50.15	0.870	14.08	7.19	0.117	4.27	19.49	1.07	2.51	0.25	99	626	286	38	85	64	357	25	205	14	281	15	56	12	14	8.10
218	MD820	51.43	0.839	14.47	7.40	0.103	4.54	17.86	1.03	2.06	0.26	120	535	330	56	100	72	380	19	176	12	281	10	46	11	13	6.08
219	MD821	50.93	0.861	12.88	8.06	0.134	4.79	19.94	0.32	1.77	0.32	99	610	465	46	97	59	301	19	171	14	200	19	54	8	14	6.33
220	MD822	50.38	0.928	14.33	7.88	0.115	4.64	18.72	1.06	1.74	0.20	123	571	331	37	76	60	388	20	177	12	308	33	36	6	10	6.20
221	MD833	51.72	0.854	14.61	8.09	0.141	6.23	14.77	1.22	2.12	0.25	129	398	289	57	81	67	586	22	188	15	387	<5	51	13	6	2.21
222	MD838	52.13	0.842	14.00	8.16	0.158	6.68	14.01	1.71	2.05	0.25	142	428	278	54	83	51	634	21	175	10	1161	14	38	<5	6	3.63
223	MD839	52.78	0.778	13.33	7.23	0.150	6.47	15.17	1.99	1.72	0.38	144	401	241	43	82	47	551	16	155	7	386	14	21	9	<5	4.30
224	MD841	52.12	0.864	14.00	8.17	0.149	6.50	14.14	1.81	2.03	0.24	146	476	267	47	76	46	581	20	173	10	505	<5	46	5	8	2.68
225	MD842	50.47	0.768	13.13	7.51	0.155	6.91	16.71	1.67	2.21	0.47	138	360	270	50	81	42	709	18	166	10	775	12	42	8	<5	4.87
226	MD843	49.32	0.891	13.34	7.91	0.134	5.84	20.77	0.25	1.34	0.20	118	593	410	45	91	60	316	22	170	13	276	12	40	10	13	4.26
227	MD849	52.41	0.896	13.91	8.22	0.132	4.99	17.35	0.24	1.51	0.34	117	508	443	48	95	68	229	23	172	12	220	38	46	8	11	2.28
228	MD856	51.22	0.844	14.70	7.69	0.133	4.76	17.69	0.81	1.89	0.27	111	489	387	39	84	75	350	23	175	15	299	11	51	14	12	4.39
229	MD816	52.07	0.840	14.74	7.70	0.117	4.77	16.49	1.06	2.05	0.17	110	518	393	43	79	71	307	21	175	13	245	7	56	12	13	4.95
230	MD817	50.68	0.846	14.38	7.72	0.115	4.62	18.60	0.75	2.01	0.29	116	511	395	41	89	73	380	19	175	13	227	14	25	12	14	6.98

Tab. 2 (Contin.) Project Northern Syria.

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
MW_001	AD 074	72.23	1.327	17.35	5.30	0.051	0.92	0.92	0.15	1.46	0.29	113	137	61	46	102	35	105	42	347	15	413	35	73	8	9	1.04
MW_002	AD 075	69.49	1.325	17.28	5.64	0.052	1.22	1.30	0.29	3.03	0.38	122	142	63	38	102	45	125	44	332	16	385	25	75	11	9	1.45
MW_003	AD 076	69.79	1.288	17.21	5.72	0.055	1.32	1.41	0.28	2.53	0.40	117	133	49	37	66	44	160	42	296	14	357	34	76	14	11	1.61
MW_004	AD 077	60.12	1.769	17.29	10.26	0.175	2.76	4.26	1.11	1.85	0.42	166	140	78	65	103	55	275	34	298	28	465	31	65	6	10	1.54
MW_005	AD 078	67.26	1.380	14.46	7.58	0.116	2.42	2.67	1.21	2.49	0.41	140	122	60	42	79	48	235	31	332	19	438	35	50	7	11	1.29
MW_006	AD 079	65.96	1.524	15.00	8.80	0.144	2.25	2.82	1.37	1.80	0.34	142	143	73	53	88	55	246	30	316	22	500	21	66	8	10	1.33
MW_007	AD 080	62.11	1.660	17.04	9.76	0.151	2.61	3.24	1.21	1.83	0.39	170	143	76	57	96	55	256	35	302	26	532	16	67	8	12	1.77
MW_008	AD 081	63.22	1.445	21.41	9.36	0.068	1.10	1.60	0.45	1.02	0.33	143	135	65	42	75	31	124	30	315	25	263	23	69	7	13	0.53
MW_009	AD 082	62.96	1.630	16.52	9.84	0.152	2.64	3.11	0.95	1.80	0.41	161	143	79	67	105	62	261	33	306	24	511	29	69	11	11	0.86
MW_010	AD 083	61.21	1.461	15.74	8.77	0.134	3.57	4.09	2.33	2.34	0.36	151	143	77	57	58	47	314	30	306	19	418	37	61	<5	8	0.87
MW_011	AD 084	63.56	1.627	20.56	7.71	0.108	1.68	2.12	0.90	1.31	0.44	153	144	55	49	75	42	160	31	294	20	396	14	53	9	11	1.18
MW_012	AD 085	62.64	1.733	17.06	9.80	0.146	2.50	3.42	0.89	1.42	0.39	159	138	75	56	95	56	241	33	327	26	463	29	69	7	11	1.38
MW_013	AD 086	65.94	1.500	15.14	8.83	0.145	2.29	3.10	0.93	1.67	0.46	152	133	67	47	88	50	261	30	297	22	479	17	50	7	11	1.43
MW_014	AD 087	64.02	0.983	19.02	6.14	0.077	1.05	1.69	1.26	5.49	0.26	58	56	37	23	76	163	137	55	571	35	755	116	163	38		0.86
MW_015	AD 088	70.33	1.449	19.70	4.71	0.060	0.77	1.35	0.34	1.12	0.17	119	147	42	32	45	28	148	40	314	17	371	34	81	12	9	3.08
MW_016	AD 089	67.40	1.489	21.76	5.46	0.061	0.80	1.02	0.37	1.47	0.17	131	155	46	33	48	32	184	44	309	18	300	42	80	14	8	2.76
MW_017	AD 090	66.15	1.451	22.77	5.41	0.057	0.85	1.39	0.30	1.46	0.17	132	152	50	38	50	31	167	57	258	17	369	44	88	10	11	3.70
MW_018	AD 091	67.58	1.438	21.28	5.95	0.074	0.96	1.42	0.14	0.96	0.19	116	156	56	36	55	34	96	41	278	18	268	55	91	13	9	1.35
MW_019	AD 092	68.70	1.457	21.44	4.91	0.054	0.84	0.95	0.37	1.10	0.18	93	146	45	33	46	28	109	41	292	16	247	38	82	14	10	1.12
MW_020	AD 093	67.45	1.501	21.38	6.19	0.078	0.98	0.96	0.23	1.01	0.21	132	154	54	40	54	35	100	42	302	20	287	31	83	6	8	0.23
MW_021	AD 094	66.19	1.475	21.88	6.74	0.095	1.12	1.10	0.16	1.01	0.22	152	160	64	43	61	36	102	47	285	17	283	38	99	13	12	0.78
MW_022	AD 095	67.28	1.435	20.74	6.12	0.069	0.98	1.24	0.25	1.50	0.40	129	151	50	26	57	34	168	41	279	18	351	40	90	13	10	2.10
MW_023	AD 096	67.42	1.496	21.29	6.13	0.077	0.97	1.19	0.21	1.00	0.21	129	152	53	35	60	33	106	41	284	18	249	46	96	13	10	0.67
MW_024	AD 097	60.19	1.783	17.48	10.38	0.180	2.75	3.70	1.04	2.03	0.46	177	146	80	65	103	56	275	34	304	27	495	35	60	<5	7	1.24
MW_025	AD 098	64.51	1.459	24.42	6.23	0.069	1.01	1.06	0.09	0.90	0.26	147	156	56	37	63	30	100	57	247	19	287	50	83	12	9	0.98
MW_026	AD 099	68.50	1.448	21.25	5.03	0.055	0.71	1.14	0.36	1.33	0.18	135	151	46	29	45	27	120	40	283	16	239	33	80	13	14	2.36
MW_027	AD 100	67.48	1.367	18.16	7.77	0.115	1.66	1.27	0.32	1.52	0.35	142	150	67	47	77	49	141	34	288	17	349	38	58	11	11	1.04
MW_028	AD 101	67.51	1.486	21.33	6.14	0.078	0.98	1.02	0.23	1.02	0.21	132	171	59	40	59	34	102	46	288	19	268	36	94	12	15	0.81
MW_029	AD 102	68.43	1.488	21.80	4.78	0.054	0.73	1.30	0.27	1.02	0.13	125	151	42	22	42	25	111	39	293	19	245	47	79	11	9	2.15
MW_030	AD 103	70.30	1.321	17.56	5.83	0.059	1.23	1.44	0.21	1.64	0.40	125	138	47	35	69	38	153	40	322	13	389	44	59	15	6	0.84
MW_031	AD 104	66.97	1.300	19.46	5.36	0.061	0.98	1.48	0.70	2.92	0.76	128	130	40	32	55	36	137	40	266	12	236	19	63	10	8	1.31
MW_032	AD 105	68.96	1.330	19.22	5.78	0.061	1.03	1.37	0.35	1.53	0.37	161	124	43	28	52	32	243	49	304	13	312	26	35	8	8	4.46
MW_033	AD 106	67.49	1.487	21.25	6.12	0.078	1.01	0.99	0.22	1.13	0.21	125	154	54	39	56	33	117	45	295	18	306	34	89	13	12	1.33
MW_034	AD 107	66.78	1.472	21.61	5.88	0.069	0.87	1.57	0.28	1.26	0.21	115	159	50	30	54	34	172	42	290	17	253	43	85	12	10	1.96
MW_035	AD 108	58.73	1.769	17.48	10.71	0.124	2.29	3.77	1.09	2.59	1.44	185	150	78	72	112	52	505	36	308	28	458	58	69	10	8	9.02
	AD 213	62.60	1.833	18.80	7.74	0.125	1.95	3.85	1.53	1.27	0.31	172	159	59	61	78	34	289	36	328	25	442	29	80	8	8	4.04
	AD 214	65.39	1.717	19.76	6.56	0.103	1.54	2.38	1.08	1.09	0.39	138	147	54	71	70	35	222	37	318	23	370	36	71	21	10	2.68
	AD 215	66.33	1.661	18.78	7.11	0.092	1.74	2.23	0.70	1.07	0.30	160	162	62	51	82	36	176	39	382	22	379	42	74	13	9	1.71
	AD 216	65.86	1.463	15.10	8.09	0.119	2.38	3.17	1.51	1.91	0.40	152	136	58	46	86	46	290	30	326	21	504	32	58	9	10	4.00
	AD 217	67.78	1.672	23.87	2.11	0.013	0.35	2.45	1.03	0.51	0.22	146	141	31	48	23	14	220	38	287	25	195	31	74	10	7	7.65
	AD 218	67.30	1.403	16.77	8.31	0.088	1.49	2.14	0.94	1.31	0.27	142	107	54	42	65	30	206	54	286	13	364	45	97	7	11	2.91
	AD 219	68.77	1.738	22.46	3.06	0.058	0.63	1.34	1.01	0.71	0.23	132	138	34	58	42	19	143	37	305	26	205	33	61	12	8	3.95
	AD 220	68.79	1.378	18.86	5.63	0.074	1.36	1.68	0.65	1.39	0.19	132	125	44	33	65	53	162	40	322	22	502	43	68	14	11	2.13
	AD 221	67.24	1.671	20.35	5.06	0.076	1.09	2.02	1.21	0.97	0.30	135	138	44	53	54	26	176	33	315	22	299	26	67	28	14	2.72
MW_036	AD 222	66.00	1.424	21.71	6.18	0.073	0.97	1.59	0.27	1.56	0.23	139	153	55	34	56	32	145	47	305	17	322	33	87	12	10	2.20
MW_037	AD 223	69.11	1.450	20.79	4.62	0.039	1.00	1.54	0.11	1.21	0.12	141	148	40	29	39	30	117	38	290	16	240	33	77	13	9	7.80
MW_038	AD 224	68.55	1.457	21.67	4.74	0.055	0.71	1.71	0.10	0.79	0.22	94	139	40	25	43	25	102	55	289	16	235	43	104	11	11	1.21
MW_039	AD 225	66.20	1.468	22.09	6.77	0.088	1.05	0.94	0.16	1.01	0.22	127	154	60	46	66	36	106	51	264	17	341	41	90	12	12	1.03
MW_040	AD 226	69.13	1.427	20.33	5.37	0.063	0.90	1.20	0.44	0.96	0.19	120	144	48	30	48	30	115	42	280	16	260	33	80	15	11	0.93
MW_041	AD 227	64.05	1.742	15.83	9.56	0.156	2.46	3.54	0.90	1.44	0.33	171	134	67	65	97	52	229	37	348	26	399	46	67	8	11	1.42
MW_042	AD 228	56.49	1.955	19.39	11.65	0.177	2.49	4.49	0.89	2.07	0.39	207	129	76	77	126	70	220	44	382	38	439	49	97	11	18	3.96
MW_043	AD 229	55.68	2.570	18.74	13.16	0.162	2.55	4.62	1.17	1.10	0.26	260	164	76	73	115	39	274	36	337	34	448	37	59	5	13	2.18
MW_107	AD 288	67.30	1.570	24.85	3.72	0.022	0.32	1.45	0.10	0.58	0.09	92	150	39	22	71	13	76	59	193	25	330	20	42	16		1.87
MW_108	AD 289	67.47	1.462	21.96	4.91	0.061	0.76	1.90	0.12	1.18	0.16	96	142	46	31	61	30	113	50	273	18	250	43	89	12	12	1.84
MW_109	AD 290	68.92	1.638	22.04	4.17	0.041	0.62	1.47	0.19	0.77	0.13	66	152	39	29	73	12	93	44	271	25	305	29	47	29		1.51
	AD 377	68.59	1.483	21.09	4.58	0.052	0.83	1.83	0.20	1.17	0.18	134	144	41	25	47	26	116	55	269	20	199	32	78	12	<5	7.60
	AD 389	69.32	1.451	21.31	4.36	0.049	0.71	1.45	0.18	1.01	0.16	142	152	41	16	39	22	104	51	267	21	210	44	83	13	<5	0.26
	AD 390	69.86	1.403	20.16	4.45	0.053	0.83	1.73	0.17	1.13	0.21	130	148	45	20	44	27	114	45	250	20	219	53	66	12	<5	0.27
	AD 391	69.32	1.430	20.59	4.55	0.057	0.84	1.69	0.18	1.14	0.20	136	150	42	19	42	29	117	47	276	19	211	33	81	12	<5	0.29
MW_110	AD 420	69.88	1.444	19.69	5.16	0.073	0.75	1.43	0.30	1.05	0.22	115	144	46	18	51	26	169	49	283	20	319	46	73	12	<5	3.41

Tab. 3 Project Musawwarat (chapter 4.3).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
MW_111	AD 421	68.82	1.412	20.55	5.46	0.064	0.90	1.42	0.25	0.90	0.22	147	148	51	23	53	28	105	49	260	24	237	55	92	9	<5	0.89
MW_112	AD 422	67.46	1.479	21.21	6.20	0.077	0.94	1.08	0.25	1.09	0.21	128	156	54	28	62	33	119	52	266	20	263	43	95	15	<5	1.08
MW_113	AD 423	67.94	1.482	21.05	5.97	0.077	0.88	1.06	0.22	1.08	0.25	136	154	54	32	61	33	106	54	271	19	271	52	97	14	<5	0.79
MW_114	AD 424	68.01	1.518	21.06	5.82	0.068	0.88	0.81	0.27	1.17	0.40	139	153	54	31	59	33	96	51	266	22	247	56	93	10	<5	0.82
MW_115	AD 425	70.10	1.469	20.50	4.30	0.048	0.58	1.33	0.38	1.15	0.15	128	142	35	18	34	23	107	43	289	21	207	40	71	13	5	2.09
MW_116	AD 426	65.89	1.437	20.23	7.47	0.105	1.23	1.13	0.34	1.87	0.28	146	156	70	38	70	44	125	53	252	24	322	51	118	14	<5	1.34
MW_117	AD 427	72.96	1.329	17.87	4.79	0.059	0.74	1.10	0.18	0.78	0.19	112	131	44	17	49	24	98	52	275	20	269	43	80	10	<5	0.87
MW_118	AD 428	68.42	1.456	14.07	8.05	0.129	2.10	2.77	1.21	1.44	0.35	147	117	61	38	84	50	207	40	295	27	433	28	77	6	6	1.54
MW_119	AD 429	66.35	1.639	17.91	7.27	0.128	1.81	2.57	0.75	1.31	0.28	154	146	62	45	80	47	199	46	300	27	468	32	80	9	<5	1.06
MW_120	AD 430	68.78	1.492	20.83	5.39	0.074	0.89	1.05	0.23	1.05	0.23	127	151	49	28	61	30	102	50	271	22	291	39	81	13	<5	0.92
MW_121	AD 431	69.22	1.459	20.79	5.08	0.052	0.67	1.15	0.42	0.98	0.17	124	149	47	25	50	25	179	49	271	22	461	47	90	9	<5	3.50
MW_122	AD 432	66.47	1.425	20.56	7.34	0.104	1.18	1.25	0.23	1.18	0.28	151	150	66	35	72	38	117	52	259	21	310	44	104	5	5	0.39
MW_123	AD 433	65.81	1.455	20.40	7.56	0.109	1.22	1.11	0.32	1.73	0.28	148	152	68	41	78	45	113	48	247	23	312	68	94	11	5	1.05
MW_124	AD 434	68.39	1.518	21.02	5.57	0.068	0.92	1.14	0.24	0.93	0.20	151	144	49	30	54	35	108	50	275	22	186	53	95	23	5	8.45
MW_125	AD 435	62.26	0.845	21.25	6.61	0.057	0.61	1.23	0.76	6.25	0.14	63	41	35	14	73	139	235	58	552	29	1233	94	167	24	16	5.21
MW_126	AD 436	69.49	1.326	19.79	5.71	0.047	0.64	1.01	0.32	0.87	0.80	136	122	55	18	46	23	141	52	250	18	244	29	59	6	<5	3.91
MW_127	AD 437	69.45	1.316	19.67	5.69	0.063	0.72	1.61	0.33	0.91	0.24	147	126	57	23	46	21	151	51	251	15	196	24	63	8	<5	6.59
MW_128	AD 438	69.79	1.353	20.41	5.56	0.065	0.72	0.91	0.23	0.77	0.19	152	126	42	23	40	24	109	57	252	16	270	40	65	11	<5	1.93
MW_129	AD 439	66.12	1.579	14.11	8.39	0.132	2.51	3.71	1.38	1.78	0.28	154	136	65	30	81	40	339	35	323	23	585	29	61	9	<5	3.35
MW_130	AD 440	62.30	1.808	16.05	10.19	0.162	2.55	3.91	1.38	1.41	0.24	189	163	72	31	92	46	358	38	309	29	736	36	68	9	<5	2.47
MW_131	AD 441	63.00	1.792	16.17	9.82	0.154	2.11	3.96	1.38	1.25	0.37	169	160	84	42	90	35	379	40	313	29	1143	30	73	7	<5	4.64
MW_132	AD 442	70.52	1.739	17.63	4.74	0.082	0.96	1.60	0.67	0.93	1.12	147	144	52	37	62	26	226	57	432	28	713	68	79	13	<5	2.80
MW_133	AD 443	68.45	1.242	17.83	7.42	0.139	1.07	1.67	0.34	1.20	0.63	147	139	77	38	72	28	228	42	220	20	569	35	69	11	<5	6.36
MW_134	AD 444	64.48	1.858	16.35	9.00	0.170	2.05	3.24	1.09	1.33	0.43	188	160	79	57	94	43	297	45	347	30	690	39	77	9	<5	1.94
MW_135	AD 445	63.98	1.849	16.30	8.96	0.167	2.12	3.83	1.06	1.39	0.34	185	164	73	56	92	43	311	47	362	28	687	45	69	10	<5	2.47
	AD 491	73.51	1.605	20.10	2.36	0.018	0.24	1.18	0.33	0.45	0.20	85	156	27	48	20	9	139	23	308	25	649			<5		3.45
	AD 492	72.65	1.581	21.29	2.19	0.010	0.18	1.11	0.39	0.44	0.16	106	161	34	19	33	14	166	41	421	26	356	41	110	11	5	2.79
	AD 493	71.19	1.577	21.16	2.92	0.016	0.30	1.35	0.58	0.76	0.14	139	172	48	39	40	17	141	51	416	23	370	51	82	13	<5	4.36
	AD 494	70.25	1.571	19.99	3.41	0.029	0.64	1.92	1.34	0.72	0.15	138	159	34	18	34	18	170	35	406	27	212	23	70	12	<5	6.04
	AD 495	67.58	1.605	15.89	8.02	0.120	1.79	2.52	0.94	1.24	0.30	156	151	65	44	81	36	234	48	340	25	539	50	47	7	<5	2.16
	AD 496	68.04	1.554	17.15	7.06	0.124	1.36	2.42	1.03	1.07	0.20	124	136	61	34	68	28	232	46	363	25	745	31	57	8	<5	3.02
	AD 497	69.97	1.474	17.31	6.09	0.088	1.33	2.01	0.55	0.81	0.36	140	147	52	38	62	26	162	37	351	26	366	42	53	12	6	1.66
	AD 498	64.17	1.798	20.78	6.61	0.094	1.36	2.93	0.91	1.08	0.27	141	149	62	35	75	23	388	56	402	36	1208	47	142	21	<5	4.93
	AD 499	64.83	1.688	18.82	7.35	0.101	1.52	3.16	0.81	1.38	0.33	150	167	74	50	90	31	401	47	337	28	1049	47	92	11	<5	4.37
	AD 500	60.75	1.910	17.03	10.74	0.181	2.53	3.50	1.40	1.63	0.32	198	168	84	53	105	51	294	43	303	32	561	40	70	10	<5	1.43
	AD 501	64.29	1.899	21.48	5.94	0.095	1.54	2.36	0.89	1.23	0.28	139	147	55	26	81	32	283	46	362	34	824	56	100	17	<5	3.40
	AD 502	66.63	1.476	17.26	6.53	0.090	1.59	3.37	1.17	1.25	0.62	151	159	68	48	79	31	265	40	347	26	591	39	77	11	<5	4.45
	AD 503	62.29	1.823	22.11	7.21	0.101	1.44	2.50	1.19	1.10	0.25	156	142	58	114	95	34	220	44	397	31	375	61	105	14	8	3.83
	AD 504	62.73	1.451	18.94	10.12	0.098	1.66	2.77	1.08	0.85	0.31	163	132	75	50	77	26	232	33	247	22	581	22	54	5	<5	2.17
	AD 505	66.59	1.429	16.67	8.57	0.097	1.45	3.00	0.84	1.12	0.24	139	114	52	44	61	24	294	56	263	20	629	48	100	5	<5	3.36
	AD 506	62.59	1.787	20.57	6.63	0.095	1.62	3.31	1.85	1.26	0.29	158	146	61	125	72	37	295	39	413	32	427	53	96	12	8	6.43
	AD 507	62.84	1.740	21.00	6.92	0.061	1.43	3.16	1.45	1.16	0.24	153	136	52	41	93	36	314	38	421	31	454	47	108	17	5	5.76
	AD 508	63.01	0.921	20.20	6.07	0.063	0.91	1.89	1.13	5.69	0.12	64	57	44	10	64	149	251	61	584	31	689	90	182	27	23	3.72
	AD 509	62.63	1.898	25.29	5.70	0.065	1.05	1.18	0.50	1.52	0.16	172	153	46	30	42	54	213	44	263	32	292	66	103	16	8	1.04
	AD 510	70.71	1.502	19.72	4.56	0.038	0.34	1.59	0.85	0.51	0.18	155	168	36	21	41	13	132	21	401	25	180	21	20	9	<5	7.19
MW_137	AD 609	68.79	1.467	21.25	5.01	0.059	0.76	1.21	0.19	1.08	0.19	126	157	49	20	49	25	95	46	281	21	214	52	77	13	<5	0.80
MW_138	AD 610	68.40	1.445	20.23	6.26	0.080	0.99	0.95	0.22	1.16	0.26	126	153	56	30	65	35	96	47	255	21	252	38	76	12	<5	0.64
MW_139	AD 611	63.57	1.579	15.95	9.59	0.164	2.39	3.03	1.60	1.73	0.40	177	140	76	51	93	45	297	40	267	29	476	34	67	9	<5	2.86
MW_140	AD 612	65.85	1.398	20.17	7.26	0.092	1.09	1.62	0.39	1.84	0.29	156	149	65	31	69	38	295	46	239	22	421	46	88	13	<5	4.18
MW_141	AD 613	63.88	1.708	17.35	8.55	0.141	2.23	3.03	0.96	1.84	0.32	170	143	68	39	84	50	218	42	303	27	467	39	71	9	<5	1.63
MW_142	AD 614	65.05	0.945	18.96	5.82	0.074	0.97	1.50	1.10	5.44	0.14	73	52	36	10	66	156	149	69	615	31	613	92	193	24	23	0.86
MW_143	AD 615	67.47	1.455	20.78	5.98	0.076	0.90	1.81	0.21	1.09	0.23	152	156	53	29	57	32	108	49	259	22	230	47	86	14	<5	1.38
MW_144	AD 616	67.47	1.444	20.10	5.78	0.070	1.18	1.77	0.95	1.03	0.21	158	149	55	34	35	29	142	51	266	22	261	44	93	8	<5	0.51
MW_145	AD 617	68.56	1.482	20.41	5.83	0.071	0.89	1.18	0.36	1.01	0.20	132	154	55	33	55	31	108	52	278	22	257	44	86	12	<5	1.11
MW_146	AD 618	67.82	1.472	21.76	5.72	0.075	0.85	0.91	0.17	0.99	0.24	134	155	52	26	57	29	92	50	258	22	247	48	84	14	<5	0.76
MW_147	AD 619	66.37	1.620	17.64	7.21	0.112	1.70	2.45	1.06	1.58	0.27	153	145	63	45	77	40	228	46	309	25	418	51	56	8	<5	3.98
MW_148	AD 620	68.71	1.491	22.40	4.72	0.072	0.57	0.92	0.21	0.71	0.21	128	142	47	21	45	22	98	57	273	21	281	48	117	14	<5	1.63
MW_149	AD 621	66.99	1.578	14.48	8.56	0.123	2.26	3.24	1.13	1.36	0.27	148	140	69	49	84	40	304	36	302	25	647	29	63	9	<5	2.77
MW_150	AD 622	67.95	1.302	18.82	7.19	0.133	1.19	1.19	0.42	1.50	0.30	137	141	73	39	68	37	169	41	241	22	386	38	81	9	<5	4.93
MW_151	AD 623	67.32	1.518	14.30	8.54	0.156	1.95	2.78	1.11	1.86	0.46	151	136	71	42	88	44	319	38	322	24	423	34	66	7	<5	3.96

Tab. 3 (Contin.) Project Musawwarat (chapter 4.3).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
MW_152	AD 624	61.96	1.853	16.06	10.11	0.174	2.74	3.57	1.48	1.44	0.62	188	161	79	57	100	50	305	40	315	27	544	36	64	10	<5	1.13
MW_153	AD 625	70.46	1.465	12.84	7.88	0.128	1.98	2.51	1.00	1.45	0.29	142	134	62	30	76	39	219	32	286	25	484	38	44	9	<5	1.42
MW_154	AD 638	65.76	1.415	25.82	4.76	0.032	0.36	0.86	0.23	0.69	0.07	153	153	46	21	38	17	107	56	201	21	292	39	67	10	<5	2.55
MW_155	AD 639	70.15	1.543	22.25	3.85	0.039	0.56	0.66	0.21	0.64	0.11	110	154	42	12	32	20	73	52	280	24	211	45	86	14	<5	1.10
MW_156	AD 640	70.32	1.596	22.62	3.13	0.030	0.38	1.07	0.18	0.59	0.07	106	158	32	8	22	17	82	52	297	22	190	29	70	15	<5	1.45
MW_158	AD 641	59.86	1.372	25.10	8.71	0.079	1.09	1.16	0.40	1.95	0.28	151	168	79	38	75	36	181	44	186	24	183	45	82	12	<5	4.26
MW_160	AD 642	66.18	1.389	24.41	5.35	0.041	0.58	0.91	0.25	0.78	0.11	145	156	45	15	38	18	116	53	200	21	415	67	65	13	<5	2.74
MW_161	AD 643	71.03	1.563	21.87	3.27	0.031	0.36	0.78	0.28	0.75	0.07	115	153	32	9	26	17	98	49	297	23	273	40	84	14	<5	1.89
MW_162	AD 644	66.06	1.507	23.52	5.72	0.072	0.81	0.99	0.26	0.89	0.17	145	161	57	24	49	27	108	62	237	23	351	53	102	14	<5	1.77
MW_163	AD 645	64.75	1.410	26.03	5.19	0.051	0.52	0.89	0.26	0.81	0.10	150	161	58	25	49	20	147	64	201	21	375	48	80	12	<5	2.30
MW_164	AD 646	63.62	1.374	27.98	3.67	0.019	0.30	1.51	0.57	0.90	0.06	135	159	51	23	43	13	153	60	182	21	250	39	42	10	<5	6.85
MW_166	AD 647	63.87	1.555	24.66	5.71	0.069	1.02	1.70	0.54	0.75	0.13	151	156	59	32	55	23	145	53	229	24	334	33	62	10	<5	1.92
MW_170	AD 648	72.35	1.447	20.67	3.42	0.030	0.42	0.90	0.12	0.56	0.09	98	122	35	10	36	18	73	59	272	22	201	60	86	11	<5	1.22
MW_176	AD 649	70.42	1.601	22.77	3.06	0.026	0.29	0.65	0.31	0.81	0.07	121	158	29	9	23	19	106	50	312	23	215	46	77	15	<5	1.81
MW_177	AD 650	65.56	1.393	24.46	5.57	0.052	0.58	1.06	0.31	0.91	0.11	144	151	55	26	46	22	139	53	197	21	343	54	70	13	<5	2.62
MW_178	AD 651	68.45	1.487	24.97	3.11	0.019	0.49	0.70	0.15	0.55	0.06	113	141	37	14	32	15	83	45	224	21	211	37	51	13	<5	1.96
MW_180	AD 652	67.52	1.493	21.81	5.52	0.068	0.75	1.07	0.41	1.21	0.14	148	158	54	23	48	28	163	55	250	22	346	49	88	12	<5	2.05
MW_181	AD 653	64.56	1.389	25.36	4.46	0.041	0.69	2.24	0.32	0.84	0.12	136	158	51	14	45	17	161	50	198	19	322	31	54	9	<5	3.56
MW_184	AD 654	66.94	1.470	21.10	6.08	0.087	0.91	1.65	0.33	1.23	0.21	155	154	58	33	55	31	165	51	256	22	285	44	75	11	<5	2.13
MW_185	AD 655	68.83	1.488	20.76	5.65	0.068	0.84	0.94	0.23	1.01	0.18	136	153	55	31	50	30	104	50	279	22	304	38	95	11	<5	1.64
MW_186	AD 656	69.69	1.596	22.54	4.02	0.039	0.46	0.67	0.22	0.67	0.09	115	161	38	15	34	21	83	51	312	23	183	55	62	13	<5	0.95
MW_191	AD 657	65.17	1.425	26.54	4.65	0.048	0.42	0.76	0.28	0.60	0.10	127	159	56	27	51	17	87	74	203	19	213	51	71	11	5	1.74
MW_193	AD 658	70.27	1.551	22.08	3.74	0.038	0.50	0.74	0.23	0.75	0.09	132	157	37	10	31	21	104	51	289	21	242	39	74	14	<5	1.79
MW_194	AD 659	63.58	1.552	24.70	5.61	0.065	0.99	2.17	0.47	0.73	0.13	136	154	56	32	54	25	150	52	221	23	297	40	52	11	<5	2.18
MW_195	AD 660	69.12	1.530	23.71	3.34	0.028	0.34	0.90	0.13	0.83	0.08	125	145	36	15	32	15	93	66	259	20	284	46	72	12	<5	2.11
MW_173	AD 713	66.02	1.446	25.43	4.73	0.037	0.40	0.96	0.21	0.67	0.08	156	149	51	23	40	13	105	64	207	20	375	35	48	12	<5	1.93
MW_213	AD 715	69.97	1.566	22.41	3.95	0.040	0.49	0.62	0.22	0.64	0.11	99	154	39	10	32	18	71	53	276	21	172	41	71	15	<5	0.97
MW_214	AD 717	69.01	1.470	21.13	5.46	0.065	0.78	0.74	0.22	0.95	0.19	119	149	51	23	49	25	88	49	250	21	228	33	61	16	<5	0.84
MW_215	AD 718	68.17	1.499	21.55	5.47	0.066	0.79	1.04	0.30	0.92	0.19	130	152	50	25	47	24	98	51	256	21	236	43	65	15	<5	1.29
MW_265	AD 897	63.31	1.315	16.99	8.94	0.143	2.76	2.63	1.98	1.67	0.26	153	122	77	57	104	61	184	41	242	27	359	44	51	15	<5	0.60
MW_266	AD 898	65.16	0.915	18.97	5.94	0.072	0.96	1.47	1.07	5.29	0.15	67	51	39	18	64	154	149	69	620	29	597	81	148	25	21	0.61
MW_267	AD 899	66.58	1.401	23.07	5.29	0.047	0.65	1.29	0.36	1.19	0.12	160	143	49	32	43	27	151	63	206	21	307	55	82	16	<5	4.89
MW_268	AD 900	60.30	1.747	16.84	10.48	0.168	3.04	3.60	1.81	1.62	0.39	172	150	81	55	100	53	269	44	281	29	451	36	55	9	<5	0.84
MW_269	AD 901	64.97	1.401	23.86	5.56	0.058	0.91	1.69	0.30	1.04	0.22	157	148	54	29	52	22	157	59	214	20	431	46	51	14	<5	2.96
MW_270	AD 902	64.58	1.668	19.43	7.73	0.117	1.62	2.42	0.70	1.37	0.36	157	143	60	42	81	41	226	46	289	28	599	34	77	12	<5	2.52
MW_271	AD 903	68.78	1.382	20.00	5.73	0.081	0.77	1.46	0.33	1.20	0.26	123	142	52	21	55	29	194	47	270	21	433	28	80	16	<5	3.04
MW_272	AD 904	62.67	0.858	20.42	6.63	0.079	0.70	1.59	0.71	5.94	0.41	60	45	40	9	78	133	305	64	557	27	1446	61	203	28	8	4.11
MW_273	AD 905	59.00	1.434	30.44	6.54	0.031	0.22	0.76	0.48	1.01	0.09	137	126	72	34	47	8	158	68	244	30	526	23	60	12	<5	2.90
MW_274	AD 906	65.89	1.466	22.59	6.55	0.081	0.93	1.11	0.21	0.95	0.21	154	159	63	32	60	30	101	57	238	22	283	41	87	15	<5	1.41
MW_275	AD 907	67.54	1.494	21.15	6.31	0.081	0.93	0.99	0.27	1.02	0.22	134	155	57	38	59	32	109	52	255	21	259	56	69	16	<5	1.02
MW_276	AD 908	66.20	1.424	23.80	5.54	0.060	0.61	1.05	0.26	0.92	0.13	131	148	50	26	45	23	128	61	211	21	386	49	89	12	<5	2.52
MW_179	AD 909	71.60	1.528	21.54	3.37	0.038	0.45	0.63	0.15	0.62	0.08	115	148	32	<5	27	16	83	50	278	23	291	38	63	12	<5	1.44
MW_182	AD 910	68.53	1.636	24.20	3.59	0.036	0.53	0.70	0.14	0.56	0.09	114	157	38	10	30	17	73	57	285	24	206	45	73	14	<5	1.10
MW_183	AD 911	68.65	1.558	22.64	4.76	0.051	0.60	0.63	0.19	0.81	0.12	151	160	43	18	40	23	91	54	276	22	206	49	61	14	<5	1.57
MW_172	AD 912	66.32	1.506	23.08	5.41	0.053	0.78	1.20	0.38	1.14	0.14	113	141	50	45	41	20	128	38	172	23	550			10		4.30
MW_190	AD 913	70.47	1.588	22.79	3.14	0.028	0.32	0.62	0.28	0.69	0.08	120	154	33	<5	22	13	95	50	297	21	210	38	67	14	<5	1.72
MW_277	AD 914	67.49	1.478	21.65	5.54	0.056	0.65	1.77	0.44	0.70	0.23	114	153	61	24	52	20	233	49	245	22	612	30	61	14	<5	4.90
MW_278	AD 915	73.69	1.147	14.48	6.06	0.093	1.03	1.52	0.32	1.16	0.49	121	121	55	17	55	30	191	39	262	19	411	31	69	11	<5	1.93
MW_169	AD 916	66.03	1.428	26.86	3.76	0.028	0.51	0.72	0.13	0.46	0.08	115	148	45	16	38	10	76	71	196	21	193	38	48	10	<5	1.41
MW_197	AD 917	67.84	1.499	21.81	5.44	0.065	0.71	1.00	0.32	1.21	0.12	145	153	52	24	43	27	154	51	252	21	281	44	65	12	<5	2.30
MW_165	AD 918	69.62	1.642	23.70	3.30	0.031	0.32	0.40	0.21	0.70	0.07	108	177	35	9	27	15	59	49	300	25	157	48	66	15	<5	0.99
MW_279	AD 919	66.53	1.482	24.67	4.80	0.050	0.53	0.95	0.18	0.69	0.12	117	150	51	13	43	19	89	67	220	22	220	51	68	13	<5	1.60
MW_232	AD 920	65.44	1.416	20.80	8.05	0.122	1.35	1.05	0.34	1.21	0.22	164	158	73	44	75	46	108	47	234	22	350	59	100	12	<5	-0.11
MW_236	AD 924	73.26	1.335	17.65	4.64	0.057	0.92	1.02	0.33	0.65	0.14	104	119	46	16	43	19	90	47	315	18	223	45	66	11	<5	0.22
MW_237	AD 925	73.61	1.315	17.39	4.62	0.056	0.92	1.00	0.32	0.64	0.14	113	124	45	14	37	22	89	49	322	18	217	56	81	9	<5	0.14
MW_238	AD 926	75.48	1.355	16.25	4.58	0.042	0.67	0.85	0.26	0.43	0.09	106	104	45	14	37	18	72	67	335	17	135	24	63	8	<5	0.16
MW_241	AD 929	73.59	1.412	17.72	4.79	0.042	0.68	0.93	0.29	0.45	0.09	113	110	49	16	38	17	74	76	350	17	150	46	61	10	<5	0.44
MW_242	AD 930	75.72	1.353	16.36	4.41	0.038	0.55	0.89	0.22	0.38	0.08	108	101	46	12	33	15	66	73	324	18	129	30	47	9	<5	0.25
MW_243	AD 931	75.71	1.342	16.53	4.37	0.036	0.52	0.82	0.21	0.38	0.08	102	105	46	11	31	15	64	74	354	17	119	29	54	7	<5	0.18
MW_246	AD 934	65.79	1.394	20.46	7.92	0.119	1.35	1.12	0.34	1.25	0.26	164	155	70	38	75	41	112	52	243	22	290	48	94	12	<5	0.22

