Reconstructing Early Cypriot Metallurgy:

the Case of Pyrgos-*Mavroraki*

Marco Romeo Pitone

Doctor of Philosophy

School of History, Classics and Archaeology

Newcastle University

February 2022

Abstract

Due to the extraordinary wealth of its ore deposits, Cyprus was the metal powerhouse of antiquity. The importance of Cypriot ore-mineral deposits has led to a wealth of research on prehistoric copper mining and production. However, this has overwhelmingly concentrated on provenance and exchange studies (via the isotopic fingerprinting of ores and ingots) at the expense of other research strands. In particular, important questions regarding Cypriot copper technology including the role and identity of bronzesmiths still await full investigation.
Among the few cases of Early-Middle Bronze Age sites which show metallurgical evidence, Pyrgos-*Mavroraki* (Limassol) an early 2nd millennium BC settlement site, excavated by the Italian National Research Council (CNR) from 1998-2012, is certainly the richest known so far.
The excavations unearthed a vast architectural complex, which hosted several workshops including an olive press, but most importantly, the complex yielded a great deal of metallurgical installations and residues.
This research, through a combination of archaeological, analytical and experimental work, including SEM-EDX slag analysis and on-field copper smelting trials, allowed to reconstruct the smelting process used at Pyrgos. The archeological evidence shows that Pyrgos's metallurgists used a rather primitive smelting technique, involving the use of simple bowl-shaped furnaces, small crucibles and blowpipe equipped with simple clay nozzles. However, despite the high viscosity of the slags obtained did not allow a complete separation of the metallic copper, the slag-analysis proved that Pyrgos's coppersmith were capable to smelt sulfidic ores, which are known to require a multiphase smelting process.

Acknowledgments

I would like to start by acknowledging the opportunities and support given to me by Newcastle University and the Northern Bridge Consortium in securing my funded PhD position and making both my research and field work possible. I would also like to thank all of the institutions and colleagues from Cyprus and Italy. First, I should thank the excavator Dr Maria Rosaria Belgiorno who first invited me to undertake this research and kindly hosted me in her Cypriot house so many times during this project.

To the Department of Antiquity of Cyprus and the Director Dr. Marina Ieronymidou-Solomidou and the Curator of Antiquities Dr. Despina Pilides goes me sincerest gratitude not only for providing me with the official permissions to study Pyrgos-*Mavroraki*'s material, but also for hosting my six months NBDTP Placement Scheme and making me feel welcome from the very beginning.

I would like to acknowledge the invaluable support provided by the University of Cyprus, and the Archaeological Research Unit for hosting me during my ERASMUS project and on many other occasions, as well as the indispensable support provided by the Cyprus American Archaeological Research Institute and Dr Lindy Crewe.

I would like to thank all my Cypriot colleagues for their warm welcome to the Island and their support. In particular, I would like to thank Konstantina Ioannou, Demetra Aristotelous, Katerina Papanikolaou and the Staff of the Archaeological Museum of Limassol District. My gratitude goes also to Efthymios Shaftacolas, Eleni Loizides and the Team of Conservators at the Cyprus Museum.

My endless gratitude goes to my supervisors Dr Andrea Dolfini and Dr Alasdair Charles, who provided support and guidance throughout the completion of this thesis.

Dr Dolfini guided me in my first approach to Archaeometallurgy, teaching me to look at the ancient metalwork "through a new lens". I am grateful for his many invaluable suggestions to improve my work.
Dr Charles has been my teacher and mentor in the more technical aspects of this research, introducing me to the mysterious world of material chemical analysis, Scanning Electron Microscopy and Emission Diffraction Spectroscopy. I owe him everything I learned on this fascinating analytical technique and its analytical protocols.
I would like to thank my trainers: Dr Marco Ferretti and Dr Isabel Arce-Garcia for being so patient with me and spending their precious time to train me in X-Ray Fluorescence Spectroscopy and Scanning Electron Microscopy and Emission Diffraction Spectroscopy.

A particular mention here goes to my "adoptive Supervisor" who always supported me, helping me to face a very challenging phase of this research. Ευχαριστώ πολύ.

To my friends and colleagues, especially those of whom who followed me in the creation of the Experimental Archaeology Newcastle (EXARN) research group goes a big thank you. Thanks to Victoria Lucas, Amber Roy, Alicia Sawyer for supporting me during my experiments.

At last, but not least, I wish to thank my Family, my mother Gabriella, my stepfather Angelo and my sister Rebecca who have always patiently put up with my PhD life. Special thanks to my mother-in-law Therese Naylor, who kindly offered to proofread most of this work.

A special thought goes to the love of my life, James, who is most admirable for his patience and his capacity of cheering me up even during the less bright moments of this project.

Table of Contents

Abstract	i
Acknowledgments	iii
Table of Contents	vi
List of Figures	x
List of Tables	xiii
Chapter 1 – Introduction	
1.1 Aim of the Work	1
1.2 Methods	3
1.3 General Overview	5
Chapter 2 – Kypros: the island of Copper	
Section I – Cyprus in the Early and Middle Bronze Age	
2I.1 Introduction	10
2I.2 Geography, archaeobotany and palaeoclimatology of Cyprus	12
2I.3 Geomorphology of Cyprus and the nearest ore deposits around Pyrgos	16
2I.4 Archaeology of Cyprus: from the Late Chalcolithic to the Prehistoric Bronze Age	23
2I.4.1 The Philia Facies	27
2I.4.2 Early Cypriot and Middle Cypriot	31
Section II – The earliest Metallurgy of Cyprus: from the Chalcolithic to the Early-Middle Bronze Age	
2II.1 Introduction	48
2II.2 The *chaîne opératoire* of copper	50
2II.3 Metallurgy in Early-Middle Bronze Age Eastern Mediterranean and the Aegean	57
2II.4 Metallurgical evidence from Early and Middle Bronze Age archaeological contexts	77
2II.5 Conclusions	90
Chapter 3 - The Archaeology of Pyrgos-*Mavroraki*	
3.1 Introduction	94
3.2 History of Research	94
3.3 The prehistoric settlement of Pyrgos-*Mavroraki*	100
3.3.1 Northern Sector	108

3.3.2 The Press Room and the production of olive oil 114
3.3.3 Southern Sector 116
3.3.4 Eastern Sector 119
3.3.5 The soundings on *Mavroraki* 121
3.4 Pyrgos's Necropolis 126
3.5 The Metallurgical Artefacts 133
3.5.1 Crucibles 133
3.5.2 Pipe-Nozzles 137
3.5.3 Moulds 140
3.5.4 Stone tools and Anvils 141
3.6 Discussion 143

Chapter 4 – Metal Technology: smelting and slag analysis
4.1 Introduction 147
4.2 Slag Analysis: History of Research 147
4.3 Analytical methods for characterising archaeological slags: Macroscopic and Microscopic characterisation 143
4.4 Cypriot copper ores and ancient slags 154
4.4.1 Cypriot ancient slags: an overview 159
4.5 Previous Approaches to the study of Pyrgos-Mavroraki's slags 164
4.6 The metallurgical slags from Pyrgos: Analytical Protocol and Macroscopic Grouping 168
4.6.1 Type 1: Viscous slags 173
4.6.2 Type 2: Coarse slags 174
4.6.3 Type 3: Mix slags 175
4.7 Sample Preparation 175
4.8 Analytical methods: Optical Microscopy, Scanning Electron Microscopy-Electron Dispersive X-Ray Spectroscopy (SEM-EDX) and Environmental Scanning Microscopy (ESEM) 176
4.8.1 Type 1: Viscous slags 177
4.8.2 Type 2: Coarse slags 182

Chapter 5 - The Metalwork at Pyrgos-Mavroraki: typology and alloy composition
5.1 Introduction 189
5.2 Pyrgos-*Mavroraki*'s metal finds in relation to the main Early and Middle Bronze Age metal types in Cyprus 190

5.2.1 Weapons 192
5.2.2 Tools 197
5.2.3 Ornaments 209
5.2.4 Miscellanea 219
5.2.5 Discussion 222
5.3 Metal composition in Early and Middle Bronze Age Southern Coast Cyprus through the chemical study of Pyrgos-*Mavroraki*'s artefacts 226
5.3.1 Previous approaches to the study of Pyrgos-*Mavroraki*'s artefacts 226
5.3.2 New pXRF analyses on published and unpublished metal finds: methods 228
5.3.3 Results, comparisons, and discussion 231
5.4 Conclusions 235

Chapter 6 – Experimental Copper Smelting at Pyrgos-Mavroraki
6.1 Introduction 238
6.2 Experimental Archaeometallurgy: History of the Discipline and contemporary guidelines for good practice 240
6.3 The first "experiential" experiments 245
6.3.1 Second generation of pilot experiments 247
6.4 The new research plan and experimental conditions 252
6.4.1 Ores, fuel, flux and technical pottery 259
6.4.2 Pyrotechnological reactors: roasting bed and bowl furnace 262
6.5 Roasting 265
6.6 Smelting 271
6.6.1 First, second and third smelting experiments (JH-SMLT I-II-III) 272
6.6.2 Fourth and fifth co-smelting experiment (JH-SMLT IV-V) 278
6.6.3 Sixth and seventh smelting experiment (JH-SMLT VI-VII) 281
6.7 OM and SEM-EDX analysis of Experimental Slags 285
6.8 Conclusions 291

Chapter 7 – Conclusions
7.1 Pyrgos-Mavroraki in the framework of Early and Middle Bronze Age Cypriot metallurgy 295
7.2 Archaeological Science and Experimental Archaeology 303
7.3 Further Research 309

REFERENCES 310

Appendix 1 - Tables of Drawings 332

List of Figures

1.1 Map of the Mediterranean's ore deposits 1

1.2 Map of Early and Middle Bronze Age sites with metallurgical indicators 6

2.1 Rain distribution and the eight biomes in Cyprus 12

2.2 Geomorphological regions of Cyprus 17

2.3 Genesis of the Troodos Ophiolite 18

2.4 Copper and Iron Pyrites in Cyprus 20

2.5 Pharmakas-Kalavasos Geological Area 21

2.6 Map of PreBA sites mentioned in the text 19

2.7 Map of Cyprus showing the location of Philia sites 30

2.8 Plank-shaped figurine 34

2.9 Map of Early and Middle Bronze Age sites mentioned in the text 37

2.10 Crucible from Yarikkaya 59

2.11 Map of the Aegean with metal ore sources and exchange centres 67

2.12 Reconstruction of the pierced shaft furnace type found in the Aegean 69

2.13 Cypriot Chalcolithic sites with metals in 74

2.14 Map of Early and Middle Bronze Age sites with metallurgical indicators 80

2.15 Moulds from Marki-*Alonia* 81

2.16 Crucible from Paramali-*Pharkonia* 84

2.17 Mould from Politiko-*Troullia* 86

2.18 Mould from Ambelikou-*Aletri* 88

3.1 Pyrgos-*Mavroraki* on the satellite map 95

3.2 *Mavroraki*'s archaeological investigation area 97

3.3 Northern Sector plan 98

3.4 Pyrgos limestone/basalt foundations 99

3.5 Plan of the "triangular building" 100

3.6 Pyrgos-*Mavroraki*, parcels from the cadastral map 102

3.7 Map of Pyrgos-*Mavroraki* 103

3.8 Wall collapsed in the western room of the Triangular Building 107

3.9 Pyrgos-*Mavroraki*, Plot 1266, Squares H-I2, levels 5-7 109

3.10 H1, stone-pebbled floor 110

3.11 Northern Sector 111

3.12 Possible shaft-furnace 113
3.13 Olive-press on Attic Skyphos 115
3.14 Pit-furnaces in the Southern Sector 117
3.15 Pit-furnace found in I9a with “jug-carburettor” 118
3.16 Clay-nozzle inserted in a stone-holder 119
3.17 The “forge” in K6 120
3.18 The Coppersmith workshop 121
3.19 Soundings on *Mavroraki*’s hill 122
3.20 Soundings on *Mavroraki*’s hill 123
3.21 Sounding AX93 124
3.22 Pyrgos Cemetery: Tomb 2a, Tomb 1, Tomb 4 128
3.23 Metal/metallurgy related artefacts from Pyrgos’s tombs 131
3.24 Crucibles from Troy VIIA and Thermi, Lesbos 136
3.25 Blowpipe nozzles and nozzle-holder from Pyrgos-*Mavroraki* 138
3.26 Blowpipe nozzles from Ambelikou-*Aletri* and Vounous 138
3.27 Moulds 352 and 351 from Pyrgos-*Mavroraki* 140
3.28 Anvil 188 from Pyrgos-*Mavroraki* 142

4.1 Reconstruction of a shaft furnace at the Geopark Visitor Centre (Cyprus) 150
4.2 Graphic reconstruction of a pit-furnace from Shiqmim (Israel) 150
4.3 The ternary system FeO–Al2O3–SiO2 152
4.4Location of major sulphide orebodies in the Troodos Pillow Lava Series 154
4.5 Diabase covered in coatings of malachite from Pyrgos-*Mavroraki* 156
4.6 Ore lump from Ambelikou-Aletri 157
4.7 Photomicrographs of tap-slags from Kalavassos-Aghios Dhimitrios 164
4.8 Fayalite laths in a slag from Pyrgos-*Mavroraki* 166
4.9 Slags’ provenance percentages 169
4.10 Level-distribution of Pyrgos’s slags in the different sectors 170
4.11 Slag types distribution 172
4.12 Viscous Type slags from Pyrgos-Mavroraki 173
4.13 Detail of a corrugated surface on sample 215 174
4.14 Viscous Slags stratigraphic provenance 175
4.15 Coarse Slags stratigraphic provenance 175
4.14 Coarse Type slag from Pyrgos-Mavroraki 176
4.17 Fe oxides in sample 302b 180

4.18 Photomicrographs of Pyrgos-*Mavroraki*'s slags 181
4.19 Photomicrographs of iron-copper sulphides in Pyrgos-*Mavroraki*'s slags 181
4.20 Pyrgos-Mavroraki slag samples on the $FeO–Al_2O_3–SiO_2$ ternary system 185

5.1 Hook-tang weapon types 192
5.2 Hook-tang weapons hafting hypotheses 194
5.3 Hook-tang weapons from Pyrgos Cemetery 196
5.4 Knives from Pyrgos-*Mavroraki* and Pyrgos Cemetery 198
5.5 Detail of flowing patterns on T21/35 199
5.6 Axes from Pyrgos Cemetery 202
5.7 Awls and chisels from Pyrgos-*Mavroraki* and Pyrgos Cemetery 206
5.8 Needles from Pyrgos-Mavroraki 208
5.9 Pins from Pyrgos-*Mavroraki* and Pyrgos Cemetery 212
5.10 Ornaments from Pyrgos-*Mavroraki* and Pyrgos Cemetery 216
5.11 Razors and tweezers from Pyrgos-*Mavroraki* and Pyrgos Cemetery 218
5.12 Miscellanea from Pyrgos-*Mavroraki* 221
5.13 Distribution of metal artefacts in Pyrgos's sectors and general stratification 223
5.14 Graph showing the amount of metal artefacts belonging to each category and type 224

6.1 Experimental roasting bed 263
6.2 Graphic reconstruction of the experimental bowl-shaped furnace 264
6.3 Bowl-shaped furnace's construction sequence 265
6.4 JH-RST I 267
6.5 JH-RST II 268
6.6 Ore crushed after JH-RST II (1-3); sample from the top of the crucible (4) 270
6.7 JH-SMLT I 274
6.8 Thermocouples set-up used during JH-SMLT III-IV 277
6.9 JH-SMLT IV 280
6.10 JH-SMLT VI 283
6.11 Photo and photomicrograph of bornite used for the project 287
6.12 JH-SMLT I: sliced crucible, sites of interested analysed 288
6.13 JH-SMLT II: sliced crucible, sites of interested analysed 289

List of Tables

2.1 Chronology of Chalcolithic and Bronze Age Cyprus 20

2.2 Funerary practices between Chalcolithic and E/M BA Cyprus 29

2.3 Main early metallurgical sites around Mount Timna 62

2.4 Metallurgical sites from the Faynan District 65

2.5 Metallurgical sites from the Aegean 71

2.6 Metal artefacts from Cypriot Chalcolithic sites 76

2.7 Early and Middle Bronze Age Cypriot sites and their metallurgical indicators 79

3.1 Radiocarbon dates for Pyrgos-*Mavroraki* 105

3.2 Metal/metallurgy related artefacts from Pyrgos's tombs 129

4.1 Ambelikou-*Aletri* samples' definitions in different authors 158

4.2 Chemical analyses of Lump 1-2 from Ambelikou-*Aletri* 158

4.3 Classification of Cyprus slags 159

4.4 Bulk analyses of slags from Alambra-*Mouttes* 162

4.5 Average chemical composition of the Fe-silicate phases in the Kalavassos-*Aghios Dhimitrios*'s slags 163

4.6 Bulk analyses of Pyrgos-*Mavroraki*'s slags by Giardino and Rovira 167

4.7 Slag quantities from Pyrgos-*Mavroraki* 169

4.8 Slag types distribution 171

4.9 Average chemical composition of Fe-silicate phases of viscous slags from Pyrgos 184

4.10 Average chemical composition of Fe-silicate phases of tap-slags from Kalavasos-*Aghios Dhimitrios* 185

4.11 Average chemical composition of Fe-silicate phases of coarse slags from Pyrgos 187

5.1 Gazetteer of Philia sites and relative metal artefacts found 191

5.2 Overview of the copper and copper-alloy items from Pyrgos-*Mavroraki* 222

5.3 ED-XRF analyses of metal artefacts from Pyrgos by Giardino et al. (2002) 226

5.4 Pyrgos-*Mavroraki* E/M BA artefacts chemical composition by pXRF 231

6.1 Experimental technical pottery dimensions 261

6.2 JH-RST I - Experimental form 266

6.3 JH-RST II - Experimental form 269

6.4 JH-SMLT I - Experimental form 273

6.5 JH-SMLT II - Experimental form 275
6.6 JH-SMLT III - Experimental form 278
6.7 JH-SMLT IV - Experimental form 279
6.8 JH-SMLT V - Experimental form 281
6.9 JH-SMLT VI - Experimental form 282
6.10 JH-SMLT VII - Experimental form 285
6.11 Ore samples' chemical compositions before and after roasting 286
6.12 Chemical compositions of copper-rich phases from JH-SMLT I samples 290
6.13 Chemical compositions of copper-rich phases from JH-SMLT II samples 290

Chapter 1. Introduction

1.1 Aim of the work

Due to the extraordinary wealth of its ore deposits, Cyprus was the metal powerhouse of antiquity. Most of the copper traded and used in the Mediterranean (fig. 1.1) from the Bronze Age to the late Roman period was sourced from, and smelted on, the island. The importance of Cypriot ore-mineral deposits has led to a wealth of research on prehistoric copper mining and production. However, this has overwhelmingly concentrated on provenance and exchange studies (via the isotopic fingerprinting of ores and ingots) at the expense of other research strands. In particular, important questions regarding Cypriot copper technology including the role and identity of bronzesmiths still await full investigation.

Cyprus is renowned for its wealth in copper ore deposits found in the pillow-lava levels of the Troodos Massif, the main orographic system of the Island. The most abundant Cypriot copper ores are copper-iron-sulphides such as Chalcopyrite and Bornite, which require a more complex multiple-phase process to be smelted compared to copper oxides. This is probably the main reason that caused to the first Cypriot metallurgy a delayed development, compared to other regions of the Eastern Mediterranean were the main ores smelted were copper oxides.

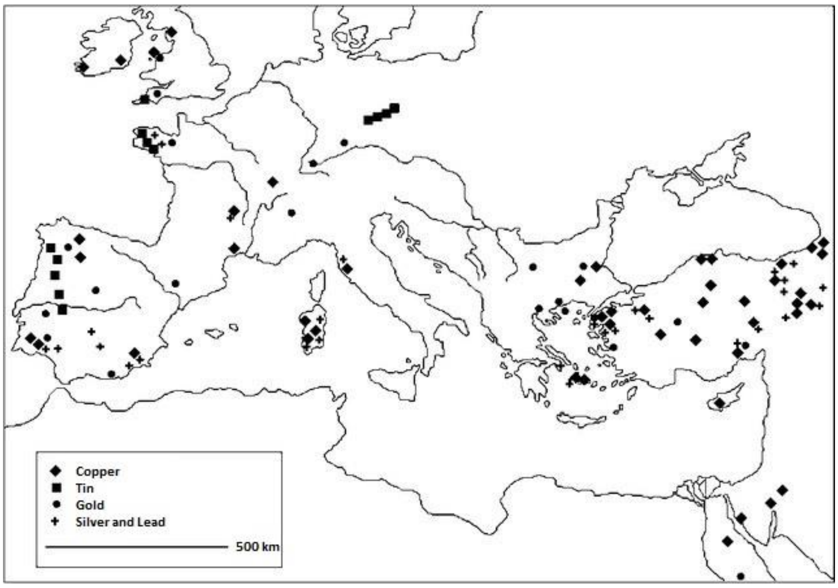


Figure 1.1 Map of the Mediterranean's ore deposits (Kassianidou and Knapp 2005, p. 219, fig. 9.1).

However, once Cypriot metallurgists overcame the initial difficulties related to sulfidic ore smelting, they could produce enough copper to be able to satisfy not only local demand but extend their trade outside the Island (Constantinou 2012: 7). By the 1300 BC, Cyprus was the main producer and exporter of copper in the Eastern Mediterranean and the Near East (Kassiandiou 2013d: 145).

The famous slag heaps of Skouriotissa represent the most impressive monument to Cypriot ancient and modern metallurgy, testifying the long-lasting connection of this Mediterranean Island with its copper resources.

Since the beginning of modern Cypriot archaeology, great attention has been paid to Cyprus's ore deposits and the role played by metallurgical production in the political and economic development of the Island (Muhly et al. 1982: V). Despite many recent studies have been published, re-examining both old and new contexts, there is a clear disparity between the Late Bronze Age (LBA) and the Early/Middle Bronze Age (E/MBA).

Metal objects appeared in Cyprus during the Chalcolithic, but the first abundant evidence for systematic copper ores exploitation by Cypriot metallurgists was found mainly in Late Bronze Age sites such as Enkomi (Kassianidou 2016), Politiko-*Phorades* (Knapp and Kassianidou 2008), Kalavassos-*Aghios Dhimitrios* (Van Brempt 2016), Alassa-*Paliotaverna* (Van Brempt and Kassianidou 2017), Maroni-*Vournes* (Doonan et al. 2012), Hala Sultan Tekke (Fisher and Bürge 2014. p. 72).

However, less information was available in regards of the earlier phases of Cypriot proto-history.

In the late Nineties' the publication of Alambra-*Mouttes* provided an all new range of information about the Early/Middle Bronze Age metallurgy, based on the smelting of copper carbonates in small crucibles and, most likely, pit-shaped furnaces (Coleman et al. 1996; Gale et al. 1996).

Pyrgos-*Mavroraki*, an early 2nd millennium BC proto-industrial settlement, is an excellent case-study on which to apply experimental archaeometallurgy because it presents many different elements connected to the *chaîne opératoire* of copper metallurgy, typical of Early/Middle Bronze Age Cyprus.

The site, excavated by the Italian Archaeological Mission of the ITABC-CNR of Rome (Institute for Technologies applied to the Cultural Heritage of the Italian National Research Council), revealed different metallurgical areas and a coppersmith workshop.

Among the metallurgical evidence of the entire copper processing (crucibles, moulds, anvils, stone tools), the huge presence of non-tapping slags all over the site and the identification of several structures interpretable as furnaces, suggested that some sort of smelting process took place at Pyrgos-*Mavroraki*. Unfortunately, the final publication of the site is still a work-in-progress by the Excavation Team.
The first goal of this work is, therefore, to provide a review, as complete as allowed by the "grey literature"[1] made available to the author by the excavator, of all the metallurgical evidence from the site of Pyrgos-*Mavroraki*.
Initially a general review of the literature available collecting in one place the most relevant metallurgical evidence found in Early/Middle Bronze Age Cypriot sites. This clarified the archaeological context in which the finds from Pyrgos-*Mavroraki* would have been framed. Ultimately, the site of Pyrgos-*Mavroraki* is used together with the other metallurgical finds from Early/Middle Bronze Age sites in Cyprus to showcase a possible scenario for metal production on the island in this period, expanding current knowledge about the earliest Cypriot metallurgy.

1.2 Methods

To face the challenge represented by the study of Pyrgos-*Mavroraki*, a preliminary dedicated literature review was carried out, in order to better understand the data collected through the study of the available grey literature. This allowed a preliminary understanding of the site and the different types of metallurgical evidence present. All the artefacts metalwork-related were catalogued and categorised, distinguishing the objects in metal artefacts, slags, crucibles and technical pottery, anvils, moulds.
The metal artefacts from Pyrgos, both from the settlement of *Mavroraki* and from the Cemetery, now under the modern village of Pyrgos, were categorised and framed within the known Early/Middle Bronze Age Cypriot metal typology. The artefacts from the settlement of *Mavroraki* have been analysed by pXRF, revealing the use of both arsenical copper and tin-bronze at the site.

[1] In this context, by "grey literature" it is intended all the available data regarding the site of Pyrgos-*Mavroraki*, provided by the excavator, extracted from the unpublished excavation's diaries. This includes for example the list of metallurgical artefacts, tools and by-products found onsite.

The most relevant evidence of metallurgy at Pyrgos-*Mavroraki* was the number of slags found, which appears exceptional when compared to the data available from other coeval sites such as Alambra-*Mouttes* where only seventeen isolated lumps of slag were found (Coleman et al. 1996, p. 382). Unlike other later archaeometallurgical contexts, in this case, no slag heap was found; instead, the slags were scattered, sometimes in small groups, all over the surface of the site.

The slags' catalogue counts 1717 slags, with a total weight of 48.62 kg. A sample of 836 slags was considered for optical analysis. All slags from the sample were visually assessed and a smaller selection was chosen for further analysis by Optical Microscopy and Scanning Electron Microscopy, coupled with Energy Dispersive X-Ray.

The slag-analysis produced an important challenging result: Pyrgos's coppersmiths, differently from the metallurgists active at Alambra-*Mouttes*, used to smelt sulphidic ores, without reaching particularly successful reduction conditions or very high temperatures.

These results, coupled with the data provided by the study of the archaeological context, gave the theoretical base to plan and design a series of experimental roasting- and smelting-trials, using a simple pit-shaped furnace, small crucibles and Chalcopyrite.

Experimental archaeology applied to archaeo-metallurgical studies (experimental archaeometallurgy) has revealed itself as an essential tool to verify scholars' hypotheses on the technological processes involved in ancient metallurgy. Experimental archaeometallurgy is a specialist field within experimental archaeology. Examples of this kind of approach can be dated back to the end of the nineteenth century (Cushing 1894), far earlier than the formal foundation of modern experimental archaeology. This discipline met an important development in the 1970s in terms of contexts and methods (Tylecote and Merkel 1985), due to the discovery of important ancient metallurgical sites such as Timna in Israel (Tylecote and Boydell 1978; Merkel 1977, 1990; Ghaznavi 1976; Tylecote et al 1977; Bachmann and Rothenburg 1980). An increasingly large number of archaeometallurgists have decided in the last decades to use experimental archaeology, beside other archaeological sciences, to confirm or refute some of their hypotheses on metallurgical contexts.

Experimental protocols have been designed for every metallurgical field, from ore mining (Timberlake 2007); smelting (Merkel 1990; Doonan 1994; Fasnacht 2009; Bunk et al. 2004; Pryce et al. 2007; Doonan and Dungworth 2013); the casting and refining of artefacts (Timberlake 2013; Barbieri et al 2015); to even the last use (applying experimental archaeology to the study of use-wear analysis) of the same artefact (Dolfini & Crellin 2016; Heeb 2014; O'Flaherty 2007; Molloy 2004).

The characteristics of every single experimental research protocol depend on different factors among which is essential to remember: the hypothesis we want to test, the specific questions we want to answer; and the archaeological and analytical data available.
The slags obtained during the experimental smelting have been sampled and analysed through Optical Microscopy and Scanning Electron Microscopy in order to be compared with the experimental slags.
These experiments proved the possibility of process sulphidic copper ores through crucible-smelting using simple pit-shaped furnaces and blowpipes. Considering that crucible fragments, possible pit-shaped furnaces and clay nozzles for blowpipes have been found in other Early/Middle Bronze Age Cypriot, sites it can be argued that this was the main smelting technology used on the island in this period, before the introduction of tap-smelting in the Late Bronze Age.

1.4 General Overview

This work is divided in two main parts: chapters 2 and 3 dedicated to the context of the research and the archaeological data related to the metallurgical activity at Pyrgos-Mavroraki. The second part (chapters 4, 5 and 6) is dedicated to the analysis of the metallurgical material from the point of view of archaeological science, investigating the chemical compositions of the metal artefacts and the metallurgical by-products. All the data collected both from the archaeological record and the slag analysis were then combined to design a series of pilot experiments to test the first stage of the copper smelting technology hypothetically in use at Pyrgos-*Mavrorak*i.

The second chapter of this work is dedicated to Cyprus in the Early and Middle Bronze Age. Cyprus is the second biggest island of the Mediterranean, located at its very eastern edge, facing the coasts of Turkey to the North and Syria and Lebanon to the East.
Despite its copper ore wealth, Cyprus "discovered" metallurgy quite late compared to Anatolia and Europe where traces of copper smelting are dated since the end of the Neolithic (5^{th} millennium BCE).
The first metal artefacts found in Cyprus are ornaments and simple tools dated to the Middle (3600/3400-2700 BCE) and Late Chalcolithic (2700-2500/2400 BCE), but no evidence of metallurgical activity dated before the Early/Middle Bronze Age has been found yet on the island (Peltenburg 2011).

During this period, relevant changes happened in Cyprus both on a social and material culture level. It has been hypothesised that a process of "hybridisation" took place between the local Chalcolithic communities and new groups coming, probably, from Anatolia. The advent of metal processing on the island is one of the main innovations of this period.
Eleven Early/Middle Bronze Age sites were recorded (fig. 1.2), seven settlements and four isolated contexts, have been found with evidence of metallurgical activity represented at least by one of the following indicators: ores, slags, crucibles, moulds, clay nozzles, furnaces, anvils, stone tools and metal artefacts.

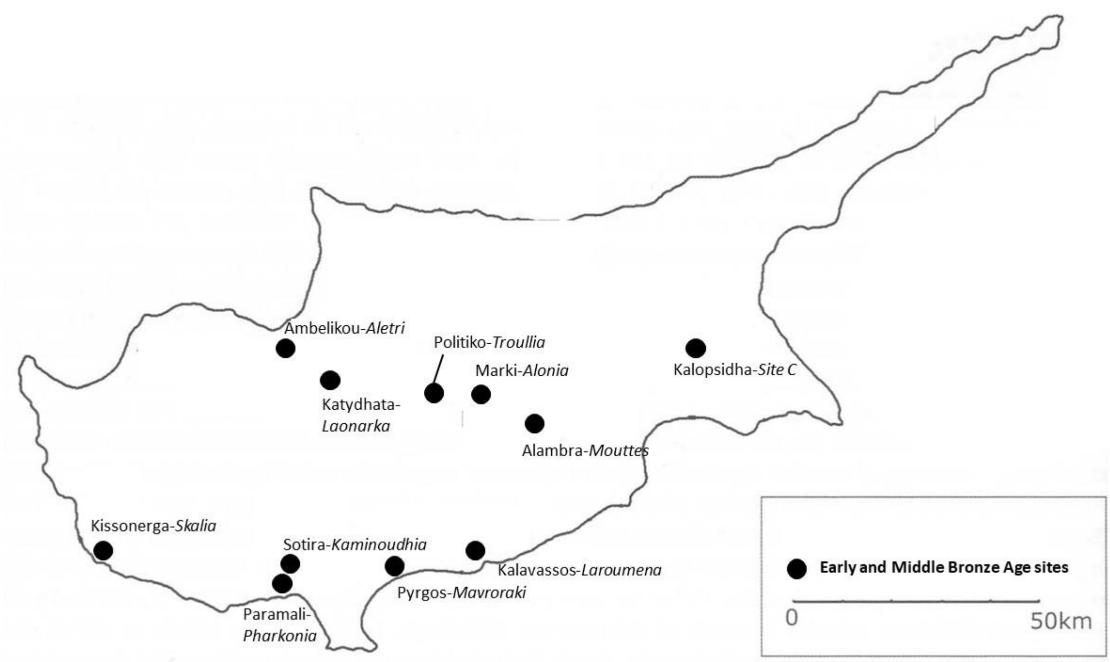


Figure 1.2 Map of Early and Middle Bronze Age sites with metallurgical indicators.

The evidence is usually restricted to the presence of a few indicators for each site, such as a few moulds in the case of Marki-*Alonia* or Politiko-*Troullia* and a small amount of copper ores and slag from Alambra-Mouttes. The technology employed at these sites to extract copper from its carbonates seems to be crucible-smelting, according to the finds from Alambra-*Mouttes*[2].
According to this early technology and the scarcity of debris, copper production in Cyprus seemed to belong to the domestic setting.
The same technology was already in use in other areas of the Eastern Mediterranean much earlier.

[2] The clay nozzle found at Ambelikou-*Aletri* suggests the use of blowpipes, differently from the Late Bronze Age when the use of large tuyères and bellows is testified at all metallurgical sites.
According to this early technology and the scarcity of debris, copper production in Cyprus seemed to belong to the domestic setting.

These sites include Pyrgos-*Mavroraki*, the archaeological context of which is investigated in the third chapter of this work.
Pyrgos-*Mavroraki* (Limassol), an early 2nd millennium BC settlement site excavated by the Italian National Research Council (CNR) from 1998-2012, yielded a great deal of metallurgical installations and residues, including ore roasting beds, smelting and casting furnaces, slags, crucibles, moulds, anvils, metalworking tools and bronze artefacts.
The finds of Pyrgos contribute hugely to our knowledge of Early and Middle Bronze Age metallurgy, doubling the evidence available for this period in Cyprus.
Different areas dedicated to metallurgical activity have been identified within the site, which has been found covered by a multitude of slags (almost 50kg, of which 42.8kg were found *in stratu*).
Many fragments of crucibles have been recovered and clay nozzles, similar to that one found at Ambelikou-*Aletri*, seem to confirm the crucible-smelting technology also in use at Alambra.
Traces of several pit-furnaces, rebuilt consecutively in the same spots, would also support the crucible-smelting technique hypothesis.
Although, the presence of two complete moulds for axes and several other mould fragments testify that the copper or copper alloy objects were cast on-site, and probably refined in the Eastern Area, where stone anvils and a large stone-slabs furnace was also recovered (Belgiorno 2009, pp. 78-87).

Chapter four is dedicated to the metal technology used at Pyrgos, including the slag analysis.
After a preliminary evaluation of the 1717 slags, it was possible to consider some important information. The Northern Sector has the highest slag density (2.8 slags per m^2) together with the Western Sector (2.1 slags per m^2).
According to a first autoptic analysis on a selected sample of around one half of the total amount, it was possible to divide the slags into 4 main categories: a “viscous” type, with smooth amorphous surfaces and a magmatic aspect; a “coarse” type, with rougher surfaces and more chunky aspect; a “mix” type, where the characteristics belonging to the first two types are both present; and finally a so-called “unknown” type, where it was not possible to recognised neither of the characteristics described before.
Samples were selected and sliced for further analysis from each sector, with a special focus on the Northern and Southern Sectors, considering that these were the areas where the vast majority of metallurgical indicators were found together with the slags.
The samples were analysed by Optical Microscopy and Scanning Electron Microscopy coupled with Energy Dispersive Spectroscopy.

The microstructure of the slags revealed that sulfidic copper ore was smelted at Pyrgos. This represents an interesting contribution to our knowledge of Early/Middle Bronze Age metallurgy in Cyprus, for which, until now, only copper carbonates were found to be smelted.
The main product obtained from the smelting was a copper rich in sulfur, also known in metallurgy as black copper or matte, which needed to be further smelted and purified.
The mineral phases identified in the slags' matrix suggest also that the ancient coppersmiths of Pyrgos were not totally in control of the redox conditions inside the furnace. This, together with the scarce control of the temperature might have affected the separation of the copper from the other mineral components, originating a viscous/chunky lump. All the slags found at Pyrgos appear broken, suggesting that the non-perfectly formed slags, once collected from the furnace needed to be crushed to recover the copper prills, which would have been re-melted and further processed.

Chapter five is dedicated to the metal artefacts found at Pyrgos-*Mavroraki* through the study of their typology and alloy composition.
The metal artefacts found at Pyrgos were analysed by pXRF in order to be compared with the artefacts found in the coeval sites from Cyprus.
The analyses revealed that the majority of these objects were made of different copper alloys, containing arsenic and in some cases tin. This type of alloys is well attested in Early/Middle Bronze Age Cyprus.
A particular object, in the shape of what seems to be a miniaturised oxhide ingot, was found to be made of lead and tin. If the analysis is correct, this object would confirm that alloying was practiced at Pyrgos-*Mavroraki.*

Chapter six is dedicated to the experimental copper smelting trials based on the data from Pyrgos-*Mavroraki*
Seven experiments of sulfidic copper ore (bornite) smelting were carried out using a pit-furnace, fueled with pine-wood charcoal and operating blowpipes. According to the literature, before being smelted, the ore was roasted for twelve hours in an open fire in the attempt to lose as much Sulphur as possible. The roasting worked effectively, and the ore was later crushed in fragments of ca. 1cm of diameter, without effort, using a stone grinder.
It was established that to reach the temperature necessary for smelting (1000°C/1200°C), at least three blowpipes need to be operated in turn consequently, in order to create a constant air flux

within the furnace. Black copper was the main result of these trials, demonstrating that this very primitive technology is effective not only for copper carbonates, but also for sulfidic copper ores.

The last chapter compares the archaeological data with the experimental data. The data produced experimentally are to be compared with what was found during the slag analysis allowing conclusive considerations.

Chapter 2. Kypros: the Island of Copper

Section I Cyprus in the Early and Middle Bronze Age

2I.1 Introduction

Cyprus, the "solitary insular giant of the far eastern Mediterranean", to use Broodbank's words (2013, p. 148), has been characterised by a marked isolation since bands of occasional settlers who visited, probably seasonally (Ammerman and Noller 2005), the island 11,000 years ago for the first time (Late Epipalaeolithic), looking for alimentary resources (Bombardieri and Graziadio 2019, pp. 15-16; McCartney et al. 2010, pp. 134-135), as well exemplified by the site of Akrotiri-*Aetokremnos* (Simmons 2009; 2011), where pigmy hippos and dwarf elephants were intensely exploited. It is still unsure where the first settlers of Cyprus came from, with scholars debating between the region of Antalya in Turkey and the Levant (Bombardieri and Graziadio 2019, p. 17). This process took at least two thousand years before the first sedentary communities settled in Cyprus in the Early Aceramic Neolithic (8500/8400-6800 BC), with the so-called Khirokitia Culture developing in the Late Aceramic Neolithic (7000/6800-5200 BC; Bombardieri and Graziadio 2019, p. 17-18; Knapp 2013, pp. 74-158).

Since its first settlers, there is limited evidence for foreign contacts until the Bronze Age, when Cyprus starts its fame as "Crossroads of the Mediterranean" (Karageorghis 2002), becoming a privileged theatre of encounters and creative admixtures of different cultures and people. Cyprus's insularity has been characterised by the polarity between isolation and interaction, moving at the two extremes of this spectrum in its prehistory and early history (Knapp 2013, p.

35). It was the island's peculiar biodiversity (dwarf species) which attracted the first Epipalaeolithic settlers, and, very likely, its mineral resources in terms of copper ores to attract a new wave of colonists to Cyprus, at the end of the Chalcolithic and, more consistently, at the beginning of the Bronze Age.

This chapter provides an overview of Cyprus during the passage between the Chalcolithic and the Bronze Age, to introduce the reader to the case-study of Pyrgos-*Mavroraki,* to which the next chapter (3) is specifically dedicated.

The chapter has been conceived in two distinct sections: Section I provides a more general background on the landscape of Cyprus, looking at the island's geography, archaeobotany and palaeoclimatology in paragraph 2.II.2 and focusing the following paragraph on its geomorphology, contextualising the copper ore deposits around Pyrgos. This first section proceeds then to describe the main archaeological feature of Cypriot archaeology correspondent to the moment of passage from the Chalcolithic throughout the Early and Middle Bronze Age. The events that brought to the emergence of the Philia Facies (2400/2350-2250 BC) are briefly described, highlighting the current debate which investigates the autochthonous and foreign elements recognisable by its material culture. This is particularly relevant to our research as the first evidence for metallurgy appears in the Middle and Late Chalcolithic on a very limited scale, while increases remarkably with the advent of the Philia Facies.

The last paragraphs of the first section of this chapter report briefly on specific aspects of the Early and Middle Bronze Age Cypriot communities such as: architecture and spatial organisation, subsistence economy, material culture and mortuary practices.

Section II of this chapter focuses on the earliest evidence of metallurgy on Cyprus, from the first artefacts to the first evidence of metal processing. The main Cypriot archaeological contexts are considered in detail providing the essential points of reference needed by the reader to approach later the case-study of Pyrgos-Mavroraki.

The last paragraph of Section II expands on the topic of early metallurgy dated to the Early-Middle Bronze Age within the Eastern Mediterranean, highlighting archaeological contexts and sites coeval and/or relevant to the case-study of the present research.

2I.2 Geography, archaeobotany and palaeoclimatology of Cyprus

Cyprus is characterised today by an arid Mediterranean climate with brief, cold and rainy winters and hot and dry summers. Lentini collected rainfall and temperature data from 25 weather stations on the island (fig. 2.1) and they were able to update Zohary's (1973) early map, producing a view of possible microclimates on Cyprus. The varying geomorphologic features of Cyprus allow the vegetation to spread over eight micro-habitats. Some of these are marked by geographic features, while others are defined by different types of climate and soil.

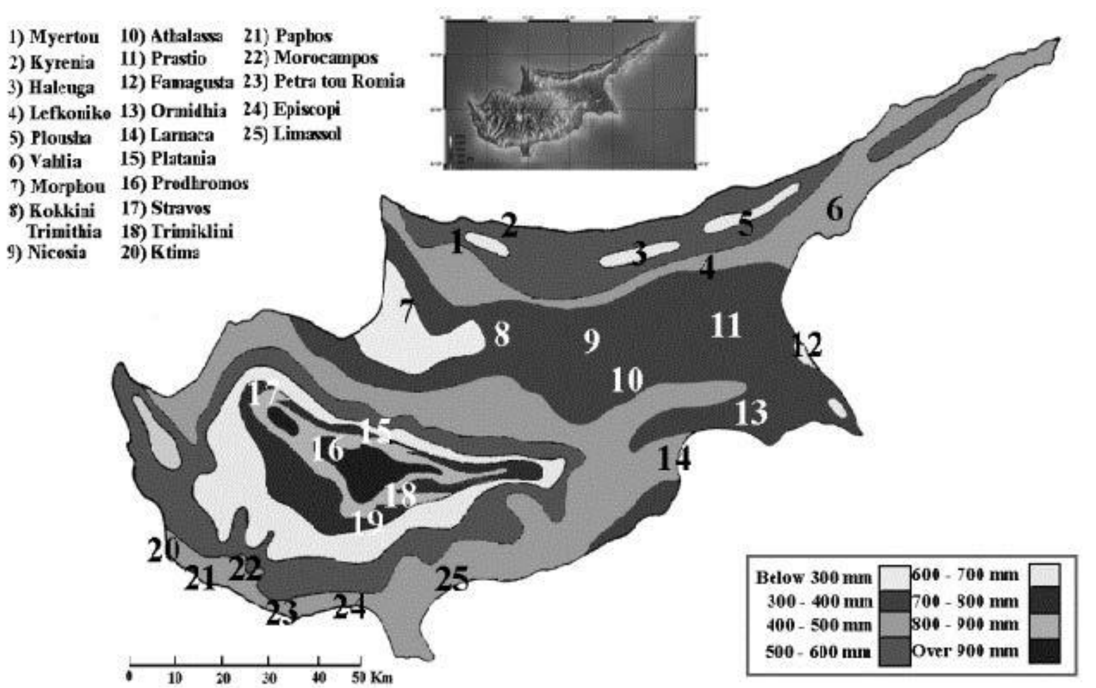


Figure 2.1 Rain distribution and the eight biomes in Cyprus (after Lentini 2015: 127, fig. 2)

In the Kyrenia mountains, three different microclimates were identified, also present beyond the Mesaoria plain. The area of the Kyrenia Mountains that slopes down towards the sea, mainly recorded by the Kyrenia weather station, is characterised by the main presence of *Juniperus phoenicea* L. (Phoenician juniper), and *Pinus brutia* (Calabrian pine) at medium to high altitudes. The second microclimate is found in three small separate areas which correspond to the highest altitudes in the Kyrenia's mountains and do not present any significant stable tree cover.

The weather station at Vahlia documents the third microclimate for a large area with allopatric features such as the area between Kormakiti (Koruçam) to the NW and Cape Andreas to the NE, separated from the other climatic areas by the Mesaoria plains to the S and SE, by Morphou's desertified area to the NW and by the foothills of the Troodos to the SW. The other weather stations, which monitor this microclimate, are all located on the southern coast, between Ktima and Larnaca. Irano-Turanic species such as *Cupressus sempervirens* L. (Mediterranean cypress), *Pinus halepensis* Mill (Aleppo pine). and *Cedrus brevinfolia* Hook.f. (Cyprus cedar) and Mediterranean species belonging to the macrofamilies: *Prunus*, *Pistacia*, *Olea europea* L., *Quercus*, *Ceratonia*, *Myrtus* and *Laurus* are characteristic of this microclimate.

The fourth microclimate corresponds to the only desertified area of Cyprus, in the District of Morphou (Güzelyurt), with a seasonal vegetation of halophytes, plants which grow in soils (or waters) of high salinity. The fifth microclimate is one of the more extended and better documented on the island (monitored by five weather stations) and includes the large Mesaoria plains. This area, with a high rate of deforestation and human activity over the millennia, is characterised mainly by "anthropocore" species (non-indigenous and testifying human presence) such as *Quercus coccifera*, *Olea europea* L. (olive), *Olea europea* L. var. *sylvestris* (wild olive), *Certonia ssp*. (carob), *Graminaceae*, *Genista ssp*., *Calycotome ssp*., *Chenopodiaceae*-

Amaranthaceae, *Asteraceae*, *Labiateae* and *Compositae*. Some marginal wetlands near Ammochostos (Gazimağusa) are also part of this microclimate, with association of halophytes. The Troodos mountains include the remaining three microclimates, with evergreens (*Cupressus sempervirens;Juniperus phoenicea*), semi-deciduous trees (*Quercus coccifera* and *infectoria*) and *Arbustus andrachne* on the lower slopes. Part of this microclimate are also large *Populus*, *Saliz* and *Alnus* riverside forests, while above 1000m are common vast pine woods of *Pinus brutia* and other endemic species (*Cedrus brevifolia*; *Quercus alnifoli* Hook.f.) and at the highest peaks *Pinus palladiana* and *Juniperus foetidissima* Willd (Lentini 2015, pp. 127-130).

The original biome[1] of Cyprus was the pine forest which was probably much more extended than today (Lentini 2015, p. 130; Quezel 1979). This data is very relevant within the study of the archaeometallurgy of this island, if we consider that these forests insisted on the main mineralisation, offering a rich source of fuel necessary for the first stages of the metallurgical process in the immediate surroundings of the extraction sites. *Pinus brutia* (Calabrian pine) charcoal was found during the analysis of slag heaps at the Late Bronze Age site of Politiko-*Phorades* and recognised as the main fuel used during copper smelting (Knapp and Kassianidou 2008, p. 142). In relation to *taxa* used in antiquity as fuels for metallurgical activity, Socratous *et alii* carried out a comprehensive analytical programme on approximately 1600 fragments of charcoal remains found at five different ancient Cypriot slag heaps, dating from the Hellenistic to the Late Roman period (2015). They were able to confirm that even for these more recent periods, the main firewood used for copper smelting was *Pinus brutia*. It is interesting to note that wild and cultivated olive and grapevine charcoal was present in these assemblages. Socratous

[1] As "biome" it is intended the biological community, related to a certain physical climate and characteristic of a specific area.

et alii (2015, p. 377) suggest that these species were also used occasionally as fuels, perhaps following seasonal pruning.

A detailed palaeo-climatic picture is not possible due to the lack of systematic studies (Bombardieri and Graziadio 2019, p. 11), however studies on specific areas have been carried out (Lucas 2014). Archaeobotanical data are available for the Early/Middle Bronze Age sites of Marki-*Alonia*, Sotira-*Kaminoudhia* and Episkopi-*Phaneromeni* (Fig. 2.7). Processing the samples through floatation, it was possible to identify barley, emmer wheat, chickpea, lentil, fig, almond, pistachio, olive, grape, either pear or apple and different wild herbaceous *taxa* (Lucas 2012, pp.141-142). The *taxa* identified from these sites are mostly considered to be food resources, but no research has been devoted to charcoal from hearths, fireplaces and ovens, which might indicate fuel resources.

Some preliminary archaeobotanical data are also available for Pyrgos-*Mavroraki*. The finds suggest that the local climate was cool and moist, a situation also observed at other Mediterranean sites dated from 2000-1900 BC (Palmieri 1980). It is most likely that in these conditions, vegetation that today only grows at medium and high altitudes would be found at lower altitudes. With the increase of human activities and a new human role in shaping landscapes through new agricultural techniques, such as the use of plough, on one hand (Knapp 2013, p.269), and the climatic evolution towards sub-arid periods on the other, the main biomes moved to higher altitudes, seeking cool and moist conditions (Lentini 2015, pp. 130-131).

Lentini (2009; 2010) carried out archaeobotanical, palynological and sedimentological investigations on the micro-remains of various food plants found at Pyrgos, and he was able to identify different kinds of cereal, domestic olive, fava bean, lentil, pea, chickpea, and grape, all comparable with the finds from the other above-mentioned Early/Middle Bronze Age sites.

Plant remains not related to food exploitation were also found at Pyrgos, such as linen and other textile fibres such as cotton (*Gossypium ssp.*), milkweed (*Asclepias*) and rosemallow (Hibiscus) (Lentini 2009, pp. 154-158), as well as various officinal plants, such as valerian (*Valeriana officinalis* L.) and opium (*Papaver somniferum*) (Lentini 2009, pp. 172-186).

The palaeocarpological (archaeological seeds) remains at Pyrgos were charred in a fire that broke out in the room where the olive press was located (Lentini and Belgiorno 2011, p. 574).

The climate would have allowed a diversified cereal farming, legumes, olive trees and grapevines cultivation.

No charcoal samples have been analysed from hearths, fireplaces or furnaces at Pyrgos-*Mavroraki*. However, the presence of olive and the production of olive oil recorded at the site (see Ch.3, paragraph 3.3.2) suggests this specific wood essence and the eventual by-products from the olive-oil production as possibly available fuels (or fuel additive) to be used in the metallurgical activity during seasonal pruning, as suggested by Socratous et alii (*supra*) for the context aforementioned. Old olive oil, not suitable for human consumption anymore, might have been reused for other purposes and, possibly, as a fuel additive to increase its calorific power.

2I.3 Geomorphology of Cyprus and the nearest ore deposits around Pyrgos

The geology of Cyprus has played an important role in the historical and cultural development of the island. Three main geomorphologic regions characterise the island, respectively from SW to NE: the Pentadaktylos Mountain Range, the Mesaoria Plain, the Mamonia Formation and the Troodos Range (fig. 2.2).

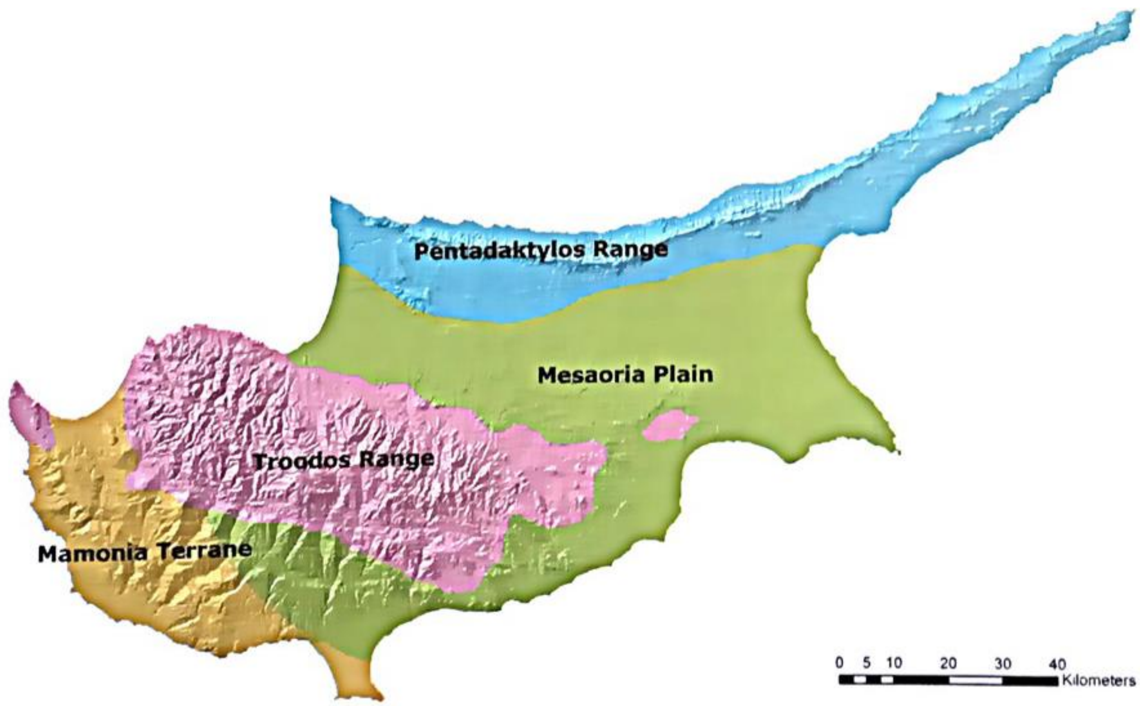


Figure 2.2 Geomorphological regions of Cyprus (from Constantinou and Panayides 2013)

The **Pentadakytlos Range**, in the Kyrenia district, occupies the northern coast of the island. It is characterised by an arciform disposition, with an east-west direction. The base of this formation is mainly composed of a series of allochthonous sedimentary rocks of Upper Cretaceous to Middle Miocene age (67-15 Ma). The stratigraphic sequence includes then younger autochtonous sedimentary rocks of Upper Cretaceous to Middle Miocene age (67-15 Ma), on which the older allochthonous formations have been thrust southward (Constantinou 2007).

Between the Pentadactylos Range to the north and the Troodos Ophiolite to the south, the vast **Mesaoria Plain** lies as a topographically low and flat area. It consists of bentonitic clays, volcaniclastics, milange, marls, chalks, cherts, limestones, calcarenites, evaporates and clastic sediments (Constantinou 2007).

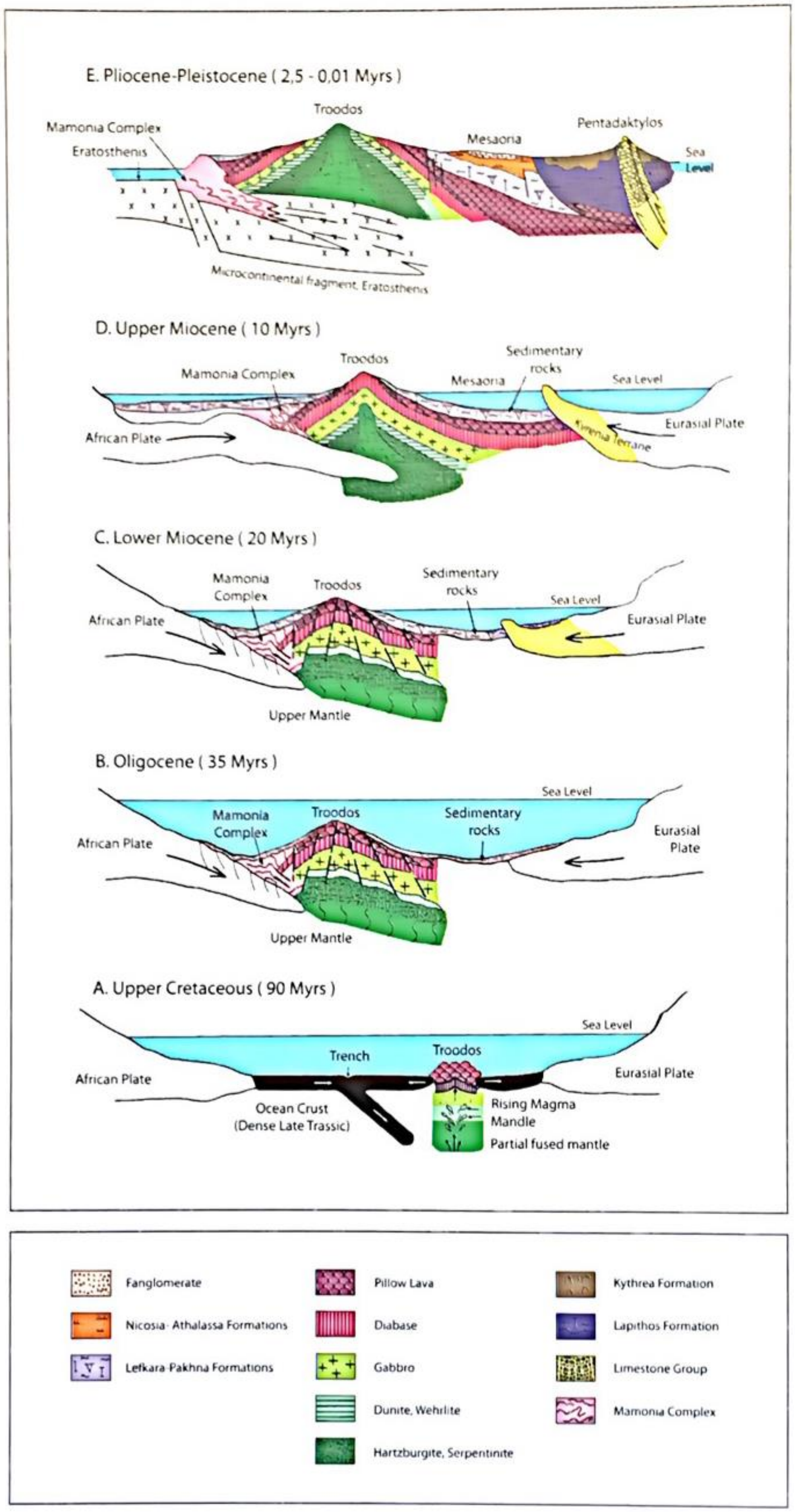


Figure 2.3 Genesis of the Troodos Ophiolite (from Constantinou and Panayides 2013: 14, fig. 2.2)

The **Mamonia Formation** occurs mainly in the district of Paphos; it consists of igneous, sedimentary and metamorphic rocks. These rocks have been identified as allochthonous with respect to the Troodos Igneous Complex. The Mamonia Formation, dating from the Middle Triassic to the Upper Cretaceous (230-75 Ma), is younger than the Troodos.

The **Troodos Range** dominates the central part of Cyprus and represents the main mountain range of the island. It was formed in the Upper Cretaceous (90 Ma) on the Tethys sea floor, as a fully developed oceanic crust, consisting of plutonic, intrusive and volcanic rocks and chemical sediments. Its current position is due to complex tectonic processes relating to the collision of the Eurasian tectonic plate to the north and the African plate to the south (fig. 2.3). The Troodos Ophiolite is formed by four main stratigraphic units, listed here in an ascending order: Plutonic (mantle sequence and cumulates), Intrusive, Volcanic and Chemical sediments. Within the archaeometallurgical interest, the most relevant unit is the one characterised by volcanic rocks, which consists of two series of pillow lavas and lava flows, mainly of basaltic composition. All major cupriferous sulphide deposits used for copper production are found in the pillow lavas (fig. 2.4, Constantinou 1982, p. 13).

Pyrgos-*Mavroraki* lies within the so-called Pharmakas-Kalavasos area. As shown in the map (fig. 2.5), this area is particularly interesting from a geological point of view, lying on the pillow-lava formations, where the most relevant amounts of copper-bearing pyrites are located. Pyrgos itself presents a Basal Group rocks mineralisation to the north/northeast of the village. The pillow lava here is present in the form of discontinuous screens of widths varying from ca. half metre to nine metres.

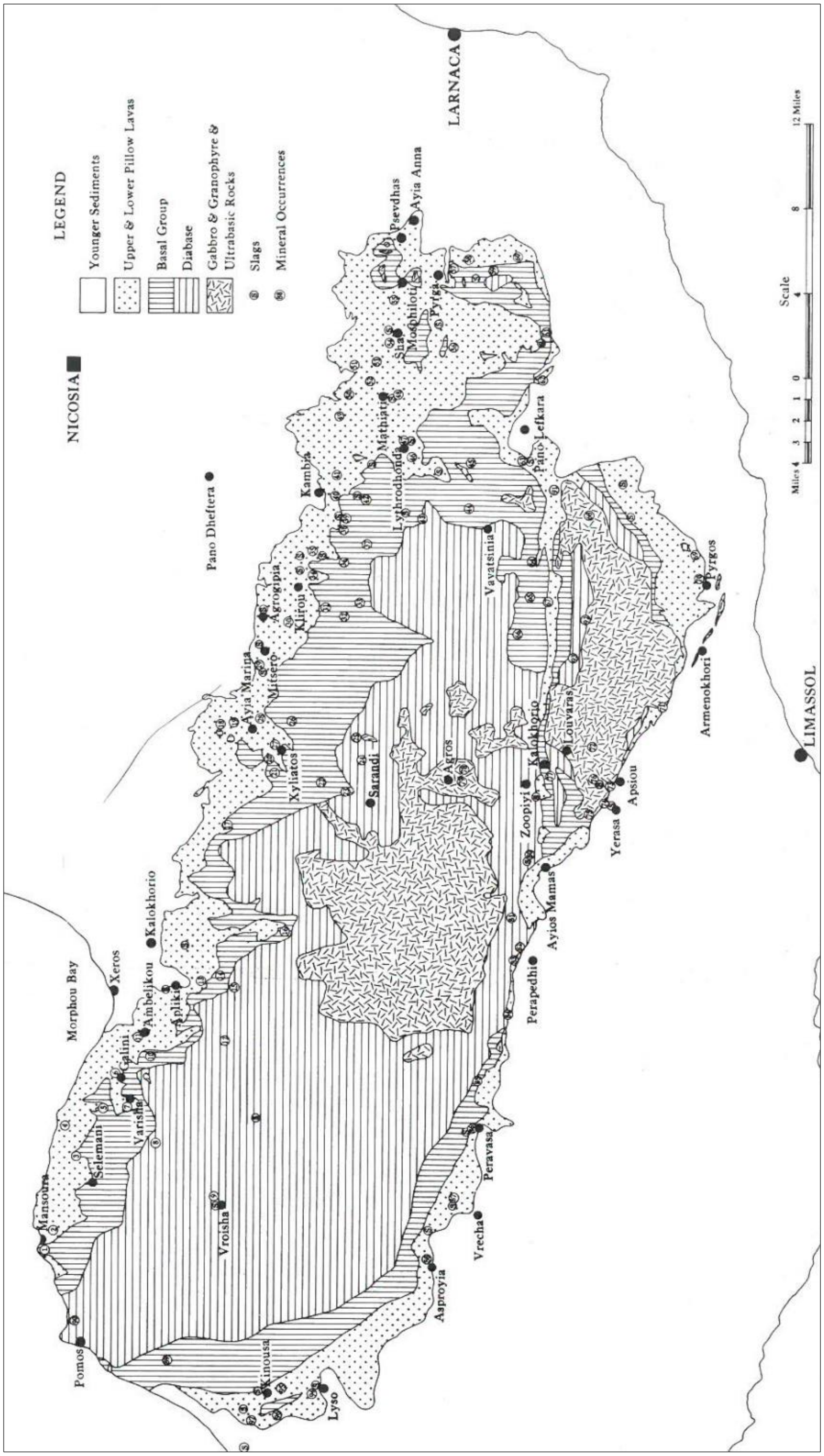


Figure 2.4 Copper and Iron Pyrites in Cyprus (from Bear 1963, p. 82)

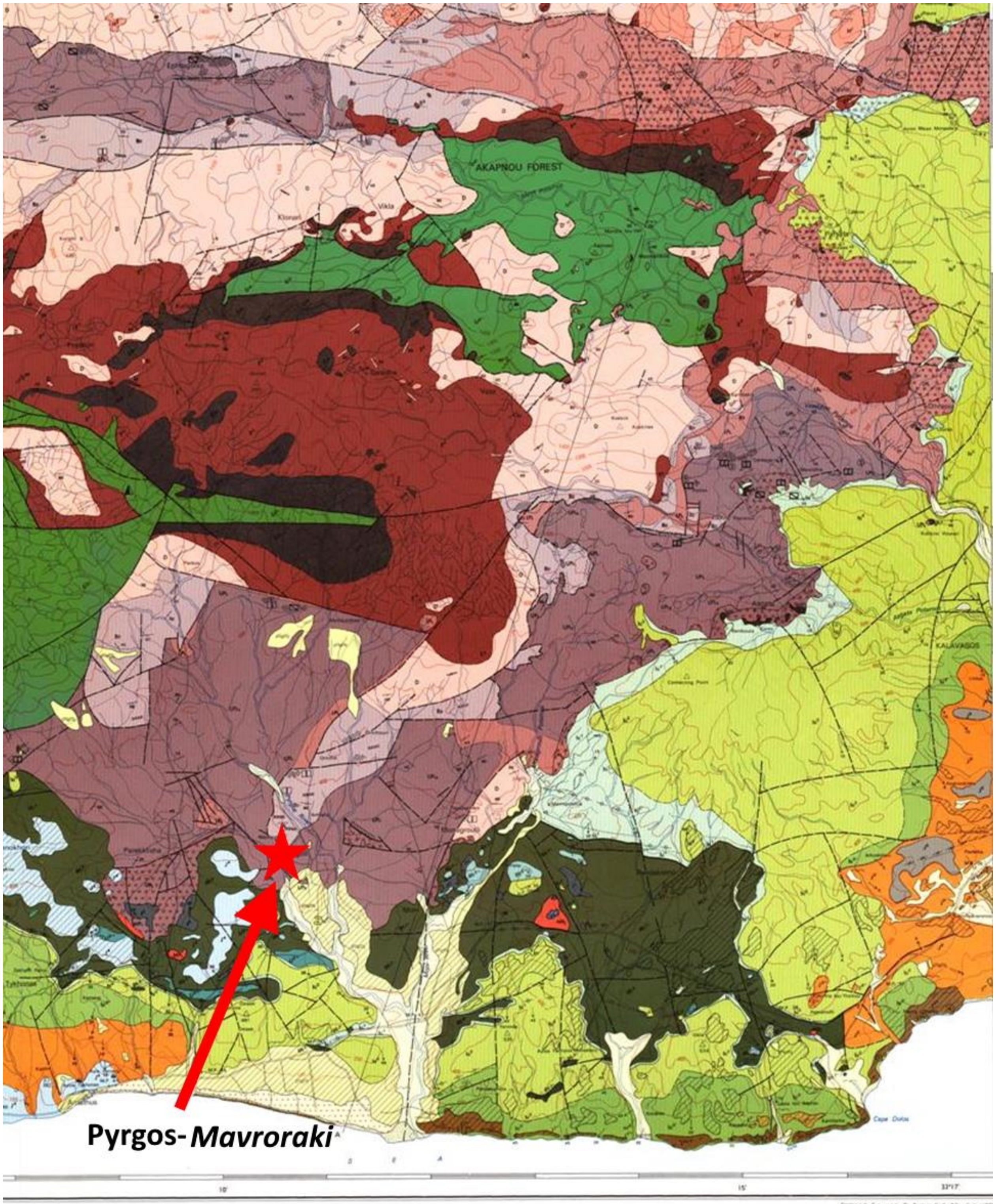


Figure 2.5 Pharmakas-Kalavassos Geological Area (Geological Survey Department)

Around the village of Monoagrulli, instead of the usual mineral formations expected in the pillow lavas, a different kind of mineralisation was found. It consists of microdiorite and microgabbro “dykes” (small intrusions) of the diabase, where sporadic indications of copper mineralisation were recorded, generally in the form of blue and green stains of malachite and azurite, as well as the presence of native copper and cuprite.

Other copper-rich formations in the direct vicinity of Pyrgos, although of small proportions, are Parreklisha and Manghaleni to the West, Ornitha, Mazokambos and Pevkos to the North.

The latter deserves a few considerations. The locality of Pevkos lies in the Limassol Forest, which probably provided most of the fuel used in antiquity for the metallurgical activities carried out in this area. The Calabrian pine (*Pinus brutia*) is one of the main essences present in the Limassol Forest (Eliades et al 2018) and it has been confirmed by paleo-botanical analyses to be the main fuel used, a few centuries after Pyrgos, at the smelting site of Politiko-*Phorades* (Knapp and Kassianidou 2008, p. 142). It is not just its vegetation outset that characterises the Limassol Forest, but its unusual mineral formations. The most common copper-rich mineral of the Pevkos formation is Valleriite, a rare iron-copper sulphide which is found here in connection with the copper sulphides Chalcopyrite and Cubanite and the nickel arsenide Maucherite which, in Cyprus, appears only in this specific formation (Panayiotou 1980, p. 109-111). Further research should be carried out on Pevkos and its surroundings, to seek evidence of prehistoric copper smelting, considering that: a) Early/Middle Bronze Age copper alloy artefacts in Cyprus are all arsenic rich, and b) Pevkos appears to be the only possible ore deposit of this kind on the island.

Further away, to the east of Pyrgos, there is an important copper deposit located in the area of Kalavasos, which we know has been exploited since antiquity, at least from the Late Bronze Age, as testified by the finds from the settlement of Aghios Dimitrios (Van Brempt 2016).

2I.4 Archaeology of Cyprus: from the Late Chalcolithic to the Prehistoric Bronze Age

The Late Chalcolithic in Cyprus (2800-2400 BC) represents the apotheosis of the so-called "village-community", opening its society to more regular contacts with the Levant and Anatolia (Bombardieri and Graziadio 2019, pp. 32-33). The apparent isolation of Cypriot communities, commenced at the end of the Early Aceramic Neolithic (7000 BC), started to break down as shown by the Anatolian and eastern Aegean influence noted, if not by direct imports, by the presence of certain materials, designs, traits and features at Kissonerga-*Mosphilia* (Knapp 2013, p. 260).

Peltenburg (2007a) highlighted the existence and importance of the interactions between Cyprus and the surrounding regions in the first half of the 3rd millennium. Considering the pre-Philia contexts of this site as a case-study, the author describes the evidence recorded at Kissonerga-*Mosphilia* as an indicator of these interactions. His study suggests that in the Late Chalcolithic, largely contemporary with EBI-II in the Aegean, Cyprus was already involved in long-range interactions. Evidence for this is supported not by direct imports, but in the appropriation of foreign ways expressed in an insular selection and adaptation of distant material traits (Peltenburg 2007a, p. 147).

Among the most evident changes and innovations of the Late Chalcolithic, the author notes the preference for monochromy in pottery as distinct from the previously very popular patterned Red-on-White style. New shapes (e.g., spouted flasks, small bowls) are also introduced, which seem to indicate new drinking customs and possibly new types of food and food consuming practices, a possible reflection of the alteration in the family structure. The author suggests that small bowls and pouring vessels might be connected also with the consumption of wine, a custom well attested in Southeast Anatolia during the EBA (Peltenburg 2007a, p. 145). Technological improvements have been noted for the new styles of pottery, including thinner walls and harder fabrics, new clays and surface finishing, a certain level of standardisation, higher firing temperatures and a higher volume of production (Knapp 2013, p. 255), these last two aspects being particularly relevant also to the development of metallurgical technologies and trade. Other pre-Philia innovations that the author traces to external sources include: the spurred annular pendants mentioned above which were common in Syro-Anatolia (Tell Bi'a, Hacinebi); faience disks and beads of types well known in the Levant and Egypt; stamp seals like those at Tarsus; the use of counters that still existed in the Near East; new sources exploited in the lithic industry (Peltenburg 2007a, p. 153; Knapp 2013, p. 254).

In addition to the new higher firing temperatures reached in pottery production, the technological traditions involved in the production of faience and metals have been linked (Peltenburg 2006, pp. 168-170) and could all represent the technological improvements necessary for the developments of these new productions.

Intra-mural metalworking, as we will look at in detail in section II of this chapter, performed in buildings containing prestige goods such as a conical seal (Kissonerga 4A – Pithos House), pre-dates the Philia phase of Kissonerga-*Mosphilia*, recalling, according to Peltenburg (2007a, p. 152) the organisational adjustments adopted for this craft at Poliochni and Thermi (Kouka 2002, p. 305).

These pre-Philia foreign interactions made the Late Chalcolithic communities familiar with external traditions, which will mark the breakdown of the island's insularity (Peltenburg 2007a, p. 152), setting the adapt context for the final acceptance of the Philia "package" which leads into the Bronze Age.

It has been argued that the Late Chalcolithic in Cyprus functioned as a transitional moment towards the initial stages of the Bronze Age. Specific material developments in settlement and mortuary dynamics foreshadow those of the Prehistoric Bronze Age, such as a reorganisation of the internal and external spaces in the traditional circular dwellings, as in the case of the terraced row of habitational structures found at Lemba-*Lakkous* and their specialised activity areas, possibly dedicated to the preparation and storage of consumables. It has been suggested to interpret the complex as a family compound (Knapp 2013, p. 247).

From a settlement point of view, the transition from the Late Chalcolithic to the Bronze Age in Cyprus is marked by important changes and the expansion of previous settlements into new areas until then unoccupied (Fig. 2.6).

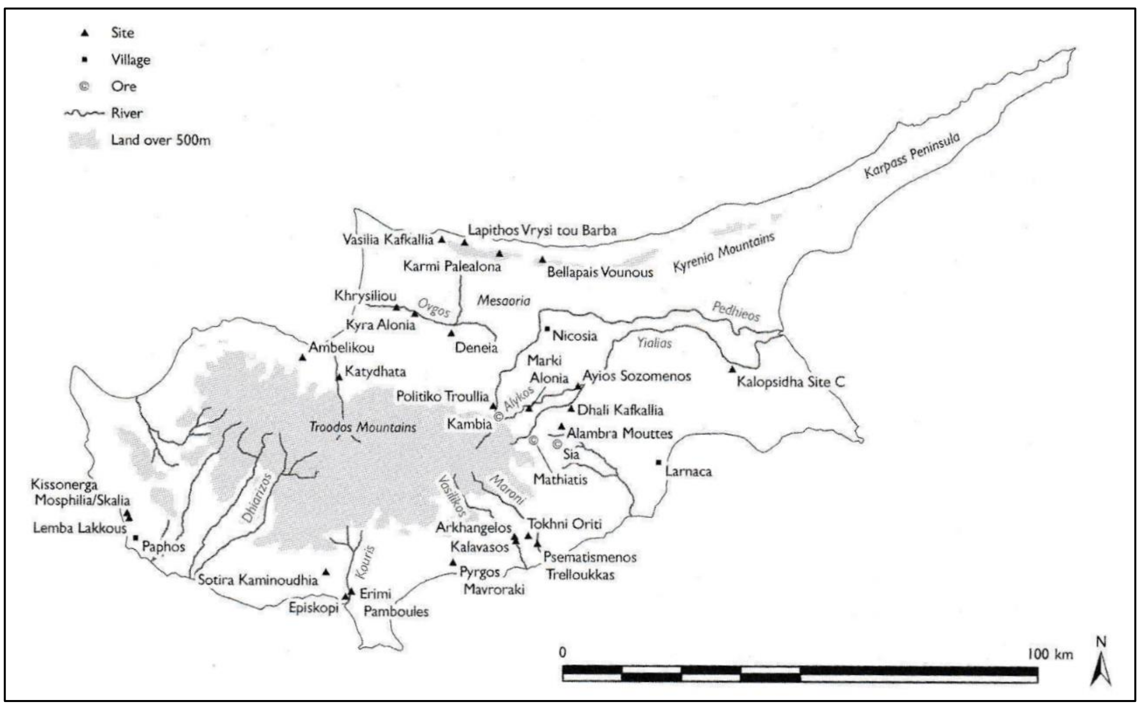


Figure 2.6 Map of PreBa sites mentioned in the text (after Knapp 2013, p. 278, fig. 69).

Among the new characterising traits of this period, we can see: new sub-rectangular, multicellular architecture; the introduction of new agricultural techniques (use of the plough) and the reintroduction of cattle; new types of pottery wares with the main being the Red Polished; a development of textile processing and the first clear evidence for metal-production (Knapp 2013,

p. 263). Within the Bronze Age of Cyprus, it is possible to identify different periods, which are summarised in Table 2.1.

In the following paragraphs, I will describe initially the cultural *facies*[2] named as the "Philia Facies", which has been recognised alongside the Early Cypriot assemblages. I will then summarise the main distinctive characteristics of the Early and Middle Cypriot periods.

Most of the novelties from the Early Bronze Age are represented by the characteristic elements of the Philia Facies, which Webb and Frankel (1999) believe to be imported from Anatolia, while other authors see these novelties as the result of a hybridisation process adopted by local communities incorporating foreign elements in response to the meeting of migrant groups (Knapp 2013, p. 268-277).

I will then summarise the main areas of change which characterised the Early-Middle Bronze Age in Cyprus, focusing on the architecture and the spatial organisation, economy, material culture and funerary practices aiming to provide the appropriate general context for the study of Pyrgos-*Mavroraki*.

Periods	**Phase/Culture**	**Dates cal BC**
Chalcolithic	Erimi	4000/3900-2500/2400
	Early Chalcolithic	3900-3600/3400
	Middle Chalcolithic	3600/3400-2700
	Late Chalcolithic	2700-2500/2400
PreBA 1 (Prehistoric Bronze Age)	Philia Facies	2400/2350-2250
	Early Cypriot I-II	2250/2000
PreBA 2 (Prehistoric Bronze Age)	Early Cypriot III – Middle Cypriot I-II	2000/1750-1700
ProBA 1 (Protohistoric Bronze Age)	Middle Cypriot III – Late Cypriot I	1700/1450

[2] In archaeology, a "*facies*" is defined as a specific part, within a certain culture or industry, which is clearly distinguishable in terms of appearance and composition (Bahn 1992, p. 166).

ProBA 2	Late Cypriot IIA – IIC early	1450/1300
ProBA 3	Late Cypriot IIC late – IIIA	1300-1125/1100

Table 2.1 Chronology of Chalcolithic and Bronze Age Cyprus (adapted by Knapp 2013, p. 27).

2I.4.1 The Philia Facies

Within the mainstream EC-MC pottery tradition, relating to the predominant red monochrome fabric, better known as Red Polished, since the 1940s, new different varieties of red burnished and other wares were being discovered initially around the village of Philia, in the modern district of Morphou, today in the area under Turkish occupation. In 1947, Porphyrios Dikaios introduced for the first time, the definition of "Philia Culture", suggesting to consider it the initial manifestation of the Early Bronze Age in Cyprus (Bombardieri and Graziadio 2019, p. 41), while successively, Philia typical productions were considered to be local variants of the contemporary ECI (Stewart 1962).

An extensive study on the Philia Facies has been carried out by Webb and Frankel (1999), who clarified several details and better characterised this cultural *facies*, also considering the material from the case-study settlement site of Marki-*Alonia* (Frankel and Webb 1996; 2006), which provided new data to the ones from the few earlier tomb findings from the village of Philia in the Ovgos Valley.

Philia material has also been recovered from the latest phase (period 5) of the mainly Chalcolithic site of Kissonerga-*Mosphilia*, showing how this *facies* immediately postdates the Late Chalcolithic.

The Philia Facies has been placed in a chronological framework established within an initial date around 2500/2400 BC, according to radiocarbon dates from Kissonerga-*Mosphilia*, Lemba-

Lakkous and Marki-*Alonia*, and a final date around 2300/2250 BC, according to radiocarbon dates from Sotira-*Kaminoudhia* (Webb and Frankel 1999, p. 5).

The excavation of the Philia levels (Phase A-B) at Marki-*Alonia*, which directly predate the ECI-II levels (Phases C-D) provided, in the late 1990s, a more accurate chronological sequence for this *facies*, which seemed have been confirmed in recent years by the excavation of Kissonerga-*Skalia* (Frankel and Webb 2006, pp. 37-41; Bombardieri and Graziadio 2019, p. 41; Crewe 2014).

In terms of material culture, Philia pottery was a key element in the recognition of the facies. A predominant red monochrome fabric characterises Philia vessels, with a few exceptions (White Painted (Philia) and Black Slip and Combed), relating this production to the Red Polished pottery which forms a continuous ceramic tradition through the EC and MC periods (Webb and Frankel 1999, p. 4).

Considering that the first evidence of metallurgy in Cyprus is dated to the Middle and Late Chalcolithic, there is no doubt that, within the Philia material culture, metalworking increased on the island, and this is testified both by the number of artefacts found for this period and the consistent enrichment of the metallurgical *repertoire* with completely new types, some of which will remain in use in ECI to MC (Frankel and Webb 2006, p. 31).

Of the nineteen sites considered by Webb and Frankel (*supra*), ten contained metal artefacts and just two show clear evidence of metallurgical activity. This topic will be further discussed in paragraph Section II of this chapter.

Other significant “fossil-guides” of the Philia facies include: clay biconical spindle whorls which differ from the EC-MC examples in shape and decoration; pierced annular earrings or pendants, carved in picrolite or shell; disk-shaped beads (Frankel and Webb 2006, pp. 33-37).

Considering other distinctive traits of this facies, beyond pottery and the material culture, a series of innovations has been identified among which has been the introduction of new types of animal husbandry. This has been testified by the appearance in the faunal record of Marki-*Alonia* of equids, cattle and possibly screw-horned goats, which are also represented in a few fragmentary terracotta figurines in the later levels of the site and in the EC iconography in general (Webb and Frankel 2007, p. 191). Significant improvements in agriculture were possible due to new harvesting techniques, such as a new backed sickle blade and the single-handled sole-ard plough, and this allowed an increase in the consumption of cereal (Webb and Frankel 2007, p. 194). These activities allowed the production of new types of food, which required a development of new domestic technologies such as new cooking equipment, including new oven types, horse-shaped hobs, baking pans, braziers, direct fire-boiling vessels (Webb and Frankel 2007, pp. 199-201).

It is important to note that, while Webb and Frankel trace for the majority of the innovations typical of the Philia facies to Anatolian “migrants” (2007, p. 189), Knapp interprets them as the result of hybridisation practices, where the indigenous and the external distinct cultures met and mixed (Knapp 2013, pp. 264-277).

In their study, Webb and Frankel listed nineteen sites, both settlements and cemeteries, identifiable as Philia. Their presence seems to be restricted to the west, southwest and centre of the island (fig. 2.7). From a settlement perspective, Philia communities systematically occupied sites with a privileged access to the copper ores deposits and fertile land to be exploited through the new agricultural technology represented by the plough powered by cattle, usually crossed by communication routes which connected with other the Philia coastal sites such as Vasilia, Episkopi and Kissonerga (Webb and Frankel 1999, pp. 7-8; Bombardieri and Graziadio 2019, p. 45).

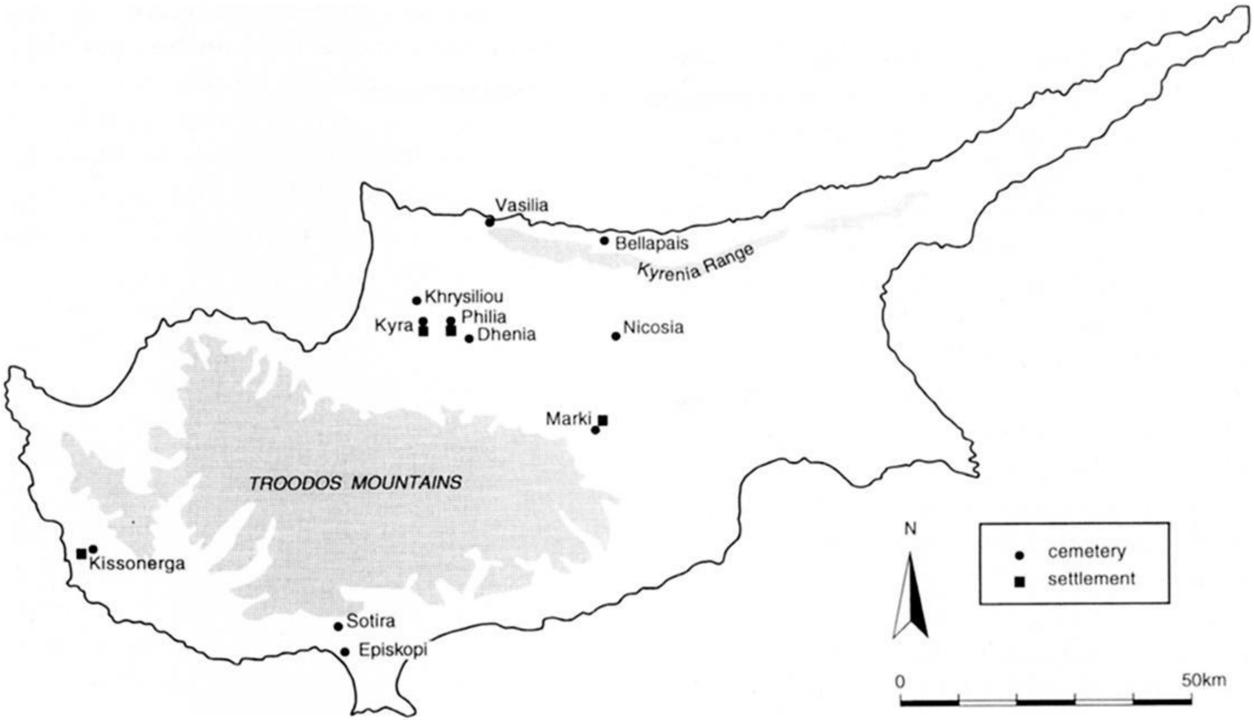


Figure 2.7 Map of Cyprus showing the location of Philia sites (from Webb and Frankel 1999, p. 5, fig. 1)

The fact that some of the above-mentioned sites are located relatively close to copper ore resources in the foothills of the Troodos, led Stewart (1962) to believe that copper exploitation was one of the main reasons in the choice of a settlement location for the first Philia communities. Mellink (1991) suggested that these communities were composed of immigrant copper prospectors and miners from Anatolia.

A new type of architecture was introduced. Rectilinear buildings with multiple rooms and courtyards were constructed with mould-made standard-sized mudbricks walls, standing on stone foundations, appearing very different from the previous Chalcolithic circular buildings. At Marki-*Alonia*, slabs of limestone or river pebbles were used for the stone foundations, while unfired mudbricks have been identified in section, about 600mm long and 100mm thick (Frankel and Webb 2006, p. 7).

Fourteen of the nineteen sites identified by Webb and Frankel (1999, p. 6) as Philia, are (or include) cemeteries, with settlement material limited to the sites of Kyra-*Alonia*, Kissonerga-*Mosphilia (*period 5) and Marki-*Alonia*, to which we can add the site of Kissonerga-*Skalia*, excavated after Webb and Frankel's publication, which shows Philia levels (Crewe 2014). Philia cemeteries testify some significant changes in the mortuary behaviour, such as the use of rock-cut chambers and pit tombs grouped in extramural cemeteries becoming the new trend, in contrast with the usually individual inhumations of the Late Chalcolithic intramural pit graves (Knapp 2013, p. 270). The chamber tombs, usually similar to each other and to the successive EC and MC chamber tombs, can show some architectural site-specific details such as the case of Vasilia with its rectangular chambers with rear buttresses and long plastered-lined, paved dromoi with benches, rebated facades and transverse blocking walls. Other novelties can be seen in the regular use of specially designated cemeterial areas and the inclusion of grave goods (Webb and Frankel 1999, p. 8).

2I.4.2 Early Cypriot and Middle Cypriot

While the elements of innovation are quite clear in the gradual transition from the Late Chalcolithic to the Philia Facies, the increase of these innovative characteristic elements and the disappearance of some typical Philia "guide-fossils" is what determines the passage into the later stages of the EC and proceeding to the MC. An accurate chronological sequence has been built for these following phases of the EC, mainly based on the modifications recorded in the pottery typology (Brown and Catling 1975, p. 12), but have been reconfirmed by radiocarbon dates. In the following paragraphs, these same characteristic elements will be examined in order to allow a better understanding and contextualisation of the site of Pyrgos-*Mavroraki*, discussed in the next chapter of this work.

Material Culture. Red Polished Ware (RP) is the most representative pottery production of this period and comprises a wide range of fabrics and many types and shapes of vessels. The main differences between the RP and its Philia predecessor (RP(P)) can be seen in a more evident uniformity and homogeneity of RP(P) over RP. The array of fabric colours recorded is far more diverse in the RP than in RP(P), the fabric texture of the RP(P) is finer, with a thicker central core, where the lamination of oxidised and unoxidised layers is clear (Webb and Frankel 1999, pp. 15-17). Homogeneity can be seen in the selection of clay type, preparation, shape and surface treatment, in sharp contrast with both LC and EC/MC monochrome wares, which show a greater degree of regional variation (Webb and Frankel 1999, p. 17).

RP is handmade and often decorated by incised geometric motifs, often filled in with a white, lime-based paste (Knapp 2013, p. 322). The vessel types include large, spouted bowls, small hemispherical bowls, basins, cooking pans and ladles, jugs and juglets, jars and amphorae and pithoi (Knapp 2013, p. 322; Frankel and Webb 2006a, figs. 4.16-4.47).
The Red Polished is accompanied, since PreBA 2, by the so called White Painted II (decorated by linear or geometric motifs painted in a lustrous, reddish-brown colour). These types are usually jugs, juglets, small bowls, spouted bowls and cups, representing a whole new complex of portable storage, pouring and serving vessels, very likely associated with liquids. The development of these specific types might be related to the consumption of alcoholic beverages, already identified in the RP(P) tradition of fine-ware pouring, mixing and serving vessels, which in the ECI-II, develop further with the addition of individually distinctive drinking vessels or ceremonial wares (Knapp 2013, p. 324). The introduction of alcohol drinking would represent a

decisive step in Early/Middle Bronze Age society, confirming the emergence of the already mentioned elites (Manning 1993, p. 45).

The pottery production typical of this period is characterised by the introduction of figurative representations in the ECI-II, expressed by the new phenomena of the "scenic compositions", usually added as protomes on the vessels' rim and shoulder, zoomorphic vessels, life-size clay models of inanimate objects such as knifes/sheaths, spindles, horns and textile combs (Knox 2013, pp. 48-49; Bombardieri and Graziadio 2019, p. 58; Belgiorno and Romeo Pitone 2016, pp. 390-391) and the "plank-shaped" figurines, typical of the MC (Knapp 2013, p. 322).

The so-called "figurative vessels" recovered on some types of Red Polished pottery are now a distinctive trait of EBA Cypriot culture (Knox 2013), whose initial epicentre seems to be the site of Bellapais-*Vounous*, but that continues to be in use during the ECIII-MC, spreading to the centre of the island (Knox 2013, p. 49). The majority of the 'scenes' seem to represent agrarian life, even, in some cases, depicting open-air sanctuaries, or some kind of social gatherings.

This new type of artefact offers an important source for the interpretation of the EC/MC communities. The "Vounous model" is an example of these figurative vessels found as part of the grave goods of a tomb at the necropolis of Bellapais-*Vounous*, dated between the ECIII-MCI (Knapp 2013, p. 333). It represents human figures, all men with the exception of one woman, and penned cattle, it has been interpreted as the representation of the emerging weapon-bearing elites from Northern Cyprus (Peltenburg 1994, p. 159).

Another famous example of this kind of production is the Red Polished jug from Pyrgos, dated to the MCI, which represent a "wine production" scene, with a female figure who is the central main character, engaged in grape-crushing. This has been interpreted as a sign of embodied division of labour, where men and women were gendered according to their productive role in society (Knapp 2013, p. 335).

The phenomenon of plank-shaped figurines (fig. 2.8) belongs to the MC, becoming the most common way of representing the human figure (a Campo 1994). These objects were cut from a single slab of clay and they present lustrous, well-finished surfaces, finely engraved detail usually treated as the RP incisions filled with white paste (Webb 2016, p. 7). They are typically flat, rectangular in shape, with a roughly human silhouette and a recognisable face, but often lack sexual characteristics, except breasts in some cases. What seems likely is that the individuals represented are wearing their own distinctive apparel, *i.e.* rich vests and face marks, possibly tattoos (Knapp 2013, p. 339). The great majority of these and other human representations appear in burials on the north-coast sites and the contextual associations of these artefacts probably show the desire of an emerging, high-status group to announce and reinforce their individual *status*, and mark their distinctive identities within the island society (Webb 2016).

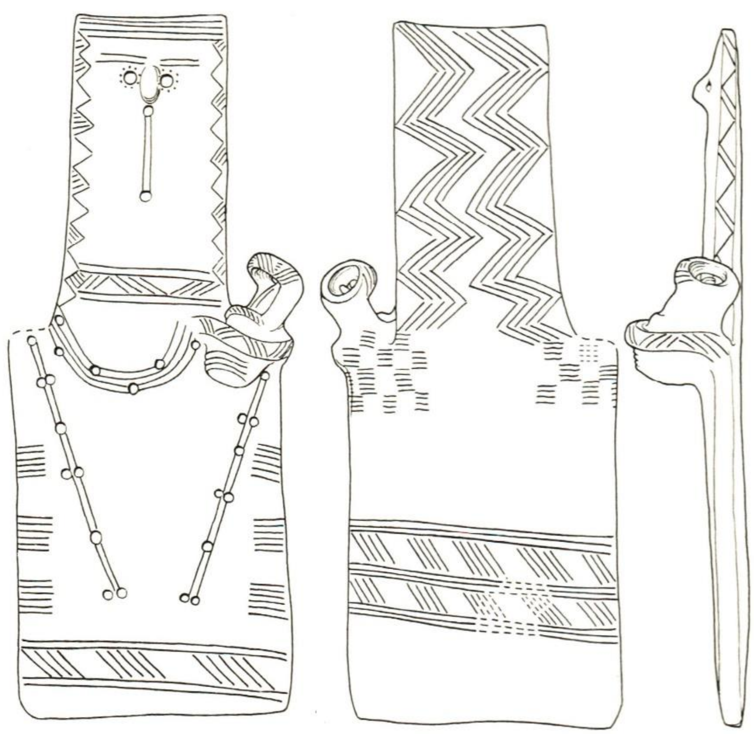


Figure 2.8 Plank-shaped figurines (from Stewart 1962, p. 238, fig. 94).

Other representations of the human figure are those modelled in the round or freestanding figurines (Knapp 2013, p. 342).

This increased attention for the representation of the human figure, mostly attested in funerary contexts, part of larger assemblages which include imported prestige goods has been seen as the material remain of an attempt to mark identity and status by the emerging elites (Knapp 2013, p. 342).

Another important innovation of this period is the development of new types of textile production, attested for the first time in the Philia facies, with the discovery of the earliest evidence of metal needles and spindle-whorls (Webb and Frankel 1999, pp.32-34). Different shapes and sizes of spindle whorls are a common occurrence (Crewe 1998). Loomweights make their first appearance with two complete (but fragmentary) examples from the Philia levels (Phase A-1 and B-1) at Marki-*Alonia*, 11 from the ECI-II levels and 66 more from the other levels of the same site (Frankel and Webb 2006a, pp. 175-177). Similar loomweights were found at Sotira-*Kaminoudhia* (ECIII levels, Swiny 2003, pp. 397-398) and Alambra-*Mouttes* (MCI-II, Coleman et al. 1996, pp. 234-235). The finds from Marki-*Alonia* confirm that the vertical warp-weighted loom was used in Cyprus from the Philia facies, and not before that, as no loomweights were ever recorded from the preceding Chalcolithic (Frankel and Webb 2006a, p, 177).

Textiles in this period seem to acquire an important social symbology, as testified by the richly well-dressed plank-shaped figurines and the iconography of the textile comb, represented in clay models as well as in characteristic picrolite comb-shaped pendants (Belgiorno and Romeo Pitone 2017).

The production of jewellery and ornaments continued with the use of picrolite (which disappears in the Late Bronze Age), quartz, calcite and jasper (beads, necklace spacers, pendants, cruciform figurines), as attested at the site of Sotira-*Kaminoudhia* (Knapp 2013. P. 327).

In the lithic production, amongst the expedient and curated tools (hammers, mortars, querns, rubbers), a decrease of cutting tools, possibly replaced by metal tools, can be witnessed (Knapp 2013, p. 327).

Another interesting novelty is the appearance in the archaeological record of so-called "gaming-stones". These multiple cupellated flat stones, both rectilinear and spiral shaped, have been recovered at Marki, Sotira and Alambra. They have been long identified with the Egyptian board games of Senet and Mehen (Swiny 1980).

Architecture and Spatial Organization. During this period, Cypriot settlements largely expanded into areas previously unoccupied (fig. 2.9), and the number of sites identified increases considerably from the Philia facies (19 sites) through the ECI-II (44 sites) and the ECIII-MCII (345) (Knapp 2013, p. 278). Georgiou, who carried out the most complete and reliable survey of Early and Middle Bronze Age sites in Cyprus, recently updated the number of identified sites to a total of 486 (Georgiou 2017, p. p.115).

The areas of the island favoured for settlement in this period are represented by fertile plains (e.g., central and western Mesaoria), due to the intensification of plough-agriculture, and new areas on the Troodos foothills, chosen for copper ore exploitation (Knapp 2013, p. 278).

As mentioned before, the site of Marki-Alonia shows how the Philia phase precedes directly the EC-I-II sequences, confirming continuity of occupation until the MCII. This chronological sequence is further supported by the site of Sotira-*Kaminoudhia*, whose Philia burials and the ECI-III settlement reflect Marki's occupational sequence (Knapp 2013, p. 279).

Other than the already mentioned sites of Kissonerga-*Mosphilia*, which we already discussed in relation to its Middle and Late Chalcolithic phases, but that shows continuity in the Philia phase, Marki-*Alonia*, occupied for over 500 years, and Sotira-*Kaminoudhia*, other EC/MC sites have been identified by survey or partial excavation. These can be listed as: Kalopsidha Site C (Crewe 2010b, p. 65), Psematismenos-*Trelloukkas* (Knapp 2013, p. 280), Ambelikou-*Aletr*i Webb and Frankel 2013), with some sites more extensively investigated than others such as Pyrgos-*Mavroraki* (Belgiorno 2009), Alambra-Mouttes (Coleman et al. 1996) and Politiko-*Troullia* (Falconer et al. 2010).