Tab. 3 (Contin.) Project Musawwarat (chapter 4.3).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
MW_248	AD 936	65.37	1.432	21.25	7.82	0.117	1.29	1.01	0.34	1.17	0.21	156	156	73	44	74	41	106	52	231	23	339	57	100	15	<5	-0.17
MW_249	AD 937	73.14	1.341	17.62	4.84	0.062	0.95	1.03	0.33	0.59	0.10	119	123	49	18	44	22	87	49	335	19	226	33	67	8	<5	0.73
MW_250	AD 938	72.04	1.341	18.25	5.00	0.062	1.04	1.11	0.34	0.68	0.15	113	125	49	20	44	24	96	48	295	21	222	51	68	14	<5	0.21
MW_251	AD 939	72.69	1.359	18.17	4.79	0.061	0.93	0.99	0.33	0.59	0.10	114	124	48	16	43	19	89	52	312	18	217	41	77	12	<5	0.20
MW_253	AD 941	66.80	1.358	19.74	7.66	0.115	1.35	1.20	0.31	1.20	0.25	161	149	70	39	75	41	112	46	227	21	269	42	94	8	<5	0.10
2013.224.1	MD 859	69.71	1.512	22.09	3.79	0.043	0.56	0.85	0.35	1.01	0.10	97	150	38	19	34	20	107	41	305	18	215	39	72	13	11	2.38
2013.224.2	MD 860	66.07	1.422	24.82	5.00	0.044	0.50	0.86	0.23	0.95	0.10	136	149	45	26	39	22	141	51	230	18	279	39	76	15	13	2.42
2013.224.3	MD 861	66.69	1.468	24.37	4.71	0.047	0.56	1.01	0.23	0.80	0.11	131	155	50	33	42	21	137	55	244	18	289	44	84	11	15	2.78
2013.224.4	MD 862	66.02	1.419	23.94	5.23	0.058	0.63	1.38	0.37	0.68	0.27	116	157	88	32	60	20	181	43	242	16	226	30	51	11	11	5.87
2013.224.5	MD 863	68.11	1.430	21.18	5.62	0.076	0.92	1.27	0.16	0.98	0.25	118	144	54	37	56	29	120	49	272	17	316	49	105	16	12	1.44
2013.224.6	MD 864	67.68	1.524	22.33	5.29	0.072	0.81	1.17	0.08	0.88	0.16	124	160	53	33	47	32	89	45	299	18	263	46	84	10	14	1.09
2013.224.7	MD 865	70.34	1.312	19.36	5.33	0.081	0.97	1.37	0.22	0.85	0.16	125	128	45	26	48	28	117	38	263	12	282	21	55	10	10	1.23
2013.224.8	MD 866	67.05	1.472	21.79	5.72	0.065	0.79	1.22	0.33	1.40	0.17	137	145	56	36	55	32	187	52	291	17	359	53	108	13	11	3.08
2013.224.9	MD 867	65.85	1.412	22.60	6.02	0.073	0.87	1.25	0.29	1.42	0.21	132	148	58	37	58	33	178	51	254	15	335	46	97	13	15	3.12
2013.224.9	MD 867B	65.36	1.434	22.95	6.11	0.074	0.88	1.16	0.33	1.49	0.21	142	148	61	41	57	35	155	54	247	18	265	45	78	11	15	2.80
2013.224.10	MD 868	67.28	1.484	22.81	4.99	0.060	0.82	1.18	0.19	1.01	0.17	142	155	48	31	46	29	109	53	271	18	261	45	104	13	12	1.77
2013.224.11	MD 869	65.64	1.443	24.34	4.88	0.049	0.63	1.11	0.30	1.46	0.15	143	155	54	29	48	24	152	46	237	16	230	25	83	19	10	2.79
2013.224.12	MD 870	65.50	1.430	23.70	5.61	0.058	0.73	1.57	0.18	1.00	0.22	130	151	53	34	51	29	120	57	237	18	238	57	103	13	14	2.38
2013.224.13	MD 871	68.71	1.523	22.35	4.25	0.054	0.64	1.05	0.21	1.05	0.16	113	149	43	22	38	21	152	46	297	17	322	44	80	12	11	2.32
2013.224.14	MD 872	66.88	1.482	22.41	5.84	0.079	0.95	1.09	0.13	0.94	0.21	119	163	59	34	55	33	101	42	279	18	281	40	97	13	13	1.24
2013.224.15	MD 873	65.64	1.434	23.29	6.00	0.071	0.86	1.45	0.12	0.92	0.21	125	154	61	41	59	29	105	50	245	18	256	43	85	12	11	1.68
2013.224.16	MD 874	67.10	1.462	22.45	5.37	0.067	0.80	1.16	0.26	1.16	0.18	131	157	54	26	50	28	159	57	271	18	353	40	106	11	14	7.50
2013.224.17	MD 875	66.86	1.417	22.39	5.72	0.070	0.77	1.28	0.23	1.06	0.20	150	149	57	34	53	29	166	50	250	18	450	60	82	12	14	2.91
2013.224.18	MD 876	68.20	1.432	21.49	5.42	0.070	0.85	1.07	0.15	1.13	0.19	140	151	54	23	52	30	102	45	279	18	258	59	88	10	12	1.48
2013.224.19	MD 877	66.78	1.475	21.81	6.18	0.078	1.05	1.10	0.17	1.17	0.20	130	157	60	36	57	35	105	40	281	19	283	41	98	13	14	0.90
2013.224.20	MD 878	65.92	1.511	22.98	6.28	0.080	0.98	0.92	0.20	0.94	0.19	136	157	60	40	57	36	91	51	267	21	272	44	101	13	13	1.39
2013.224.21	MD 879	66.17	1.419	22.73	5.67	0.064	0.84	1.22	0.32	1.40	0.16	120	147	53	24	45	28	109	42	227	16	202	52	89	12	16	2.71
2013.224.22	MD 880	66.20	1.492	25.06	4.74	0.049	0.56	0.97	0.13	0.69	0.11	119	165	54	27	46	22	90	57	243	19	252	43	82	13	15	1.51
2013.224.23	MD 881	64.23	1.454	27.23	4.73	0.043	0.51	0.87	0.11	0.71	0.10	112	164	57	23	47	19	76	44	221	17	182	19	60	11	15	1.44
2013.224.24	MD 882	67.11	1.456	24.65	4.72	0.051	0.54	0.64	0.15	0.59	0.11	109	148	48	26	45	21	76	55	248	19	235	45	82	12	13	1.15
2013.224.25	MD 883	67.45	1.529	24.59	4.18	0.041	0.56	0.79	0.14	0.62	0.09	109	147	48	22	37	20	85	57	259	20	213	42	97	13	12	1.51
2013.224.26	MD 884	66.69	1.485	24.63	4.74	0.049	0.56	0.85	0.19	0.70	0.11	128	150	51	31	44	21	90	55	250	17	199	38	72	13	13	2.14
2013.224.27	MD 885	64.92	1.437	26.77	4.61	0.042	0.49	0.72	0.15	0.75	0.10	125	163	54	26	48	20	109	42	221	17	208	38	51	11	15	1.97
2013.224.28	MD 886	65.64	1.394	24.97	4.90	0.045	0.54	1.05	0.37	1.00	0.09	140	153	50	34	44	24	132	48	232	17	363	21	73	12	14	3.82
2013.224.29	MD 887	65.93	1.495	25.19	5.14	0.055	0.67	0.63	0.10	0.66	0.13	135	156	55	38	47	23	82	56	245	19	225	57	87	17	18	1.17
2013.224.30	MD 888	66.15	1.466	24.47	4.69	0.046	0.57	1.13	0.39	0.98	0.09	146	148	50	31	44	23	150	53	242	18	300	48	77	14	16	4.05
2013.224.31	MD 889	66.92	1.447	23.47	5.33	0.058	0.67	0.83	0.18	0.96	0.13	154	152	49	26	47	25	109	50	263	17	242	54	92	14	11	1.61
-	MD 890	65.69	1.578	14.13	8.23	0.132	2.76	3.54	1.24	2.26	0.44	141	142	65	42	70	49	295	29	353	19	503	12	66	<5	8	0.25
2013.224.33	MD 891	64.39	1.421	26.21	4.52	0.040	0.47	1.39	0.35	1.11	0.10	143	159	53	35	47	20	156	43	221	18	166	33	50	12	14	3.61
2013.224.34	MD 892	70.76	1.322	18.89	5.63	0.070	1.05	0.99	0.14	0.93	0.22	133	123	48	30	46	32	95	35	276	14	218	20	44	10	14	1.01
2013.224.35	MD 893	64.08	1.363	28.01	3.63	0.021	0.37	1.05	0.53	0.89	0.06	141	157	52	41	42	15	159	52	195	16	255	41	41	12	13	7.61
2013.224.36	MD 894	64.15	1.466	22.34	7.91	0.090	1.06	1.03	0.25	1.53	0.17	133	154	70	48	67	38	113	45	254	18	309	36	89	11	15	1.25
2013.224.37	MD 895	64.89	1.424	24.82	5.10	0.057	0.76	0.87	0.39	1.56	0.13	139	148	57	39	56	35	152	83	278	25	332	95	214	10	14	2.63
2013.224.38	MD 896	66.85	1.424	22.46	6.07	0.078	0.88	0.87	0.07	1.10	0.20	112	148	61	43	57	34	94	52	258	19	253	57	96	13	16	0.81
2013.224.39	MD 897	66.69	1.407	21.72	6.18	0.082	0.95	1.32	0.26	1.18	0.22	147	147	58	38	57	33	177	47	259	18	403	52	106	13	15	2.79
224.40	MD 898	64.37	1.429	26.50	4.56	0.041	0.48	1.17	0.39	0.95	0.10	140	157	54	30	47	21	117	43	223	20	169	19	53	9	15	3.25
122-17.1	MD 899	69.60	1.274	18.96	6.37	0.046	0.79	1.42	0.20	0.87	0.47	106	121	64	39	65	25	193	35	261	15	460	33	72	10	15	6.04
I-7/8.1	MD 900	66.96	1.480	21.98	5.88	0.079	0.78	1.33	0.26	0.80	0.45	135	152	60	33	50	28	170	48	282	19	402	55	99	16	11	4.02
I-8/9.1	MD 901	69.86	1.308	19.55	6.45	0.049	0.88	0.74	0.06	0.89	0.21	123	123	56	32	67	28	144	35	277	15	526	32	74	10	7	1.47
I-8/9.2	MD 902	69.90	1.194	16.92	6.51	0.065	1.14	2.12	0.22	1.04	0.89	104	124	57	43	87	34	290	30	257	15	600	30	72	11	7	6.96
05 SHE.096_048.002	MD 903	54.79	0.913	13.44	5.85	0.073	2.92	19.67	0.66	1.28	0.40	130	127	49	32	96	44	610	24	260	16	436	33	60	12	13	7.32
05 SHE.086_001.001	MD 904	56.03	0.912	13.29	5.85	0.068	3.06	18.55	0.63	1.26	0.34	107	130	50	36	91	49	523	20	305	13	415	16	50	8	15	6.20
05 SHE.098_004.009	MD 905	60.91	1.274	18.98	8.94	0.099	3.12	2.58	1.40	2.34	0.35	139	122	70	58	137	119	189	32	263	21	557	44	81	15	24	1.10
05 SHE.084_001.001	MD 906	65.90	1.126	17.72	6.14	0.089	1.87	2.44	1.81	2.71	0.18	106	92	36	22	94	135	509	31	353	19	885	39	84	19	19	3.15
05 SHE.124_003.001	MD 907	61.87	1.101	19.95	7.58	0.084	1.45	3.01	1.89	2.83	0.24	115	112	61	21	93	144	311	23	325	15	992	54	113	20	33	5.09
05 SHE.081_001.006	MD 908	63.65	1.045	22.23	5.58	0.101	1.05	1.58	1.77	2.91	0.10	92	77	32	14	66	111	143	44	468	21	638	60	108	30	32	1.09
05 SHE.099_028.002	MD 909	63.45	1.251	17.15	8.59	0.111	2.37	3.23	1.63	1.89	0.33	157	115	61	43	108	99	229	27	289	24	536	31	85	10	22	0.99
05 SHE.100_003.001	MD 910	61.15	1.358	18.44	9.14	0.089	3.00	2.12	1.86	2.62	0.21	153	117	57	57	140	160	217	24	274	21	509	29	51	14	21	1.94
04 US_026A_002.002	MD 911	70.95	1.660	20.93	3.45	0.037	0.64	1.22	0.49	0.47	0.16	91	168	45	21	29	9	125	31	378	26	340			8		2.25
06 US.097_004.001	MD 912	68.82	1.564	19.00	6.24	0.063	1.16	1.55	0.46	0.93	0.22	159	122	52	43	59	34	127	62	305	19	803	48	79	9	9	0.54

Tab. 3 (Contin.) Project Musawwarat (chapter 4.3).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
08 US 050_005.002	MD 913	60.81	1.777	16.26	9.53	0.163	2.98	4.68	1.04	2.18	0.58	177	141	76	71	105	50	267	35	296	22	406	26	84	5	11	0.70
08 US 075_004.011	MD 914	62.95	1.880	17.34	8.42	0.109	2.64	3.66	1.13	1.34	0.53	192	163	68	58	87	31	247	24	286	22	415	14	44	11	10	1.05
08 US 051_001.001	MD 915	56.87	1.989	17.17	11.45	0.156	3.81	4.51	2.06	1.55	0.44	220	154	81	71	114	57	321	30	299	26	452	32	74	9	17	1.27
08 US 051_001.005	MD 916	58.57	1.924	16.33	10.55	0.164	3.77	4.58	2.04	1.65	0.43	190	147	76	61	105	51	359	52	326	26	585	27	74	14	14	3.23
08 US 051_001.003	MD 917	57.78	2.140	17.21	11.42	0.175	3.36	4.28	1.63	1.57	0.44	226	210	89	64	113	56	313	36	356	26	520	32	72	8	14	1.41
08 US 097_005.001	MD 918	56.81	1.969	17.19	11.48	0.139	3.69	4.84	1.73	1.61	0.54	210	154	80	87	117	58	358	28	302	27	677	35	73	7	13	3.50
08 US 063_003.007	MD 919	59.35	1.604	17.07	9.81	0.117	2.79	5.13	1.75	2.04	0.33	159	122	65	67	108	65	310	33	316	23	594	46	114	11	26	5.60
08 US 081_003.001	MD 920	63.69	1.791	23.51	7.06	0.055	1.01	1.38	0.61	0.66	0.23	197	168	45	59	68	18	134	29	324	31	353	18	40	10	11	1.13
08 US 036_002.002	MD 921	65.28	1.663	18.98	6.85	0.099	1.89	2.18	1.32	1.46	0.28	155	128	78	51	121	52	192	37	319	21	423	25	83	14	12	2.21
08 US 058_001.001	MD 922	61.78	1.072	9.36	7.72	0.093	15.52	2.71	0.94	0.67	0.13	111	793	511	32	53	24	158	13	226	12	225	11	22	5	12	4.59
08 US 092_002.001	MD 923	57.98	2.026	21.59	11.69	0.083	1.99	2.31	0.94	1.27	0.12	170	168	37	39	69	52	191	20	359	21	331	26	74	11	18	0.97
05 US 035_003.001	MD 924	59.05	1.562	17.54	9.78	0.133	2.95	4.62	1.64	2.38	0.34	176	129	65	54	120	98	283	31	327	23	573	33	99	13	26	4.38
Raw materials																											
MW_047	AD 230	82.66	1.290	14.29	1.21	0.011	0.10	0.13	0.01	0.17	0.14	53	61	16	<5	8	<5	26	373	271	12	87	218	539	12	<5	5.03
MW_048	AD 231	80.25	0.970	11.77	5.13	0.085	0.73	0.62	0.02	0.37	0.05	89	84	38	22	83	13	49	24	257	11	173	28	70	10	7	4.21
MW_049	AD 232	72.96	1.627	23.54	1.09	0.006	0.14	0.07	0.02	0.50	0.04	109	108	13	<5	7	12	45	70	287	17	199	42	95	9	10	7.67
MW_050	AD 233	65.97	1.599	18.46	7.57	0.130	2.01	2.15	0.80	1.16	0.16	167	155	59	42	72	43	175	41	347	19	360	32	68	10	10	6.59
MW_051	AD 234	87.43	0.800	8.46	2.30	0.040	0.24	0.42	0.02	0.24	0.04	54	48	14	<5	11	8	26	24	224	7	97	7	40	5	7	3.03
MW_052	AD 235	83.84	1.700	12.29	1.95	0.019	0.01	0.06	0.01	0.09	0.02	100	85	14	<5	7	<5	13	49	498	21	32	15	21	6	<5	4.71
MW_053	AD 236	75.66	1.417	17.02	4.07	0.036	0.51	0.74	0.15	0.33	0.08	98	99	38	22	31	11	60	62	356	14	129	12	42	10	12	6.20
MW_054	AD 237	70.88	1.486	19.36	5.22	0.050	0.88	1.23	0.27	0.52	0.11	122	116	50	32	46	19	87	73	343	18	186	22	60	12	13	7.93
MW_055	AD 238	89.31	0.688	6.68	2.38	0.047	0.30	0.37	0.01	0.19	0.03	53	49	17	<5	14	10	28	15	224	6	121	<5	37	5	5	2.54
MW_057	AD 240	82.55	1.830	13.71	1.41	0.010	0.00	0.32	0.02	0.08	0.07	80	72	19	<5	11	<5	20	184	472	13	51	114	238	9	<5	5.72
MW_058	AD 241	66.97	1.535	26.04	3.68	0.007	0.06	0.93	0.27	0.45	0.06	192	147	20	<5	16	12	67	84	231	20	200	82	91	20	<5	9.24
MW_059	AD 242	60.49	1.499	24.18	8.96	0.008	0.22	4.36	0.00	0.21	0.07	190	134	44	43	22	7	76	105	238	19	164	43	55	9	10	11.35
MW_060	AD 243	58.12	1.442	23.89	11.77	0.013	0.23	4.00	0.01	0.37	0.16	199	130	72	45	34	10	78	397	241	15	181	142	264	13	14	10.89
MW_061	AD 244	61.08	1.411	22.28	10.29	0.024	0.40	3.85	0.09	0.44	0.14	170	123	61	42	42	13	81	289	262	16	191	89	181	12	13	10.22
MW_062	AD 245	71.81	1.556	14.76	6.03	0.075	1.44	2.42	0.80	0.99	0.13	137	135	43	27	55	34	168	56	439	15	341	31	62	9	7	5.17
MW_063	AD 246	71.69	1.662	13.72	6.82	0.100	1.78	2.11	0.86	1.11	0.15	141	153	48	32	63	40	178	34	568	17	354	21	67	10	11	4.56
MW_064	AD 247	67.27	1.680	27.29	1.73	0.009	0.09	1.43	0.01	0.44	0.04	122	149	18	7	12	13	60	55	278	20	176	35	70	10	12	9.61
MW_065	AD 248	70.49	1.526	16.43	6.25	0.082	1.49	1.86	0.75	1.00	0.13	148	143	46	30	52	37	164	30	411	17	317	30	46	10	8	5.45
MW_066	AD 249	66.85	1.282	18.32	8.32	0.114	2.03	1.54	0.27	1.10	0.17	151	140	72	49	73	48	128	29	277	17	314	35	57	11	13	8.39
MW_067	AD 250	59.31	1.504	25.15	10.25	0.172	1.28	0.97	0.16	1.08	0.14	190	168	92	60	67	49	91	36	278	20	345	35	92	15	17	9.23
MW_068	AD 251	90.39	0.560	5.12	2.71	0.045	0.44	0.33	0.02	0.36	0.02	54	50	20	5	15	14	37	12	279	6	142	<5	16	6	<5	2.01
MW_069	AD 252	79.58	1.001	8.87	4.62	0.070	1.19	2.90	0.62	1.02	0.13	85	76	29	16	41	36	142	17	341	13	319	20	22	5	9	4.22
MW_070	AD 253	54.58	2.846	17.26	13.09	0.206	3.03	6.00	1.30	1.39	0.31	273	166	73	71	126	49	301	36	388	38	480	42	60	9	16	8.54
MW_071	AD 254	78.34	0.810	11.78	4.67	0.087	1.07	1.16	0.27	1.77	0.04	69	63	26	12	45	60	120	17	299	10	610	17	60	9	13	2.83
MW_072	AD 255	76.43	1.129	11.41	4.79	0.070	1.00	2.20	0.84	2.04	0.10	72	56	25	17	56	71	175	22	477	17	573	46	64	15	18	3.56
MW_073	AD 256	55.23	1.173	23.18	11.79	0.134	3.13	3.85	0.08	1.28	0.16	163	127	68	58	155	86	228	37	185	19	422	48	117	12	21	10.28
MW_074	AD 257	54.73	1.253	20.43	10.75	0.139	3.06	7.59	0.42	1.46	0.16	154	122	64	49	142	89	330	41	225	21	573	58	112	13	18	11.35
MW_075	AD 258	68.04	1.402	15.93	6.47	0.097	1.49	2.59	1.69	2.19	0.10	100	86	36	18	72	96	208	22	509	24	609	51	101	14	20	3.98
MW_076	AD 259	76.26	1.490	18.42	2.92	0.018	0.17	0.25	0.01	0.41	0.06	141	149	24	6	14	12	49	39	509	15	186	27	84	10	9	6.37
MW_077	AD 260	92.29	0.539	6.81	0.20	0.012	0.03	0.02	0.01	0.06	0.02	30	15	<5	<5	<5	<5	9	<5	145	<5	43	<5	5	5	<5	2.43
MW_078	AD 261	53.42	2.837	19.11	14.15	0.235	2.78	4.90	1.03	1.24	0.30	279	167	84	81	128	51	257	40	369	40	427	37	79	6	13	9.11
MW_079	AD 262	64.84	1.706	15.54	9.40	0.155	2.42	3.53	0.86	1.28	0.27	177	138	66	54	89	49	223	32	338	24	409	23	65	12	13	6.60
MW_080	AD 263	64.53	1.705	15.47	9.47	0.163	2.43	3.67	0.88	1.35	0.32	180	134	65	57	95	54	232	35	348	24	424	28	67	8	12	5.84
MW_081	AD 264	68.32	1.317	12.48	6.84	0.098	2.84	5.42	1.38	1.17	0.14	184	138	52	34	59	39	340	24	322	13	387	18	43	9	9	6.40
MW_082	AD 265	70.52	1.350	16.28	6.97	0.128	1.37	1.38	0.64	1.20	0.17	141	137	58	45	67	41	141	35	276	17	338	30	65	13	8	10.81
MW_083	AD 266	73.76	1.298	14.32	6.37	0.099	1.35	1.19	0.41	1.04	0.16	122	122	51	32	53	36	109	28	341	14	271	21	63	8	15	5.62
MW_084	AD 267	56.37	2.495	17.31	12.43	0.196	2.85	5.45	1.24	1.36	0.29	256	153	72	72	118	52	289	39	370	38	519	25	74	10	12	8.09
MW_085	AD 268	81.92	0.809	9.69	4.03	0.039	0.75	0.90	0.27	1.57	0.03	74	52	23	7	32	57	98	17	481	15	408	21	48	11	11	2.92
MW_086	AD 269	66.51	1.387	17.52	8.08	0.128	2.00	2.30	0.66	1.29	0.14	147	147	67	48	70	51	189	31	282	17	377	37	60	11	15	6.67
MW_087	AD 270	71.37	1.194	13.65	6.57	0.111	1.79	3.44	0.54	1.24	0.10	115	115	52	33	62	50	171	31	403	15	415	35	74	10	10	6.32
MW_088	AD 271	53.36	2.760	18.79	13.79	0.248	3.01	5.17	1.16	1.36	0.35	276	141	81	78	137	54	277	46	393	46	478	56	89	8	14	8.81
MW_090	AD 273	33.96	0.868	7.32	3.79	0.137	5.78	45.32	0.37	1.81	0.65	81	81	28	66	171	<5	8904	18	457	8	1484	7	51	<5	<5	35.89
MW_091	AD 274	19.45	0.524	3.94	2.10	0.067	3.36	60.49	0.49	8.21	1.36	50	39	19	87	51	36	2557	6	237	<5	595	16	40	<5	<5	37.93
MW_092	AD 275	41.51	0.731	5.54	2.84	0.091	3.03	44.11	0.25	1.58	0.32	65	58	17	41	51	<5	5272	12	410	7	641	<5	32	<5	<5	28.17
MW_093	AD 276	71.56	0.591	4.69	2.48	0.088	3.73	7.19	0.59	3.99	5.08	53	64	35	93	210	75	440	9	291	7	447	12	25	5	<5	3.56
MW_095	AD 277	67.34	1.336	21.19	2.95	0.033	0.72	3.31	0.13	1.81	1.18	107	117	27	27	50	20	208	86	260	16	199	53	79	9	8	2.29
MW_096	AD 278	61.96	0.845	8.32	4.21	0.116	3.17	9.01	1.54	6.82	4.01	68	63	49	133	190	47	440	21	139	18	464	26	31	11		7.43

Tab. 3 (Contin.) Project Musawwarat (chapter 4.3).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
MW_097	AD 279	87.12	0.591	4.45	2.16	0.052	0.98	3.01	0.06	0.81	0.75	44	49	16	12	40	14	149	11	256	6	189	5	21	<5	<5	2.36
MW_098	AD 280	87.69	0.565	3.95	1.80	0.047	1.02	3.27	0.07	0.83	0.76	44	42	13	12	38	16	167	13	326	5	173	14	40	5	<5	2.41
MW_099	AD 281	84.14	0.556	5.57	1.97	0.055	1.21	4.52	0.07	0.95	0.95	47	50	18	21	50	16	208	11	241	5	199	<5	35	<5	5	3.49
MW_100	AD 291	66.81	1.386	19.93	7.70	0.121	1.34	1.05	0.29	1.17	0.21	160	147	65	46	71	48	107	40	252	18	458	46	84	12	17	6.89
MW_101	AD 292	53.09	2.603	20.74	14.43	0.260	2.60	3.95	0.78	1.24	0.31	277	165	94	92	130	60	217	44	372	41	424	46	82	11	19	10.35
MW_102	AD 293	71.81	1.506	23.28	2.64	0.004	0.10	0.14	0.01	0.43	0.08	85	96	18	6	15	12	66	89	238	17	209	62	101	18	10	7.74
MW_103	AD 399	65.99	1.449	22.43	3.23	0.032	0.60	2.97	0.25	2.15	0.90	110	127	35	54	64	16	164	64	195	25	326			15		1.21
MW_104	AD 400	64.93	1.383	22.54	3.46	0.041	1.00	3.58	0.08	1.37	1.63	93	126	33	46	72	19	205	93	178	25	412			15		0.90
MW_105	AD 378	72.86	0.806	7.91	4.01	0.105	2.07	6.63	0.59	3.46	1.56	80	74	36	48	102	45	314	27	232	13	321	17	52	14	<5	3.81
MW_106	AD 379	72.80	0.876	8.01	4.01	0.098	2.16	5.12	0.72	3.81	2.39	84	74	38	54	144	49	335	31	227	14	329	<5	41	10	<5	7.94
MW_198	AD 662	74.86	1.431	20.14	2.68	0.012	0.10	0.29	0.02	0.34	0.13	141	142	28	<5	21	11	42	59	310	21	148	56	64	14	<5	6.99
MW_199	AD 663	77.93	1.523	18.43	1.70	0.008	0.01	0.11	0.02	0.20	0.07	120	138	15	<5	10	6	25	43	397	19	116	41	52	14	<5	6.28
MW_200	AD 664	71.47	1.342	18.71	3.38	0.037	0.78	3.15	0.12	0.82	0.18	128	136	32	12	33	18	119	41	261	19	192	30	63	11	<5	7.00
MW_201	AD 665	80.64	1.184	12.50	3.76	0.036	0.50	0.71	0.22	0.37	0.08	89	89	38	9	28	15	59	55	315	15	127	32	42	7	<5	4.89
MW_202	AD 666	68.34	1.330	18.94	7.90	0.141	1.04	0.94	0.30	0.95	0.12	151	143	76	40	61	38	94	35	333	21	320	32	74	11	<5	7.22
MW_203	AD 667	74.41	1.263	17.21	4.15	0.057	0.67	1.21	0.15	0.67	0.20	126	131	41	15	39	24	89	42	261	18	187	37	59	12	<5	6.50
MW_204	AD 668	74.85	1.237	16.24	4.29	0.056	0.73	1.42	0.16	0.73	0.27	114	125	42	18	40	24	104	43	266	17	209	39	55	9	<5	6.58
MW_205	AD 669	58.04	2.729	14.49	11.61	0.146	3.58	6.18	1.67	1.33	0.24	275	260	94	60	105	35	346	40	409	32	439	40	55	5	<5	5.63
MW_206	AD 670	62.05	2.220	13.25	10.09	0.131	3.50	5.47	1.74	1.34	0.21	231	234	84	44	90	32	372	34	303	28	494	26	48	5	<5	4.08
MW_207	AD 671	65.23	1.354	15.33	6.43	0.109	2.06	4.88	3.27	1.18	0.16	138	123	45	17	61	34	384	34	363	17	464	20	30	10	<5	3.06
MW_208	AD 672	68.44	2.112	9.68	8.26	0.109	3.02	5.83	1.33	1.04	0.18	211	261	68	27	73	22	306	30	407	24	363	18	35	<5	<5	3.27
MW_209	AD 673	53.28	2.551	18.78	13.61	0.216	3.53	5.28	1.13	1.29	0.33	276	166	107	89	127	48	281	51	330	41	387	58	103	7	<5	9.19
MW_210	AD 674	53.45	2.246	20.76	13.65	0.272	3.17	4.02	0.85	1.31	0.29	251	181	108	90	123	54	230	50	309	42	419	46	82	10	<5	11.01
MW_211	AD 675	66.29	1.754	13.01	8.88	0.152	2.73	4.22	1.55	1.23	0.18	185	185	71	38	79	35	326	33	306	21	545	19	52	<5	<5	4.26
MW_212	AD 676	68.26	1.499	21.80	4.66	0.059	0.82	1.44	0.16	1.14	0.16	136	155	46	18	42	27	107	46	272	21	210	40	78	13	<5	8.07
MW_216	AD 874	75.19	1.373	16.34	4.61	0.043	0.69	0.95	0.27	0.44	0.09	114	99	47	17	36	15	72	73	341	17	139	33	46	10	<5	6.23
MW_219	AD 877	73.84	1.430	17.54	4.71	0.046	0.69	0.91	0.29	0.46	0.09	108	110	46	15	36	16	73	72	328	19	140	41	49	10	<5	6.52
MW_220	AD 878	74.79	1.373	16.55	4.53	0.038	0.55	1.49	0.22	0.38	0.09	106	102	43	13	32	15	68	75	348	16	114	23	46	7	<5	6.58
MW_221	AD 879	75.59	1.345	16.37	4.33	0.034	0.51	1.15	0.21	0.37	0.08	115	102	43	12	30	14	68	75	318	16	116	22	56	8	<5	6.29
MW_222	AD 880	74.21	1.298	16.80	4.68	0.069	0.93	1.01	0.33	0.57	0.10	105	118	46	14	43	20	88	45	317	19	223	42	66	9	<5	6.39
MW_223	AD 881	72.58	1.331	17.92	4.86	0.041	1.03	1.08	0.33	0.67	0.15	113	127	48	18	46	24	91	47	294	18	210	34	72	9	<5	12.57
MW_225	AD 883	72.87	1.349	18.02	4.77	0.061	0.91	1.00	0.33	0.58	0.10	118	121	48	17	39	22	87	49	333	21	221	40	73	11	<5	6.65
MW_226	AD 884	74.07	1.311	17.02	4.56	0.051	0.90	1.00	0.32	0.63	0.14	107	114	47	17	42	21	89	49	326	19	214	41	63	10	<5	10.32
MW_227	AD 885	65.71	1.412	20.58	7.99	0.121	1.34	1.06	0.36	1.21	0.22	174	155	72	44	74	45	109	49	242	21	349	43	83	13	<5	7.36
MW_228	AD 886	66.49	1.374	19.91	7.76	0.136	1.34	1.14	0.35	1.24	0.27	162	146	69	45	76	42	112	46	222	22	324	44	90	13	6	12.58
MW_229	AD 887	67.75	1.326	19.14	7.44	0.120	1.32	1.18	0.33	1.15	0.25	156	147	70	42	69	40	110	45	227	20	324	31	93	13	<5	9.48
MW_230	AD 888	65.61	1.419	21.04	7.79	0.117	1.28	1.01	0.36	1.16	0.21	165	156	69	41	69	44	105	47	226	21	306	47	99	13	5	7.49
MW_255	AD 871	72.33	0.736	6.44	3.56	0.107	2.75	8.08	0.42	3.36	2.21	65	59	32	42	60	33	362	40	220	11	322	8	27	<5	<5	0.98
MW_256	AD 872	68.13	1.015	7.19	4.05	0.116	5.80	8.44	0.97	3.03	1.25	92	93	35	31	116	28	626	29	367	15	721	14	88	8	<5	6.88
MW_257	AD 873	77.83	0.909	6.48	3.52	0.080	1.76	5.01	0.55	2.42	1.43	68	67	28	27	66	25	265	23	286	15	259	24	32	5	<5	0.99
MW_258	AD 890	54.22	1.435	11.23	7.32	0.137	5.44	16.75	2.50	0.82	0.14	202	112	50	33	67	25	963	37	278	25	375	31	52	<5	<5	15.57
MW_259	AD 891	80.00	0.942	7.30	4.48	0.069	1.56	3.52	1.45	0.61	0.08	159	84	35	8	33	20	190	22	330	17	278	12	31	<5	<5	4.10
MW_260	AD 892	58.21	2.539	15.23	11.86	0.169	2.96	5.79	1.59	1.38	0.27	258	153	64	45	104	40	355	41	334	36	497	31	55	13	<5	5.50
MW_261	AD 893	52.88	2.489	20.14	13.95	0.256	2.74	4.92	0.94	1.34	0.36	266	147	88	76	132	56	244	56	369	51	434	60	100	8	<5	10.13
MW_262	AD 894	62.49	2.298	14.35	10.84	0.167	2.56	4.53	1.16	1.26	0.35	234	152	63	49	102	38	274	41	366	33	406	33	54	10	<5	6.68
MW_263	AD 895	54.58	2.634	17.89	13.61	0.203	2.98	5.29	1.29	1.24	0.30	271	154	82	74	119	43	309	52	332	42	451	59	69	5	<5	9.22
MW_264	AD 896	57.78	1.520	20.57	11.01	0.181	3.33	2.86	0.82	1.66	0.27	177	143	98	62	125	67	204	51	271	34	377	44	90	14	<5	8.70

Tab. 3 (Contin.) Project Musawwarat (chapter 4.3).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm														%
P1	MD528	66.79	1.442	20.27	6.12	0.020	1.35	0.87	0.06	2.96	0.12	85	144	44	<5	52	80	63	18	315	14	172	25	39	12	20	1.13
P4	MD529	66.77	1.445	20.31	6.09	0.020	1.36	0.85	0.08	2.97	0.11	83	148	43	<5	52	80	63	21	317	15	171	10	54	14	19	1.18
P10	MD530	63.61	1.369	20.81	6.73	0.027	2.11	2.31	0.08	2.80	0.14	71	143	40	<5	39	81	84	23	306	16	157	10	63	15	17	1.06
P11	MD531	66.69	1.454	20.18	6.21	0.019	1.64	0.76	0.08	2.86	0.11	81	150	40	<5	40	79	64	22	330	17	171	12	39	14	20	0.92
P13	MD532	63.66	1.359	21.60	6.73	0.024	1.56	1.79	0.05	3.02	0.21	86	145	44	31	43	84	102	18	300	14	166	11	66	14	18	1.59
P15	MD533	65.75	1.427	20.80	6.42	0.021	1.38	1.15	0.08	2.85	0.12	91	148	42	15	42	72	136	19	310	16	484	22	55	24	15	2.28
P23	MD534	53.44	1.016	21.81	7.73	0.059	2.32	7.85	0.20	3.02	2.55	121	131	50	12	90	80	378	20	196	11	194	21	36	16	15	1.83
P24	MD535	54.50	0.949	23.25	7.87	0.038	2.14	7.92	0.06	3.07	0.19	142	139	57	12	102	76	246	14	164	9	126	13	39	13	18	0.97
P29	MD536	55.81	1.002	21.61	7.89	0.046	2.25	7.78	0.23	3.19	0.20	116	115	47	11	95	70	265	15	182	11	182	11	53	12	13	2.02
DH 85	AD394	58.59	1.068	21.56	7.67	0.062	2.69	4.78	0.22	3.01	0.35	140	119	46	42	60	87	139	26	222	12	120	20	73	11	14	1.68
DH 87	AD395	64.17	1.418	21.72	6.61	0.022	1.88	1.14	0.11	2.81	0.12	99	144	44	5	45	81	85	21	297	16	145	6	43	13	15	1.21
DH 87	AD396	54.35	1.008	22.48	8.01	0.070	3.39	7.30	0.22	3.01	0.16	126	127	49	21	70	88	166	19	172	11	100	16	45	11	15	0.78
DH 87	AD397	55.89	1.091	17.22	6.41	0.080	4.31	11.98	0.28	2.43	0.32	107	107	41	24	63	78	236	27	310	16	231	30	59	11	16	0.68
DH 88	AD398	65.35	1.433	20.53	6.21	0.022	1.58	1.69	0.12	2.89	0.19	81	143	39	15	51	80	166	20	312	16	289	21	43	25	15	1.80
Samples found in Tayma provided for analysis by A. Hausleiter and F. Tourte																											
Tayma	MD990	56.83	1.140	25.40	8.41	0.087	2.21	2.29	0.20	3.18	0.25	156	148	53	41	136	137	266	34	224	18	644	55	136	126	30	0.12
Tayma	MD991	64.85	0.941	22.16	6.05	0.035	1.21	1.17	0.24	3.16	0.18	122	129	28	25	81	135	203	24	192	15	600	62	117	112	29	0.85
Tayma	MD992	56.29	0.990	21.86	7.62	0.050	2.52	6.95	0.38	3.09	0.25	118	120	47	18	79	80	197	16	187	11	111	<5	37	14	15	1.95

Tab. 4 Project Petra (chapter 4.4).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
CC 125	MD556	68.26	0.945	15.35	5.82	0.122	1.37	1.86	0.67	2.24	0.37	113	114	46	27	80	112	111	35	361	14	758	41	100	22	24	2.99
CC 127	MD557	66.92	0.887	16.04	5.89	0.091	2.28	1.95	0.89	2.98	0.38	121	118	52	41	110	128	147	31	283	15	718	26	84	23	23	1.84
CC 141	MD558	61.97	0.838	17.48	5.79	0.170	1.50	1.89	0.97	2.56	1.25	128	113	64	49	99	126	164	29	237	17	1540	37	80	27	21	5.94
CC 143	MD559	64.22	0.921	18.77	7.21	0.057	1.90	1.26	1.26	2.50	0.23	130	124	46	41	121	142	150	31	261	18	778	35	71	25	26	1.88
CC 144	MD560	69.71	0.939	15.25	5.61	0.139	1.33	1.76	0.52	2.04	0.36	118	116	47	21	84	106	105	35	354	17	816	29	85	22	24	2.53
CC 1156	MD571	75.46	0.754	11.63	4.04	0.072	0.79	1.46	0.84	1.49	0.17	86	75	31	9	54	69	101	22	317	12	689	6	64	16	13	2.20
CC 1168	MD569	69.71	1.006	15.82	6.12	0.206	1.54	1.20	0.52	2.18	0.40	112	109	51	19	85	118	105	39	399	17	588	42	99	21	22	1.17
CC 1182	MD570	65.66	0.965	15.30	5.59	0.097	1.30	2.12	0.85	2.04	3.29	94	108	47	17	81	101	197	36	397	18	1752	39	104	20	16	2.79
CI 004	MD537	64.79	0.814	17.22	6.51	0.089	1.60	1.54	0.59	1.81	2.01	116	109	52	29	103	97	125	24	225	12	1120	36	85	18	15	3.16
CI 005	MD538	64.72	0.750	15.28	5.94	0.176	1.12	1.88	1.10	1.49	3.22	91	74	52	18	71	68	176	22	228	9	1746	26	42	12	14	4.27
CI 006	MD593	57.67	0.890	20.45	8.05	0.138	2.02	1.34	0.68	2.30	3.19	163	124	61	39	138	109	154	35	209	14	1631	28	88	24	21	2.99
CI 008	MD594	58.55	0.829	19.07	7.04	0.071	1.60	1.05	0.78	2.42	1.91	152	121	74	60	120	118	118	35	200	11	1063	40	70	24	25	6.36
CI 010	MD539	56.73	0.914	21.46	8.09	0.078	2.03	1.31	0.77	2.80	2.01	162	143	62	52	136	155	128	31	174	14	1081	45	76	25	25	4.34
CI 011	MD540	54.45	0.891	20.12	7.75	0.064	1.73	1.11	0.81	2.62	3.40	151	129	68	54	125	129	141	33	188	13	1405	23	76	25	23	7.13
CI 012	MD595	58.12	0.942	20.63	8.42	0.216	2.10	1.47	0.79	2.49	2.63	158	136	73	36	145	133	150	36	213	14	1414	36	95	26	23	3.17
CI 015	MD596	67.11	0.960	14.93	6.14	0.106	1.18	2.16	0.79	2.01	0.95	108	108	52	27	77	101	155	37	405	17	1137	38	95	21	23	4.21
CI 022	MD619	67.30	0.874	14.77	5.51	0.075	1.49	1.54	0.88	2.41	0.26	99	103	40	29	90	122	128	27	326	16	719	31	72	22	18	4.65
CI 024	MD541	66.87	0.833	14.59	5.37	0.104	1.57	2.13	0.98	2.20	1.18	110	100	52	30	108	98	194	32	309	14	1327	29	72	17	14	4.15
CI 026	MD597	67.33	0.939	14.88	5.77	0.092	1.16	1.77	0.77	2.22	0.69	106	114	48	31	80	105	223	34	371	16	899	33	88	22	18	4.20
CI 027	MD598	61.85	1.042	16.69	6.41	0.080	1.07	0.90	0.58	1.88	4.42	116	115	52	34	78	98	118	36	392	19	1222	47	106	22	21	5.34
CI 028	MD542	65.17	0.935	15.21	5.77	0.093	1.17	2.23	0.87	2.23	2.47	102	108	51	26	79	105	211	35	361	15	1358	41	81	21	20	4.25
CI 029	MD543	63.60	0.842	15.38	5.67	0.076	1.73	2.17	0.80	2.40	1.51	104	108	46	33	131	117	179	30	279	14	1290	33	73	18	20	5.66
CI 036	MD599	66.79	0.961	15.57	5.71	0.099	1.05	1.91	0.76	1.99	1.86	91	109	51	25	74	102	230	37	377	18	1397	57	82	22	20	3.55
CI 037	MD544	65.00	0.886	14.11	5.39	0.101	1.28	2.97	0.67	2.05	1.77	101	107	51	23	95	99	244	33	364	16	1408	50	79	18	17	6.05
CI 038	MD600	66.51	0.909	14.91	5.63	0.088	1.26	1.89	0.84	2.28	1.12	105	113	48	29	88	104	217	34	356	16	1282	26	98	20	19	4.59
CI 040	MD620	56.71	0.894	19.75	7.67	0.071	1.77	0.97	0.92	2.53	2.13	152	128	65	57	117	127	119	31	196	14	1006	34	85	26	16	6.85
CI 041	MD545	57.93	0.800	19.46	7.15	0.070	1.44	1.72	0.84	2.49	2.99	151	123	78	45	110	124	197	38	181	12	1601	39	68	24	24	5.15
CI 042	MD621	56.17	0.912	20.64	8.08	0.070	1.75	1.53	0.67	2.76	3.46	163	132	51	40	134	145	156	33	188	15	1440	44	77	24	23	4.06
CI 043	MD601	55.49	0.884	19.21	7.31	0.082	1.80	1.88	0.78	2.69	3.49	144	128	60	54	121	123	208	33	198	14	2036	31	89	21	19	6.33
CI 044	MD602	56.36	0.947	20.28	7.24	0.067	1.66	1.12	0.82	2.91	3.58	143	133	60	50	120	136	141	36	214	16	1537	38	75	23	24	5.47
CI 045	MD546	66.61	0.864	14.78	5.54	0.111	1.44	2.31	0.86	2.03	0.89	106	103	48	23	92	105	179	32	311	14	1280	38	86	20	19	5.16
CI 051	MD603	65.88	0.964	15.21	5.70	0.077	1.32	1.31	0.91	2.19	2.61	89	100	52	26	82	102	137	35	369	17	1626	36	74	22	19	3.83
CI 053	MD622	67.26	0.965	15.37	5.76	0.087	1.26	1.40	0.95	2.06	2.34	97	106	40	31	80	105	143	35	390	18	1274	40	99	20	16	2.70
CI 054	MD547	65.59	0.956	15.18	5.57	0.110	0.99	1.52	0.76	2.12	2.77	102	108	49	22	73	102	158	35	377	15	1476	48	91	21	25	4.33
CI 063	MD604	65.23	0.969	15.10	5.81	0.066	1.30	1.48	0.95	2.16	2.73	103	106	53	31	97	115	178	38	390	17	1895	49	95	20	20	4.65
CI 066	MD548	51.96	0.884	19.19	7.53	0.082	1.74	1.73	0.88	2.95	6.02	148	121	60	56	139	125	227	32	192	14	3105	39	70	23	19	6.83
CI 070	MD605	59.96	0.718	17.71	6.20	0.044	1.44	2.09	0.90	2.18	2.83	136	107	63	60	125	125	214	29	175	12	2176	28	60	20	17	6.00
CI 073	MD606	64.66	1.000	16.05	5.87	0.100	1.16	1.20	0.78	2.08	3.09	108	111	65	32	86	110	145	39	394	17	1489	34	102	24	23	4.61
CI 074	MD607	61.16	1.007	15.88	5.65	0.076	0.80	1.49	0.69	1.84	6.25	94	110	40	38	73	83	186	39	390	16	1974	41	87	24	22	4.76
CI 077	MD623	54.12	0.929	20.14	7.81	0.053	1.37	1.33	0.80	2.44	4.95	144	133	49	43	99	133	165	33	200	14	2220	43	75	24	19	5.85
CI 080	MD549	65.21	0.942	14.75	5.08	0.110	1.09	2.10	0.78	2.02	3.00	98	104	49	24	89	99	204	33	366	16	2083	42	85	23	21	4.74
CI 082	MD550	64.79	0.888	16.20	5.74	0.121	1.88	1.53	0.84	2.69	0.58	122	111	51	34	109	126	136	29	256	15	1101	27	77	20	18	4.84
CI 089	MD608	61.62	1.003	16.17	6.39	0.104	0.94	1.14	0.81	1.89	4.87	116	111	56	29	67	97	153	38	382	17	1866	59	117	29	21	4.87
CI 095	MD551	66.02	0.951	15.27	5.77	0.077	1.39	1.74	0.49	2.30	1.77	102	111	56	28	83	111	145	34	355	16	1735	30	79	19	25	4.12
CI 097	MD609	64.38	0.944	15.51	5.88	0.107	1.13	1.91	0.88	2.33	3.33	99	109	47	21	87	102	194	35	359	18	2043	47	94	19	19	3.93
CI 098	MD610	66.75	1.010	16.16	6.12	0.165	1.25	1.46	0.81	2.10	2.13	109	116	55	21	79	104	139	38	395	16	1357	40	111	24	21	2.10
CI 099	MD611	67.67	1.009	16.44	6.26	0.081	1.48	1.05	0.59	1.87	1.32	119	113	46	21	82	105	102	38	383	18	799	47	88	23	22	2.09
CI 100	MD612	63.62	0.958	15.71	6.01	0.090	0.88	1.07	0.92	1.86	3.83	108	109	40	23	58	87	130	40	367	15	1186	42	82	19	20	4.98
CI 101	MD613	64.50	0.917	14.77	4.99	0.048	1.26	2.60	0.87	2.21	3.84	86	107	37	20	85	100	236	38	363	15	2113	40	81	19	18	3.99
CI 102	MD552	67.85	0.937	15.11	5.65	0.078	1.55	1.38	0.56	1.87	0.81	114	108	44	22	75	105	117	32	351	16	729	26	81	20	20	3.96
CI 109	MD553	67.33	0.831	16.33	5.88	0.035	1.44	2.00	0.83	2.41	0.60	112	107	48	26	115	104	130	26	272	12	820	16	59	19	19	3.11
CI 110	MD624	65.18	0.956	15.27	5.58	0.100	1.01	2.19	0.49	1.96	3.00	112	108	43	19	75	82	161	34	367	17	1938	47	76	23	23	4.52
CI 114	MD614	64.19	0.955	14.78	5.49	0.108	1.07	2.33	0.65	1.83	3.42	109	105	45	26	70	88	180	36	383	15	1748	37	81	19	22	5.19
CI 115	MD554	65.91	1.012	16.13	6.44	0.226	1.30	1.67	0.62	2.00	2.23	113	116	59	33	82	114	151	38	398	19	1338	40	98	26	20	3.04
CI 118	MD555	64.15	0.937	15.00	5.57	0.096	1.15	2.13	0.58	1.94	3.07	107	110	47	25	77	88	226	36	357	16	1595	28	78	19	19	5.25
CI 1187	MD615	66.65	0.948	15.41	5.80	0.096	1.33	1.89	0.50	1.84	2.07	107	107	47	15	75	94	145	37	347	16	1298	41	101	22	20	3.10
CI 1192	MD616	65.98	0.982	15.88	6.24	0.132	1.25	1.99	0.52	1.80	1.52	111	113	48	22	77	103	137	38	377	15	968	40	96	24	23	4.00
CI 1193	MD576	57.27	0.924	19.25	7.80	0.157	1.69	2.16	0.93	2.68	2.91	143	127	63	35	115	124	215	34	215	15	1441	48	100	24	22	3.91
CI 1194	MD625	63.86	0.956	14.90	5.55	0.085	1.10	2.17	0.57	1.78	3.18	106	111	46	27	68	78	183	40	370	16	1707	30	98	20	20	6.35
CI 1196	MD617	65.73	0.943	14.31	5.34	0.100	1.06	1.95	0.67	2.09	2.97	99	104	41	21	70	83	172	34	376	16	1643	47	86	23	22	4.33