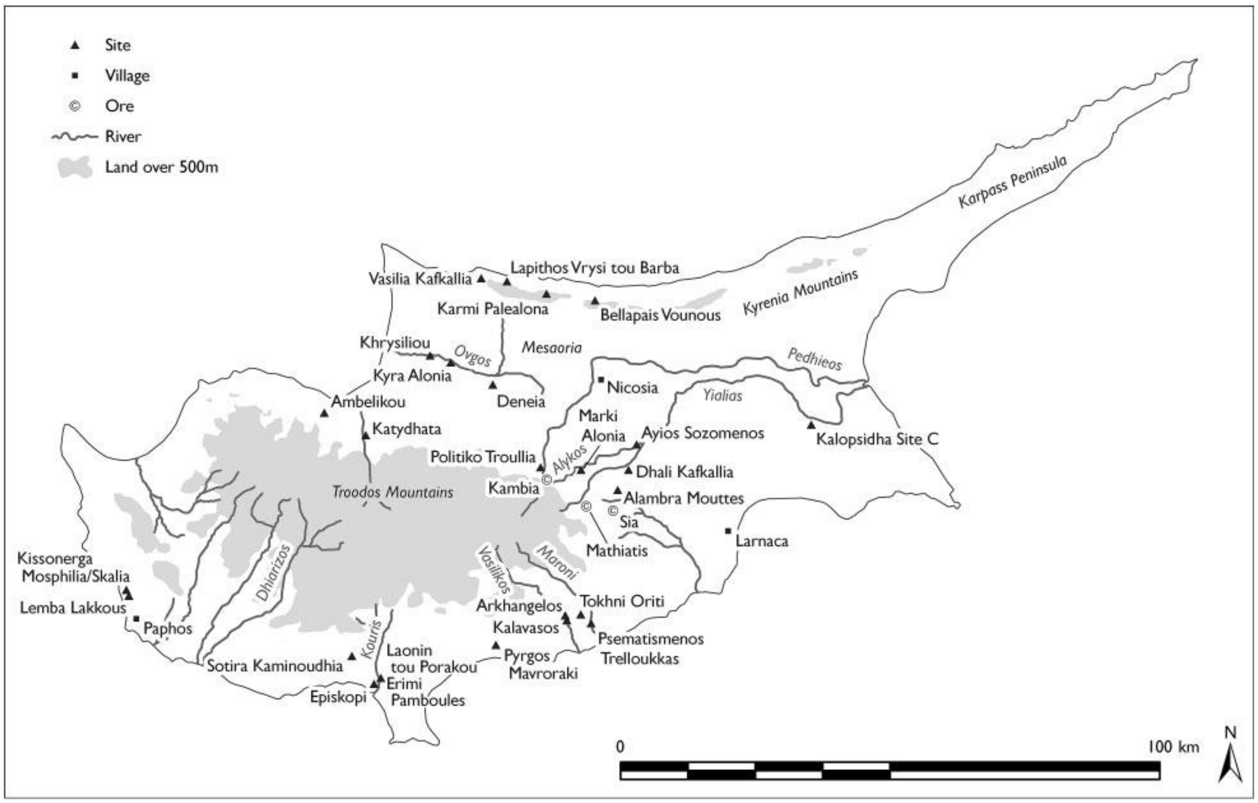


Figure 2.9 Map of Early and Middle Bronze Age sites mentioned in the text (from Knapp 2013, p.278, fig. 69).

The buildings are usually of a rectilinear, multi-cellular shape, in clear contrast with the previous Neolithic and Chalcolithic curvilinear tradition. The walls were built as mudbrick structures, resting on stone foundations. The architectural remains from the site of Marki-*Alonia* show the use of clay and lime plaster to cover the walls and, in some cases, traces of red colouring were found on the lime plaster fragments (Frankel and Webb 2006a, p. 8).

Episodes of re-edification at the same site, show how the practice of rebuilding thinner walls on the thicker wall-foundations, belonging to a previous phase, would have transformed the old wall stumps projecting beyond the new wall-line in functional benches (Frankel and Webb 2006a, p. 8). Floors were usually composed of hard-packed clay, often making their archaeological identification difficult to distinguish from outdoor surfaces. However, the excavators of Marki pointed out that, in some cases, floors in interior spaces presented a "characteristic purplish colour", while, occasionally, it was possible to identify areas of gravel or pebblecrete used in courtyards as well as the use of small rubble and sherds in the preparation of streets and passageways (Frankel and Webb 2006a, p. 10).

The presence of doors is clearly indicated by doorways in the corner of the rooms, built by stopping one wall short of the other one. Occasionally stone thresholds or low door sills have been found in sites such as Alambra-*Asproyi*, Alambra-*Moutte*s, Sotira-*Kaminoudhia*, where the finding of pivot stones testifies the presence of solid wooden (or wooden-framed), swinging doors. (Frankel and Webb 2006a, p. 10).

The buildings are composed of two or three rooms, set within a larger courtyard, where there are recognisable postholes, which may represent remnants of animal pens or roof supports.

A wide range of installations are known from this period's architecture, including: floor emplacements, benches, mealing bins, storage bins, hearths and ovens.

Emplacements are interpreted as supports for pithoi, fixed in place for permanent storage or temporary holders for vessels destined to multiple activities (Frankel and Webb 2006a, p. 13). Moving to pyrotechnological structures, hearths are usually set against interior walls and at the site of Marki-*Alonia* have been found in different shapes and sizes, usually built against low mudbrick and plaster benches, or having shorter sections of the latter to either side, forming a firebox (Frankel and Webb 2006a, p. 14). At the same site, hearths may present mudbrick or plaster kerbs or fenders, which are not commonly found elsewhere (Frankel and Webb 2006a, p. 14). Ceramic horseshoe-shaped hobs, usually with a flat base, incurving arms and a raised backward-sloping centrepiece and terminals (Frankel and Webb 1996, pp. 180-186) can be found in connection with hearths and ovens. This type of object represents one of the new artefacts that belong to the Philia/EC innovations “package” (Webb and Frankel 1999, p. 35; Belgiorno 2009, pp. 64-65). Ovens, differently from simple hearths, are recognisable in this period as they are characterised by a sub-rectangular or elliptical chamber enclosed by vertical slabs of fire-hardened bricks (Frankel and Webb 2006a, p. 21) or limestone (Bombardieri et al. 2012, p. 117; Belgiorno 2009, p. 54). Although no direct archaeological evidence for furniture could survive, the rounded shape of vessels in this period suggests that food would have not been consumed around a table before the Late Bronze Age, when vessels with flat or ring bases were introduced (Steel 2016, p. 83).

Although long-term planning is not recognisable in this kind of architecture, it is possible to detect a certain continuity in size (100 m^2) and structure through time.

A sensible indication of significant status or wealth differences between the inhabitants of these dwellings is not detectable, even if in some cases (e.g. Marki-*Alonia*), we witness some small modifications of the spatial organisation, which indicate a trend towards increased privacy and security, such as the enclosed courtyards, the absence of animal pens and the work stations within the compounds, relocation of ovens and screen walls built to conceal the hearths from the exterior (Knapp 2013, p. 284).

This may indicate the existence of some notions of inheritable property and the control and manipulation of space and household resources (Knapp 2013, p. 284).

Mortuary Practices. In the EC and MC some important elements of innovations, which can be individuated in a few cases since the Late Chalcolithic period (Knapp 2013: 258-260), became typical within the mortuary practice (see Table 2.3). As mentioned earlier, during the Chalcolithic, the most common form of burial was a pit grave, with or without a capstone. The burials were usually connected with a building, when not placed directly inside it. In Early Chalcolithic, it seems common not to have a formalised location to bury the dead; indeed, human remains are often found in a fragmentary and disarticulated state, in pits and general deposits, with domestic discard and animal bones. During the Middle Chalcolithic, evidence of more formal and differential mortuary practice has been recorded, which persisted into the Late Chalcolithic, when intra-settlement graves and tombs represented the main data set for the mortuary practice (Knapp 2013, pp. 217-227; Peltenburg et al. 2003, pp. 221-224, 263; 1998, pp. 70-71).

It is important to mention that the earliest use of the chamber tomb, testified at the site of Kissonerga-*Mosphilia* (Peltenburg et al. 1998), dates within the Late Chalcolithic. This is composed of a vertical, circular shaft, which leads to one or two chambers. This type of burial developed further in the Early/Middle Bronze Age.

The Chalcolithic tradition of single inhumation in intra-settlement pit graves was almost completely abandoned, replaced by the use of new, large and formal extramural cemeteries with the preponderant use of pit and rock-cut chamber tombs, in some cases containing multiple chambers or niches and often characterised by multiple burials (Keswani 2004, p. 37). The chamber tomb consisted of three parts; the *dromos*, an open entrance passage or hollow of varying depth; the *stomion*, a narrow, often circular, passage or opening, running off the *dromos* and giving entry to the chamber and a domed, irregular chamber roughly hewn into the bedrock (Knapp 2013, p. 311). For the first time, carved decorations, representing wooden doorways, architectural implements and even human figures, were used to embellish and characterise the *façade* of tombs (Knapp 2013, p. 313).

While the use of grave goods was quite modest in the Early and Middle Chalcolithic, consisting of pottery (Red-on-White and Red and Black Stroke-Burnished flasks, jars, bottles and bowls), lithic implements such as groundstone discs, bowls and tools, conical stones, chalk bowls and beads or personal ornaments such as picrolite beads, pendants and figurines, dentalium shells and necklaces, this declined during the Late Chalcolithic (Knapp 2013, pp. 258-260).

In the EC-MC, the practice of placing grave goods in the tomb was "resumed" and, in contrast with the more austere customs of earlier periods, a rich and vast range of items used to accompany the dead in the underworld. These items included pottery, metal weapons, implements and jewellery, spindle whorls, shell and stone pendants, beads and picrolite. (Knapp 2013, p. 311). Funerary rituals and ceremonies became more elaborate, involving rites of secondary treatment and reburial (Keswani 2004, p. 37). The nature of this multi-stage burial program, which involved the use of both pit graves and chamber tombs, is still a topic of debate (Keswani 2004, pp. 150-153; Webb et al. 2009, pp. 240).

Funerary sites, during the first half of the 20th century, have been specifically targeted by archaeologists with the (not particularly scientific) aim of acquiring intact pieces for museums, but nevertheless, contributed to the first consistent development of the archaeology of the Early and Middle Bronze Age, slightly biased by the preference towards the northern part of the island (Georgiou 20017, p. 114). Bellapais-*Vounous*, Lapithos-*Vrysi tou Barba* and Karmi-*Lapatsa* and *Palealona*, three of the most important funerary sites for this period, were excavated in those early days by Cypriot, French and British/Australian teams (Knapp 2013, p. 313).

The tombs excavated in these sites were characterised by a rich variety of grave goods with an exponential increase in copper-based metal objects such as daggers, knives, swords, "hook-tang" weapons, axes, razors, tweezers, pins and rings.

As a simple example of this considerable increase in metalwork as part of grave goods, we cite the case of the Chalcolithic site of Kissonerga-*Mosphilia*, (KM 1182, Peltenburg 2011, pp. 7-8), where a single metal, spiral hair-ring with expanded and pointed terminals was recovered and typologically linked by Gale (1991, p. 57) with Anatolia, while, in the - necropolis of Lapithos-*Vrysi tou Barba*, from the Early Bronze Age to the Middle Bronze Age, the percentage of metal in the tombs increased by 56% (Keswani 2004, pp. 67-71).

It has been argued that certain cemeteries dating to the EC-MC became focal points for competitive display, the possible emergence of social inequalities, the negotiation of social identities and the veneration of ancestors as a tool to establish the rights of specific social groups to the land, legitimising new elites in Cyprus (Knapp 2013, p. 321; Keswani 2005, pp. 348-349). For the purpose of this work, specifically focused on the early metallurgy of Cyprus, it seems relevant to highlight that Keswani argued that these new competitive mortuary celebrations would have provided stimulus for the intensification of copper production in this period (2005, pp. 388-389).

While the lack of fieldwork aimed at researching settlement sites on the Northern coast of Cyprus has been made impossible since 1974, due to the Turkish invasion, the data collected before then confirms that metal objects were particularly important in the mortuary display, set up by these new elites, an aspect which seems to be less evident in the Southern funerary sites, as can be surprisingly observed in the case of the cemetery connected (most likely) with the metallurgical site of Pyrgos (Ch. 3).

The new mortuary practices described above highlight new ideological, but also economic activities, which might also be evidence for a now increased exposure of Cyprus and its rich copper resources to the wider Eastern Mediterranean world, possibly enhancing its involvement in the regional exchange networks of the late 3rd millennium BC (Knapp 2013, p. 321).

PERIOD	BURIAL STRUCTURE	GRAVE GOODS
Early/Middle Chalcolithic (Knapp 2013, pp. 217-227)	Pit grave with or without a capstone, associated with buildings in the settlements, a few placed inside them. No formalised location.	"Trash burials", fragmentary, disarticulated remains. Picrolite beads, pendants, figurines, dentalium shell beads and necklaces, Red-on-White and Red and Black Stroke-Burnished flasks, jars, bottles and bowls; groundstones discs, bowls and tools; conical stones; chalk bowls and beads, one metal spiral ring.
Late Chalcolithic (Knapp 2013, pp. 258-260)	Earliest use of the chamber tomb, a vertical, circular shaft descending to one or two smaller chambers. Differential mortuary practices, new tomb types. Mosphilia's mortuary enclosure.	Decline in grave goods. Differently sexed and aged individuals were buried together.
Early/Middle Bronze Age (Knapp 2013, pp. 311-322)	Large formal extra-mural cemeteries often situated on the hill-slopes within sight of a settlement. Pit or rock-cut chamber tombs.	One or more burials, pottery, metal weapons, implements and jewellery, spindle whorls, shell and stone pendants and beads and picrolite.

Table 2.2 Main characteristics in the funerary practice between Chalcolithic and Early/Middle Bronze Age Cyprus.

Subsistence Economy. Important innovations influenced the economy of the Early and Middle Bronze Age, with new techniques and technologies being introduced on the island, impacting sensibly the scale of production on many levels.

As mentioned earlier, settlement in this period expanded into areas previously unoccupied, showing a new interest in the mineral-rich Troodos foothills and the arable lands of the Mesaoria and the Northern fertile plain (Knapp 2013b, p. 21). The agropastoral subsistence economy which characterised the Late Chalcolithic on a much smaller scale, seems now to intensified, and evidence of this intensification is the introduction of the elbow plough which probably replaced the use of the hoe (Knapp 2013a, p. 305). Unlike later periods, where copper-alloy plough shares have been found, such as the example from Erimi-*Pitharka* (Papanikolau 2012, p. 313), in the Early and Middle Bronze Age there is no direct evidence from the archaeological record of this type of artefacts. However, ploughing scenes are represented on ceramic models such as the example from Bellapais-*Vounous* (Keswani 2005, p. 352, fig. 5). Other pastoral or agricultural scenes depict grape-pressing scenes (Herscher 1997, pp. 28-30), the preparation of wine and bread (Cullen and Wheeler 1986, pp.151-154) and, possibly, corn grinding (Karageorghis 1958; Morris 1985, p. 275).

The use of the plough allowed for the cultivation of larger areas of land, making it necessary to clear by axe, large portions of what was once forest. The use of the plough reveals that in this period, cattle is not kept just for meat production anymore, instead its traction-power is now the object of interest.

Animal husbandry development regarded not only cattle farming, but various sites such as Marki-*Alonia*, Sotira-*Kaminoudhia*, Episkopi-*Phaneromeni* for the Early Bronze Age and Alambra-*Mouttes* and Politiko-*Troullia* for the Middle Bronze Age, showed the increase of certain species over others in the archaeofaunal remains (Knapp 2013b, pp. 304-305; Keswani 1994, p. 269). Cattle was reintroduced in Cyprus in this period after its first appearance in the Ceramic Neolithic (Knapp 2013b, p. 171), together with the introduction for the first time of pack animals such as equids, perhaps one of the most important elements in goods and people transport (Knapp 1990, p. 158) and for the first time sheep, goat and cattle have been found to be preponderant in these sites, over wild deer and pig, and often archaeozoological analyses confirmed a general very mature age of death, suggesting that at least some of these animals were kept not only for their meat (Spiegelman 2006). The decrease of deer and pig might correspond with the progression of deforestation and land clearance in favour of this new systematic agricultural system, carried out on a larger scale (Keswani 1994, p. 269).

However, Keswani (1994, p. 269) already pointed out that while the cattle remains usually belong to mature individuals, confirming their use as draft or for milk-production, the caprine remains, all belong to young females and therefore cannot be consistent with a focus on milk or wool production.

Overall, the archaeozoological data, when considered in relation to the introduction of the vertical loom, mentioned previously, and a whole series of new types of vessels, likely related to dairy processing (Knapp 2013b, p. 304), represent the most direct evidence of the Cypriot Secondary Product Revolution (Knapp 1990; Knapp 2013b, p. 305).

As discussed in the paragraph dedicated to the transformation of Cypriot ancient architecture in this period, the first signs of private, secluded areas within the households are now evident, usually dedicated to storage as, in a few cases, testified by the presence of large pithoi such as those ones found at Sotira-*Kaminoudhia* (Swiny et al. 2003, p. 44), Marki-*Alonia* (Frankel and Webb 2000, p. 71; 2006, pp. 129-130), Alambra-*Mouttes* (Barlow 1996, p. 1996) and, as we shall see, at Pyrgos-*Mavroraki* (Belgiorno 2009, pp. 52-53). The necessity of new, private storage spaces points to the fact that the transformations in the subsistence economy of the EC-MC allowed the production of a general surplus, owned by the small self-reliant communities, whose members were involved in the plough-based farming, which typically involves more intensive work cycles compared to hoe-based farming (Knapp 2013b, p. 305).

As a consequence, the development of an intensive agro-pastoral economy may also have caused the attachment of certain family groups to some specific fields or landscapes sectors, if we consider a specific emphasis on the hereditary transmission of property. The image that authors have reconstructed depicts EC-MC agropastoral villages as autonomous communities with households or extended family units that owned the land as well as its products (Frankel and Webb 2006, 314–15).

Related to the fast-paced development of the agro-pastoral economy, a general growing of wealth has been observed, that can be seen also in several new types of specialised productions such as metal weapons, tools and ornaments (bead and shell pendants, silver and gold jewellery), terracotta figurines (Bolger 1996; Frankel and Bolger 1997; Keswani 2005), new pottery shapes (perhaps linked to milk production such as the Red Polished “milk” and “cream” bowls) as well as new terracotta models (Manning 1993, p. 47). It is relevant to note that prestigious goods were usually buried and so removed from circulation, with two possible main aims: on the one hand, the display of status through funerary/ceremonial offering and on the other hand, the elimination of any “inflation” risk. This would have kept the precious goods restricted, ensuring their socio-economical value, which appears based on the accumulation of power and wealth by the elites (Manning 1993, p. 48).

Knapp (2013b, p. 19) argues that gradual growth in metallurgical and agricultural production enabled emergent power groups to establish pre-eminence in the northern part of the island by at least 2000 BC, while Keswani suggests that it is the establishment of social hierarchies which stimulates the production of copper on the island (2005).

Regardless which position one might agree with, the emergence of metallurgy undoubtedly is one of the most important technological and economical developments of this period. Evidence of copper-based metalwork has been found in a few important EC-MC sites; however, it has been stated that none of these sites offer enough evidence to demonstrate the level or intensity of copper production (Knapp 2013b, p. 24), interpreting this period's metallurgy as a self-sufficient activity.

While Section I of this chapter provided a general introduction and overview to the archaeological context regarding the passage from the Late Chalcolithic to the Early and Middle Bronze Age, Section II will now investigate in more depth the metallurgical phenomenon in Cyprus at its earliest stages, putting it in a wider contemporary Eastern Mediterranean context.

Chapter 2. Kypros: the Island of Copper

Section II The earliest Metallurgy of Cyprus: from the Chalcolithic to the Early-Middle Bronze Age

2II.1 Introduction

Many authors believe that Cyprus was the location of the Middle/Late Bronze state referred to by the toponym "Alashiya", which was known to be located in the Eastern Mediterranean and mentioned in ancient Ugaritic, Hittite, Akkadian, Egyptian and Mycenaean texts, often in connection with metal-trade (Crewe 2007, p. 8; Hellbing 1979, pp. 1-2; Knapp 2011, p. 250). The earliest references to Alashiya pertain to the Prehistoric Bronze Age and are found in cuneiform texts from Mari, Alalakh and Babylonia, dated between the 19th-17th century BC (Knapp 2008, p. 307).

Alashiya is mentioned in texts from the town of Mari, on the right bank of the Euphrates River (modern Syria), always in reference to the import of metals, either copper (Sumerian URUDU‒Akkadian eruˆ) or bronze (ZABAR‒siparru), distinguishing amongst "copper", "mountain copper" and "refined, quality copper" (Knapp 2008, p. 307).

Silver received from Alashiya is mentioned in an economic text from the town of Alalakh, in modern-day Turkey, while an unprovenanced tablet from Babylonia, dated to the mid-18th century BC, records 12 minas[1] of copper from Alashiya (Knapp 2008, p. 308).

[1] Ancient unit of weight (and currency) used in the Near East.

The majority of textual references to Alashiya, however, are dated to the Protohistoric Bronze Age (Knapp 2008, p. 308).

At the Syrian coastal city of Ugarit, letters in Akkadian were preserved from the 13th century BC (Knapp 2008, p. 311), issued by Alashiya, and accounting documents mention the presence of Cypriots and the importation to the city of merchandise such as oil, wheat and copper (Yon 2000, p. 192).

Eight of the famous Amarna Letters, written in Akkadian cuneiform, were sent from the kingdom of Alashiya and they regarded mainly the amount of copper sent from Alashiya and the silver and ivory asked in return. The author was an unnamed king of Alashiya (EA 33-39) writing to an unnamed Pharaoh, calling him 'brother' and a governor of Alashiya (EA 40), who spoke directly to his equal in Egypt.

From the Amarna Letters, it is possible to deduce that Alashiya was an important state, which, between the 14th and the 13th centuries BC, maintained economic and political contacts with Egypt, whose rulers were perceived to be of equal rank by the Cypriot administrators. It was capable of copper production on such a scale as to allow the export of large amounts of the metal (Goren et al 2003).

Goren *et alii* (2003) carried out petrographic and geochemical analyses on the tablets from Alashiya, demonstrating that the tablets sent from Alashiya were effectively sent from Cyprus, specifically from an area on the margin of the Troodos, identifiable as either Kalavasos-*Aghios Dhimitrios* or Alassa-*Paliotaverna/Pano Mandilaris*, which could suggest that Alashiya was possibly a specific kingdom within Cyprus and possibly did not refer to the entire island (Goren et al. 2003, pp. 250-251).

However, archaeological research reveals evidence of metallurgy in Cyprus since the Chalcolithic, through the finding of ornaments and tools, and starting from the Early-Middle Bronze Age of metallurgical activity.

2II.2 The chaîne opératoire of copper

The term chaîne opératoire, literally "chain of operations", was introduced by the French anthropologist and archaeologist André Leroi-Gourhan (1964, p. 164) to develop a theoretical framework for the study of technical processes pertaining any productive practice. Each technical act can be interpreted also as a social act, being influenced by social and cultural aspects (Stöllner 2015, p. 134). Leroi-Gourhan applied this analytic technique to archaeological enquiry as a powerful conceptual framework, capable of linking material and social practices (Ottaway 2001, p. 88), which provides technology studies "with both the empirical rigor they require and the human face they deserve" (Dobres 1999, p. 124).

Ottaway deconstructed the production sequences of copper and bronze, identifying the following: prospecting, mining, beneficiation, smelting, or roasting and smelting, refining, alloying, casting, smithing and fuel production (2001, p. 90).

The first step of the chaîne opératoire related to the production of copper-based artefacts, is the **prospection** of copper ores. The skillset essential to a good prospector, such as the attention for indicator plants, colour and taste of water near a mineral source (Ottaway 2001, p. 90), the type of soil and what we would call today as "geological formations", must have been well developed already if we think that sourcing raw materials, especially rocks and minerals, accompanied humanity since the invention of the first artefacts in the Palaeolithic and Neolithic periods.

In Cyprus, for example, the search for picrolite, a pale green to olive green rock composed by serpentine minerals antigorite, chrysotile and lizardite, or a combination of these, started in the

Neolithic and intensified in the Chalcolithic for the production of pendants, beads, figurines, vessels and other decorative objects (Peltenburg 1982, p. 54). Picrolite is found in serpentinite bodies and, in Cyprus, these are restricted to specific locations such as the Akamas, in isolated pockets along the western flanks of the Paphos Plateau, at the edge of the Pakhna formation, in the Limassol Forest and in the central Troodos (Peltenburg 1982, p. 54). The Chalcolithic communities of Cyprus were therefore obliged to source this material only from these limited locations as for the settlement of Lembas, which could not rely on its closest source, Mavrokolymbos, as it is characterised by an extremely sheared rock, too fibrous and refractory to be used for carving (Peltenburg 1982, p. 54).

As the search for picrolite intensified, the first copper artefacts appeared in Cyprus, Peltenburg (1982, pp. 54-55) suggested that, considering the similarity in colour between picrolite and oxidised copper ores, picrolite-prospectors might have been able to collect nuggets of native copper from rivers’ beds, displaced from their mineralisation areas by the same rivers such as the Dhiarizzos and some of its tributaries (Peltenburg 1982, p. 55). The use of native copper at the beginning of Cypriot metallurgy has not been confirmed yet (Gale 1991, 57), however the relationship between the intensification of picrolite sourcing and the earliest copper metallurgy on the island cannot be dismissed yet, as the picrolite wasters found at the Middle Chalcolithic site of Souskiou include quarried slabs, clearly extracted from serpentinite sources on the hills (Peltenburg 2011, p. 6), confirming some sort of existing quarrying activity on Cyprus in this period.

While the collection of outcropping pieces of colourful oxidic copper ore, possibly followed by the digging of superficial open pits or trenches might have represented the first steps in **mining** (Ottaway 2001, p. 90), the early use of copper sulphides in Cyprus, usually found at lower levels below the surface, would suggest the beginning of underground mining. The earliest evidence for copper ore mining in Cyprus has been found at the site of Ambelikou-*Aletri*, where diagnostic pottery and stone tools have been found from ancient mine shafts (Kassianidou 2012, p. 77). Underground mining, differently from surface collection and open cast mining, requires more specialistic skills for the construction of sinking shafts, underground galleries, specialistic tool kit for extraction work and to carry out the potentially dangerous extractive activities in a safe manner (Ottaway 2001, p. 91).

Once the ore has been mined, it requires a further selection process which involves the hand-sorting of the more colourful and heavier minerals from the gangue (Ottaway 2001, p. 92). This operation could have also been carried out with the aid of water (Heeb and Ottaway 2014, p. 167). This process, known as ore concentration or **beneficiation**, aimed to enrich the ore charge for the furnace, improving the metal extraction and reducing both the amount of fuel used and slag produced (Giardino 2010, p. 55; Doonan 1994).

Archaeological evidence for beneficiation can be found in the stone tool kit used for crushing the ore, such as hammers, dressing stones or anvils (Ottaway 2001, p. 92; Heeb and Ottaway 2014, p. 167). This activity might have taken place at the mining site, as testified by the large set of stone tools found at Ambelikou-*Aletri*, or at the settlement where the smelting process was carried out, as proven at the site of Selevac (Ottaway 2001, p. 93) or, possibly, at the site of Pyrgos-*Mavroraki*, where a similarly vast stone tool kit resembling that found at Ambelikou-*Aletri* was recovered (Belgiorno 2009, pp. 85-86).

The concentrated ore would have then been prepared for the furnace, in the next step of the copper *chaîne opératoire* known as **smelting**. This process involves the application of heat to convert the mineral into metal, according to the following simple reaction:

$$Mineral + Heat + RedOx\ atmosphere \rightarrow Metal + Slag + Gas.$$

This can be translated in the following equation when applied to the conversion of an oxidic copper ore, such as malachite to cuprite and finally metallic copper (Hauptman 2020, p. 310):

$$Cu_2\,[(OH)2CO_3] + CO \rightarrow\ Cu_2O + 2CO_2 + H_2O$$

$$Cu_2O + CO \rightarrow 2Cu + CO_2$$

In order to concentrate the heat and maintain consistently high temperatures as well as a reducing atmosphere for the entirety of the process, many different solutions have been adopted since the beginning of metallurgy. Charcoal was preferred as fuel for smelting operations because of its capacity of maintaining high temperatures and producing carbon monoxide (CO) gas, ideal to create the reductive atmosphere necessary for the chemical reactions described above (Craddock 2000, p. 161). From the earliest crucible smelting performed in small bowl-shaped hearths (Ottaway 2001, p. 93), to the use of more complex pyro-technological structures, the furnace is the technological focus of this step in the *chaîne opératoire*.

It has been argued that the earliest smelting attempts performed in bowl-shaped hearths were not efficient enough to complete the process as the lack of control on temperatures and atmosphere inside the furnace did not allow a complete separation of the metal from the slag, instead copper prills would have solidified inside a rather viscous slag. The slag would have been then crushed to collect the copper prills by hand (Ottaway 2001, p. 94). In the case of Cyprus, the first ores to be smelted would have probably been, together with native copper, copper sulphates which would have been easily spotted on the surface because of their vivid colours and collected from the weathered mineral deposits (Constantinou 2012, p. 6). Once these sources started to get exhausted, the ancient miners penetrated the gossans further, reaching the zones of secondary copper enrichment which contain sulphide minerals (Constantinou 2012, p. 6).

While copper oxides and carbonates, once beneficiated, would have been ready for smelting, copper sulphides would have normally needed to undergo an additional pre-treatment aimed at freeing the mineral from its sulphidic content under oxidising conditions: this process is known as **roasting** (Ottaway 20012, p. 96). Roasting, differently from smelting, does not need particularly high temperatures and can be carried out in shallow pits or "beds", where the mineral was exposed to the open air at a temperature of ca. 800°C (Doonan 1994).

Different reactions can take place during the roasting and smelting of copper sulphidic ores and different authors suggested different processes for their conversion into metallic copper. As already noted by Van Brempt (2016, pp. 43-44), different authors suggested different pathways to the reduction of sulphidic copper ores:

A. Complete roast and reduction smelt:

Ore roasting under oxidising conditions. The sulphur is removed and the iron oxidised:

$$CuFeS_2 \text{ (chalcopyrite)} + 3O_2 \rightarrow FeO \text{ (slag)} + CuO + 2SO_2$$

$$C + O_2 \rightarrow CO_2$$

The roasted ore is smelted in a reducing environment:

$$CO_2 + C \rightarrow 2CO$$

$$CuO + CO \rightarrow Cu \text{ (metal)} + CO_2$$

B. Partial roast and co-smelt:

Partial ore roasting under oxidising conditions, copper oxide and sulphide are formed:

$$2CuFeS_2 + 3O_2 \rightarrow CuO + FeO \text{ (slag)} + CuS + FeS + 2SO_2$$

The products of the partial roast are smelted together in a mildly oxidising smelt allowing the oxide and sulphide copper to interact:

$$2Cu + CuS \rightarrow 3Cu \text{ (metal)} + SO_2$$

$$FeS + CuO \rightarrow CuS + FeO \text{ (slag)}$$

C. Matte smelting:

The ore is smelted to remove some of the sulphur and produce a metalloid substance comprising copper, iron and sulphur (CuS + FeS), known as matte:

$$2CuFeS_2 + heat \rightarrow CuFeS + S$$

$$CuFeS + heat \rightarrow CuS + FeS + FeO \ (slag)$$

The matte is either dead roasted and smelted under reducing conditions, or partially roasted and resmelted:

$$CuS + FeS + 5O_2 \rightarrow CuS + Fe_3O_4 + 3SO_2$$

The copper will remain sulphidic until all the FeS is oxidised and slagged off:

$$CuS + O_2 \rightarrow Cu \ (metal) + SO_2$$

The further processing of the products of first smelting such as copper prills, black copper (iron-contaminated copper from smelting copper oxides using a flux) or matte aimed to transform these into metallic copper is commonly known as **refining** (Ottaway 2001, p. 97).

Once metallic copper was obtained, it could have been used as a pure metal or, more often, mixed with other metals in the process of **alloying**. Alloys, when compared to pure metals, show a higher hardness, making them suitable for a range of different tools, lower melting temperatures, which improved the casting process and a characteristic change in colour (Hauptman 2020, p. 381).

In his "sensory update to the chaîne opératoire" applied to copper-compositions, Kuijpers recently stressed on the importance of perceptive categories in the analysis of production processes and in the specific case of alloying, he argues that colour was the main referent for copper-composition to the ancient metalworkers. Different colours of copper alloys such as red (3% arsenic, antimony, nickel and/or silver; or less than 5% tin), orange (3-7% arsenic, antimony, nickel and/or silver; or 4-5% tin), yellow (5-12% tin), gold (12-20% tin), white (≥7% arsenic, antimony, nickel and/or silver) or silver ((≥20% tin) would have preliminary informed the ancient metalworkers about the properties of a certain alloy, probably conceived as a specific metal in itself (Kuijpers 2018, pp. 873-878).

It has been long debated if the earliest alloys were intentional or accidental, as copper does occasionally occur in association with arsenical ores (Ottaway 20012, p. 98), as is the case for the arsenides found in Cyprus, in the area of Pevkos, in the Limassol Forest (Foose et al. 1985).

The next steps in the *chaîne opératoire* of copper metallurgy are more directly related to the manufacture of artefacts. It is possible to shape metal by cold hammering alone or by a cycle of cold hammering and reheating of the metal called annealing, however, casting would have been the main technique to work the metallic copper in more complex shapes, pouring the molten metal in moulds. The cast would have been then finalised through smithing, which could involve the hammering, grinding and polishing of the artefact (Ottaway 20012, p. 102), all activities which leave on the object specific marks, subject of use-wear analysis studies (Dolfini and Crellin 2016).

Finally, the production of fuel, as correctly noted by Ottaway (2001, p. 101), should be included as part of the chaîne opératoire of copper metallurgy as several of its different stages require a large quantity of accurately selected fuel. Fuels used in prehistoric metallurgy can include wood, charcoal, peat, bone, dung and other organic material, and according to the step of the operational chain involved, a specific type of fuel might be more effective than another one, as in the case of roasting, which needs the oxidising atmosphere obtained with wood, while charcoal should be used to secure a reducing atmosphere during smelting (Ottaway 2001, p. 102).

Archaeological evidence for all or some of these steps of the chaîne opératoire of copper metallurgy have been identified in Cyprus, in a series of contexts from different periods. Before we delve further into the study of ancient Cypriot metallurgy, the following paragraph will provide the reader with a general overview on the early metallurgy which developed in different countries of the Eastern Mediterranean and the Aegean, both areas which were certainly in contact with Cyprus in the Early/Middle Bronze Age and even before (Mellink 1991).

2II.3 Metallurgy in Early-Middle Bronze Age Eastern Mediterranean and the Aegean

As stated before by Muhly (1991, p. 367), to attempt any explanation of the earliest metallurgy of Cyprus, it is essential to carefully consider the broader context to understand any possible contacts and influences that the Eastern Mediterranean and the Aegean might have had with the island.

The most relevant evidence of metallurgical activity practiced around Cyprus in the Early and Middle Bronze Age comes from Anatolia to the North, the Levant to the East and the Aegean to the West.

Anatolia is one of the earliest regions where communities participated in complex metallurgical traditions (Lehner and Yener 2014, p. 530). Although recent discoveries in Serbia moved the earliest known extractive metallurgy to the Central Balkans (Radivojević et al. 2010), Anatolia remains one of the most important countries in the development of early metallurgy, and its vicinity to Cyprus makes it even more relevant to our research.

The highlands of Anatolia are rich in metal-bearing mineral concentrations, such as polymetallic deposits of copper, iron, lead, silver and zinc, with rarer deposits of antimony, arsenic, nickel, gold and tin. Ergani, in the eastern Taurus, Küre and Murgul/GöktaşŸ are the sites of the largest Anatolian sulfide ore bodies (Lehner and Yenaer 2014, p. 531).

The first evidence attested in Anatolia of cold-worked native copper comes from the Neolithic site of ***Çayönü***, in southeastern Turkey and seems to be related to the production of ornaments, probably used to demarcate social boundaries (Lehner and Yener 2014, p. 538). A similar, early connection between metalwork and the production of ornaments has been recorded, much later, for the Middle Chalcolithic metallurgical evidence in Cyprus (Peltenburg 2011).

In the Early and Middle Chalcolithic (6000-4000 BCE), Anatolia underwent a significant socioeconomic reorganisation, witnessing new regionalised political affiliations and exchange networks mainly focused on local materials. During this time, the *repertoire* of metal objects increased and tools and weapons started to be produced. From the beginning of the fifth millennium BCE, a series of artefacts from the site of ***Mersin***, in Cilicia, demonstrated the development of casting technologies and possibly ore-smelting. This data has been deduced by the objects' metallographic and chemical analyses, as no by-products, nor pyrotechnological installations have been found yet (Lehner and Yener 2014, pp. 539-540).

Interestingly, this first stage of Anatolian metallurgy points to a household-production, as demonstrated by the numerous households, not specialised workshops, excavated at the site of ***Değirmentepe*** (end 5th-beginning 4th millennium BCE). Here, slags, ores, crucibles and metal artefacts have been found in multiple households within the same site. This suggests that each household would have been directly involved with different phases of the *chaîne opératoire* (ore processing, smelting, melting and casting) and, possibly, with the administrative tasks related to this early metal production (Lehner and Yener 2014, p. 540).

Further evidence of metalwork has been found in South-eastern Anatolian settlements, such as ***Norşuntepe***, ***Tepecik*** and ***Tülintepe***. This includes, other than metal artefacts, ores and slags from the Chalcolithic and Early Bronze Age periods, which all point to the practice of arsenical copper alloying (Çukur and Kunç 1989). An independent household or nucleated workshop-level production has also been suggested for these settlements (Lehner and Yener 2014, p. 541). In contrast to the type of metal production practiced at the aforementioned sites, the Late Chalcolithic site of ***Arslantepe*** revealed to be the centre of a vast network of villages, actively interacting with Uruk Mesopotamian communities interested in trading for metal materials or finished products, possibly through the actions of a local independent elite (Lehner and Yener 2014, p. 541). While Late Chalcolithic communities used polymetallic ores, in the Early Bronze Age, Anatolia witnessed a shift to the predominant, though not exclusive, use of copper-iron sulphides (Hauptman et al. 2002).

The main smelting technology employed, made use of small crucibles to extract the metal from its ores and open moulds to cast it into the desired shape. An example of this can be found in the Late Chalcolithic site of ***Yarikkaya***, where a characteristic oblong crucible incrusted with a thin layer of metalliferous residue was identified (Lehner and Yener 2014, p. 543; fig. 2.10). This shows an uncanny resemblance to two open moulds found at the Cypriot site of Pyrgos-*Mavroraki*, as we shall see in chapter 3.

Figure 2.10 Crucible from Yarikkaya (from Lehner and Yener 2014, p. 543, fig. 20.6).

In the Early Bronze Age (3000-2000 BCE) several Anatolian communities started to participate in long-distance trade and Anatolian metallurgy faced two major innovations: intentional copper-tin alloys on one hand, and the development of so-called second-tier processing sites in mining regions, where the seasonal extraction of ores and intensive extraction of polymetallic ores was carried out by specialised communities, as demonstrated by the mining village of Göltepe and the Kestel mining complex (Lehner and Yener 2014, pp. 544-545).

In the Early Bronze Age II, Anatolian metallurgy developed further and became more sophisticated. The smelting operations were then to be carried out on the extraction sites, as testified by the large slag heaps, and transported in the form of ingots. Although tin-copper alloys spread rapidly, they did not replace arsenical copper completely. Innovations of this period include the use of multifaceted and two-piece closed moulds and the lost-wax technique (Yener 2000, pp. 67-69).

Moving to the Middle East, the Arabah Valley, which today lies in between the modern countries of **Israel**, **Palestine** and **Jordan** also played an important role in early metallurgy.

The Western Arabah Valley, between Israel and Jordan, offered to its ancient inhabitants a generous wealth in copper ore deposits.

Four main early sites have been recognised as key sites in the surroundings of ***Timna*** and the adjacent Arabah (see Table 7). Site F2, Site 39, Site 201A and Site 149 show evidence of all three local chronological phases established for the Arabah (Sinai-Arabah Copper Age-Early, Middle and Late Phases), corresponding to a period between the Late Pottery Neolithic and the end of the Early Bronze Age. All these sites show evidence of metallurgical activity (Tab. 2.1), which well reflects a diachronic development, parallel to the culture-historical phases. Among the metallurgical remains, slagged furnace fragments, ores, slags, tuyères and crucible fragments were recovered. The progression of metallurgical technology is testified by evident differences in many factors, such as the nature and shape of the slags, which appear to be nut-sized, highly viscous and heterogeneous to begin with, then develop into large lumps of well-formed homogeneous tapped slags (Hauptmann 2007).

Other indicators are the shape-evolution of smelting installations from simple holes in the ground (bowl-shaped furnaces), to stone-built shaft furnaces adapted for tapping-smelt, and the diachronic increase in the "scale of production" (Merkel and Rothenberg 1998).

Site F2 presents all the main metallurgical indicators: copper ore nodules, nut-sized, irregular and porous slags, small tuyères (or blowpipe-nozzles?), a possible crucible fragment, a large stone mortar, anvils and hammer-stones (Merkel and Rothenberg 1999, p.151). Neolithic Qatifian pottery and stone tools, dating to the 6^{th}-5^{th} millennium BC make this site, according to Merkel and Rothenberg (1999, p.153), the earliest evidence for extractive metallurgy in the Levant. Hauptman (2007, p. 148) disagrees, putting forward the analysis of one of the slagged tuyères from Site F2 by thermoluminescence, which suggests a Late Bronze Age dating of the artefact, and pointing out that the chronology of the artefact-types considered by Merkel and Rothenberg has been proven incorrect.

Site 39 is located at the foot (39a) and on top (39b) of a hill located to the SE of Mount Timna. 39a is characterised by three buildings and a semi-attached enclosure, where stone tools, copper ore nodules and small slag fragments were recovered. This space has been interpreted as a workshop to prepare the ores (or the slags) for smelting, an activity which probably took place on site 39b, where major concentrations of viscous "primitive" furnace slags and a smelting hearth were found (Merkel and Rothenberg 1999, pp. 154-155).

About 3 km from Timna, *Site 201* was partly excavated by the Arabah Expedition. The lumps of slags from this site were found broken, probably due to the intentional recovery of trapper copper prills, similarly to the earlier sites, but some of them were instead more homogenous, with the typical texture of tapped slags. These remains might indicate a transition phase with the first trials of tapping technology, which was not efficient enough to produce a fully liquefied slag. Therefore, the recovery of viscous slag-lumps from the furnace was still necessary to collect the trapped copper prills. Compared to the previous Early Phase metallurgy, the new technique recorded at site 201 demonstrates a better control of fluxing and more efficient use of fuel. No smelting furnace was found *in situ*, but nearby two small slagged stone settings were interpreted to be the possible upper part of shaft furnaces (Rothenberg 1996-97, pp. 16-17).

Finally, the metal-workshop found in the wide estuary of Wadi Timna, Site 149, showed evidence of a proper "industrial plant" for the extraction and production of metal. Evidence of both smelting and melting activity was found. The fayalitic homogeneous slags from this site appear to belong to a furtherly developed technology, with a better control of fuel and air supply conditions. This advancement has been interpreted by Rothenberg (1996-97, p. 19) as a consequence of a possible immigration of metalsmiths from the north, or the influx of a "northern" metallurgical know-how which reached Timna through Palestine.

Site	Chron.	Ores	Slags	Cruc.	Moulds	Noz./Tuy.	Furn.	Anvils	St.	Metals
Site F2	Early Phase	x	x	x		x	x	x	x	x
Site 39	Early Phase	x	x				?		x	
Site 201 A	Middle Phase	x	x				?	x	x	
Site 149	Late Phase	x	x	x			?	x	x	

Table 2.3 Main early metallurgical sites around Mount Timna (cruc.: crucibles; Noz./Tuy.: nozzles/tuyeres; furn.: furnaces; st.: stones tools).

Moving to the South, the Chalcolithic village of ***Shiqmim***, in the Beersheva valley, showed evidence of early metallurgy (Shalev and Northover 1987). Not only were metal artefacts found at this site, but fragments of ores, slags and crucibles. The analysis of the ore revealed that it was most probably transported a distance of over 100 km from the Faynan District (Jordan). They consist of rich oxidic ores, such as cuprite and were smelted on the settlement (Levy and Shalev 1989, p. 359). The chemical composition of the slags shows poor temperature control (Shalev and Northover 1987, pp. 363-364).

Haptmann (2007) listed over fifty metallurgical sites dating to different periods from fifteen different areas in the ***Faynan District*** in Jordan. Thirteen of these sites date to the Early Bronze Age and here a brief description is given.

Wadi Fidan 4, and possibly the few remains from *Wadi Fidan 5***,** show evidence of the earliest extractive metallurgy in the Faynan District found until now. The ore was transported from the mine (possibly Umm ez-Zuhur and Qalb Ratiye) to the settlement for smelting on a "household or workshop" level, which is understandable if we think about the contemporary extensive ore exports from this area to the Beersheba valley (Haptmann 2007, p. 149). The sites of *Faynan 17* and *Wadi Faynan 100* belong to the same period and show the same type of nut-sized pieces of slag recovered at the two previous sites. From Wadi Faynan, a hundred numerous crucible fragments, ores and casting moulds were also found (Haptmann 2007, pp. 109-111).

Faynan 9 and *Faynan 15* show remarkable evidence for the Early Bronze Age II/III. The slags found fragmented and scattered at these sites, once reconstructed, resemble a peculiar cone shape block formed by many single drop-shaped and cushion-shaped parts.

The remains of 27 furnaces from Faynan 9, 7 from Faynan 15 were recovered, built in a favourable elevated position, most likely to use the winds coming from the Jordanian plateau as the main air-supply during the smelting. Only the bottom and the rear walls of these structures were preserved, showing multiple layers which belong to different use episodes and so confirming the re-use of the same spot for the construction of new reactors. For the upper part, a dome shape or a sort of shaft superstructure were hypothesised, both suggested by the slagged clay fragments recovered on site. Another typical metallurgical find for this period and region, and well testified also in these sites, is represented by the thousands of clay rod fragments (so-called "ladyfingers") interpreted as part of the furnace internal structure (Hauptmann 2007, pp. 105-106).

In the Wadi Ghwair valley, the EBA II/III sites of *Wadi Ghwair 2-3-4*, were found to be rich in slags, the above-mentioned clay rods fragments and furnace walls (Hauptmann 2007, pp.111-112.).

Indicators of a more sophisticated metallurgy in the area came from the last phases of the Early Bronze Age. The most representative sites for this period are *Khirbet Hamra Ifdan (Wadi Fidan 3)* in the Wadi Fidan valley and *Barqa el-Hetiye*.

Khirbet Hamra Ifdan is a multi-phase site occupied since the Early Bronze Age II/III until the Islamic period. The excavations revealed the largest EBA III metal workshop in the Middle East with an impressive space availability: Eighty rooms have been counted; courtyards and other spaces were dedicated to metal processing. The complex archaeometallurgical assemblage found at this site includes smelting and melting crucibles, prills and lumps of copper, slags, ores, copper tools and particular T-shaped bar ingots, moulds (for ingots and tools) and smelting furnace remains. The same type of moulds for the production of T-shaped ingots were found at the top-hill settlement site of Barqa el-Hetiye, together with evidence for the production of other ingot types (rod-shaped; plano-convex). A series of smelting furnaces were built at the upper end of the heap, resembling the type found at Faynan 9, well exposed to the winds. The ores found at the site could have been transported from the mine of Umm ez-Zuhur, 7 km to the north. The metallurgical assemblage includes also slags, metal prills, stone tools and metal artefacts (Hauptmann 1997, pp. 141-142).

Khirbet Faynan and Vicinity										
Site	**Chron.**	**Ores**	**Slags**	**Cruc.**	**Moulds**	**Noz./Tuy.**	**Furn.**	**Anvils**	**St.**	**Metals**
Faynan 17	EBA I		x							
Wadi Faynan 100	EBA I	x	x	x	x					
Faynan 9	EBA II-III		x				x			
Faynan 15	EBA II-III		x				x			
Wadi Ghwair										
Site	**Chron.**	**Ores**	**Slags**	**Cruc.**	**Moulds**	**Noz./Tuy.**	**Furn.**	**Anvils**	**St.**	**Metals**
Wadi Ghwair 2	EBA II/III		x				x			
Wadi Ghwair 3	EBA II/III		x							
Wadi Ghwair 4	EBA II-/II		x				x			
Wadi Fidan										
Site	**Chron.**	**Ores**	**Slags**	**Cruc.**	**Moulds**	**Noz./Tuy.**	**Furn.**	**Anvils**	**St.**	**Metals**
Wadi Fidan 4	3500 BC EBA Ia	x	x	x				x	x	
Wadi Fidan 5	3500 BC EBA Ia?		x							
Wadi Fidan 12	EBA II/III		x				x			
Wadi Fidan 13	EBA II/III ?		x							
Wadi Fidan 3 - Khirbet	EBA III/IV		x	x	x					x

Hamra Ifdan										
Barqa el-Hetiye										
Site	**Chron.**	**Ores**	**Slags**	**Cruc.**	**Moulds**	**Noz./Tuy.**	**Furn.**	**Anvils**	**St.**	**Metals**
Smelting site on top of the hill	EBA II/III	x	x	x	x					x

Table 2.4 Metallurgical sites from the Faynan District (cruc.: crucibles; Noz./Tuy.: nozzles/tuyeres; furn.: furnaces; st.: stones tools).

Moving towards the West, it is useful to briefly consider the ***Aegean*** context (fig. 2.11), because of its connections with Cyprus (Day et al 1998; Stos-Gale and Gale 2002). The first evidence for Aegean metallurgy dates to the early Late Neolithic, in the late 6th – early 5th millennia BCE, with polymetallic tools, such as awls, flat axes and even gold and silver ornaments, accompanied in the latter period by chisels, spatulas and, possibly, shaft-hole axes (Sherrat, 2007, p. 247; Zachos 2007). Renfrew (1972, p. 308) argued that a generalised loss of interest in metals characterised the first phase of the Early Bronze Age, rapidly rising again in the middle of the 3rd millennium BCE. His statement was clearly based on the knowledge available at the time. Since then, the revision of absolute chronology due to a gradually increasing number of new calibrated radiocarbon dates which pushed upwards the early periods, on one hand, and an overall recent increase and development of analytical studies in Aegean archaeometallurgy, dedicated for example to metallography, technology and provenance, shed light on the Early/Middle Bronze Age Aegean metalwork (Sherratt 2007, p. 246).