Tab. 5 Project Cornești (chapter 4.5).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
CI 1199	MD626	65.04	1.012	16.28	6.13	0.098	1.17	1.43	0.82	1.71	3.41	110	120	47	16	80	88	146	39	394	17	1422	38	95	24	20	3.11
CI 1202	MD627	65.82	1.004	15.92	6.11	0.096	1.32	1.32	0.75	1.77	2.67	98	117	49	18	79	88	128	37	396	19	1333	57	92	24	23	3.34
CI 1203	MD628	62.45	1.014	15.05	5.71	0.088	1.15	1.50	0.64	1.98	4.65	105	109	49	32	81	94	196	39	415	20	2294	57	97	22	20	5.66
CI 1208	MD573	64.88	0.892	15.94	5.55	0.102	1.50	2.49	0.89	2.66	2.13	102	106	41	34	100	128	186	31	295	14	1243	33	85	20	18	2.89
CI 1209	MD572	64.77	0.983	15.51	5.76	0.076	1.19	2.43	0.79	1.90	3.40	96	109	41	19	82	103	195	36	398	19	1257	43	82	22	19	3.00
CI 1210	MD618	65.46	1.027	16.37	6.17	0.072	1.25	1.87	0.54	1.70	3.05	113	116	46	24	85	101	166	38	400	18	1308	43	99	22	23	2.74
CI 1213	MD574	66.33	0.995	15.39	5.85	0.083	1.27	2.23	0.69	2.01	2.21	106	107	44	18	77	107	162	38	409	18	1089	42	87	23	23	2.44
CI 1217	MD575	63.78	0.882	14.03	5.23	0.158	1.15	3.25	0.52	1.90	2.19	99	100	43	25	80	84	187	31	337	15	1534	29	85	21	18	6.18
CI 2003	AD840	61.39	0.830	16.56	6.69	0.060	1.55	1.63	0.98	2.04	2.29	119	112	68	28	103	111	155	40	227	15	1414	43	81	25	9	5.97
CI 2007	AD841	59.89	0.731	17.37	6.78	0.045	0.91	1.56	0.99	2.19	3.86	114	111	49	46	88	93	163	36	156	13	1372	29	62	25	5	5.68
CI 2054	AD846	66.30	0.852	16.97	4.43	0.061	1.18	1.79	1.49	2.02	1.57	103	108	52	14	74	85	195	34	229	22	1260	49	79	26	8	3.35
CR 151	AD849	64.72	0.864	16.14	5.68	0.069	2.06	1.59	1.42	1.69	0.09	114	103	54	37	70	102	187	27	265	20	659	40	76	23	8	5.67
CR 152	AD850	57.75	0.900	20.13	6.86	0.090	1.56	2.18	0.86	2.13	0.35	134	132	67	43	111	125	173	34	184	21	1026	36	69	29	9	7.20
CR 158	AD851	66.13	0.915	15.60	5.60	0.101	1.69	1.45	1.37	1.91	0.14	108	108	54	56	78	97	151	35	307	19	684	36	73	19	8	5.08
CR 215	AD852	62.55	0.901	18.72	6.36	0.051	1.58	1.92	1.09	3.14	0.50	122	127	52	35	117	126	159	37	210	20	944	35	62	24	9	3.18
CR 220	AD853	66.30	0.940	17.69	6.48	0.058	1.76	1.73	1.34	2.32	0.31	120	122	52	28	94	128	151	38	264	22	716	40	75	25	6	1.07
CR 222	AD854	60.53	0.812	14.21	5.52	0.094	2.04	5.32	1.01	2.08	0.23	92	104	52	25	84	103	155	33	252	16	807	37	53	20	7	8.17
DD 131	AD063	61.56	0.902	17.16	5.28	0.028	1.16	1.73	0.84	2.32	3.44	109	107	49	48	119	123	305	37	286	16	2206	35	86	24	18	5.52
DD 136	AD064	60.43	1.009	20.55	7.02	0.102	1.59	1.11	0.91	2.43	2.23	143	122	47	40	133	137	170	39	266	18	1439	56	111	27	26	2.57
DD 141	MD577	58.84	0.809	17.02	6.43	0.058	1.48	2.51	0.82	3.15	3.48	120	116	54	50	115	137	314	29	209	14	1612	37	74	21	17	5.73
DD 142	MD578	63.37	0.912	16.57	5.62	0.062	1.37	1.97	1.05	2.42	2.28	101	104	53	38	110	132	245	36	322	16	1409	50	101	25	22	4.31
GM 002	MD579	68.44	0.687	13.10	4.36	0.135	0.82	1.92	1.21	1.92	3.12	79	66	41	17	71	82	374	22	249	14	1677	40	76	15	13	4.29
GM 003	MD580	61.53	0.896	17.02	6.02	0.051	1.25	2.26	1.24	2.23	2.84	106	111	45	40	111	115	375	29	263	17	2158	24	73	22	18	4.59
GM 004	MD581	65.10	0.924	18.19	6.66	0.060	1.85	1.53	1.31	2.48	0.54	120	114	57	47	125	135	180	32	271	21	808	39	86	24	17	1.37
GM 016	MD582	66.12	0.892	14.91	5.15	0.062	1.17	1.83	1.22	2.06	1.53	87	90	51	34	93	93	261	29	333	15	1827	32	94	21	17	3.84
GM 028	MD584	56.33	0.931	19.48	6.70	0.060	1.39	2.38	0.93	2.30	4.25	116	121	50	47	133	121	452	32	237	19	2203	43	68	26	15	4.88
GM 039	AD065	66.75	0.931	18.38	6.58	0.060	1.84	1.47	1.54	2.32	0.17	124	116	49	31	111	135	172	29	276	19	727	36	82	24	17	0.56
GM 051	MD583	64.76	0.919	15.82	5.79	0.083	1.19	1.89	1.16	2.06	2.52	98	102	47	19	84	106	285	32	323	18	1944	35	87	19	14	2.89
GM 058	MD585	68.80	0.951	17.05	6.12	0.097	1.54	1.52	1.17	2.25	0.30	108	108	44	18	89	127	146	33	326	17	687	33	84	21	19	0.44
GM 059	AD066	64.74	0.881	15.38	5.33	0.090	1.25	2.46	1.13	2.13	2.55	97	96	48	26	100	105	377	28	309	16	2152	36	69	23	15	4.54
HP 201	MD565	61.76	0.783	18.84	7.05	0.068	1.82	1.72	0.94	2.85	0.24	146	120	59	58	120	139	139	28	178	13	829	35	75	25	25	4.46
HP 207	MD566	66.52	0.865	14.53	5.35	0.073	1.81	1.74	0.90	2.39	0.33	95	108	46	38	94	116	125	29	321	13	836	29	80	19	20	5.62
HP 211	MD567	60.70	0.775	19.29	7.05	0.067	1.70	1.99	0.81	3.26	0.47	150	119	67	47	134	140	150	29	167	12	934	23	62	25	21	3.79
HP 225	AD067	69.30	0.898	13.71	4.91	0.095	1.92	2.31	1.26	2.68	0.57	86	96	41	22	84	110	161	35	368	14	1119	38	100	19	17	1.87
HP 230	MD568	61.30	0.835	18.95	6.88	0.094	1.78	1.81	0.93	2.80	0.68	146	121	55	46	122	156	161	31	193	11	943	24	73	24	22	4.00
PN 112	MD591	63.49	0.978	19.21	6.54	0.066	1.98	1.40	1.23	2.84	0.29	110	123	50	44	136	153	154	30	247	20	735	31	86	25	20	1.57
PN 115	AD068	63.17	0.931	19.82	6.08	0.056	2.26	1.76	1.58	2.74	0.48	134	127	47	37	134	149	167	34	257	17	737	32	85	27	18	0.92
PN 116	MD592	62.90	0.883	17.07	6.45	0.086	2.00	1.71	1.22	2.53	0.58	124	112	52	40	101	118	227	27	264	17	915	21	74	21	16	3.80
PN 170	AD855	59.90	0.943	19.56	6.44	0.061	1.75	1.47	1.03	2.11	0.16	135	130	55	58	120	116	145	37	219	21	863	24	75	33	15	6.58
PN 171	AD856	56.78	0.956	19.80	7.38	0.178	2.56	1.48	0.97	2.18	0.12	140	130	71	53	113	130	145	29	199	22	837	28	75	29	10	7.59
PN 175	AD857	61.80	0.906	16.36	5.94	0.028	1.45	1.72	1.17	2.34	2.31	111	120	58	49	105	113	279	34	266	20	1103	32	78	24	8	5.97
PN 176	AD858	60.51	0.998	19.95	6.06	0.056	1.40	1.97	1.05	2.06	0.11	134	133	54	48	109	97	177	40	250	24	675	44	84	32	12	5.84
PN 188	AD859	61.40	0.918	18.53	6.87	0.053	1.84	1.62	1.22	2.30	0.97	120	127	62	33	102	111	184	40	231	22	1176	36	68	26	9	4.28
PN 189	AD860	59.64	0.829	17.14	5.81	0.068	1.78	2.52	1.06	2.50	1.54	123	119	52	60	132	109	283	33	217	18	1425	35	64	28	7	7.11
PN 200	AD861	58.39	0.886	19.74	6.87	0.064	1.87	2.11	0.96	2.42	1.42	138	130	61	43	118	120	240	36	179	20	1448	43	73	28	9	5.29
PN 203	AD862	56.75	0.926	20.45	7.05	0.095	2.38	1.39	0.86	2.25	0.36	142	141	86	55	114	136	126	29	195	20	864	37	76	31	13	7.49
PN 205	AD863	59.32	0.890	18.86	6.39	0.101	2.15	1.58	1.32	2.32	0.64	142	131	73	58	112	116	193	37	208	21	1096	40	102	34	13	6.43
TF 153	MD561	64.18	0.855	15.50	5.50	0.061	1.41	1.98	1.14	1.95	1.89	97	104	57	46	99	111	251	30	286	17	1363	38	71	20	17	5.46
TF 157	MD562	56.76	0.971	21.07	6.88	0.068	1.73	1.22	1.09	2.79	1.37	145	134	64	48	133	135	180	32	220	19	1140	44	83	28	23	6.19
TF 188	MD563	65.23	0.945	15.56	5.07	0.052	1.16	1.41	1.37	1.99	2.95	98	104	49	47	90	103	227	33	325	18	1270	38	99	22	19	4.21
TF 199	MD564	50.38	0.839	20.57	6.72	0.086	1.35	2.35	0.58	2.22	5.40	137	136	60	63	154	123	335	29	183	15	2560	24	76	26	18	9.33
TF 169	MD629	60.62	0.900	17.63	5.86	0.041	1.45	1.74	1.04	2.17	2.56	113	112	58	45	115	120	243	35	278	19	1931	36	86	25	19	5.43
TF 185	MD630	61.53	0.893	16.81	6.15	0.062	1.60	2.20	1.09	2.28	2.58	115	116	56	44	113	116	313	31	282	18	1477	39	70	22	17	5.04
TF 200	MD631	63.85	0.913	17.16	5.29	0.043	1.33	1.49	1.36	2.34	2.89	96	107	41	32	104	106	216	35	288	17	1402	36	83	26	21	3.12
TF 1005	AD865	55.31	0.911	20.18	7.61	0.045	1.17	1.35	0.78	2.16	2.41	139	134	64	65	122	104	170	42	194	19	1071	44	71	27	15	8.06
TF 1008	AD866	63.57	0.932	16.76	5.24	0.030	1.42	1.34	1.28	2.08	2.17	104	113	68	37	87	106	172	40	270	20	1024	52	85	26	9	5.17
TF 1010	AD867	60.57	0.981	17.27	5.58	0.026	0.96	1.51	1.28	2.05	4.95	104	115	56	150	73	89	235	49	297	22	1684	46	79	27	5	4.82
V 068	MD587	60.00	0.870	19.42	7.36	0.050	1.75	1.98	0.91	2.75	0.44	144	124	45	50	136	154	240	27	206	18	1144	30	75	28	22	4.03
V 074	MD588	63.64	0.916	19.65	6.39	0.040	1.47	1.74	0.95	2.53	0.21	139	120	42	50	105	151	139	28	228	19	788	35	89	26	20	2.52
V 076	MD586	66.04	0.946	17.39	5.91	0.080	1.68	1.74	1.25	2.59	0.29	106	111	46	34	104	137	200	31	308	19	927	26	73	21	19	2.11

Tab. 5 (Contin.) Project Cornești (chapter 4.5).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
V 091	AD069	63.26	0.944	19.74	6.15	0.045	1.76	1.78	0.98	2.69	0.22	119	121	54	41	111	149	230	28	256	19	1077	37	58	23	16	2.49
V 104	AD070	65.99	0.970	17.18	6.38	0.107	1.93	1.64	1.26	2.58	0.27	109	114	47	25	102	134	166	33	315	19	729	32	88	23	21	1.12
V 105	MD589	60.41	0.891	19.07	6.11	0.051	1.83	2.31	0.84	2.40	0.38	134	120	50	44	129	150	257	27	215	18	1522	30	83	24	24	5.80
V 110	MD590	65.37	0.878	16.23	5.49	0.064	1.52	2.49	1.13	2.52	0.54	111	106	39	29	97	125	236	31	298	18	1022	29	83	21	18	3.36
V 179	AD868	56.15	0.785	17.84	6.02	0.104	1.92	2.61	0.82	2.42	4.76	126	120	56	41	116	118	257	34	184	20	1032	37	66	22	5	6.57
V 183	AD869	60.04	0.937	21.35	7.91	0.079	2.00	1.58	0.60	2.72	0.63	147	136	56	47	130	137	155	39	186	22	956	36	81	29	10	2.16
V 185	AD870	54.13	0.801	15.41	5.02	0.164	1.25	4.44	0.93	2.21	9.63	102	104	67	28	94	100	222	34	209	19	719	51	67	21	7	6.01
Loams from excavation																											
Daub	AD381	64.03	0.990	14.13	5.56	0.105	1.02	2.22	0.90	2.27	4.60	73	99	50	28	111	81	209	43	378	19	2544	47	83	21	13	4.18
CI2020	AD842	66.07	1.007	15.23	6.02	0.099	1.07	1.05	0.87	2.29	2.30	96	114	68	19	91	90	114	46	381	20	909	48	103	24	8	3.99
CI2020	AD842	66.07	1.007	15.23	6.02	0.099	1.07	1.05	0.87	2.29	2.30	96	114	68	19	91	90	114	46	381	20	909	48	103	24	8	3.99
CI2026	AD843	67.81	0.993	15.15	6.09	0.118	1.69	2.35	0.98	2.31	0.45	103	116	71	35	50	111	100	44	381	19	490	43	100	2	11	2.04
CI2026	AD843	67.81	0.993	15.15	6.09	0.118	1.69	2.35	0.98	2.31	0.45	103	116	71	35	50	111	100	44	381	19	490	43	100	2	11	2.04
CI2048	AD844	64.83	0.927	14.85	5.76	0.098	1.12	2.78	0.76	2.28	2.68	90	112	56	17	76	94	184	39	380	19	1680	53	72	20	9	3.90
CI2048	AD844	64.83	0.927	14.85	5.76	0.098	1.12	2.78	0.76	2.28	2.68	90	112	56	17	76	94	184	39	380	19	1680	53	72	20	9	3.90
CI2051	AD845	61.34	0.853	12.76	4.87	0.092	1.55	10.52	0.98	2.64	0.94	95	91	45	12	74	90	180	36	336	18	688	36	74	6	6	3.47
CI2051	AD845	61.34	0.853	12.76	4.87	0.092	1.55	10.52	0.98	2.64	0.94	95	91	45	12	74	90	180	36	336	18	688	36	74	6	6	3.47
CI2058	AD847	66.42	0.905	15.15	5.71	0.094	1.35	1.78	0.75	2.46	1.60	87	116	61	28	114	94	130	43	351	19	1049	46	82	22	10	3.80
CI2061	AD848	65.40	0.873	12.90	4.95	0.121	1.35	2.86	0.94	2.10	1.42	94	94	48	38	100	103	118	39	347	16	487	42	76	21	9	7.07
PN210	AD864	65.26	0.990	16.04	6.29	0.111	2.20	2.50	1.30	2.47	0.45	100	118	62	30	92	96	135	40	309	21	588	36	79	24	8	2.38
Raw materials																											
clay	AD455	67.37	0.956	14.60	5.70	0.120	1.29	1.10	0.93	2.05	0.12	110	104	51	18	74	116	93	42	366	21	479	49	89	25	15	5.76
clay	AD456	68.45	0.931	12.36	4.67	0.146	1.10	1.56	1.00	2.27	0.67	84	88	43	43	111	107	105	44	369	17	477	48	87	25	9	6.86
clay	AD481	73.44	0.719	12.15	4.24	0.096	1.32	1.18	1.85	2.18	0.25	70	68	36	73	54	80	148	28	205	18	470	24	62	20	5	2.59
clay	AD485	63.28	0.905	14.19	5.62	0.120	2.00	2.31	1.31	2.31	0.26	103	96	45	34	80	111	136	37	294	20	505	43	71	27	13	7.70
clay	AD486	66.00	0.872	13.95	4.77	0.063	1.59	1.30	1.24	2.60	0.21	89	90	40	25	88	120	116	39	281	19	438	42	66	25	7	7.41
clay	AD488	68.93	0.738	14.23	4.82	0.131	1.08	1.19	1.62	2.29	0.15	86	67	33	140	71	100	156	31	265	16	533	41	69	26	8	4.82
clay	AD489	66.10	0.900	13.81	5.25	0.139	1.60	1.59	0.96	2.06	0.20	99	100	45	22	73	113	108	45	332	18	481	40	84	26	10	7.39

Tab. 5 (Contin.) Project Cornești (chapter 4.5).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
BV0006	MD690	62.81	0.632	15.79	5.21	0.126	1.30	6.96	1.23	3.36	2.57	94	78	38	22	158	165	428	20	206	11	1320	10	72	18	18	5.55
BV0007	MD691	64.09	0.776	15.98	5.90	0.100	1.75	4.92	0.87	3.57	2.04	106	94	51	16	110	169	549	27	246	15	856	33	79	21	13	3.77
BV0008	MD692	65.44	0.825	16.13	6.44	0.109	1.68	3.64	0.61	3.53	1.60	114	101	55	17	105	159	287	34	243	16	808	28	85	20	17	2.65
BV0009	MD693	65.45	0.839	16.86	6.97	0.081	1.65	2.05	0.99	3.35	1.77	112	91	40	17	113	165	306	27	283	18	733	27	93	20	28	1.94
BV0010	MD694	64.64	0.696	14.65	5.46	0.120	1.43	5.93	0.72	3.18	3.18	93	85	42	16	109	173	413	25	230	14	682	27	63	21	16	6.32
BV0011	MD695	61.43	0.697	15.20	6.07	0.167	1.75	7.48	0.94	3.15	3.12	100	85	45	21	102	182	403	26	205	15	711	24	82	18	17	8.39
BV0013	MD696	62.57	0.625	15.39	5.51	0.104	1.58	7.75	0.88	2.94	2.65	106	88	41	16	108	171	428	18	194	15	760	28	55	18	15	7.48
BV0014	MD697	65.44	0.714	14.99	5.61	0.069	1.58	5.19	0.75	3.19	2.47	96	94	47	20	93	178	300	38	233	13	726	31	88	21	21	6.22
BV0015	MD698	65.53	0.814	16.85	6.42	0.093	0.92	2.64	1.08	3.10	2.55	97	78	32	11	94	145	330	40	261	17	816	32	79	32	19	4.25
BV0016	MD732	64.15	0.693	15.31	5.70	0.165	1.57	6.39	1.01	2.81	2.20	93	99	45	18	135	173	336	20	193	14	1032	30	51	19	16	5.82
BV0017	MD699	75.07	0.612	12.63	4.57	0.054	0.98	1.38	0.65	2.68	1.37	68	80	33	13	88	125	209	11	265	10	968	12	33	17	14	2.39
BV0018	MD700	68.84	0.752	14.92	5.84	0.066	1.20	2.28	0.85	3.07	2.18	98	84	37	20	104	172	282	20	276	16	916	33	65	17	17	3.99
BV0021	MD701	68.04	0.777	15.37	4.92	0.109	1.47	3.97	1.03	2.82	1.49	86	73	38	20	101	162	317	22	243	16	942	27	58	18	13	5.20
BV0023	MD702	68.65	0.746	15.19	5.68	0.114	1.35	2.51	0.66	2.64	2.46	107	93	41	20	130	173	339	24	252	15	1198	8	90	22	14	5.29
BV0024	MD703	70.94	0.687	14.16	5.06	0.081	1.10	2.01	0.79	2.64	2.53	95	85	39	14	117	152	322	16	261	22	978	23	56	17	26	3.00
BV0025	MD704	65.89	0.834	17.57	5.57	0.063	1.19	2.70	0.47	2.56	3.14	118	101	48	23	115	163	422	24	215	17	719	27	74	18	13	4.18
BV0026	MD705	68.24	0.783	15.22	5.20	0.086	1.26	2.48	0.84	2.86	3.03	114	138	45	12	124	186	369	14	256	19	961	42	86	20	22	4.25
BV0038	MD654	65.34	0.687	16.29	5.77	0.049	1.62	3.43	0.85	3.64	2.32	101	96	46	24	127	214	313	25	187	14	727	43	78	24	18	6.26
BV0041	MD663	63.97	0.740	14.92	5.72	0.065	2.07	7.62	0.66	3.78	0.46	105	90	40	26	77	168	201	34	246	15	467	40	88	16	19	0.34
BV0043	MD645	84.09	0.496	7.38	2.22	0.030	0.67	2.57	0.34	1.84	0.35	33	37	21	5	38	69	109	12	255	8	359	5	28	9	<5	0.81
BV0044	MD706	65.30	0.799	16.29	6.48	0.085	1.39	2.68	1.06	3.06	2.86	98	85	37	20	125	157	394	28	253	15	919	30	76	21	20	3.21
BV0045	MD707	64.66	0.799	15.69	6.25	0.094	1.57	3.34	0.64	3.43	3.53	116	92	54	22	122	165	472	34	241	16	864	25	100	19	13	4.44
BV0046	MD647	82.28	0.535	6.89	2.03	0.057	0.45	3.38	0.52	1.99	1.88	28	49	20	17	110	74	281	13	353	9	1093	10	36	14	10	3.81
BV0047	MD648	79.17	0.763	10.06	4.62	0.043	0.82	0.67	0.60	2.83	0.42	66	74	39	28	57	98	100	34	463	14	564	18	69	14	14	0.71
BV0049	MD649	78.79	0.513	8.45	3.25	0.095	0.70	3.55	0.70	2.37	1.59	42	45	28	7	66	86	270	15	273	7	715	13	34	15	<5	3.15
BV0051	MD650	94.87	0.195	2.33	0.73	0.005	0.32	0.28	0.09	0.88	0.49	8	7	13	11	8	34	55	8	271	<5	171	<5	19	8	9	0.53
BV0056	MD733	65.00	0.795	16.85	6.36	0.090	1.58	2.63	0.85	3.89	1.95	110	89	53	22	120	184	333	38	232	17	888	54	76	22	21	2.25
BV0059	MD646	85.90	0.451	6.63	2.16	0.048	0.54	1.36	0.34	2.00	0.58	34	39	22	6	35	71	116	12	296	8	333	<5	37	12	11	1.03
BV0066	MD708	65.31	0.562	13.61	4.63	0.113	1.33	8.26	1.35	3.14	1.68	76	71	33	20	120	186	291	44	248	19	805	40	98	20	26	8.32
BV0070	MD709	66.65	0.792	16.74	6.20	0.057	1.57	1.98	0.77	3.32	1.92	122	110	57	19	99	176	270	29	237	18	703	60	121	22	21	3.14
BV0075	MD710	66.51	0.793	17.42	5.58	0.086	1.41	2.55	0.80	2.96	1.90	108	95	41	16	114	177	339	25	244	16	739	40	63	22	17	3.89
BV0076	MD711	76.18	0.630	12.71	4.60	0.032	1.11	0.95	0.42	2.74	0.64	84	76	25	7	88	138	144	9	240	13	480	16	52	16	19	1.28
BV0082	MD712	66.56	0.794	15.67	6.19	0.100	1.56	3.66	0.84	3.11	1.52	113	92	50	16	107	151	311	30	246	17	807	36	90	19	21	3.27
BV0085	MD657	69.87	0.801	15.33	5.53	0.090	1.22	1.93	0.85	3.15	1.23	98	89	51	17	95	171	205	29	251	15	719	26	79	19	25	3.63
BV0086	MD658	75.15	0.637	13.51	4.89	0.038	1.26	0.87	0.56	2.89	0.19	89	81	36	18	56	131	99	22	252	11	421	32	86	20	13	0.83
BV0087	MD713	69.10	0.750	14.79	5.39	0.081	1.33	2.52	0.95	3.22	1.87	93	80	49	24	146	187	299	36	258	15	1079	40	71	18	18	4.14
BV0088	MD714	66.27	0.773	15.53	5.03	0.123	1.25	5.62	0.85	2.29	2.25	94	85	41	17	168	153	380	20	286	15	1147	31	71	19	13	7.45
BV0091	MD659	66.71	0.686	17.90	6.13	0.085	1.83	1.63	0.75	3.98	0.30	106	98	58	26	83	179	111	40	197	12	500	35	73	21	19	0.60
BV0092	MD655	60.85	0.825	16.62	6.00	0.075	2.02	7.96	0.64	3.33	1.67	121	107	46	23	138	228	391	22	218	15	1099	32	81	21	20	8.32
BV0096	MD715	69.45	0.729	15.26	5.98	0.095	1.33	1.87	0.69	3.02	1.58	96	91	50	16	104	146	283	21	269	14	1340	21	86	19	16	3.17
BV0098	MD716	67.13	0.744	17.20	4.71	0.089	0.94	2.72	1.28	2.91	2.26	100	84	35	23	114	164	386	37	234	15	1205	47	71	23	22	4.03
BV0101	MD717	66.37	0.742	15.87	6.00	0.059	1.44	3.59	0.96	2.88	2.09	102	88	43	16	133	175	334	21	255	15	1088	31	80	18	15	5.45
BV0102	MD718	66.29	0.697	17.01	5.35	0.063	1.36	4.11	0.92	3.14	1.05	102	98	48	19	91	173	270	21	205	13	656	34	60	20	18	3.38
BV0103	MD719	65.68	0.733	13.63	5.16	0.063	1.60	8.33	0.90	2.81	1.10	95	84	40	19	112	153	264	22	243	13	736	25	58	18	16	8.34
BV0104	MD720	64.95	0.955	17.79	6.66	0.025	1.33	2.27	0.74	2.88	2.39	154	127	41	19	87	154	341	19	255	23	652	24	64	19	15	3.17
BV0110	MD652	65.00	0.844	16.61	6.58	0.081	2.00	1.81	1.03	5.39	0.67	90	90	50	35	109	198	135	33	266	17	635	48	90	21	22	1.17
BV0112	MD721	68.42	0.784	15.14	5.57	0.106	1.29	2.26	0.83	2.91	2.68	127	139	43	16	115	167	362	17	245	18	818	50	99	20	29	3.78
BV0114	MD660	71.63	0.637	14.95	5.25	0.062	1.22	1.03	1.20	3.44	0.57	85	75	39	27	85	154	136	29	237	15	706	22	65	23	18	1.16
BV0117	MD722	70.24	0.628	14.05	4.67	0.076	1.19	3.28	1.09	3.40	1.38	84	68	39	15	88	190	222	29	207	13	706	21	65	14	21	4.45
BV0118	MD723	68.92	0.738	14.53	5.55	0.090	1.37	3.48	0.78	2.99	1.56	90	83	40	21	127	135	285	26	247	13	870	67	119	20	21	1.96
BV0120	MD724	63.95	0.695	16.70	6.07	0.114	1.44	4.34	1.00	2.85	2.84	113	94	52	23	122	180	349	24	207	15	1014	36	78	20	16	5.82
BV0124	MD725	66.05	0.756	17.49	5.27	0.094	0.97	2.64	0.88	2.99	2.85	99	97	42	27	130	187	337	36	237	16	857	37	81	26	18	4.03
BV0125	MD726	72.49	0.639	12.95	4.80	0.157	1.04	2.07	0.51	2.72	2.63	81	81	36	17	163	154	285	9	259	13	1273	33	64	16	16	3.86
BV0126	MD653	67.96	0.781	15.11	4.27	0.201	0.80	3.23	0.91	2.55	4.18	86	93	35	24	335	153	459	40	322	17	1290	34	89	28	19	5.00
BV0128	MD727	66.11	0.624	16.28	5.53	0.065	1.45	4.00	0.79	3.60	1.55	116	89	42	22	82	169	285	20	181	10	663	22	81	22	17	5.76
BV0133	MD651	71.59	0.664	13.01	4.80	0.067	1.00	4.07	0.72	2.90	1.16	73	71	35	11	87	140	234	18	289	14	754	33	71	19	23	4.03
BV0135	MD661	57.40	0.733	15.95	6.71	0.100	1.99	12.06	0.58	3.36	1.12	112	101	39	31	110	165	349	24	200	16	682	44	82	17	16	3.74
BV0140	MD728	67.54	0.725	16.67	5.51	0.043	1.19	2.14	0.74	3.15	2.29	100	95	41	30	114	191	353	16	247	14	854	29	79	22	21	4.48
BV0141	MD729	70.84	0.667	14.71	5.35	0.080	1.32	2.10	0.09	2.32	2.53	106	99	53	36	154	165	353	19	182	13	1032	25	58	19	14	5.55
BV0142	MD656	68.59	0.710	14.98	5.38	0.059	1.34	2.56	1.18	2.83	2.37	88	83	47	22	117	137	382	33	272	13	1315	38	78	21	17	3.71

Tab. 6 Project Lossow (chapter 4.6).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
BV0147	MD730	67.04	0.728	14.92	5.55	0.052	1.43	4.52	0.66	3.14	1.96	106	88	44	18	80	189	312	25	244	15	831	37	86	20	21	6.26
BV0154	MD731	68.53	0.758	15.51	6.01	0.129	1.12	2.90	0.63	1.92	2.49	94	103	36	25	97	148	353	36	284	14	824	30	74	21	16	5.48
BV0156	MD662	67.23	0.690	15.21	6.11	0.189	1.08	3.83	1.03	2.96	1.68	86	79	33	14	95	144	286	28	236	13	905	39	59	21	24	1.51
BV0158	MD734	67.84	0.803	16.67	5.70	0.241	0.98	0.90	0.82	3.27	2.78	105	104	42	20	69	116	184	23	273	15	933	28	67	24	23	5.90
BV0159	MD735	69.43	0.706	15.99	6.38	0.065	1.16	0.72	1.16	3.08	1.31	95	100	60	22	97	121	149	32	245	15	748	52	77	18	26	6.37
BV0160	MD736	63.45	0.812	19.06	7.56	0.042	1.14	0.82	0.94	3.46	2.70	113	106	62	29	121	138	148	30	230	16	839	45	100	23	26	6.85
BV0161	MD737	65.84	0.866	19.56	6.72	0.048	1.37	0.79	0.86	3.77	0.18	115	108	64	27	97	223	61	38	301	22	541	39	109	29	36	5.11
BV0162	MD738	71.32	0.817	16.53	5.57	0.036	1.15	0.67	0.78	2.85	0.28	103	95	41	22	202	130	99	15	278	16	584	21	61	22	26	5.64
BV0163	MD739	67.65	0.779	19.53	6.28	0.021	1.36	0.58	0.39	3.26	0.15	124	111	42	21	76	163	51	10	183	14	575	14	48	25	23	5.29
BV0164	MD740	66.91	0.711	15.53	5.16	0.081	0.90	1.76	1.09	3.14	4.72	83	129	48	42	196	127	502	30	262	16	1665	18	85	19	15	5.38
BV0165	MD741	64.95	0.735	17.49	9.08	0.073	1.34	0.81	0.88	3.19	1.44	105	95	53	37	242	169	85	24	229	17	721	25	76	21	30	5.03
BV0166	MD742	66.80	0.765	17.33	7.22	0.035	0.78	0.79	1.01	3.21	2.08	106	97	36	24	81	138	134	23	260	15	870	21	84	28	22	4.79
BV0167	MD743	64.11	1.059	23.71	4.05	0.021	0.93	0.58	0.74	3.03	1.77	131	124	44	47	131	155	88	26	226	23	486	33	91	32	24	7.81
BV0168	MD744	65.69	0.875	19.58	5.92	0.047	1.51	1.44	0.61	2.85	1.48	115	97	45	23	102	120	109	17	213	15	470	41	90	21	27	5.55
BV0169	MD745	67.07	0.855	17.70	5.87	0.044	1.15	1.23	0.69	2.96	2.44	107	103	46	33	72	138	97	24	282	19	447	27	77	23	23	5.75
BV0170	MD746	68.87	0.641	14.87	5.38	0.149	0.74	1.93	1.19	2.82	3.40	76	76	28	28	181	121	397	39	310	14	1319	35	94	21	20	5.31
BV0171	MD747	59.44	0.961	22.23	10.05	0.057	1.73	0.48	0.48	3.38	1.19	172	141	71	26	96	150	85	24	238	21	676	31	70	28	27	10.50
BV0172	MD748	65.70	0.747	16.64	6.42	0.214	0.91	2.65	0.99	3.17	2.57	102	96	32	29	147	181	240	46	263	15	1422	46	85	26	22	5.57
BV0173	MD749	68.49	0.667	14.94	6.07	0.168	0.79	2.59	1.30	2.41	2.57	81	81	33	33	160	154	238	34	307	16	1297	48	105	23	26	5.02
BV0174	MD750	62.66	0.695	16.86	6.04	0.099	1.77	4.15	0.95	4.11	2.67	102	101	41	28	185	193	485	23	192	15	1246	24	73	20	17	5.93
BV0175	MD751	62.88	0.711	18.00	6.63	0.248	2.13	2.59	1.26	3.77	1.79	117	116	49	61	483	199	363	26	189	14	975	41	71	20	18	5.13
BV0176	MD752	67.71	0.784	15.10	5.57	0.087	0.98	2.00	0.85	3.06	3.85	92	87	38	30	186	120	363	42	319	14	1689	28	92	20	21	5.30
BV0177	MD753	70.04	0.787	14.58	5.93	0.084	1.05	1.50	0.93	2.35	2.75	88	87	31	54	233	124	246	38	344	15	1781	47	92	21	20	5.38
BV0178	MD754	71.40	0.698	13.46	5.57	0.058	0.90	1.47	0.81	3.32	2.32	70	74	34	15	111	122	352	21	352	19	1262	33	87	18	15	2.64
BV0179	MD755	64.93	0.755	16.04	5.91	0.067	1.24	2.57	0.99	3.41	4.09	99	89	44	39	578	165	531	38	266	18	2224	34	109	21	17	6.26
BV0180	MD756	68.90	0.809	14.61	5.62	0.047	1.20	1.41	1.04	3.51	2.86	88	78	39	42	377	157	345	27	340	20	1687	35	107	21	17	5.07
BV0181	MD757	68.05	1.030	20.55	4.79	0.078	0.68	0.87	0.67	2.64	0.66	128	111	81	25	187	115	108	25	288	21	537	33	98	27	20	6.86
BV0182	MD758	69.74	0.747	17.49	5.55	0.114	0.68	0.80	1.00	3.10	0.78	93	85	167	15	478	133	96	19	220	16	496	22	64	18	24	5.51
BV0183	MD759	65.39	0.698	18.46	7.43	0.057	1.18	0.98	1.05	3.31	1.44	111	106	51	19	189	186	97	28	226	20	727	30	75	23	31	5.64
BV0184	MD760	63.21	0.700	18.60	8.69	0.065	1.22	1.61	1.36	2.78	1.78	92	86	45	19	146	132	145	23	230	13	772	27	67	23	19	5.67
BV0185	MD761	66.35	0.717	14.63	9.62	0.168	1.00	1.47	0.87	4.31	0.88	89	90	34	26	107	173	155	41	319	13	998	45	96	22	22	2.44
BV0186	MD762	68.01	0.667	15.03	6.49	0.061	1.02	2.40	0.89	3.00	2.45	97	87	28	28	103	165	272	42	256	11	1080	40	78	23	19	5.48
BV0187	MD763	65.87	0.793	16.08	7.10	0.070	1.13	2.66	1.01	2.89	2.39	105	95	34	26	87	137	310	45	276	15	1021	49	110	22	21	5.27
BV0188	MD764	67.63	0.716	15.26	5.74	0.047	0.90	2.43	1.01	3.13	3.16	96	89	28	32	147	153	271	41	273	14	1385	42	73	23	18	5.51
BV0189	MD765	73.32	0.753	13.85	4.83	0.140	1.19	0.82	0.95	2.92	1.22	77	80	41	15	106	113	127	24	368	15	766	30	69	25	20	3.64
BV0190	MD766	71.05	0.632	15.93	5.91	0.028	0.47	0.72	1.17	3.08	1.01	81	77	33	16	54	138	77	36	220	14	446	15	82	26	42	5.33
BV0191	MD767	72.87	0.629	12.28	5.76	0.075	1.08	1.88	0.72	2.68	2.03	81	77	36	18	69	131	284	18	284	12	1907	17	67	19	18	4.52
BV0192	MD768	73.52	0.505	11.56	5.05	0.063	0.81	2.02	0.94	3.08	2.44	63	51	30	11	60	132	330	13	281	12	2035	22	44	21	15	3.74
BV0193	MD769	63.83	0.855	16.65	5.76	0.077	1.38	2.41	2.07	3.67	3.29	76	70	31	25	123	141	341	37	334	20	2095	46	120	22	21	3.77
BV0194	MD770	67.42	0.762	15.91	6.40	0.071	1.73	2.47	0.55	2.62	2.06	137	143	68	38	119	164	211	17	221	17	1259	27	68	20	21	6.45
BV0195	MD771	66.81	0.750	15.95	5.32	0.187	1.14	1.88	1.21	3.14	3.61	91	85	38	37	352	169	487	33	279	14	2372	31	68	21	15	5.87
BV0196	MD772	71.48	0.754	14.94	5.91	0.069	1.47	0.76	0.87	2.91	0.84	95	99	48	58	71	142	94	19	288	17	559	24	79	21	22	5.34
BV0197	MD773	66.39	0.693	16.21	5.71	0.062	1.54	2.40	1.22	3.64	2.15	88	86	38	22	195	179	295	29	217	13	1302	27	83	19	20	4.42
BV0198	MD774	66.94	0.687	13.77	8.39	0.048	1.33	1.87	0.96	2.99	3.03	92	76	48	19	77	156	382	33	274	13	1993	27	93	19	16	4.52
BV0199	MD775	69.85	0.679	14.47	5.14	0.065	1.25	2.02	0.89	3.19	2.45	82	76	44	27	195	155	286	25	265	12	1590	33	85	18	16	4.05
BV0200	MD776	66.33	0.732	15.00	5.51	0.145	1.37	3.90	0.70	2.90	3.41	96	79	39	18	198	159	550	19	231	11	1969	34	73	14	17	5.13
BV0201	MD777	62.36	0.805	17.60	6.38	0.082	2.33	5.43	0.87	3.78	0.36	116	98	53	19	91	168	278	26	211	16	622	29	78	22	20	0.91
BV0202	MD778	67.75	0.772	16.11	9.10	0.349	1.05	1.53	0.55	2.21	0.57	119	102	32	26	108	122	157	43	280	14	887	38	83	23	25	1.19
BV0203	MD779	72.04	0.720	14.41	5.28	0.068	1.37	1.59	0.87	3.26	0.39	89	77	39	15	77	150	128	29	251	15	570	28	82	20	23	0.83
BV0204	MD780	72.05	0.696	14.40	5.20	0.068	1.44	1.69	0.84	3.38	0.25	89	76	40	11	76	152	112	28	252	13	553	34	75	20	27	0.72
BV0206	MD782	66.47	0.772	17.29	6.48	0.141	1.48	0.98	1.38	3.81	1.20	106	84	42	42	94	160	130	30	275	15	702	48	104	27	26	4.20
BV0207	MD783	70.33	0.744	15.83	5.89	0.049	1.25	0.81	0.88	3.40	0.82	116	82	37	21	73	133	147	18	252	15	604	37	84	21	23	5.10
BV0208	MD784	67.53	0.863	16.80	5.73	0.042	1.73	1.94	0.75	2.95	1.68	121	118	52	38	182	145	173	19	252	23	1199	33	80	18	22	5.59
BV0209	MD785	71.88	0.621	13.70	4.24	0.049	0.82	1.67	1.27	3.01	2.73	73	70	30	11	53	129	283	16	285	14	1548	38	74	19	16	3.78
BV0210	MD786	61.17	1.800	17.68	9.25	0.105	2.68	2.18	1.36	2.77	1.01	163	94	50	34	119	101	258	40	310	17	653	51	96	20	19	3.70
BV0211	MD787	61.22	2.027	17.16	9.58	0.108	2.60	2.18	1.37	2.72	1.03	156	90	56	32	116	91	246	34	322	17	638	52	91	21	18	3.80
BV0212	MD788	63.55	0.890	18.68	6.72	0.062	2.30	2.32	1.20	3.43	0.85	145	110	75	41	106	138	240	23	226	25	683	45	99	19	22	5.46
BV0213	MD789	66.50	0.842	16.98	6.98	0.075	1.91	1.46	0.86	3.75	0.65	122	109	52	20	93	159	154	32	266	17	673	48	91	24	22	1.54
BV0214	MD790	67.63	0.806	15.78	5.43	0.055	1.23	1.50	1.09	3.49	2.99	88	86	40	14	104	135	141	26	297	19	1620	37	91	21	26	2.59
BV0215	MD791	69.69	0.747	15.15	5.94	0.081	1.26	1.70	1.10	2.67	1.67	98	91	34	22	134	125	287	26	295	15	1332	35	69	18	19	2.40

Tab. 6 (Contin.) Project Lossow (chapter 4.6).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
BV0360	AD129	72.48	0.684	15.00	5.64	0.054	1.10	0.63	0.73	3.09	0.60	94	83	41	24	57	129	103	15	241	14	528	10	66	19	17	4.49
BV0367	AD130	68.86	0.645	16.39	5.81	0.125	1.01	1.07	1.35	3.06	1.67	80	75	34	19	59	116	197	25	223	13	737	38	63	22	22	5.20
BV0368	AD131	68.61	0.809	16.61	7.19	0.049	1.30	1.21	0.97	2.56	0.69	111	94	26	17	62	125	152	9	297	14	575	16	38	15	22	4.56
BV0370	AD132	69.93	0.809	16.16	6.41	0.042	1.00	0.76	0.82	3.13	0.94	86	88	34	13	72	125	150	17	321	15	656	31	54	20	22	3.58
BV0373	AD133	68.24	1.008	15.72	7.62	0.049	0.92	0.74	0.86	3.32	1.52	93	89	30	18	46	105	113	23	332	18	541	24	66	19	20	4.86
BV0382	AD134	67.81	0.820	18.19	6.69	0.023	1.40	0.80	0.92	3.22	0.13	109	97	42	19	69	151	128	10	245	17	690	9	27	22	25	4.54
BV0418	AD135	71.77	0.848	13.93	6.69	0.091	1.22	0.77	0.75	3.36	0.58	75	63	29	14	50	119	111	17	259	13	517	20	53	15	20	4.83
BV0420	AD136	70.03	0.782	16.67	5.93	0.070	1.28	0.80	0.83	3.00	0.62	100	88	42	21	64	136	135	22	259	17	640	45	94	24	28	5.58
BV0439	AD137	68.09	0.855	17.18	6.09	0.035	0.97	0.60	1.08	3.48	1.64	114	114	45	12	78	186	122	27	258	28	423	36	110	25	31	4.58
BV0446	AD138	61.96	0.603	12.27	4.43	0.078	1.62	13.83	0.83	2.66	1.73	70	63	27	17	115	131	357	18	213	11	1146	37	52	13	13	11.43
BV0447	AD139	64.38	0.568	12.15	4.24	0.078	1.38	11.95	1.01	2.59	1.65	62	56	27	12	103	128	351	20	217	9	1042	25	62	14	10	10.05
BV0450	AD140	65.53	0.721	14.84	5.48	0.077	1.75	5.80	0.99	3.21	1.60	75	68	34	9	108	123	241	24	234	13	1317	32	64	20	19	2.58
BV0451	AD141	67.65	0.746	16.86	5.34	0.057	1.32	1.89	0.74	3.69	1.71	98	90	42	14	89	173	257	22	230	15	1068	24	79	25	18	3.61
BV0452	AD142	69.61	0.759	15.27	5.54	0.041	1.41	2.32	0.69	3.38	0.99	103	95	42	9	97	161	180	19	209	16	1461	36	71	18	18	3.78
BV0454	AD143	71.45	0.819	12.73	5.32	0.043	1.09	2.51	1.02	3.43	1.59	57	56	23	9	65	124	232	22	325	14	930	12	60	19	13	3.73
BV0455	AD144	63.79	0.820	15.76	6.10	0.077	1.86	6.52	0.78	3.92	0.36	90	86	42	18	82	152	187	28	245	16	668	39	100	15	20	0.84
BV0457	AD145	61.77	0.961	19.68	6.87	0.034	2.10	1.05	0.86	3.01	3.66	142	196	97	84	969	146	179	28	214	21	954	40	92	23	19	7.31
BV0458	AD146	69.00	0.754	14.95	5.80	0.072	1.55	2.00	0.83	3.63	1.40	83	69	34	67	130	133	140	30	250	15	836	40	69	18	22	1.56
BV0460	AD147	73.20	0.732	13.70	5.39	0.041	0.93	0.72	1.01	2.72	1.55	84	97	46	43	124	106	102	25	277	20	405	41	70	16	15	5.00
BV0462	AD148	73.58	0.646	13.49	5.27	0.021	0.81	0.74	0.70	2.64	2.10	70	82	43	35	151	122	92	20	267	12	833	24	52	20	18	4.23
BV0464	AD149	65.02	0.929	17.91	7.10	0.117	1.90	0.90	0.75	3.77	1.59	105	108	60	50	224	159	118	27	265	21	872	25	88	20	24	4.76
BV0467	AD150	63.77	0.992	18.71	7.34	0.066	1.58	1.66	0.96	3.46	1.46	108	107	46	34	134	122	173	29	297	18	886	41	82	24	23	6.69
BV0470	AD384	69.20	0.698	16.08	5.66	0.091	1.37	1.34	0.94	3.73	0.88	99	80	47	21	206	175	171	29	211	19	1116	35	69	24	8	4.42
BV0476	AD385	72.75	0.759	16.35	2.39	0.026	0.29	1.30	0.97	2.47	2.68	71	64	16	<5	92	92	226	32	285	20	1598	44	78	29	8	3.97
BV0484	AD386	62.13	0.989	19.50	6.42	0.096	1.16	1.97	0.91	2.92	3.90	121	112	50	34	103	112	291	42	247	21	1568	40	84	22	9	4.13
BV0486	AD387	80.13	0.529	8.78	4.68	0.064	0.39	0.77	0.38	1.69	2.58	36	55	20	<5	62	55	133	16	285	15	1123	9	26	14	<5	2.94
BV0498	AD388	70.42	0.716	14.84	5.46	0.073	1.27	1.54	0.80	2.76	2.12	104	89	47	15	153	109	249	29	224	16	1159	33	83	21	<5	3.78
BV0519	AD700	78.10	0.487	8.98	2.90	0.072	0.99	4.79	0.48	2.57	0.64	56	51	25	<5	78	99	176	18	178	14	685	25	18	13	<5	2.41
BV0520	AD701	78.66	0.438	8.14	2.79	0.053	1.15	5.72	0.52	2.25	0.29	49	45	21	<5	47	87	161	23	172	10	410	18	59	12	<5	3.44
BV0521	AD702	78.01	0.469	8.81	2.88	0.041	1.10	5.35	0.43	2.31	0.60	55	54	26	9	108	122	176	21	159	11	631	8	46	10	<5	5.33
BV0522	AD703	78.87	0.458	8.53	2.84	0.033	1.03	4.76	0.50	2.28	0.70	52	48	25	11	117	126	171	19	160	12	654	14	39	10	<5	4.73
BV0523	AD704	72.99	0.639	12.72	4.85	0.131	1.25	2.33	0.67	2.91	1.52	77	75	45	16	176	169	249	32	249	14	1051	40	73	21	<5	3.16
BV0524	AD705	78.52	0.426	7.83	2.52	0.051	0.91	6.56	0.44	2.12	0.62	47	40	22	<5	68	100	191	19	166	12	491	15	45	11	<5	5.62
BV0525	AD706	77.74	0.440	9.00	2.85	0.063	1.05	4.88	0.56	2.69	0.73	57	48	27	<5	83	117	205	18	150	14	635	30	25	18	<5	4.03
BV0526	AD707	77.95	0.517	11.04	3.86	0.051	0.93	1.95	0.39	2.52	0.80	79	56	31	9	75	122	162	19	131	13	567	13	49	18	5	2.60
BV0527	AD708	74.85	0.499	10.84	3.92	0.049	1.15	4.59	0.47	2.59	1.05	66	63	35	17	84	142	178	22	191	13	623	32	53	17	<5	4.82
BV0528	AD709	74.92	0.595	12.54	4.07	0.049	1.37	1.97	0.78	3.20	0.51	87	65	32	5	64	161	152	21	165	15	622	18	49	20	6	2.11
BV0529	AD710	74.50	0.508	11.00	3.88	0.060	1.19	4.69	0.54	2.68	0.94	66	64	37	11	87	137	176	22	181	13	610	24	52	17	<5	4.90
BV0530	AD711	78.55	0.425	8.76	3.06	0.043	0.95	5.03	0.49	2.17	0.52	55	47	25	<5	48	93	164	20	135	13	458	25	29	10	<5	3.85
BV0531	AD712	77.56	0.437	8.87	3.16	0.062	1.07	5.67	0.63	2.22	0.32	51	48	25	<5	70	90	155	21	151	12	459	14	37	13	<5	3.09
Rathsdorf	AD834	68.29	0.689	16.37	5.71	0.075	1.30	0.84	1.50	3.50	1.73	88	81	40	25	74	143	114	39	237	16	750	37	68	26	8	5.55
Rathsdorf	AD836	71.53	0.666	15.41	6.27	0.063	0.56	1.07	1.05	2.81	0.58	91	81	31	24	85	112	107	40	232	17	594	41	71	30	8	5.41
Rathsdorf	AD839	67.00	0.725	17.34	6.27	0.041	1.06	1.12	1.17	3.32	1.94	111	97	41	13	66	138	146	25	212	19	555	25	50	22	10	4.51
Rathsdorf	AD833	69.13	0.785	15.46	6.43	0.059	1.23	1.08	1.16	3.41	1.25	106	86	44	42	71	129	151	32	262	17	659	26	65	25	10	4.10
Rathsdorf	AD837	71.72	0.684	14.09	7.12	0.071	0.72	0.99	1.12	2.56	0.92	89	82	31	15	67	123	97	35	300	17	537	30	73	25	10	5.09
Rathsdorf	AD838	69.23	0.813	16.21	6.91	0.080	1.06	1.11	1.11	2.76	0.73	110	107	36	19	70	123	178	41	324	20	669	44	94	27	11	6.42
Rathsdorf	AD835	67.75	0.813	17.37	7.50	0.095	1.01	1.13	0.82	2.51	1.01	122	103	41	41	97	148	132	34	250	20	674	35	86	28	15	6.24
Raw materials																											
1	MD633	78.16	0.476	7.33	2.55	0.033	0.94	7.84	0.64	1.94	0.09	45	36	16	<5	174	70	189	13	286	9	378	17	61	11	8	7.17
2a	MD634	84.58	0.428	7.14	2.47	0.048	0.73	1.88	0.51	2.09	0.12	37	37	18	<5	45	74	78	12	261	8	347	16	38	12	11	3.22
3	MD635	85.49	0.597	8.28	2.71	0.038	0.44	0.30	0.34	1.74	0.07	44	45	19	<5	50	78	58	15	281	11	363	6	42	16	9	2.99
4	MD636	79.13	0.871	12.78	2.69	0.019	0.80	0.54	0.54	2.51	0.14	78	74	25	9	49	125	91	21	329	17	430	29	41	19	16	3.57
5	MD637	82.74	0.607	9.07	4.11	0.019	0.48	0.39	0.44	2.00	0.15	52	55	18	5	30	97	74	13	318	12	391	28	30	16	7	2.88
6	MD638	83.52	0.569	8.93	3.27	0.042	0.67	0.54	0.35	1.98	0.13	52	64	18	<5	37	79	70	16	264	8	321	23	35	12	9	2.73
7	MD639	82.60	0.452	8.03	5.00	0.123	0.46	1.11	0.43	1.49	0.30	47	39	18	11	86	65	78	16	248	7	439	10	40	24	14	5.79
8	MD640	82.10	0.475	8.74	4.74	0.162	0.53	0.89	0.45	1.65	0.27	67	50	17	6	60	72	74	19	213	8	414	<5	52	21	14	5.63
8a	MD641	83.19	0.438	8.33	3.76	0.138	0.53	1.27	0.47	1.62	0.26	98	69	17	6	70	70	80	16	194	10	447	13	34	25	11	7.19
10	MD642	86.30	0.503	7.96	1.84	0.017	0.45	0.63	0.60	1.65	0.06	39	45	15	<5	36	67	67	20	361	8	364	13	49	14	8	3.65
-	MD643	72.25	0.391	5.46	1.91	0.029	0.63	17.59	0.26	1.38	0.09	33	33	18	<5	72	49	113	13	255	7	271	1	22	8	9	13.38
-	MD644	85.78	0.503	7.45	2.75	0.034	0.66	0.50	0.37	1.87	0.09	44	39	17	<5	36	65	57	14	266	10	277	14	41	13	9	1.91

Tab. 6 (Contin.) Project Lossow (chapter 4.6).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	N_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
Br17	AD349	61.87	1.065	21.84	8.48	0.062	2.13	0.30	0.21	3.14	0.91	162	143	72	26	271	162	52	25	192	24	588	20	63	29	16	7.98
Br18	AD350	58.60	1.139	23.51	8.82	0.057	2.27	0.44	0.20	3.43	1.53	180	161	77	24	178	173	58	29	202	23	613	41	83	28	16	9.30
Br19	AD351	58.45	1.031	22.56	8.26	0.374	1.98	2.75	0.19	3.47	0.94	160	150	70	28	229	175	123	37	181	21	723	49	87	28	16	5.03
Br20	AD352	68.01	1.195	23.80	2.69	0.006	0.90	0.23	0.05	2.44	0.67	160	126	40	6	174	169	84	28	185	26	556	33	81	37	12	3.35
Br21	AD353	62.74	1.108	20.83	7.92	0.045	2.06	0.36	0.29	3.24	1.41	169	142	65	26	166	156	67	26	202	25	592	25	81	26	15	7.45
Br24	AD354	63.12	1.053	20.76	7.92	0.105	1.83	0.83	0.22	3.12	1.04	165	143	70	27	136	158	95	33	187	21	912	49	84	24	15	8.73
Br27	AD355	59.94	1.032	22.31	8.35	0.039	2.53	0.99	0.21	3.43	1.16	163	150	72	26	229	169	86	24	173	22	564	21	60	23	12	7.41
Br29-1	AD356	58.86	1.085	23.75	8.69	0.054	2.07	0.45	0.18	3.38	1.48	157	155	78	31	313	167	64	29	188	23	601	36	88	27	14	8.17
Br33-1	AD357	64.57	1.067	18.83	8.28	0.063	1.75	0.43	0.27	3.16	1.57	155	134	66	24	173	142	64	28	226	26	566	34	66	27	13	5.93
Br33-2	AD358	61.40	1.019	21.35	8.15	0.047	1.85	1.57	0.18	3.34	1.10	165	153	71	20	194	167	111	28	175	22	631	40	73	27	16	6.12
Br33-3	AD359	60.12	1.150	21.48	8.95	0.042	1.82	0.82	0.16	3.48	1.98	182	165	75	26	168	167	94	31	200	25	603	38	87	28	15	7.49
Br33-4	AD360	62.24	1.097	21.41	7.84	0.048	2.06	0.38	0.27	3.26	1.40	159	143	71	22	169	162	65	31	199	23	566	39	77	27	13	7.04
J74345.	AD361	65.95	0.716	17.45	6.09	0.049	1.83	3.44	0.74	3.54	0.20	128	103	48	18	84	171	108	29	187	18	564	26	76	33	10	2.88
J74385	AD362	57.48	0.919	20.59	7.58	0.070	2.72	6.82	0.24	3.40	0.17	169	137	60	24	114	172	159	35	165	19	449	36	79	27	8	2.13
J75208	AD363	71.70	0.743	15.78	5.20	0.058	1.33	1.05	0.78	3.23	0.13	100	80	56	17	61	133	95	44	231	16	491	40	79	15	5	1.77
J79244/J86093	AD364	57.67	0.966	20.70	7.47	0.079	2.48	6.99	0.25	3.24	0.16	156	137	63	26	97	167	125	33	174	20	469	32	89	20	12	3.42
J77006	AD365	63.82	0.873	16.65	6.04	0.068	2.31	6.87	0.41	2.78	0.19	136	104	53	19	72	115	128	32	226	19	445	44	74	6	13	3.43
J77048	AD366	66.49	1.007	18.97	6.93	0.086	1.67	1.07	0.29	3.34	0.14	137	120	61	15	92	155	81	37	210	21	480	51	86	24	14	1.66
J78776	AD367	64.87	0.968	21.07	7.57	0.062	1.86	0.25	0.19	3.02	0.14	150	136	73	31	134	147	46	22	178	23	543	32	67	19	12	6.99
J78848	AD368	57.65	0.893	20.15	7.43	0.071	2.71	7.38	0.25	3.30	0.17	168	131	54	27	104	171	165	30	161	19	458	33	91	23	10	1.33
J78565	AD369	73.15	0.981	16.15	4.55	0.022	1.55	0.44	0.25	2.77	0.14	140	132	75	28	102	137	60	38	269	20	410	29	79	37	15	1.47
J77135 3	AD370	65.86	0.911	17.29	6.21	0.085	1.78	3.87	0.50	3.32	0.17	131	106	53	15	87	147	121	35	210	21	502	41	73	24	11	0.66
J78596	AD371	59.14	1.153	24.87	8.96	0.053	1.75	0.33	0.18	3.35	0.21	160	155	78	36	162	159	54	29	209	28	580	29	86	29	16	9.24
J75631	AD372	66.56	1.001	18.76	6.97	0.087	1.67	1.12	0.30	3.36	0.17	141	117	59	20	93	158	85	37	214	23	494	49	92	22	12	1.17
J75835	AD373	64.37	0.891	16.62	6.12	0.069	2.28	5.84	0.46	3.15	0.21	117	110	53	17	78	139	121	33	229	22	434	28	80	13	11	3.38
J75835	AD374	63.79	0.843	15.66	5.77	0.071	2.27	7.87	0.49	3.07	0.17	107	99	47	16	80	137	157	33	214	18	433	44	81	12	7	1.47
J73711	AD375	71.83	1.546	19.00	4.44	0.021	0.63	0.47	0.13	1.80	0.15	142	106	36	5	57	130	90	37	360	36	495	44	100	42	9	0.98
J73553	AD376	59.78	1.045	21.65	7.88	0.087	2.11	3.55	0.25	3.01	0.65	150	140	66	474	114	142	116	35	179	23	660	38	87	26	12	5.92
Sw 4-6	AD598	68.35	1.066	18.91	7.04	0.023	0.95	0.54	0.25	2.59	0.28	138	122	54	20	83	123	68	36	297	24	505	38	76	26	11	4.93
Bk 10	AD599	61.71	0.956	20.94	7.83	0.058	2.25	1.36	0.22	3.44	1.23	151	140	74	31	211	156	133	33	190	20	1304	34	77	28	10	6.24
Bd 1-4	AD600	62.10	0.835	15.52	5.96	0.074	2.33	9.25	0.47	2.94	0.50	123	105	51	31	82	139	142	32	227	19	478	18	73	16	7	0.77
Bd 6-1	AD601	64.93	0.906	16.77	6.34	0.095	2.28	4.51	0.40	3.22	0.54	112	115	59	52	90	151	119	36	245	21	487	36	79	24	11	2.20
Bd11-1	AD602	64.90	0.941	16.84	6.59	0.101	2.33	3.95	0.37	3.21	0.77	129	122	61	43	94	155	108	36	257	21	515	35	76	17	13	3.14
Bd 22	AD603	68.91	0.923	16.09	6.43	0.116	1.67	0.60	0.40	4.07	0.77	96	105	53	46	88	145	80	41	266	20	584	40	79	24	6	2.25
Gz 58	AD604	61.08	0.959	19.38	9.41	0.088	2.30	0.95	0.38	3.40	2.06	153	134	79	29	166	136	121	34	224	20	1026	45	74	29	13	6.85
Ew 1-3	AD605	65.11	1.091	20.08	7.38	0.027	0.80	0.28	0.23	2.52	2.49	123	122	52	19	109	116	93	34	296	26	933	44	66	38	12	6.31
Ew 3-1	AD606	66.12	1.113	20.19	7.42	0.031	0.90	0.22	0.23	2.46	1.32	131	123	56	27	126	114	59	34	303	24	577	31	58	28	14	7.43
Gb 1	AD607	65.29	0.978	19.19	7.55	0.031	2.07	0.62	0.30	3.11	0.85	146	129	88	33	126	151	100	28	233	25	689	46	68	26	9	5.98
Gb 4	AD608	61.43	1.123	27.11	4.34	0.024	0.80	0.88	1.14	2.17	0.97	169	134	42	25	96	111	520	26	222	37	1088	52	110	60	12	7.71
Lieb003-1	AD677	69.18	1.038	18.15	6.84	0.019	1.18	0.31	0.21	2.58	0.50	128	115	43	14	83	134	90	33	280	25	792	50	61	26	5	0.89
Lieb005	AD678	69.26	1.038	18.00	6.71	0.024	1.18	0.37	0.30	2.71	0.40	127	117	41	21	85	138	88	29	281	23	879	35	54	23	11	0.79
Lieb009	AD679	58.80	3.800	29.42	3.50	0.019	0.59	0.63	0.15	2.59	0.48	241	113	29	31	71	164	157	41	493	125	971	86	122	58	15	1.49
Gh001	AD680	70.19	1.123	17.69	5.83	0.026	0.83	0.50	0.68	2.25	0.86	126	154	49	37	84	109	81	52	358	24	510	60	105	28	10	6.45
Zwt001	AD681	68.14	0.851	15.08	8.06	0.012	0.87	1.47	0.67	2.24	2.60	110	94	43	19	88	85	297	33	302	22	1273	39	69	26	9	4.44
Zwt008	AD682	73.82	0.842	14.35	6.49	0.039	1.00	0.58	0.65	2.12	0.11	97	89	41	9	65	114	117	32	284	21	529	43	70	20	10	0.64
Zwt009	AD683	70.46	0.906	15.64	7.22	0.045	1.04	0.98	0.69	2.44	0.58	112	98	46	18	70	106	158	36	297	22	731	45	54	23	12	1.63
Ngd001	AD684	69.79	0.990	17.33	6.36	0.019	0.87	0.43	0.24	2.38	1.59	117	115	38	12	75	115	100	24	275	23	806	33	56	30	12	3.22
Ngd002	AD685	67.62	1.083	19.21	6.73	0.058	1.16	0.32	0.23	2.47	1.12	139	120	47	21	128	137	76	25	274	24	692	34	64	29	9	7.14
Leu001	AD686	59.36	3.224	28.83	4.26	0.009	0.41	0.53	0.36	2.03	0.97	230	105	32	84	142	134	71	34	446	109	759	92	130	50	14	8.62
zeu 1-1	AD687	69.64	0.982	16.27	6.09	0.064	1.47	0.64	0.48	3.53	0.84	94	108	49	19	101	124	83	39	267	23	625	52	72	26	10	1.88
zeu 1-6	AD688	66.38	0.943	16.96	6.48	0.079	1.69	1.94	0.47	3.34	1.711	109	111	53	23	101	120	97	43	257	22	699	51	94	24	10	4.76
zeu 1-7	AD689	64.87	1.021	19.22	7.46	0.076	1.63	0.64	0.42	3.57	1.10	130	123	70	25	146	137	71	48	238	22	860	58	98	25	10	5.66
zeu 1-17	AD690	64.32	1.002	18.57	7.30	0.096	1.85	1.30	0.37	3.87	1.32	124	119	66	26	111	139	87	47	230	20	649	53	109	23	12	3.26
zeu 2-1	AD691	64.14	0.927	16.33	6.09	0.083	2.55	4.91	0.54	3.54	0.90	113	107	56	21	101	134	124	45	226	21	625	43	87	19	7	1.52
gz 81-1	AD692	62.87	0.965	19.94	8.01	0.065	2.41	0.67	0.35	3.33	1.399	146	133	80	17	244	144	123	36	200	21	808	50	88	25	11	5.78
gz 93	AD693	65.07	1.112	18.29	6.98	0.069	1.11	0.94	0.26	2.97	3.197	111	120	62	15	94	108	162	45	249	23	1172	43	93	22	10	5.38
gz 96	AD694	67.31	1.451	20.90	6.61	0.015	0.30	0.43	0.06	1.68	1.241	171	129	36	15	57	81	84	38	357	36	659	42	97	32	12	7.74
gz 103	AD695	67.66	1.325	19.81	4.70	0.042	0.69	0.63	0.06	2.11	2.981	137	116	37	6	92	114	139	35	323	31	952	48	81	28	10	5.30
wk 9	AD696	65.48	0.821	17.22	8.72	0.020	1.09	2.50	0.48	1.53	2.129	132	120	49	20	134	92	289	43	224	17	1869	44	85	28	11	5.77
wk 10	AD697	58.66	0.919	16.65	6.08	0.067	1.97	11.06	0.33	2.75	1.51	113	105	54	16	161	138	303	33	182	22	1374	34	58	20	8	11.33

Tab. 7 Project Brandenburg-Sachsen (chapter 4.7).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	N_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
ph 1	AD698	65.03	1.053	18.53	4.40	0.056	1.30	2.21	0.51	3.06	3.848	106	113	48	21	104	105	182	43	264	25	952	49	90	25	13	7.84
hg 1-1	AD699	60.02	0.983	22.24	8.27	0.108	2.25	1.17	0.19	3.34	1.438	159	152	86	33	298	144	178	34	172	21	1856	48	74	26	10	6.43
Glie003	AD721	63.48	0.861	18.27	7.47	0.072	1.84	2.59	0.33	3.24	1.85	132	120	57	19	109	135	218	38	211	17	696	43	79	25	5	5.08
Glie007	AD722	75.18	0.655	13.30	5.24	0.033	1.11	0.43	0.32	2.35	1.38	88	87	36	10	105	93	80	20	275	17	915	19	55	24	3	3.89
Bd24-2	AD723	71.39	0.767	16.02	6.34	0.041	1.45	0.47	0.27	2.93	0.33	109	109	47	19	79	144	61	24	274	19	455	20	61	19	11	0.90
Sp4-1	AD724	62.24	1.084	20.33	7.67	0.122	1.60	0.47	0.26	3.26	2.96	139	134	79	23	163	133	94	37	221	22	1248	42	82	29	12	5.61
Gz82-5	AD725	68.87	0.896	16.44	6.05	0.054	1.60	0.92	0.42	2.82	1.93	108	105	59	14	229	113	124	33	254	21	920	41	83	20	5	4.76
Sw6-1	AD726	70.51	0.949	17.22	6.00	0.026	1.03	0.59	0.27	2.41	1.01	127	108	54	19	125	113	84	30	340	22	548	38	72	25	7	4.88
Bw4-1	AD727	68.06	0.896	16.66	6.93	0.043	1.31	0.92	0.37	2.86	1.95	120	112	46	22	115	109	120	31	291	20	1175	31	65	23	8	5.06
Btz001-1	AD728	56.97	3.050	32.23	5.52	0.020	0.29	0.36	0.02	1.08	0.46	209	182	84	335	153	58	191	39	590	148	474	143	213	147	14	1.21
Btz002-1	AD729	72.45	1.156	17.37	5.23	0.020	0.71	0.41	0.14	2.01	0.50	127	106	34	475	66	111	71	39	346	27	462	50	101	35	11	1.16
Btz003-1	AD730	68.83	1.313	23.61	2.55	0.008	0.87	0.15	0.06	2.40	0.21	153	130	34	62	90	166	72	30	252	27	475	37	69	34	14	1.34
Btz004-1	AD731	71.21	1.668	19.27	5.24	0.117	0.37	0.45	0.04	1.40	0.24	109	99	26	17	49	89	34	53	362	33	471	62	87	27	13	1.17
Btz006-1	AD732	68.38	1.004	16.74	9.30	0.039	1.07	0.63	0.51	2.00	0.33	128	115	43	49	69	102	114	38	329	24	625	46	93	28	10	0.34
Btz008-1	AD733	77.09	1.479	15.15	4.05	0.083	0.31	0.27	0.00	0.99	0.56	88	79	23	310	39	59	26	51	361	28	366	53	104	139	9	1.38
Btz008-3	AD734	67.35	1.304	23.54	2.50	0.008	0.70	0.14	0.05	2.35	2.07	145	136	32	402	93	152	61	29	245	27	813	43	70	48	11	3.37
Btz009	AD735	65.89	1.248	19.29	6.39	0.065	1.39	2.20	0.27	2.82	0.45	147	124	60	33	94	126	116	43	312	40	537	65	105	31	11	1.33
Btz010-1	AD736	68.29	0.998	16.78	9.20	0.035	1.06	0.61	0.55	1.99	0.50	123	111	40	56	66	105	113	35	331	27	667	53	83	31	10	1.10
Btz012-2	AD738	79.96	1.544	12.83	3.35	0.029	0.26	0.13	0.05	1.48	0.37	77	69	20	29	33	80	18	48	377	27	281	43	73	27	10	1.11
Btz012-4	AD739	77.32	1.473	15.14	4.05	0.096	0.29	0.27	0.02	0.95	0.39	88	78	24	112	36	59	26	56	363	31	353	41	113	19	10	1.19
Btz013-3	AD740	73.39	0.862	13.84	5.67	0.027	2.03	0.62	0.38	2.63	0.55	105	100	40	77	293	110	72	12	356	21	496	24	51	428	6	1.94
Btz014-1	AD741	68.22	1.086	19.27	7.02	0.020	1.22	0.35	0.16	2.30	0.35	136	125	41	88	79	127	69	26	283	23	462	21	59	24	12	1.34
Btz016-2	AD742	75.77	1.444	16.18	4.52	0.081	0.30	0.25	0.02	1.22	0.22	95	84	24	55	38	67	26	42	336	28	390	54	71	23	13	0.90
Burk001	AD743	69.46	0.987	22.95	2.95	0.018	0.58	0.35	0.15	1.79	0.77	101	95	35	115	61	101	62	52	254	27	336	58	114	33	13	2.13
Liebon001	AD744	60.35	0.975	18.80	6.96	0.070	2.23	6.18	0.32	3.05	1.07	135	127	63	63	96	140	142	40	190	21	630	38	78	25	9	1.80
Liebon002	AD745	60.26	0.942	18.17	6.68	0.076	2.30	7.82	0.32	3.04	0.39	133	119	59	35	99	140	155	38	185	20	568	52	71	21	3	0.32
D-K001	AD746	66.75	1.022	17.86	6.85	0.030	1.11	0.69	0.25	2.50	2.95	126	115	50	36	348	130	199	36	257	23	1649	29	82	28	11	5.85
Gby001	AD747	55.43	3.255	30.79	4.54	0.018	0.53	0.63	0.15	2.29	2.37	258	110	42	76	173	169	144	46	420	112	1107	108	190	56	15	7.82
Gbg001	AD748	67.51	1.075	19.01	6.66	0.020	1.01	0.28	0.25	2.39	1.80	129	118	47	30	115	115	93	30	270	25	979	38	60	27	15	6.62
Gw001-1	AD749	63.30	3.403	26.02	2.99	0.017	0.51	0.67	0.23	2.32	0.54	190	92	22	38	68	135	120	46	592	114	963	62	94	45	13	2.08
FR-S001	AD750	58.07	3.641	31.70	3.42	0.010	0.45	0.20	0.16	1.70	0.66	274	111	37	85	69	137	82	26	486	123	495	67	102	71	17	12.56
Oel001	AD751	62.71	3.452	26.05	2.88	0.015	0.44	0.36	0.14	2.31	1.64	197	92	27	39	108	129	101	48	589	118	898	67	96	49	8	7.84
Oel002-1	AD752	68.72	1.044	18.42	6.66	0.018	1.22	0.43	0.28	2.75	0.46	139	122	37	23	75	138	83	33	274	23	536	41	73	26	9	0.94
Oel002-3	AD753	68.73	1.077	18.57	6.76	0.016	1.23	0.36	0.17	2.66	0.42	122	118	39	22	79	131	77	28	277	24	515	40	46	25	10	1.24
Oel002-7	AD754	55.98	3.187	32.03	4.55	0.014	0.51	0.46	0.14	2.26	0.85	248	110	35	71	178	155	124	35	399	110	795	96	148	60	17	6.37
Leu002	AD755	52.83	3.310	33.08	4.33	0.015	0.51	0.50	0.13	2.02	3.29	246	110	51	48	320	156	126	32	367	109	1198	55	106	56	13	9.22
Leu003	AD756	64.22	1.087	19.27	6.97	0.038	1.67	0.99	0.34	3.04	2.39	133	127	76	30	174	136	98	41	228	23	1194	57	67	26	9	5.58
Leu005	AD757	68.84	0.998	17.77	6.04	0.013	1.08	0.86	0.25	2.19	1.95	119	115	45	16	177	123	95	28	275	24	881	36	50	24	4	5.94
Str001	AD758	65.24	1.107	19.97	7.56	0.025	0.90	0.27	0.27	2.50	2.16	137	127	77	30	152	120	65	43	272	24	918	47	75	29	8	5.63
Str002-2	AD759	60.47	1.491	24.19	7.33	0.048	0.49	2.05	0.09	2.11	1.74	140	119	30	3	70	104	207	49	292	31	1295	57	70	24	6	6.61
Zeit001	AD760	70.53	1.034	15.27	6.21	0.017	1.04	0.79	0.46	2.65	2.01	109	106	51	17	173	106	192	37	355	23	1750	33	62	23	7	4.19
Zeit004-1	AD761	66.49	1.092	20.05	6.82	0.033	1.31	0.63	0.13	2.64	0.81	137	123	64	268	147	142	108	50	247	22	927	61	103	42	9	2.21
Zeit004-2	AD762	68.86	0.970	16.78	5.78	0.055	1.08	1.93	0.33	2.58	1.62	107	108	44	22	105	119	244	29	256	22	1327	21	79	22	9	3.36
Gh00x	AD763	67.35	1.208	19.18	7.43	0.024	1.33	0.43	0.22	2.48	0.35	133	123	53	63	104	102	53	24	194	23	697	-9	40	25		1.18
Lieb011	AD764	71.35	1.015	16.74	4.68	0.025	1.38	0.67	0.59	2.77	0.77	107	112	45	15	122	134	151	39	308	24	829	38	78	28	8	1.41
Lieb014-2	AD765	69.19	1.043	18.60	6.23	0.022	1.36	0.38	0.22	2.68	0.27	124	123	45	32	93	143	90	35	271	22	546	41	86	27	11	0.95
Lieb014-7	AD766	67.95	1.089	17.96	6.41	0.036	1.46	0.62	0.38	3.35	0.74	133	117	40	233	94	136	97	38	278	23	869	39	81	26	10	1.45
Lieb016	AD767	58.78	3.425	29.71	4.37	0.016	0.68	0.43	0.07	2.16	0.35	248	112	28	91	108	158	127	38	476	114	539	76	145	51	15	1.66
Lieb018-2	AD768	55.53	3.556	31.76	4.81	0.008	0.38	0.26	0.10	2.19	1.41	218	113	40	108	527	180	108	42	414	120	1146	105	168	57	16	8.66
Lieb019	AD769	63.46	1.001	16.92	6.30	0.079	1.69	5.16	0.42	3.17	1.80	127	110	53	27	233	141	186	39	272	23	1179	47	70	23	7	1.63
Lieb021-1	AD770	71.04	1.032	16.04	6.52	0.024	1.25	0.49	0.38	3.00	0.22	118	108	40	11	89	124	78	32	320	24	498	41	56	26	11	0.62
Zwt010	AD771	69.57	0.922	16.15	8.99	0.037	1.00	0.68	0.55	1.92	0.18	119	102	42	7	60	101	125	36	303	24	599	53	90	25	9	0.22
Zwt013	AD772	68.40	0.966	16.59	8.14	0.048	1.00	0.84	0.58	2.28	1.16	128	108	45	16	81	115	170	38	304	24	975	35	84	26	7	1.10
Zwt016	AD773	70.09	0.918	16.14	7.98	0.043	1.12	0.84	0.54	2.12	0.22	113	98	46	17	70	111	142	37	284	22	604	33	72	25	11	0.77
Zwt018	AD774	69.47	0.926	15.96	9.29	0.031	1.02	0.64	0.55	1.99	0.13	122	99	46	15	63	109	123	36	300	23	588	43	78	25	9	-0.15
Zwt021	AD775	67.05	0.924	15.86	8.90	0.033	0.91	1.12	0.61	2.28	2.30	114	101	42	11	71	97	225	33	300	23	1153	40	77	26	10	2.41
Zwt024	AD776	70.42	0.826	14.41	6.86	0.051	0.87	1.28	0.63	2.49	2.16	97	85	46	10	74	106	251	31	284	20	1246	24	73	25	9	2.96
Zwt036	AD777	63.10	0.968	19.70	8.57	0.026	1.09	1.53	0.48	2.45	2.09	142	120	56	22	80	93	259	43	221	24	1199	55	76	28	7	3.99
Zwt058	AD778	63.59	0.969	19.65	9.78	0.035	1.09	1.09	0.47	1.96	1.36	139	121	54	20	80	101	212	41	236	26	1012	35	93	31	8	1.51
Zwt059	AD779	70.53	0.906	15.90	8.15	0.027	1.00	0.56	0.56	2.23	0.14	115	100	44	10	61	110	115	34	296	23	618	42	74	25	12	0.33