Sherratt (2007, p. 249) suggests that the apparent lack of visibility of metal in the Aegean Early Bronze Age I was due to its absence among grave goods, in contrast to coeval sites in other regions.

Recent studies of Early Bronze Age I sites such as the *Zas* cave on *Naxos* (Zachos and Douzougli 1999), *Aghia Photia* and *Poros-Katsambas* (Dimopoulou 2012, p. 136), demonstrated that metallurgy was practiced in this period, when, possibly, the Neolithic common practice of cave communal deposition of metal artefacts testified in sites such as *Alepotrypa*, *Zas* and probably *Ayia Marina* suddenly stopped. Metal was probably ubiquitous in this period, in contrast with what once believed by Renfrew, however Sherratt argues that it was not common enough to be deliberately taken out of circulation by individuals, burying it in the ground (Sherratt 2007, p. 250). This community-level possession value that metal held in the Aegean Neolithic and Early Bronze Age I will shift in the Early Bronze Age II to a symbolic asset relevant to the individual (Sherratt 2007, p. 250).

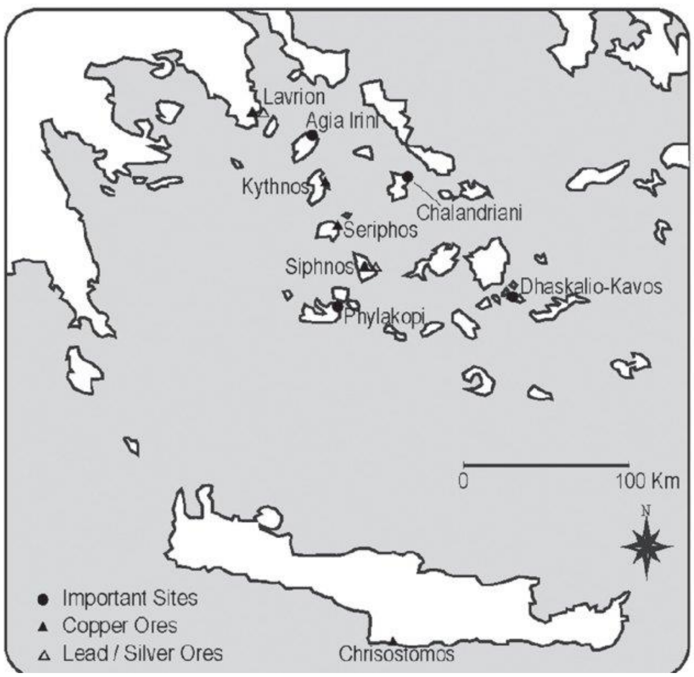


Figure 2.11 Map of the Aegean with metal ore sources and exchange centres (from Legarra Herrero 2004, p. 33, fig. 2).

In the following paragraphs, the most representative early metallurgical sites from this area are briefly described.

Kythnos, which forms with Kea, Seriphos, Siphnos and Melos, the western boundary of the Cycladic islands, provided evidence of metallurgical activity in several Early Bronze Age sites, some of which are mentioned in this paragraph.

The site of *Skouries* owes its name to the large slag heaps which cover the seaward slopes to the north of its promontory. Amongst the slags, fragments of oxidised copper ore, fragments of clay bowl-shaped furnace lining and spherical stone hammers, possibly connected to the processing of the ores and the slags, were discovered. The slags, which showed the production of arsenical copper, were dated to the Early Cycladic II, thanks to the radiocarbon dating of the charcoals trapped in their matrix, and the ore source identified in the nearby secondary copper mineralisation (thin veins of malachite) and, possibly, the open-cast mine on Cape Tzoulis (Bassiakos and Philanioutou 2007, p. 25).

The site of *Pounta*, similarly to Skouries, was found rich in dull-black or dark-grey slags with green copper incrustations on the surface. Two possible stone anvils used for ore/slag crushing were found at the northwest of the site, amongst the slags.

At *Sideri*, amongst heaps of angular copper slags and ores, an anvil, similar to the one found in Pounta and several fragments of furnace lining were found, which belonged both to bowl-shaped furnaces and to a pierced shaft type, which seems to be peculiar of the Aegean early metallurgy (fig. 2.12). Similar finds were made at *Paliopyrgos*, *Aspra Kellia*, *Petra* and, in the Southeast of Kythnos, at the site of *Lefkes* (Bassiakos and Philanioutou 2007, pp. 27-36).

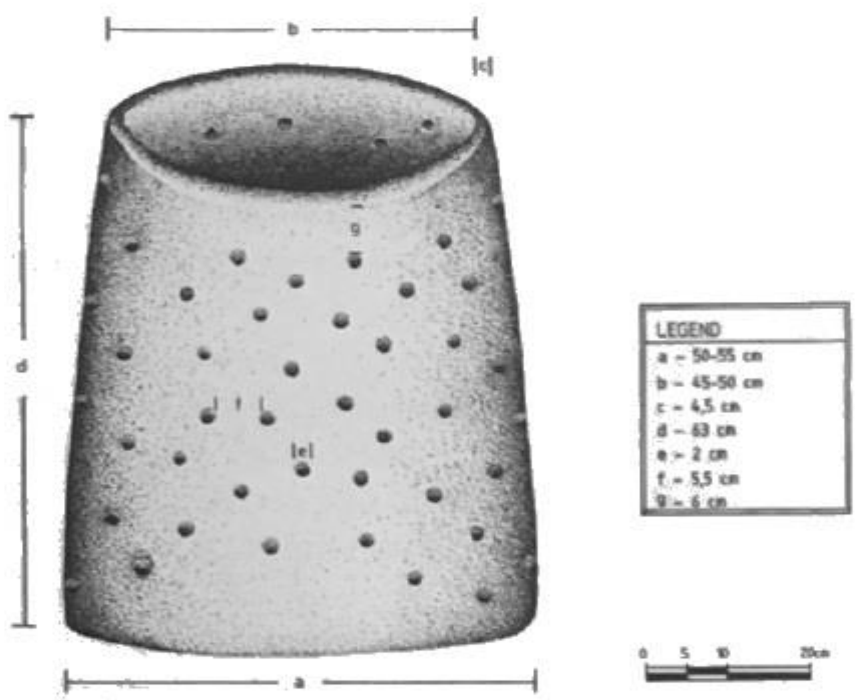


Figure 2.12 Reconstruction of the pierced shaft furnace type found in the Aegean (from Bassiakos and Philaniotou 2007, p. 46, Fig. 2.8)

On the island of ***Kea***, metallurgical activity related to the Early/Middle Bronze Age, testified by the presence of slags and crucibles fragments in the northern sites of Kephala, Paoura, Ayia Irini and Troullos (Caskey 1971; Coleman 1977).

On the island of **Seriphos,** a few slag heaps in the sites of *Kephala* and *Phournoi* have been dated to the EBA and analysed, confirming the production of unalloyed copper (Georgakopulou et al 2011).

On the western end of the island of ***Keros***, an interesting metallurgical context has been identified at the certainly interconnected sites of Kavos, on the coast, and the frontal islet of Dhaskalio, both dated to the Early Bronze Age II-III period (ca. 2750/2300 BCE; Renfrew et al. 2012, p. 155).

While at the coastal site of Kavos fourteen slags were found and were attributed to the smelting of two different types of ore aimed to the production of unalloyed copper and arsenical copper, among the metallurgical finds from Dhaskalio, just three slags were found. These have been described as rounded and well-fitting in one's palm and therefore were interpreted as tools, brought to the site, probably from the nearby Kavos promontory, for secondary usage, as documented in some of the western Cycladic smelting sites (Georgakopoulou 2013, p. 672). This scarcity of slags suggested to the excavators that smelting operations very likely did not take place on the islet. In contrast, several copper-based metal fragments, encrusted with calcareous rock and soil conglomerate were found in all the three different phases of occupation identified at the site (A, B, C, and interpreted as possible remains of metal spills (Georgakopoulou 2013, p. 667). From the layers belonging to Phase A (ca. 2750/2550 BCE), other than the aforementioned possible metal spills, a few fragments of copper-based metal and the fragment of a possible crucible, it is with Phase B (ca. 2550/2400 BCE) and Phase C (ca. 2400/2300 BCE) that the amount of metal artefacts increases in number and size, with the recovery of as a copper-based needle, a fishing hook, a few lead objects and a single golden bead from Phase B and, among others, some larger copper-based objects from Phase C such as an axe-adze, a flat axe, a shafthole axe and a knife and more lead fragments and rivets, possibly used to fix broken pottery. In terms of metallurgical remains, three small clay nozzles (tuyères), two of which bearing incised marks, have been found testifying the use of blowpipes (or simple bellows made of organic material such as leather and wood) and two fragments of crucibles were excavated from the layers of Phase B, and more metal spills, numerous fragments of pottery clearly involved in the metallurgical process as testified by the thin layers of slagged material, another clay nozzle and a clay mould were recovered from the levels of Phase C (Georgakopoulou 2013, pp. 670-688).

On ***Crete***, at the site of *Knossos Poros-Katsambas*, metalworking is well attested in the EM I and IIA, by the finding of fragments of crucibles (both for copper and silver melting) and moulds, a blow-pipe nozzle, slagged refractory ceramic, copper spillageas, slags, roasted ore and a possible ingot fragment (Dimopoulou 2012, p. 136).

Chrysokamino is possibly the most famous copper smelting site in Crete. The metallurgical evidence is rich and mainly composed by: one ton of slag fragments, tens of thousands of clay perforated walls, belonging to wind-powered shaft furnaces, fragmentary pot bellows and tuyères (fig. 2.12), stone tools and remains of oxidised copper ores. The analyses carried out on the copper prills trapped in the slags from Chrysokamino showed the presence of Arsenic and Nickel, not found in the analysed ores. This led the scholars to suggest an intentional arsenical ores addition to the charge, to produce arsenical copper (Catapotis and Bassiakos 2007, p. 69).

Site	**Chron.**	**Ores**	**Slags**	**Cruc.**	**Moulds**	**Noz./Tuy.**	**Furn.**	**Anvils**	**St.**	**Metals**
Seriphos			x							
Kythnos-Skouries		x	x				x		x	
Kythnos-Pounta			x					x		
Kythnos-Sideri		x	x				x	x		
Kythnos-Paliopyrgos		x	x							
Kythnos-Aspra Kellia		x	x							
Kythnos-Petra		x	x							
Kythnos-Lefkes		x	x				x			
Kea-Aghios Symeon		x	x							
Crete-Chrysokamino		x	x			x	x		x	
Crete Poros-Katsambas		x	x	x	x	x				x

Daskaleios-Kavos	EB II	x	x							x
Crete Aghia Photia				x						
Crete Kephala Petras		x	x	?						

Table 2.5 Metallurgical sites from the Aegean *(cruc.: crucibles; Noz./Tuy.: nozzles/tuyeres; furn.: furnaces; st.: stones tools).*

As outlined in the brief gazetteer of metallurgical sites analysed above, in the regions surrounding Cyprus, metallurgy can be usually traced back to the Late Neolithic, such as the case of Anatolia, where the first evidence of annealed native copper attested at the site of Çayönü Tepesi, dates to the end of the 9th millennium (Kassianidou 2013a, p. 231). This largely antedates the first evidence of metalwork recorded in Cyprus; therefore, when researching the development of the earliest Cypriot metallurgy, it must be acknowledged that the related technological expertise was already quite sophisticated outside Cyprus. An example of this is the Nahal Mishmar hoard, dated to the first half of the 4th millennium BCE. This contained more than 400 objects, made both of copper or copper alloys, of which some demonstrate for their complexity, the use of lost wax technique (Kassianidou and Charalambous 2019, p. 280 for further references), known in Cyprus only from the Late Bronze Age.

The following paragraphs will examine more in depth, the first copper metallurgy of Cyprus, analysing its evidence site by site, from the Chalcolithic to the Early and Middle Bronze Age.

2II.3 Metallurgical evidence from Chalcolithic Cyprus

The most ancient archaeological evidence of metal presence in Cyprus, with the exception of a fishing hook found at *Mylouthkia* (Gale 1991, p. 43), that we excluded from this brief overview due to the scarcity of context data (Peltenburg 2011, p.5), dates only to the Middle Chalcolithic (c. 3400-2900 BCE), which is, however, much earlier than the first mentions of Alashiya in the cuneiform texts from Mari or the Amarna Letters. As already pointed out, contacts between Cyprus and the surrounding regions in relations to copper metallurgy, are confirmed by written sources from the Middle Bronze Age, however, the Chalcolithic metalwork found on the island seems to suggest that a certain level of contacts related to metal technology were probably already in place much earlier.

Chalcolithic Cypriot metallurgy is almost completely represented by finished metal artefacts, with only a few exceptions for earlier steps of the *chaîne opératoire* such as a few fragments of oxidised sulphidic lumps of ore (Gale 1991, p. 46; Kassianidou and Charalambous 2019, pp. 281, 285-286) and a stone crucible (Peltenburg 2011, p. 7).

It has been argued that the so-called “trinket” metallurgy, which involves the use of hammered native copper, representing what is considered the most ancient type of metallurgical technology, recorded for example in Anatolia, is absent in the development of early Cypriot metallurgy. Some Chalcolithic artefacts from Cyprus, chemically analysed by Instrumental Neutron Activation Analysis, showed to be made of pure copper, though inconsistent with the four sources of Cypriot native copper analysed by Gale (1991, p. 50) such as Limni, Kambia-Peristerka, Kokkinorotsos and Troodos. Others were found instead to be made of arsenical copper (Gale 1991, p. 47) and, therefore, to be the product of arsenical copper ore smelting[2]. These considerations can be valid only if the possibility of the said artefacts to be imports or the result of the recycling of imported objects/ingots/ores is completely ruled out (Gale 1991, p. 53).

Peltenburg (2011, p. 8) recognised a shift in the production of metal artefacts from the Middle Chalcolithic to the Late Chalcolithic. Middle Chalcolithic communities used copper mainly for ornaments on necklaces with anthropomorphic figures, interpreted as medium of visual display and a specific ideology expressed by birthing figures. This connection between early metallurgy

[2] The arsenic content levels do not necessarily point to deliberate alloying process (Gale 1991, p. 47).

and ornaments has been highlighted also in the Aegean Neolithic site of Sitagroi (Phase II, about 4800 BCE, Gale 1991, p. 37). The Late Chalcolithic sees an increase in the presence of more utilitarian items and shows the first evidence of the possible start of a small-scale production (Peltenburg 2001, p. 8).

Metallurgical evidence has been recorded from five Chalcolithic sites (fig. 2.13) in Cyprus and a brief overview is provided below.

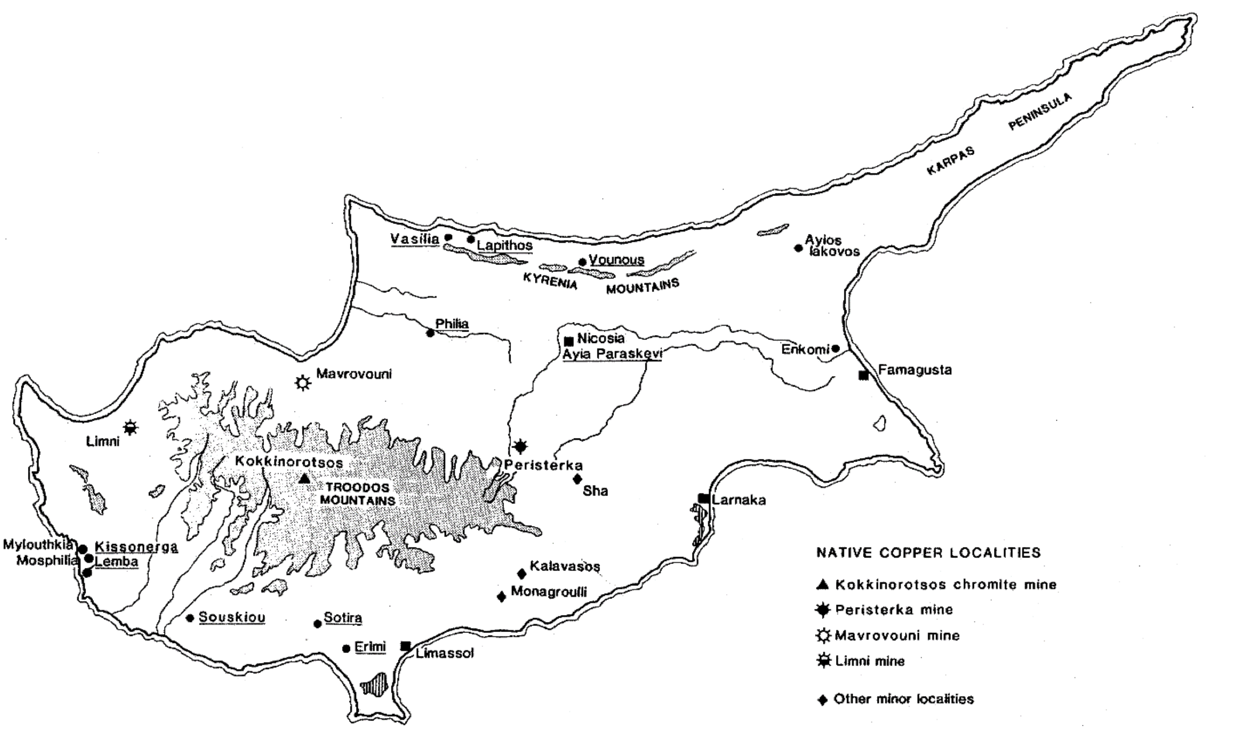


Figure 2.13 Chalcolithic sites with metals, other archaeological sites and localities where native copper has been reported in Cyprus (from Galle 1991, p. 43, fig. 5).

From **Erimi-*Pamboula*** (in the modern District of Limassol) was found the tip of a chisel, a hook and the fragment of a possible knife, dated to 3200 BC (Gale 1991).

The metallographic analysis of the hook showed evidence of cold-working and annealing, confirming that these techniques were known and practiced in Chalcolithic Cyprus (Galle 1991, p. 53).

From the Middle Chalcolithic site of **Souskiou-*Vathyrkakas*** (tombs 23, 78) came a spiral ornament and a corroded piece of copper. Together with another spiral ornament from **Souskiou-*Laona*** (Tomb 158) and the above-mentioned objects from Erimi, these are the earliest evidence of copper artefacts, and were believed by Peltenburg (2011) to be of Cypriot manufacture as suggested the multi-material ornament production at Souskiou (Peltenburg 2011, p. 6). These artefacts have been analysed and found to be made of pure copper (Kassianidou and Charalambous 2019, pp. 285-286).

It is in the Late Chalcolithic that it is possible to recognise some indicators of indigenous metalworking and casting activities from the settlement of **Kissonerga-*Mosphilia***, where lumps of oxidised sulphidic copper ore, and two possible crucibles, have been recovered around the Pithos House. Two objects from Kissonerga (KM 694 and KM 2174), were found bearing traces of tin and one of them also contains traces of iron and sulphur. The presence of tin cannot be interpreted other than representing a foreign source for the metal, as tin is absent, even in traces, from Cypriot ores. This compositional data led Kassianidou and Charalambous (2019, p. 285) to suggest two different hypotheses: either the artefacts or the metal used were imported to Cyprus; or they were casted with copper locally smelted from iron-sulphide copper ores mixed with imported metallic tin or tin smelted from imported minerals.

The crucible from Kissonerga (KM 693), consists of a copper-rich stone dish with a pouring lip, which could have facilitated its use as a crucible. This artefact, another possible crucible (KM 1007) and the presence of the aforementioned copper ore from the archaeological levels (KM 633), confirm local knowledge of copper ores and the small-scale working of copper and, possibly, to the start of extractive metallurgy on the island. (Kassianidou and Charalambous 2019, p. 286).

Two more copper-based objects come from the site of **Lemba-*Lakkous*** (modern District of Paphos), a chisel and the corroded trapezoidal fragment of a possible blade, dated to the 2500 BC (Gale 1991, p. 44; Peltenburg 2011, p. 4; p. 7, fig. 1.2 D-E). Once analysed, the blade-fragment was found bearing traces of tin (Kassianidou and Charlambous 20129, p. 285).

Very recently, the first copper axe has been found, among other rare artefatcs, in a large jug jar, due to a rescue excavation project started in 2015 at the site of **Chlorakas-*Palloures*** in the modern District of Paphos, not far from the above-mentioned sites of Lemba-*Lakkous*, Kissonerga-*Mosphilia* and Kissonerga-*Mylouthkia*. The object belongs to the category of the flat axes, but for shape and size does not have any *comparanda* in Cyprus in the Chalcolithic, Philia Facies, or Early Bronze Age, with the possible exception of the axe butt, found at Kissonerga-*Mosphilia*. Interestingly, similar shaped artefacts are testified from Anatolia and the Aegean (Düring et al 2018). At the same site, a copper spiral and a snake/spiraliform pendant have been found, well comparable with the artefacts from Souskiou-*Laona* (Kassianidou 2013a, pp. 248-249, n. 1-2).

Site	Chronology	Ornaments	Tools
Kissonerga-*Mylouthkia*	Early Chalcolithic		Fishing hook
Erimi-*Pamboula*	Middle Chalcolithic	Bead (unfolded spiral bead?)	Blade, needles, chisel
Souskiou-*Laona*	Middle Chalcolithic	Spiral bead, pendants	blade
Souskiou-*Vathyrkakas*	Middle Chalcolithic	Spiral bead	
Kissonerga-*Mosphilia*	Late Chalcolithic	Ear/hair ring	Awl, axe butt, chisels, ores, crucibles
Lemba-*Lakkous*	Late Chalcolithic		Chisel, blade

Chlorakas-*Palloures*	Late Chalcolithic		Axe

Table 2.6 Metal artefacts from Cypriot Chalcolithic sites.

The recent study carried out by Kassianidou and Charalamobous (2019) shed further light on Chalcolithic metallurgy in Cyprus, revealing that copper smelted by sulphidic ores was already in use during the Late Chalcolithic, and tin-bronzes were either imported or produced alloying Cypriot copper with imported tin or tin-bronze artefacts. This general overview provides a wider context to the further development of Cypriot metallurgy in the Early and Middle Bronze Age.

2II.4 Metallurgical evidence from Early and Middle Bronze Age archaeological contexts

As already mentioned in Section I of this chapter, the development of metallurgical technology in Cyprus, with an increase in the number of copper-based artefacts and the first evidence for an articulated operations chain is considered characteristic of the Philia Facies, the earliest phase of the Cypriot Early Bronze Age.

In the Philia phase, the amount of metal objects on the island has been documented largely within funerary contexts such as the cemeteries of Dhenia-*Kafkalla*, Kyra-*Kaminia*, Marki-*Davari*, Nicosia-*Ayia Paraskevi*, Philia-*Laksia tou Kasinou*, Sotira-*Kaminoudhia*, Vasilia-*Kafkallia*, Vasilia-*Kilistra*, Vasilia-*Alonia* (Webb and Frankel 1999). Unfortunately, there is less evidence concerning the main metalwork *chaîne opératoire.*

Webb and Frankel (2007: 199), and others before, (Stewart 1962; 1988; Mellink 1991) argued a possible direct Anatolian influence on the development of metallurgy in Early Bronze Age Cyprus. Although several types of metal items show strict parallels with Anatolian tools and implements, the evidence for an active, local metallurgical technology is demonstrated by moulds to cast tools and, possibly, ingots such as those ones found at the site of Marki-*Alonia*. When compared to the Late Chalcolithic, the number of copper-based mould-cast artefacts increased noticeably during the Philia phase. The most innovative aspect of Philia metallurgy when compared with the previous period, is that the main metal types belonging to this period are all new to the island except for chisels, awls and axes, which were also present in the Late Chalcolithic southwest. Considering the apparent contemporaneity between Philia and Late Chalcolithic in this specific area, however, it could be argued that this metallurgical evidence is related to intrusive Philia groups (Webb and Frankel 1999, p. 31).

Some of these new types are characteristics only for the Philia facies, such as spiral earrings/hair rings in copper or gold, heavy copper or copper alloy arm rings, hook-tanged poker-butt spearheads and will disappear during the following period. Other types have survived in the EC to MC I, such as flat-tanged knives with or without rivets, toggle pins with solid conical heads and drilled or punched apertures, although they are very distinguishable from their Philia predecessors (Balthazar 1990, p. 97). Another category of artefacts, which includes razors/scrapers with flat rectangular blades and flat square tangs, hook-tang weapons, chisels, awls and needles, persisted in the EC, undergoing only minor morphological changes.

It has been suggested that Cyprus could have been in contact with Anatolia, whose metallurgical industries were in need of copper in the Early Bronze Age. Mellink (1991, p. 173) argued that these contacts, due to the Anatolian demand for copper supplies could have enhanced a transfer of knowhow to the island, stimulating the development of its own metallurgical industry. However, based also on the analytical study carried out by Kassianidou and Charlambous (2019), I would argue that the trade with Anatolia can be seen more as an equal exchange, developed from previous networks (see the presence of tin in Late Chalcolithic artefacts), involving the export of Cypriot copper and the import of Anatolian tin (or tin-bronze artefacts). This would have been employed in the local metallurgical industry, adding it to Cypriot copper to form tin-bronze or arsenical-tin-bronze.

In terms of *chaîne opératoire*, eleven Early/Middle Bronze Age sites have been found with evidence of metallurgical activity, represented by a series of indicators briefly summarised in Table 2II.5. For the sake of this research, this paragraph will consider in more depth only the sites which, other than mere metal objects, show archaeological indicators of the metallurgical operations chain.

Site	Chron.	Ores	Slags	Cruc.	Moulds	Noz./Tuy.	Furn.	Anvils	St.	Metals
Marki-*Alonia*	Philia-MCII				3			1		61
Sotira-*Kaminoudhia*	Philia-ECIII									25
Alambra-*Mouttes*	MC	40	17	16	3					8
Pyrgos-*Mavroraki*	**Philia?-MCII**		**1713**	**29**	**7**	**3**	**x[3]**	**6**	**x[4]**	**36**
Paramali-*Pharkonia*	EC-MC			1						
Kissonerga-*Skalia*	EC-MC	1?	3?					x		23
Politiko-*Troullia*	MCII-III	x	x	x	1		1?			x
Ambelikou-*Aletri*	MC	2	1	1	1(+1?)	1	2		x	2
Katydata-*Laonarka*	MCII		x							
Kalavassos-*Laroumena*	MC			1						
Kalopsidha - Site C	MC			1?	x					

Table 2.7 EC/MC sites and their metallurgical indicators (Cruc.: crucibles; Noz.Tuy.: blowpipe-nozzles and tuyeres; Furn.: furnaces; St.: stone tools related to ore/metal processing. X indicates that the relative literature does not indicate a precise number for the artefacts found at the site belonging to the specific category)

[3] Pit-furnaces have been described by the excavator (Belgiorno 2009: 78-87), but a defined number has not been reported yet.

[4] The lithic assemblage was not part of this study, but a vast amount of stone tools has been recovered from the site of Pyrgos-Mavroraki and delivered to the Archaeological Museum of Limassol District.

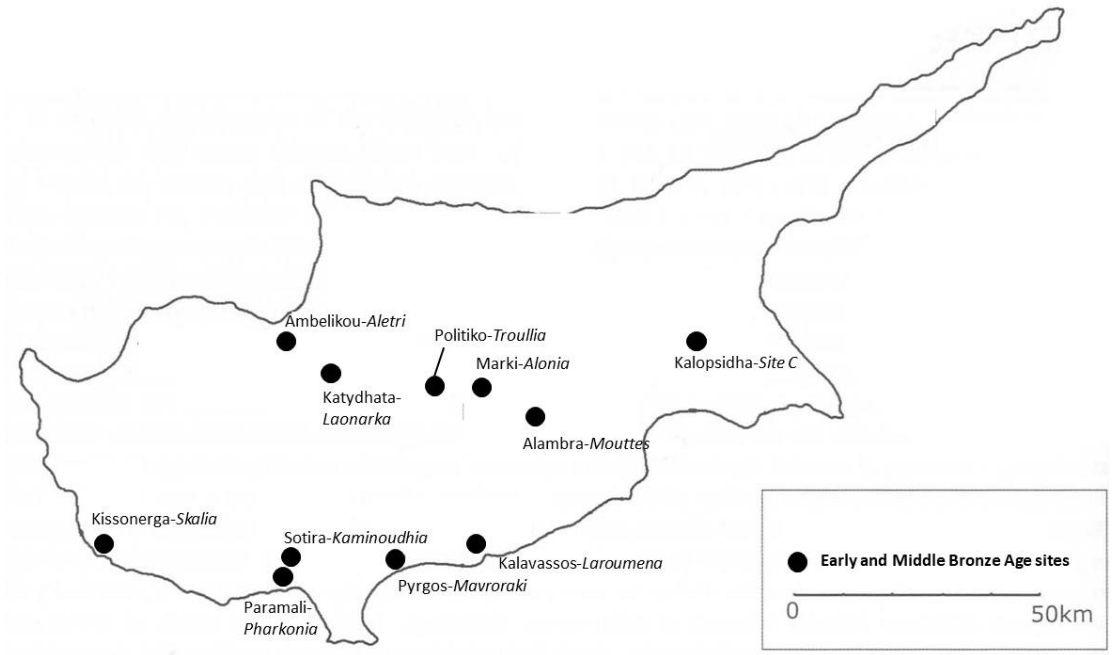


Figure 2.14 Map of Early and Middle Bronze Age sites with metallurgical indicators.

Only a few of these sites (fig. 2.14) show material evidence of few steps in technological operations chain, however, all the remains listed above, show, to a certain extent, the existence of metalwork in the surrounding areas.

Proceeding in chronological order, the first evidence of metalwork for this period comes from the site of **Marki-*Alonia***, and it is related to the casting process. Three chalk casting moulds for the production of what has been recognised by the excavators as an axe, or axe-shaped ingot, have been recovered from the site (fig. 2.15), which may have owed its foundation to its proximity to the ore sources at Mathiatis, Kampia and Sia (Frankel & Webb 2006: 217).

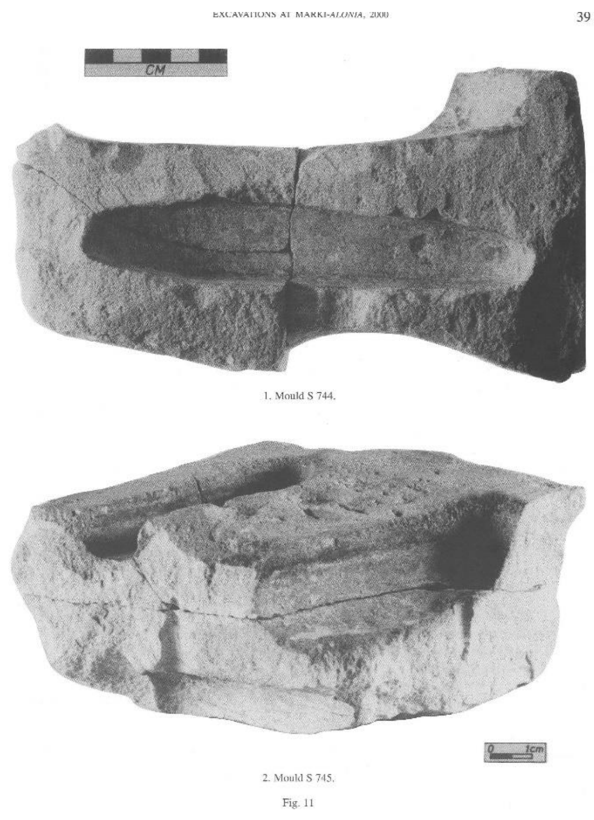


Figure 2.15 Moulds from Marki-Alonia (Frankel and Webb 2006).

Among the several metal artefacts from the EC site of **Sotira-*Kaminoudhia***, which provide additional evidence of metalworking for this period and the knowledge of alloying metals (Swiny et al. 2003: 380; Giardino et al. 2003: 392), two objects from the slightly earlier Philia facies Cemetery A are particularly interesting.

One is a Philia dagger of 99% pure copper, contemporary with the moulds from Marki, while the other is a small casting blank of a dagger blade (M12) from a burial (Tomb 6). After being cast in an open mould, it was placed in the burial without yet being shaped by hammering.

Giardino et al. (2003, p.391) however, argued against this interpretation, pointing out the considerable thickness of the artefact (7-12 mm) which would have required “an inordinate amount of metal” to be removed from the “blank” in order to produce a dagger of typical Philia or EC proportions. The authors suggested instead to interpret this object as an arsenical copper ingot, with a recorded amount of 3.5% arsenic, indicating that similar weapon-shaped ingots have been found in prehistoric Aegean contexts, such as two similar objects from Mochlos (Branigan 1974, pl. 25:3297A and 3298).

The excavator reported that small lumps of copper ore and slag were found in Area B from the northwest corner of Unit 12 (Swiny 2008, p. 49). To my knowledge, these findings still need a full examination.

The MC settlement of **Alambra-*Mouttes*** provides, without considering Pyrgos-*Mavroraki*, the most complete amount of metalwork evidence for the Cypriot Middle Bronze Age known to date (Gale et al. 1996). The site, beyond twenty-three metal artefacts (12 from the settlement and 11 from the tombs), produced fragments of three moulds and sixteen fragments of crucibles (7 with slag adhering), with diameters never exceeding 20cm and 8cm deep (Gale et al. 1996, p. 136). Two of the moulds found at Alambra (A10 and A11), made of pottery, point to the production of small bar-shaped ingots (Gale et al.1996, p. 135). The excavators did not identify any "tuyeres" remains at Alambra and justified this apparent absence in the archaeological record, suggesting these types of artefacts might have been reused multiple times and, therefore, kept as a valuable item within the coppersmith's tools set (Coleman et al. 1996, p. 383). However, it could be argued that what the excavators interpreted as a limestone "mould" (A9), is more likely to be the fragmented half of a blowpipe nozzle, similar to other few examples made of pottery, coming from coeval sites on the island such as Ambelikou-*Aletri*, Bellapais-*Vounous* Tomb 119 (Webb and Frankel 2013, pp.180-181) and, as described in more detail in chapter 3, Pyrgos-*Mavroraki*. Forty pieces of ore, or gossan and seventeen pieces of slag (2 of them still contained charcoal), suggesting that the extraction, smelting and casting of local oxidised copper ores continued as the PreBA progressed. Despite the wealth of metallurgical evidence, no clear sign of a workshop was found. Similarly to Pyrgos, the metallurgical finds at Alambra represent much more metallurgical activity than one might think, if considering only the metal artefacts. (Gale et al. 1996, p. 360). These finds have all been chemically analysed. Sixteen out of the forty mineral samples were found to be copper-rich, probably brought into the site from the volcanic area; once analysed they proved to be all carbonate ores (Gale et al 1996, p. 370).

The crucible fragments have been found vitrified only internally, suggesting that the air supply was provided by pipes from the top of the furnace, directly through the small charcoal heap which used to cover the crucibles (Gale et al 1996, p. 382).

Twelve metal objects were selected by Gale et al. (1996) for chemical analysis, while Pernicka first (cited in Balthazar 1990, table 58), and Rapp subsequently (1982, p. 37; Balthazar 1990, table 42), had the chance to analyse three more objects, a total of fifteen objects being analysed. They were all found to be made of copper, with a few exceptions, where tin was detected, and small quantities of arsenic were present. The chemical analyses carried out on Alambra's slags will be discussed further in relation to the study of Pyrgos's samples in chapter 4.

A single crucible fragment with copper prills embedded in a slagged layer on its inner wall was found during the Sotira Archaeological Project's surveys near the EC/MC site of **Parmali-*Pharkonia***. Although this is a sporadic surface find from the fill of a terrace, it shows evidence of metallurgical activity carried out in the Paramali Valley (modern District of Limassol), far from the known copper orebodies (Swiny and Mavromatis 2000: 435). The original crucible would have resembled a small cup with a diameter of about 10cm (fig. 2.16).

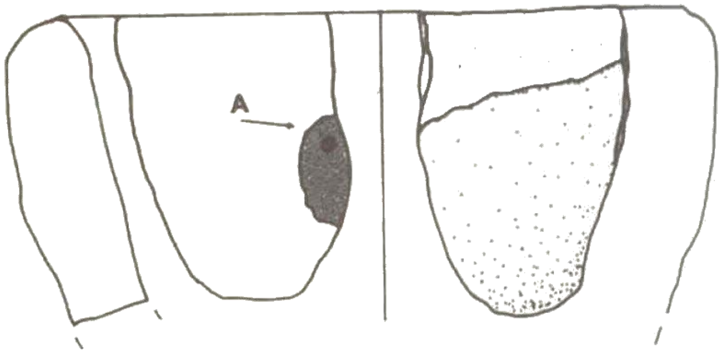


Figure 2.16 Crucible from Paramali-Pharkonia (from Giardino et al. 2003, p. 396, SAP).

The compositional analyses carried out on the slag, adhering to the crucible's internal surface showed a high iron content and the presence of arsenic (Giardino et al 2003, p. 391), which might suggest the use of polymetallic ores from the Limassol Forest region.
Another crucible fragment from the Episkopi region, slightly more recent, has been found during the survey of the nearby LC IA settlement of Episkopi-*Phaneromenoi*, encrusted with copper prills containing iron and arsenic (Zwicker 1982, p. 67).

At the Early/Middle Bronze Age settlement of **Kissonerga-*Skalia*** (Crewe 2017), in the modern District of Paphos, interesting new metallurgical evidence was recently discovered[5]. Other than twenty-three metal artefacts, among which, two were copper fishhooks, several copper needles, a hook-tang weapon, one half of a flat axe and various copper/copper alloy fragments, a few items which show evidence of metallurgical activity were found. Among these, can be considered the fragment of what appears to be an ingot and four possible slags (one of which could also be a

[5] I would like to thank Dr Lindy Crewe, Director at the Cypriot American Archaeological Research Institute, and Director of the Archaeological Mission at Kissonerga-*Skalia*, for providing me with a list of her very recent and unpublished metallurgical finds, which I hope I will be able to study in more detail in the future.

fragment of oxidised copper ore). This material, once analysed, will provide further information on the Middle Bronze Age Cypriot metallurgy.

From Areas B and D of the MC settlement of **Politiko-*Troullia*** (Falconer et al. 2010) slag, copper ores, crucible fragments, and a limestone casting mould (Fig. 2.17) have been recovered closely associated to a pit interpreted as a "rudimentary furnace" (Falconer and Fall 2013, p. 108; Fall et al. 2008, pp. 195-196), suggesting some level of metallurgical production in the exterior workspace identified at Politiko-*Troullia* East (Falconer and Fall 2013, p. 112), an activity likely sustained by the proximity of the site to the copper ore resources of Kokkinorotsos. The excavators briefly mention that copper slag have been found at the site, describing them as "tap-slag" (Falconer and Fall 2013, p. 108). This finding, together with an isolated case from Katydhata and another single fragment from Ambelikou-*Aletri*, to my knowledge all still in need of archaeometallurgical analysis, represent an exceptional finding for this period. Indeed, considering that this advanced technology, tap-smelting, has been attested in Cyprus only since the LC in sites such as Kalavassos-*Aghios Dimitrios* (Van Brempt 2016), while other slags from MC sites such as Alambra-*Mouttes*, demonstrated to be the by-products of a more "primitive" metallurgical technology, utilising small crucibles heated, possibly with the aid of blowpipes, in pit-shaped furnaces probably covered in charcoal (Gale et al. 1996, pp. 380-390). It is worth mentioning though, that in regard to the pair of copper tongs found at Politiko-*Troullia* and interpreted by the excavators as metallurgical tongs (Fall et al. 2008: 195), following an autoptical analysis, according to the writer, the object is far too small for any sort of metallurgical activity, and therefore the excavators' interpretation might be in need of review.

An interesting data regards the type of fuel identified through the analysis of Politiko's charcoal by Scanning Electron Microscopy, which revealed that the essence utilised was Calabrian Pine

(*Pinus brutia*), the same wood identified as main source for the charcoal found in the later slag heaps present on the island (Socratous et al. 2015). In their description, the excavators did not outline any detailed study of the metallurgical debris which might have provided the reader with further details on the *chaîne opératoire* that characterised copper production at Politiko-Troullia's.

Figure 2.17 Limestone mould (3 fragments) from Politiko-Troullia (after Falconer and Fall 2013: 108, fig. 9)

Moving to the northwest of the island, **Ambelikou-*Aletri*** is the sole Cypriot site of the PreBA (MC I) for which we have some limited evidence for the actual mining and extraction of copper in this period (Dikaios 1946). The site was first discovered in 1942 by Mr Costas Perikles Manglis, Manager of the Hellenic Company of Chemical Products and Manures Ltd (now the Hellenic Mining Company Ltd), who recognised fragments of red polished pottery and alerted the Department of Antiquities of Cyprus, which, in the person of the then Assistant Curator at the

Cyprus Museum and later Director of the Department of Antiquities of Cyprus. Mr Porphyrios Dikaios, officially identified it as a Bronze Age settlement (Webb and Frankel 2013, p. 7).

It is only in relatively recent times that the site details have been published in their entirety by Webb and Frankel (2013), who described earlier the archaeological remains, only partly mentioning these in brief excavation-reports (Dikaios 1945; 1946; 1960; 1961) and in later works (Buchlolz and Karageorghis 1973, p. 132. Fig. 53; Wright 1992, n. 158; Swiny 1989, p. 21, fig. 2.3).

Ambelikou-*Aletri* lies in a high mineralised formation, on the western slope of the modern Ambelikou mine shafts, in the modern district of Morphou (now Güzelyurt, part of the occupied area of the Turkish Republic of Northern Cyprus), consisting of two excavated areas (Area 1 and Area 2). The ore body at Ambelikou is located about 150 m east of the excavation at Aletri.

The main architectural features are short, dry, stone walls, which unfortunately, do not constitute complete buildings. It is not clear if these remains represent the stone foundations of mudbrick walls or the remains of a complete set of stone-built buildings, as might be suggested by the quantity of stone scatters found on-site. The walls were built directly on the bedrock, which in some cases was found to have been artificially cut and levelled (Webb and Frankel 2013, p. 36), as can be seen in Alambra-*Mouttes* and Pyrgos-*Mavroraki*. Speaking about the Area 1, a "*hearth in the eastern side of the wall, which is made up of stones and cut stones*" was found, as states a letter from Mr Kakoullis Georgiou (who replaced as foreman Mr Anastasiou) to Dikaios dated 7th May 1942. This was recognised by Webb and Frankel (2013, p. 36) as feature T (wall J, Unit II, Area 1), and for which they suggested a possible use for melting and casting. Beside this hearth, a double sided, open clay mould for a flat axe was found (fig. 2.18), a blowpipe nozzle from Unit VII, a fragment of coarse clay, tempered with large inclusions and organic, and a dark, inner surface with copper and slag adhering to it, interpreted as part of the wall of a small cylindrical furnace. The absence of earth traces on the outer surface led Webb and Frankel (2013, p. 181) to suggest that the furnace might have been at least partially free-standing.

Lumps of copper ore and manganese (possibly used as flux) have been found in Unit III, Area 2. A fragment of metallurgical debris, identified by Webb and Frankel (2013, p. 184) as a tap-like slag was recovered and has been analysed (Zwicker 1982; Georgakopoulou and Rehren 2013). It will be discussed further in Ch. 4.

Figure 2.18 Mould from Ambelikou-Aletri (from Webb and Frankel 2013m p. 179, fig. 8.9).

At **Katydata,** a very peculiar discovery was made when unusual tap-style slags were found in relation to a series of MCII tombs by the Cyprus Water Authority during the excavation of a trench in one of the village's roads. The slags' shape resembles that of a flat, thin, circular cake with a homogeneous texture, making these slags very different from the ones found in the coeval sites mentioned above, although chemical analyses still need to be carried out (Kassianidou 2008, pp. 255-256).

The settlement of **Kalavasos-*Laroumena***, separated from the modern village only by the course of the Argaki tis Asgatas, has been intercepted by the old road, which leads northwards from the village to the mines, exposing in its roadside sections, stone walls and pavements, pottery and stone tools, dating to the Middle Cypriot period. To this context belongs the discovery of a crucible fragment (Todd 1988: 135, 139-140; 2013, pp. 25-26; South 2012, p. 37), found in Location C in the section of the cut road. The crucible has been analysed by Zwicker et al (unpublished report no. UB 329/81 dated 3rd December 1985, mentioned in Todd 2013, p. 26) and the metallic prills trapped in its adhering slag, proved to contain a small amount of tin (~0.4 %) allowing the identification of the fragment as part of a melting crucible. Directly above the crucible, a Red Polish III fragment was collected from the road section. This material, even though the site would need further systematic investigation, suggests the existence of some sort of metallurgical activity at Kalavassos-*Laroumena*, probably in the MC (Todd 2013, pp. 25-26). A nodule of slag was also found at this site and considered by Koucky and Steinberg (1982, p. 117) to represent the earliest type of his selection. It is important to note however, that the accurate discovery location was unknown to Koucky and Todd (2013, p. 25-26) indicating that most of the slags which can possibly be seen nowadays, scattered on that road, near the site, are not in situ, but were probably brought there from the slag heap at Skourka, near the Petra mine, as construction material for an old road, today no longer visible.

Finally, it should be mentioned that among the artefacts within the Cypriot collections of the Medelhavsmuseet in Stokholm, there is a possible intact crucible (Stewart 1962, fig. 90.1; Webb and Frankel 2012, p. 111) with provenance from Alambra-Mouttes or **Kalopsidha** (Astrom 1966: 25-28; Crewe 2010; Webb 2012, p.4; Stewart 1992; Webb and Frankel 2012). From the latter, fragments of furnace-slags where identified (Webb 2012, p.4).

2II.5 Conclusions

The passage from the Chalcolithic and the Early Bronze Age presented some innovations in various aspects of the prehistoric Cypriot communities. The first secure evidence of the copper *chaîne opératoire* showed a remarkable development in metallurgy and increase in metal artefacts from the Late Chalcolithic to the Middle Bronze Age. According to the archaeological record pertaining specifically to the earliest Cypriot copper *chaîne opératoire* examined up to now, the metal was extracted, smelting both oxidised (Alambra-Mouttes) and sulphidic local ores (Kissonerga-*Mosphilia*), using probably the same type of crucibles (Alambra-*Mouttes*, Paramali-*Pharkonia*, Ambelikou-*Aletri*) which were utilised for remelting the copper prills and producing alloys (Kalavassos-*Laroumena*). The temperature necessary to carry out these processes was reached with the artificial air supply provided by blowpipes or simple bellows made of organic material and equipped with clay nozzles (Alambra-Mouttes; Ambelikou-*Aletri*; Bellapais-*Vounous*) directed on top of small stone-lined hearths or pit-shaped furnaces (Ambelikou-*Aletri*; Politiko-*Troullia*) covered in charcoal. The use of resinous wood such as Calabrian Pine might have been preferred by Cypriot coppersmiths. Onsite melting and casting activities have been testified by clay or limestone moulds found at EC and MC sites such as Marki-*Alonia*, Ambelikou-*Aletri*; Politiko-*Troullia*.

The relative paucity and general condition of early metallurgical remains, such as those ones from Late Chalcolithic Cyprus, is usually interpreted as an indication of a “primitive” or “provincial” copper production or consumption, destined in this period to fill the needs of village-based communities alone (Gale 1991, p. 46). However, recent studies have further reinforced the evidence that sees Cypriot metallurgy connected with a wider network since its very beginning (Kassianidou and Charalambous 2019). This picture has been already suggested in the past, using the evidence provided by lead-isotopes analysis, which demonstrated the presence of Cypriot copper outside the island, since the early third millennium BC. This has been shown by the findings from Pella in Jordan (Philip et al 2003), and Aghia Pothia on Crete (Day et al 1998; Stos-Gale and Gale 2003).

The vast and always increasing number of chemical composition analyses available for Cypriot metalwork (Charalambous and Webb 2020), which will be discussed in more detail in chapter 4, confirms the positioning of Cyprus within a wider trade network.

If we accept the identification of the Middle Bronze Age country of Alashiya, mentioned by 19th century BCE written sources, with Cyprus, this should lead the interpretation of some of the archaeometallurgical finds from Early and Middle Bronze Age sites on the island.

In terms of the earlier stages of the *chaîne opératoire*, a few more indicators from these periods indicate a gradual increase of interest in this trade network which regards also the exchange of metals copper. The moulds found both at Marki-*Alonia* and Pyrgos-*Mavroraki*, as described in more detail in chapter 3, were used for the production of pierced-butt flat axes, interpreted by some scholars as possible axe-shaped ingots (Webb and Frankel 2013, p. 180). The use of copper ingots in MC Cyprus is further confirmed by the recent (mission 2015) discovery, still unpublished, of two small copper ingots from Alambra-*Mouttes* which the author had the opportunity to view in the storerooms of the Cyprus Museum during his PhD fieldwork. The presence of ingots would suggest a surplus production of copper, which might support the argument towards offsite copper distribution an early interest for either internal (*i.e.*, with other MC settlements) or external trade (*i.e.*, with the regions surrounding Cyprus).

The contacts established between Cyprus and the Eastern Mediterranean and Aegean, which were in place since the beginning of the island's metallurgy, provide the appropriate framework to contextualise the striking fact that the knowledge of sulphidic copper ore smelting and tin-copper alloys developed almost in parallel with other areas of the Eastern Mediterranean.