Tab. 7 (Contin.) Project Brandenburg-Sachsen (chapter 4.7).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	N_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
Zwt003	AD780	68.07	0.944	16.08	7.54	0.051	1.06	1.32	0.65	2.58	1.69	122	101	45	13	88	107	238	37	309	24	1027	50	72	23	8	3.70
Zwt012	AD781	66.91	0.940	15.56	8.78	0.032	0.78	1.31	0.64	2.24	2.80	115	101	37	11	115	96	291	36	332	23	1460	45	70	26	8	3.14
Zwt034	AD782	67.99	0.878	14.95	8.10	0.030	0.78	1.17	0.66	2.40	3.03	106	91	43	9	81	89	249	40	320	21	1508	42	84	22	8	3.55
Zwt043	AD783	69.80	0.959	15.86	7.99	0.040	0.97	0.73	0.66	2.09	0.90	115	97	43	11	76	107	158	34	297	21	899	41	81	25	9	0.87
Zwt073	AD784	68.39	0.889	16.30	9.67	0.014	0.96	0.88	0.62	1.86	0.42	119	105	45	13	57	94	151	38	277	22	704	40	81	24	10	1.12
Lieb022-1	AD785	67.33	1.066	19.16	6.96	0.018	1.06	0.34	0.25	2.46	1.34	120	121	62	28	191	125	66	32	278	25	624	40	58	28	11	4.96
Lieb026-1	AD786	68.35	1.033	17.87	6.31	0.040	1.07	0.70	0.31	2.79	1.54	124	118	67	26	143	156	102	52	283	22	1102	53	102	24	7	1.92
Oel002-4	AD787	68.40	1.049	17.98	7.13	0.022	1.11	0.52	0.16	2.26	1.36	123	117	42	13	90	118	99	31	291	25	1040	31	70	21	9	1.70
Btz007	AD788	68.64	1.293	23.21	2.55	0.007	0.93	0.31	0.05	2.61	0.41	144	123	36	43	127	177	70	31	235	27	557	42	72	40	12	1.56
Btz017-1	AD789	59.90	1.807	27.30	8.16	0.011	0.42	0.18	0.04	1.86	0.32	112	156	77	25	110	149	38	78	441	42	401	92	133	131	14	2.92
Btz018-1	AD790	76.99	1.467	15.13	4.02	0.083	0.35	0.26	0.03	1.05	0.61	98	76	27	289	35	57	26	56	366	28	462	50	112	16	8	1.02
Gz22	AD791	65.19	0.956	17.85	6.57	0.113	1.29	1.54	0.29	3.14	3.07	123	118	62	19	178	131	328	41	206	21	2514	42	86	21	<5	4.45
Gz33-1	AD792	67.97	0.878	16.04	5.84	0.059	1.61	3.18	0.41	2.92	1.10	106	107	47	24	60	109	127	33	235	19	644	31	73	21	7	3.85
Gz36	AD793	68.39	1.360	19.59	5.42	0.012	0.49	0.59	0.05	1.83	2.28	144	118	36	14	95	85	138	30	322	35	1073	34	70	26	8	7.90
Gz50	AD794	66.47	1.034	18.30	6.41	0.129	1.16	1.40	0.28	2.29	2.53	123	116	57	19	171	105	207	33	281	22	1565	31	66	27	<5	5.43
Gz75	AD795	60.42	1.034	21.05	8.49	0.067	2.30	1.19	0.36	3.61	1.49	160	146	77	19	204	139	107	37	220	23	693	42	78	28	14	6.53
Gz76-1	AD796	57.86	0.974	21.02	7.92	0.114	2.27	4.73	0.23	3.53	1.36	155	152	66	24	121	168	179	35	176	20	729	45	88	28	11	3.07
Gz76-2	AD797	67.90	1.040	18.18	6.96	0.020	1.19	0.39	0.60	3.39	0.32	122	117	57	17	92	143	69	34	273	24	469	34	65	24	7	0.83
Gz104	AD798	64.78	1.052	19.15	7.73	0.050	1.26	0.86	0.22	2.33	2.57	140	122	62	24	107	133	116	38	250	24	972	38	70	32	12	5.66
Bs2	AD799	64.82	0.882	18.67	7.34	0.037	1.74	1.73	0.23	3.14	1.41	132	121	44	13	109	146	218	22	193	22	1097	35	67	22	8	4.55
WK3	AD800	64.15	0.949	17.83	7.54	0.066	1.86	1.59	0.50	4.23	1.30	114	111	59	31	172	167	195	43	209	18	1244	62	88	20	8	4.47
Bk8	AD801	58.76	0.996	20.66	9.00	0.094	3.06	1.01	0.26	4.59	1.58	141	139	68	27	145	177	96	41	208	20	1097	48	94	28	12	5.84
Bk11	AD802	61.60	0.972	21.15	7.85	0.051	2.20	1.19	0.29	3.33	1.37	151	141	67	26	248	151	120	32	171	20	1249	47	72	27	11	5.91
Ew1-2	AD803	70.13	0.990	18.07	6.44	0.017	0.98	0.20	0.21	2.28	0.69	131	112	42	18	132	107	57	25	269	24	569	28	49	28	8	5.76
Sp5-1	AD804	66.47	0.895	17.42	6.62	0.086	1.79	0.98	0.34	2.98	2.41	111	118	69	10	188	120	153	36	229	20	1332	38	75	23	9	5.04
Bd027	AD805	64.51	0.915	17.24	6.37	0.129	2.17	4.11	0.42	3.28	0.85	123	115	63	35	84	146	116	34	235	21	533	35	76	24	12	2.76
Bd028	AD806	68.88	0.955	16.00	6.68	0.101	1.62	0.67	0.56	3.87	0.68	91	102	58	50	86	123	60	30	184	24	787		48	16		1.76
FR-S002	AD807	50.25	3.489	38.90	4.36	0.011	0.62	0.26	0.06	1.57	0.49	268	105	50	115	101	103	33	18	220	76	644		102	57		13.50
Schw2-3	AD808	68.37	1.011	19.82	4.84	0.026	1.15	0.80	0.67	2.98	0.33	135	123	44	46	115	168	168	53	237	24	724	55	107	29	14	1.28
Br 61	AD809	56.61	1.124	23.35	12.43	0.023	1.86	0.36	0.16	3.28	0.81	162	152	85	60	222	115	49	25	121	26	785		23	14		10.03
Br 62	AD810	57.35	0.917	19.83	8.53	0.064	2.49	6.34	0.31	3.29	0.89	152	136	67	28	109	166	164	33	162	22	587	47	98	22	11	1.80
Br 65	AD811	60.56	1.038	21.07	7.90	0.071	1.96	3.44	0.27	3.35	0.35	149	149	71	28	102	158	120	37	181	22	577	45	80	26	15	4.10
Br 66	AD812	62.31	1.081	21.47	8.19	0.065	1.60	1.20	0.19	3.22	0.68	156	158	82	27	104	155	103	44	190	22	712	49	92	31	11	6.47
Glie001	AD813	62.57	0.844	18.00	7.39	0.077	2.23	3.79	0.38	3.45	1.28	136	120	56	14	91	147	172	37	216	18	693	50	80	26	6	2.97
Glie002	AD814	62.17	0.832	17.63	7.29	0.077	2.48	4.93	0.37	3.45	0.77	132	119	57	16	90	154	144	36	214	17	569	42	83	21	10	1.26
Bd24-1	AD815	56.37	1.017	20.42	8.19	0.130	2.88	6.25	0.39	3.75	0.60	141	127	67	44	121	144	116	25	125	19	739	58	61	11		2.51
Bd25-2	AD816	64.92	0.920	17.41	6.46	0.108	2.24	3.41	0.36	3.20	0.97	131	116	57	85	90	145	106	37	247	20	556	43	79	22	5	2.90
Glie005	AD817	60.50	0.890	17.92	8.73	0.116	2.13	4.07	0.52	3.66	1.46	134	119	54	17	87	154	113	41	231	23	671	56	102	25	13	3.16
GM5-1	AD818	65.44	1.041	17.44	7.05	0.117	2.11	1.26	0.32	3.69	1.51	114	117	56	64	110	97	49	29	161	22	734		70	22		4.63
GM13	AD819	63.74	1.018	17.20	6.68	0.104	2.72	3.33	0.36	3.56	1.28	115	117	53	35	63	121	86	40	267	23	624	37	83	13	12	6.78
GM21	AD820	76.68	0.940	14.94	4.28	0.013	0.87	0.39	0.10	1.43	0.36	109	120	53	24	60	82	63	38	334	22	256	41	77	24	7	1.28
Lieb001	AD821	68.68	1.061	18.58	6.82	0.020	1.23	0.33	0.18	2.72	0.38	128	120	46	20	82	140	90	30	273	24	788	41	70	29	7	0.73
Lieb002-1	AD822	67.15	1.067	19.60	7.02	0.055	1.30	0.44	0.17	2.65	0.54	132	122	57	27	104	135	91	40	262	24	739	42	87	26	9	1.30
Gbf001	AD823	65.94	0.891	18.52	7.02	0.037	1.63	0.62	0.47	3.29	1.58	128	119	61	17	128	130	107	36	220	20	787	42	84	23	10	4.92
Gbf002	AD824	73.34	0.723	13.77	5.15	0.031	1.17	0.55	0.67	3.03	1.56	81	83	42	10	89	109	102	30	247	17	805	32	74	21	9	4.05
Bd23-1	AD825	58.90	1.005	16.97	7.10	0.119	3.57	5.75	0.40	3.91	2.26	121	120	55	73	89	152	121	39	227	22	734	41	91	18	8	5.84
Bd026	AD826	71.34	0.772	16.01	6.43	0.043	1.44	0.47	0.27	2.89	0.34	118	112	44	16	77	140	61	22	280	18	430	26	57	21	10	1.02
Lieb006-1	AD827	67.55	1.084	17.11	9.31	0.028	1.12	0.66	0.61	2.09	0.44	104	108	47	46	79	91	97	29	251	23	832		70	16		1.51
Br51	AD828	57.60	0.923	20.13	7.44	0.089	2.73	7.09	0.32	3.49	0.17	156	135	68	30	106	174	158	33	169	19	475	47	69	23	6	1.35
Lieb017	AD829	67.85	1.055	19.04	6.98	0.025	1.18	0.46	0.20	2.73	0.47	120	117	65	27	97	135	81	43	276	22	507	51	77	24	9	1.10
Br59	AD831	59.54	1.118	23.78	8.92	0.044	2.45	0.32	0.22	3.21	0.41	148	145	105	62	232	145	41	18	127	23	848		42	21		8.69
Ar001	AD832	59.05	3.616	28.38	3.18	0.014	0.68	0.88	0.13	2.83	1.24	204	100	29	56	90	147	155	46	565	123	880	86	112	51	13	4.35
Glie001	AD944	64.11	0.846	18.14	7.44	0.090	1.98	2.24	0.32	3.29	1.53	130	120	60	21	100	137	178	33	221	17	774	52	81	26	11	

Tab. 7 (Contin.) Project Brandenburg-Sachsen (chapter 4.7).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
ES-O-12	AD058	65.02	0.853	14.42	5.74	0.087	2.41	8.07	0.63	2.61	0.15	121	106	45	22	69	116	226	28	316	13	537	33	84	20	16	0.98
ES-O-103	AD059	70.67	0.621	12.01	4.68	0.103	1.80	6.96	0.64	2.30	0.21	104	92	42	21	70	113	193	20	207	11	470	14	62	16	17	3.60
ES-Koz-79	AD060	66.86	0.815	12.84	4.98	0.080	2.17	9.11	0.66	2.30	0.18	109	92	43	23	69	101	279	30	383	12	486	24	76	17	11	1.73
ES-ZjM-5.	AD061	55.38	0.727	14.69	6.00	0.152	2.13	16.61	0.78	3.09	0.44	142	103	50	22	86	124	266	19	191	11	426	37	54	15	16	6.41
ES-ZjM-53.	AD062	54.48	0.704	12.88	5.74	0.082	2.10	21.11	0.36	2.27	0.28	110	101	46	20	80	111	299	21	197	13	474	18	56	18	17	7.90
ES-O-60	AD071	61.44	0.848	19.65	8.17	0.103	2.67	3.45	0.23	3.29	0.17	183	149	86	37	118	189	167	24	167	16	475	37	69	25	19	0.83
ES-NK-9	AD072	76.07	0.870	14.87	4.56	0.036	0.83	1.55	0.03	0.79	0.46	117	82	30	10	61	33	79	22	244	14	152	21	62	19	12	1.51
ES-ZjM-7.	AD073	60.04	0.823	16.24	6.69	0.113	2.31	8.78	0.69	4.02	0.29	149	121	63	30	104	152	237	22	185	15	502	36	77	21	25	6.66
O-29	AD340	58.90	0.783	16.66	6.55	0.123	2.68	9.98	0.67	3.38	0.27	165	130	60	56	108	148	198	25	140	15	403	18	65	21	14	9.94
O-48	AD341	64.20	0.802	14.38	5.91	0.115	1.98	8.80	0.63	2.98	0.21	141	107	54	27	78	135	211	29	248	19	512	32	89	20	10	1.10
O-50	AD342	68.90	0.892	16.08	6.91	0.107	1.96	1.29	1.67	2.06	0.14	142	184	84	36	92	82	142	31	182	15	403	26	62	17	10	0.80
O-54	AD343	65.49	0.782	13.89	5.94	0.091	2.03	8.30	0.77	2.54	0.15	123	100	50	26	71	124	191	29	237	16	428	30	65	12	12	0.49
O-81	AD344	60.59	0.803	15.21	6.51	0.118	2.52	9.21	0.90	3.55	0.58	128	106	66	47	95	121	201	28	154	18	717	<5	26	5		2.57
O-114	AD345	59.89	0.845	16.42	6.60	0.135	2.43	9.50	0.76	3.24	0.18	131	122	63	24	93	152	235	29	180	16	482	30	78	24	9	1.05
ES-PT-16	AD346	65.91	0.769	13.29	5.56	0.159	2.51	7.06	1.03	3.37	0.34	128	107	51	10	86	123	251	31	276	17	488	45	78	20	12	6.17
ES-Zjm-8	AD347	63.76	0.763	21.11	4.79	0.089	1.17	2.53	0.63	4.90	0.26	115	95	40	24	86	181	145	27	225	16	672	31	82	34	22	2.36
ES-Zjm-10	AD348	78.22	0.770	11.13	3.61	0.092	1.27	2.35	0.64	1.74	0.18	96	85	32	9	53	79	152	22	334	18	534	18	76	19	11	2.72
ES-AK-18	MD500	75.57	0.740	16.53	2.84	0.033	0.92	1.22	0.29	1.76	0.09	113	100	35	29	57	112	123	19	205	12	518	39	76	21	20	1.01
ES-Koz-16	MD501	56.57	0.781	15.41	6.46	0.162	2.13	13.86	0.64	3.57	0.42	155	113	57	37	88	148	369	22	168	13	9277	19	83	16	17	1.94
ES-Koz-30	MD502	71.64	0.832	14.66	5.14	0.065	1.93	2.44	0.62	2.12	0.55	107	106	46	25	78	119	184	23	258	12	411	35	83	19	21	0.81
ES-Koz-72	MD503	73.48	0.725	14.25	5.45	0.093	1.65	1.42	0.36	2.36	0.20	120	102	48	19	80	127	144	21	228	13	687	24	69	23	20	0.87
ES-Koz-82	MD504	74.91	0.778	14.26	4.20	0.058	1.07	1.77	0.37	2.48	0.11	98	84	38	14	58	103	119	27	392	12	647	44	99	19	29	1.41
ES-NK-2	MD505	76.14	0.882	15.77	4.43	0.018	0.41	1.86	0.01	0.32	0.18	86	59	24	13	32	17	93	29	407	20	375	29	76	26	25	1.79
ES-NK-3	MD506	64.44	0.805	16.13	6.04	0.069	2.65	5.55	0.69	3.12	0.51	137	127	62	26	99	157	234	20	204	13	451	17	66	16	22	2.50
ES-NK-6	MD507	72.41	0.782	12.89	4.60	0.050	1.97	4.01	0.69	2.28	0.31	105	95	46	21	76	90	167	23	285	13	432	30	62	17	22	3.48
ES-NK-8	MD508	69.06	0.740	10.64	4.00	0.063	2.07	10.86	0.62	1.74	0.20	96	82	38	18	51	81	252	24	406	12	504	22	50	13	13	3.05
ES-Slk-1	MD509	59.34	0.736	14.02	5.86	0.188	2.14	13.73	0.70	3.03	0.26	138	105	55	26	85	134	269	23	227	12	504	21	58	16	17	1.68
ES-StB-3	MD510	57.72	0.780	15.40	6.34	0.106	2.34	12.74	0.75	3.59	0.23	136	112	59	49	118	136	294	22	184	12	433	34	53	21	21	11.08
ES-Stv-8	MD511	69.65	0.994	17.81	5.50	0.081	1.85	1.44	0.39	2.19	0.10	119	121	52	25	86	103	159	28	269	16	532	38	88	22	24	3.85
ES-Stv-9	MD512	72.72	0.881	15.73	5.45	0.053	1.51	1.30	0.33	1.86	0.16	114	110	45	23	77	104	199	25	247	14	554	24	67	19	28	2.72
ES-Stv11	MD513	72.77	0.786	10.77	4.28	0.063	1.87	6.95	0.68	1.66	0.17	82	83	39	18	61	81	189	19	392	12	415	37	68	7	18	0.93
ES-Pt-9	MD514	56.75	0.800	15.98	6.51	0.132	2.36	13.41	0.60	3.15	0.31	143	119	65	38	108	151	304	26	174	12	680	14	77	22	21	4.22
ES-Pt-18	MD515	75.48	0.760	13.34	4.79	0.091	1.36	0.86	0.62	2.58	0.13	102	98	48	25	76	112	94	22	280	12	489	15	63	19	22	2.36
ES-Pt-20	MD516	80.83	0.773	10.89	3.47	0.056	0.93	0.78	0.48	1.71	0.09	75	79	30	16	51	95	71	22	364	13	343	24	58	16	17	0.47
ES-Pt-23	MD517	77.92	0.596	11.71	4.32	0.046	1.61	1.03	0.42	2.22	0.13	100	82	42	23	67	100	91	16	170	10	338	21	61	14	19	3.43
ES-Rd-1	MD518	55.90	0.829	16.42	6.76	0.171	2.30	13.73	0.54	3.07	0.28	119	119	64	37	87	150	319	24	184	14	727	21	67	22	21	2.57
ES-ZjM-11	MD519	58.52	0.753	15.24	6.11	0.113	2.29	12.71	0.63	3.12	0.50	146	113	57	49	77	136	295	23	183	10	453	12	82	12	14	1.34
ES-O-19	MD520	59.44	0.743	14.61	5.98	0.109	2.31	11.80	0.91	3.81	0.29	152	106	57	52	110	135	251	22	199	11	479	25	60	24	20	9.57
ES-O-33	MD521	70.35	0.657	13.82	5.25	0.099	1.97	4.59	0.27	2.83	0.18	127	106	55	33	87	136	140	18	163	12	418	28	46	16	15	2.10
ES-O-44	MD522	67.82	0.812	12.36	4.69	0.079	1.99	9.04	0.68	2.35	0.18	102	92	45	25	64	100	273	26	404	14	487	33	71	18	17	1.62
ES-O-89	MD523	65.21	0.803	16.59	5.38	0.052	2.91	5.18	0.38	3.28	0.23	148	129	59	33	104	163	200	22	205	14	457	22	72	19	22	2.66
ES-O-89	MD523	65.21	0.803	16.59	5.38	0.052	2.91	5.18	0.38	3.28	0.23	148	129	59	33	104	163	200	22	205	14	457	22	72	19	22	2.66
ES-O-105	MD524	72.94	0.617	12.34	4.57	0.084	1.80	4.31	0.66	2.54	0.15	100	91	45	30	73	112	161	15	200	9	374	14	46	16	16	3.27
Raw materials																											
clay 1	MD525	78.13	0.757	12.10	4.37	0.048	1.36	0.43	0.70	1.97	0.13	78	87	38	18	65	104	102	29	293	12	333	29	50	12	18	3.69
clay 2	MD526	70.49	0.800	15.45	6.29	0.064	2.10	0.88	0.81	3.03	0.09	126	119	64	37	102	142	136	18	258	13	330	36	83	22	23	4.70
clay 3	MD527	77.23	0.786	12.58	4.57	0.082	1.48	0.34	0.77	2.08	0.07	87	94	44	20	68	106	100	19	293	11	335	31	71	16	22	3.80

Tab. 8 Project Olbia (chapter 4.8).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
2	MD3519	72.65	0.894	13.56	5.59	0.071	1.57	0.91	0.95	3.45	0.36	113	113	45	18	69	93	103	31	350	14	509	20	66	25	18	3.38
7	MD3520	83.53	0.792	9.51	4.13	0.012	0.70	0.79	0.11	0.35	0.09	90	83	34	12	16	14	54	13	170	15	215	7	26	18	11	0.71
12	MD3521	72.33	0.922	14.64	5.86	0.096	1.59	1.07	0.90	2.48	0.12	129	123	54	25	77	107	111	37	381	12	527	29	91	26	23	1.43
14	MD3522	70.66	0.909	15.35	6.22	0.116	1.34	1.93	0.70	2.56	0.22	125	124	59	31	73	79	119	30	284	15	400	40	85	24	21	2.57
15	MD5340	75.89	0.843	12.86	4.99	0.056	1.10	1.42	0.40	2.25	0.18	104	101	35	15	55	82	96	26	436	15	508	23	58	19	20	1.21
16	MD3523	74.66	0.998	14.48	6.29	0.013	0.87	1.15	0.23	1.19	0.13	95	122	27	18	26	22	82	18	202	20	536	12	21	25	20	2.56
22	MD3524	74.68	0.865	12.99	5.09	0.073	1.38	1.72	0.72	2.33	0.14	105	120	47	19	67	95	105	37	404	12	459	35	70	29	16	0.51
27	MD5341	65.34	1.117	22.11	8.87	0.024	0.55	1.28	0.02	0.51	0.17	182	156	42	18	26	19	97	14	252	18	176	8	13	30	23	4.52
31	MD5342	76.42	0.909	13.62	4.57	0.058	1.01	1.19	0.33	1.63	0.27	108	106	32	10	49	81	97	26	409	16	415	37	69	23	19	0.41
35	AD1057	77.40	0.957	13.36	4.50	0.024	0.78	1.34	0.30	1.07	0.27	116	112	34	12	36	45	125	24	310	24	455	29	48	24	7	2.64
38	MD5343	68.31	0.971	16.06	6.66	0.037	1.06	5.85	0.18	0.76	0.12	133	118	32	16	32	42	134	18	298	16	488	<5	23	26	18	1.47
41	MD5344	72.57	0.879	14.64	5.77	0.074	1.60	1.18	0.74	2.40	0.16	123	116	49	19	74	106	113	29	390	15	505	24	75	19	19	1.36
42	MD3525	79.62	0.947	13.14	3.74	0.012	0.57	1.09	0.16	0.64	0.08	119	110	23	16	27	36	76	19	282	18	267	23	52	27	18	0.83
44	MD5345	78.71	0.961	13.42	3.96	0.015	0.60	1.23	0.16	0.79	0.15	115	114	27	17	27	31	104	13	299	17	392	25	39	19	16	2.95
45	AD1058	77.52	0.915	12.89	5.99	0.008	0.50	1.61	0.07	0.37	0.14	116	109	32	10	18	13	113	13	206	23	463	7	<5	18	<5	0.39
50	MD3526	78.33	0.951	13.87	3.33	0.010	0.52	1.29	0.44	1.16	0.10	127	120	25	17	25	32	134	19	267	15	486	26	67	33	19	2.73
51	MD5346	74.40	0.899	13.50	5.25	0.072	1.23	1.84	0.58	2.12	0.11	110	108	42	10	62	109	92	32	461	15	520	33	94	17	19	0.92
53	MD3527	78.15	0.943	12.67	4.34	0.019	0.70	1.36	0.59	1.13	0.11	113	115	31	18	29	39	103	22	300	15	381	24	46	22	18	3.19
57	MD5347	78.12	0.931	13.09	4.49	0.020	0.74	1.09	0.28	1.14	0.10	104	102	24	13	30	45	101	15	354	16	418	22	48	18	17	2.24
62	MD3528	74.90	1.160	16.40	3.65	0.035	0.92	1.09	0.29	1.41	0.15	184	157	32	23	41	66	151	25	323	21	402	56	95	46	18	0.76
69	MD3529	77.35	0.919	13.80	4.34	0.015	0.63	1.45	0.27	0.96	0.26	143	126	26	14	30	36	136	20	292	16	598	31	65	30	18	4.96
79	MD3530	73.46	0.986	19.44	2.98	0.010	0.57	0.92	0.19	1.10	0.34	81	90	32	9	35	44	75	23	218	19	306	26	46	26	8	3.51
82	MD3531	75.41	0.893	12.51	5.00	0.078	1.29	1.25	0.86	2.52	0.19	93	89	37	18	59	99	111	31	490	24	496	85	102	<5	<5	0.48
84	MD3532	75.48	1.080	18.87	2.03	0.007	0.53	0.84	0.07	0.92	0.18	196	181	28	23	29	52	177	18	255	20	413	70	104	67	27	1.31
99	AD1066	77.61	1.102	13.73	4.28	0.017	0.59	1.49	0.30	0.72	0.15	134	121	30	15	31	35	215	20	334	25	505	40	46	28	7	5.94
100	AD1059	79.33	0.844	12.07	4.71	0.032	0.76	1.08	0.29	0.78	0.10	104	96	38	12	26	33	93	20	243	22	341	7	21	15	<5	1.88
106	MD3919	63.18	0.845	15.07	6.26	0.096	2.01	8.80	1.03	2.43	0.28	162	138	52	13	76	95	293	29	228	14	587	28	93	20	21	4.90
110	MD5348	75.62	0.867	12.99	4.94	0.075	1.33	0.93	0.74	2.41	0.11	95	110	41	17	57	103	107	31	501	14	488	33	82	16	17	0.24
117	AD1067	77.35	1.114	13.83	4.60	0.018	0.69	0.88	0.19	1.16	0.17	135	121	30	13	34	38	98	25	343	26	369	31	43	26	12	1.85
118	AD1061	72.94	0.889	14.35	5.77	0.060	1.18	1.50	0.75	2.20	0.37	125	128	49	12	77	91	136	34	440	20	723	28	88	18	9	3.19
119	AD1062	73.88	0.889	14.37	5.20	0.042	1.15	1.42	0.73	2.17	0.15	121	118	48	13	54	85	125	29	452	18	696	26	55	18	8	3.73
120	AD1063	72.86	0.914	14.79	5.76	0.054	1.15	1.25	0.71	2.19	0.33	127	123	54	12	62	82	117	33	466	19	700	33	67	23	9	4.05
129	AD1064	68.22	1.006	20.44	7.02	0.041	0.73	1.10	0.21	0.89	0.34	154	142	49	13	41	45	102	27	279	22	343	28	73	30	13	1.60
131	AD1060	74.07	0.877	14.12	5.36	0.070	1.20	1.63	0.62	1.79	0.27	110	116	45	12	57	79	112	32	394	19	413	32	53	20	<5	0.49
135	MD3920	76.67	1.160	14.02	3.47	0.024	0.74	2.60	0.20	0.82	0.30	180	124	29	11	25	37	156	21	279	20	683	36	72	32	24	3.77
139	AD1065	66.86	1.039	16.00	6.51	0.023	0.66	7.99	0.16	0.61	0.16	146	128	41	13	28	30	123	24	249	25	321	11	32	24	8	5.55
143	MD3921	72.18	1.892	14.26	4.87	0.033	0.74	4.82	0.15	0.92	0.15	212	138	31	5	29	41	103	33	339	34	406	16	49	35	22	3.05
144	MD5349	69.09	1.063	16.48	6.68	0.035	0.67	5.11	0.09	0.51	0.28	142	127	35	13	24	28	129	15	259	19	465	7	49	23	22	4.53
147	MD5350	73.06	0.889	13.57	5.35	0.078	1.44	2.11	0.71	2.36	0.43	117	116	46	17	70	102	132	30	459	15	598	34	77	18	17	1.84
154	MD3922	77.31	0.910	11.77	4.04	0.043	1.21	1.52	0.62	2.45	0.13	113	120	32	<5	53	89	125	38	529	10	510	36	89	22	18	0.78
159	MD3923	67.83	1.021	17.50	8.29	0.019	0.69	2.47	0.18	1.49	0.50	176	137	34	9	24	28	148	20	201	19	304	<5	44	34	23	2.99
160	MD3924	75.19	0.796	12.28	5.57	0.116	1.61	1.31	1.08	1.87	0.18	123	107	41	15	68	84	128	30	325	12	673	45	88	22	18	4.14
161	MD5351	74.16	0.913	13.84	5.54	0.080	1.46	1.13	0.68	2.13	0.07	92	101	45	19	65	87	172	25	478	15	614	21	75	20	19	3.42
166	MD5352	74.76	0.893	13.68	5.26	0.090	1.33	1.15	0.55	2.15	0.13	105	105	40	15	65	101	102	32	458	14	479	17	73	20	20	0.13
167	AD593	76.61	1.396	16.59	2.70	0.009	0.46	0.99	0.06	0.94	0.25	185	161	30	25	28	44	159	20	317	34	424	56	59	50	13	0.31
175	MD3925	73.12	0.884	13.40	5.24	0.085	1.51	1.68	0.93	2.84	0.30	136	118	46	7	68	91	118	34	415	11	547	42	79	23	19	1.11
177	MD5353	73.87	1.033	15.56	6.52	0.072	0.75	1.07	0.17	0.88	0.07	138	117	40	8	33	46	72	19	324	18	278	<5	58	20	24	0.59
179	MD5354	72.45	1.094	17.19	6.82	0.033	0.67	1.03	0.00	0.62	0.09	158	134	41	10	33	20	74	25	290	18	134	24	93	26	26	0.82
180	MD3926	71.51	0.797	10.32	3.65	0.064	1.40	8.36	0.72	3.01	0.18	93	88	33	8	45	80	151	34	479	8	422	48	76	20	17	8.26
Voj-181	AD409	78.23	0.958	13.70	4.87	0.017	0.34	1.22	0.05	0.52	0.10	121	99	36	<5	17	24	59	16	270	23	247	18	45	24	10	0.74
Voj-182	AD410	78.74	0.911	12.92	3.92	0.026	0.67	1.12	0.36	1.25	0.08	103	98	27	5	29	39	87	18	264	23	350	20	29	20	10	1.53
Voj-192	AD411	76.26	0.875	12.61	4.80	0.048	1.32	1.14	0.67	2.03	0.24	106	99	40	10	74	86	169	36	454	20	621	32	88	21	7	3.95
Voj-193	AD412	76.65	1.056	17.72	2.53	0.006	0.54	0.75	0.03	0.56	0.15	165	136	28	13	21	38	89	17	271	25	213	29	21	29	<5	1.81
Voj-195	AD413	75.47	0.891	13.09	5.16	0.057	1.16	1.17	0.66	2.17	0.18	85	96	39	11	58	80	189	35	485	21	621	31	70	21	5	3.20
Voj-196	AD414	72.49	0.823	11.88	4.47	0.052	1.61	5.43	0.94	2.08	0.23	91	90	37	<5	56	82	321	36	449	18	662	42	66	18	5	6.20
Voj-199	AD203	76.60	0.890	17.38	3.38	0.007	0.44	0.67	0.07	0.50	0.07	155	147	24	8	27	34	70	8	216	17	183	21	20	30	26	4.20
Voj-202	AD415	76.63	0.934	12.59	4.69	0.049	1.06	1.32	0.62	1.99	0.13	118	112	40	<5	107	75	187	35	514	20	614	41	84	20	8	3.73
Voj-203	AD416	75.83	1.138	17.82	2.41	0.008	0.33	1.32	0.13	0.73	0.28	188	163	25	5	23	40	216	16	273	28	523	58	74	54	13	5.90
Voj-208	AD204	77.61	0.812	12.45	6.83	0.007	0.51	0.73	0.03	0.85	0.17	179	116	17	16	18	26	81	8	277	14	395	9	24	26	23	3.22
Voj-211	AD205	78.16	0.893	13.94	4.12	0.023	0.73	0.78	0.16	1.06	0.13	128	111	26	16	32	53	101	17	330	16	442	34	54	25	22	0.54

Tab. 9 Project Voitenki (chapter 4.9).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
Voj-214	AD206	78.26	0.876	12.29	4.51	0.021	0.82	1.28	0.35	1.44	0.14	102	96	23	8	35	57	102	13	382	15	469	21	42	20	19	3.56
Voj-217	AD207	74.24	0.935	13.90	5.51	0.096	1.37	1.11	0.47	2.28	0.10	116	115	43	22	68	112	91	29	451	15	520	18	68	22	19	0.00
Voj-242	AD417	79.37	0.816	11.93	3.91	0.023	0.62	1.20	0.27	1.34	0.52	107	90	23	<5	30	42	125	25	315	18	669	33	50	24	5	2.62
Voj-252	AD208	74.33	1.210	18.87	3.41	0.006	0.50	0.74	0.01	0.82	0.10	226	162	25	43	29	51	141	11	288	21	585	40	60	46	26	1.09
Voj-253	AD418	75.11	0.979	15.25	5.52	0.041	0.80	0.83	0.29	1.12	0.07	136	108	44	6	41	55	72	27	329	23	345	23	55	26	10	0.20
Voj-255	AD209	71.23	0.987	17.09	7.62	0.021	0.74	1.00	0.11	0.85	0.35	158	124	38	20	44	46	101	18	286	17	393	19	29	26	23	1.43
Voj-262	AD419	75.56	0.875	12.94	4.95	0.083	1.33	0.93	0.78	2.45	0.10	106	104	41	<5	63	98	104	36	439	17	482	30	82	20	9	0.32
Voj-263	AD210	74.18	0.936	14.95	5.63	0.053	1.10	0.90	0.43	1.68	0.15	112	106	42	19	52	77	92	27	376	15	370	32	61	19	14	0.25
Voj-269	AD194	76.28	0.836	12.65	4.89	0.092	1.29	0.96	0.74	2.18	0.09	89	99	39	19	112	96	104	28	465	14	454	22	72	16	18	0.41
Voj-277	AD211	72.19	0.913	15.04	5.96	0.077	1.46	1.34	0.78	2.15	0.10	127	116	51	24	70	89	136	27	415	15	751	36	63	18	18	3.93
Voj-281	AD212	75.63	0.859	13.49	5.23	0.070	1.10	1.58	0.35	1.56	0.12	108	102	42	22	60	80	143	24	376	16	686	27	60	22	18	7.98
Voj-283	AD195	77.70	0.981	13.57	4.55	0.021	0.59	1.02	0.56	0.87	0.13	119	99	25	12	29	41	88	15	311	18	377	26	35	20	23	3.70
Voj-284	AD546	70.30	0.964	14.19	8.28	0.111	1.59	1.29	0.79	2.35	0.12	376	764	88	48	81	81	95	30	313	18	757	12	79	23		4.07
Voj-285	AD547	71.59	0.921	15.23	6.26	0.064	1.68	1.25	0.82	2.12	0.06	129	129	54	18	76	99	163	31	394	20	618	32	74	21	6	1.76
Voj-286	AD548	72.92	0.924	14.05	6.29	0.059	1.30	1.20	0.76	2.23	0.26	147	125	43	12	66	95	154	31	390	19	561	28	65	22	10	0.09
Voj-287	AD549	70.13	1.050	18.21	8.09	0.019	0.75	1.25	0.10	0.35	0.04	165	140	42	11	51	45	87	19	235	26	154	17	27	29	10	0.51
Voj-288	AD550	73.29	0.903	14.28	5.65	0.072	1.44	1.05	0.72	2.46	0.14	124	115	48	16	68	106	110	36	430	18	489	53	76	23	9	2.91
Voj-289	AD551	78.36	0.812	11.22	4.37	0.028	0.79	2.25	0.44	1.65	0.09	87	90	34	<5	41	70	162	32	489	18	449	36	71	19	6	0.99
Voj-290	AD552	74.97	1.008	14.98	4.79	0.040	0.83	1.83	0.29	1.12	0.07	161	148	38	23	45	55	118	22	302	24	355	49	60	30	11	0.99
Voj-291	AD553	77.83	1.046	15.43	3.54	0.017	0.50	0.66	0.13	0.74	0.10	157	136	29	18	31	39	147	18	292	24	442	52	74	36	17	0.23
Voj-292	AD554	74.91	0.905	13.41	5.29	0.086	1.32	1.09	0.66	2.24	0.09	111	108	44	12	66	94	100	36	456	20	467	29	63	20	11	7.48
Voj-293	AD555	73.88	1.066	16.64	6.04	0.022	0.41	1.26	0.16	0.45	0.07	139	121	40	6	28	28	161	17	308	24	298	23	51	26	13	2.99
Voj-294	AD556	76.23	0.936	13.07	4.96	0.051	0.81	1.29	0.51	2.04	0.09	110	108	42	6	78	86	166	37	516	20	568	45	86	22	11	0.80
Voj-295	AD557	67.47	1.129	21.46	8.41	0.009	0.53	0.62	0.03	0.27	0.07	175	153	51	<5	32	28	63	20	226	26	121	15	27	32	11	3.07
Voj-296	AD558	76.74	0.874	12.43	4.89	0.040	1.22	1.05	0.68	1.93	0.14	100	101	41	<5	58	69	116	34	525	19	601	34	79	18	10	1.42
Voj-297	AD559	70.77	1.017	15.79	10.03	0.026	0.48	1.22	0.08	0.40	0.18	185	146	38	26	29	21	65	18	243	25	135	5	18	28	11	0.38
Voj-298	AD560	75.42	0.893	13.20	5.19	0.075	1.29	1.11	0.62	2.10	0.11	111	112	48	14	66	98	94	40	455	18	469	45	73	19	11	1.11
Voj-299	AD561	74.91	0.903	13.35	5.18	0.072	1.22	1.24	0.71	2.17	0.23	115	110	46	12	68	94	125	39	450	20	486	50	85	16	9	1.16
Voj-300	AD562	76.22	1.465	17.83	2.69	0.006	0.41	0.57	0.04	0.69	0.08	214	170	28	18	23	45	140	17	332	32	314	50	52	55	14	0.20
Voj-301	AD563	74.05	0.863	14.09	5.61	0.071	1.32	1.15	0.69	2.03	0.13	118	114	45	11	60	87	104	35	390	18	409	33	67	23	6	1.25
Voj-302	AD564	77.27	0.860	11.80	4.59	0.069	1.17	1.18	0.68	2.24	0.14	97	107	45	8	55	86	106	36	574	19	469	30	59	21	7	2.03
Voj-303	AD565	74.45	0.933	13.79	5.42	0.059	1.05	1.26	0.71	2.13	0.20	121	117	49	11	66	90	132	37	458	20	547	47	75	23	10	5.64
Voj-304	AD566	76.39	0.819	13.83	5.38	0.022	0.78	1.48	0.26	0.80	0.24	129	104	42	9	47	36	103	24	257	21	508	18	42	22	8	4.54
Voj-305	AD567	73.55	0.925	13.68	5.38	0.061	1.04	1.73	0.73	2.10	0.79	113	117	48	9	73	77	216	42	464	21	929	44	81	21	8	2.31
Voj-306	AD568	74.35	0.916	13.62	5.36	0.056	0.98	1.46	0.72	2.13	0.41	124	116	46	9	63	91	135	38	446	18	674	38	72	22	9	4.29
Voj-307	AD569	74.52	0.932	13.86	5.44	0.051	0.81	1.60	0.67	1.99	0.12	127	115	41	10	58	80	136	37	451	19	589	40	78	21	6	2.72
Voj-308	AD570	75.48	1.241	18.44	2.54	0.005	0.34	0.74	0.10	0.73	0.38	214	183	30	13	26	42	153	18	292	28	385	70	71	59	14	0.66
Voj-309	AD571	74.76	0.878	13.16	4.93	0.068	1.29	1.40	0.67	2.74	0.11	104	108	45	5	64	98	105	34	454	18	454	32	80	20	9	0.41
Voj-310	AD572	78.05	1.034	12.28	4.74	0.009	0.97	0.45	0.03	2.36	0.08	164	160	17	5	42	112	63	29	437	24	365	49	103	21	9	7.55
Voj-311	AD573	69.76	0.766	10.19	3.50	0.055	1.24	10.81	0.69	2.59	0.40	77	85	29	6	41	73	316	32	503	16	548	20	82	14	<5	1.51
Voj-312	AD574	76.71	1.426	12.89	4.27	0.039	0.77	2.40	0.25	1.12	0.12	122	107	31	24	33	46	88	30	389	31	297	28	37	19	8	0.41
Voj-313	AD575	77.78	1.458	13.13	4.43	0.041	0.75	0.94	0.27	1.10	0.09	125	108	32	29	35	49	79	30	397	32	319	24	48	17	12	3.19
Voj-314	AD576	73.72	1.001	19.63	3.28	0.011	0.50	0.96	0.06	0.68	0.16	183	181	32	12	20	39	89	15	234	26	232	22	52	36	12	0.71
Voj-315	AD577	75.09	1.094	19.91	2.05	0.004	0.42	0.54	0.03	0.79	0.08	200	182	28	27	31	50	160	14	258	25	381	57	76	65	17	0.06
Voj-316	AD578	75.08	1.004	20.06	2.01	0.004	0.41	0.52	0.04	0.82	0.06	187	182	29	17	27	53	155	14	255	25	389	67	84	60	10	3.67
Voj-317	AD579	78.59	1.641	12.38	3.79	0.011	0.45	1.88	0.09	0.59	0.58	110	103	22	32	23	20	147	23	335	36	660	20	33	15	8	3.28
Voj-318	AD580	78.32	1.518	12.69	3.99	0.023	0.63	1.47	0.21	0.99	0.17	116	104	27	22	29	35	125	28	361	33	440	15	25	17	7	3.97
Voj-319	AD581	78.64	1.599	12.59	4.14	0.017	0.57	1.34	0.13	0.80	0.17	120	102	26	30	23	31	112	24	357	37	411	23	30	18	11	0.38
Voj-320	AD582	76.04	1.038	13.02	4.96	0.080	1.14	1.05	0.57	1.98	0.12	105	109	42	12	53	84	99	38	462	19	471	35	65	20	9	0.90
Voj-321	AD583	76.06	0.875	12.16	5.17	0.018	1.76	0.96	0.34	2.61	0.04	136	119	37	<5	56	117	293	27	386	21	338	35	60	16	5	0.59
Voj-322	AD584	74.72	0.898	13.49	5.45	0.092	1.31	0.98	0.65	2.32	0.10	109	111	46	9	69	96	93	36	465	20	455	40	75	21	13	1.10
Voj-323	AD585	73.48	0.959	13.59	5.62	0.076	1.34	1.43	0.67	2.32	0.51	102	108	51	41	80	88	200	36	371	23	849	<5	70	20		0.57
Voj-324	AD586	76.28	0.981	13.53	4.71	0.040	1.08	0.76	0.25	2.25	0.12	151	141	32	37	50	103	84	30	411	23	397	50	93	21	10	1.77
Voj-325	AD587	75.79	1.188	15.01	3.28	0.016	0.59	3.27	0.12	0.68	0.07	181	133	27	16	25	43	135	20	272	27	363	47	52	37	12	0.28
Voj-326	AD588	75.58	0.887	13.11	5.15	0.081	1.29	1.05	0.64	2.10	0.11	112	109	49	8	63	96	95	37	429	15	471	27	81	19	9	0.61
Voj-327	AD589	75.69	1.342	18.19	2.71	0.010	0.48	0.55	0.08	0.86	0.08	189	183	34	12	26	51	174	19	328	33	313	67	89	62	14	-0.15
Voj-328	AD590	74.32	0.999	15.97	6.23	0.026	0.64	0.77	0.16	0.75	0.15	138	138	44	<5	5	45	69	25	316	25	237	21	41	23	10	0.16
Voj-329	AD591	76.46	0.913	14.57	5.53	0.031	0.70	0.92	0.20	0.61	0.08	126	118	40	7	33	35	74	22	295	22	273	26	46	23	10	4.24
Voj-330	AD592	65.52	1.160	22.46	8.37	0.027	0.43	1.28	0.19	0.34	0.21	188	161	45	14	35	25	195	28	275	27	303	38	59	30	12	1.74
Voj-331	AD1068	76.76	0.860	12.18	4.63	0.049	1.16	1.52	0.62	2.15	0.06	97	112	42	16	56	89	108	32	563	19	508	51	71	22	<5	4.70

Tab. 9 (Contin.)Project Voitenki (chapter 4.9).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pb	Th	l.o.i.
		per cent by weight										ppm															%
X2	MD3927	72.25	0.980	19.53	2.64	0.014	0.69	2.05	0.16	0.93	0.76	213	176	27	28	33	45	185	16	237	21	654	46	72	48	22	2.18
X3	MD3928	74.47	0.880	13.23	5.14	0.060	1.42	1.37	0.96	2.35	0.12	128	113	44	16	56	90	131	35	422	12	651	34	91	18	19	2.80
X5	AD404	74.98	0.870	13.08	5.07	0.082	1.24	1.43	0.64	2.24	0.38	107	102	47	5	63	94	140	35	422	17	745	40	77	22	11	1.83
X6	MD3929	69.90	0.968	13.88	7.76	0.035	0.91	3.71	0.37	2.34	0.13	161	128	38	6	31	41	105	23	245	16	332	14	43	27	25	1.63
X10	MD3930	78.43	0.821	11.55	4.53	0.068	1.01	1.12	0.49	1.87	0.12	117	99	40	10	57	85	85	31	420	11	450	20	78	21	22	0.88
X11	MD3931	76.06	1.163	17.66	2.26	0.011	0.55	0.78	0.19	1.21	0.12	224	164	26	18	28	53	140	17	268	20	324	51	106	60	29	0.56
X12	MD3932	75.70	0.938	14.00	4.94	0.040	1.11	1.06	0.49	1.53	0.19	148	116	37	15	49	65	103	28	321	17	474	33	62	24	14	0.35
X16	MD3918	75.24	1.081	15.85	5.96	0.025	0.53	0.80	0.07	0.17	0.27	172	129	38	6	25	17	81	26	261	19	220	25	40	25	19	0.68
X26	MD3933	75.16	1.263	17.53	3.93	0.010	0.52	0.57	0.04	0.84	0.14	333	191	27	22	24	44	139	19	303	23	277	51	80	56	22	1.07
X28	MD3934	72.38	1.109	18.92	4.71	0.009	0.36	1.15	0.18	0.49	0.69	131	136	28	10	17	22	70	17	385	18	343	14	30	20	17	4.64
X29	MD3935	73.88	0.885	13.31	4.95	0.077	1.41	1.65	0.94	2.43	0.47	125	114	46	16	71	82	156	35	413	13	908	29	85	21	17	2.83
X37	MD3936	71.99	1.445	16.61	5.07	0.011	1.24	0.90	0.07	2.55	0.13	253	220	27	18	48	127	110	52	356	26	388	80	156	26	14	0.85
X41	MD3937	76.51	0.984	12.60	6.03	0.022	0.70	1.46	0.29	1.02	0.39	184	126	29	16	34	35	114	24	282	17	546	36	61	26	18	3.88
X44	MD3938	73.42	1.243	20.12	2.76	0.008	0.59	0.69	0.14	0.95	0.09	264	178	26	41	29	54	144	19	266	23	483	38	70	53	26	1.55
X45	AD401	77.68	0.880	13.38	3.51	0.022	0.65	2.94	0.06	0.80	0.07	89	93	27	<5	23	40	83	17	298	20	238	36	35	15	7	1.34
X46	AD402	76.90	0.827	12.54	4.74	0.011	0.69	1.54	0.17	1.39	1.18	91	90	32	10	44	81	141	29	376	18	959	30	59	17	9	4.16
X47	AD196	72.15	0.950	15.63	6.52	0.071	1.24	1.11	0.45	1.76	0.12	136	121	46	18	56	85	91	26	390	16	369	15	52	24	18	0.17
X48	AD197	65.84	1.151	21.27	8.59	0.015	0.36	1.82	0.03	0.40	0.51	185	152	36	7	18	16	124	10	258	21	580	<5	<5	25	23	3.69
X49	AD403	68.72	1.070	20.03	7.93	0.009	0.43	1.21	0.05	0.37	0.18	160	136	41	10	23	30	79	24	211	24	177	18	29	31	14	2.67
X50	AD405	66.69	1.087	20.55	8.15	0.017	0.32	1.39	0.09	0.47	1.23	164	139	40	8	28	18	138	18	238	26	759	22	31	26	13	3.05
X51	AD406	65.40	1.111	22.85	8.87	0.022	0.41	0.76	0.06	0.36	0.17	184	157	36	<5	26	20	68	19	226	25	211	16	27	28	14	2.41
X52	AD198	70.49	0.932	16.29	6.38	0.070	1.23	2.11	0.53	1.79	0.16	135	121	44	16	55	83	120	28	372	15	465	16	79	23	21	1.15
X53	AD407	79.58	0.830	11.47	4.56	0.038	0.95	1.12	0.27	0.98	0.21	97	90	40	8	36	48	73	23	246	18	281	16	37	17	11	1.09
X54	AD408	74.23	0.919	17.89	3.95	0.014	0.51	1.32	0.10	0.74	0.33	166	134	27	7	23	39	107	14	224	22	445	27	45	32	13	3.21
X55	AD199	72.74	0.901	14.42	5.69	0.078	1.53	1.37	0.67	2.32	0.27	111	114	48	20	75	109	117	32	421	14	544	38	80	21	16	0.40
X58	AD193	76.60	1.029	15.49	3.78	0.014	0.62	0.96	0.28	0.88	0.34	145	131	25	23	26	43	164	14	329	18	583	36	62	31	25	3.37
X61	AD200	73.78	0.898	13.90	5.36	0.091	1.43	1.19	0.66	2.46	0.22	107	107	45	20	63	110	112	29	458	14	511	22	85	20	20	0.98
X66	AD201	75.15	0.698	12.76	5.51	0.169	1.40	1.23	0.48	1.98	0.63	96	93	39	12	61	97	162	24	210	11	648	23	50	14	17	1.35
X69	AD202	75.11	1.021	16.93	3.48	0.033	0.85	0.71	0.22	1.47	0.18	164	146	31	21	39	75	161	19	352	18	458	51	84	36	24	0.92
	Raw materials																										
clay	MD4119	77.64	0.808	8.83	3.01	0.054	1.41	5.30	0.79	2.07	0.09	44	111	37	18	57	81	127	34	647	35	432	11	61	<5		8.26
clay	MD4120	76.35	0.834	9.52	3.37	0.064	1.44	5.37	0.85	2.12	0.09	70	97	32	16	53	81	148	35	639	28	485	14	97	5		8.65
clay	MD4121	77.09	0.882	11.87	4.56	0.083	1.15	1.05	0.97	2.27	0.08	84	111	47	20	100	98	100	36	585	31	531	41	66	19		7.81
clay	MD4122	93.98	0.261	3.08	1.72	0.022	0.26	0.28	0.05	0.31	0.04	41	42	24	10	20	22	22	13	253	16	216	40	33	<5		2.64
clay	MD4123	76.55	0.905	11.81	4.82	0.075	1.16	2.31	0.54	1.74	0.10	79	154	54	18	60	90	89	36	493	30	437	13	23	28		8.42
clay	MD4124	71.13	0.993	15.31	6.48	0.114	1.87	1.13	0.72	2.17	0.10	121	124	67	22	119	118	122	41	405	27	621	92	44	20		10.04
clay	MD4125	75.07	0.918	13.02	5.31	0.094	1.50	1.49	0.58	1.94	0.09	102	116	49	29	70	100	124	36	473	33	534	34	93	37		8.71
clay	MD4400	76.20	0.817	10.00	3.42	0.059	1.29	5.29	0.63	2.21	0.08	62	79	23	5	39	80	159	37	562	14	427	36	69	14	7	
clay	MD4401	73.07	0.846	11.89	4.44	0.085	1.36	5.26	0.66	2.30	0.09	92	98	37	10	54	91	145	35	467	16	449	29	98	22	10	
clay	MD4402	76.48	0.868	12.52	4.68	0.081	1.19	0.98	0.77	2.36	0.07	93	99	37	<5	54	92	102	38	485	16	461	17	97	20	12	
clay	MD4403	78.55	0.818	11.36	4.04	0.071	0.95	0.89	0.77	2.47	0.08	78	192	94	<5	48	89	103	36	518	15	456	32	89	20	11	
clay	MD4404	76.82	0.867	12.41	4.42	0.084	1.13	1.00	0.68	2.45	0.14	78	88	31	<5	50	82	86	35	430	13	446	22	82	17	12	
clay	MD4405	72.31	0.930	14.84	6.29	0.360	1.37	1.18	0.44	2.19	0.09	127	119	65	22	78	105	98	41	411	16	636	38	111	22	12	
clay	MD4406	77.55	0.839	12.00	4.43	0.072	1.13	0.88	0.70	2.31	0.09	87	92	33	<5	47	85	94	34	471	16	428	31	73	17	<5	

Tab. 9 (Contin.) Project Voitenki (chapter 4.9).