Charlambous and Webb (2020) recently highlighted further the important role played by Lapithos, and earlier by Vasilia (Webb et al. 2006, p. 283), in the direct involvement of Cyprus with the trade of raw metals conducted along maritime ways which passed between its northern coast and the south coast of Anatolia in the first half of the 2nd millennium BCE. Although it has not been possible to investigate further the northern coast of Cyprus after the Turkish invasion in 1974, looking for the settlements related to this and other cemeteries, it is clear the discrepancy between the evident abundance of prestigious metal grave goods found in the norther burial sites in contrast with the much humbler contexts from the central and southern burials, where the main metallurgical sites for this period have been found on the metalliferous Troodos foothills. Material from contemporary agricultural villages situated nearer the Troodos copper ore sources indicates the use of more utilitarian copper objects, suggesting that people from these two regions held different social attitudes towards metals during life and after death (Knapp 2013b, p. 26).

The extent of the interaction between these northern and southern sites within the framework of the early metallurgical industry of Cyprus needs further investigation.

In this general framework, the pre-industrial early 2nd millennium BC settlement site of Pyrgos-*Mavrorak*i provides further evidence towards the understanding of the metallurgical *chaîne opératoire* characteristic for the Early and Middle Bronze Age in Cyprus.

The excavations unearthed a vast architectural complex, which hosted several workshops including an olive press, a textile-making workshop, a jewellery workshop, and a perfume 'factory'. Importantly, the complex yielded a great deal of metallurgical installations and residues including ore roasting beds, smelting and casting furnaces, slags, crucibles, moulds, anvils, metalworking tools and bronze artefacts.

Pyrgos-*Mavroraki* is probably the richest and best-preserved metallurgical workshop of this period ever found in Cyprus. The following chapter will examine its archaeological context and the related quality of the metallurgical evidence in the attempt to reconstruct in detail where and how different activities and tasks were carried out within the workshop.

Chapter 3. The Archaeology of Pyrgos-Mavroraki

3.1 Introduction

More than eighty papers and nine monographs designed for the wider public have been published, and several exhibitions have been organised all over the world about the Early Bronze Age site at Pyrgos-*Mavroraki*. Despite all of this, a comprehensive scientific report of the site has not been yet published.

This chapter attempts to summarise what has been done until now, providing a general overview of the site in order to describe the archaeological context, which is the background of this research. The first section briefly outlines the history of research from the site's discovery by Dr Maria Rosaria Belgiorno in 1996, to the end of the last fieldwork (2012) season.

To conclude our considerations about the archaeological contexts, an extended paragraph was dedicated to Pyrgos' Necropolis, very likely related to the settlement object of this research.

In the following paragraphs, the different areas of the site are briefly described, underlining the major metallurgical occurrences.

The second section provides a general overview of the metallurgical tools found at Pyrgos-*Mavroraki*, such as crucibles, technical pottery, moulds, stone tools, and anvils. This section aims to place these objects in the wider context of E/M BA Cypriot metallurgy.

3.2 History of Research

The site of Pyrgos-*Mavroraki* is located in the municipality of Pyrgos, on the southern coast of Cyprus, between Limassol and Kalavassos. The site is located at the foothills of the Troodos Mountain and is crossed by the Pyrgos River (fig. 3.1).

Figure 3.1 Pyrgos-Mavroraki on the map (adapted from ©Google Earth).

Since the mid-20th century, it was presumed that a prehistoric settlement would lie in the vicinity of the modern village of Pyrgos. This was due to the early discovery of several looted Early-Middle Bronze Age burials (see paragraph 3.1.2 in this chapter). Some of the tombs, however, were discovered untouched and have been excavated by the Department of Antiquities of Cyprus (Belgiorno 1997; 2002; 2019). In November 1993, a rich tomb (Tomb 21), probably belonging to a coppersmith (Belgiorno 1997), was discovered, with several copper grave goods.

Two considerations led to investigating the territory of Pyrgos: firstly, the considerable disproportion between the abundance of metal artefacts recorded in the already known

Early/Middle Bronze Age necropolis and the exiguity of the related settlements, and secondly, the historical-economic importance of the site, attested by the Anatolian cultural influences recognisable in some of the grave goods (Belgiorno 1995b: 148).

A project aiming to identify the settlement related to the necropolis of Pyrgos, one of the richest of the Southern Coast of Cyprus, was therefore conceived within the archaeological research activity of the ex-ISMEA, the Istituto per gli Studi Micenei ed Egeo-Anatolici (Institute for Micenean and Egean-Anatolian Studies)[1] of the Italian National Research Council (CNR). In 2001, the project passed under the aegis of the ITABC-CNR, the Istituto per le Tecnologie Applicate ai Beni Culturali (Institute for Technologies Applied to Cultural Heritage). Since its inception in 1994, Dr Maria Rosaria Belgiorno has coordinated the project (Belgiorno 1998; 1999a; 1999b; 1999c; 2000a; 2000b; 2009).

In 1994, a short survey was carried out in the area of the necropolis, which identified 12 archaeological sites from the Neolithic to the Middle Ages, with an apparent gap in the Late Bronze Age (Belgiorno 1999b: 72). The survey continued in the following year, leading to the successful identification of a large site featuring thousands of Red Polished III sherds (typical of Early-Middle Bronze Age Cyprus), stone tools and grinders, and dry-stone walls (Belgiorno 1995b: 148). The settlement was located in a propitious position along the north-western branch of the Pyrgos' river, 4 km from the coastline and 3 km from *Mazokambos* mine (Belgiorno 1995b: 148), where pyrites and cupreous pyrites are found.

Following the clues provided by the survey conducted from the site of Tomb 21, in 1996, an archaeological excavation took place from June 24 to July 16, which led to the discovery of the settlement. This was found at just 500 mt. from Tomb 21, on the North side of the main branch of

[1] This is now called ISMA, Istituto di Studi sul Mediterraneo Antico (Institute for Ancient Mediterranean Studies).

Pyrgos riverbank, in the Northwest area of the modern village (fig. 3.2), at the foot of the hill of *Mavrorachi* (Belgiorno 1999b: 72; Belgiorno 1996).

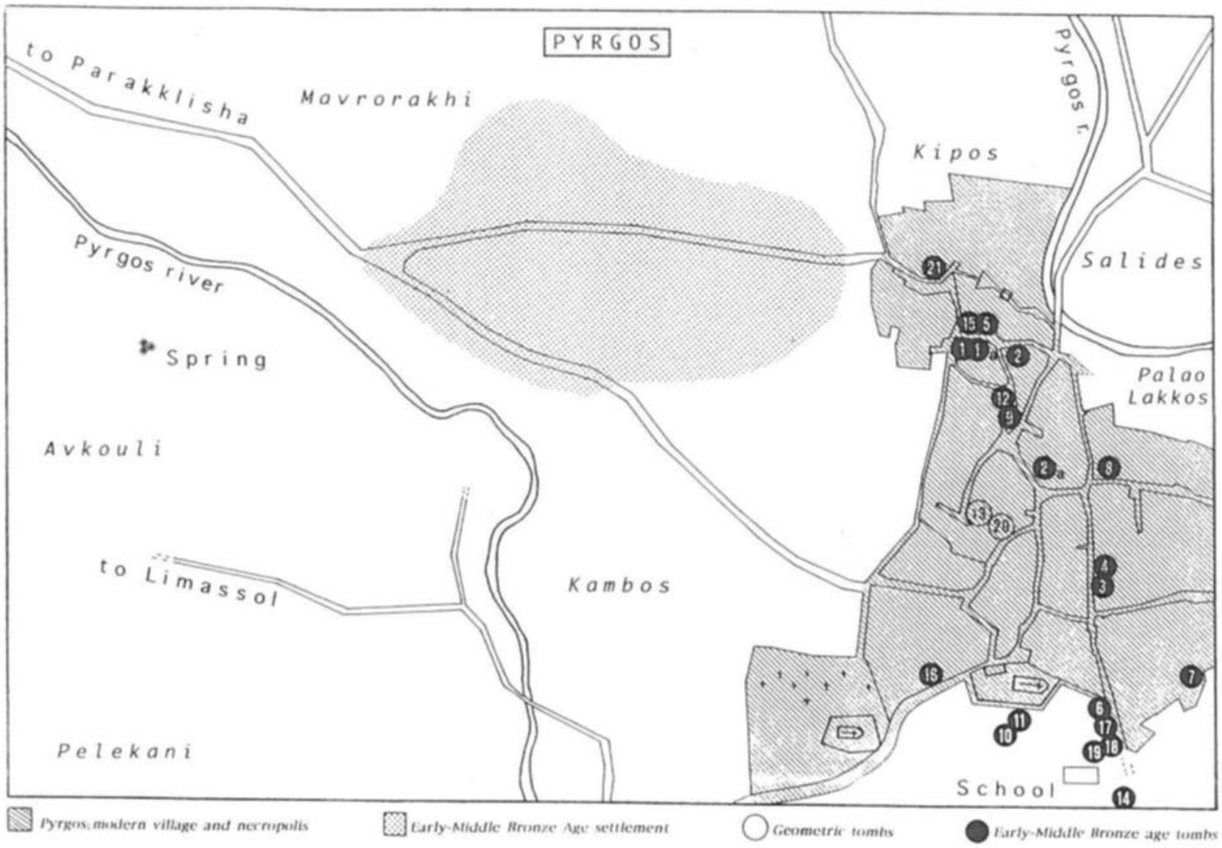


Figure 3.2 Archaeological investigation area on the hill of Mavroraki (Belgiorno 1996, p.194)

In 1996 and 1997, the fieldwork involved the enlargement of the most interesting soundings, while 1998 saw the start of more systematic excavations, which initially unearthed a large portion of a prehistoric courtyard with traces of metallurgical activity (fig. 3.3).

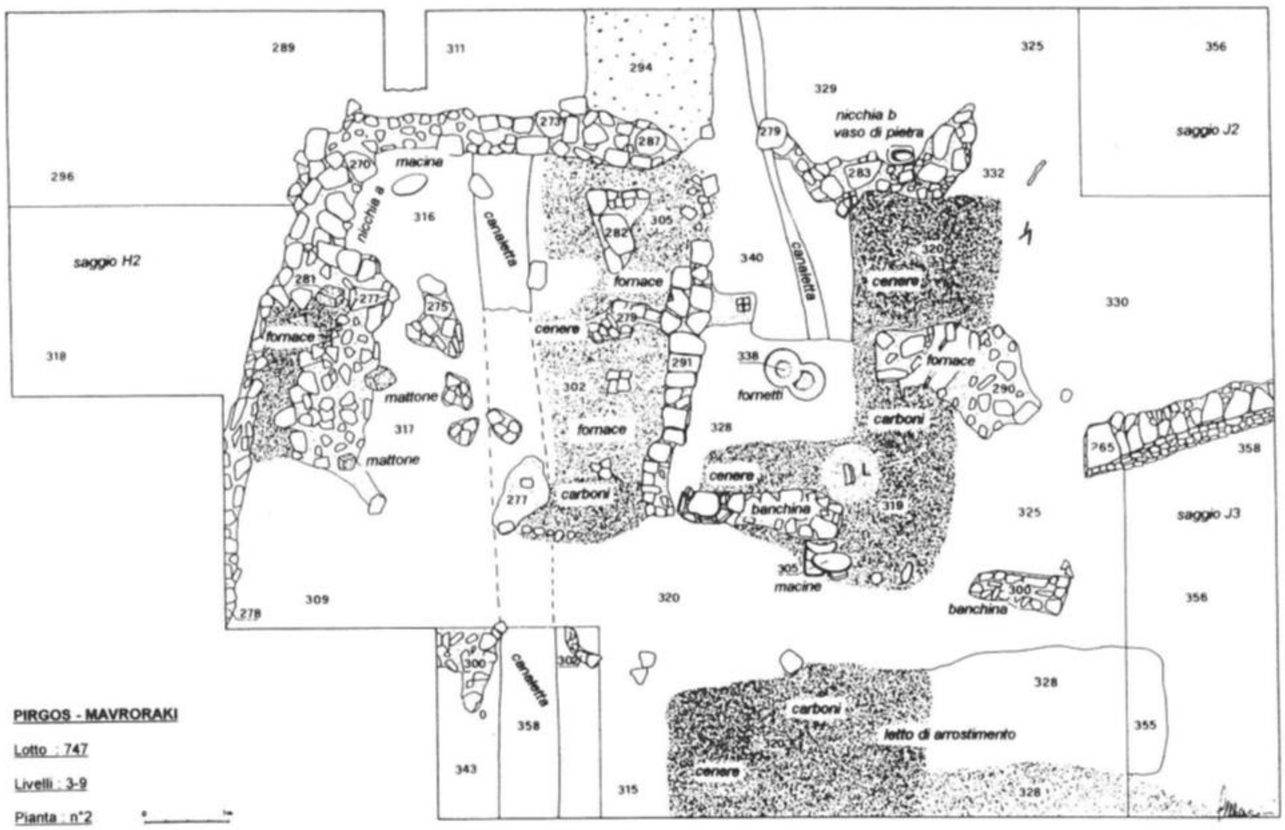


Figure 3.3 Northern Sector - 1998 Archaeological Campaign at Pyrgos-Mavroraki (from Belgiorno 1998, p. 297, fig. 1).

In 2000, the excavation was extended to the South, identifying the remains of the foundations pertaining to a rectangular building (15x13 m) with 70-80 cm thick walls. The excavation continued in 2001/2002 towards the south unearthing a large collapsed wall, still *in situ*, which showed that the building technique in Pyrgos consisted of the creation of a raw mud-brick level, overlying on a double stone foundation (basalt on the bottom and calcarenite on the top: fig. 3.4). In 2002, ITABC-CNR performed geophysical prospections on the site. This showed that the architectural complex extended across an area of ca. 3000 m^2.

Figure 3.4 Pyrgos foundations with limestone levels overlaying on a double level of basalt blocks (picture by the author).

The simultaneous collapse of the walls in this building has been interpreted as the result of a prehistoric earthquake. Under the collapsed wall, a structure interpreted as an olive press has been discovered (Belgiorno 2009: 50-54). On the Western side of the “press room”, the excavation brought to light a feature interpreted as a “forge” (Belgiorno 2009, p. 54), a structure that is usually found in connection with ironwork, but in this case needs to be associated with the processing of copper-based artefacts, possibly through annealing and reworking.

In 2003, in the area of the olive press, the excavator brought to light a series of 14 pits. Each pit contained small jugs covered in ash remains, which have been interpreted as functional to producing fragrances through maceration (Belgiorno 2007).

During 2004 and 2005, the excavation focused on the area to the east of the “press room”, uncovering an area possibly dedicated to textile production, as it seems to be suggested by the recovery of many loom weights and basins, alleged to be used to dye fabrics (Belgiorno 2009: 66-76).

The subsequent campaigns were dedicated to completing the excavation of the Northern and Southern Sectors, focusing on the possible metallurgical features.

The last discovery of consequence was made in 2008, when the excavators found a triangular building interpreted as a possible shrine (Fig. 3.5, Belgiorno 2009: 87-97). The excavator suggested a ritual purpose for this last unusual building, basing her hypothesis on exceptional finds such as a possible "altar", a channel lined by 25 basalt *basoli* (paving stones) and covered in white calcareous plaster, and 4 limestone "horns" (Belgiorno 2009, pp. 87-97).

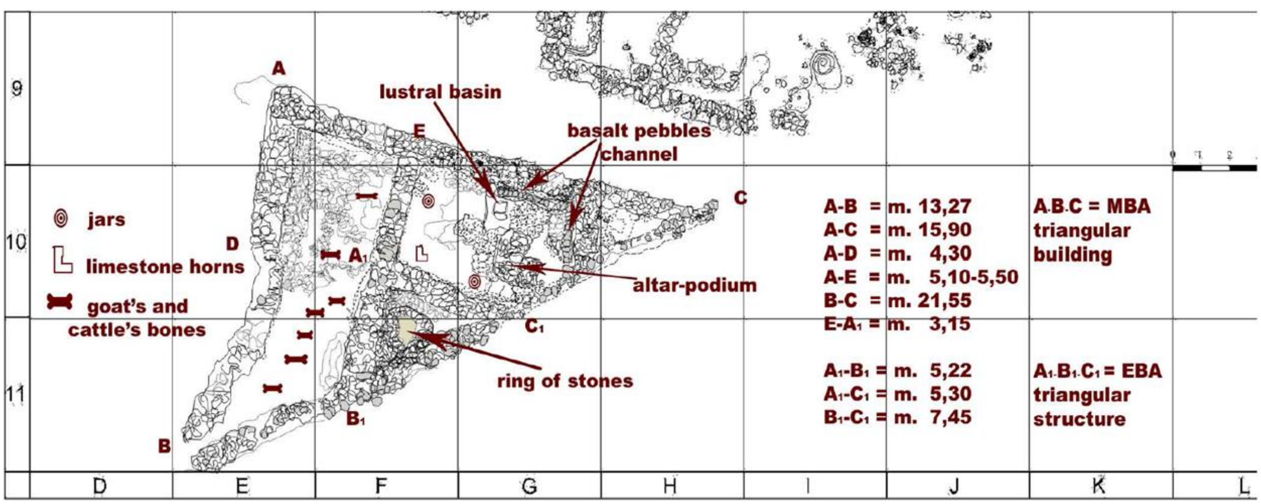


Figure 3.5 Plan of the "triangular building" (Belgiorno 2008, p. 1)

The Italian Archaeological Mission at Pyrgos-*Mavroraki* ceased the fieldwork 2012. It is currently working on the assessment and analysis of the small finds, which should provide the final data for the general publication of the site.

3.3 The prehistoric settlement of Pyrgos-*Mavroraki*

The origin of the word Pyrgos in ancient Cypriot has been usually associated to the word "Tower", and a Latin version *Peregus* is attested in ancient documents dated to the 1200 AD (Shabel 2000; Belgiorno 2002: 2). The toponym *Mavroraki* refers to a low hill on the West side of the village of Pyrgos, and means literally "Black Hill", due maybe to the lost memory of the prehistoric metallurgical activity carried out on the site and the dark, vitreous slags, which can still be found today.

The geological map of this area[2] (Morel 1964) shows that Pyrgos lies on the ophiolitic complex, which characterizes the foothills of the Troodos Mountains. So-called pillow-lava rocks, which are the main component of this complex, host the most abundant deposits of copper and iron ores on the island (olivine, pyroxene, malachite, chrysocolla, gabbro). This geology certainly provides an ideal environment for a metallurgical settlement.

The site of Pyrgos is located on the road to Parreklisha, and the excavation was carried out in the parcels 1640 and 1773 (parcels 1625 and 1627 belong to the excavation area but were not investigated yet) of the Pyrgos' cadastral map (Belgiorno 1999b: 74).

---

[2] See Ch. 2, Fig. 2.6.

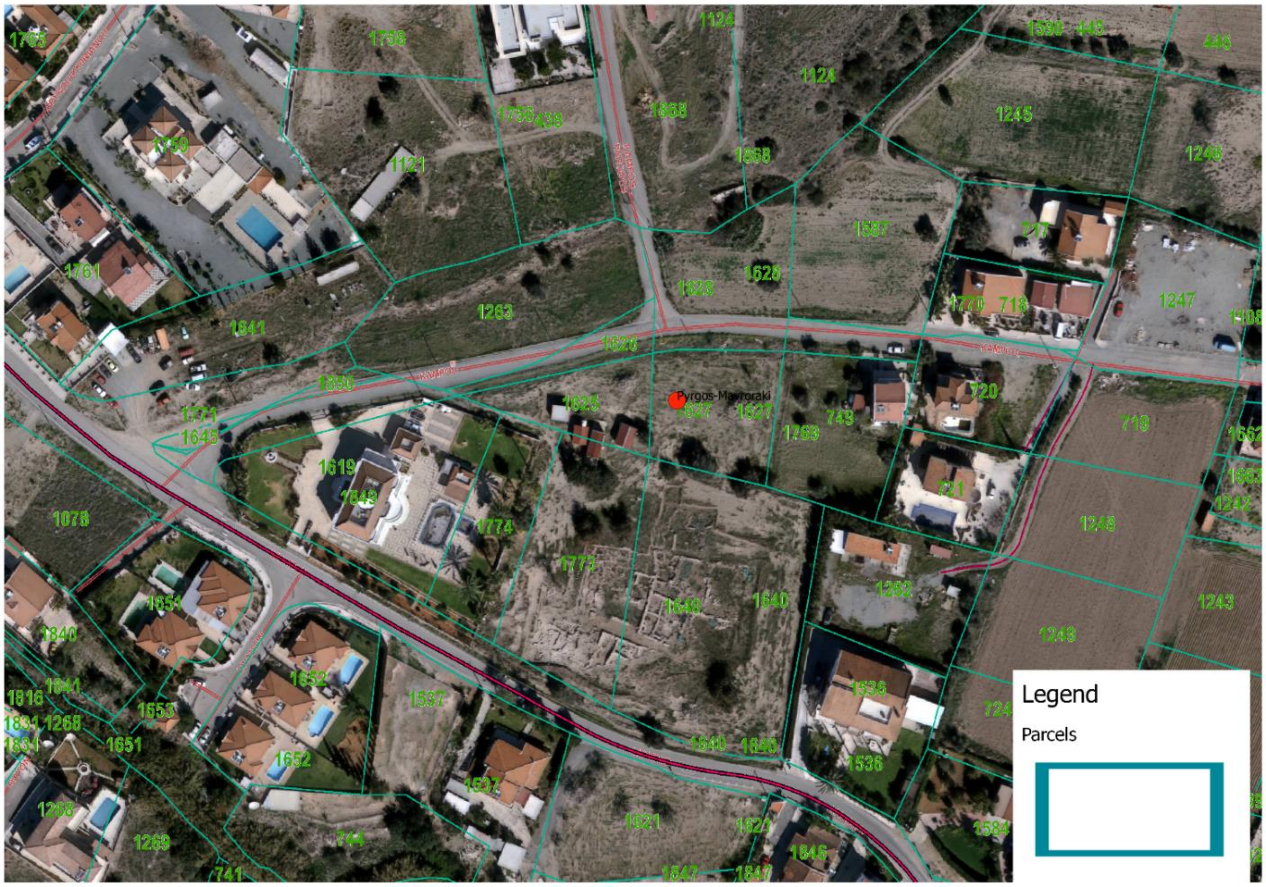


Figure 3.6 Pyrgos-Mavroraki, parcels from the cadastral map (©Survey Department of Cyprus)

The archaeological site appears as a vast architectural complex (2000 m² ca), characterized by several buildings and rooms whose stone foundations are still visible on the ground surface. It represents probably the workshop area of a much bigger settlement (as the geophysical prospections have shown: Gabrielli et al 2004; Belgiorno *et al.* forthcoming). The site's map (fig. 3.7) has been divided by the excavators in a grid, orientated on a North-South axis, formed by squares measuring 5x5 m, each one respectively divided in 4 quarters: a, b, c, d to be read from left to right (Belgiorno 2009: 40).

Figure 3.7 Map of Pyrgos-Mavroraki (Belgiorno 2017, p. 13, Fig. 9).

The excavations in the southern area of the site unearthed the remains of a large prehistoric road, which crosses the settlement in direction of Parreklisha. The presence of a well recognisable road suggests the importance of the site and its role in the region's economy since the Early Bronze Age.

Among the structures excavated, Belgiorno identified several workshops, including what has been interpreted as an olive press (2009: 49-54), an area dedicated to textile production (2009: 66-78), a jewellery workshop (Belgiorno & Romeo Pitone 2016: 388-391), and a perfume workshop (Belgiorno 2009: 55-57). Apart from human consumption, olive oil could have been used in textile production for softening the wool during carding, spinning and weaving (Belgiorno 2008); it can also be used in the production of perfumes and cosmetics (Belgiorno 2017).

The site is characterized by a shallow stratification within which it has been possible to recognise, underneath the surface level (level 1), two levels pertaining to the Archaic period abandonment of the site, where different types of pottery have been found mixed together. According to the author, evidence for the following periods (Early and Middle Bronze Age) is well represented by Level 4 and the sequent ones[3].

The first phase of the site seems to date back to the end of Philia Facies (ca. 2200 BCE) (Calderoni 2009: 190; see Table 3.1).

Building foundations pertaining to the Philia Facies have been found in the Northern courtyard, underneath the perimeter wall which divides the area of textiles from the Press Room, on the floor of the same room, along the external western perimeter of the Western Sector, within the foundations of the southern wall of the metallurgical area in the Southern Sector and in the area to the West of the structures beyond the “road” (Belgiorno 2009: 98).

The main axial walls East-West and North-South have been recognised as pertaining to the first phase of the workshop complex. The Press Room and the large rooms which characterise the Eastern and Southern sectors belong to this phase and their architectural system is based on a double level of foundations with basalt blocks on the lower portion of it, surmounted by limestone blocks.

The excavators recognised a second phase of the remodelling of some parts of the building. In the Press Room, the northern portion of the East wall, the relining in mudbricks of the southern

[3] As the monography of the site has not been published yet, the information about the stratigraphic context is due to a personal communication of the excavator Dr. M.R. Belgiorno.

portion of the West wall and the dividing partition in the Western Sector (Pithoi Room) belong to this phase. Some restorations were already carried out in prehistory in the area interpreted as a textiles-workshop, with the creation of a support wall for the loom and the "dyeing basins". At the same moment, the large room of the Southern Sector was completely reshaped through the creation of two smaller rooms on the west side, both communicating with the remaining larger area of the sector. The chronology of this phase is subsequent to the previous but still in the frame of MBA I.

A third phase of restoration, testified to by some new foundations superimposed on the previous ones, has been recognized in several areas of the site. It is in this phase that the large room of the Southern Sector has been modified in order to create an open courtyard (Belgiorno 2009: 99).

It has been possible to draw more reliable hypotheses about the abandonment of the site through radiocarbon dating (see Table 2), which dates it to 1900-1850 BC.

Samples' context[4]	Lab identifier	Conventional ^{14}C age (yr BP)	I Overall calibrated range (yr BC)[5]	II Overall calibrated range (yr calBC)[6]
From Furnace in I5-L7.	Rome-1489	3705 ± 55	2195 - 1980	2249 - 1943
From the giant pithos in H7.	Rome-1490	3640 ± 55	2125 - 1920	2171 - 1883
From J6-L3 (-19cm)	Rome-1500	3680 ± 50	2140 - 1980	1931
From K7, door-pit	Rome-1501	3620 ± 50	2110 - 1890	1878 - 1829
From J6-L3, section West (-10cm)	Rome-1502	3570 ± 50	2010 - 1780	2105 - 1755
From H/I5-L6	Rome-1503	3765 ± 55	2280 - 2050	2422 - 1985
From H5-L6	Rome-1504	3600 ± 55	2100 - 1830	1754

[4] The description of the samples' contexts (quite general) are reported here according to the ones submitted by Belgiorno to Calderoni (2009: 190).

[5] Calibration performed with the data set after Stuiver et al. (1998).

[6] Calibration performed with OxCal v4.3.2 Bronk Ramsey (2017); IntCal13 atmospheric curve (Reimer et al 2013).

From H6	Rome-1537	3720 ± 55	2200 - 1985	1960
From K7b-L4 (Philia spindle-whorl)	Rome-1538	4005 ± 130	2845 - 2345	2199 - 2153
From H7-L4	Rome-1539	5170 ± 200	4230 - 3710	4416 - 3536

Table 3.1 Conventional and calibrated radiocarbon ages (± 1σ) for Pyrgos-Mavroraki (adapted from Calderoni 2009: 190)

The sudden abandonment, as testified to by several artefacts found in situ in the habitation levels, probably occurred due to a violent earthquake, whose traces are still clearly evident in the archaeological record (fig. 3.8) (Belgiorno 2004: 21; Belgiorno 2009: 37-38). The structural differences in the use of the raw materials towards the building of the walls' foundations also confirms the two main occupations phases of the site. The first foundations do not exceed 40 cm of thickness and were built mixing limestone and basalt medium-size stones. The Middle Bronze Age foundations, on the other hand, reach 60 cm in thickness and, in contrast to the previous structures, two layers of calcarenite/limestone slabs lay on one or two layers of large basalt stones (Belgiorno et al *forthcoming*, p. 4).

Figure 3.8 Wall Collapsed in the western room of the Triangular Building (pictures by ©Antonio De Strobel)

Unfortunately, the excavation's diaries and the entirety of data collected (so-called "grey literature") during the archaeological missions at Pyrgos-*Mavroraki* by the excavator and her team, were not made available to the writer from the excavator in due course of the present research, therefore the documentation which informed part of this work is only partial, due mostly to the study season which is officially in progress since 2012. For this reason, it has been particularly difficult to reconstruct in detail the original contexts, and so the main part of this research will be based on the material kept in Limassol District Archaeological Museum, which has been made available for study by Dr Belgiorno, of the Institute of Technologies Applied to

Cultural Heritage – National Research Council of Italy (Rome). The accurate chemical analyses carried out on both the archaeological (see Ch. 4 and 5) and the experimental material produced during this project (see Ch. 6) will provide the data necessary to draw hypotheses and interpretations around Pyrgos' metallurgy.

3.3.1 Northern Sector

In 1998, enlarging one of the trial trenches dug in plot n. 1266 of the Pyrgos' Cadastral Map (Belgiorno 1999b: 74-78), the systematic excavation started to reveal a large portion of a courtyard, found in connection with the remains of older structures.

The first Early-Middle Bronze Age layer (level IV) was found at a depth of 90 cm, but partially compromised by the later Archaic layer (level III).

The squares opened in plot 1266 (I-H/1-2) are crossed by some wall bases, forming a quadrangular courtyard with an earthen floor, some sort of channels and a highly carbonaceous stratification, rich in sherds, ground minerals and copper slags (Belgiorno 1997a: 283).

In squares H-I-J/2-3, among the functional adaptation of some walls pertaining to a previous room, four roughly circular structures were identified built in stone blocks and mudbricks. According to the excavator, all four structures were characterised by the same carbonaceous stratification rich in "roasted minerals", slags, chipped-stone blades, ground stone tools and some E-MBA sherds, and so interpreted as furnaces (Belgiorno 1999b: 75-76; Belgiorno 2000: 8-10).

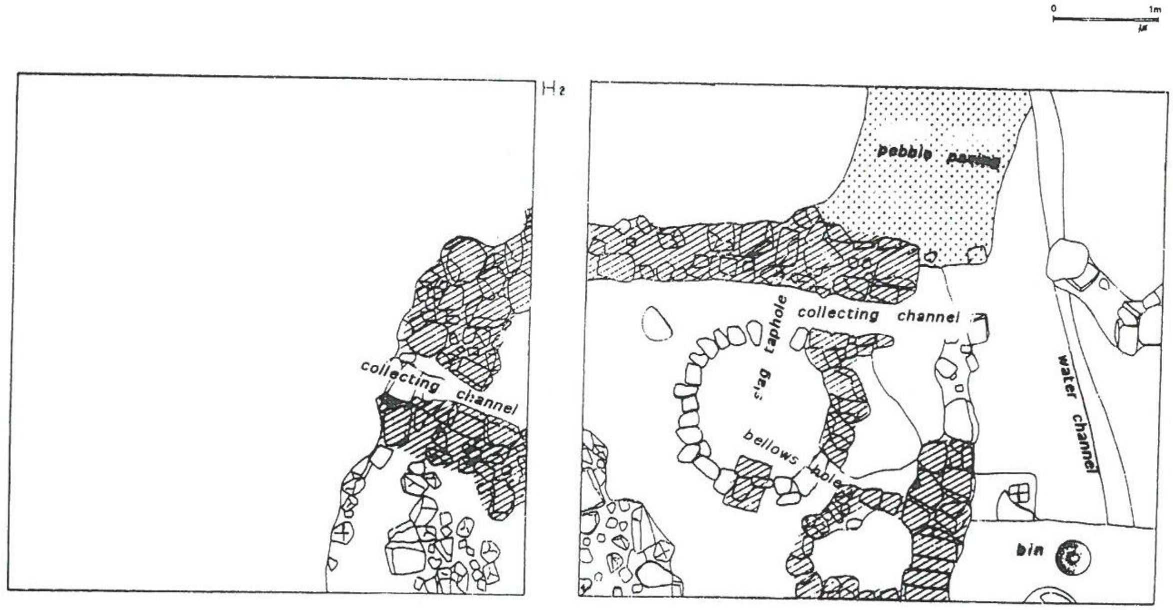


Figure 3.9 Pyrgos-Mavroraki. Plot 1266, Squares H-I2, levels 5-7. Copper smelting installation with furnace setting (from Belgiorno 1999b: 75, fig. 2)

Furnaces 1 and 2 were found South leaning against the Eastern wall of the room (fig. 3.9). The excavator noticed that both furnaces showed traces of demolishing and rebuilding (Belgiorno 2000: 8). Furnace 3 was found between H-2/3 against the Western wall and the pottery found in this context date it to the end of the MBA II.

The fourth structure, the largest one with a diameter of about 1 m, was found outside of the open court, partly built with mudbricks, not easily datable because of the absence of dating pottery, if not sherds from the abandonment level dating to MBA III.

According to the excavator, the context seems to suggest that furnaces 2 and 3 were air-supplied with a collecting channel obtained with additional small walls. The traces of what the excavator interpreted as three possible pipes in perishable material were recovered in the hard stratification of the mud, but the lack of accurate plans of these interesting features makes their interpretation difficult to discuss any further in this instance.

What looks like part of a water channel was found, full of sand, along the Eastern wall of I/2, running diagonally from North to South, passing under the remains of a wall and descending under a low bench obtained in North-East corner. Part of a stone-pebbled floor (possibly in connection with the installation found in H/1, see fig. 3.10) was found outside the North wall, towards the water channel (40 cm below).

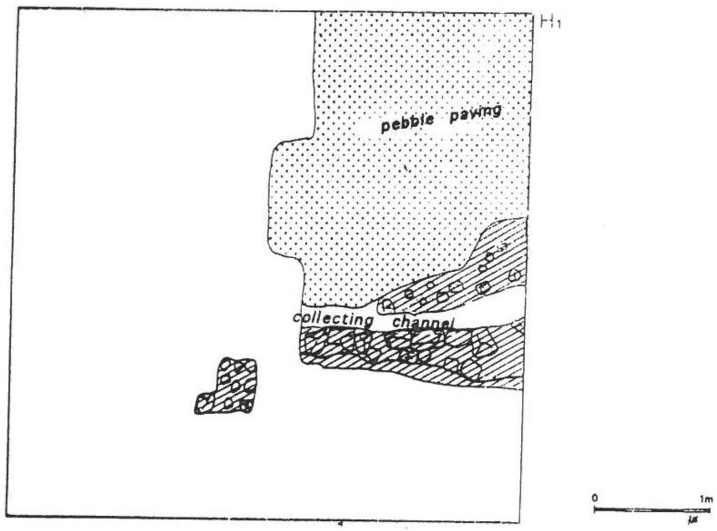


Figure 3.10 H1, stone-pebbled floor (by Belgiorno 1999b: 75, fig. 2).

The Western wall of the Northern Sector's main structure (room 1) was found in H/2, interrupted by another collecting channel, where pottery sherds, flints, stone tools, slags and ores were recovered.

In 1999 the major discoveries were in the Southern portion of the Sector, beyond an area characterized by a thick carbonaceous stratification found in 1998, identified by Belgiorno (1999c: 296) as possible roasting-beds for the preliminary desulphurisation of chalcopyrite (fig. 3.11).

Figure 3.11 Northern Sector. Structures and carbonaceous levels (by Belgiorno 2009: 79, fig. 33)

In 2004 the excavation of the metallurgical structures in the Northern Sector was completed. The excavation confirmed that the rectangular courtyard, which occupies the largest portion of the sector, was open on the southern side. Other fragmentary structures, defined as benches, were identified in I3b and J2c, surrounded by the usual large number of stone tools (mortars, pestles, reused axes).

In J4b a particular stone-built structure, interpreted as a different type of furnace, was found. Its tronco-conical shape measures 50 cm circa in height and it has an internal diameter of ca. 35 cm. Similarly to the walls' foundations already testified at Pyrgos-*Mavroraki*, its base was built using massive basalt blocks, smoothened by the action of the water while transported to valley from the mountains (very common in this area) and overlaid with an upper level of calcarenite slabs (fig. 3.12). The structure has been recovered full of a thick level of ashes and burnt soil (Belgiorno 2009: 79).

Structures with a similar shape were found in other coeval Cypriot sites such Erimi-*Laonin Tou Porakou* (Bombardieri 2017: 18, 34-37, 41) and Marki-*Alonia* (Frankel and Webb 1996: 60; pl. 11, fig.a). Usually defined as “emplacement”, this type of structure is usually slightly smaller than the one found in Pyrgos (except for the case of Marki, where, however, this type of structure, in contrast to Pyrgos, is usually built against a wall) and it is usually interpreted as a support for *pithoi* (large storage vases). Despite the fact that Pyrgos’ *pithoi* are generally larger than those found at coeval sites (the bigger one is 120cm in height, Belgiorno 2009: 53) and so probably would have necessitated larger props, the thick level of ashes and burnt soil found inside the structure points to a possible interpretation as the base of a shaft furnace, sustaining an upper mud-brick cylindrical structure which would have enabled the chimney effect, getting air from a possible frontal opening and letting it pass through the entire structure (fig. 3.12).

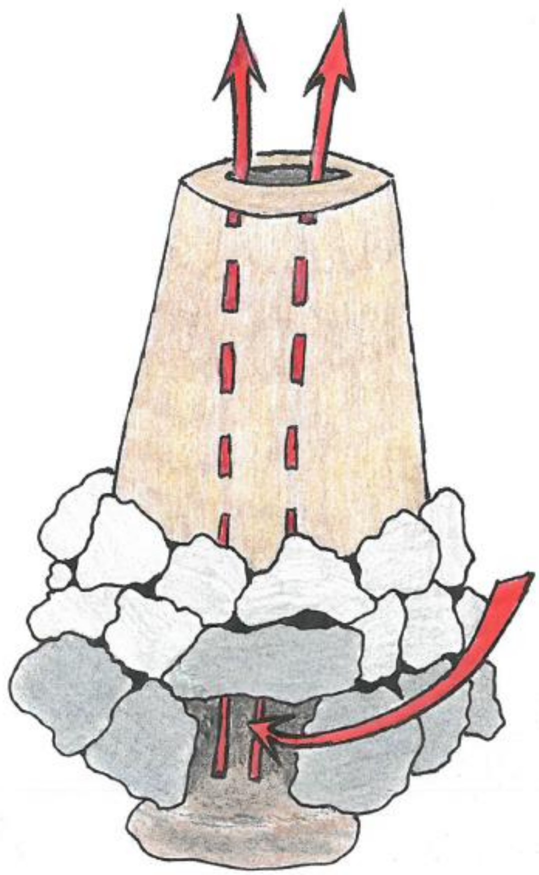


Figure 3.121 On the left: Northern Sector, J4, base of a possible shaft furnace (picture by the author). On the right: reconstruction of the possible original shape for the shaft-furnace found in J4 (Romeo Pitone 2018: fig. 4).

As already mentioned, the excavator did not provide the entirety of the unpublished data from the site, such as plans and excavation's plans, therefore, the descriptions of the context mentioned above are based on preliminarily published reports only, which, unfortunately, does not always allow a full evaluation of the contexts. No size was given for the first three furnaces found in the Northern Sector and the author was not able to see any accurate plan of them, although, according to the excavator's descriptions, furnaces 1, 2 and 3 seem to belong to the "shaft-furnace" category.

The fourth structure was also interpreted by the excavator as a large shaft furnace employed to produce copper through the slag-tapping-technique[7], but its 1m diameter and the fact that its plan was for the most part a graphic reconstruction suggested by the excavator (see fig. 3.9), make its interpretation as a metallurgical furnace problematic. The large diameter of this structure would have required a very tall mudbrick superstructure, which finds no contemporary comparisons. Moreover, no tapping-slags have been recognised in Pyrgos yet to confirm the smelting technique used in relation to this type of furnace.

Belgiorno, in a later publication (2009: 78-80) does not mention the large shaft furnaces, but points to the existence of a series of superimposed furnaces built along the foundations of the three walls of the Northern Sector, which from the pictures (Belgiorno: 80) look more like pit-furnaces. Because of the confused state of the information about the structures interpreted as shaft-furnaces in the Northern Sector, the author will not consider them in his experimental protocol to test Pyrgos' metallurgical technological process.

3.3.2 The Press Room and the production of olive oil

---

[7] The slag formed in the shaft-furnace would have been tapped out from the combustion chamber through a hole created in the furnace's wall. The slag would have been collected in a bowl-shaped basin just outside the furnace, leaving in the bottom of the combustion chamber a plano-convex ingot of copper which would have been then re-melted and casted in an ingot.

Between 2000 and 2001, after the removal of the debris originated by the collapse of the southern wall's, a large room came to light. This was found perpendicularly divided in two distinct spaces by a 7 m long bench, 60 cm high on the floor level (oriented South/North) which hosted a sort of channel. The southern extremity of the bench was 3.5 m distant from the southern wall of the room, built, differently from the other walls, entirely in stone blocks and not mud-bricks, an anomaly that suggests a specific function of this wall which clearly needed to be reinforced and to be more stable than the others. In the gap between the channel and the southern wall, the excavator recognised the traces of a possible wooden structure, built to reinforce the installation. The unusual building technique used to build the southern wall, together with the elements listed below, led the excavator to interpret this structure as an olive oil press (Belgiorno 2009: 50-53).

Figure 3.13 Lever press as depicted on an Attic Skyphos, about 520-510 B.C. (Photograph © Museum of Fine Arts, Boston)

The long bench would have hosted a wooden pole used as a lever to press the olive oil from the paste obtained by crushing the olives with the many stone mortars and grinders found in the room. This type of installation, and the pressing technique used with it, are well exemplified on a black-figured Attic skyphos dating to the 6th century BC (fig. 3.13; Hadjisavvas 1992: 21. Fig. 35).

At the other side of the “press-bench”, weightstones were found which could have been used to lower the press. On the Est of the same bench was found a large calcarenite slab, accurately polished on its top surface, roughly 80x80 cm in size, with a small circular/hemispherical groove, 6 cm in diameter, which could have hosted a wooden pole upon which to pile the circular baskets containing the pulp of the crushed olives to be pressed.

Similar installations, testified by large flat press-beds in stone, have been individuated in later Cypriot sites (Hadjisavvas 1992: 21-40).

3.3.3 Southern Sector

Another large courtyard (15 x 13 m), modified subsequently to obtain two additional small rooms in its western area, occupies the squares J-I-H/7-8-9. After this modification, in the main area of the courtyard, a sort of artificial heap of limestone-rich soil was artificially obtained in the centre of it, bordered to the north and south by stone-built benches.

The northern bench, 90 cm thick and 30 cm high at floor level, was used as a sort of rear support for a series of pit furnaces, found one superimposed on another and leaning against the bench.

On the opposite side, in front of the southern bench, a series of pit furnaces for crucibles was found dug into the artificial limestone-rich soil heap, each one found covered with a stone-slab, interpreted by the excavator as a sort of lid (fig. 3.13).

Figure 3.14 Pit furnaces in the Southern Sector (picture ©by Antonio De Strobel).

These furnaces never exceed the internal diameter of 20 cm and the depth of 30 cm. The thickness of the ring-shaped wall, made by mudbricks, is usually between 7 and 10 cm. Reading these structures is made more difficult by the fact that one structure was often built in the same location as a previous one, obliterating it.

The connection made between these furnaces and the casting process has been formulated due to the discovery of the vast majority of Pyrgos's crucible fragments in this same area (Belgiorno 2017: 23, fig. 18). In two cases, buried inside the mudbrick ring around the pit, a small jug has been recovered, heavily marked by high temperatures, with its spout facing the "combustion chamber" and its belly broken towards the upper surface of the earth-ring (Fig. 3.15)

Figure 3.15 Pit-furnace found in I9a with the small "jug-carburettor" (picture from ©Antonio De Strobel)

This artefact has been interpreted as a sort of "carburettor" used to drop olive oil into the furnace as a fuel, after it had been started with some wood kindling or charcoal. Olive oil has a high calorific power (9996 kcal/kg, 42 MJ/kg) and could have been used to reach high temperatures sooner (Belgiorno 2009: 83).

In this area almost 2000 slags were found, as well as pottery nozzles (with stone nozzle-holders), moulds and a vast amount of stone tools such as grinders, mortars, pestles, hammers and anvils (Belgiorno 2009: 78-87). The use of ceramic-nozzles is well explained by the recovery of one of them still inserted in its stone holder, facing a pit-furnace in J8 (Fig.3.16).

Figure 3.16 Clay-nozzle inserted in a stone-holder facing towards a pit-furnace in J8 (from Belgiorno 2009: 84, fig. 46).

3.3.4 Eastern Sector

The Eastern Sector, beyond the eastern wall of the Press Room, is characterized by a series of particular structures which can be interpreted as part of a coppersmith workshop.

The workshop occupies a vast area (6 x 12 m), and just the Western and Southern walls are today recognisable.

A structure constructed with large stone slabs was found lining on the Western wall (in K8c) and was interpreted by the excavator as a forge. The term forge belongs usually to iron-metallurgy and it is used to reheat the bloom or the unfinished objects to facilitate the hammering. In this case, this structure might have been used in the last annealing steps of the objects refining, to harden blades for example. Copper re-crystallises at 120°C, so a simple fireplace, in this case well delimitate by a permanent stone-built structure, would have been effective. The squared-shaped structure occupies an area of approximately 50x50 cm^2, with a rim 20 cm high, made of pressed-earth, straw and plaster. This was protected in a sort of niche built on the eastern side with massive stone-slabs (40 cm ca. in height) found *in situ* held together with earth as mortar (Fig. 3.17). Both on the base of the furnace and on the vertical slabs are well recognisable the traces of the high temperatures, confirming its pyro-technological use.

Figure 3.17 The "forge" in K6 (pictures by the author)

A rectangular double-chambered structure (Ft 4) was found in the coeval site of Erimi-*Laonin Tou Poraku* and interpreted as a hearth (Bombardieri 2017: 38, Fig. 3.30), but no trace of metallurgical activity or very high temperature were found in connection to it. Beside the forge, a rich stone toolkit was found, including axes, hammers, grey basalt anvils (Fig. 3.18), all surrounded by a significant amount of discard, slags and two bronze needles (inventory numbers: 164, 165). A similar structure has been found in the eastern extremity of the excavated area of the Sector, in M5.

Figure 3.18 The Coppersmith workshop (pictures by ©Antonio De Strobel).

3.3.5 The soundings on *Mavroraki*

The surveys organised between 1996 and 2001 to explore the surroundings of the site demonstrated that the Early/Middle Bronze Age site extended along the Pyrgos river for 700 m, including the localities of *Kolla*, *Perivolia* and *Mavroraki*. Remains of dwellings, domestic stone-tools such as grinders, mortars and pestles found in connection with Early/Middle Bronze Age pottery were found on the fluvial terrace on the southern riverside opposite to Pyrgos's settlement, in the locality of *Aulaki* (Belgiorno 2009: 46). From this area, also, 14 slags were collected.

In 2010, a team from the University of Chieti, Italy, carried out a preliminary topographical study and geo-archaeological prospections on a series of cadastral parcels in the territory of Pyrgos. The study merged a series of different sources and data such as cadastral maps, topographic maps high-definition satellite images, altimetry and topographic data obtained from the Differential GPS and radar data towards the creation of an accurate GIS. The non-invasive geo-archaeological prospection was carried out combining geo-radar, magnetometer/gradiometer and georesistivimeter.

The analysis highlighted a series of anomalies, which led to the excavation of two different soundings in plot 1263: respectively squares AW 94 and AX 93 on the excavation grid established for Pyrgos-*Mavroraki*, beyond the road which borders the northern limit of the excavation area (fig.3.19).