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Sn	Ba	La	Ce	Pb	Co	Sb
		per cent by weight										ppm																
61	MD5178	65.91	0.073	2.57	0.98	0.962	0.65	8.48	19.69	0.58	0.11	23	12	16	54	11	8	517	5	66	<5	6	324	<5	21	<5	<5	<5
105	MD5180	69.31	0.130	2.35	0.76	0.153	0.93	7.02	18.71	0.59	0.05	10	12	11	18	22	8	529	nd	89	<5	7	126	<5	20	21	<5	4734
124	MD5174	69.55	0.064	2.79	0.37	1.041	0.52	8.13	16.86	0.59	0.08	12	7	11	5	11	9	450	<5	66	<5	<5	304	<5	<5	9	<5	10
284	MD5170	68.11	0.244	2.72	1.16	1.160	0.97	5.98	19.03	0.56	0.07	26	25	19	102	20	6	547	6	136	<5	<5	380	<5	17	39	24	163
285	MD5183	67.69	0.290	2.84	1.39	1.488	0.67	5.48	19.52	0.59	0.06	27	44	35	282	34	<5	491	11	139	7		452			292		
370	MD5185	70.05	0.081	2.50	0.43	0.501	0.53	7.72	17.67	0.42	0.09	9	21	10	39	<5	6	463	<5	72	<5	7	333	<5	6	8	<5	24
420	MD5179	66.67	0.099	2.62	0.77	0.903	0.39	10.30	17.14	0.92	0.19	8	20	22	60	22	<5	474	7	61	<5		574			169		
422	MD5177	71.99	0.090	1.82	0.49	1.054	0.67	5.52	17.98	0.34	0.03	11	5	14	9	8	6	416	<5	79	nd	23	295	<5	9	5	<5	20
426	MD5189	70.93	0.079	2.66	0.42	1.202	0.74	8.29	15.01	0.56	0.11	11	13	15	<5	9	8	457	<5	73	<5	<5	291	<5	<5	8	<5	<5
436	MD5181	70.30	0.090	2.76	0.56	0.843	0.80	7.95	16.14	0.46	0.09	27	7	11	10	9	7	474	<5	72	<5	<5	548	<5	15	7	6	<5
438	MD5191	69.52	0.109	1.92	0.66	1.270	0.44	5.88	19.82	0.34	0.03	12	<5	23	28	8	<5	401	8	65	5		326			20		
439	MD5190	67.64	0.110	1.95	0.79	0.891	0.40	7.36	20.25	0.54	0.07	12	21	19	260	22	<5	599	14	82	5		339			341		
444	MD5186	69.29	0.190	2.54	0.88	1.635	0.94	4.50	19.59	0.38	0.05	33	23	14	16	8	6	363	<5	105	<5	<5	193	<5	6	<5	6	42
445	MD5184	71.46	0.091	1.87	0.43	1.085	0.71	5.54	18.45	0.32	0.03	16	<5	10	<5	<5	6	412	<5	79	<5	<5	182	<5	<5	6	<5	<5
447	MD5176	69.43	0.187	2.54	0.89	1.642	0.93	4.48	19.19	0.67	0.05	28	14	16	13	9	7	357	<5	101	<5	36	191	6	24	<5	7	18
630	MD5187	69.71	0.166	2.21	0.99	1.028	0.52	5.13	19.85	0.36	0.03	11	21	26	59	13	<5	491	18	91	<5		338			44		
633	MD5175	67.42	0.264	2.84	1.23	1.354	0.62	5.46	20.35	0.40	0.05	18	33	20	34	14	<5	439	10	119	7		315			19		
636	MD5188	68.19	0.129	1.92	0.72	1.288	0.48	6.51	20.40	0.33	0.04	5	14	22	15	6	<5	487	12	75	<5		337			13		
647	MD5182	69.85	0.114	1.98	0.61	1.403	0.94	6.18	18.57	0.32	0.03	20	8	14	8	9	5	518	<5	86	<5	31	701	<5	12	<5	<5	16
650	MD5171	68.64	0.266	2.88	1.21	1.475	1.03	5.03	18.84	0.57	0.06	29	30	17	17	26	6	483	5	148	<5	19	318	<5	24	6	6	<5
409 gray	MD5173	68.14	0.268	2.78	1.07	1.522	1.01	4.32	20.37	0.48	0.04	32	30	17	9	13	7	377	<5	147	<5	<5	306	<5	13	<5	6	<5
409 green	MD5172	71.23	0.265	2.67	1.06	1.568	1.01	3.38	18.20	0.57	0.05	31	31	17	9	13	8	320	<5	135	<5	<5	301	<5	8	5	5	44
															%											%		
332	MD5169	70.07	0.084	2.13	0.68	0.377	0.19	6.24	19.62	0.51	0.09	14	<5	41	1,8	332	<5	325	159	56	17		278			2,8		

Tab. 10 Project Komariv (chapter 4.10).

Bibliography

'Amr 1987
Khairieh 'Amr. *The Pottery from Petra. A Neutron Activation Analysis Study*. British Archaeological Reports, International Series 324. Oxford: British Archaeological Reports, 1987.

'Amr, Akasheh, and Na'es 2018
Khairieh 'Amr, Talal Akasheh, and Maram Na'es. *Recovery and Reproduction Technology of Nabataean Painted Fine Ware*. 2018. URL: www.cultech.net/sites/default/files/Amr.pdf.

Abdi 2003
Kamyar Abdi. "The Early Development of Pastoralism in the Central Zagros Mountains." *Journal of World Prehistory* 17 (2003), 395–448.

Abe et al. 2012
Yoshinari Abe, Rodan Harimoto, Tadashi Kikugawa, Ken Yazawa, Akiko Nishisaka, Nozomu Kawai, Sakuji Yoshimura, and Izumi Nakai. "Transition in the Use of Cobalt-Blue Colorant in the New Kingdom of Egypt." *Journal of Archaeological Science* 39 (2012), 1793–1808.

Adams 1986
William Y. Adams. *Ceramic Industries of Medieval Nubia*. Memoirs of the UNESCO Archaeological Survey of Sudanese Nubia 1, Part 1. Lexington, KY: University Press of Kentucky, 1986.

Adlington 2017
Laura W. Adlington. "The Corning Archaeological Reference Glasses: New Values for ‚Old' Compositions." *Papers from the Institute of Archaeology* 27.1 (2017). DOI: 10.5334/pia-515.

Adlington 2021
Laura W. Adlington. "Radiation Exposures to Handheld XRF Operators Analyzing Glass." *Academia Letters* 1373 (2021).

Adlington and Freestone 2017
Laura W. Adlington and Ian C. Freestone. *Using Handheld pXRF to Study Medieval Stained Glass: A Methodology Using Trace Elements*. New York: Cambridge University Press, 2017.

Åkerstrom 1967
Åke Åkerstrom. "Mycenaean Potter's Factory at Berbati Near Mycenae." In *Atti e Memorie del 1°Congresso Internazionale di Micenologia. Roma 27 Settembre–3 Ottobre 1967*. Ed. by Rome Congresso internazionale di micenologia. Rome: Edizioni dell-Atereo, 1967, 48–53.

Alawneh and Bala'awi 2012
Firas Alawneh and Fadi Bala'awi. "Chemical and Mineralogical Study of Nabataean Painted Pottery from Petra, Jordan." *Mediterranean Arhaeology and Archaeometry* 12.2 (2012), 183–191.

Alizadeh 1988
Abbas Alizadeh. "Socio-Economic Complexity in Southwestern Iran During the Fifth and Fourth Millennium B.C.: The Evidence from Tall-e Bakun A." *Iran* 26 (1988), 17–34.

Alizadeh 2003
Abbas Alizadeh. *Excavations at the Prehsitoric Mound of Chogha Bonut, Khuzestan, Iran. Seasons 1976/77, 1977/78 and 1996*. Oriental Institute Publications 120. Chicago, IL: The Oriental Institute, 2003.

Alizadeh 2006
Abbas Alizadeh. *The Origins of State Organizations in Highland Iran: The Evidence from Tall-e Bakun A*. Oriental Institute Publications 128. Chicago, IL: Chicago: Oriental Institute, 2006.

Alizadeh 2008
Abbas Alizadeh. *Chogha Mish. Volume II. The Development of a Prehistoric Regional Center in Lowland Susiana, Southwestern Iran. Final Report on the Last Six Seasons of Excavations, 1972–1978*. Oriental Institute Publications 130. Chicago, IL: The Oriental Institute, 2008.

Alizadeh 2010
Abbas Alizadeh. "The Rise of the Highland Elamite State in Southwestern Iran: "Enclosed" or Enclosing Nomadism?" *Current Anthropology* 51 (2010), 353–383.

Andrusieczko 1972
Adam Andrusieczko. *Technologia szkła*. Warsaw: Arkady, 1972.

Arnold 1993
Dorothea Arnold. "Methods of Surface Treatment." In *An Introduction to Ancient Egyptian Pottery. Fascicle 1*. Ed. by D. Arnold and J. Bourriau. Mainz: Philipp von Zabern, 1993, 85–87.

Auer and Daszkiewicz 2017
Martin Auer and Małgorzata Daszkiewicz. "Archaeological Expectations and Archaeometric Results. Some Considerations on Imported Coarse Wares and Local Pottery Production in Aguntum, Austria." In *Roman Pottery and Glass Manufactures. Production and Trade in the Adriatic Region. Proceedings of the 3rd International Archaeological Colloquy, Crikvenica (Croatia), 4th–5th November 2014*. Ed. by G. Lipovac Vrkljan, B. Šiljeg, I. Ožanic Roguljić, and A. Konestra. Crikvenica: Crikvenica Institut za Arheologiju and Muzej Grada Crikvenice, 2017, 97–124.

Auer and Sitz 2014
Martin Auer and Stephanie Sitz. "Die Firmalampenproduktion des EVCARPVS – Eine Studie zur römischen Keramikproduktion. Mit Beiträgen von Gerwulf Schneider, Aaron Plattner und Lambrini Koutoussaki." *Germania* 92 (2014), 85–125.

Balarie et al. 2016
Andrei Balarie, Bernhard S. Heeb, Alexandru Szentmiklosi, Katharina Teinz, Rüdiger Krause, Matthias Wemhoff, and Anthony Harding. "Erste Ergebnisse der Feldforschung an der spätbronzezeitlichen befestigten Siedlung Corneşti-Iarcuri im Sommer 2015." *Acta Praehistorica et Archaeologica* 48 (2016), 51–54.

Baranowski, Daszkiewicz, and G. Schneider 2021
Marcin Baranowski, Małgorzata Daszkiewicz, and Gerwulf Schneider. "Chemical Analysis Using WD-XRF and p-ED-XRF and Using Macroscopic Analysis of Fabrics in Studying Moesian Sigillata." In *Using pXRF for the Analysis of Ancient Pottery – An Expert Workshop in Berlin 2014*. Ed. by M. Hegewisch, M. Daszkiewicz, and G. Schneider. Berlin Studies of the Ancient World 75. Berlin: Edition Topoi, 2021, 111–156.

Barth 1961
Fredrik Barth. *Nomads of South Persia. The Basseri of the Khamseh Confederacy*. Oslo: University Press, 1961.

Baud 2008
Michel Baud. "The Meroitic Royal City of Muweis: First Steps into an Urban Settlement of Riverine Upper Nubia." *Sudan & Nubia* 12 (2008), 52–63.

Baxter, Crummy, and Heyworth 1981
M. J. Baxter, M. P. Crummy, and M. P. Heyworth. "Compositional Analysis of the Roman Vessel Glass from Colchester, Essex." *Colchester Archaeological Report* 8 (1981), 261–306.

Bebermeier et al. 2016
Wiebke Bebermeier, Dennis Beck, Iris Gerlach, Torsten Klein, Daniel Knitter, Kay Kohlmeyer, Jan Krause, Dirce Marzoli, Julia Meister, Bernd Müller-Neuhof, Claudia Näser, Philipp von Rummel, Dorothée Sack, Stephan G. Schmid, Brigitta Schütt, and Ulrike Wulf-Rheidt. "Ancient Colonization of Marginal Habitats. A Comparative Analysis of Case Studies from the Old World." *eTopoi. Journal of Ancient Studies. Special Volume* 6 (2016), 1–44.

Behrendt, Mielke, and Mecking 2012
Sonja Behrendt, Dirk Paul Mielke, and Oliver Mecking. "Die portable Röntgenfluureszenzanalyse (P-RFA) in der Keramikforschung: Grundlagen und Potenzial." *Restaurierung und Archäologie* 5 (2012), 93–110.

Beier and Mommsen 1994
T. Beier and Hans Mommsen. "Modified Mahalanobis Filters for Grouping Pottery by Chemical Composition." *Archaeometry* 36 (1994), 287–306.

Beilke-Voigt 2010
Ines Beilke-Voigt. "Methodische Überlegungen zu bronze-/früheisenzeitlichen Zentralorten mit Bezug auf den Burgwall von Lossow bei Frankfurt (Oder)." In *Zwischen Fjorden und Steppe. Festschrift für Johann Callmer zum 65. Geburtstag*. Ed. by C. Claudia Theune, F. Biermann, R. Struwe, and G. H. Jeute. Internat. Arch. Studia honoraria 31. Rahden/Westf: Verlag Marie Leidorf, 2010, 41–56.

Beilke-Voigt 2012
Ines Beilke-Voigt. "Endlich wiederentdeckt. Das Gräberfeld von Lossow, Stadt Frankfurt (Oder)." *Archäologie in Berlin und Brandenburg 2011* (2012), 45–49.

Beilke-Voigt 2014a
Ines Beilke-Voigt. "Das Burgzentrum Lossow im Spiegel seiner Fernkontakte." In *Ressourcen und Rohstoffe in der Bronzezeit. Nutzung – Distribution – Kontrolle. Beiträge zur Sitzung der AG Bronzezeit auf der Jahrestagung des Mittel- und Ostdeutschen Verbandes für Altertumsforschung in Brandenburg an der Havel, 16. bis 17. April 2012*. Ed. by B. Nessel, I. Heske, and D. Brandherm. Arbeitsberichte zur Bodendenkmalpflege in Brandenburg 26. Wünsdorf: Brandenburgisches Landesamt fur Denkmalpflege und Archaologisches Landesmuseum, 2014, 133–146.

Beilke-Voigt 2014b
Ines Beilke-Voigt. *Das jungbronze- und früheisenzeitliche Burgzentrum von Lossow. Ergebnisse der Ausgrabungen 2008 und 2009. Lossower Forschungen 3*. Materialien zur Archäologie in Brandenburg 8. Rahden/Westf.: Verlag Marie Leidorf, 2014.

Beilke-Voigt 2016
Ines Beilke-Voigt. "Eine Widderfigur im östlichen Brandenburg und ihre Beziehungen zu Tierfiguren des griechischen Mittelmeerraumes und den iranischen Bronzen der Eisenzeit." In *Europa w okresie od VIII w.p.n. Chr. do I w.n.e. [Europa zwischen dem 8. Jh. v. Chr. und 1. Jh. n. Chr. Geb.] Tagungsband zur gleichnamigen Tagung in Biskupin 1.-4.07.2014. Biskupińskie Prace Archeologiczne 11. Polnische Akademie der Wissenschaften Abteilung Wrocław*. Prace Komisji Archeologiczcnej 21. Wrocław: Biskupin, 2016, 87–120.

Beilke-Voigt 2018
Ines Beilke-Voigt. "Lossow, Olympia und der Vordere Orient. Zum Fund einer spätgeometrischen Widderfigur im östlichen Brandenburg." In *KunstHandWerk. Beiträge der 26. Tagung der AG Eisenzeit gemeinsam mit der Keltenwelt am Glauberg und der hessenARCHÄOLOGIE im Landesamt für Denkmalpflege Hessen in Bad Salzhausen, 3.–6. Oktober 2013*. Ed. by M. Augstein, I. Balzer, J. Fries-Knoblach, C. E. Later, K. Ludwig, C. Tappert, P. Trebsche, S. Wefers, and J. Wiethold. Beitr. Ur- u. Frühgesch. Mitteleuropa 84. Langenweißbach: Beier & Beran, 2018, 51–68.

Bemmann 2001
Jan Bemmann. "Die Niemberger Fibeln und die Chronologie der Völkerwanderungszeit in Mitteldeutschland." *Slovenská Archeológia* 49 (2001), 59–101.

Bemmann 2008
Jan Bemmann. *Körperbestattungen der jüngeren Römischen Kaiserzeit und der Völkerwanderungszeit Mitteldeutschlands. Katalog*. Veröffentlichungen des Landesamtes für Archäologie Sachsen-Anhalt, Landesmuseum für Vorgeschichte 61. Halle/Saale: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Landesmuseum für Vorgeschichte, 2008.

Bennet 2011
John Bennet. "The Geography of the Mycenaean Kingdoms." In *A Companion to Linear B. Mycenaean Greek Texts and their World, Vol. 2*. Ed. by Y. Duhoux and A. Morpurgo Davies. Bibliothèque des cahiers de L'Institut de Linguistique de Louvain 127. Warpole, MA: Peeterslouvain-la-Neuve, 2011, 137–168.

Bernbeck 2008
Reinhard Bernbeck. "An Archaeology of Multi-Sited Communities." In *The Archaeology of Mobility. Old World and New World Nomadism*. Ed. by H. Barnard and W. Wendrich. Los Angeles, CA: Cotsen Institute of Archaeology, UCLA, 2008, 43–77.

Bernbeck, Fazeli, and Pollock 2006
Reinhard Bernbeck, Hassan Fazeli, and Susan Pollock. "Life in a Fifth Millennium Village: Excavations at Rahmatabad, 2005." *Near Eastern Archaeology* 68.3 (2006), 94–105.

Bezborodow 1965
M. A. Bezborodow. "Analysis of Glasses from Glass Workshop III–IV cen. AD in Komariv." *материали и дослидження з археологии прикарпаття и волини, випуск* 5 (1965). Title translated, original text in Russian, 81–85.

Bock 2013
Jan Bock. "Der kaiser- und völkerwanderungszeitliche Siedlungsplatz Großs Meckelsen, Ldkr. Rotenburg (Wümme). Bedeutung und Perspektiven seiner Erforschung." In „*Landschaft, Besiedlung und Siedlung*". *Archäologische Studien im nordeuropäischen Kontext. Festschrift für Karl-Heinz Willroth zu seinem 65. Geburtstag*. Ed. by I. Heske, Nüsse H.-J., and J. Schneeweiss. Neumünster and Hamburg: Wachholtz, 2013, 209–216.

Bóna 1975
István Bóna. *Die Mittlere Bronzezeit Ungarns und ihre Südlichen Beziehungen*. Budapest: Akadémiai Kiadó, 1975.

Bönisch, Daszkiewicz, and G. Schneider 2012
Eberhard Bönisch, Małgorzata Daszkiewicz, and Gerwulf Schneider. "Gefäßausstattung eines jüngstbronzezeitlichen Kammergrabes der Lausitzer Kultur mit Briquetage – Interpretation unter Einbeziehung von Keramikanalysen." In *Finden und Verstehen. Festschrift für Thomas Weber zum sechzigsten Geburtstag*. Ed. by H.-J. Beier, S. Ostritz, M. Küßner, D. Schäfer, V. Schimpff, A. Wagner K. Zimmermann, K. Valoch, C. Pasda, A. Rudolph, and T Weber. Beiträge zur Ur- und Frühgeschichte Mitteleuropas 66. Langenweissbach: Beier & Beran, 2012, 195–222.

Borchardt 1907
Ludwig Borchardt. "Voruntersuchung von Tell el-Amarna im Januar 1907." *Mitteilungen der Deutschen Orient-Gesel lschaft (MDOG)* 34 (1907), 14–31.

Borchardt 1911
Ludwig Borchardt. "Ausgrabungen in Tell el-Amarna 1911. Vorläufiger Bericht." *Mitteilungen der Deutschen Orient-Gesel lschaft (MDOG)* 46 (1911), 1–37.

Borchardt 1912
Ludwig Borchardt. "Ausgrabungen in Tell el-el-Ama 1911/12. Vorl ¨aufiger Bericht." *Mitteilungen der Deutschen Orient-Gesel lschaft (MDOG)* 50 (1912), 1–45.

Borchardt 1913
Ludwig Borchardt. "Ausgrabungen in Tell el-Amarna 1912/13. Vorläufiger Bericht." *Mitteilungen der Deutschen Orient-Gesel lschaft (MDOG)* 52 (1913), 1–55.

Borchardt 1914
Ludwig Borchardt. "Ausgrabungen in Tell el-Amarna 1913/14. Vorläufiger Bericht." *Mitteilungen der Deutschen Orient-Gesel lschaft (MDOG)* 55 (1914), 3–39.

Borchardt 1917
Ludwig Borchardt. "Aus der Arbeit an den Funden von Tell el-Amarna." *Mitteilungen der Deutschen Orient-Gesel lschaft (MDOG)* 57 (1917), 1–32.

Borchardt and Ricke 1980
Ludwig Borchardt and Herbert Ricke. *Die Wohnhäuser in Tell el-Amarna, Ausgrabungen der Deutschen Orient-Gesellschaft in Tell El-Amarna, Band V*. Wissenschaftliche Veröffentlichungen der Deutschen Orient-Gesellschaft 91. Berlin: Gebr. Mann Verlag, 1980.

Boulanger 2014
Matthew Boulanger. *Egyptian Ceramics: Compositional and Descriptive Database*. tDAR id: 372352. Lawrence Berkeley National Laboratory. 2014. DOI: doi:10.6067/XCV8ZC8187.

Brather 2010
Martina-Johanna Brather. "Ein kaiser- und völkerwanderungszeitliches Brandgräberfeld bei Briesnig, Lkr. Spree-Neiße." *Veröffentlichungen zur Brandenburgischen Landesarchäologie* 41/42 (2010), 161–230.

Brüggler and Berke 2009
Marion Brüggler and Hubert Berke. *Villa rustica, Glashütte und Gräberfeld. Die kaiserzeitliche und spätantike Siedlungsstelle HA 132 im Hambacher Forst*. Mainz: Philipp von Zabern, 2009.

Brumfiel and Earle 1987
Elizabeth M. Brumfiel and Timothy K. Earle. *Specialization, Exchange, and Complex Societies*. Cambridge: Cambridge University Press, 1987.

Catling, Richards, and Blin-Stoyle 1963
Hector William Catling, E. E. Richards, and A. E. Blin-Stoyle. "Correlations between Composition and Provenance of Mycenaean and Minoan Pottery." *The Annual of the British School at Athens* 58 (1963), 94–115.

Connoly and Lake 2006
James Connoly and Mark Lake. *Geographical Information Systems in Archaeology*. Cambridge Manuals in Archaeology. Cambridge: Cambridge University Press, 2006.

Costin 1991
Cathy L. Costin. "Craft Specialization: Issues in Defining, Documenting, and Explaining the Organization of Production." *Archaeological Method and Theory* 3 (1991), 1–56.

Cribb 1991
Roger Cribb. *Nomads in Archaeology*. Cambridge: Cambridge University Press, 1991.

Czukor et al. 2017
Péter Czukor, Anna Priskin, Csaba Szalontai, and Vajk Szeverényi. "Késő bronzkori földvárak a Dél-Alföldön. Late Bronze Age Fortified Settlements in the Southern Great Pannonian Plain." In *A második hajdúböszörményi szitula és kapcsolatrendszere. The Second Situla of HajdúBöSzöRméNy and Its Relations*. Ed. by V. G. Szabó, M. Bálint, and G. Váczi. Studia Oppidorum Haidonicalium XIII. Budapest and Hajdúböszörmény: Eötvös Loránd Tudományegyetem, Régészettudományi Intézet, 2017, 211–230.

Dardeniz 2017
Gonca Dardeniz. "Sharing Technologies and Workspaces for Ceramic and Vitrified Material Production at Tell Atchana-Alalakh." In *Overturning Certainties: A Festschrift Dedicated to K. Aslıhan Yener on her 40th year of Archaeological Research*. Ed. by Ç. Maner, M. Horowitz, and A. S. Gilbert. Leiden: Brill Publications, 2017, 139–156.

Daszkiewicz 2006
Małgorzata Daszkiewicz. "Composition and Technology of a Glass Vessel From Tell Arbid." *Damaszener Mitteilungen* 15 (2006), 95–99.

Daszkiewicz 2014
Małgorzata Daszkiewicz. "Ancient Pottery in the Laboratory – Principles of Archaeological Investigations of Provenance and Technology." *Novensia* 25 (2014), 177–197.

Daszkiewicz and Bobryk 1998
Małgorzata Daszkiewicz and Ewa Bobryk. "Untersuchung und Charakterisierung von „Fehlbränden"." In *Archäometrie und Denkmalpflege – Kurzberichte 1998*. Ed. by A. Hauptmann. Würzburg, 1998, 90–92.

Daszkiewicz and Bobryk 2001
Małgorzata Daszkiewicz and Ewa Bobryk. "Pottery Manufacturing Technology Detected from Ceramic Properties (K-H Method)." In *Archäometrie und Denkmalpflege – Kurzberichte 2001*. Ed. by U. Schüssler and R. Fuchs. Cologne, 2001, 113–115.

Daszkiewicz and Bobryk 2011
Małgorzata Daszkiewicz and Ewa Bobryk. "Pottery from Delos (Greece) – Estimation of Original Firing Temperature." *Études et Travaux* 24 (2011), 67–75.

Daszkiewicz and Bobryk 2013
Małgorzata Daszkiewicz and Ewa Bobryk. "Gypsum on Pottery Surfaces Detected by pXRF – Alteration, Forming or Geometry?" In *Archäometrie und Denkmalpflege 2013. Jahrestagung an der Bauhaus-Universität Weimar*. Ed. by A. Hauptmann, O. Mecking, and M. Prange. Metalla, Sonderheft 6. Bochum: Deutsches Bergbau-Museum, 2013, 154–158.

Daszkiewicz and Bobryk 2014
Małgorzata Daszkiewicz and Ewa Bobryk. "Analysis of Ceramic Vessel Surfaces Using pXRF: Preliminary Results of Experiments with Gypsum Moulds and Salt Production by Boiling Brine." In *Using pXRF for the Analysis of Ancient Pottery – An Expert Workshop in Berlin 2014*. Ed. by M. Hegewisch, M. Daszkiewicz, and G. Schneider. Berlin Studies of the Ancient World 75. Berlin: Edition Topoi, 2014, 303–320.

Daszkiewicz, Bobryk, and G. Schneider 2000
Małgorzata Daszkiewicz, Ewa Bobryk, and Gerwulf Schneider. "Waterpermeability and Thermal Shock Resistance of 6th–3rd Millennium Cookingpots from North Mesopotamia." In *Archäometrie und Denkmalpflege – Kurzberichte 2000. Zusammenfassung der Vorträge und Poster der Jahrestagung 2000, Landesamt für Archäologie Dresden*. Ed. by G. Schulze and I. Horn. Berlin: Mensch & Buch Verlag, 2000, 98–101.

Daszkiewicz, Bobryk, and G. Schneider 2003
Małgorzata Daszkiewicz, Ewa Bobryk, and Gerwulf Schneider. "Continuity and Change in Pottery Making from the Mesolithic to Christian Period in the Fourth Cataract Region (Sudan)." In *Gdansk Archaeological Museum*. Ed. by H. Paner. African Reports 2. Gdansk, 2003, 81–91.

Daszkiewicz, Bobryk, and Wetendorf 2016
Małgorzata Daszkiewicz, Ewa Bobryk, and Manja Wetendorf. "Why Did Meroitic Potters Need Organic Temper? Based on Findings from Musawwarat es-Sufra (Sudan)." In *Archäometrie und Denkmalpflege 2016*. Ed. by S. Greiff, A. Kronz, F. Schlütter, and M. Prange. Metalla, Sonderheft 8. Bochum: Deutsches Bergbau-Museum, 2016, 140–143.

Daszkiewicz, Bobryk, and Wetendorf 2017
Małgorzata Daszkiewicz, Ewa Bobryk, and Manja Wetendorf. *An Experimental Study on Evaluation of Density Measurements by He-Pycnometer in the Reconstruction of Ancient Pottery Forming Techniques, EMAC2017 – European Meeting on Ancient Ceramics (6–9 Sept 2017 Bordeaux, France)*. 2017.

Daszkiewicz, Krogulska, and Bobryk 2000
Małgorzata Daszkiewicz, M. Krogulska, and Ewa Bobryk. "Composition and Technology of Roman Brittle Ware from a Kiln Site in Palmyra (Syria)." *Rei Cretariae Romanae Fautorum Acta* 36 (2000), 537–548.

Daszkiewicz, Liesen, and G. Schneider 2014
Małgorzata Daszkiewicz, Bernd Liesen, and Gerwulf Schneider. "Provenance Study of Hellenistic, Roman and Byzantine Kitchen Wares from the Theatre-Temple Area of Umm Qais/Gadara, Jordan." In *Roman Pottery in the Near East. Local Production and Regional Trade*. Ed. by B. Fischer-Genz, Y. Gerber, and H. Hamel. Roman and Late Antique Mediterranean Pottery 3. Oxford: Archaeopress, 2014, 147–158.

Daszkiewicz and Malykh 2017
Małgorzata Daszkiewicz and Swietlana Malykh. "Pottery Samples Recovered from Abu Erteila (Sudan) – Correlation of Macroscopically Identified Fabrics with Laboratory-Defined Raw Material Groups." *Studia Europaea Gnesnensia* 15 (2017), 9–35.

Daszkiewicz and Maritan 2016
Małgorzata Daszkiewicz and Lara Maritan. "Experimental Firing and Re-Firing." In *The Oxford Handbook of Archaeological Ceramic Analysis*. Ed. by A. M. W. Hunt. Oxford: Oxford University Press, 2016, 487–508.

Daszkiewicz and G. Schneider 2001a
Małgorzata Daszkiewicz and Gerwulf Schneider. "Chemical and Mineralogical-Petrographic Composition of Fabrics from Musawwarat Es-Sufra, Sudan." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 12 (2001), 80–91.

Daszkiewicz and G. Schneider 2001b
Małgorzata Daszkiewicz and Gerwulf Schneider. "Klassifizierung von Keramik durch Nachbrennen von Scherben." *Zeitschrift für Schweizerische Archäologie und Kunstgeschichte* 58 (2001), 25–32.

Daszkiewicz and G. Schneider 2011
Małgorzata Daszkiewicz and Gerwulf Schneider. "Keramik aus Meroe und Hamadab. Bericht über die ersten Ergebnisse zur Klassifikation durch Nachbrennen (MGR-Analyse) und chemische Analyse (WD-XRF)." *Archäologischer Anzeiger* 2 (2011), 247–265.

Daszkiewicz and G. Schneider n.d.
Małgorzata Daszkiewicz and Gerwulf Schneider. "Naturwissenschaftliche Analysen." In *Keramik der Černjachov-Kultur. Untersuchungen an Materialien aus Vojtenki (Ostukraine)*. Ed. by E. Schultze and M. V. Ljubičev. in press.

Daszkiewicz, G. Schneider, Baranowski, et al. 2018
Malgorzata Daszkiewicz, Gerwulf Schneider, Marcin Baranowski, David Petrut, Viorica Rusu-Bolindeţ, and Nicoleta Man. "Moesian and Dacian Sigillata – Exploring Regional Patterns. A Methodological Approach Using Chemical Analysis by WD-XRF and p-ED-XRF." *Rei Cretariae Romanae Favtorvm Acta* 45 (2018), 541–549.

Daszkiewicz, G. Schneider, Wetendorf, et al. 2015
Małgorzata Daszkiewicz, Gerwulf Schneider, Manja Wetendorf, and Ewa Bobryk. "The Alteration Effect of Ashes – Model Analysis on Raw Materials from Musawwarat es Sufra (Sudan)." In *Archäometrie und Denkmalpflege 2015*. Ed. by T. Gluhak, S. Greiff, K. Kraus, and M. Prange. Metalla, Sonderheft 7. Bochum: Deutsches Bergbau-Museum, 2015, 89–91.

Daszkiewicz, van Ess, and G. Schneider 2012
Małgorzata Daszkiewicz, Margarete van Ess, and Gerwulf Schneider. "Pottery and Clay from Uruk, Southern Iraq – Laboratory Analysis of Pottery Fabrics from the Late Uruk to the Seleucid Periods." *Zeitschrift für Orient-Archäologie* 5 (2012), 90–102.

Daszkiewicz and Wetendorf 2014
Małgorzata Daszkiewicz and Manja Wetendorf. "A New Series of Laboratory Analyses of Coarse Wares from 'Pottery Courtyard' 224 of the Great Enclosure in Musawwarat Es-Sufra (Sudan)." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 24 (2014), 99–104.

Daszkiewicz and Wetendorf 2017
Małgorzata Daszkiewicz and Manja Wetendorf. "Experimental Archaeology: First Steps to Understanding the Firing Technology of Meroitic Pottery from Musawwarat es-Sufra." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 28 (2017), 7–14.

Daszkiewicz, Wetendorf, et al. 2016
Małgorzata Daszkiewicz, Manja Wetendorf, Ewa Bobryk, and Gerwulf Schneider. "Musawwarat es-Sufra – In Search of Ceramic Raw Materials." *Novensia* 27 (2016), 181–220.

Davies 1933
Norman de Garis Davies. *The Tombs of Menkheperrasonb, Amenmose, and Another (Nos. 86, 112, 42, 226)*. London: Egypt Exploration Society, 1933.

Dekówna 1980
Malgorzata Dekówna. *Szko w Europie wczesnośredniowiecznej*. Warsaw, 1980.

Devulder and Degryse 2014
Veerle Devulder and Patrick Degryse. "The Sources of Natron." In *Glass Making in the Greco-Roman Word, Results of the ARCHGLASS Project*. Ed. by P. Degryse. Leuven: Leuven University Press, 2014, 87–96.

Dittmann 1984
Reinhard Dittmann. *Eine Randebene des Zagros in der Frühzeit. Ergebnisse des Behbehan-Zuhreh Surveys*. BBVO 3. Berlin: Dietrich Reimer, 1984.

Dittrich 2003
Annett Dittrich. "Meroitische und spätmeroitische Keramik aus Hamadab." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 14 (2003), 77–91.

Dobrzańska 1990
Halina Dobrzańska. *Osada z późnego okresu rzymskiego w Igołomi, woj. Krakowskie. Część I. Materiały, Część II.* Wroclaw et al.: Zakład Narodowy Imienia Ossolińskich, 1990.

Dollfus 1978
Geneviève Dollfus. "Djaffarabad, Djowi, Bendebal: Contribution à l'etude de la Susiane au 5e millénaire et au début du 4e millénaire." *Paléorient* 4 (1978), 141–167.

Domański 1982
Grzegorz Domański. *Cmentarzysko w Luboszycach (II–IV w.)* Wroclaw: Zakład Narodowy Imienia Ossolińskich, 1982.

Dušek 1992
Sigrid Dušek. *Römische Handwerker im germanischen Thüringen. Ergebnisse der Ausgrabungen in Haarhausen, Kr. Arnstadt*. Weimarer Monographien zur Ur- und Frühgeschichte 27. Stuttgart: Theiss, 1992.

Earle 1981
Timothy K. Earle. "Comments on the Evolution of Specialized Pottery Production: A Trial Model." *Current Anthropology* 22.3 (1981), 230–231.

Eccleston 2008
Mark Eccleston. "Replicating Faience in a Bread Oven at Amarna." *Egyptian Archaeology* 32 (2008), 33–35.

Edwards 1998
David N. Edwards. "Report on the Musawwarat Pottery." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 8 (1998), 62–67.

Edwards 1999
David N. Edwards. *A Meroitic Pottery Workshop at Musawwarat es Sufra. Preliminary Report on the Excavations 1997 in Courtyard 224 of the Great Enclosure*. Meroitica 17.2: Musawwarat es Sufra III. Wiesbaden: Harrassowitz, 1999.

Egami and Sono 1962
Namio Egami and Toshihiko Sono. *Marv Dasht II. Excavations at Tall-i Gap, 1959*. Tokyo: University of Tokyo, 1962.

Egypt – Ministry of Culture – Supreme Council of Antiquities n.d.
Arab Republic of Egypt – Ministry of Culture – Supreme Council of Antiquities. *Law on the Protection of Antiquities: Law No. 117 of 198*. last accessed 06/14/2021. Unesco Digital Library. URL: https://unesdoc.unesco.org/ark:/48223/pf0000066629.

Eide et al. 1998
Tormod Eide, Tomas Hägg, Richard Holton Pierce, and László Török, eds. *Fontes Historiae Nubiorum, Textual Sources for the History of the Middle Nile Region between the Eighth Century BC and the Sixth Century AD, Vol. 3: From the First to the Sixth Century AD*. Bergen: Klassisk Institutt, Universitetet i Bergen, 1998.

Eigner 1999
Dieter Eigner. "Bemerkungen zu den ‚nichtsakralen' Teilen der Großen Anlage." *Nürnberger Blätter zur Archäologie, Sonderheft Sudan* (1999), 45–46.

Eigner 2010
Dieter Eigner. "Where Kings Met Gods – The Great Enclosure at Musawwarat es Sufra." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 21 (2010), 7–22.

Emberling and Minc 2016
Geoff Emberling and Leah Minc. "Ceramics and Long-Distance Trade in Early Mesopotamian States." *Journal of Archaeological Science: Reports* 7 (2016), 819–834.

Endesfelder and Priese 1984
E. Endesfelder and K.H. Priese. "Heft 9/10. Historisch-biographische Urkunden aus der Zeit Thutmosis III. (Heft 9/10, Nr. 201–215)." In *Urkunden der 18. Dynastie, Übersetzung zu den Heften 5–16*. Ed. by K. Sethe, W. Helck, E. Blumenthal, I. Müller, W. F. Reinike, and A. Burkhardt. Berlin: Akademie Verlag, 1984.

Fischer and Peter 2009
Andreas Fischer and Markus Peter. *Vorsicht Glas! Die römischen Glasmanufakturen von Kaiseraugst*. Forschungen in Augst 37. Augst: Augusta Raurica, 2009.