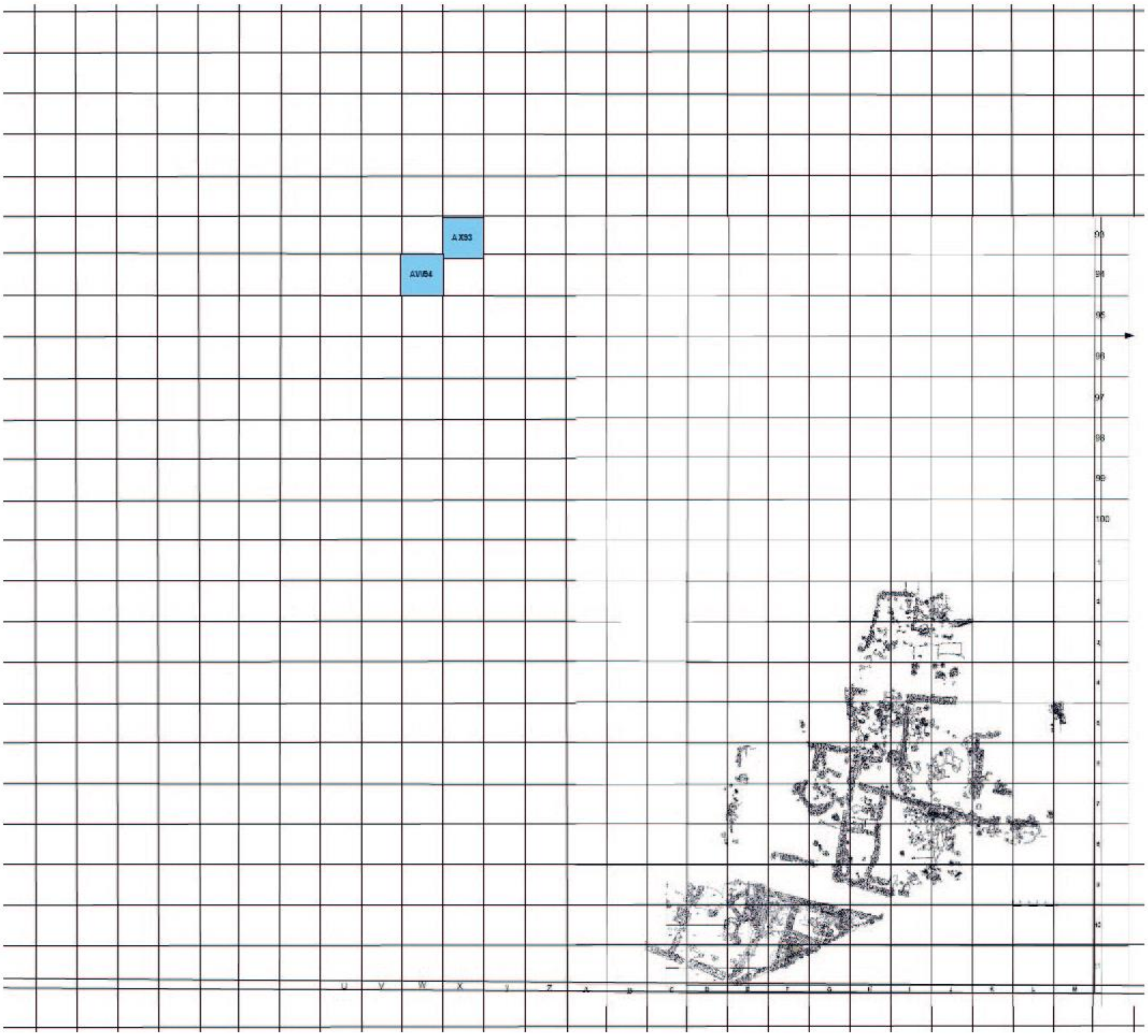


Figure 3.19 Soundings on Mavroraki's hill (Belgiorno et al. forthcoming)

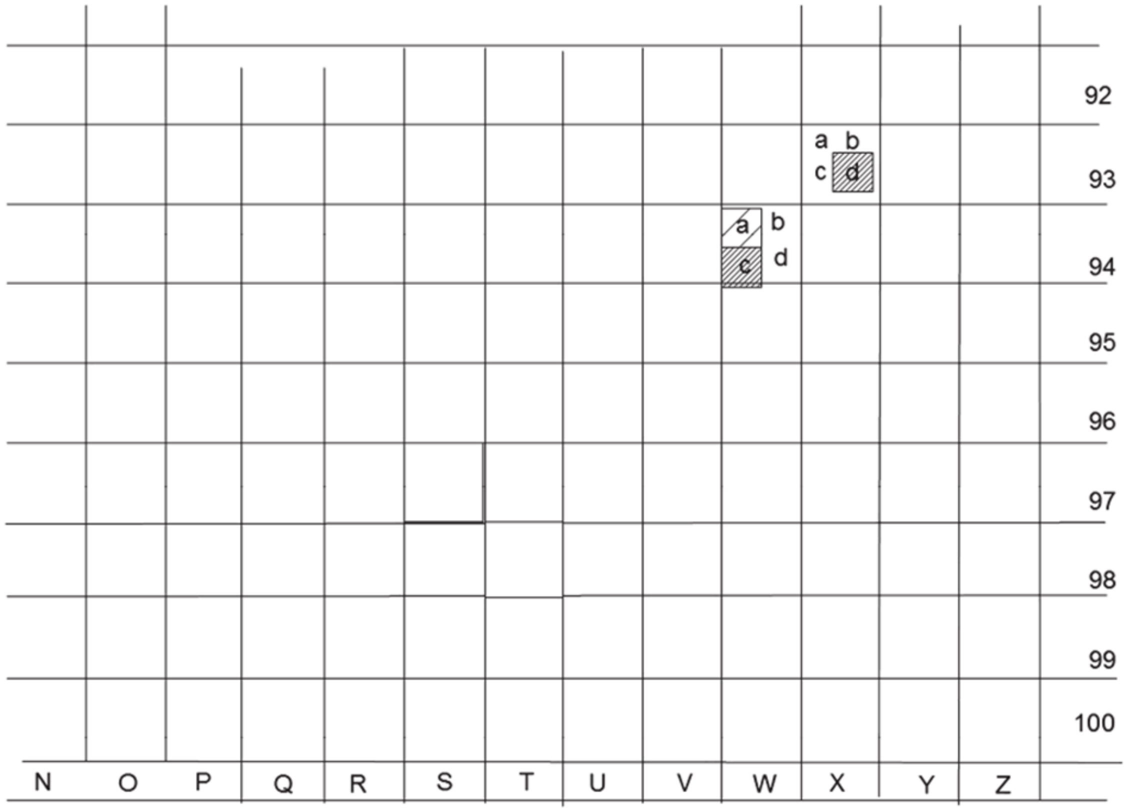


Figure 3.20 Soundings on Mavroraki's hill (Belgiorno et al. forthcoming)

AW/94 (2.50 x 3.75 x 1 m depth) intercepted, under a level of only 35 cm of soil, the top surface of the bedrock (mainly basaltic rocks). This was found forming a sort of step in the sub-square "*a*" (fig. 3.20). In the sub-square "c", after a compact layer of earth, interpreted as a collapsed mudbrick wall, the remains of an Early/Middle Bronze Age workshop were found, testified by a mortar dug into the basalt floor (covered with a 10 cm thick lime plaster), stone-tools such as querns, grinders, basalt pestles and a possible anvil, two fragments of moulds and 11 slag fragments (218 g).

The excavator noted that "remains of metal minerals inside the marks" (Belgiorno et al forthcoming: 14) were observed under the microscope on the top smooth surface of the anvil from this context (inventory number 77.AW94a-c), but no further details were provided.

The pottery found in relation with this context dates it to the beginning of the Bronze Age, with no evidence of Red Polished IV, the type of pottery which dates the abandonment of Pyrgos-*Mavroraki* in the Middle Bronze Age II.

The second sounding, dug in square AX/93 (2.50 x 2.50 x 1 m depth), intercepted the remains of the stone foundations of a collapsed wall (fig. 3.21).

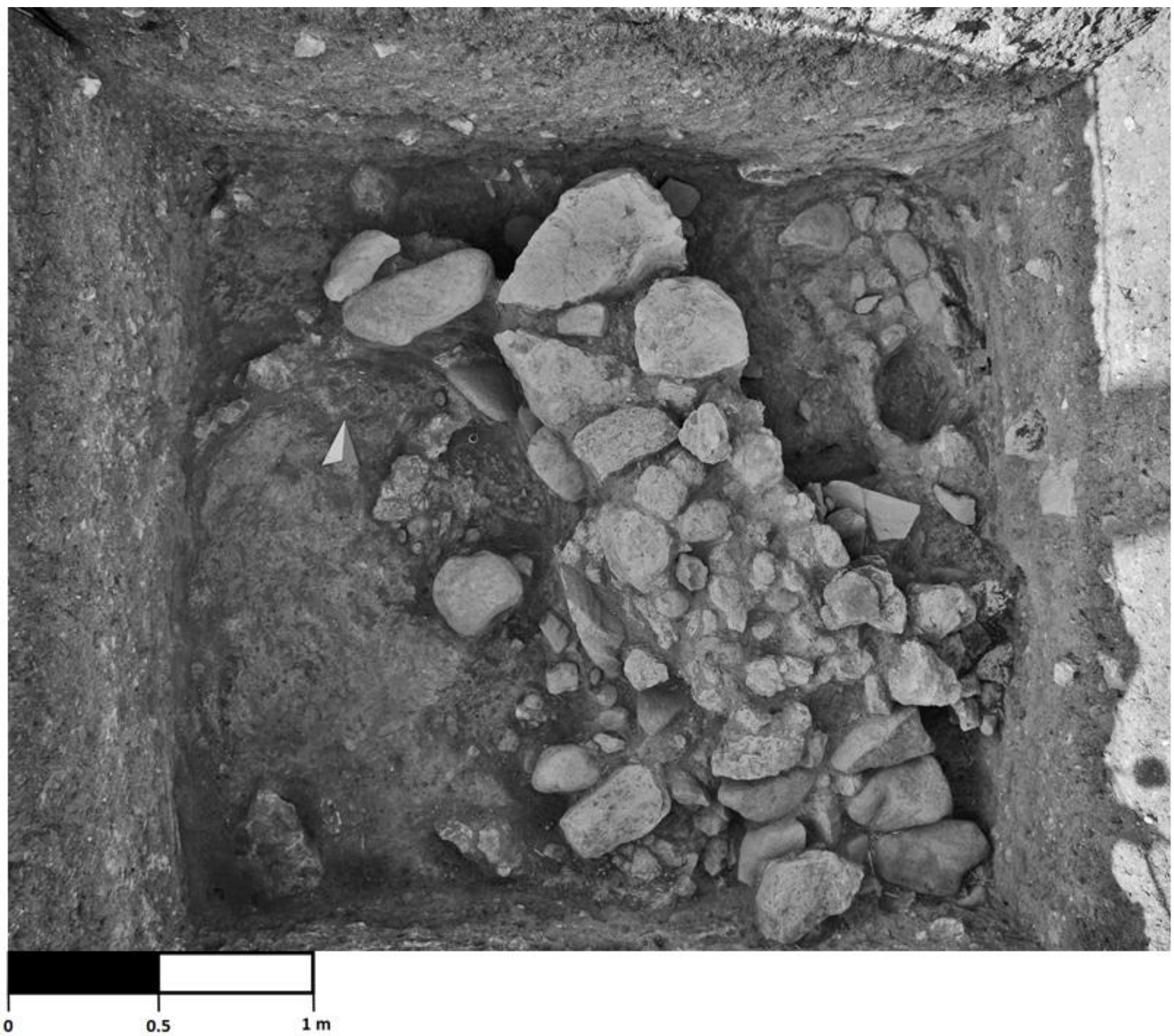


Figure 3.21 Sounding AX 93 (from Belgiorno et al forthcoming: 360, fig.22)

The bedrock was found just beneath the foundations, at 1 m of depth from the surface. The building technique adopted for this wall is directly comparable with the main site of Pyrgos, consisting of two parallel lines of large basalt blocks with two superimposed layers of calcarenite slabs, superficially partly disassembled, probably due to the abandonment of the site. Two fragmentary jugs, dating to the Early Bronze Age III – Middle Bronze Age I, were recovered at the top of the stonewall foundations. The excavator explains their position suggesting that these almost complete vases rolled over the foundations of the wall after the collapse of its mudbricks portion due to the abandonment of the structure (Belgiorno et al forthcoming: 11). An andesite quern was found in the sub-square “d” of AX/93, for which the excavator suggests a metallurgical use, due to the presence of a copper oxide concretion found on one side of the artefact (Belgiorno et al forthcoming: 13), but no further details are provided in this publication. Although no furnace remains were found, it is interesting that artefacts related to metallurgical activity were recovered during this investigation north to the main excavated area of the site, confirming that metallurgy was practiced in a vast area of the site and not limited to the area that has been already excavated.

Due to the recent modern construction industry development occurring in the surroundings of Pyrgos, the Department of Antiquities of Cyprus established the southern slopes of *Mavroraki*’s hill as a protected archaeological area. The archaeological investigations in the surroundings of the site are made more difficult by the constant construction of new residential buildings encroaching onto the archaeological heritage.

This area certainly deserves more extended investigations, considering that the top of *Mavroraki*’s hill might have been a privileged area to host intense metallurgical activity, being the highest zone of the settlement, well exposed to the wind, a very important factor if we think about both the managing of the waste-gases from the smelting activity, but also the possibility of taking advantage of the air currents blowing from the coast to operate the eventual furnaces through natural wind-draught.

3.4 Pyrgos' Necropolis

As mentioned above, CNR's mission moved its first steps in the research of Pyrgos' settlement, due to the presence of one of the richest cemeteries of the South Coast of Cyprus.

According to the official DAC internal register of archaeological finds, the first mention of an Early Bronze Age tomb accidentally discovered at Pyrgos dates back to the 1940s (Belgiorno 2002: 2). Since then, due to its problematic location under the modern village of Pyrgos, which was also the probable main cause of several past lootings, the site could not be systematically excavated.

All the discoveries made in this necropolis were accidental, so it is still very difficult to understand the real extent of the cemetery, and just a few considerations can be put forward.

Tombs **1**, **2**, **3**, **4** (LM 11, 121, 124-125[8]), accidentally found between 1951 and 1954[9](Belgiorno 2002), **1a** and **2a** (LM 653-654), found in 1978 and T.**21** (LM 1575, figs. 4-5), found in 1993 (Belgiorno 1997), have been published. The first Early/Middle Bronze Age 18 tombs (T. 1-19) are in press at the moment by Belgiorno (forthcoming A).

We have mention of a fifth tomb (T. **5**, LM 327) found in 1963 (Karageorghis 1964: 326) and six more tombs (T. **6-11**, LM 351-358[10]) found in 1964 by Mr. Nikos Petrides, archaeological officer

---

[8] The alpha-numerical codes marked with an initial LM correspond to the entries recorded onto the official DAC register consulted by the author at the Archaeological Museum of Limassol District.

[9] Belgiorno (2002: 4) reports an inventory number, 1941/III-12, stating that this tomb was found in 1941. The author states that the grave goods from this tomb, together with the items from a second tomb also registered as T. 1 and later named T.1a to distinguish it from the previous one, were moved in 1978 from the storeroom of the Cyprus Museum in Nicosia to the Archaeological Museum of Limassol District. According to the official DAC catalogue provided to me by the officers of Limassol Museum, T.1 (LM 11) was found on the 12/2/1951, while T.1a and T.2a (LM 653, 654) were effectively the tombs involved in the transfer from the Cyprus Museum to Limassol in December 1978.

[10] The label LM 356 was assigned to an additional delivery from T. 7-8-9 dated 25/09/1964.

at the Archaeological Museum of the Limassol District (Karageorghis 1965: 250). Three new tombs were found in 1966: two from the Early-Middle Bronze Age (T. **12-14**, LM 388, 391) and one (T. **13**, LM 389) dated to the Cypriot I (Belgiorno 1997: 119?). In 1970 a new tomb (T. **15**, LM 473) was found (Karageorghis 1971: 357) while in 1983 the Limassol District Archaeological Museum acquired the grave goods from Pyrgos' T. **16** (LM 925; Karageorghis 1983: 907). According to the DAC inventory deposited at the Limassol Museum, T. **17** was excavated in 1987, but dates to the Classical period, while T.**18-19** were not recorded on this same registrar.

T. **21** (LM 1575), found in 1993 as mentioned above, revealed among its grave goods very interesting artefacts related to metallurgical activity and therefore interpreted by Belgiorno (1997) as the burial of a coppersmith. Tombs **22-42** (LM 1788-1807, 1810) were excavated by Dr Eleni Procopiou, archaeological officer at the Archaeological Museum of the Limassol District in 1997. In 1999, two more tombs (T. **43-44**, LM 1889-1890) and one in 2001 (T. 45, LM 1991), were excavated by the personnel of the DAC. Tombs **46-47** (LM 2323-2324) were discovered in 2010, but no entries were recorded on the DAC registrar for the necropolis of Pyrgos until T.**55**, the last one recorded up to 2017 when the author had the possibility to consult the registrar, also excavated in 2010 from the Department of Antiquities Cyprus, but recorded on the Limassol Museum registrar only in September 2016 by Mr. Yiannis Violaris, archaeological officer at the Archaeological Museum of Limassol District. It was not possible for the author to check whether missing tombs **48-54** were part of the 2010 excavations and were simply not recorded yet at the time of the author's archival research.

Pyrgos's tombs are excavated in the *havara* (Belgiorno 1997: 120); the local name of a superficial clastic rock, which appears soft, white and porous, and is widely spread in Cyprus (Shrimer 1998), in a roughly squared pit or as a circular/ellipsoid hypogeic chamber, from what is visible in the plans conserved. The size is less than 1 m in diameter for the pits and between 3 m and 4 m in diameter for the chamber tombs. The tombs, with the exception of T. 21, usually survive to a depth of 30-70 cm (Belgiorno 2002).

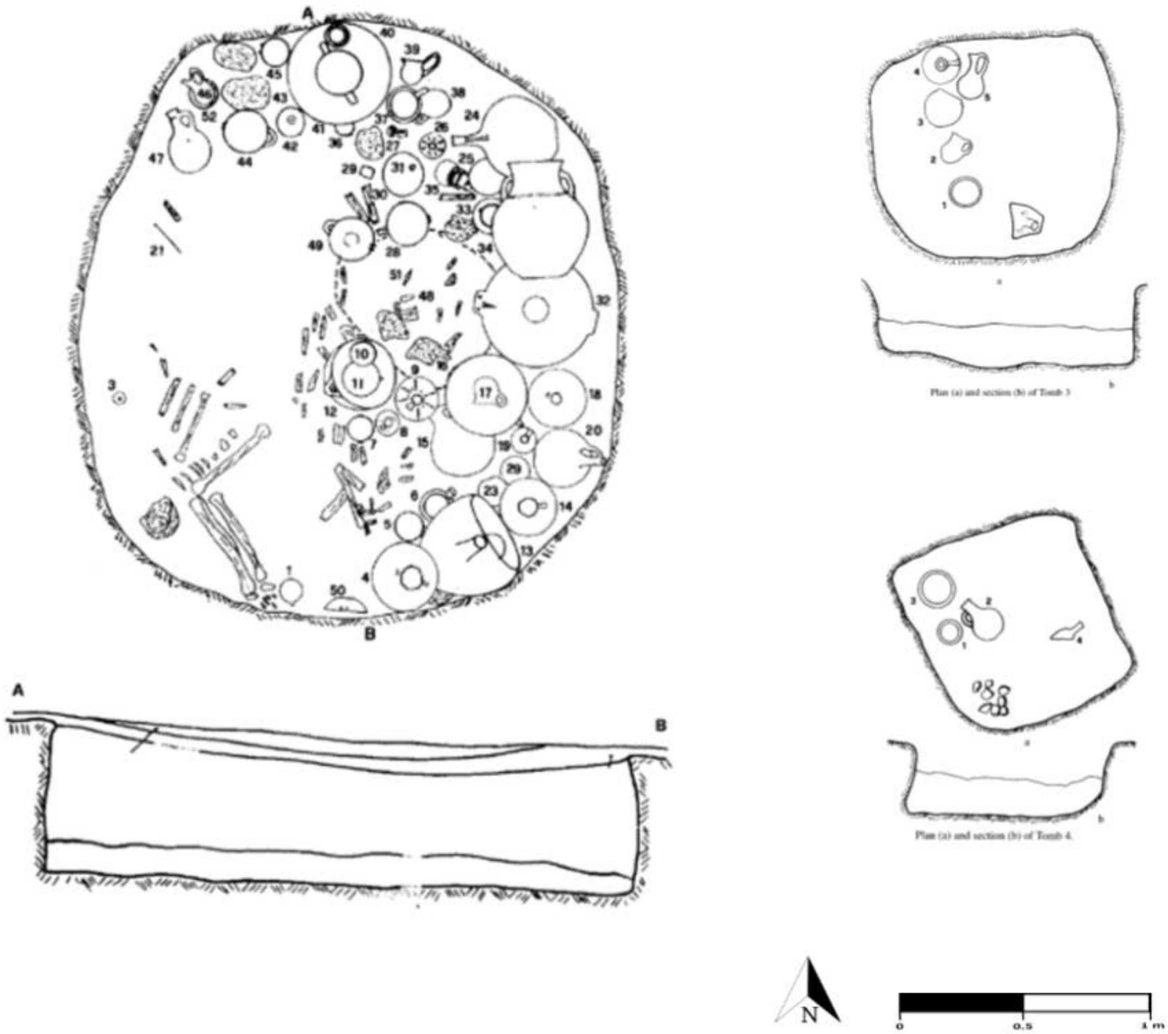


Figure 3.22 From the left to the top right: plan and section of T. 2a, T. 1 and T.4 (from Belgiorno 2002).

Considering that only seven tombs from Pyrgos's necropolis were briefly published in the Reports of the Department of Antiquities of Cyprus (Belgiorno 2002), and only recently Belgiorno dedicated a monography which includes tombs published in the past and new previously unpublished material (tombs 1-19; Belgiorno 2019), it is difficult to draw a systematic interpretation on this cemetery, still largely unpublished.

T.2a (fig, 3.22) contained the bones of eight individuals, 6 of which were moved to leave space to the last two inhumations (Belgiorno 2002: 11). Belgiorno (1997: 121) states that T.21 held only one body, but according to a personal comment provided to the author by Mrs Demetra Aristotelou, archaeological officer at the Museum of Limassol, two different individuals were buried in this context. The very poor state of conservation of the bones does not allow any further consideration about age or gender.

Apart from T.2a and T.21, the lack of published osteological data also hinders an accurate and complete social interpretation of this context.

The author was able to visually examine the non-ceramic artefacts contained in the tombs listed in Table 2.

Table 2 includes all the metal or metallurgy-related artefacts found within the Pyrgos tombs grave goods assemblages found until now. Some of these objects find accurate comparisons from the settlement (see Catalogue).

TOMB	GRAVE GOODS			REFERENCES
	Weapons	Tools	Ornaments/Toiletry	
1	1 hook-tang weapon with notched, heart-shaped shoulders (6)[11]		1 pair of Pinched-spring bronze tweezers (7)	Belgiorno 2002; Balthazar 1990
2a		1 bronze awl with pointed tang (51, n. inv. LMRR 121/51) 2 Whetstones (2; 48)	1 bronze pin (21, n. inv. LMRR 121/21?)	Belgiorno 2002; Balthazar 1990
4		1 possible crucible (1)		Belgiorno 2002; Giardino et al. 2002
21		2 axes (6; 27) 2 chisels (26; 30) 3 knives (29; 35; 44) 1 awl (31) 1 scraper (37) 5 whetstones (38; 58; 59; 61a; 61b)	1 necklace (60a) 1 bracelet (60b) 2 pairs of Tweezers (25; 41)	Belgiorno 1997; analysed by Giardino et al. 2002

[11] The inventory numbers of the metal artefacts part of the grave goods are indicated among brackets.

		4 stone mace heads (39; 40; 42; 47)		
24		1 needle (2)		Unpublished
35		1 whetstone (40)		Unpublished
36		1 chisel (22) 2 whetstones (3; 4) (one of them is covered in red ochre)		Unpublished
37		4 whetstones (4; 7; 10; 14)	Earing (5)	Unpublished
42	1 Hook-tang weapon (45)	3 whetstones (93; 118; 128)		Unpublished
44	1 Knife (5)	1 copper alloy blade (small knife?) (6) 1 whetstone (7)		Unpublished
54		fragments of oxidised copper (16)	*1 comb shaped pendant in pycrolite (8)*[12]	Unpublished
55	1 Hook-tang weapon (1)	1 small knife (16)		Unpublished

UNCERTAIN PROVENANCE	GOODS			REFERENCES
	Weapons	Tools	Ornaments/Toiletry	
Unknown, donation.	1 Hook-tang weapon (LMRR 520/1)			(Swiny 1986) (Balthazar 1990)
Generally from Pyrgos			2 Pins with conical necked head (LMRR 351/1; LMRR 352/2)	(Swiny 1986)

Table 3.2 Metal/metallurgy-related artefacts from Pyrgos's tombs.

[12] This artefact has been mentioned since, as a piece of jewellery, it might suggest the nature of the small metal fragments found in the same tomb.

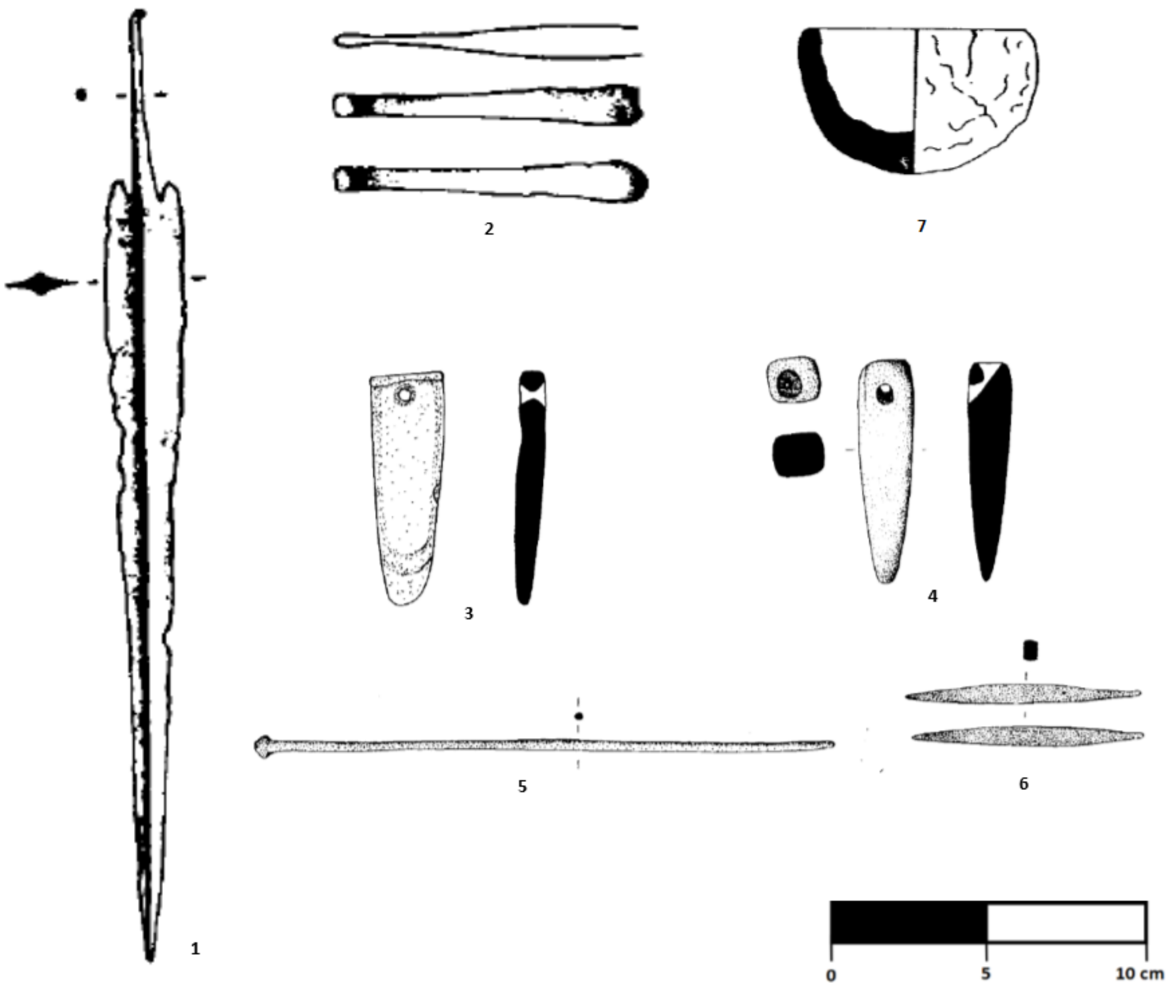


Figure 3.23 Some of the metal/metallurgy-related artefacts from Pyrgos Cemetery: n.1: hook-tanged weapon, n.2: pinched-spring tweezers (T.1 from Belgiorno 2002: 5, fig.1, nn. 6-7); n.3-4: whetstones, n.5: squared knob head pin, n.6: awl (T.2a from Belgiorno 2002: 22, fig.10, nn.2, 48, 21 and 51); n. 7: possible crucible (T.4 from Belgiorno 2002: 28, fig. 12, n. 1).

Only twelve tombs, out of the fifty-three excavated dated to the Early/Middle Bronze Age, contained metal or metallurgy-related artefacts (fig. 3.23).

Although it is difficult to draw accurate considerations about the grave goods found in these tombs, as the majority of them were found disturbed or looted, the number of contexts containing metals or metal/metallurgy related objects seems exiguous if compared to the coeval northern sites of *Vounous* Site B and Lapithos (Keswani 2004) and more in line with the contexts of Karmi-*Lapatsa* and *Palealona* (Webb et al. 2009, pp. 232-235).

Only three hook-tanged weapons come from a secure tomb context within Pyrgos cemetery (T.1 n. 6, T.42 n.45, T.55 n.1), as well as one which has been recorded in the museum archive as a donation from a villager who "retrieved it from a tomb many years ago" in the vicinity of Pyrgos (Swiny 1986; Balthasar 1980). The first two hook-tanged weapons together with the "gifted" one currently on display at the Archaeological Museum of Limassol District, belong to Catling's A.1.c type (1964) with notched shoulders, while the one from T.55 seems to be more ancient, belonging to Catling's A.1.b-stud terminal type, with hammered heart-shaped shoulders and stud terminal.

Whetstones of various shapes and size are more frequent, while metal ornaments/toiletry tools were found in just three tombs - four if we argue that the fragments of oxidised metal found in T. 54 were originally part of an ornament - considering that they were found in connection with a pycrolite comb-shaped pendant.

The chemical composition of these is discussed in Ch. 5.

Due to the lack of a comprehensive publication of Pyrgos's necropolis, and, consequently, of an accurate chronology for each tomb, it is impossible to establish at the moment if the presence of metal artefacts increases in the late EC III-MC I-II, mirroring the phenomenon noted in Karmi, Lapithos and Vounous Site B (Webb et al 2009: 232). Looking at just the few tombs preliminary published by Belgiorno (2002), it is interesting to note though that metal or metallurgy-related artefacts are present just in tombs dated by the author to the MC I-II or, in the case of T. 2a, in use until that period.

The pottery types recorded in the published tombs show correspondences in shape and decoration with the Limassol area, while certain vases might have been imported from other Cypriot regions on the Northern coast of the Island.

Moreover, there are some artefacts (amphora from T. 16: Belgiorno 1985; the large amphora and chisels from T. 21 Belgiorno 1995: 62) whose typology reveals an Anatolian influence (Belgiorno 1985). The grindstone from T. 21 is comparable to samples coming from Greece (Argolis), as well as a small ivory spindle found together with a picrolite spindle-whorl from T. 12 (Belgiorno 1995: 64).

These extra-Cypriot *comparanda* might suggest that Pyrgos's community was in contact with other regions of the Mediterranean, and directly involved in a certain level of long-distance exchange. This could have happened through the contact with the coeval sites located on the Northern coast and therefore in a more direct and geographically privileged position towards Anatolia, but also in a more direct way, taking advantage of the natural anchorages located as just 4 km far from the site.

3.5 The Metallurgical Artefacts

One of the first kinds of evidence, which suggested the existence of the site was the consistent presence of metallurgical slags which covered the entire area, suggesting that metallurgical activity was carried out at Pyrgos-*Mavroraki*.

This section discusses the different categories of artefacts related to the metal processing, described in detail in the catalogue reported in Appendix 1. Metal artefacts are not listed below, as they will be discussed in Ch. 5.

3.2.1 Crucibles

A group of 29 sherds interpreted as crucibles fragments were submitted, just for visual analysis, by the excavator to the author and, despite the absence of further scientific investigation, because of the relevance of these finds, it has been decided to include them in this study. The fragments which clearly show evidence of high temperatures and copper encrustations were selected and recorded through graphic and photographic documentation.

From a preliminary autopsy, the most relevant consideration is that the presence of vitrification or copper incrustations has been detected just on the internal surface of almost all fragments, confirming the technology hypothesised for Alambra-*Mouttes*, Ambelikou-*Aletri* and Politiko-*Troullia* with the use of blowpipes to maintain the temperature of the charcoal in a bowl-shaped furnace.

12 of the sherds from Pyrgos-*Mavroraki* interpreted by the excavator as crucibles are rims; 4 are bases; while the remaining are parts of walls not identifiable. Among the rims, PYCR.18 is the only fragment where a spout is recognisable and an approximation of 13 cm diameter is possible, highlighting a vague similarity to a crucible kept in the Medelhavsmuseet Museum in Stokholm with an uncertain provenance from Alambra or Kalopsidha.

18 more sherds have been recorded from Pyrgos, which do not belong to crucibles, but have clearly been in contact with very high temperatures. Differently from the crucibles, these fragments show vitrification both on the internal and external surface, and in some cases, also in the cross-section, confirming that they have been exposed to high temperatures as fragments and not as whole artefacts.

The excavator did not make available for microscopic and chemical analysis the sherds that she interpreted as fragments of crucibles. Belgiorno (2012, p. 31) states that “a large number” of samples has been analysed from all the technical pottery and on some of the crucibles found, but these precious analyses remain only partly published and therefore, unavailable.

Giardino (2000, p. 27) had the opportunity to analyse a fragment of a crucible wall (1.7 cm thick). He describes its internal green vitrification and its grey, friable fabric, tempered with large, pink pottery fragments. The slag adhering on the internal surface of this sample proved to contain prills of pure copper in a fayalitic Fe/Si matrix. The only additional "analytical" information comes from 5 crucible-fragments analysed by Belgiorno et al (2012, pp. 30-31). The authors positioned the samples in a ternary diagram indicating the compounds Al+Fe+Mg, Si and K+Na+Ca, characteristic for montmorillonite, kaolinite and illite to prove their exposure at high temperatures.

Looking at other Cypriot contexts, the number of crucibles found in the Early/Middle Bronze Age is very limited.

Before the finds from Pyrgos-*Mavroraki*, 16 fragments from Alambra-*Mouttes* (Coleman et al 1996: 382-3), 1 fragment from Paramali-*Pharkonia* (Swiny and Mavromatis 2000: 435), 1 crucible from Ambelikou-*Aletri* (Webb and Frankel 2013: 177), one fragment from Kalavassos-*Laroumena* (Todd 2013: 26), 2 fragments from Politiko-*Troullia* (Falconer and Fall 2013: 108) and another crucible, part of the Cypriot Collections at the Medelhavsmuseet Museum in Stokholm, with uncertain provenance referred either to Alambra-*Mouttes* or Kalopsidha (Webb and Frankel 2012: 111).

The two complete crucibles (Ambelikou and Alambra/Kalopsidha) are very different in shape. The first one appears very shallow, while the second is deeper. They both have a small pinched spout. The only other complete example of possible (unused) crucible is the coarse bowl found in Tomb 4 at Pyrgos's cemetery (Appendix 1, p. XX), which has a different shape compared to the previous ones, looking thicker and without a spout.

The presence of a spout on 494 and the “Swedish/Cypriot” crucible from Alambra/Kalopsidha suggests their used for melting activities, as argued by Webb and Frankel (2013, p.177). The chemical analyses carried out by Zwicker (1982; 1986; Zwicker et al 1981) on the slag found on the surface of 494 and the copper prills trapped in it support this hypothesis.

Ten fragments from Alambra-*Mouttes* allow to reconstruct their shape (shallow dish-shaped similar to 494) and their original diameter which never exceeds 20cm (Coleman et al 1996: 382). This shape reminds examples from Troy and Thermi (fig. 3.24).

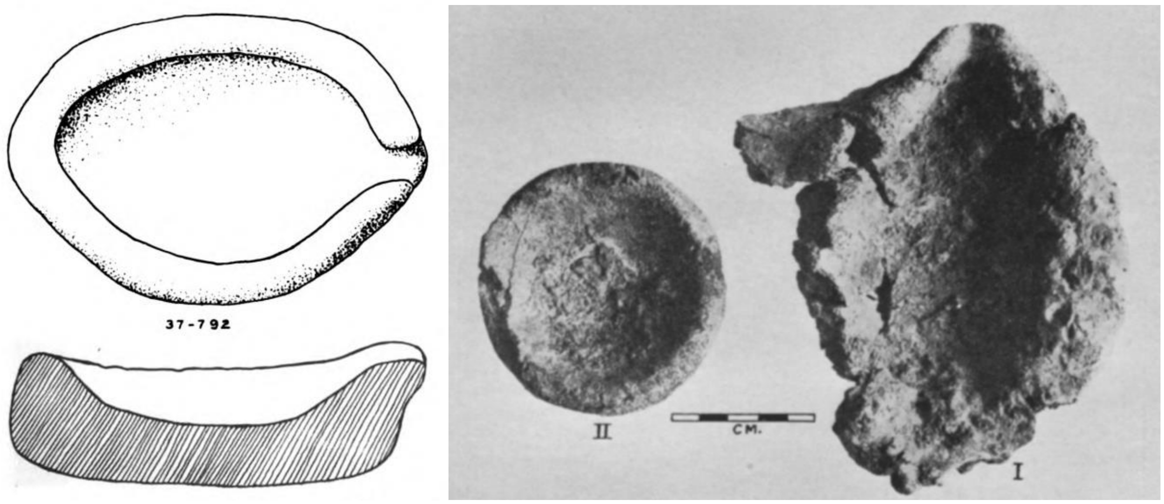


Figure 3.24 Crucibles: on the left from Troy VIIA (from Blegen 1958: pl. 221, n.37-792); on the right from Thermi, Lesbos (Lamb1928-29-1929-30: pl. IX.

Similarly to the crucible from Ambelikou-*Aletri*, nine of Alambra-*Mouttes*’s crucible fragments show vitrification and slag adhering on the internal surface, suggesting that the heating of the charge was operated by the above, maybe through blowpipes, confirmed in the case of Ambelikou by the discovery of a ceramic nozzle. Among these finds two fragments were spouts, and considering the estimated size of the crucibles, Gale et al (1996:136) pointed out a strict similarity to the example from Ambelikou, allowing the possibility that Alambra’s crucibles were used both for smelting and melting activities (Coleman et al 1996: 382).

The crucible found at Kalavassos-*Laroumena* was most likely a melting crucible, considering that the analyses carried out show a small amount of tin in the copper prills trapped within the slag

(Todd 2013: 26). Little information has been published about the fragments from Politiko-*Troullia* and Paramali-*Pharkonia*, for which no chemical analyses are available yet. In both cases the authors mention the presence of slag or copper incrustation on the surface of these fragments, without specifying the position of it if internal or external (Falconer and Fall 2013, p.108; Swiny and Mavromatis 2000, p. 435). Webb and Frankel report that the fragments from Politiko "appear to come from roughly conical bowls with rudimentary spouts" (2013: 178), while the one from *Pharkonia* might have been cup shaped.

3.5.2 Pipe-Nozzles

The temperature reached by a normal hearth fed just by a natural air-draft is usually between 500° and 700°. A natural air-draft can be used to reach copper-smelting temperatures with certain kind of shaft-furnaces, such as the examples of Chrysokamino in Crete (Catapotis et al. 2008), or Ayn Soukna in Egypt (Verly 2017).

In the case of a simple bowl-shaped furnace, it is necessary to apply a forced draught to the furnace, and to do so two kind of tools were used in antiquity: blowpipes and bellows.

Blowpipes were probably made of hollow reeds, and for this reason they are not preserved within the archaeological record. An archaeological indicator of the use of blowpipes is recognisable in the short, hollow clay nozzles often found in the earliest metallurgical sites, used at the distal edge of the pipes to prevent its deterioration by the high temperatures. These objects should not be confused with the tuyères, larger bellow-nozzles (Webb and Frankel 2013, p. 180), attested in Cyprus just from the LC I with the finds of the smelting site of Politiko-*Phorades* (Kassianidou 2011, pp. 42-45).

Four nozzle-fragments have been found to date at Pyrgos-*Mavroraki*, two of which probably belong to the same object (fig. 3.25). The first ones come from the Southern Sector and the tip fragment has been found inserted in a sort of sandstone holder (see 3.2.4 Stone Tools and Anvils), while the other two fragments were found in square E11d, within the structures which lie beyond the road. None of these artefacts shows vitrification or slagging. The diameter of the rounded tip-edge's hole is smaller (0.4/0.5cm) than the internal diameter at the base (1.0/1.8cm), which ends in a flat rim.

Figure 3.25 Pyrgos's blowpipe nozzles (pictures and drawings by the author).

Two other Bronze Age blowpipe nozzles have been discovered in Cyprus to date (fig. 3.26). A complete example comes from Tomb 119 at Bellapais-Vounous Site A (Webb and Frankel 2012, p. 111, Class. XXVIIa, fig. 24.4) dating to the EC 1. It has a conical shape for a total length of 10.5cm, 0.2cm of internal diameter at the tip-edge's hole and 2.5cm of internal diameter at the base. A second fragmentary example comes from the site of Ambelikou-*Aletri* (Webb and

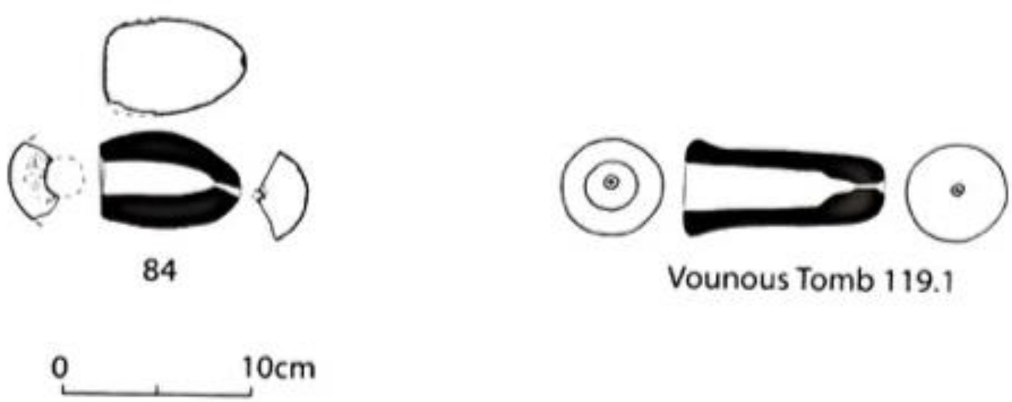


Figure 3.26 Blowpipe nozzles from Ambelikou-Aletri and Vounous (Webb and Frankel 2013).

Frankel 2013, p. 180). It differs from the objects from Pyrgos and Vounous for its oval shape with convex sides.

Pyrgos's nozzles are comparable with fragments from Poliochni (Lemnos) and Boğazköy (Turkey) (Hundt 1988: 101, fig. 1., nn.7, 9).

Hundt (1988) lists a few examples dating to the Early Bronze Age from this object category. These artefacts are usually not longer than 5-8cm, with at least half of their internal perforation uniform in diameter, and the other half slightly widening from the middle towards the base (probably to be secured to the blowpipe). The examples chosen by Hundt, similarly to the ones from Pyrgos, don't show any trace of slagging or vitrification and the author consider this element essential in the interpretation of these objects as a caster tool used by the bronze-smith rather than by the founder (Hundt 1988, p. 99). Our experiments showed that traces of strong vitrification are clearly visible on the nozzles after use, so we might suggest that the artefacts from Pyrgos could not show any vitrification because they were not have been used yet.

Batora (2002) expanded the list of these type of objects in his catalogue of metalworkers' burials, where he distinguishes metal funders' from blacksmiths's tombs. In his considerations, he assigns the clay nozzles as characteristic of the first ones, without mentioning their specific function (smelting or casting?) or if any traces of slagging or vitrification were found on the nozzles.

When Hauptman (2007: 99) describes the tuyères used at Faynan 5, he mentions the existence of two different size of tuyère, and in what he calls "small tuyères", we would be tempted to interpret them as blowpipes nozzles. He also points out that these artefacts, based on comparisons with Timna (Rothemberg 1990, p. 35), could be considered earlier than the larger ones found on-site. Unfortunately, the size of these "small tuyères" does not match with our nozzles, having an internal width of 1.5/2.8 cm (Hauptman 2007, p. 99), much bigger compared to the ones from Pyrgos.

3.5.3 Moulds

Four clearly recognisable terracotta moulds for axes (1652, 1654, 351, 352), one fragment of a double-sided mould (1653) and a few more sherds, interpreted by the excavator as fragments of moulds, were found in the settlement. Two more fragmentary moulds were found during the soundings on *Mavroraki*, one in clay (M216), possibly for axes, and one in calcarenite (type of limestone) (M215) for the production of needles or small awls. Belgiorno et al (forthcoming: 15) notes that in both of these cases “remains of copper” were detected under the microscope.

1652 and 1654 are quite shallow (1.7/1.4 cm) and the average thickness is 0.7 cm on the walls, while there is a considerable difference in the base thickness which is 1.3 cm for 1652, while for 1654 increases to 2.4 cm.

Figure 3.27 Moulds 352 (on the left) and 351 (on the right).

351 and 352, larger than the previous ones (respectively 23 and 21 cm) and similarly to 1654, with thick base (6.1 and 5.4 cm), were found, whole (fig. 3.27). The axe-butt portion of these moulds presents two small holes on the bottom surface. The Early/Middle Bronze Age flat-axe typology in Cyprus informs the interpretation of these features: a specific type of flat-axe is characterised by a pierced butt, interpreted as functional to the handling of the tool, or, more likely in my opinion, to allow the transportation and trade of these objects, conceived as valuable form of ingots before their actual use (Webb and Frankel 2006, p. 217). Both these moulds were recovered inside two pit-furnaces in the Southern Sector and the excavator suggested two possible explanations for this context: one possibility is that the moulds were kept warm in the furnaces to avoid thermal shock while pouring the liquid metal from the crucible (clearly melted in one of the other close furnaces); a second possibility is that this type of mould was used as a crucible to melt the copper prills, obtained from the smelting process, directly in an axe or axe-shaped ingot. This theory might also explain the thick base of this type of mould. It would be interesting to establish if Abedi and Omrani (2015: 63, fig. 8.1) were inferring a similar theory when they reported a "metal smelting [*sic*] mould" from the Chalcolithic site of Kul Tepe Jolfa in North-Western Iran.

While the metal artefacts produced with this kind of moulds are common in Cyprus, the moulds from Pyrgos seem to be unique.

3.5.4 Stone Tools and Anvils

A vast amount of stone tools was found at Pyrgos-*Mavroraki*, some of which were most likely used during different stages of the metallurgical process, such as querns, grinders, pestles and recycled old axes to crush ores and slags to recover copper prills that needed to be remelted, and anvils to shape the freshly casted metal artefacts.

The largest self-standing anvil (inventory number: 188), was found in K6c lying on a side, leaning on the Western wall right in front of a sort of stone sit which suggest that the anvil has never been moved from its original position (see above fig. 3.18). This artefact has been carved from a grey basalt block cut at the edges so to obtain two opposite and parallel horizontal surfaces (fig. 3.28).

Figure 3.28 Anvil 188.

The basalt block was hammered and smoothed out accurately in prehistory, and a deep groove was carved on its top, possibly to accommodate the midrib of daggers and swords during the hammering and the sharpening of these weapons (Belgiorno 2017: 28).

A second anvil, with a triangular shape which might have facilitated a more stable housing of this tool in the ground, presents the same characteristic groove on the top surface.

A possible block of basalt from Marki-*Alonia*, recognised from Frankel and Webb as a working surface (2006: fig. 6.35, inventory number: S597) which presents a similar shape to the anvils described above and a shallow groove carved on one surface. Two similar objects were found in Kissonerga-*Skalia* and are currently in study by PhD Student Ellon Souter at the University of Manchester[13].

Apart from these possible *comparanda*, which will need more accurate observation in the future, the author was unable to find any comparisons neither in Cyprus or abroad for this type of anvils. Other small anvils (inventory numbers: 1462, 1543, 3056, 87), have been identified by the excavator (Belgiorno 2019: 24-28), in this case more simply shaped, but showing clear traces of hammering, and more comparable with some earlier and coeval possible exemplars from Turkey (Horejs et al 2010: 15, fig.4.1), Egypt (Scheel 1989, p. 28, figs. 28-29), Spain (Delgado Raack and Risch 2008: 240, fig.5.2) and the Netherlands (Kuijipers 2008: 98-99)

3.6 Discussion

The metallurgical remains found at Pyrgos-Mavroraki testify the exceptional importance of metallurgical production at this site.

The different contexts, described by the excavator in her reports, show that possibly different stages of copper processing were carried out at the site, making Pyrgos a good representation of the Early/Middle Bronze Age Cypriot metallurgical chaîne opératoire.

The vicinity of the site to different copper-ore deposits such as the oxidised outcrops individuated on Mavroraki's hill itself, but also the Cupreous Pyrites in Mazokambos, Ornitha, Manghaleni

[13] I would like to thank the colleague E. Souter for this personal communication.

certainly facilitated the mineral supplying. While the smelting of oxidised copper ores is straight-forward and easily manageable in a single-step process, sulfidic ores such as Chalcopyrite and Bornite would have required a more complex multiple-steps procedure, involving a preliminary desulfurisation of the ores (roasting) to make the following smelting process possible.

The excavator interpreted the large carbonaceous layers found in the Northern Sector as roasting-beds (Belgiorno 1999c: 296). However, considering that the ore deposits are all located in areas surrounded by forests, vital fuel supply for the high-consuming roasting activities, it seems time- and energy-consuming to transport both ores and fuel charge from the mining areas to the settlement. Once roasted on the mining site, the semi-reduced minerals could have been transported to the site and smelted with the use of charcoal (smelting requires much less fuel than the roasting process, which can last days).

When considering the possible metallurgical furnaces, it has been decided to leave out the mysterious large circular features interpreted by the excavator as tapping shaft-furnaces, which, as already mentioned, cannot be surely attributed to metallurgical activity. The possible shaft-furnace found in J4, preliminary tested by the author before to start the present research, was also discarded. The tapping technology used with the shaft-furnaces is not represented in Pyrgos neither in its slag types (see Ch. 4) neither in the presence of tuyeres, large clay nozzles which would have been attached to leather bellows, a technology which is not attested in Cyprus before the Late Bronze Age (Kassianidou 2011).

The only features found at Pyrgos, considered in these research as possible metallurgical furnaces are therefore the remaining small pits found both in the Northern and Southern Sectors, which represent the most primitive type of metallurgical reactor known in early metallurgy (Zwicker et al. 1985).

Another essential data towards the understanding of Pyrgos metallurgy is the large amount of crucible fragments. According to the only published SEM-EDX analysis carried out on a crucible from Pyrgos by Giardino (2000), crucibles were used for casting. However, the lack of a systematic analytical programme on Pyrgos crucibles cannot tight these artefacts to the only casting process but leaves space to the possibility that they were used during smelting as well, as already testified at Alambra-*Mouttes* (Gale et al. 1996, pp. 382-383).

To complete the image of a possible reconstruction for Pyrgos metallurgy, another important component is represented by the clay blowpipe-nozzles found at the site. These objects are usually related with the smelting technology characterised by the combination of pit-shaped furnaces and crucibles (Zwicker et al. 1985). The use of blowpipes and pit-shaped furnaces is further attested at the coeval Cypriot sites of Ambelikou-*Aletri* and, possibly, at Alambra-*Mouttes* (Webb and Frankel 2013, p.36; 180-181).

Very specialised metallurgy-related tools were found at Pyrgos-Mavroraki, such as the stone-holders, possibly used to sustain the clay-nozzles or the blowpipes in a certain position onto the pit-shaped furnaces, or the accurately shaped basalt anvils, provided with grooves to possibly facilitate the hammering of hook-tanged weapons and knives. These objects, together with the type of sulfidic copper ore selected for smelting, as confirmed by the analytical work carried out on Pyrgos metallurgical discard, testify a certain level of specialisation in one of the earliest evidence of metallurgical chaîne opératoire found in Cyprus making the possibility of a surplus production not impossible.

If we adopt Webb and Frankel's suggestion to interpret the pierced-butt flat axes as possible ingots (2006. P. 217), the finding at Pyrgos of two moulds for this type of object might suggest that among the metalsmiths' aims was that one to produce a certain surplus. This, in the shape of ingots, could have been traded with other sites on the Island or abroad.

The scarcity of metal artefacts from the funerary contexts of Pyrgos seems to contrast with the metallurgical vocation of this site. It could be suggested that a possible alternative focus of Pyrgos-Mavroraki's community was to trade the precious goods produced at its workshops, such as jewels, olive oil, essences, including copper and metal artefacts with other groups on the Island and abroad.

The peculiar coexistence of all these different kinds of artisanal productions located in different workshops (often open courtyards) within the same buildings seems also to refute the old common idea of a guild of metallurgists who used to keep the secrets of their art for themselves (Amzallag 2009, p. 396). Metallurgy was rather a common activity which possibly involved different members of the community, possibly simultaneously involved in different craft-activities, as it is also suggested by the presence of metallurgical activity in several different areas of the site, including the soundings on *Mavroraki*'s hill and the survey at *Aulaki*.

Chapter 4. Metal Technology: smelting and slag analysis

4.1 Introduction

After the accurate evaluation of the archaeological context, in order to expand our knowledge of Pyrgos' metallurgy, it was necessary to gather as much scientific data as possible of the material remains that were made available by the excavator. The most relevant evidence of metallurgy at Pyrgos-*Mavroraki* was the exceptional amount of slags found. Differently from other archaeometallurgical contexts, in this case, no slag heap was recovered; instead the slags were scattered, sometimes in small groups, across the surface of the excavation.

The archaeometallurgical database (Appendix 5) counts 1717 slags, with a total weight amount of 48.62 kg. After a brief introduction to the field of slag analysis and a mention of the preliminary analytical work published on metallurgical waste products found at Pyrgos, this chapter focuses on the analysis carried out on a sample of 836 slags. These samples have been considered autoptically and a smaller selection was chosen for further analysis by Optical Microscopy and Scanning Electron Microscopy, coupled with Energy Dispersive X-Ray. These techniques will be outlined in paragraph 4.6.

4.2 Slag Analysis: History of Research

Slag Analysis developed as a field of research alongside the "New Archaeology" in the late 1960s. Pioneer Beno Rothemberg organised a team composed of Hans-Gert Bachmann, Alexandru Lupu and Ronald F. Tylecote to study the prehistoric site of Timna in Israel (Rothemberg 1990).

In the same period, Morton and Wingrove (1969; 1972) worked on Roman and Medieval iron bloomery slags, discussing their composition through phase diagrams, and the same diagrams were applied at Timna by Milton (1976).

In the early 1980s, Koucky and Steinberg studied the prehistoric slags from Cyprus, but it was Bachmann who set the standard for archaeological slag analysis with his textbook: "The identification of Slags from Archaeological Sites" (Bachmann 1982). Bachmann's study, which remains an essential reading for archaeological scientists, has been recently advanced by the work of Kronz and Keesmann (2007), who have broadened our knowledge of the petrology and mineralogy of slags. More recently, Hauptmann made slag analysis more accessible to researchers who approach archaeometallurgy for the first time (2007, Ch. 6; 2015).

In the last decades, important studies on slags from Chalcolithic and Early Bronze Age sites from Europe and the Eastern Mediterranean have been carried out; allowing a better understanding of the early stages of metallurgy (Addis et al. 2016; Ambert et al. 2014; Artioli et al 2015; Bassiakos and Catapotis 2006; Van Brempt and Kassianidou 2016; Murrillo-Barroso et al. 2017).

Slags are one of the most abundant material remains from ancient and historic metalworking sites; they allow us to investigate ancient metal processing using scientific analysis. Considering the definition of slag, as any metal-containing material that has been once fired or melted, it is possible to list as slag, beyond the actual waste, also metal-rich slag, scrap metal, and casting remains (Hauptmann 2014, p.92). Different types of slag originate from different stages of the metallurgical *chaîne-opératoire* such as smelting, melting, casting, and refining. Important information on these processes can be provided by the macroscopic, microscopic and chemical analyses of archaeological slags.

As summarised by Hauptmann (2014, p. 92) the most conspicuous ancient slags heaps are datable from the Late Bronze Age to the Byzantine Period and are mainly composed by smelting slags, such as the ones found in Rio Tinto in Spain (Rothenberg and Blanco-Freijeiro 1981; Unthank-Salkield 1987), Skouriotissa in Cyprus, or Faynan in Jordan (Hauptmann 2007) .

The slag heaps from the earlier stages of the history of metallurgy are less spectacular, consisting generally of a few kilograms of material, coherently to the scale of metal production in that period.

4.3 Analytical methods for characterising archaeological slags: Macroscopic and Microscopic characterisation

The investigation of both technological and provenance aspects of slags allows for the reconstruction of craft-related and economic systems from the past. From a technological point of view, the scientific analysis of archaeological slags normally aims to:

- establish the kind of metal or alloy produced during the slag formation;
- identify the stage of the metallurgical process which produced the slag (e.g. melting vs. smelting);
- identify the original ore smelted and the eventual deliberate/undeliberate use of any fluxes;

- estimate the firing conditions such as the temperature, the gas atmosphere and the duration of the cooling process;
- identify the ore source location (Bachmann 1982; Hauptmann 2014).

Considering that no provenance studies were carried out during this research, we will focus onto the analytical methods used to characterise the technological aspects related to the slags' formation.

According to the slag's size, a macroscopic analysis of the appearance, shape, colour, orientation and distribution of specific features should be carried out.

Slag porosity can be evaluated to distinguish it from a natural mineral. Bubbles of air and gas, for example, tend to accumulate towards the surface of the slag, while metal prills will gather at the bottom of it (Bachmann, p.3).

Among other factors, slags vary in colour, shape and texture. The high percentage of iron silicates, usually contained in the slags, is responsible for their black or dark grey colour (Bachmann 1982, p. 3), which might show red (rusty) oxidation on a superficial level. White incrustations are usually due to the lime-rich soils of the finding context whereas green/blue or even yellow oxidation is normally due to the weathering of copper and sulphur inclusions. These visual aspects provide archaeometallurgists with preliminary information about the slag mineral composition in terms of silica, iron and copper and, therefore, about the ores involved in the metallurgical process. The presence of sulphur can be also detected in a preliminary fashion through its characteristic smell, revealing the smelting of a sulphidic ore.

Figure 4.1 Reconstruction suggested for the tapping furnaces used at the Late Bronze Age site of Politiko-Phorades (Geopark Visitor Centre, after Kassianidou 2017, p.116). Top level: pot-bellows. Middle level: shaft furnace. Bottom level: pit to collect the molten slag

When identifiable, the original shape of slags and slag-cakes, or their highly fragmented status, also inform the researcher about the metallurgical process that originated them. Highly liquid and homogeneous slags that show a flowing texture form were most probably "tapped-out" from the furnace in a small pit (fig. 4.1).

They owe their fluidity to a more successful control over the redox conditions, which allows a better separation from the metal during the smelting process. This technology would have been possible in Cyprus from the Late Bronze Age, due to the use of a specific type of shaft-furnace (Knapp and Kassianidou 2008). However, two earlier exceptions are known: the site of Katydata, where tapping slags were found (Kassianidou 2008: 251) and a slag from Ambelikou-*Aletri*, which also seems to show a flowing texture. Both sites date back to the Middle Bronze Age (Webb and Frankel 2013: 184). This type of tapping-furnace is more efficient in terms of mastering the redox conditions and reaching higher temperatures when compared to the earlier bowl-shaped pits used to smelt copper minerals since the Copper Age in Europe, the Mediterranean, Anatolia and the Levant (fig.4.2).

The latter instead produced coarse, chunky slags very likely originating inside the furnace where they were left to cool down before being collected. It is very likely that they needed a second smelting before actual copper collection. Because of the high viscosity of this type of slag, its crushing would have been necessary to recover prills of copper or its semi-product "matte" (copper with high content of sulphur and iron) trapped inside the slag (Bourgarit 2007).

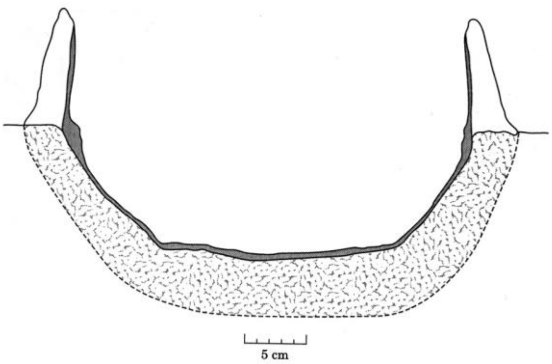


Figure 4.2 A reconstruction of a furnace from Shiqmim (after Golden et al. 2001, p. 958)

Depending on the geographical and chronological context, the microstructural composition of slags also varies remarkably in relation to the specific technological process which originated them. This process can be reconstructed starting from the analysis and interpretation of the mineral phases observed within the slags themselves. This kind of analysis can help us investigate the nature of the ore from which the slags originated, their formation under high temperature processes, the technological skills of smiths who were controlling these temperatures and the redox atmosphere in the reactor.
The identification of chemical composition can be established through powdered samples that are analysed through X-Ray Fluorescence Spectroscopy (XRF), inductively coupled plasma mass spectrometry (ICP-MS) or X-Ray Diffraction (XRD). Although the bulk analysis of the slag's matrix produces useful data that can be easily compared and plotted in charts, this type of analysis can be impaired in the study of earlier slags because of their heterogeneous composition (Hauptmann 2014: 97). It is therefore advisable to study single sections via thin-section or mounted samples on the microscale.
For this purpose, samples are studied under Optical and Scanning Electron Microscopy coupled with energy-dispersive X-Ray (SEM-EDX) (Hauptmann 2014: 97). Another method, which could provide data comparable to those ones obtained by SEM-EDX, is the Raman micro-spectroscopy, which also allows the characterisation of mineral phases (Portillo et al 2018: 247, 250-252).

Reducing firing conditions were not widely accessible in the earliest period of ancient metallurgy, *i.e.* the Chalcolithic and the Early Bronze Age (Bourgarit 2007, p. 5), this is why we find high concentrations of iron oxides and silica in ancient slags. FeO, SiO_2, CaO and Al_2O_3 make the 80 w% (weight percent) of the slag's matrix chemistry, and the predominant constituent is Fayalite (Fe_2SiO_4). Varying amounts of Mg, Ba, Na, K, P, Cu, Pb, Sn, and Zn can also be present.
These oxides can be used to determine the thermodynamic and physical properties of slags such as temperature and viscosity, making use of suitable ternary or quaternary phase diagrams, as they are known in material science.
The most commonly used ternary systems in slag analysis lie within the materials tetrahedron of CaO-SiO_2-FeO-Al_2O_3. To place the slag of interest into a phase diagram, the main components are converted to SiO_2+FeO+Al_2O_3 to equal 100%, in order to obtain the so-called "reduced analysis".
Although phase diagrams are merely an approximation, they are a useful tool to discuss temperatures.

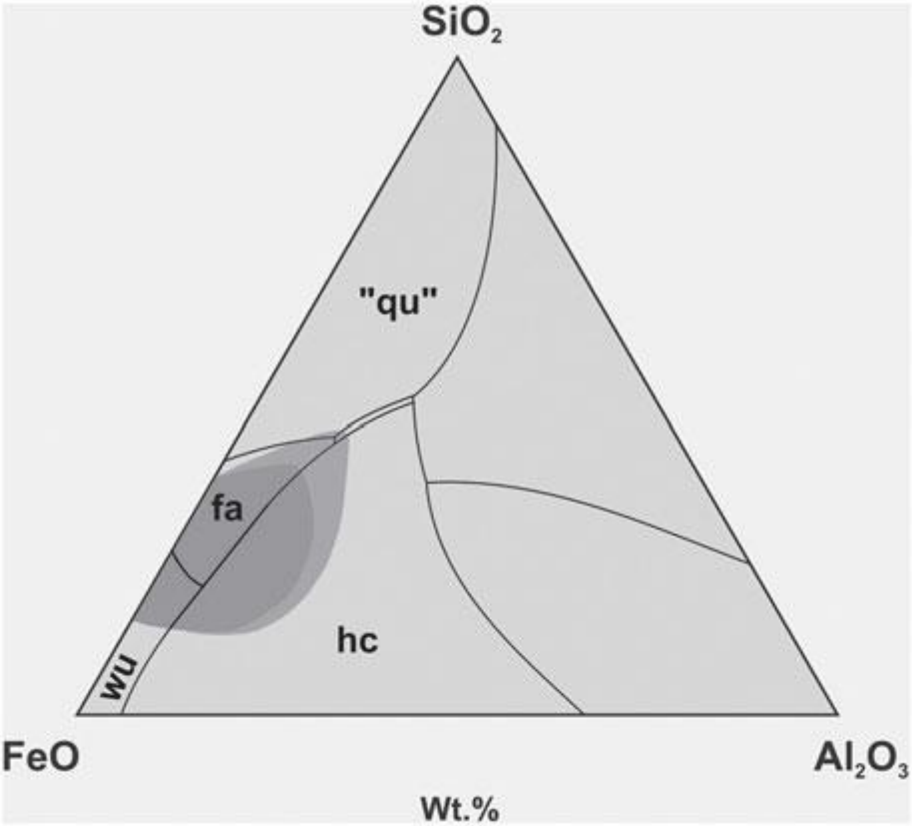


Figure 4.3 Average composition of archaeometallurgical slags from copper smelting (medium-shaded area) and

iron smelting (dark-shaded area) shown in the ternary system FeO–Al2O3–SiO2 (weight percent). The compositions match mainly the eutectic area of the fayalite region (fa) in the system. It is surrounded by steeply arising areas of quartz ("qu") and spinel (hc hercynite). These are components which crystallise from very high temperatures or, vice versa, are stable up to high temperatures. (From Hauptmann 2007)

There are few ways in which all the low-melting slags could have been produced. Supplying mineral to the molten slags, furnace walls act as a source material for the final turning of low-melting compositions. The charged ore does not pass over from the solid to the liquid state at a distinct temperature, but parts of the material form a liquid as soon as the temperature of the lowest eutectic is reached.

Assuming that the charge is made of chalcopyrite and quartz, while the chalcopyrite will be quickly decomposed to various oxides, the quartz, which is much more refractory, remains unaltered for a certain time. Only part of the charge will reach fully liquid state at 1200°C, and this depends on how close the charge comes to the eutectic composition in the system. Sometimes we are able to identify remains of unreacted material into the slags, which can hamper the separation of metal and clog up the furnace or crucible. The earliest slags from Iran, Jordan and the Iberian Peninsula are rich in this kind of undecomposed inclusions (Hauptman 2014, p. 101).

In the past, this kind of slag has been named "free silica" slag. This denomination sees the unreacted materials as deliberately added fluxes. However, if too much quartz is present in the

original gangue of a certain ore, it is unlikely that all of it will react with the iron oxide at the temperature of 1200°C (Hauptmann 2014, p. 101).
The **viscosity** of slags is also an important factor to be taken into account because it largely depends on the temperature reached by the slag in question. Bachmann (1982: 19) suggested a method to calculate a "viscosity index", starting from the ratio of the "basic" oxides (CaO, MgO, FeO, MnO, Alk_2O) against the "acid" oxides (SiO_2, Al_2O_3) present in a slag and expressed in weight percentages. Bachmann's equation was simplified by Addis et al (2015: 107) and adopted by Van Brempt (2016: 175) as follows: $K = (CaO + MgO + FeO + MnO + K_2O + Na_2O) / (SiO_2 + Al_2O_3)$.
As a general rule, the lower the viscosity index (K), the higher the viscosity of the slag. To obtain an efficient separation between the metal and the slag, the latter needs to reach a low level of viscosity. This can be accomplished through a high temperature, and/or through the addition to the charge of appropriate fluxes, which will lower the melting point and optimise the fluidity of the slag.

Slags were formed under reducing conditions obtained more or less efficiently by the burning of charcoal, subject to fluctuations of the oxygen pressure in the gas atmosphere. These fluctuations were also determined by the size and shape of the reaction vessel, the type of air supply device employed, and other manual techniques and recurrent gestures possibly peculiar to each different furnace operator, such as the alternate rhythm adopted while operating the blow-pipes or the bellows. Metal oxides such as CaO, MnO, MgO require extremely reducing conditions to be reduced to metal, so they are still recognisable when captured in the slags and they can be used to reconstruct the redox conditions. For example, if the oxygen concentration in the gas atmosphere is high, magnetite and silica-rich compound (pyroxene) crystallises first, so that iron is mainly bound as an oxide. On the other hand, if oxygen is low, no magnetite will be formed; instead, fayalite (or even metallic iron), precipitates (Hauptmann 2014, p. 102).

Several copper sulphides liquefy at 900°C, or even lower temperatures, so that many droplets originate from only partially melted slag, accumulating into a sort of cake at the bottom of the furnace. These prills, composed by copper sulphides enriched in copper, also known as "matte" (Hauptmann 2014, p. 103), needed to be reprocessed by further smelting to be turned into copper metal, or even into ingots. It is sometimes possible to recognise a negative imprint left by the matte ingot at the bottom of the slag (Hauptmann 2011: 191).

However, intergrowths between copper and copper/iron sulphides are not necessarily evidence for a deliberate matte smelting; they could be the result of a casual smelting of mixed oxidic and sulfidic ores. Nevertheless, the so-called “roasting” process used to oxidise sulphur in sulfidic ores is difficult to identify from an archaeological point of view.

4.4 Cypriot copper ores and ancient slags

The pillow lavas (fig. 4.4) that characterise the Troodos Range are the geological formation where the vast majority of copper can be found in Cyprus, occurring as sulphidic ores in conjunction with iron pyrite.

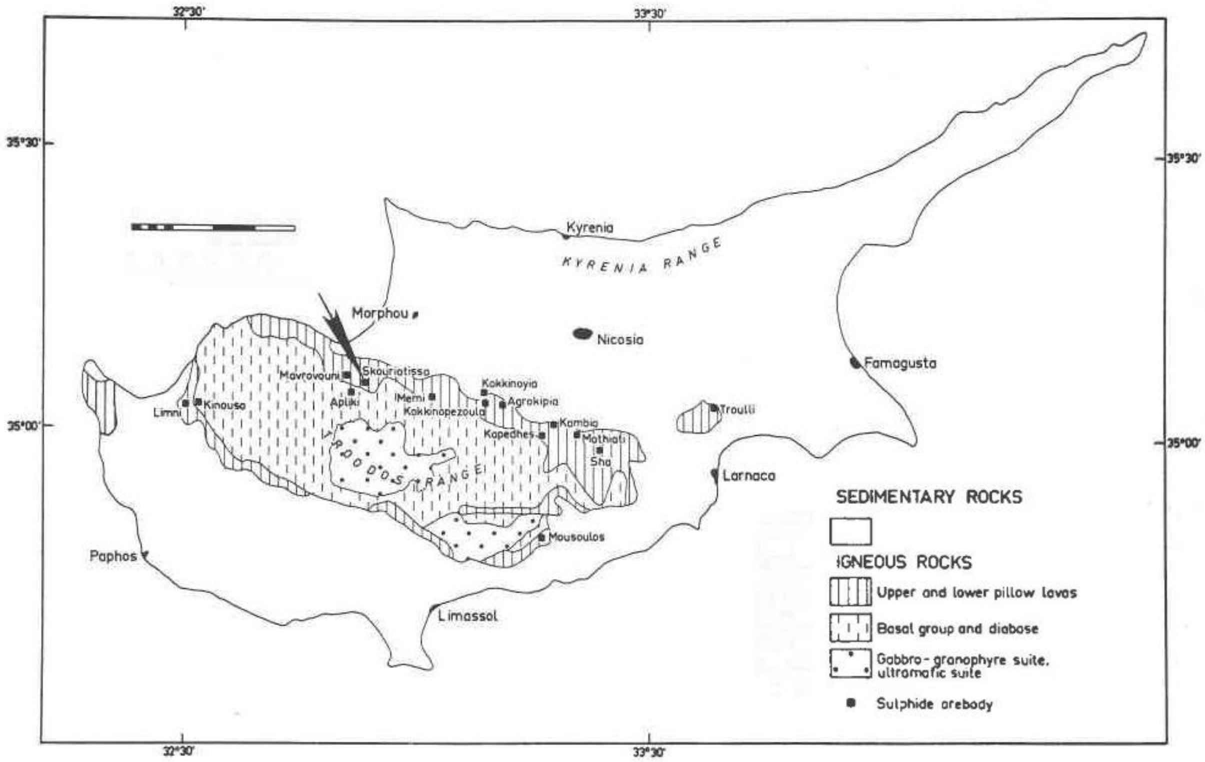


Figure 4.4 Location of major sulphide orebodies in the Troodos Pillow Lava Series (after Constantinou 1975, p. 1014).

The main concentrations of cupriferous ore deposits are located in the mine districts of Skouriotissa, Mitsero, Tamassos, Kalavassos and Limni (fig. 4.4). Most of the ore is massive pyrite and marcasite, with chalcopyrite, bornite and chalcocite, enriching it towards the top to about 3% Cu. Their average Cu content ranges from 0.5 to 5%, but this varies considerably, not only from orebody to orebody, but also in different layers of the same orebody. Some zones of secondary enrichment may contain from 8% to 25% of copper (Constantinou and Panayides 2013: 19), with the exceptional content of 30% in Kambia (Gale et al 1996: 365).

Unlike the deposits of Spain, Italy, Greece, Turkey, Saudi Arabia and Oman, the Cypriot massive sulphide ores have a conglomeratic structure, consisting of solid sulphide blocks, embedded in a matrix of friable sandy, sugary sulphides (Gale et al 1996, p. 365, Constantinou and Panayides 2013, p. 17).

The primary Cypriot sulphides ores are: iron pyrite and chalcopyrite with minor sphalerite, while the secondary enriched ore assemblage includes:

- Cu Sulphides: chalcopyrite ($CuFeS_2$), covellite (CuS), digenite ($Cu_{2-x}S$), chalcocite (Cu_2S), bornite (Cu_5FeS_4), idaite (Cu_5FeS_6), tennantite ($Cu_{12}As_4S_{13}$);
- Cu Oxides: cuprite (Cu_2O), tenorite (CuO), paramelaconite (CuO) and delafossite ($CuFeO_2$);
- Cu Sulphates: chalcanthite ($CuSO_4.5H_2O$) and brochantite ($Cu_4(OH)_6SO_4$).

Gale et al. (1996) state that no copper carbonates nor silicates have been found in any of the Cypriot sulphide ores, not even in zones of very high secondary enrichment, but this does not exclude the existence of this type of ores in “amounts sufficient to be potentially important for the production of copper in the Early/Middle Bronze Age” (Gale et al. 1996, p. 365).

Constantiou and Panayides report the occurrence of diabase covered in coatings of malachite, azurite, chalcocite and minor cuprite in the areas of Pyrgos, Monoagrulli and Louvara (fig. 4.5).

Figure 4.5 Diabase covered in coatings of malachite from Pyrgos-Mavroraki *(photo ©M.R. Belgiorno)*

These mineral formations are due to the reaction between supergene acid solutions, rich in copper sulphates, sulphuric acid and iron, and the calcium aluminosilicates of the diabase. According to Constantinou and Panayides (2013, p. 16), the highly visible and very colourful copper carbonates were exploited in the early stages of Cypriot metallurgy through simple crucible smelting.

Native copper (see chapter 2, section II) is much rarer in Cyprus. Samples of native copper have been recorded from Kalavassos, Mavrovouni, Old Sha mine, Monoagrulli, Kokkinorotsos, Pitharo-Homa, Peristerka and Limni (Gale et al 1996, p. 365).

It is important to mention another particular copper ore deposit located in the plutonic complex of the Limassol Forest, in the localities of *Pevkos* and *Laxia tou Mavrou*, not very far from the site of Pyrgos-*Mavroraki*. Here we find a polymetallic mineralisation in the form of lenses, veins and disseminations of sulphides and minor arsenites. This mineralisation is rich in chalcopyrite and cubanite and the general chemical composition for *Pevkos* ores is 30% S, 2-13% Cu, 1% Ni and 0.7% As (Webb and Frankel 2013, p. 15). This is the only polymetallic Cu-As-S formation in Cyprus and it has been suggested that it could have been a source for the typical arsenical copper artefacts produced on the island in the Early/Middle Bronze Age.

Not many ores samples have been found within the archaeological record of the early metallurgical sites of Cyprus. At present, Ambelikou-*Aletri* and Alambra-*Mouttes* are the only Early/Middle Bronze Age metallurgical sites where geological material has been recovered. Three lumps from Ambelikou-*Aletri* of what could be interpreted at a first sight as ores or slags from this site were microscopically observed and analysed by electron microprobe for the first time by Zwicker et al (1981), but chemical analyses were reported for two only, (Lump 1-2). As part of the recent publication of the old excavation at Ambelikou-*Aletri* by Webb and Frankel (year), Georgakopoulou and Rehren (2013, p. 198) reanalysed the first two lumps (the third one was not found among the materials kept at the Cyprus Museum) already investigated by Zwicker's team.

The first lump was found to be manganese oxide, while the second consists of a "mixture of copper ore or roasting products" (Webb and Frankel 2013, p.183). The samples analysed by Georgakopoulou and Rehren were initially exported by Sven van Lokeren, who prepared polished sections, unfortunately labelled without a direct accordance to the relative list of samples exported. For the same reason it is not therefore possible to match the analyses carried out by Zwicker's team and those of Georgakopoulou and Rehren; only mere speculations could be suggested, according to the main chemical components which point to interpret Lump as n. 839 and Lump 2 as n. 470 (Fig. 4.6) in Webb and Frankel's catalogue (see tab. 1).

*Figure 4.6 Ore lump from Ambelikou-*Aletri*, n. 470 in Webb and Frankel catalogue (2013: 183) (photo by the author)*

Some major differences occurred between the two analytical projects, mainly regarding the content of sulphur, higher in Zwicker team's analyses (see tab. 4.2).

While in Zwicker team's analysis of Lump 2, the sulphur content reaches up to 19%, in Georgakopoulou and Rehren's analyses, in all five samples, it is less than 1%. This might suggest that sulphidic copper ores were smelted at Ambelikou; however, the analyses carried out cannot fully support the evidence for an intermediate smelting stage at the site.

Table of Samples Correspondeces		
Zwicker et al. 1982	Georgakopolou and Rehren 2013	Webb and Frankel 2013 (inv. n.)
Lump 1	AMB1-3	839
Lump 2	AMB2-5	470
Lump 3	?	Not found

*Table 4.1 Ambelikou-*Aletri *samples' definitions in different authors.*

Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**	**BaO**	**PbO**
Zwicker et al. 1982 *(--: non detected; n.r.: non reported in the original paper; b.d.l.: beyond detection limits)*															
--Lump 1 P1	--	--	--	--	--	--	--	65.0	0.8	--	--	--	--	--	--
Lump 1 P2	--	--	--	--	--	--	0.5	0.3	44.0	--	--	--	--	--	--
Lump 1 P3	--	--	--	--	--	--	--	0.5	55.0	--	--	--	--	--	--
Lump 2 P1	--	--	--	--	3.8	--	--	--	--	--	28.0	28.0	--	--	--
Lump 2 P2	--	--	--	--	19.0	--	--	--	--	--	11.0	28.0	--	--	--
Georgakopoulou and Rehren 2013															
AMB1	n.r.	0.5	0.1	0.5	0.9	0.1	n.r.	5.4	n.r.	81.8	0.3	b.d.l.	0.3	1.8	n.r.
AMB2	n.r.	3.4	0.4	1.8	0.6	b.d.l.	n.r.	3.6	n.r.	b.d.l.	47.0	39.6	4.3	b.d.l.	n.r.
AMB3	n.r.	0.8	0.3	1.1	0.2	0.1	n.r.	34.7	n.r.	50.6	0.8	11.2	0.3	0.4	n.r.
AMB4	n.r.	0.2	0.1	4.2	0.3	b.d.l	n.r.	0.2	n.r.	b.d.l.	76.8	10.7	0.2	b.d.l.	n.r.
AMB5	n.r.	0.1	0.4	1.5	0.4	b.d.l.	n.r.	0.2	n.r.	b.d.l.	73.8	18.8	0.4	b.d.l.	n.r.

Table 4.2 Electron microprobe analysis of Lump 1-2 by Zwicker et al. (1982: 65, tab.1); results os semi-quantitative chemical analyses using WD-XRF after Georgakopoulou and Rehren (2013: 198).

Geological samples were found at the site of Alambra-*Mouttes*, where thirteen copper ores were analysed by electron microprobe and Instrumental Neutron Activation Analysis (INAA). The samples all proved to be carbonate ores with malachite as the main copper ore, bearing from 10% to 50% Cu. The data from Alambra proved that in the Early Bronze Age, copper ores originated by secondary oxidation were smelted in Cyprus. Gale et al. suggested that some sort of iron flux should have been used to smelt these types of ores (1996, p. 370), in order to facilitate the slag formation and increase the copper yield.

Considering that most of the analyses published on Cypriot copper ores were aimed at modern industry and would probably not have been of much importance in the Bronze Age, to allow effective comparisons, Gale's team analysed a series of rich oxidised and sulphidic copper ores from Cyprus, which could have been selected by the ancient coppersmiths for smelting. The minerals were collected from the mines of Agrokipia, Apliki, Kambia, Limni, Skouriotissa, Peristerka, Pitharo Homa, Sha and Troulli. The Cu content varied from a minimum of 2.7%, for the oxidic ores and 4.4% for the sulphidic ores, to a maximum of 98.0% for the oxidic ores and 37.7% for the sulphidic ores (1996, p. 406-7).

4.4.1 Cypriot Ancient Slags: an Overview

Ronald F. Tylecote (1971), one of the "fathers of archaeometallurgy", first described slags from the ancient slag-heaps of Ora, Kalavassos and Kition, Cyprus. Soon afterwards, Zwicker's team (1972) extended the number of samples analysed. The vast majority of the slags analysed up to then was sampled from the large slag heaps distributed along the ring-shaped pillow-lava formations located around the volcanic protrudence of the Troodos. Arthur Steinberg and Frank Koucky (1974; 1982a; 1982b) published more on Cypriot slags, including slags from archaeological settlements such as Enkomi, Kition and, particularly Idalion, suggesting an attempt of typological classification.

These studies clarified a few important questions. The slag-heaps found in Cyprus, although constantly endangered by modern quarrying and mining activities, present an evident stratification, which could be dated through the archaeological material found in each stratigraphic context. The slags, once distinguished merely into Phoenician and Roman types, were then more accurately reorganised in a typology of seven sub-categories, part of three main groups has been suggested (Table 4.3).

	**Nodular shaped (N) semi ovaloid** Highly oxidised. Manganese concretions closely resemble this type of slag. "Votive" slags from Athienou.
	**Crucible shaped (C) variable interior**

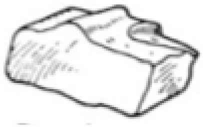
	Many are heterogeneous, multi-coloured. Interior has charcoal impressions, Cu-prills, prills of Cu-sulphide. Surface oxidised, brown. Enkomi, Kition, Idalion.
 Flat surface with ridges and/or holes  Flat with shallow v-indentations	**Highly oxidised blockey (P)** Red slags, formerly called "Phoenician". Interior usually dark brown. Skouriotissa, Platies, Kokkinoyia.
	Slightly oxidised blockey (B) Most fragments have flat surface. Exterior dark brown, interior black. Similar to (P). Platies, Petra, Sha.
	**Non-oxidised collapsed ropy Mn-rich (M)** Fresh, nearly unaltered. Silver black color. Surface flow structure subdued compared to (R) type. Surface often knobby. Spilli, Teredhia, Skouriotissa.
	**Glassy blocky conchoidal fracture (G)** Black, resembles obsidian. Gray weathered surface. S. Mathiati.

Table 4.3 *Classification of Cyprus slags (adapted after Koucky 1982b: 309, fig. 5)*

Type N (nodular slags), at the time of its publication (Koucky 1982), included just one fragment found on the surface in the area of Kalavassos, near a Middle Bronze Age site. The fragment was described as small, nodular and black; and it was distinguished from the various fragments of natural pyrolusite (MnO_2) which often occurs on the flanks of the Troodos (Koucky and Steinberg 1982a: 117).

More information was given on the main characteristics of the second Type C (crucible-shaped slags). These slags were recovered more frequently in the city-sites (Enkomi, Kition and Idalion) and rarely close to the mines. Easily recognisable for its characteristic curved base, these types of slags rarely exceed a 12-13 cm diameter and 5-6 cm thickness. Crucible slags can be heterogeneous, where the distinct portions of material differ in colour (red, yellow and brown oxidation) with irregular, large porosities (Bronze Age), or more homogeneous both in colour and texture (Cypro-Classical). In both categories of crucible-slags, it is possible to find congealed copper and sulphide prills, usually highly altered in weathered samples. This type of slag was interpreted as the result of a small batch operation, such as the copper refining, instead of primary smelting.

Slags pertaining to Types N and C were left to cool down slowly inside the furnace, while the other five types P (Blocky shaped – Highly oxidised), B (Blocky shaped – Slightly oxidised), R (Ropy surface – Irregular shape), M (Collapsed Ropy – Mn-rich) and G (Glassy slag – Blocky – Conchoidal) were "tapped out" of the furnace (Koucky and Steinberg 1982a: 118-119).

This classification allowed scholars to understand that the major slag-heaps are stratified and each level is usually marked by a *hiatus* in the smelting operations (Koucky and Setinberg 1982a: 120).

There are no new studies of early Cypriot slags until the end of the "1990s", with the exception of the remains adhering to a crucible fragment from **Ambelikou-*Aletri***, analysed by Zwicker et al (1981: 337-8; Zwicker 1982: 63). According to the high purity of the copper, it was suggested that the crucible was used for re-melting copper prills obtained during the smelting process.

Among the archaeometallurgical remains from Ambelikou-*Aletri*, Webb and Frankel described a piece of slag, dark brown to black with an irregular bubbly surface and a smooth glassy appearance [*with some*] green staining and "incrustation" (2013: 183-184). They suggested that it belongs to the tap-slag category because of its "flow structure". Unfortunately, no microstructural and chemical analysis were published for this slag.

Since the 1980s, the most relevant contribution to the knowledge on Early/Middle Bronze Age slags was the study of the metallurgical discard from the site of **Alambra-*Mouttes***, which is contemporary to Pyrgos-*Mavroraki*.

Both copper ores and slags from this site were analysed by electron microprobe and instrumental neutron activation analysis (INAA). The ores were seen to be all carbonate with malachite as the chief copper mineral. The sulphur content of the copper ores analysed is very low (Table 4.4).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	P_2O_5	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO	BaO	PbO
A 1001	0.4	3.9	6.7	28.0	0.7	0.3	1.1	9,66	0.6	0.3	37.8	1.5	0.3	0.9	0.1
A 1002	0.4	7.5	9.2	39.2	0.0	0.2	1.4	9,31	0.3	0.5	14.8	10.0	0.0	0.1	0.0
A 1005	0.2	4.4	6.6	27.2	0.4	0.3	0.6	5.8	0.5	0.1	29.0	17.9	0.0	2.6	0.0
A 1006	0.0	2.1	5.4	33.4	0.3	0.3	0.6	8.2	0.3	0.2	30.6	8.9	0.2	1.0	0.0
A 1007	0.0	5.7	6.7	30.9	0.1	0.2	0.3	4.8	0.3	0.1	31.3	14.3	0.1	0.2	0.0
A 1008	0.0	3.0	3.8	60.7	0.0	0.3	0.4	6.4	0.3	0.2	17.3	5.6	0.1	0.1	0.0
A 1009	0.6	7.8	10.9	42.9	0.0	0.2	0.7	8.7	0.5	0.2	11.2	11.6	0.0	0.1	0.0
A 1010	0.2	5.3	6.2	26.9	0.0	0.4	0.8	9.1	0.2	0.2	35.0	5.6	1.1	0.1	0.0
A 1011	0.2	3.8	4.5	21.8	0.3	0.2	0.6	7.1	0.2	0.2	27.2	7.2	0.4	0.2	0.0
A 1012a	0.0	2.0	5.3	37.4	0.2	0.4	0.5	8.5	0.2	0.1	10.1	21.6	0.0	0.2	0.0
A 1012b	0.0	2.2	6.3	27.5	0.2	0.2	0.7	10.0	0.2	0.1	17.0	19.9	0.0	0.2	0.0
A 1013	0.0	2.3	6.1	33.9	0.2	0.1	0.6	4.0	0.3	0.1	16.2	26.8	0.0	0.4	0.0
A 1014	0.3	1.9	9.2	36.5	0.1	0.5	1.4	8.9	0.3	0.1	14.5	19.9	0.0	0.2	0.1
A 1028	0.9	8.6	12.1	36.6	0.2	0.9	0.5	6.5	0.7	0.5	22.7	6.9	0.1	1.7	0.0
A 1030	0.2	3.2	8.4	29.2	0.0	0.2	1.2	6.0	0.3	0.3	12.6	27.5	0.0	0.1	0.0
A 1031	0.6	5.7	12.6	45.0	0.0	0.2	0.7	8.7	0.5	0.2	19.6	5.8	0.1	0.1	0.0
Lot A 12(5)	0.1	4.0	8.0	26.7	0.1	0.3	0.8	8.6	0.6	0.2	31.5	17.6	0.2	1.8	0.0
Lot A(88)	0.1	1.9	10.8	24.8	0.0	0.2	0.9	2.6	0.6	0.1	39.2	13.1	0.0	1.9	0.0
MEAN	**0.2**	**4.2**	**7.7**	**33.8**	**0.2**	**0.3**	**0.8**	**7.1**	**0.4**	**0.2**	**23.2**	**13.4**	**0.1**	**0.6**	**0.0**
STDEV	0.3	2.2	2.6	9.3	0.2	0.2	0.3	2.1	0.2	0.1	9.6	7.7	0.3	0.8	0.0
RSTDEV	114.7	51.6	33.7	27.4	118.0	58.8	43.9	29.2	45.0	58.4	41.2	57.3	187.4	123.8	83.0

Table 4.4 Bulk chemical analyses of slags from Alambra (after Gale et al 1996: 418)

The slags were divided in two main categories: slags found adhering on crucible fragments, defined by the authors as "crucible slags" found adhering to crucible fragments, and isolated slag fragments.
The bulk chemical composition of eighteen slags was calculated with the same method applied to the ores, but petrographic analyses on polished thin sections were also carried out under the microscope to assess mineral phases. The slags were found to be oxidic, with very low sulphur content (<1.0%) and were interpreted as the result of a small-scale extractive copper metallurgy carried out in crucibles and based on non-sulphidic ores.

The Middle Bronze Age sites of **Politiko-*Troullia*** (Fall et al. 2008: 195-196) and **Kissonerga-*Skalia*** have also produced metallurgical waste (Lindy Crewe's personal communication); together with the crucible fragments from **Kalavassos-*Laroumena*** (Todd 1988: 135, 139-140; 2013, pp. 25-26; South 2012, p. 37) and the very unusual find of tap-slags from **Katydhata-*Laonarka*** (Kassianidou 2008, pp. 255-256). The microstructural and chemical analysis of these slags might uncover a very early example of tapping-technology in the Early/Middle Bronze Age Cypriot metallurgy.

No other Early/Middle Bronze Age Cypriot slags, but those from Alambra, have been studied to date. Hauptmann (2011) published the analyses on seven samples from the later sites of **Kition** and **Enkomi** and Knapp and Kassianidou (2008), presenting preliminary results on the study of the slags from the LCI primary smelting site of **Politiko-*Phorades***.

The next important analytical plan carried out on Cypriot Bronze Age slags, is that by Kassianidou and Van Brempt (2016). The authors published the metallurgical waste from the Late Bronze Age site of **Kalavassos-*Aghios Dimitrios***. Despite the later date of this site in comparison to Pyrgos, the analyses carried out on *Aghios Dimitrios*'s slags have been considered in this study as a highly valuable term of comparison both in terms of method and research outcomes.

Unlike Pyrgos, within the metallurgical assemblage of Kalavassos-*Aghios Dimitrios* two main slag types were identified: furnace-slags (formed inside the furnace) and tap-slags (tapped out of the smelting reactor). Furnace-slags appear as heterogeneous large lumps, covered in layers of different inclusions and products of corrosion. Their microstructural composition is characterised by a rather homogenous and crystalline slaggy matrix, containing different mineral inclusions, charcoal and rare metallic inclusions. The surface looks rough and a few of the largest lumps may show a possible plano-convex shape.

On the other hand, tap-slags show a very characteristic flow texture on the preserved upper surface; they are dark in colour and sometimes they present an internal layered structure with metallic inclusions a few mm in size. Most of these fragments have a plano-convex shape which probably corresponds to a bowl-shaped pit of about 15 cm in which the slags were likely "tapped".

Thirteen fragments of tap-slags and fourteen fragments of furnace-slags from Aghios Dimitrios were selected for microscopic and chemical compositional analysis. One of the main differences identified between the two types is the frequent presence of unreacted ore and large phases of iron- and copper-sulphides in furnace-slags. In contrast, tap-slags, instead, are characterised by the presence of elongated lath-shaped fayalite crystals, which indicates fast cooling (Van-Brempt and Kassianidou 2016: 542).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	P_2O_5	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO	BaO	PbO
Tap-slags															
MEAN	**1.1**	**1.9**	**6.2**	**23.0**	**5.3**	**n.r.**	**0.6**	**2.5**	**0.3**	**n.r.**	**57.0**	**1.5**	**n.r**	**n.r**	**n.r**

STDEV	0.7	0.4	1.2	3.5	2.0		0.1	1.0	0.1		4.4	0.7			
Furnace-slags															
MEAN	**2.2**	**1.8**	**9.9**	**33.6**	**1.8**	n.r.	**0.8**	**3.6**	**0.4**	n.r.	**43.8**	**1.2**	n.r.	n.r.	n.r.
STDEV	1.0	0.6	2.8	5.5	0.9		0.3	1.3	0.2		8.3	1.1			

Table 4.5 Average chemical composition of the Fe-silicate phases of the samples of tap-slags and furnace-slags, determined by SEM-EDS (adapted by Van Brempt and Kassianidou 2016: 549)

Defined prills of metallic iron/copper sulphides have been located and identified as *matte* (Fig. 4.7), which was possibly the semi-product outcome of the smelting activity carried out at Kalavassos-*Aghios Dhimitrios*.

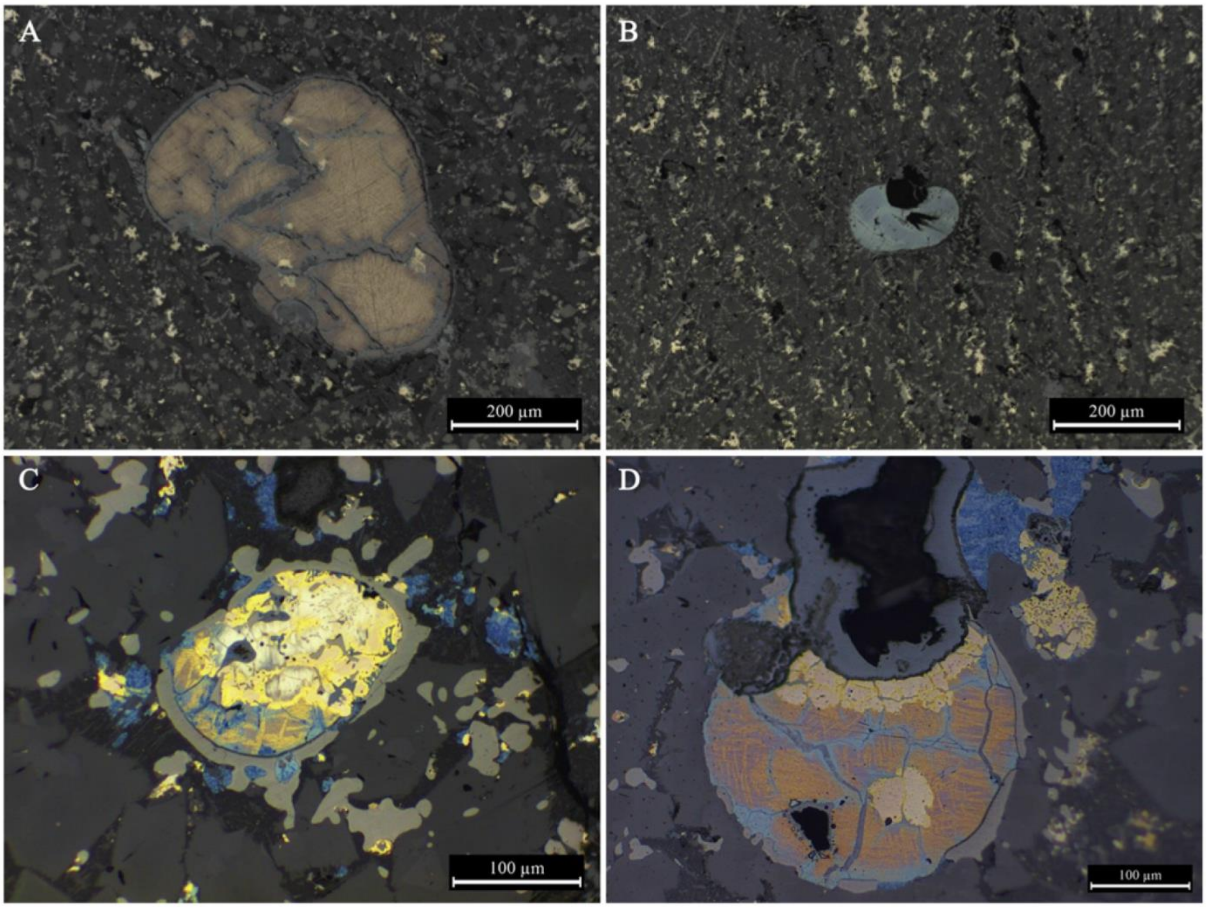


Figure 4.7 Photomicrographs (mag.100x and 200x) of tap-slags showing matte prills (Van Brempt and Kassianidou 2016: 546, fig. 9)

4.5 Previous Approaches to the study of Pyrgos-*Mavroraki*'s slags

The "Pyrame" (Pyrgos Archaeological and Archaeometallurgical Research) research project was carried out on site (Belgiorno 2000), aiming to identify and preserve the archaeometallurgical evidence found at Pyrgos. It involved a preliminary archaeometric study of a small selection of slags and artefacts, both from the settlement and from the necropolis.

While the chemical analyses were carried out on all the metal artefacts known at the time (Giardino et al 2002)[1], less attention was paid to the large amount of slags found on site. Belgiorno mentions that some slag analysis was carried out by the Chemical Engineering Department of "La Sapienza" University in Rome (Belgiorno 1998: 296) and other research institutions (Belgiorno 1999c: 295) but the data was not published. Belgiorno briefly describes the main macroscopical features of the slags, stating that they never exceed 10 cm in size (Belgiorno 1998: 296); she suggests that they were probably intentionally crushed in order to collect the large amount of copper prills still trapped in their glassy matrix. This hypothesis is supported by the vast amount of stone tools such as grinders, mortars and pestles, recovered all over the site, especially near the furnaces.

In a preliminary paper (2002), Giardino describes the microstructural composition of some slags from Pyrgos, analysed by different techniques (ED-XRF; XRD; OM; SEM-EDX; FTIR Fourier-Transform Infrared Spectrorscopy), without providing the number of samples analysed and other useful information such as the inventory number and the reasons for the selection. He mentions the context of some of the finds in the captions of a few pictures (Giardino 2000, p. figs. 1, 3-7, 9). The author describes the slags as black in colour on freshly exposed surfaces and notes the presence of green "inclusions of secondary copper minerals". The slags are described as chunky, "rather heavy" and, based on their appearance, the author suggests that they originated inside the furnace (Giardino 2000, p. 21). Considering their fragmented state, the author confirms what was stated by Belgiorno, *i.e.* that the slags were broken in prehistory to collect the copper prills still trapped within the glassy matrix (Giardino 2000, p. 23). Fayalite lath-shaped crystals were also detected in the slags (Fig. 4.8), as well as "some additional particles of metallic copper" (Giardino 2000, p. 26, fig. 7), showing that the slags must have been cooled inside the furnace.

[1] See Ch. 5.