Frankfort and Pendlebury 1933
Henri Frankfort and John Devitt Stringfellow Pendlebury. *The City of Akhetaten. Part II: The North Suburb and the Desert Altars, The Excavations at Tell el-Amarna during the Seasons 1926–1932*. Excavation Memoirs 40. London: The Egypt Exploration Society, 1933.

Freestone 2015
Ian C. Freestone. "The Recycling and Reuse of Roman Glass: Analytical Approaches." *Journal of Glass Studies* 57 (2015), 29–40.

Freestone, Hughes, and Stapleton 2008
Ian C. Freestone, Michael J. Hughes, and Colleen P. Stapleton. "The Composition and Production of Anglo-Saxon Glass." In *Catalogue of Anglo-Saxon Glass in the British Museum*. Ed. by V. I. Evison, S. Marzinzik, I. C. Freestone, M. J. Hughes, and C. P. Stapleton. London: British Museum Press, 2008, 29–46.

Friedman 1998
Florence D. Friedman. *Gifts of the Nile: Ancient Egyptian Faience*. London: Thames and Hudson, 1998.

Galetti 1994
Guilio Galetti. "Analisi di ceramica antica con fluorescenza X. Confronto dei risutati di tre laboratori, 1st European Workshop on Archaeological Ceramics." In *Proceedings of the 1st Workshop on Archaeological Ceramics, 10.–12.10.1999*. Ed. by F. Burragato, O. Grubessi, and L. Lazzarini. Rome: Dip. Scienze della Terra, Università degli Studi di Roma "La Sapienza", 1994, 205–227.

Ganslmeier 2008
Robert Ganslmeier. *Turbanmode in Mitteleuropa. Riefenrandgefäße als Wandschmuck und Gefäßdeckel. Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt. Landesmuseum für Vorgeschichte. Fund des Monats März 2008*. Last accessed: 12.06.2017. Sachsen-Anhalt: Landesamt für Denkmalpflege Archäologie Sachsen-Anhalt, Landesmuseum für Vorgeschichte, 2008. URL: http://www.lda-lsa.de/landesmuseum_fuer_vorgeschichte/fund_des_monats/2008/maerz/.

Gerullat 2001
Ines Gerullat. "Zusammenfassender Bericht zur vorläufigen Dokumentation der Keramikfunde der Ausgrabungskampagnen in den Jahren 1960 bis 1968 in Musawwarat es Sufra." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 12 (2001), 64–79.

Girgard 2017
D. Girgard. *Das spätbronzezeitliche Brandgräberfeld von Lossow (Brandenburg)*. Masters thesis. MA thesis. Berlin: Freie Universität Berlin, 2017.

Gogâltan 2004
Florin Gogâltan. *Bronzul mijlociu în Banat. Opinii privind Grupul Corneşti-Crvenka, in Festschrift für Florin Medeleț*. Timişoara: Muzeul Banatului Timişoara, 2004.

Gogâltan and Sava 2010
Florin Gogâltan and Victor Sava. *Sântana Cetatea Veche. A Bronze Age Earthwork on the Lower Mureş*. Arad: Complexul Muzeal Arad, 2010.

Guksch et al. 1995
Heike Guksch, Irmtraut Munro, John H. Taylor, and Dieter Johannes. *Die Gräber des Nacht-Min und des Men-cheper-Ra-seneb: Theben Nr. 87 and79*. Mainz: Philipp von Zabern, 1995.

Gumă 1993
Marian Gumă. *Civilizaţia primei epoci a fierului în sud-vestul României*. Bucharest: Istitutul Român de Tracologie, 1993.

Gunneweg, Perlman, and Asaro 1988
Jan Gunneweg, Isadore Perlman, and Frank Asaro. "The Origin, Classification and Chronology of Nabataean Painted Fine Ware." *Jahrbuch des Römisch-Germanischen Zentralmuseums* 35 (1988), 315–345.

Gustavs 1989
Sven Gustavs. "Werkabfälle eines germanischen Feinschmiedes von Klein Köris, Kr. Königs Wusterhausen." *Veröffentlichungen des Museums für Ur- und Frühgeschichte Potsdam* 23 (1989), 147–180.

Hankey 1979
V. Hankey. "Crete, Cyprus and the South-Eastern Mediterranean, 1400–1200 B.C." In *Acts of the International Archaeological Symposium "The relations between Cyprus and Crete, ca. 2000–500 BC", Nicosia, 16th April–22nd April 1978*. Nicosia: Department of Antiquities, Cyprus, 1979.

Hankey 1997
V. Hankey. "Aegean Pottery at el-Amarna: Shapes and Decorative Motifs." In *Ancient Egypt, the Aegean and the Near East. Studies in Honour of Martha Rhoads Bell*. Ed. by J. Phillips and M. et al. Rhoads Bell. Vol. I. San Antonio: Van Siclen, 1997, 193–218.

Heeb, Jahn, and Szentmiklosi 2014
Bernhard S. Heeb, Christoph Jahn, and Alexandru Szentmiklosi. "Geschlossene Gesellschaft? Zur Gestaltung und Bedeutung bronzezeitlicher Festungstore." In *Festschrift für Alix Hänsel zum 63. Geburtstag und Abschied aus dem Museumsdienst*. Ed. by M. Wemhoff. Acta Praehistorica et Archaeologica 46. Berlin: Staatliche Museen zu Berlin, Preußischer Kulturbesitz, 2014, 67–103.

Heeb, Szentmiklosi, Harding, et al. 2012
Bernhard S. Heeb, Alexandru Szentmiklosi, Anthony Harding, and Rüdiger Krause. "Die spätbronzezeitliche Befestigungsanlage Corneşti-Iarcuri im rumänischen Banat – Ein kurzer Forschungsbericht der Jahre 2010 und 2011." *Acta Praehistorica et Archaeologica* 44 (2012), 47–58.

Heeb, Szentmiklosi, and Krause 2015
Bernhard S. Heeb, Alexandru Szentmiklosi, and Rüdiger Krause. "Corneşti-Iarcuri – Ergebnisse der archäologischen Untersuchungen 2007 bis 2014 an der größten prähistorischen Befestigung Europas." *Mitteilungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* 36 (2015), 57–68.

Hegewisch 2011
Morten Hegewisch. "Zur Drehscheibenkeramik im Westen der *Germania magna* – Anfänge, Weiterentwicklung und Verbreitung." In *Drehscheibentöpferei im Barbaricum – Technologietransfer und Professionalisierung eines Handwerks am Rande des Römischen Imperiums. Akten der 3. Internationalen Tagung in Bonn vom 11. bis 14. Juni 2009*. Ed. by J. Bemmann, M. Hegewisch, M. Meyer, and M. Schmauder. Bonner Beiträge zur Vor - und Frühgeschichtlichen Archäologie 13. Bonn: Vor- und Frühgeschichtliche Archäologie, Rheinische Friedrich-Wilhelms-Universität Bonn, 2011, 119–174.

Hegewisch and Meyer 2011
Morten Hegewisch and Michael Meyer. "Naturwissenschaftliche Analysen kaiserzeitlicher Drehscheibenkeramik aus Brandenburg – Archäologischer Kommentar." In *Drehscheibentöpferei im Barbaricum – Technologietransfer und Professionalisierung eines Handwerks am Rande des Römischen Imperiums. Akten der 3. Internationalen Tagung in Bonn vom 11. bis 14. Juni 2009*. Ed. by J. Bemmann, M. Hegewisch, M. Meyer, and M. Schmauder. Bonner Beiträge zur Vor - und Frühgeschichtlichen Archäologie 13. Bonn: Vor- und Frühgeschichtliche Archäologie, Rheinische Friedrich-Wilhelms-Universität Bonn, 2011, 35–44.

Helwing 2010
Mojgan Helwing Barbara und Seyedin. "Bakun-Period Sites in the Darre-ye Bolaghi, Fars." In *Beyond the Ubaid: Transformation and Integration in the Late Prehistoric Societies of the Middle East*. Ed. by R. A. Carter and G. Philip. Studies in Ancient Oriental Civilization 63. Chicago, IL: The Oriental Institute, 2010, 277–292.

Henderson 2013
Julian Henderson. *Ancient Glass: An Interdisciplinary Exploration*. Cambridge: Cambridge University Press, 2013.

F. Hintze 1984
Fritz Hintze. "Diskussionsbeitrag zum Thema „Meroitische Architektur"." In *Meroitische Forschungen 1980, Akten der 4. Internationalen Tagung für meroitische Forschungen*. Meroitica 7. Berlin: Akademie Verlag, 1984, 332–346.

F. Hintze and U. Hintze 1970
Fritz Hintze and Ursula Hintze. "Einige neue Ergebnisse der Ausgrabungen des Instituts für Ägyptologie der Humboldt-Universität zu Berlin in Musawwarat es Sufra." In *Kunst und Geschichte Nubiens in christlicher Zeit*. Ed. by E. Dinkler. Recklinghausen: Bongers, 1970, 49–70.

Hodder and Orton 1976
Ian Hodder and Clive Orton. *Spatial Analysis in Archaeology*. Cambridge: Cambridge University Press, 1976.

Hodgkinson 2010
Anna K. Hodgkinson. "High-Status Industries in the Capital- and Royal Cities of the New Kingdom." In *Commerce and Economy in Ancient Egypt: Proceedings of the Third International Congress for Young Egyptologists 25–27 September 2009, Budapest*. Ed. by A. Hudecz and M. Petrik. British Archaeological Reports, International Series 2131. Oxford: Archaeopress, 2010, 71–79.

Hodgkinson 2012
Anna K. Hodgkinson. "Excavation of the 'Industrial Area': IA1." *Journal of Egyptian Archaeology* 98 (2012), 46–48.

Hodgkinson 2015
Anna K. Hodgkinson. "Archaeological Excavations of a Bead Workshop in the Main City at Tell el-Amarna." *Journal of Glass Studies* 57 (2015), 279–284.

Hodgkinson 2016
Anna K. Hodgkinson. "Amarna Glass: From Egypt through the Ancient World." *Egyptian Archaeology* 48 (2016), 23–27.

Hodgkinson 2017
Anna K. Hodgkinson. *Technology and Urbanism in Late Bronze Age Egypt*. Oxford Studies in Egyptology 1. Oxford: Oxford University Press, 2017.

Hodgkinson 2020
Anna K. Hodgkinson. "Manufacturing Colourful Glass Objects in New Kingdom Egypt: A Spatial and Statistical Analysis." In *The Value of Colour. Material and Economic Aspects in the Ancient World*. Ed. by D. A. Warburton and S. Thavapalan. Berlin Studies of the Ancient World 70. Edition Topoi, 2020, 125–176.

Hodgkinson and Bertram 2020
Anna K. Hodgkinson and Miriam Bertram. "Working with Fire: Making Glass Beads at Amarna using Methods from Metallurgical Scenes." In *Contributions of Experimental Archaeology to Excavation and Material Studies*. Ed. by F. W. Rademakers, G. Verly, F. Téreygeol, and J. Auenmüller. Journal of Archaeological Science: Reports 33. 2020, 102488.

Hodgkinson and Frick 2020a
Anna K. Hodgkinson and Daniel A. Frick. *Data set of Major, Minor and Trace Elements in Co-Coloured Egyptian Glass Objects from the 18th Dynasty Workshops at Amarna, Egypt*. last accessed 04/14/2021. GFZ Data Services. 2020. DOI: https://doi.org/10.5880/GFZ.3.3.2019.001. URL: https://dataservices.gfz-potsdam.de/panmetaworks/showshort.php?id=escidoc:3907909.

Hodgkinson and Frick 2020b
Anna K. Hodgkinson and Daniel A. Frick. "Identification of Cobalt-Coloured Egyptian Glass Objects by LA-ICP-MS: A Case Study from the 18th Dynasty Workshops at Amarna, Egypt." *Mediterranean Archaeology and Archaeometry* 20.1 (2020), 45–57.

Hodgkinson, Röhrs, et al. 2019a
Anna K. Hodgkinson, Stefan Röhrs, Katharina Müller, and Ina Reiche. *Portable X-Ray Fluorescence Analysis of Late Bronze Age Glass from Amarna, Documentation*. last accessed 06/14/2021. Edition Topoi. 2019. DOI: 10.17171/2-15-1. URL: http://repository.edition-topoi.org/collection/KBLT/object/9999.

Hodgkinson, Röhrs, et al. 2019b
Anna K. Hodgkinson, Stefan Röhrs, Katharina Müller, and Ina Reiche. "The Use of Cobalt in 18th Dynasty Blue Glass from Amarna: The Results from an on-site Analysis using Portable XRF Technology." *STAR: Science & Technology of Archaeological Research* 5.2 (2019), 1–17.

Höhne (ehemals Hofmann) 2021
Antonia Höhne (ehemals Hofmann). "Evaluation and Calibration of the p-ED-XRF Analyser "Tracer" (Co. Bruker) for Classifying Pottery from the Middle Euphrates in Comparison with WD-XRF-Results." In *Using pXRF for the Analysis of Ancient Pottery – An Expert Workshop in Berlin 2014*. Ed. by M. Hegewisch, M. Daszkiewicz, and G. Schneider. Berlin Studies of the Ancient World 75. Berlin: Edition Topoi, 2021, 157–176.

Hole 1987
Frank Hole. "Archaeology of the Village Period." In *The Archaeology of Western Iran: Settlement and Society from Prehistory to the Islamic Conquest*. Ed. by F. Hole. Wahsington, D.C.: Smithsonian Institution Press, 1987, 29–78.

Hummel and Soeters 1999
J. Hummel and G. Soeters. "Speicherareal der Extraklasse." In *Archäologie in Berlin und Brandenburg 1998*. Ed. by Archaologische Gessellschaft in Berlin und Brandenburg. Stuttgart: Theiss in Kommission, 1999, 68–71.

Hunt 2017
Alice Hunt. *The Oxford Handbook of Archaeological Ceramic Analysis*. Ed. by Alice Hunt. Oxford: Oxford University Press, 2017.

Istenič and G. Schneider 2000
Janka Istenič and Gerwulf Schneider. "Aegean Cooking Ware in the Eastern Adriatic." *Rei Cretariae Romanae Fautorum Acta* 36 (2000), 341–348.

Jackson and Nicholson 2010
Caroline M. Jackson and Paul T. Nicholson. "The Provenance of Some Glass Ingots from the Ulubrun Shipwreck." *Journal of Archaeological Science* 37 (2010), 295–301.

Jasim 1985
Sabah A. Jasim. *The Ubaid Period in Iraq. Recent Excavations in the Hamrin Region*. British Archaeological Reports, International Series 267. Oxford: Archaeopress, 1985.

Kaczmarczyk 1986
Alexander Kaczmarczyk. "The Source of Cobalt in Ancient Egyptian Pigments." In *Proceedings of the 24th International Archaeometry Symposium, Washington, DC*. Ed. by J. S. Olin and M. J. Blackman. Washington, D. C.: Smithsonian Institution Press, 1986, 369–376.

Kaiser and Shugar 2012
Bruce Kaiser and Aaron N. Shugar. "Glass Analysis Utilizing Handheld X-Ray Fluorescence." In *Handheld XRF for Art and Archaeology*. Ed. by A. N. Shugar and J. L. Mass. Studies in Archaeological Sciences 3. Leuven: Leuven University Press, 2012, 449–470.

Kemp 1977
Barry J. Kemp. "The City of el-Amarna as a Source for the Study of Urban Society in Ancient Egypt." *World Archaeology* 9.2 (1977), 123–139.

Kemp 1989
Barry J. Kemp. "Appendix: Workshops and Production at el-Amarna." In *Amarna Reports V*. Ed. by B. J. Kemp. Egypt Exploration Society Occasional Publications 6. London: The Egypt Exploration Society, 1989, 56–63.

Kemp 2012
Barry J. Kemp. *The City of Akhenaten and Nefertiti: Amarna and its People*. London: Thames and Hudson, 2012.

Kemp and Garfi 1993
Barry J. Kemp and Salvatore Garfi. *A Survey of the Ancient City of El-'Amarna*. Egypt Exploration Society Occasional Publications 9. London: The Egypt Exploration Society, 1993.

Kemp, Samuel, and Luff 1994
Barry J. Kemp, Delwen Samuel, and Rosemary Luff. "Food for an Egyptian City: Tell el-Amarna." In *Whither Environmental Archaeology?* Ed. by R. Luff and P. Rowley-Conwy. Oxbow Monograph 38; Symposia of the Association for Environmental Archaeology 11. Oxford: Oxbow Books, 1994, 133–153.

Kemp and Stevens 2010a
Barry J. Kemp and Anna Stevens. *Busy Lives at Amarna: Excavations in the Main City (Grid 12 and the House of Ranefer, N49.18). Volume I: The Excavations, Architecture and Environmental Remains*. London: The Egypt Exploration Society, 2010.

Kemp and Stevens 2010b
Barry J. Kemp and Anna Stevens. *Busy Lives at Amarna: Excavations in the Main City (Grid 12 and the House of Ranefer, N49.18), Volume II: The Objects (Excavation Memoirs)*. Excavation Memoirs 91. London: The Egypt Exploration Society, 2010.

Knudtzon 1964a
Jörgen Alexander Knudtzon. *Die el-Amarna-Tafeln, Teil I*. Aalen: Zeller, 1964.

Knudtzon 1964b
Jörgen Alexander Knudtzon. *Die el-Amarna-Tafeln, Teil II*. Aalen: Zeller, 1964.

Krapivina 2007
Valentina V. Krapivina. "Olbia Pontica in the 3rd–4th Centuries AD." In *Ancient Greek Colonies in the Black Sea*. Ed. by D. V. Gramennos and E. Petropoulos. British Archaeological Reports, International Series 1675. Oxford: Archaeopress, 2007, 591–626.

Krapivina and Schultze 2011
Valentina V. Krapivina and Erdmute Schultze. "Grey Ware in Olbia and in the Settlements of the Chernyakhov Culture in the Lower Bug. Region. Current State of Research and Possibilities for Further Investigations." In *Drehscheibentöpferei im Barbaricum – Technologietransfer und Professionalisierung eines Handwerks am Rande des Römischen Imperiums. Akten der 3. Internationalen Tagung in Bonn vom 11. bis 14. Juni 2009*. Ed. by J. Bemmann, M. Hegewisch, M. Meyer, and M. Schmauder. Bonner Beiträge zur Vor - und Frühgeschichtlichen Archäologie 13. Bonn: Vor- und Frühgeschichtliche Archäologie, Rheinische Friedrich-Wilhelms-Universität Bonn, 2011, 417–428.

Kronz, Simon, and Dodt 2018
Andreas Kronz, Klaus Simon, and Michael Dodt. "Frühmittelalterliche Glaswerkstätten am Kölner Hafen." In *Archäometrie und Denkmalpflege 2018: 20.–24. März 2018, DESY, Hamburg, Deutschland*. Ed. by L. Glaser. Hamburg: Verlag Deutsches Elektronen-Synchrotron, 2018, 124–127.

Krzyżanowska and Frankiewicz 2015
Marta Krzyżanowska and Mateusz Frankiewicz. "An Archaeological Experiment with Early Medieval Glass Bead Production in an Open Hearth – Results." *Slavia Antiqua* LVI (2015), 109–127. DOI: DOI:10.14746/sa.2015.56.6.

Kunow 1983
Jürgen Kunow. *Der römische Import in der Germania libera bis zu den Markomannenkriegen. Studien zu Bronze- und Metallgefäßen*. Neumünster: Wachholtz, 1983.

Langsdorff 1942
Donald Eugene Langsdorff Alexander und McCown. *Tall-i Bakun A: Season of 1932*. Oriental Institute Publications 54. Chicago, IL: The Oriental Institute, 1942.

Laser 1982
R. Laser. "Hinweise auf Glasverarbeitung in der spät kaiserzeitlichen Siedlung von Mühlberg (Kreis Gotha)." In *Produktivkräfte und Gesellschaftsformationen in vorkapitalistischer Zeit*. Ed. by J. Herrmann. Berlin: Akademie Verlag, 1982, 479–485.

Le Brun 1971
Alain Le Brun. "Recherches stratigraphiques à l'Acropole de Suse, 1969–1971." *Cahiers de la Délégation Archéologique en Iran* 1 (1971), 163–216.

Lehmphul et al. 2018
Ralf Lehmphul, A. Georgescu, Bernhard S. Heeb, Alexandru Szentmiklosi, Andrei Balarie, Katharina Teinz, Rüdiger Krause, and Matthias Wemhoff. "Häuser, Gruben und ein »Lausitzer« Gefäß – Ergebnisse der Feldforschungen 2016 und 2017 an der spätbronzezeitlichen Siedlung Corneşti-Iarcuri im rumänischen Banat." *Acta Praehistorica et Archaeologica* 50 (2018), 31–43.

Levi 1932
A. Levi. "L'analyse chimique des terres cuites anciennes et leur provenance." *Mouseion* 15 (1932), 64–66.

Ljubičev and Schultze 2011
Michail V. Ljubičev and Erdmute Schultze. "Zur Herstellung von Drehscheibenkeramik in Vojtenki. Archäologische und naturwissenschaftliche Ergebnisse." In *Drehscheibentöpferei im Barbaricum – Technologietransfer und Professionalisierung eines Handwerks am Rande des Römischen Imperiums. Akten der 3. Internationalen Tagung in Bonn vom 11. bis 14. Juni 2009*. Ed. by J. Bemmann, M. Hegewisch, M. Meyer, and M. Schmauder. Bonner Beiträge zur Vor - und Frühgeschichtlichen Archäologie 13. Bonn: Vor- und Frühgeschichtliche Archäologie, Rheinische Friedrich-Wilhelms-Universität Bonn, 2011, 283–298.

Lund Hansen 1987
Ulla Lund Hansen. *Römischer Import im Norden. Warenaustausch zwischen dem Römischen Reich und dem freien Germanien während der Kaiserzeit unter besonderer Berücksichtigung Nordeuropas*. Nordiske Fortidsminder 10, Serie B. Copenhagen: Det Kongelige nordiske Oldskriftselskab, 1987.

Lund Hansen 2009
Ulla Lund Hansen. "Glass and Beads." In *Sorte Muld. Wealth, Power and Religion at an Iron Age Central Settlement on Bornholm*. Ed. by M. Stoltze, S. G. Goodale, and C. Adamsen. Rønne: Bornholms Museum, 2009.

Maran et al. 1997
Joseph Maran, Anno Hein, Doris Ittameier, and Hans Mommsen. "Neutron Activation Analysis of Mycenaean and Related Pottery from the Greek Mainland." In *Optical Technologies in the Humanities*. Ed. by D. Dirksen and G. von Bally. Optics within Life Sciences 4. Berlin and New York: Springer, 1997, 122–124.

Marsland and Oosthuysen 2001
S. Marsland and J. Oosthuysen. "Certificate of Anylysis CERAMIC-1." *SARM* 69 (2001), 1–5.

Mashkour 2004
Marjan Mashkour. "Tracing Ancient 'Nomads': Isotopic Research on the Origins of Vertical 'Transhumance' in the Zagros Region." *Nomadic People* 7 (2004), 36–47.

Mass, Wypyski, and Stone 2002
Jennifer L. Mass, Mark T. Wypyski, and Richard E. Stone. "Malkata and Lisht Glassmaking Technologies: Towards a Specific Link Between Second Millennium BC Metallurgists and Glassmakers." *Archaeometry* 44.1 (2002), 67–82.

Matoïan 1997
Valérie Matoïan. "Glass, Frit and Faience." In *The Excavations at Tell Brak 1: The Mitanni and Old Babylonian Periods*. Ed. by D. Oates, J. Oates, and H. McDonald. McDonald Institute Monographs. London and Cambridge: British School of Archaeology in Iraq and McDonald Institute for Archaeological Research, 1997, 81–100.

Matoïan 2000
Valérie Matoïan. "Données nouvelles sur le verre en Syrie au IIe millénaire av. J.-C.: le cas de Ras Shamra-Ougarit." In *La Route du verre. Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Âge. Colloque organisé en 1989 par l'Association française pour l'Archéologie du Verre (AFAV)*. Ed. by M.-D. Nenna. Travaux de la Maison de l'Orient méditerranéen 33. Lyon: Maison de l'Orient et de la Méditerranée Jean Pouilloux, 2000, 23–47.

Matoïan and Bouquillon 2003
Valérie Matoïan and Anne Bouquillon. "Vitreous Materials in Ugarit: New Data." In *Culture through Objects: Near Eastern, Studies in Honour of P. R. S. Moorey*. Ed. by T. Potts, M. Roaf, and D. Stein. Oxford: Griffith Institute, 2003, 333–346.

Mayet and Picon 1986
François Mayet and Maurice Picon. "Une sigillée phocéenne tardive ("Late Roman C Ware") et sa diffusion en Occident." *Figlina* 7 (1986), 129–142.

Mecking and Seidel 2018
Oliver Mecking and Mathias Seidel. "Analyse von keltischen Gläsern und die Frage ihrer Herkunft." In *Archäometrie und Denkmalpflege 2018: 20.–24. März 2018, DESY, Hamburg, Deutschland*. Ed. by L. Glaser. Hamburg: Verlag Deutsches Elektronen-Synchrotron, 2018, 128–131.

Mehner 2010
Andreas Mehner. "Landschaftsarchäologische Forschungen im näheren Siedlungsumfeld des Burgwalls von Lossow. Erste Ergebnisse aus dem Bereich der Vorburgsiedlung." In *Lossow. Alte Forschungen und neue Projekte*. Ed. by I. Beilke-Voigt and F. Schopper. Materialien zur Archäologie in Brandenburg 4. Rahden/Westf.: Verlag Marie Leidorf, 2010, 75–90.

Meyer 2015
Michael Meyer. "Roman Cultural Influence in Western *Germania Magna*." In *The Oxford Handbook oft the Archaeology of Roman Germany*. Ed. by S. James and S. Krmnicek. Oxford Handbooks Online. 2015. DOI: 10.1093/oxfordhb/9780199665730.001.0001.

Miller 2009
Heather Margaret-Louise Miller. *Archaeological Approaches to Technology*. London and New York, NY: Routledge, 2009.

Moghaddam 2021
Abbas Moghaddam. "A Fifth-Millennium BCE Sanctuary at Tol-e Chega Sofla in the Northern Persian Gulf." *Archaeological Research in Asia* 27 (2021), 100291.

Mommsen 2007
Hans Mommsen. "Tonmasse und Keramik: Herkunftsbestimmung durch Spurenanalyse." In *Einfuhrung in die Archäometrie*. Ed. by G. A. Wagner. Berlin and Heidelberg: Springer Verlag, 2007, 179–192.

Mommsen, Beier, Diehl, et al. 1992
Hans Mommsen, T. Beier, U. Diehl, and C. Podzuweit. "Provenance Determination of Mycenean Sherds found in Tell el-Amarna by Neutron Activation Analysis." *Journal of Archaeological Science* 19 (1992), 295–302.

Mommsen, Beier, and Hein 2002
Hans Mommsen, T. Beier, and Anno Hein. "A Complete Chemical Grouping of the Berkeley Neutron Activation Analysis Data on Mycenaean Pottery." *Journal of Archaeological Science* 29 (2002), 613–637.

Mommsen, Beier, Hein, et al. 1994
Hans Mommsen, T. Beier, Anno Hein, C. Podzuweit, E. Pusch, and E. Eggebrecht. "Neutron Activation Analysis of Mycenaean Sherds from the Town of Ramesses II Near Qantir and Greek-Egyptian Trade Relations." *Archaeometry* 94 (1994), 169–178.

Mommsen, Kreuser, and Weber 1988
Hans Mommsen, A. Kreuser, and J. Weber. "A Method for Grouping Pottery by Chemical Composition." *Archaeometry* 30 (1988), 47–57.

Mommsen, Lewandowski, et al. 1988
Hans Mommsen, E. Lewandowski, J. Weber, and C. Podzuewit. "Neutron Activation Analysis of Mycenean Pottery from the Argolid: The Search for Reference Groups." In *Proceedings of the 26th International Archaeometry Symposium, Held at University of Toronto, Toronto, Canada, May 16th to May 20th, 1988*. Ed. by R. M. Farquhar, R. G. V. Hancok, L. A. Pavlish, and Archaeometry Laboratory the University of Toronto Department of Physiscs. Toronto: Archaeometry Laboratory, Dept. of Physics, University of Toronto, 1988, 165–171.

Mommsen and Sjöberg 2007
Hans Mommsen and B. L. Sjöberg. "The Importance of the 'Best Relative Fit Factor' when Evaluating Elemental Concentration Data of Pottery Demonstrated with Mycenaean Sherds from Sinda, Cyprus." *Archaeometry* 49 (2007), 357–369.

Moran 1992
William L. Moran. Baltimore: Johns Hopkins University Press, 1992.

Moreno García 2012
Juan Carlos Moreno García. *Households*. last accessed 05.10.2018. UCLA Encyclopedia of Egyptology. 2012. URL: http://escholarship.org/uc/item/2bn8c9gz.

Mountjoy 2008
Penelope A. Mountjoy. *The Mycenaean and the Minoan Pottery*. Frankfurter Archäologische Schriften 6. Wiesbaden: Reichert, 2008.

Mountjoy and Mommsen 2001
Penelope A. Mountjoy and Hans Mommsen. "Mycenaean Pottery from Qantir-Piramesse, Egypt." In *The Annual of the British School at Athens. No. 96, 2001*. Ed. by British School at Athens. London: The School, 2001, 123–155.

Mountjoy and Mommsen 2015
Penelope A. Mountjoy and Hans Mommsen. "Neutron Activation Analysis of Aegean-Style IIIC Pottery from 11 Cypriot and Various Near Eastern Sites." *Egypt and Levante* 25 (2015), 421–508.

Mühlenbruch and Mommsen 2011
Tobias Mühlenbruch and Hans Mommsen. "Neutronenaktivierungsanalysen an mykenischer Keramik aus Kusakli-Sarissa und Sirkeli (Turkei), Kamid el-Loz-Kumidi (Libanon) und dem Fayum (Ägypten)." *Ägypten und Levante* 21 (2011), 281–290.

Nagel, Paz, and Behrendt 2018
Stefanie Nagel, Boaz Paz, and Sonja Behrendt. "Tief ins Glas geschaut… Das Potential zerstörungsfreier Analysenmethoden am Beispiel spätantiker figürlich gravierter Gläser." In *Archäometrie und Denkmalpflege 2018: 20.–24. März 2018, DESY, Hamburg, Deutschland*. Ed. by L. Glaser. Hamburg: Verlag Deutsches Elektronen-Synchrotron, 2018, 136–139.

Näser 2010
Claudia Näser. "The Great Hafir at Musawwarat es-Sufra: Fieldwork of the Archaeological Mission of Humboldt University Berlin in 2005 and 2006." In *Between the Cataracts. Proceedings of the 11th Conference of Nubian Studies, Warsaw University, 27 August–2 September 2006, Part Two, Fascicule 1: Session Papers*. Ed. by W. Godlewski and A. Łajtar. Polish Archaeology in the Mediterranean, Supplement Series 2.2/1. Warsaw: University of Warsaw Press, 2010, 39–46.

Näser 2016
Claudia Näser. "Hugging the Wall. New Insights into the Building History and the Uselife of the Great Enclosure at Musawwarat." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 27 (2016), 7–18.

Näser and Daszkiewicz 2013
Claudia Näser and Małgorzata Daszkiewicz. "New Data from the Ceramic Workshop in Courtyard 224 of the Great Enclosure in Musawwarat es Sufra." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 24 (2013), 15–22.

Näser and Scheibner 2012
Claudia Näser and Thomas Scheibner. "Wassermanagement im antiken Sudan: technologische Innovationen und ihr sozio-kultureller Kontext am Beispiel neuer Feldforschungen in Musawwarat es Sufra." In *Die Kulturen Nubiens – Ein afrikanisches Vermächtnis*. Ed. by S. Wenig and K. Zibelius-Chen. Dettelbach: Röll, 2012, 405–420.

Näser and Wetendorf 2014
Claudia Näser and Manja Wetendorf. "The Musawwarat Pottery Project 2014." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 25 (2014), 73–93.

Näser and Wetendorf 2015
Claudia Näser and Manja Wetendorf. "The Musawwarat Pottery Project 2014/15." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 26 (2015), 35–74.

Nicholson 1989
Paul T. Nicholson. "The Pottery Kilns in Building Q48.4." In *Amarna Reports V*. Ed. by B. J. Kemp. Occasional Publications 6. London: The Egypt Exploration Society, 1989, 64–81.

Nicholson 2007
Paul T. Nicholson. *Brilliant Things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1*. Excavation Memoirs 80. London: The Egypt Exploration Society, 2007.

Nicholson 2008
Paul T. Nicholson. "Glass and Faience Production Sites in New Kingdom Egypt: a Review of the Evidence." In *Vitreous Materials in the Late Bronze Age Aegean*. Ed. by C. M. Jackson and E. C. Wager. Sheffield Studies in Aegean Archaeology 9. Oxford: Oxbow Books, 2008, 1–13.

Nicholson 2009
Paul T. Nicholson. *Faience Technology*. Last accessed on 03/04/2017. UCLA Encyclopedia of Egyptology. 2009. URL: http://escholarship.org/uc/item/9cs9x41z.

Nicholson 2010
Paul T. Nicholson. *Kilns and Firing Structures*. Last accessed on 03/04/2017. UCLA Encyclopedia of Egyptology. 2010. URL: http://escholarship.org/uc/item/47x6w6m0.

Nicholson 2011
Paul T. Nicholson. *Glass Working, Use and Discard*. Last accessed on 03/04/2017. UCLA Encyclopedia of Egyptology. 2011. URL: http://escholarship.org/uc/item/2w17t0cw.

Nicholson and Jackson 2007
Paul T. Nicholson and Caroline M. Jackson. "Compositional Analysis of the Vitreous Materials Found at Amarna." In *Brilliant Things for Akhenaten: The Production of Glass, Vitreous Materials and Pot- tery at Amarna Site O45.1*. Ed. by P. T. Nicholson. Excavation Memoirs 80. London: The Egypt Exploration Society, 2007, 101–116.

Nicholson, Jackson, and Trott 1997
Paul T. Nicholson, Caroline M. Jackson, and Katherine M. Trott. "The Ulu Burun Glass Ingots, Cylindrical Vessels and Egyptian Glass." *Journal of Egyptian Archaeology* 83 (1997), 143–153.

Nissen 1973
Hans J. Nissen. "Tepe Sohz." *Iran* 11 (1973), 206–207.

Nissen 1976
Hans J. Nissen. "The Behbehan Plain in the 5th Millennium B.C." In *Memorial Volume of the VIth International Congress of Iranian Art and Arrchaeology*. Ed. by M.Y. Kiani. Tehran: Iranian Centre for Archaeological Research, 1976, 273–280.

Nissen and Redman 1971
Hans J. Nissen and Charles Redman. "Preliminary Notes on an Archaeological Surface Survey in the Plain of Behbehna and the Lower Zuhreh Valley." *Bastan Chennasi va Honar-e Iran* 6 (1971), 48–50.

Nowotny 1969
Waclav Nowotny. *Szkła barwne*. Warsaw: Arkady, 1969.

Onasch 2004
Hans-Ulrich Onasch. "Die Keramikwerkstatt im Hof 224." In *Neueste Feldforschungen im Sudan und in Eritrea. Akten des Symposiums vom 13. bis 14. Oktober 1999 in Berlin*. Ed. by S. Wenig. Meroitica 21. Wiesbaden: Harrassowitz, 2004, 63–70.

Oppenheim 1970
A. Leo Oppenheim. "The Cuneiform Texts." In *Glass and Glassmaking in Ancient Mesopotamia*. Ed. by A. L. Oppenheim, R. H. Brill, D. Barag, and A. von Saldern. Corning, NY: Hudson Hills Press, 1970, 2–104.

Peet and Woolley 1923
Thomas E. Peet and C. Leonhard Woolley. *The City of Akhenaten. Part I: Excavations of 1921 and 1922 at el-Amarna*. Excavation Memoirs 38. London: The Egypt Exploration Society, 1923.

Pendlebury 1951a
John Devitt Stringfellow Pendlebury. *The City of Akhenaten. Part III. The Central City and the Official Quarters. The Excavations at Tell el-Amarna during the Season 1926–1927 and 1931–1936*. Excavation Memoirs 44. London: The Egypt Exploration Society, 1951.

Pendlebury 1951b
John Devitt Stringfellow Pendlebury. *The City of Akhenaten Part III. The Central City and the Official Quarters. Vol. 2: Plates*. Egypt Exploration Society, 1951.

Perlman and Asaro 1969
Isadore Perlman and Frank Asaro. "Pottery Analysis by Neutron Activation." *Archaeometry* 11 (1969), 21–52.

Petrauskas 2014
Oleg V. Petrauskas. "Komariv. Ein Werkstattzentrum barbarischen Europas aus spärömischer Zeit (Forschungsgeschichte, einige Ergebnisse und mögliche Perpektiven)." *Ephemeris Napocensis* 24 (2014), 87–115.

Petrie 1894
William Matthew Flinders Petrie. *Tell el-Amarna*. London: Methuen, 1894.

Phelps et al. 2016
Matt Phelps, Ian C. Freestone, Yael Gorin-Rosen, and Bernard Gratuze. "Natron Glass Production and Supply in the Late Antique and Early Medieval Near East: The Effect of the Byzantine-Islamic Transition." *Journal of Archaeological Science* 75 (2016), 57–71.

Picon, Vichy, and Meille 1971
Maurice Picon, M. Vichy, and E. Meille. "Composition of the Lezoux, Lyon and Arezzo Samian Ware." *Archaeometry* 13 (1971), 191–208.

Płoński 1963
Ignacy Płoński, ed. *Poradnik Ceramiczny*. Warszawa: Arkady, 1963.

Pollock 1983
Susan Pollock. "Style and Information: An Analysis of Susiana Ceramics." *Journal of Anthropological Archaeology* 2 (1983). [Mit neuem Kommentar. 2000. Iranian Journal of Archaeology and History 13(2)/14(1):7–9, 25–46 (übersetzt von K. Abdi)], 354–390.

Pollock 1989
Susan Pollock. "Power Politics in the Susa A Period." In *Upon this Foundation - the 'Ubaid Reconsidered*. Ed. by E. Henrickson and I. Thuesen. Copenhagen: Carsten Niebuhr Institute, 1989, 281–292.

Pollock and Moghaddam 2018
Susan Pollock and Abbas Moghaddam. *Tepe Sohz and Tol-e Chegha Sofla. Heritage at Risk*. Teheran: Tourism and Research Institute of Cultural Heritage, 2018.

Potts 2011
Daniel T. Potts. "Nomadismus von der Frühzeit bis in die Moderne. Eine Untersuchung aus archäologischer als auch aus historischer Sicht." *Eurasia Antiqua* 16 (2011), 1–19.

Potts 2014
Daniel T. Potts. *Nomadism in Iran. From Antiqutiy to the Modern Era*. Oxford: Oxford University Press., 2014.

Pusch and Rehren 2007
Edgar B. Pusch and Thilo Rehren. *Hochtemperatur-Technologie in der Ramses-Stadt: Rubinglas für den Pharao*. Forschungen in der Ramsesstadt 6. 2 volumes. Hildesheim: Gerstenberg Verlag, 2007.

Rademakers, Rehren, and Pusch 2018
Frederik Rademakers, Thilo Rehren, and Edgar B. Pusch. "Bronze Production in Pi-Ramesse: Alloying Technology and Material Use." In *Mining for Copper: Essays in Memory of Professor Beno Rothenberg*. Ed. by E. Ben-Yosef. Monograph Series 37. Tel Aviv: Tel Aviv University, 2018, 503–525.

Rau 1972
Günter Rau. "Körpergräber mit Glasbeigaben des 4. nachchristlichen Jahrhunderts im Oder-Weichsel-Raum." *Acta Praehistorica et Archaeologica* 3 (1972), 109–214.

Rehren, Pusch, and Herold 1998
Thilo Rehren, Edgar B. Pusch, and Anja Herold. "Glass Coloring Works within a Copper-Centered Industrial Complex in Late Bronze Age Egypt." In *The Prehistory & History Glassmaking Technology: (Proceedings) Symposium on Prehistory and History of Glassmaking Technology at the 99th Annual Meeting of the American-Ceramic-Society*. Ed. by P. McCray. Westerville, OH: Ohio American Ceramic Soc., 1998, 227–250.

Renfrew 1984
Colin Renfrew. *Approaches to Social Archaeology*. Edinburgh: Edinburgh University Press, 1984.

Rice 1987
Prudence M. Rice. *Pottery Analysis: A Sourcebook*. Chicago and London: University of Chicago Press, 1987.

Rice 2005
Prudence M. Rice. *Pottery Analysis: A Source Book*. Chicago, IL: University of Chicago Press, 2005.

Rind 1999
Michael M. Rind. *Höhenbefestigungen der Bronze- und Urnenfelderzeit. Der Frauenberg oberhalb Kloster Weltenburg I*. Regensburger Beiträge zur Prähistorischen Archäologie 6. Regensburg: Regensburg Universität Verlag, 1999.

Rind and Schopper 2002
Michael M. Rind and Franz Schopper. "Turbanrandteller in einer urnenfelderzeitlichen Siedlungsgrube aus Schwarzach – Lausitzer Einfluss in der Oberpfalz?" *Beiträge zur Archäologie in der Oberpfalz und in Regensburg* 5 (2002), 99–118.

Robertson and Hill 2004
John H. Robertson and Edna M. Hill. "The Meroitic Pottery Industry." In *Meroe. The Capital of Kush 2. Meroe Excavations 1973–1984*. Ed. by P. L. Shinnie and J. R. Anderson. Meroitica 20. Wiesbaden: Harrassowitz, 2004, 109–214.

Rücker 2007
Julia Rücker. *Das spätbronze- und früheisenzeitliche Gräberfeld von Eisenhüttenstadt. Studien zur Lausitzer Kultur in Ostbrandenburg*. Dissertation. Bonn: Rheinische Friedrich-Wilhelms-Universität zu Bonn, 2007.

Sava, Hurezan, and Mărginean 2011
Victor Sava, George P. Hurezan, and Florin Mărginean. *Şagu Sit A1_1. O Aşezare a Epocii Finale A Bronzului la Mureşul de Jos*. Cluj-Napoca: Mega, 2011.

Sayre and Dodson 1957
Edward V. Sayre and R.W. Dodson. "Neutron Activation Study of Mediterranean Potsherds." *American Journal of Archaeology* 61 (1957), 35–41.

Schallin 1997
Ann-Louise Schallin. "The Late Bronze Age Potter´s Workshop at Mastos in the Berbati Valley." In *Trade and Production in Premonetary Greece: Production and the Craftsman*. Ed. by Carole Gillis, Christina Risberg, and Birgitta Sjöberg. Studies in Mediterranean Archaeology and Literature 143. Jonseered: Åströms, 1997, 73–88.

Schallin 2002
Ann-Louise Schallin. "Pots for Sale: The Late Helladic IIIA and IIIB Ceramic Production at Berbati." In *New Research on Old Material from Asine and Berbati*. Ed. by Berit Wells. Stockholm: Svenska Institutet I Athen, 2002.

Schapova 1978
Ju. L. Schapova. "Masterskaja po proizvodstvu stekla u s. Komarovo (III–IV vv.)." *Sovetskaja Arch.* 3 (1978), 230–242.

Scheibner 2011
Thomas Scheibner. "Neue und alte 14C-Daten aus Musawwarat es-Sufra und ihre Aussagemöglichkeiten zur absoluten und relativen Chronologie des Fundplatzes." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 22 (2011), 7–40.

Schmid 1995
Stephan G. Schmid. *Die Feinkeramik der Nabatäer. Typologie, Chronologie und kulturhistorische Hintergründe*. PhD thesis. Universität Basel, 1995.

Schmitz 2008
Martin Schmitz. *Bedingungen, Prozesse und Stoffdynamik der Bildung tertiärer kaolinitischer Tonlagerstätten in Sachsen und Sachsen-Anhalt und deren Auswirkungen auf die anwendungstechnischen Eigenschaften der Rohstoffe*. PhD thesis. Technische Universität Berlin, 2008.

G. Schneider 1978
Gerwulf Schneider. "Anwendung quantitativer Materialanalysen auf Herkunftsbestimmungen antiker Keramik." *Berliner Beiträge zur Archäometrie* 3 (1978), 63–122.

G. Schneider 1993
Gerwulf Schneider. "X-Ray Fluorescence Analysis and the Production and Distribution of Terra Sigillata and Firmalampen." In *The Inscribed Economy – Production and Distribution in the Roman Empire in the Light of Instrumentum Domesticum. Proceedings of a Conference Held at the American Academy in Rome on 10–11 January, 1992*. Ed. by W. V. Harris. Journal of Roman Archaeology, Supplementary Series 6. Ann Arbor, MI: University of Michigan Press, 1993, 129–137.

G. Schneider 2017
Gerwulf Schneider. "Mineralogical and Chemical Alteration." In *The Oxford Handbook of Archaeological Ceramic Analysis*. Ed. by A. Hunt. Oxford: Oxford University Press, 2017, 162–180.

G. Schneider and Daszkiewicz 2011
Gerwulf Schneider and Małgorzata Daszkiewicz. "Archäokeramologische Klassifizierung am Beispiel kaiserzeitlicher Drehscheibenkeramik." In *Drehscheibentöpferei im Barbaricum – Technologietransfer und Professionalisierung eines Handwerks am Rande des Römischen Imperiums. Akten der 3. Internationalen Tagung in Bonn vom 11. bis 14. Juni 2009*. Ed. by J. Bemmann, M. Hegewisch, M. Meyer, and M. Schmauder. Bonner Beiträge zur Vor - und Frühgeschichtlichen Archäologie 13. Bonn: Vor- und Frühgeschichtliche Archäologie, Rheinische Friedrich-Wilhelms-Universität Bonn, 2011, 15–31.

G. Schneider and Daszkiewizc 2001
Gerwulf Schneider and Małgorzata Daszkiewizc. "Stone Ware and Ninevite 5 – Notes on Composition and Technology of Pottery from Tell Brak." In *Excavations at Tell Brak, Vol. 2: Nagar in the Third Millennium*. Ed. by D. Oates, J. Oates, and H. McDonald. Cambridge: British School of Archaeology in Iraq, 2001, 194–216.

G. Schneider, Knoll, et al. 1994
Gerwulf Schneider, Heinz Knoll, Kostas Gallis, and Jean-Paul Demoule. "Production and Circulation of Neolithic Thessalian Pottery: Chemical and Mineralogical Analyses." In *La Thessalie – Quinze années de recherches archéologiques, 1975–1990. Actes du colloque international, Lyon, 17–22 Avril 1990*. Ed. by E. Kypraiou and D. Zapheiropoulou. Athens: Ypourgeio Politismou, 1994, 61–70.

G. Schneider and Mommsen 2009
Gerwulf Schneider and Hans Mommsen. "Eastern Sigillata C von Pergamon und Çandarlı (Türkei)." In *Archäometrie und Denkmalpflege – Kurzberichte 2009, Jahrestagung in München*. Ed. by A. Hauptmannn and H. Stege. Metalla Sonderheft 6. Munich: Metalla, 2009, 223–225.

G. Schneider, Vokaer, et al. 2007
Gerwulf Schneider, Agnès Vokaer, Karin Bartl, and Małgorzata Daszkiewicz. "Some New Results of Archaeometric Analysis of Brittle Wares." In *LRCW 2. Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean, Archaeology and Archaeometry*. Ed. by M. Bonifay and J.-C. Treglia. British Archaeological Reports, International Series 1662. Oxford: Archaeopress, 2007, 715–729.

J. Schneider 1958
Johannes Schneider. "Die Keramik des Aurither Stils westlich der Oder. In: Johannes Schneider, Werner Coblenz, Hans-Jürgen Gomolka, and Rudolf Moschkau." In *Studien zur Lausitzer Kultur. Forschungen zur Vor- und Frühgeschichte 3*. Ed. by J. Schneider, W. Coblenz, H.-J. Gomolka, and R. Moschkau. Leipzig: J. A. Barth, 1958, 5–70.

Schopper 1995
Franz Schopper. *Das urnenfelder- und hallstattzeitliche Gräberfeld von Künzing, Lkr. Deggendorf (Niederbayern)*. Materialien zur Bronzezeit in Bayern 1. Regensburg: Universitäts Verlag Regensburg, 1995.

Schreiber 2018
Stefan Schreiber. *Wandernde Dinge als Assemblagen. Neo-Materialistische Perspektiven zum ‚römischen Import' im ‚mitteldeutschen Barbaricum'*. Berlin Studies of the Ancient World 52. Berlin: Edition Topoi, 2018.

Schultze 2009
Erdmute Schultze. "Die Drehscheibenkeramik der Černjachov-Kultur – Auswirkungen einer neuen Herstellungstechnik auf Wirtschaft und Kultur." In *Keramik jenseits von Chronologie: Beiträge der Arbeitsgemeinschaft „Theorie in der Archäologie" bei der Tagung des West-und Süddeutschen Verbandes für Altertumsforschung e.V. in Xanten, 7.–8. Juni 2006. Internationale Archäologie, Arbeitgemeinschaft, Symposium, Tagung Kongress.* Band 14. Ed. by P. Stockhammer. Rahden/Westf.: Marie Leidorf, 2009, 39–54.

Schultze, Liubichev, et al. 2010
Erdmute Schultze, Michael V. Liubichev, Małgorzata Daszkiewicz, Ewa Bobryk, and Gerwulf Schneider. "Archaeoceramological Studies of Pottery from Voitenki, Chernyakhov Culture (Ukraine)." In *LRCW 3. Late Roman Corse Wares, Cooking Wares and Amphorae in the Mediterranean*. Ed. by S. Menchelli, S. Santoro, M. Pasquinucci, and G. Guiducci. British Archaeological Reports, International Series 2185. Oxford: Archaeopress, 2010, 1023–1032.

Schultze and Ljubičev 2007
Erdmute Schultze and Michail V. Ljubičev. "Zur Herstellung von Drehscheibenkeramik in der Černjachov-Kultur. Ein Brennofen aus der Siedlung Vojtenki 1 (Ostukraine)." *Ethnographisch-Archäologische Zeitschrift* 44 (2007), 187–202.

Schultze, Magomedov, and Bujskich 2006
Erdmute Schultze, Boris V. Magomedov, and Sergej B. Bujskich. "Grautonige Keramik des Unteren Buggebietes in römischer Zeit. Nach Materialien der Siedlungen in der Umgebung von Olbia." *Eurasia Antiqua* 12 (2006), 289–352.

Schulz 2008
Deborah Schulz. "Verbrannt und zugeweht. Germanische Gräber bei Jänschwalde." *Ausgrabungen Niederlausitzer Braunkohlerevier* 20 (2008), 176–185.

Schuster 2005
Jan Schuster. "Die Beziehungen der Gebiete Ostbrandenburgs zur Wielbark- und Przeworsk-Kultur im späten 2. und beginnenden 3. Jah. n. Chr." *Veröffentlichungen zur Brandenburgischen Landesarchäologie* 36/37.2002/2003 (2005), 89–161.

Schweigart 2018a
Fleur Schweigart. "Archäometrische Untersuchungen zur Drehscheibenkeramik der spätkaiserzeitlichen Siedlung Glienick 14, Lkr. Teltow-Fläming." In *Frühe Eisenverhüttung bei Glienick. Siedlungs- und wirtschaftsarchäologische Forschungen zur vorrömischen Eisen- und römischen Kaiserzeit in Brandenburg*. Ed. by M. Brumlich. Berliner Archäologische Forschungen 17. Teil II. Rahden/Westf.: Marie Leidorf GmbH, 2018, 605–610.

Schweigart 2018b
Fleur Schweigart. *Kaiserzeitliche Drehscheibenkeramik zwischen Elbe und Oder. Produktion, Distribution und Konsumption*. Unpublished. PhD thesis. Freie Universität Berlin, 2018.

J. C. Scott 2017
James C. Scott. *Against the Grain. A Deep History of the Earliest States*. New Haven, CT: Yale University Press, 2017.

R. B. Scott and Degryse 2014
Rebecca B. Scott and Patrick Degryse. "The Archaeology and Archaeometry of Natron Glass Making." In *Glass Making in the Greco-Roman Word, Results of the ARCHGLASS Project*. Ed. by P. Degryse. Leuven: Leuven University Press, 2014, 15–26.

Searle and Grimshaw 1960
Alfred B. Searle and Rex W. Grimshaw. *The Chemistry and Physics of Clays and Other Ceramic Materials*. London: Benn, 1960.

Seiler 1998
Anne Seiler. "Feine meroitische Ware aus Musawwarat es Sufra. Erste Ergebnisse der Bearbeitung der Keramik aus Hof 224 der Grossen Anlage." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 8 (1998), 56–61.

Seiler 1999
Anne Seiler. "Die Keramik – Form und Funktion." In *Die Kleine Anlage*. Ed. by M. Fitzenreiter. Meroitica 17.1: Musawwarat es Sufra II. Wiesbaden: Harrassowitz, 1999, 53–78.

Shortland 2000
Andrew J. Shortland. *Vitreous Materials at Amarna*. British Archaeological Reports, International Series 827. Oxford: Archaeopress, 2000.

Shortland 2009
Andrew J. Shortland. "Glass Production." *UCLA Encyclopedia of Egyptology* 1.1 (2009). Last accessed: 19/07/2017. URL: https://escholarship.org/uc/item/4jv3f665.

Shortland, Nicholson, and Jackson 2001
Andrew J. Shortland, Paul T. Nicholson, and Caroline M. Jackson. "Glass and Faience at Amarna: Different Methods of Both Supply for Production, and Subsequent Distribution." In *The Social Context of Technological Change: Egypt and the Near East, 1650–1550 BC, Proceedings of a Conference Held at St Edmund Hall, Oxford 12–14 September 2000*. Ed. by Andrew J. Shortland. Oxford: Oxbow Books, 2001, 147–160.

Shortland, Rogers, and Eremin 2007
Andrew J. Shortland, Nick Rogers, and Katherine Eremin. "Trace Element Discriminants between Egyptian and Mesopotamian Late Bronze Age Glasses." *Journal of Archaeological Science* 34 (2007), 781–789.

Shortland, Tite, and Ewart 2006
Andrew J. Shortland, Michael S. Tite, and Ian Ewart. "Ancient Exploitation and Use of Cobalt Alumns from the Western Oases of Egypt." *Archaeometry* 48.1 (2006), 153–168.

Sinopoli 1991
Carla M. Sinopoli. *Approaches to Archaeological Ceramics*. New York, NY: Springer Science+Business Media, 1991.

Smirniou and Rehren 2011
Melina Smirniou and Thilo Rehren. "Direct Evidence of Primary Glass Production in Late Bronze Age Amarna, Egypt." *Archaeometry* 53.1 (2011), 58–80.

Smirniou and Rehren 2013
Melina Smirniou and Thilo Rehren. "Shades of Blue: Cobalt-Copper Coloured Blue Glass from New Kingdom Egypt and the Mycenaean World: A Matter of Production or Colourant Source?" *Journal of Archaeological Science* 40 (2013), 4731–4743.

Smirniou and Rehren 2016
Melina Smirniou and Thilo Rehren. "The Use of Technical Ceramics in Early Egyptian Glass-Making." *Journal of Archaeological Science* 67 (2016), 52–63.

Smischko 1964
M. Ju. Smischko. "Poselennya III–IV st. n.e. iz sl-idamy' sklyanogo vy'robny'cztva bilya s. Komariv Chernivecz'koyi oblasti." *Materialy' i doslidzhennya z arheologiyi Pry'karpattya ta Voly'ni* 5 (1964), 67–80.

Stawiarska 1984
Teresa Stawiarska. "Szkła z okresu wpływów rzymskich z północnej polski. Glasses from Roman Period Excavated in Northern Poland. A Chemical Assays." *Bibliotheca Antiqua* 19 (1984), 149–156.

Stevens 2007
Anna Stevens. *Database (Latest Version), Amarna Project Website*. Last accessed on 03/04/2017. Amarna Project. 2007. URL: http : / / www . amarnaproject.com/pages/recent_projects/material_culture/small_finds/database.shtml.

Sumner 1972
William Sumner. *Cultural Development in the Kur River Basin, Iran: An Archaeological Analysis of Settlement Patterns*. PhD. Ann Arbor, MI: University of Pennsylvania, 1972.

Sumner 1994
William Sumner. "The Evolution of Tribal Society in the Southern Zagros Mountains, Iran." In *Chiefdoms and Early States in the Near East: The Organizational Dynamics of Complexity*. Ed. by G. J. Stein and M. G. Rothman. Madison, WI: Prehistory Press, 1994, 47–65.

Szentmiklosi 2009
Alexandru Szentmiklosi. *Aşezările culturii Cruceni-Belegiş în Banat*. Unpublished. PhD thesis. Alba Iulia: Universitatea "1 Decembrie 1918" din Alba Iulia, 2009.

Szentmiklosi 2016
Alexandru Szentmiklosi. "Cercetările Arheologice de la Peciu Nou-Bocar." *Jud. Timiş. Banatica* 26 (2016), 203–237.

Szentmiklosi, Heeb, et al. 2011
Alexandru Szentmiklosi, Bernhard S. Heeb, Julia Heeb, Anthony Harding, Rüdiger Krause, and Helmut Becker. "Cornești-Iarcuri – A Bronze Age Town in the Romanian Banat?" *Antiquity* 85.329 (2011), 819–838.

Szentmiklosi and Medeleț 2016
Alexandru Szentmiklosi and Florin Medeleț. "Sondajul Arheologic din Aşezarea de Epoca Bronzului de la Voiteg-Groapa cu Vulpi." *Banatica* 26 (2016), 239–255.

Tempelmann-Mączyńska 1985
Magdalena Tempelmann-Mączyńska. *Perlen im mitteleuropäischen Barbaricum*. Mainz: Philipp von Zabern, 1985.

Tite 1972
Michael S. Tite. *Methods of Physical Examination in Archaeology*. London and New York: Seminar Press, 1972.

Tite, Kilikoglou, and Vekinis 2001
Michael S. Tite, K. Kilikoglou, and G. Vekinis. "Review Article: Strength, Toughness and Thermal Shock Resistance of Ancient Ceramics, and Their Influence on Technological Choice." *Archaeometry* 43 (2001), 301–324.

Tite and Shortland 2003
Michael S. Tite and Andrew J. Shortland. "Production Technology for Copper- and Cobalt-Blue Vitreous Materials from the New Kingdom Site of Amarna – A Reappraisal." *Archaeometry* 45.2 (2003), 285–312.

Török 1997
László Török. *Meroe City – An Ancient African Capital. John Garstang's Excavations in the Sudan I. Text, II. Figures and Plates*. Occasional Publications 12. London: Egypt Exploration Society, 1997.

Van der Leeuw 1977
Sander Ernst Van der Leeuw. "Towards a Study of the Economics of Pottery Making." In *Ex Horreo: IPP 1951-1976*. Cingula 4. Amsterdam: Universiteit van Amsterdam, Albert Egges van Giffen Instituut voor Prae- en Protohistorie, 1977, 68–76.

Vandersleyen 2002
C. Vandersleyen. "Keftiu = Crète? Objections préliminaires." *Göttinger Miszellen* 188 (2002), 109–112.

Verhagen and Gazenbeek 2006
Philip Verhagen and Michiel Gazenbeek. "The Use of Predictive Modeling for Guiding the Archaeological Survey of Roman Pottery Kilns in the Argonne Region (Northeastern France)." In *GIS and Archaeological Site Location Modeling*. Ed. by M. W. Mehrer and K. L. Wescott. New York, NY: Taylor & Francis, 2006, 447–459.

Vogt 2002
Uwe Vogt. "Zur Glasverarbeitung in der Germania Magna." In *Vom Grosssteingrab zur Domburg. Forschungsorientierte Denkmalpflege im Osnabrücker Land. Festschrift für Wolfgang Schlüter*. Ed. by A. Friederichs, K. Igel, and B. Zehm. Rahden/Westf.: Marie Leidorf, 2002, 100–106.

Vranić 2002
Svetlana Vranić. *Belegiš, Stojića Gumno – Nekropola spaljenih pokojnika. Belegiš, Stojića Gumno – A Necropolis of Cremation Burials*. Beograd: Muzej grada Beograda, 2002.

Walton et al. 2012
Marc S. Walton, Katherine Eremin, Andrew J. Shortland, Patrick Degryse, and Sarah F. L. Kirk. "Analysis of Late Bronze Age Glass Axes from Nippur – A New Cobalt Colourant." *Archaeometry* 54.5 (2012), 835–852.

Wedepohl 2003
Karl Hans Wedepohl. *Glas in Antike und Mittelalter – Geschichte eines Werkstoffs*. Stuttgart: Schweizerbart, 2003.

Wedepohl, Simon, and Kronz 2011
Karl Hans Wedepohl, Klaus Simon, and Andreas Kronz. "Data on 61 Chemical Elements for the Characterization of Three Major Glass Compositions in Late Antiquity and the Middle Ages." *Archaeometry* 53.1 (2011), 81–102.

Wenig and Wolf 1998
Steffen Wenig and Pawel Wolf. "Feldarbeiten des Seminars für Sudanarchäologie und Ägytpologie der Humboldt- Universität in Musawwarat es Sufra. Erste Hauptkampagne, 16.10.1995–13.1.1996." *Der Antike Sudan. Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.* 8 (1998), 24–37.

Whitbread 2017
Ian Whitbread. "Fabric Description of Archaeological Ceramics." In *The Oxford Handbook of Archaeological Ceramic Analysis*. Ed. by A. Hunt. Oxford: Oxford University Press, 2017, 200–216.

Wiesenberg 2016
Frank Wiesenberg. "Prinzipstudie Perlenofen: Glasperlen und Fläschchen." In *Experimentelle Archäologie: Studien zur römischen Glastechnik*. Bd.1. Ed. by B. Birkenhagen and F. Wiesenberg. Schriften des Archäologieparks Römische Villa Borg 7, ARCHEOglas 3. Merzig: Kulturstiftung Merzig-Wadern, 2016, 110–146.

Wolf 1997
Pawel Wolf. "Recent Fieldwork at Musawwarat es-Sufra." *Sudan & Nubia* 1 (1997), 20–29.

Wolf 2001
Pawel Wolf. "Die Höhle des Löwen, Zur Deutung der Großen Anlage von Musawwarat es Sufra." In *Begegnungen, Antike Kulturen im Niltal, Festgabe für Erika Endesfelder, Karl-Heinz Priese, Walter Friedrich Reineke, Steffen Wenig*. Ed. by C.-B. Arnst and A. Hafemann I. und Lohwasser. Leipzig: Wodtke und Stegbauer, 2001, 473–508.

Wolf, Nowotnick, and Hof 2014
Pawel Wolf, Ulrike Nowotnick, and Catharine Hof. "The Meroitic Urban Town of Hamadab in 2010." In *The Fourth Cataract and Beyond. Proceedings of the 12th International Conference for Nubian Studies, British Museum, London, from 1st–6th August 2010*. Ed. by D. A. Welsby and J. R. Anderson. Leuven: Peeters, 2014, 719–738.

Yoffee 2005
Norman Yoffee. *Myths of the Archaic State: The Evolution of the Earliest Cities, States, and Civilizations*. Cambridge and New York: Cambridge University Press, 2005.

Бобринский 1991
Александр А. Бобринский. *Гончарное мастерские и горны Восточной Европы*. Москва: Наука, 1991.

Буйских 1991
Сергей Б. Буйских. *Фортификация Ольвийского государства (первые века нашей эры)*. Киев: Наукова думка, 1991.

Бураков 1976
Анатолий В. Бураков. *Козырское городище рубежа и первых столетий нашей эры*. Киев: Наукова думка, 1976.

Крапивина 1993
Валентина В. Крапивина. *Ольвия. Материальная культура I–IV вв. н.э.* Киев: Наукова Думка, 1993.

Круг 1965
Олга Ю Круг. "Некоторые особенности технологии керамического производства на чернявском поселении Журавка." *Советская Археология* 3 (1965), 269–277.

Магомедов 2001
Борис В. Магомедов. *Черняховская культура. Проблема этноса*. Lublin: Wydawnictwo Uniwersytetu Marii Curie-Skłodowskiej, 2001.

Магомедов 2007
Борис В. Магомедов. "Ольвія і вавари в пізньоантичний період." *Археологія* 2007.4 (2007), 47–54.

Шультце et al. 2013
Эрдмуте Шультце, Михаил Любичев, Erdmute Schultze, and Michail V. Ljubičev. "Два гончарных горна из поселения Войтенки: сравнительная характеристика." In *Keramikherstellung in Osteuropa: Spätrömische Zeit – Frühmittelalter – Neuzeit*. Ed. by E. Schultze. Ostrogothica-Serie 2. Char'kov: V. N. Karazin Kharkiv National University, 2013, 43–52.

Illustration and table credits

Chapter 1 **Illustrations:** 1 F. Schweigart.

Chapter 2 **Illustrations:** 1–5 A. Höhne.

Chapter 3 **Illustrations:** 1 M. Daszkiewicz and H. Baranowska. 2–3 G. Schneider. 4 Photo: M. Baranowski. 5–6 M. Daszkiewicz; photos: M. Baranowski. 7 G. Schneider; photos: M. Baranowski. 8 M. Daszkiewicz; photos: M. Baranowski. **Tables:** 1–2 G. Schneider.

Chapter 4.1 **Illustrations:** 1 R. Bernbeck. 2–3 M. Daszkiewicz. **Tables:** 1–4 R. Bernbeck.

Chapter 4.2.1 **Illustrations:** 1 S. Nehls.

Chapter 4.2.2 **Illustrations:** 1 Base map: OpenStreetMap; illustration: A. K. Hodgkinson. 2 Illustration: A. K. Hodgkinson. 3 Photos: A. K. Hodgkinson. 4 Illustration: A. K. Hodgkinson. 5 Photos: A. K. Hodgkinson. © Staatliche Museen zu Berlin, Ägyptisches Museum und Papyrussammlung, Stiftung Preußischer Kulturbesitz. 6 Plots: A. K. Hodgkinson.

Chapter 4.3 **Illustrations:** 1 Photo: T. Scheibner. 2 Cartographic and graphic implementation: C. Dorstewitz. 3 Macro photos: M. Baranowski; compilation: H. Baranowska and M. Daszkiewicz. 4 Drawings: S. Bruck, J. Halik, M. Wetendorf; graphic implementation and compilation: M. Wetendorf. 5 Mapping: M. Wetendorf. 6 Photos: C. Näser. 7 Photos: M. Wetendorf. 8 Photo: M. Wetendorf; thermocouble measurements: M. Daszkiewicz. 9 Analysis and graphic implementation: M. Daszkiewicz. 10 Vessel production and photo: M. Wetendorf. 11 Data collection: M. Daszkiewicz; data processing and map design: M. Wetendorf.

Chapter 4.4 **Illustrations:** 1–3 H. Baranowska; photos: G. Schneider. 4 G. Schneider. 5 M. Daszkiewicz; macro photos: M. Baranowski. 6–7 G. Schneider. 8 M. Daszkiewicz. **Tables:** 1–4 M. Daszkiewicz and G. Schneider.

Chapter 4.5 **Illustrations:** 1 D. Schäffler. 2 Statistics: M. Daszkiewicz; chart: H. Baranowska. 3 M. Daszkiewicz. **Tables:** 1 M. Daszkiewicz.

Chapter 4.6 **Illustrations:** 1 Photo: K. Ziedler, Frankfurt/Oder, 8. Aug. 2017, 2393. 2 Drawing: T. Stupp, Berlin, 2013. 3 BLDAM and I. Beilke-Vogt. 4–5 M. Daszkiewicz. 6 Macro photographs: M. Baranowski; chart: H. Baranowska/M. Daszkiewicz. 7–8 Photomicrographs: G. Schneider; macro photos: M. Baranowski; chart: M. Daszkiewicz. 9 Drawing: T. Stupp, Berlin, 2013. 10 H. Baranowska. 11 Macro photos: M. Baranowski; chart: H. Baranowska; Table: M. Daszkiewicz. 12–15 Statistics: M. Daszkiewicz; chart: H. Baranowska. **Tables:** 1–2 M. Daszkiewicz.

Chapter 4.7 **Illustrations:** 1 Schweigart 2018b, Fig. 76. 2 After Schweigart 2018b. 3–5 F. Schweigart. 6 Revised after Schweigart 2018a, Fig. 2; illustration of vessel by M. Brumlich. **Tables:** 1 F. Schweigart.

Chapter 4.8 **Illustrations:** 1 Drawing: Z. Magomedova; revision: A. Reuter. 2 Adapted from Крапивина 1993, Fig. 3. 3 Following Schultze, Magomedov, and Bujskich 2006, Fig. 25. 4 Following Schultze, Magomedov, and Bujskich 2006, Fig. 26. 5 F. Schweigart. 6 Macro photos: M. Baranowski. 7–8 F. Schweigart. 9 Drawing: W. Rust. **Tables:** 1 M. Daszkiewicz, F. Schweigart.

Chapter 4.9 **Illustrations:** **1** Graph: A. Kaeselitz. **2** 1 graph A. Kaeselitz; 2–3 Germanic-Slavonic Archaeological Expedition of the V. N. Karazin Kharkiv National University. **3** Germanic-Slavonic Archaeological Expedition of the V. N. Karazin Kharkiv National University. **4** E. Schultze. **5** M. Daszkiewicz; macro photos: M. Baranowski. **6** M. Daszkiewicz. **7** E. Schultze. **8** M. Daszkiewicz. **9** E. Schultze. **10** M. Daszkiewicz; macro photos: M. Baranowski. **11** Graph: A. Kaeselitz. **Tables:** **1** M. Daszkiewicz. **2** E. Schultze.

Chapter 4.10 **Illustrations:** **1** H.-J. Karlsen. **2** Eastern Atlas, Details: H.-J. Karlsen. **3** H.-J. Karlsen. **4–8** M. Daszkiewicz. **9–10** Statistics: M. Daszkiewicz; chart: H. Baranowska, M. Daszkiewicz. **11–14** M. Daszkiewicz. **15** M. Daszkiewicz/E. Bobryk. **16–17** M. Daszkiewicz. **Tables:** **1–2** M. Daszkiewicz and G. Schneider.

Chapter 5 **Illustrations:** **1–9** M. Daszkiewicz; macro photos: M. Baranowski. **10** M. Daszkiewicz; photo: G. Schneider. **11** E. Bobryk and M. Daszkiewicz. **12–14** M. Daszkiewicz; macro photo: M. Baranowski. **15** G. Schneider and M. Daszkiewicz. **16** Macro photo: M. Baranowski. **17** M. Daszkiewicz; macro photo: H. J. Karlsen. **18** M. Daszkiewicz. **Tables:** **1** M. Daszkiewicz. **2** M. Daszkiewicz and G. Schneider.

Chapter 6 **Illustrations:** **1** M. Daszkiewicz. **2** E. Bobryk. **3** Photos: M. Baranowski. **4** M. Daszkiewicz and G. Schneider. **5–7** G. Schneider. **8–9** M. Daszkiewicz. **10** M. Daszkiewicz; macro photo: M. Baranowski. **11** M. Daszkiewicz and E. Bobryk. **12** M. Daszkiewicz; macro photo: M. Baranowski. **13–22** M. Daszkiewicz and H. Baranowska. **23–24** M. Daszkiewicz. **25–26** M. Daszkiewicz and H. Baranowska. **Tables:** **1–5** M. Daszkiewicz and G. Schneider.

Chapter 8 **Tables:** **1–10** M. Daszkiewicz and G. Schneider.

Authors

ANDREI BĂLĂRIE

is archaeologist at the Muzeul Național al Banatului, with a scientific focus on the Middle and Late Bronze Age in southeast Europe. He is the curator of the Bronze Age collection of the Muzeul Național al Banatului.

Andrei Bălărie
Muzeul Național al Banatului
Bastionul Maria Theresia, str. Martin Luther, nr.4
300054 Timisoara, Romania
E-Mail: andrei.balarie@gmail.com

INES BEILKE-VOIGT

Dr. phil. (HU Berlin 1995), Habilitation (HU Berlin 2005), Heisenberg Fellow (2006–2011), and visiting professors at the University of Saarland (2009–2010, 2011) and Freie Universität Berlin (2016–2017). Research assistant in Topoi, head of the DFG research project 'Lossow' (2007–2019), and excavation leader in a private excavation company since 2017. Main areas of research: cult and sacrificial activities, burials, childhood, gender studies, customs, ethnology, and rock art.

Dr. Ines Beilke-Voigt
Archäologie Manufaktur GmbH
Friedrich-Rumpf-Str.15
14641 Wustermark, Germany
E-Mail: ines.beilke-voigt@archaeologie-manufaktur-gmbh.de

REINHARD BERNBECK

teaches Western Asian archaeology at the Freie Universität Berlin. He is co-editor of Subjects and Narratives in Archaeology (2015, with Ruth van Dyke) and Reclaiming the Past for the Future: Oral History, Craft, and Archaeology (2018, with Arwa Badran and Susan Pollock). He also co-edits the online journal Forum Kritische Archäologie. His most recent monograph is Archäologische Spuren des nationalsozialistischen Terrors (2017).

Prof. Reinhard Bernbeck
Institut für Vorderasiatische Archäologie
Freie Universität Berlin
Fabeckstr. 23–25
14195 Berlin, Germany
E-Mail: rbernbec@zedat.fu-berlin.de

EWA BOBRYK

Master of Science. Ewa graduated from the Faculty of Chemistry of the Warsaw University of Technology in 1978. A leading specialist in designing advanced ceramic materials, Ewa has authored and co-authored numerous publications and patents in the field of ceramic technology, and is also involved in a long-standing collaboration with Małgorzata Daszkiewicz and Gerwulf Schneider on archaeometric research projects.

Ewa Bobryk
Warsaw University of Technology
Faculty of Chemistry
Division of Inorganic Technology and Ceramics
ul. Noakowskiego 3
00-664 Warsaw, Poland
E-Mail: Bobryk@ch.pw.edu.pl

MAŁGORZATA DASZKIEWICZ

MA Warsaw 1979 in Physical Geography, PhD Warsaw University 1993 in Humanities. Since 1994 she has worked in collaboration with *AG Archäometrie* FU Berlin. Formerly a part-time employee at TOPOI, she is currently an associated member of the Institute for Prehistoric Archaeology FU Berlin and also runs ARCHEA, a laboratory in Warsaw for archaeometric analysis and research. Her main research interests are determining the technology and provenance of archaeological ceramics and devising techniques for the classification of bulk ceramic finds.

Dr. Małgorzata Daszkiewicz
Institut für Prähistorische Archäologie
Freie Universität Berlin
Fabeckstraße 23–25
14195 Berlin, Germany
and
ARCHEA
ul. Ogrodowa 8m95
00-896 Warszawa, Poland
E-Mail: m.dasz@wp.pl

BERNHARD HEEB

is an archaeologist with a focus on the Late Bronze Age in southeast Europe. He is a curator at the Museum for Pre- and Early History in Berlin for the Bronze Age, Troy and the anthropological collection. He obtained his PhD in 2009 in Frankfurt/Main. Since 2007, he has been conducting a research project about the Late Bronze Age Mega-Site Cornşti-Iarcuri in collaboration with the Muzeul Naţional al Banatului in Timişoara and the Johann Wolfgang Goethe-Universität Frankfurt/ Main.

Dr. Bernhard Heeb
Museum für Vor- und Frühgeschichte
Staatliche Museen zu Berlin – Stiftung Preußischer Kulturbesitz
Archäologisches Zentrum
Geschwister-Scholl-Str. 6
10117 Berlin, Germany
E-Mail: b.heeb@smb.spk-berlin.de

MORTEN HEGEWISCH

is an archaeologist with a focus on the Roman Imperial age in Germanic regions, with a specialization on Germanic pottery. He worked at the Roman-Germanic Commission of the German Archaeological Institute, Rheinisches Landesmuseum Bonn, Museum of Westlausitz, Topoi Excellence Cluster, Rheinische Friedrich-Wilhelms-Universität Bonn, and is now permanently at the Institute of Prehistoric Archeology of the Free University Berlin as editor of the Praehistorische Zeitschrift.

Dr. Morten Hegewisch
Institut für Prähistorische Archäologie
Freie Universität Berlin
Fabeckstraße 23–25
14195 Berlin, Germany
E-Mail: hegewisc@zedat.fu-berlin.de

ANNA K. HODGKINSON

(PhD: Liverpool 2014), has recently completed a post-doctoral research fellowship and a Marie-Skłodowska-Curie Individual Fellowship at the Topoi Excellence Cluster in collaboration with the Egyptian Museum Berlin and the Amarna Project. Her research focuses on Late Bronze Age (LBA) Egyptian settlement archaeology, LBA glass industries, and chemical analysis of LBA glass objects. She has conducted archaeological fieldwork the LBA Egyptian sites of Amarna, Gurob, and Qantir.

Dr. Anna K. Hodgkinson
Freie Universität Berlin
Fachbereich Geschichts- und Kulturwissenschaften
Ägyptologisches Seminar
Fabeckstraße 23–25
14195 Berlin, Germany
E-Mail: hodgkinson.anna@gmail.com

ANTONIA HÖHNE (EHEM. HOFMANN)

studied restoration of archaeological cultural heritage at the University of Applied Sciences Berlin (HTW). Since 2012, in context of her doctoral project in cooperation with Freie Universität Berlin and HTW, she has been working on the differentiability of survey ceramics from Syria using the p-ED-XRF in addition to the record of technological features in order to provide information on the development of production and distribution systems of former societies.

Dr. Antonia Höhne (ehem. Hofmann)
Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences
Fachbereich Gestaltung und Kultur
Department of design and culture
Konservierung und Restaurierung/Grabungstechnik/ programme conservation and excavation engineering
Wilhelminenhofstraße 75A
12459 Berlin, Germany
E-Mail: Antonia.Hofmann@HTW-Berlin.de

HANS-JÖRG KARLSEN

was in 2016 chair of the Pre- and Protohistoric Archaeology, Universität Rostock; 2011–2016 professor and scientific assistant of the Topoi Excellence Cluster, Freie Universität Berlin; 2011 Habilitation, Freie Universität Berlin; 2004–2010 scientific assistant, Freie Universität Berlin; 2003-2004 scientific assistant, Georg-August-Universität Göttingen; 2003 PhD, Georg-August-Universität Göttingen; and 1994–1999 Studies, Georg-August-Universität Göttingen.

Prof. Dr. Hans-Jörg Karlsen
Universität Rostock
Heinrich-Schliemann-Institut für Altertumswissenschaften
Lehrstuhl für Ur- und Frühgeschichte
Neuer Markt 3
18055 Rostock, Germany
E-Mail: hans-joerg.karlsen@uni-rostock.de

MICHAEL MEYER

Dr. phil. (Marburg 1990), Habilitation (HU Berlin 2005), is a professor of Prehistoric Archaeology at Freie Universität Berlin and has been the spokesperson of the Topoi Excellence Cluster from 2011 to 2019. His research focus lies on the archaeology of the centuries before and after the birth of Christ, on settlement, conflict, and economic archaeology.

Prof. Dr. Michael Meyer
Institut für Prähistorische Archäologie
Freie Universität Berlin
Fabeckstraße 23–25
14195 Berlin, Germany
E-Mail: michael.meyer@fu-berlin.de

HANS MOMMSEN

was born 07.09.1942. He received a Diploma in Physics in 1968, a PhD in Physics in 1971, a Dr. habil in 1988, apl. professorship 1994–2007, and from 1971 to 2007 was a staff, now retired, corresponding member of the German Archaeological Institute. He conducted research in: XRF, PIXE, SyXRF, XRD, geomagnetic prospection, and NAA, which remains his only active field now.

apl. Prof. Dr. Hans Mommsen
Helmholtz-Institut für Strahlen- und Kernphysik
University Bonn
Nussallee 14–16
53115 Bonn, Germany
E-Mail: mommsen@hskp.uni-bonn.de

CLAUDIA NÄSER

MPhil. (Cambridge 1995), Dr. phil. (HU Berlin 2001), is a lecturer of Egyptian Archaeology at the University College London. Her research interests include the archaeology of Egypt and the Middle Nile Valley from prehistory to Islam, archaeological theory, the politics of archaeology, and critical heritage studies. She directed the Archaeological Mission to Musawwarat es-Sufra (2005–2015) and directs the Mograt Island Archaeological Mission and the Shalfak Archaeological Mission.

Dr. Claudia Näser
Institute of Archaeology
31–34 Gordon Square
London WC1H 0PY
United Kingdom
E-Mail: c.naeser@ucl.ac.uk

SASKIA NEHLS

is an Egyptologist (FU Berlin 2012) and has recently submitted her dissertation, which deals with imported Mycenaean pottery from Tell el-Amarna/Egypt. Her research focus lies on the archaeology of the intercultural connections between Egypt and the eastern Mediterranean during the New Kingdom.

Saskia Nehls M.A.
Ägyptologisches Seminar
Freie Universität Berlin
Fabeckstraße 23–25
14195 Berlin, Germany
E-Mail: saskia.nehls@gmx.net

STEPHAN G. SCHMID

is a professor of Classical Archaeology at the Institute for Archaeology at Humbolt University Berlin and the Topoi Excellence Cluster. His research interests include Nabataean fine ceramics, Hellenistic ceramics, iron mining and smelting in the Tyrrhenian Sea, urban planning development in Jordan, and Rocher des Aures.

Prof. Stephan G. Schmid
Kultur-, Sozial- und Bildungswissenschaftliche Fakultät
Institut für Archäologie
Universitäts-Hauptgebäude
Unter den Linden 6
10117 Berlin, Germany
E-Mail: stephan.g.schmid@culture.hu-berlin.de

GERWULF SCHNEIDER

Dr.rer.nat. 1968, habilitation 1979, both at Freie Universität Berlin, was a research associate at Excellence Cluster Topoi and now at the Insitute of Prehistoric Archaeology at FU Berlin. Since 1975 his main focus has been on chemical and mineralogical analysis of archaeological ceramics. His research focusses on Roman pottery in Germany, Hellenistic to Late Antique pottery in the Mediterranean region, and on pottery in Europe, Mesopotamia and Sudan. Schneider is a member of the German Archaeological Institute and of various archaeometric societies.

Dr. Gerwulf Schneider
Freie Universität Berlin
Institut für Prähistorische Archäologie
Fabeckstraße 23–25
14195 Berlin, Germany
E-Mail: schnarch@zedat.fu-berlin.de

ERDMUTE SCHULTZE

Dr. phil. (Berlin 1984), is an employee of the German Archaeological Institute: 1992–2000 Roman-Germanic Commission Frankfurt/Main, and since 2001 in the Eurasia-Department. Her special fields are archaeology of the Roman Iron Age and Early Migration Period of Middle and East Europe, landscape archaeology, and Chernyakhov Culture

Dr. Erdmute Schultze
German Archaeological Institute
Eurasia-Department
Im Dol 2–6
14195 Berlin, Germany
E-Mail: Erdmute.Schultze@dainst.de

FLEUR SCHWEIGART

finished her PhD thesis in 2019 on the topic of "Wheel-Thrown Pottery between Elbe and Oder – Production, Distribution and Consumption". The thesis was also part of the EXC 264 Topoi Research group "Economic Space: Wheel-Thrown Pottery of the Imperial Period in Barbaricum (A-6-4)". She is member of the German Archaeological Institute (DAI) and part of the Math+ research project EF5-2: "Data-Driven Modelling of the Romanization Process in Northern Africa."

Dr. Fleur Schweigart
Zuse Institute Berlin (ZIB)
Takustr. 7
14195 Berlin, Germany
E-Mail: schweigart@zib.de

FRIEDERIKE SEYFRIED

is an honorary professor of Egyptology at the Freie Universität Berlin and also director of the Ägyptisches Museum und Papyrussammlung, Staatliche Museen zu Berlin – Stiftung Preußischer Kulturbesitz. Her research interests focus on the New Kingdom, Archaeology and history of the Amarna period; New Kingdom tomb architecture and decoration; and museum educational services, especially for handicapped people.

Friederike Seyfried
Ägyptisches Museum und Papyrussammlung
Geschwister-Scholl-Str. 6
10117 Berlin, Germany
E-Mail: aemp@smb.spk-berlin.de

ALEXANDRU SZENTNMIKLOSI (†2019)

was a scientific researcher and head of the Archaeology Department at the Muzeul Național al Banatului. He was an archaeologist with a focus of research on the Late Bronze Age in southeast Europe. He obtained his PhD in 2009 in Alba Iulia.

MANJA WETENDORF

has a professional education in pottery (1999–2002), pottery assistant (2002–2004), student of Archaeology and African Studies at Humboldt University Berlin and Prehistoric Archaeology at Freie University Berlin (2004–2014), M.A. (Humboldt University Berlin 2014), and researcher in the Archaeological Mission to Musawwarat es-Sufra (2014). Doctoral studies at the Berlin Graduate School of Ancient Studies within the PhD program 'Material Cultures and Object Studies' since 2014 (Humboldt University).

Manja Wetendorf, MA
Humboldt-Universität zu Berlin
Institut für Archäologie
und Kulturgeschichte Nordostafrikas
Unter den Linden 6
10099 Berlin, Germany
manja.wetendorf@gmail.com

MICHAEL MEYER is a Professor of Prehistoric Archaeology at the Freie Universität Berlin and has been the spokesperson of the Excellence Cluster 264 *Topoi*. His work focuses on archaeology of the centuries around Christ's birth, settlement-, and economic archaeology, as well as the archaeological study of war and violence.

Within the BERLIN STUDIES OF THE ANCIENT WORLD series, monographs and volumes of all fields of ancient studies are published. These publications form the results of research conducted within the Excellence Cluster *Topoi. The Formation and Transformation of Space and Knowledge in Ancient Civilizations*, a research association between the Freie Universität Berlin and the Humboldt-Universität zu Berlin as well as the partner institutions Berlin-Brandenburgische Akademie der Wissenschaften, Deutsches Archäologisches Institut, Max-Planck-Institut für Wissenschaftsgeschichte and Stiftung Preußischer Kulturbesitz.
The series is part of the research platform *Edition Topoi* and fully accessible at www.edition-topoi.org.

ISBN 978-3-9819685-8-3

64 BERLIN STUDIES OF THE ANCIENT WORLD

www.edition-topoi.org