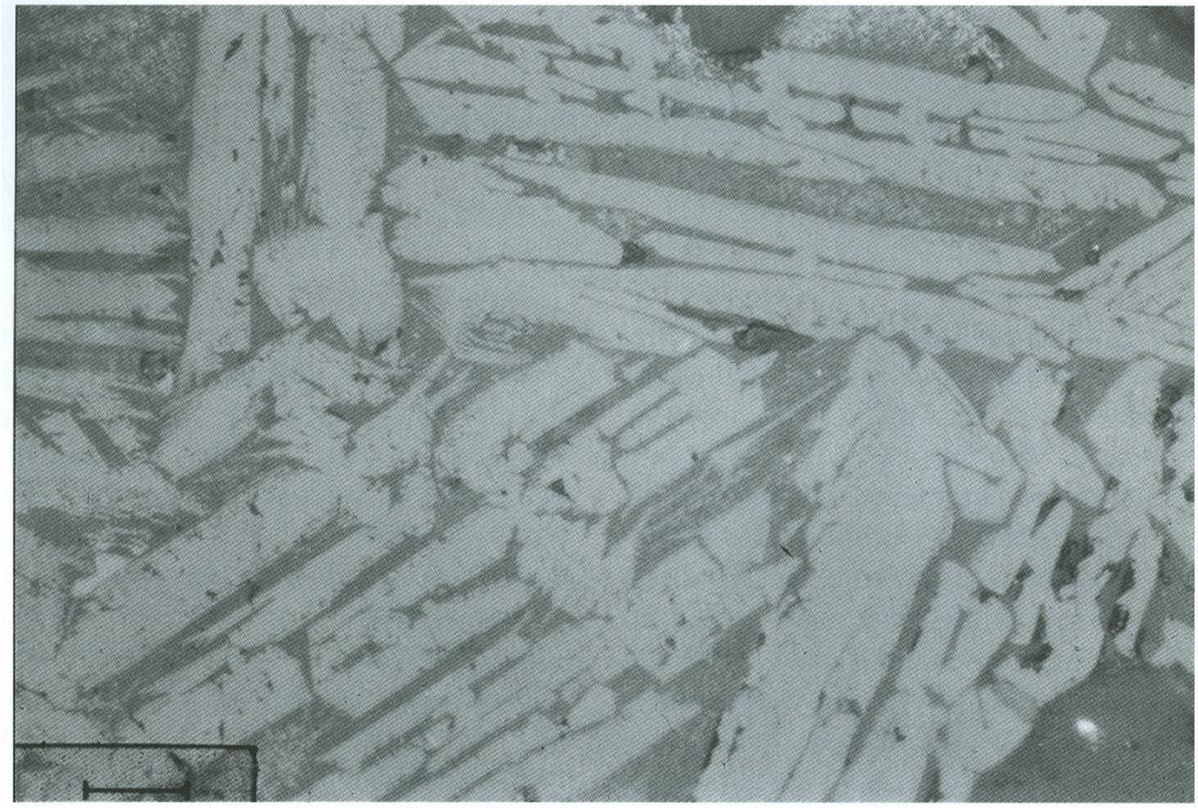


Figure 4.8 Fayalite laths in a slag from Pyrgos-Mavroraki (Giardino 2000: 20, fig.1)

Moreover, Giardino observed crystals of Wüstite and fragments of copper sulphides interpreted as Covellite, Chalcocite and Chalcopyrite. The author considers "the excess of iron minerals and the presence of sulphide ore" as indicators of a possible multi-stage metallurgical process that took place in the same furnace but using different redox conditions. The presence of cuprite around fragments of copper sulphide was considered as a further indication of the oxidising conditions (Giardino 2000: 23-24, fig. 6) obtained in the furnace during a possible preliminary roasting process (Giardino 2000: 23). However, according to Van Brempt's observations in regards to the slags from Kalavassos-*Aghios Dimitrios*, Cuprite formations could have also originated as corrosion products. Large fragments of quartz, interpreted as part of the gangue (the non-metal bearing component of the mineral), were also detected. Unfortunately, no chemical composition data that could be used in this study as a comparison was reported in the paper.

Subsequently, Giardino and Rovira (2007) carried out some preliminary archaeometric analyses (OM; SEM-EDX) on just five slags. The samples' labels indicated in their paper (CY991; CY992; CY993; CY997; CY99A1), do not match up with any inventory numbers provided by the excavator to the author of the present study, but they are all reported as coming from different levels of the Northern Sector (H-I-J/2-3).

The authors describe the slags as usually heterogeneous, characterised by a dark grey or black colour in section, still very rich in copper, as shown by green and blueish spots of copper salts, visible on the outer surface (Giardino & Rovira 2007: 2). It is mentioned that the slags are strongly magnetic.

Fayalite crystals, both lath- and blocky-shaped were recorded, in the presence of abundant Magnetite. Ore relics were also found, interpreted as Chalcopyrite and Chalcocite. Table 4.6 reports the bulk chemical compositions of the five samples analysed by Giardino and Rovira. Their validity for comparison is though limited by the fact that no information is available about the devices and settings that were used for the analysis and the analytical protocol followed.

Site/Sector	**Sample**	**Weight percent (wt%)**													
		Na_2O	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl_2O**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
Pyrgos/North	**CY991**	0.0	0.0	2.6	10.3	0.4	1.1	0.0	0.0	0.0	0.0	0.0	77.1	8.4	0.0
Pyrgos/North	**CY992**	0.0	1.7	6.0	20.9	1.1	0.0	0.6	0.27	0.91	0.0	0.0	63.8	4.7	0.0
Pyrgos/North	**CY993**[2]	0.0	1.3	5.2	18.9	1.3	0.3	0.0	0.3	0.9	0.0	0.0	65.8	5.6	0.0
Pyrgos/North	**CY997**	0.0	0.7	3.0	22.4	1.8	0.2	0.0	0.2	1.4	0.0	0.0	63.9	6.4	0.0
Pyrgos/North	**CY99A1**	0.0	1.8	2.4	31.6	1.3	0.3	0.0	0.3	3.8	0.0	0.0	55.7	2.9	0.0
MEAN			**1.1**	**3.8**	**20.8**	**1.2**	**0.4**	**0.1**	**0.2**	**1.4**	**0.0**	**0.0**	**65.3**	**5.6**	**0.0**
STDEV			0.8	1.6	7.6	0.5	0.4		0.1	1.4			7.7	2.0	
Inter RSTDEV			68.3	42.7	36.7	43.0	111.1		58.6	102.4			11.8	36.4	

Table 4.6 Bulk chemical analysis of Pyrgos's slags (adapted after Giardino and Rovira 2007: 6, tab. 6). The content of Cl was expressed as as Cl_2O in the original publication.

These results once again confirm that the smelting performed at Pyrgos involved mainly sulphide copper ores, testified by the presence of many fragments of unreacted minerals. Giardino and Rovira interpreted the presence of magnetite, which points to an oxidising atmposphere in the furnace (Giardino and Rovira 2007, p. 3), and the consistent copper loss within the slag as indicators of a primitive process running in unstable redox conditions. Once again, the hypothesis of using the same furnace for both roasting and smelting the ores was suggested, this time noting the absence of fire structures interpretable as roasting beds, in contrast with what was previously stated by Belgiorno (Belgiorno 1997b, p. 282).

According to Giardino and Rovira, despite the advanced capacity to smelt copper sulphides, the technology sustaining Pyrgos's metallurgy seems to be quite primitive and accompanied

[2] For this sample Giardino and Rovira collected the bulk composition through two readings within the same slag. Here we report a mean calculated between these two readings.

by a difficulty in mastering the control of the redox atmosphere inside the furnaces (2007, p. 5).
The high content of copper and sulphur is higher when compared with the results shown in paragraphs 4.6.1-2; this could be due to the specific analytical protocol adopted by Giardino and Rovira, who might have included considerable Cu/S features in the area of the bulk-analysis.
Overall, the past analyses pointed out that sulphidic copper ores were smelted at Pyrgos, using a technology which did not allow to fully control the reduction conditions inside the furnace. However, the past analyses were the outcomes of single studies and not part of a systematic analytical programme that considers the entire archaeological context and assemblage found at Pyrgos.
Considering the preliminary analyses on the archaeometallurgical materials from Pyrgos carried out in the past, it appears essential to draw a multi-analytical scientific protocol in order to extend the poor catalogue of compositional analyses available. The systematic study of a larger amount of slag samples selected from the different areas of the site aims to clarify the presence of different slag types eventually related to different metallurgical activities and their distribution within the different areas of the site.

4.6 The metallurgical slags from Pyrgos: Analytical Protocol and Macroscopic Grouping

As part of this research, I examined 1713 slags from the settlement of Pyrgos-*Mavroraki*, thirty-five slags from four archaeological soundings on Mavroraki's hill and fourteen slags collected during the survey carried out South of Mavroraki, in the Aulaki area, just across the Pyrgos river.
I divided the entire excavation of Pyrgos in six different sectors, following the ones established by the excavator, except for the Sector "Beyond The Road (B.T.R.)", which has been considered altogether due to the low density of metallurgical activity evidence. These sectors were described in chapter 3: Northern Sector (H-J/2-4; K4); Central Sector (H-J/5-6; I-J/7a-b); Western Sector (D-G/5-8); Eastern Sector (K-M/5-7); Southern Sector (H/7; I-J/7c-d; H-L/8; H/9a-b; I-J/9); Sector Beyond The Road (B-G/9-11; H/9c-d; H/10-11).
I then divided the slags according to their provenance, calculating their density in slags per square meter. These preliminary observations are summarised in Table 4.7.

SECTOR	AREA sqm	PIECES	WEIGHT Kg	DENSITY slag/sqm	SHAPED slags	OTHER METALLURGICAL FEATURES
NORTH	93.75	455	11.5	4.9	3	Furnaces; Crucibles (2)
CENTRAL	83.75	313	7.4	3.6		Mould (1)
WEST	120	310	10.5	2.6	1	Furnace (for annealing?); crucibles (10); moulds (2)
EAST	83.75	65	2.2	0.8	2	Crucible (1); moulds (3)
SOUTH	70	148	4.5	2.1	1	Furnaces; crucibles (9); moulds (3); blow-pipe nozzle (1); nozzle holders (3)
B.T.R.	180	422	12.4	2.3	6	Crucibles (7); moulds (2); blow-pipe nozzles (2)
Total		***1713***	***48.4***			
Mavroraki	20	35	1.8	1.8		Moulds (2)
Aulaki	--	14	0.9	--		
Total		***49***	***2.8***			

Table 4.7 Slag quantities from Pyrgos-Mavroraki.

As mentioned above, the stratigraphy of this site is still in study by the excavator and the stratigraphic data for the slags object of this study were kindly provided by the excavator, Dr Belgiorno. The percentages of slags recovered in the archaeological levels increase if compared with that one relative to the surface (Fig. 4.9).

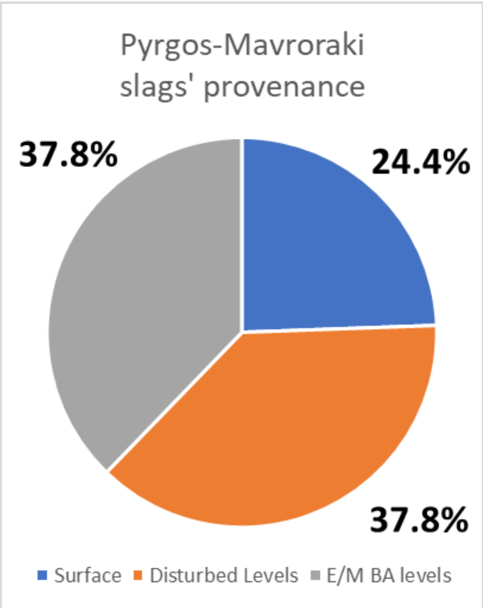


Figure 4.9 Slag's provenance percentages.

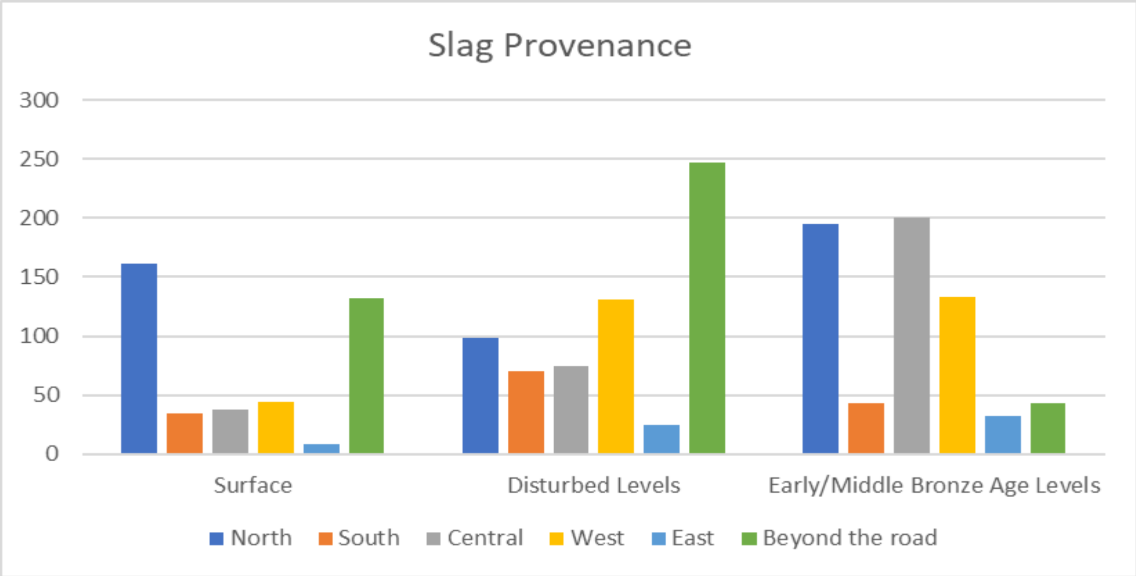


Figure 4.10 Level-distribution of Pyrgos's slags in the different sectors.

The Northern Sector, where a series of possible furnaces were found, is the richest in number and density of slags, while in the Southern Sector, despite the presence of furnaces, the density of slags is very low compared to the other sectors (fig. 4.10). This might be due to the different nature of the metallurgical processes carried out in this sector, or to an intentional attempt to keep this area clean from slags, accumulated or dumped elsewhere. While we can assume that the Northern Sector was dedicated to smelting, the Southern Sector's metallurgical finds, such as the flat-axe moulds, still in their furnace, might be considered as an indicator that casting was performed in this area. Together with the Northern Sector, the Central Sector produced the highest number of slags from its Early/Middle Bronze Age levels. This is quite surprising, considering that no metallurgical structures were found in this area of the site. Moreover, the slags have been found scattered all over the site, and this might be explained if one looks at the slope of the site. The Northern Site is on a higher slope level compared to the South, which is closer to the riverbed.

The orography of the site might have caused the displacement of the slags over time, from a higher to a lower altitude, until they were scattered on the entire site's surface. This could also explain the high number of slags found in the disturbed levels in the area named as "beyond the road"; these might have accumulated here after centuries of natural erosion of Early/Middle Bronze Age levels, located somewhere in the northern, more elevated areas of the site.

Omitting the smallest fragments, **836** samples were photographed and subsequently divided into three main typological categories (Viscous Type – VT; Coarse Type – CT; Mix Type –

MIX). Only 1% of the entire assemblage was represented by very minute fragments of slags and for this reason was not included in the typological categories (XT), because their size would have caused the impairment of an accurate assignment into the macroscopic groups. A further 6%, composed by minerals or misinterpreted stones was also discounted (tab. 4.11).

SECTOR	**Slags Photographed**	**Viscous**	**Coarse**	**Mix**	**Unidentified**	**Minerals/ stones?**
NORTH	215	127	42	30	3	13
CENTRAL	109	69	18	18		4
WEST	169	85	43	31	1	9
EAST	24	19	3	2		
SOUTH	111	66	23	14		8
B.T.R.	159	96	35	16	2	13
Mavroraki	35	26	8		1	
Aulaki	14	7	5			2
TOTAL	***836***	***495***	***177***	***111***	***7***	***49***

Table 4.8 Slag Typology distribution tables.

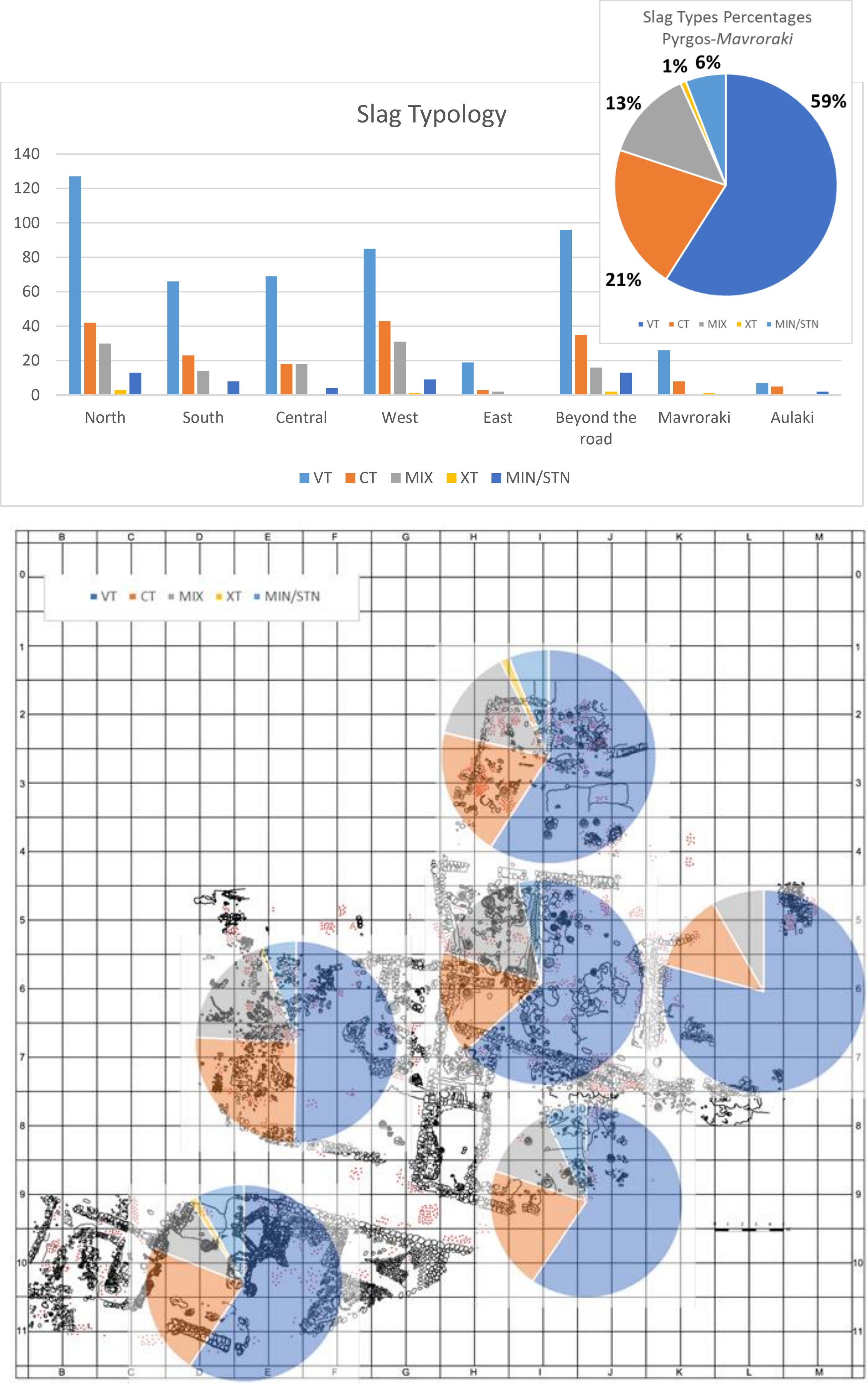


Figure 4.11 Slag types distribution in Pyrgos-Mavroraki's sectors (VT: Viscous Type; CT: Coarse Type; MIX: Mix Type; XT: unclassifiable slags).

4.6.1 Type 1: Viscous slags (VT)

The first type encompasses both whole and fragmentary slags. Fragments rarely exceed 7 cm, with a glossy outer surface that suggests their viscous (or semiliquid), but not fully liquid, state at the moment of cooling (fig. 4.11).

Figure 4.12 Viscous Type slags from Pyrgos-Mavroraki (inv. N. 215, 345).

The majority of these slags were found in the Northern Sector (7.4 kg) and the area "beyond the road" (6.5 kg). The average weight per piece is 34.1 g, with an unusual maximum of 537.0 g recorded for slag 13, found in the Northern Sector.

It is difficult to establish the original position during their formation of Pyrgos slags due to ther usual amorphous shape, however seven samples (83; 96; 252a; 339; 354; 367) seem to have a recognisable plano-convex shape, four of which could have cooled down in a small circular container of ca. 7cm of diameter. The complete absence of flow texture suggests that these slags formed inside the furnace. Though tt is difficult to say if this happened inside a crucible or directly at the bottom of the bowl-shaped furnace. Slag 392 could have been adhering to a bottom corner of a crucible base according to its shape.

Viscous slag is the most represented type, constituting the 59% of the overall total slags from Pyrgos photographed (836 samples) and the most abundant, when compared to the other types considered in each sector (North: 59.1%; South: 59.5%; Central: 63%; West: 50.3; East: 79.2; Beyond the road: 59.3).

The glossy black or dark surface is sometimes covered in layers of corrosion products due to the high iron and copper content, with occasional remains of charcoal. A corrugated pattern has been occasionally detected, possibly due to the bursting of bubbles rather than the imprint left by a piece of charcoal (fig. 4.13).

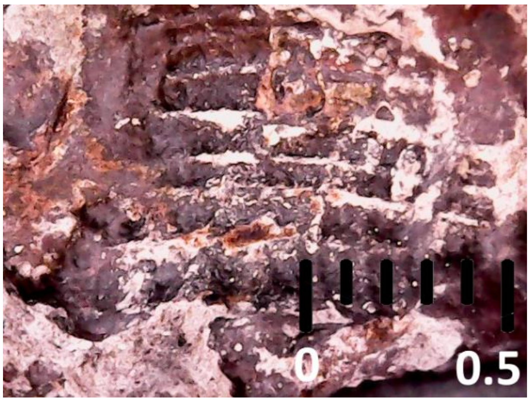


Figure 4.13 Detail of a corrugated surface on sample 215 (scale in cm).

The cross sections reveal the heterogeneity of these slags, composed of a dark grey matrix with many inclusions and no layered structure, comparable to the tap-slag samples from Aghios Dimitrios (Van Brempt 2016: 143). Visible unreacted mineral fragments, spinels of white crystals, probably gypsum of secondary origin inside voids, product of weathering and leaching after deposition, iron and copper corroded phases were detected. It was also possible to recognise shiny/metallic inclusions visible to the naked eye in the form of very small prills and larger metallic phases, which could vary in colour from bronze to blue (copper sulphides?).

Further information about Pyrgos-*Mavroraki*'s stratigraphy is required, nonetheless it must be mentioned that almost 50% of these types of slags (11.9 kg) come from those levels dated by the excavator to the Early and Middle Bronze Age (Fig. 4.13). Even on the small quantities collected during the survey at *Aulaki* and the soundings on Mavroraki's hill, this is still the most represented type of slag (7 frr. on 14 and 26 frr. on 35).

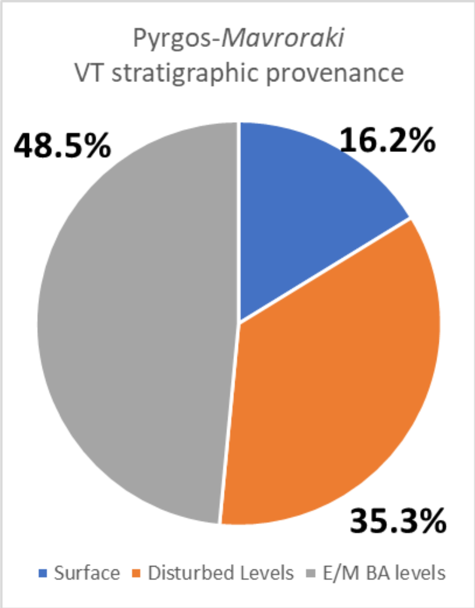


Figure 4.14 Viscous Slags stratigraphic provenance.

4.6.2 Type 2: Coarse slags (CT)

This type of slag includes fragments of chunky heterogeneous lumps, similar in size to VT, but presents a much rougher surface that is covered in corrosion products and debris. Among the 836 samples visually examined, 177 fragments have been identified belonging to this category, with an average weight of 28.4 g.

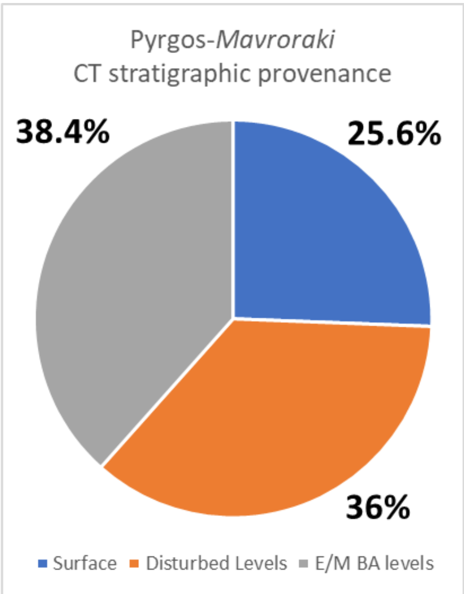


Figure 4.15 Coarse Slags stratigraphic provenance.

At first sight, these slags remind us of a much smaller version of what Van Brempt named "furnace slags" (2016, p. 146-149), being commonly covered by layers of various corrosion

products, pebbles and debris. The glossy surfaces which characterise the VT are completely absent in the coarse slags and no shaped samples have been identified within this category. Their appearance seems to suggest that these slags were also formed inside a furnace but did not reach the same level of viscosity shown in the VT.
The cross-sections revealed an increase of the inclusions already noted in the VT, such as unreacted minerals, spinel crystals of gypsum and different colourful products of corrosion, which may vary from red to green and, in some cases, to yellow, possibly revealing a high content of sulphur, not recorded in the VT (fig. 4.16).

Figure 4.16 Coarse Type slag from Pyrgos-Mavroraki (inv. N. 7).

4.6.3 Type 3: Mix Slags

After the initial optical evaluation of the slag-assemblage from Pyrgos, a third type was identified, which superficially shows the two main characteristics typical of the previous two, VT and CT. This category includes those slags (13% of the total amount) that present a surface characterised both by areas with a glossy, dark aspect and knobbly texture, but also areas with a rough surface, usually encrusted by thick layers of corrosion and debris.
The cross-sections of these slags, however, did not show any visible differences with the VT, suggesting that these slags might simply belong to the first type but may have undergone a more prolonged and active weathering process.

4.7 Sample Preparation

171 fragments (10% of the total amount) coming from the six previously mentioned sectors and different levels[3], were selected as representation of the main types recognised.
They were sampled at the Archaeological Museum of Limassol District, using a diamond-wheel wet tile-cutter, washed in methylated spirit, dried and collected in labelled nylon bags.

[3] According to the data collected from the documentation provided by the excavator.

The samples were legally exported for analysis (Export License: 008783; 008802) from Cyprus to the UK and re-examined at the Wolfson Archaeological Laboratory, Newcastle University, and the polished sections were prepared and analysed at the ACMA (Advanced Chemical and Materials Analysis) Electron Microscopy Unit, Newcastle University.
Initially, the samples were visually analysed for macroscopic features (colour, texture, shape, thickness, presence/absence of visible quartz, charcoal, voids, and magnetism). Twenty-six samples were then selected among the two most representative types (23 VT and 3 CT) for further measurements (density, volume) and analysed under the microscope (OM, SEM-EDX, ESEM), in the attempt to obtain information about their production process on the basis of the compounds recognised. The slags were selected from the Northern and Southern Sectors, where the most relevant evidence of metallurgical activity was found.
After placing the samples in small glass beakers, they were washed in an ultrasonic bath (Transsonic T310-Gamlab) for five minutes. The samples were then re-washed in methylated spirit to remove any residue of water and hot air dried, using a specimen dryer (METASERV). The samples were then weighed, and their weight recorded to the first decimal.
The samples' volume was measured in distilled water, using glass measuring cylinders (50ml; 100ml; 250ml; 500ml) and then the density was calculated. The samples were re-washed in methylated spirit to remove any residue of water and dried to be prepared as polished sections.
Each sample selected for microscopic analysis had to be recut using a metallographic low speed saw (Buehler ISOMET, equipped with a MK-303 professional lapidary blade) cooled by water, to fit a 32mm diameter polypropylene mounting mould. Paraffin was substituted to water in a few trials on the same sample, to check that no water-soluble chemical elements (*e.g.* As) were washed away during this operation, but no difference was noticed. The samples obtained had to be newly washed in alcohol and dried.
The dried sample was placed in the mould, previously lubricated with a mould release silicone grease. A thick-paper printed label with the details of the sample was inserted in the mould together with a thick-paper indicator to point to the surface (if recognisable) of the original slag. The mould was filled with a mix of EPO-SET resin (4 parts) and hardener (1 part) and left to dry for 24 hours at room temperature.
The hard resin-samples were prepared for polishing with a grinder (DISCOPLAN, to remove their back edges and any excess of resin on the analytical surface. Four polishing phases were then performed, grinding the samples on silicon carbide abrasive papers of finer grades (1200 and 600) and then polishing on 6 and 1 micron diamond wheels. Each polishing phase lasted a

total of ten minutes, during which, after five minutes, the samples were rotated 90° and the operation repeated. The samples were always washed and dried before proceeding from one polishing step to another to avoid the contamination of the polishing cloths.
The progress of the polishing was regularly checked, looking at the samples under the metallographic microscope (Union 8073).

4.8 Analytical methods: Optical Microscopy, Scanning Electron Microscopy-Electron Dispersive X-Ray Spectroscopy (SEM-EDX) and Environmental Scanning Microscopy (ESEM)

The preliminary microscopic analyses were carried out using a ZEISS Axiovert 100A, equipped with a Leica DFC 295 camera. The first goal reached with Optical Microscopy was to create a low-magnification (x30) general map of each sample to facilitate the analysis at higher magnifications.
Through Optical Microscopy, it was possible to investigate the composition of the slags, identifying certain phases in the slag analysis, such as olivine, spinel, and pyroxene (Hauptmann 2007). Particular attention was paid to Cu prills, Fe compounds found in the matrix and eventually, on unusual features. Specific sites of interest were identified and selected for SEM-EDX investigation.
The device used for this kind of analysis was a JEOL JSM 5600 LV, equipped with a INCAx-act Oxford Instruments EDX thin windows detector for the ID and semi-quantification of elements with an atomic mass upwards from C. The sites of interest individuated through OM were re-observed under this microscope and EDX analyses were performed to identify/confirm the different compounds.
Where possible, area analyses were preferred to spot analysis, to implement the reliability of the result. Back-scattered electron images, to confirm the metallic distribution within certain phases, was also performed, in order to visualise the distribution of the bigger-atoms elements.

The composition of Cu prills have been also investigated through Electron Back-scattered Diffraction with an XL30 ESEM-FEG equipped with a Centaurus Detector with Back-scatter Tip. To prepare the samples for this kind of analysis, a STRUERS DAP7 polisher has been used with a Colloidial Silica 0.4 micron suspension.

4.8.1 Type 1: Viscous Slags

<u>I. Microstructural composition</u>

Eleven samples from the Northern Sector, seven from the Southern Sector, three from Mavroraki's sounding and one from the survey in *Aulaki*, were selected for this type of analysis.

The main bulk of the slag is composed of a dark glassy matrix, usually corresponding to Cristobalite (SiO_2), within which **iron silicates** such as different types of olivines are present both as laths and blocky crystals.

In the samples where an original outer surface was clearly recognisable, it has been observed that fayalite crystals have the tendency to change from a blocky shape to a fine lath shape, decreasing in size, moving from the core of the slag to the surface. This microstructural sequence recorded for the fayalite crystals is directly connected with a sudden rapid cooling of the surface which interrupted their growing in a blocky shape, still visible in the crystals found towards the core of the slag. The main reason for it might be that the slags, left to cool down in the furnace for a while, were, at a certain point removed from it, possibly to speed up the cooling process. This type of microstructure, when identified in a sample, where the original outer surface was not preserved, might clarify what area of the original slag-nodule or slag-cake the fragment investigated comes from.

It was possible to identify **Fe-oxides** in the slag matrix. Their presence is due to the oxidising redox conditions of the smelting process. From a chemical composition point of view the Fe/O ratio is larger for Wüstite (FeO) than Magnetite (Fe3O4) and the latter can contain low amounts of Mg, Mn, Zn, Al and Cr (Van Brempt 2016, p. 162).

However, it might be difficult to distinguish between these iron-oxides (Hauptmann 2011: 195) only focusing on their chemical composition, while it has been proven more effective to consider their shape (Van Brempt 2016, p. 162). Magnetite occurs either as crystals or skeletons while Wüstite appears as dendrites (fig. 4.17).

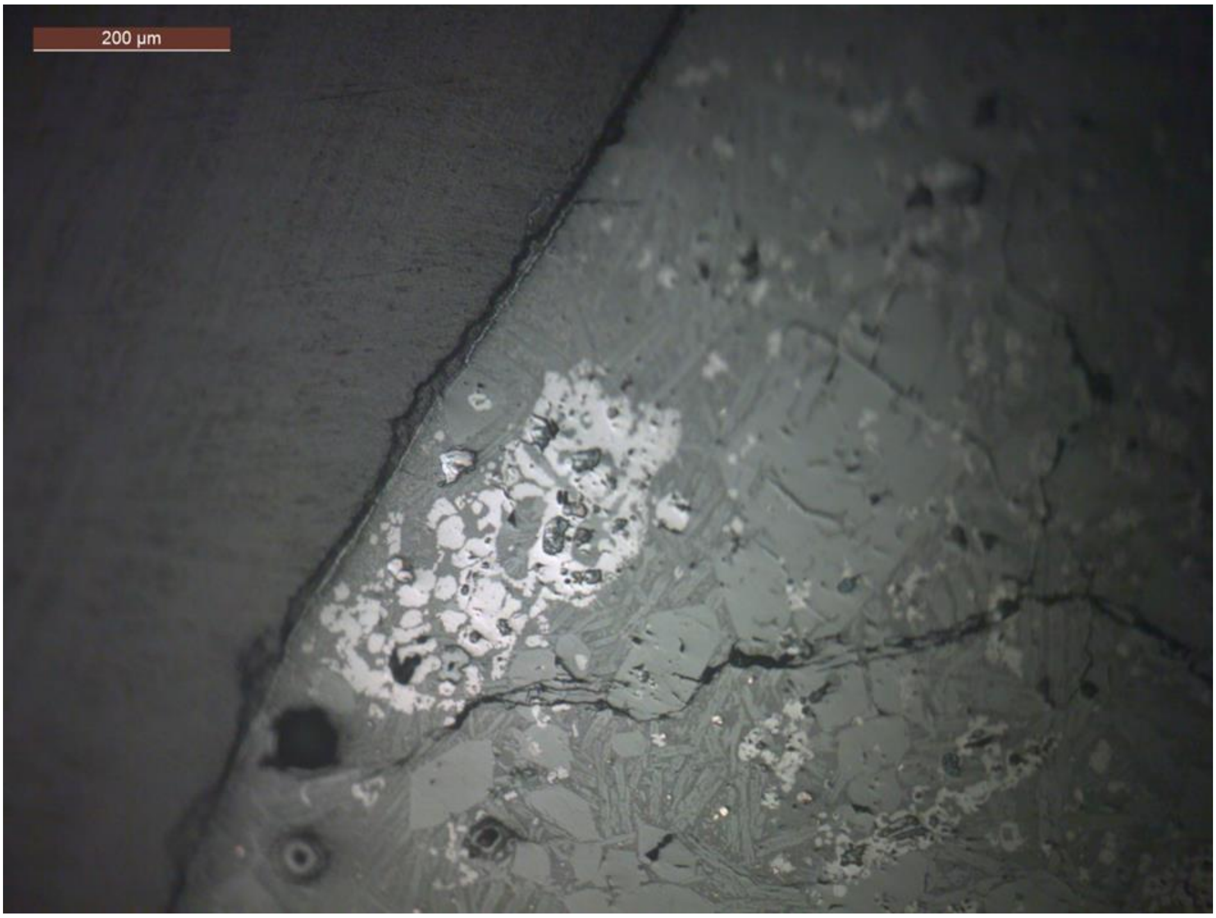


Figure 4.17 Fe oxides (light grey) in sample 302b.

In the VT slags from Pyrgos, the major iron-oxide detected was Magnetite, while Wüstite dendrites have been recorded very rarely. This suggests that the analysed slags formed in a rather oxidising atmosphere within the furnace. These considerations neatly support the hypothesis that simple reactors, such as bowl-shaped pits dug in the ground were used at Pyrgos-*Mavroraki*. The air supply was provided by blowpipes, which have a better chance of being moved through the charcoal heap, avoiding the formation of a reducing atmosphere. The way in which the blowpipes were used with the pit-furnaces might also have caused a certain degree of temperature fluctuation, which would explain the coexistence of different fayalite crystal-shapes.

Iron-copper sulphides appear very often in Pyrgos's VT slags, in a variety of shapes. Following the example of Van Brempt (2016, p. 164-173), the author distinguished five main types for these features, according to their size and shape: 1) small prills (a) or irregular phases (b) of max 100µm, embedded in the iron-silicate phase, but sometimes visible to the naked eye as metallic shiny points; 2) defined or rounded prills of max 500-600µm; 4) rounded or defined inclusions larger than 1000µm, usually well identifiable by the naked eye;

5) large irregular phases larger than 1000µm, often occurring with corrosion products (fig. 4.18; 4.19).

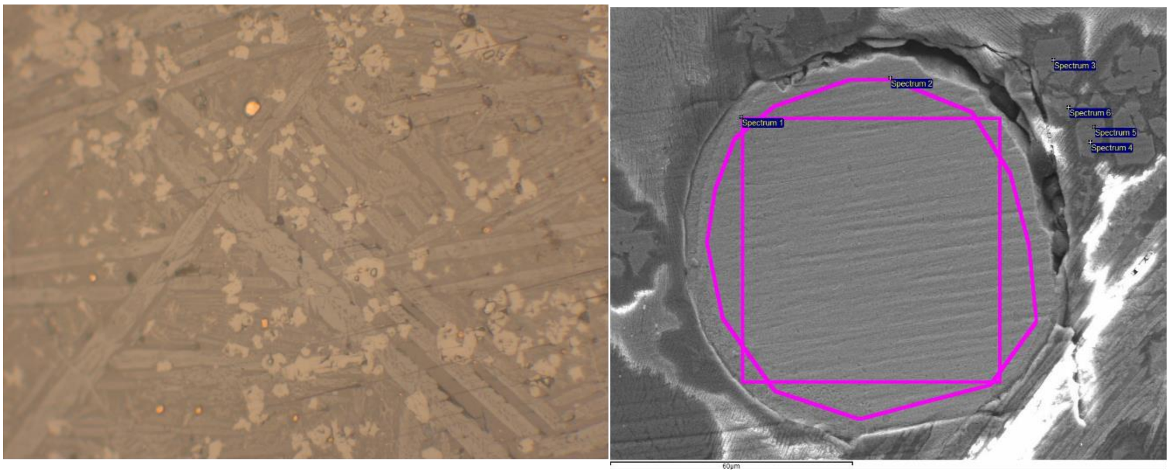


Figure 4.18 On the left photomicrograph of the 1st Type of Iron-copper sulphides found in Pyrgos's slags. Small prill embedded in fayalitic matrix (Optical Microscopy 20x), on the right the same feature magnified through SEM-EDX (scale: 60µ). In pink the areas analysed for chemical composition.

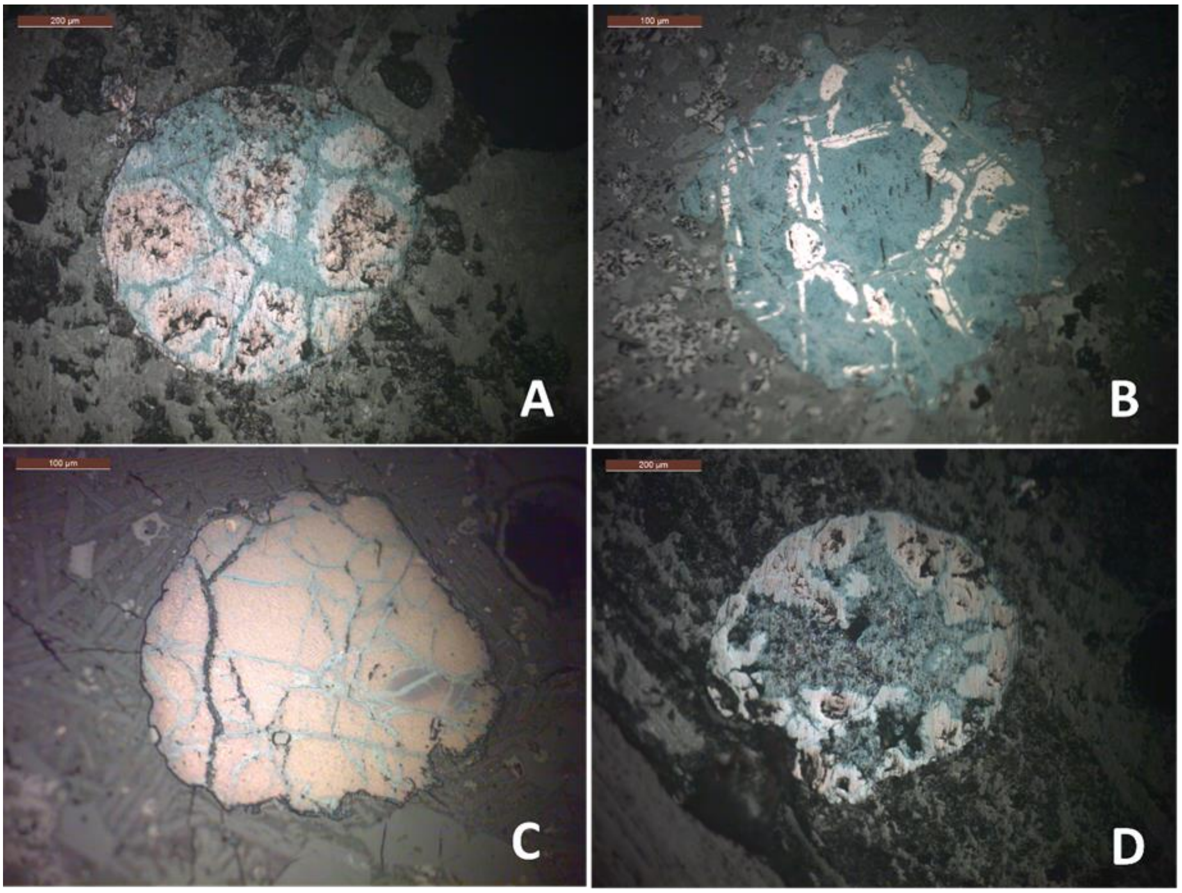


Figure 4.19 Photomicrographs of different iron-copper sulphides belonging to the 2nd Type, from samples 315a (A,D), 33 (B), 302b (C).

Despite the different Cu/Fe/S ratios, all these features, similarly to that established for Aghios-Dimitrios (from now on A.D.), can be identified as matte.

The smallest of these features, visible between fayalite laths within the glassy matrix, are represented by two different types: metallic copper prills, usually containing a small amount of iron (up to 1%), never exceeding 100µm and irregular phases always smaller than 50µm. Under the OM, the metallic copper prills appear orange, sometimes surrounded by a small blue rim, richer in sulphur. The irregular phases, not very common, if considering the assemblage of slags analysed, are chemically closer to Bornite with an average composition of 68% Cu, 10% Fe and 20% S. Van Brempt (2016, p. 164-165) found similar small phases, with the core of the features generally iron-rich with a composition that varies from Cubanite (CuFe2S3) and Triolite (FeS). Kassianidou, in the study on the slags from the Late Bronze Age smelting site of Politiko-Phorades, suggested interpreting this kind of small angular iron-copper sulphides as fragments of crushed ores that did not fully react during the smelt (2003, p. 216). As already mentioned, the small iron-copper sulphide features found embedded in Pyrgos' slag matrix are richer in copper than those ones recorded by Van Brempt and Kassianidou, and chemically closer to Bornite. Following the interpretation of Kassianidou, it could be argued that Bornite (richer in Cu than Chalcopyrite) was smelted at Pyrgos. Another hypothesis could be that these features represent fragments of matte obtained during previous smelting stages, now being reprocessed to obtain a better product.

The larger and more defined prills or phases which belong to the second category rarely exceed 500/600µm and show different aspects under the OM, which correspond to specific iron-copper sulphide phases. The iron, copper and sulphur ratios vary from bornite (Cu_5FeS_4), to covellite (CuS) and chalcocite (Cu_2S). Under the OM, the areas identified as bornite, show an orange/pink colour and light blue veins, identifiable as covellite or chalcocite. Sometimes the covellite composition extends to the majority of the prill, leaving just small core portions of it chemically closer to bornite. Light blue prills of this size have also been recorded with a chemical composition which averages between covellite and chalcocite.

The majority of this prills are usually surrounded by a band of iron oxide, similarly to what already observed in the slags from A.D. (Van Brempt 2016, p. 166). Despite the different ratios which characterise their composition, these prills are often accompanied by gas vesicles originated by the sulphur release occurred during the smelting process. The bright yellow phases rich in iron, recorded by Van Brempt in the slags from Aghios Dimitrios, are absent in Pyrgos-Mavroraki's slags.

Finally, iron-copper sulphidic phases with a rounded or well-defined shape larger than 1000μm have been recorded during the analysis of Pyrgos's slags. These features can be identified more commonly with Covellite.
Larger inclusions have been found in some slags, accompanied by corrosion products. These might represent large fragments of the original ore which did not fully react and weathered after deposition, creating the corrosion products.

II. General chemical composition

The general chemical composition of the slag samples was determined with the SEM-EDX taking three low magnification (100x) measurements of representative parts of the Fe-silicate phases, typically analysing areas of 1.2 by 0.8 mm. The large iron-copper sulphidic phases and the other irregularities were not included in the analysis.
The chemical data is here expressed in oxides to make it comparable with the available literature, but we are aware that this is a shared convention in the field of archaeological science and some of the oxides/elements mentioned (SO_3, Cl, P_2O_5) will not be present in this form within the slags. The content of Cl and P is anyway negligible.
The major oxides occurring in the VT are silica (SiO_2), iron oxide (FeO) and alumina (Al_2O_3), while the minor oxides are lime (CaO), magnesia (MgO) and soda (Na_2O) similar to that which has been recorded for the tap slags of A.D.
The mean chemical composition corresponds to 46.4% FeO, 36.0% SiO_2, 6.4% Al_2O_3, 4.0% CaO and 2.6% MgO. While the contents of soda, chlorine, phosphorus, potash, titanium and manganese are negligible, it is interesting to note how the FeO and SO_3 are lower, when compared with the results from A.D., while magnesia, silica, lime and copper are higher.
The viscosity index (K-index) was calculated and its average value of 1.1%, confirming a high viscosity of these slags, did not allow a full separation of the metal from the slag during the smelting process.
The STDEV show that the chemical composition of the slags analysed is characterised by considerable inhomogeneity, both on an intra-sample and inter-sample level. Considering the coefficients of variation lower than 10% within the range of usual analytical uncertainty, as suggested by Van Brempt (2016, p. 173; Humphries et al. 2009, p. 364), this inhomogeneity is also confirmed by the calculation of the inter-sample relative standard deviation (RSTDEV) and the average of the intra-sample relative standard deviation. The values, which are closer to a consistent value, are Fe and Si.
This data is consistent with the results obtained for the VT from the Southern Sector and Mavroraki's soundings, but not with Aulaki's VT, which, despite its external viscous

appearance, shows in section a very heterogenous matrix rich in large mineral inclusions such as quartz.

Site/Sector	**Sample**	**Weight percent (wt%)**													
		Na_2O	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
	VT														
Pyrgos/North	**252a**		3.1	6.9	40.5	0.6	0.1		0.3	4.3	0.2		42.0	2.0	
Pyrgos/North	**256**		1.7	5.0	27.0	1.8	0.1		0.2	1.1		0.2	61.9	1.0	
Pyrgos/North	**315a**	0.2	2.2	6.4	40.3	1.9			0.4	6.2	0.2		41.1	1.0	
Pyrgos/North	**315b**		1.3	5.2	36.4	1.9			0.2	1.3			52.5	1.3	
Pyrgos/North	**27b**	0.4	3.5	5.0	39.6	0.6			0.3	3.5	0.2		44.3	2.6	
Pyrgos/North	**30**	0.4	10.0	12.5	36.6	1.5				3.3	0.3		33.8	1.8	
Pyrgos/North	**388**		3.8	4.6	24.5	0.6	0.1		0.1	5.8			56.6	3.8	
Pyrgos/North	**209**		3.7	9.8	45.4				0.1	3.7	0.1		33.1	4.0	
Pyrgos/North	**255b**	0.3	3.1	4.7	29.2	0.9	0.3		0.4	6.4	0.2		51.8	2.7	
Pyrgos/North	**33**		2.0	5.0	38.1	1.9	0.1		0.3	5.3			45.4	2.0	
Pyrgos/North	**302b**	0.3	1.0	4.9	38.2	1.5	0.2		0.4	3.5			48.0	2.0	
MEAN		***0.3***	***3.2***	***6.4***	***36.0***	***1.3***	***0.2***		***0.3***	***4.0***	***0.2***	***0.2***	***46.4***	***2.2***	
STDEV		*0.1*	*2.4*	*2.5*	*6.4*	*0.6*	*0.1*		*0.1*	*1.8*	*0.0*		*9.0*	*1.0*	
Inter RSTDEV		*27.1*	*76.0*	*40.0*	*17.8*	*43.5*	*45.1*		*46.5*	*44.7*	*22.4*		*19.3*	*45.8*	
Mean Intra RSTDEV		*28.9*	*34.7*	*23.7*	*14.0*	*38.4*			*38.5*	*41.7*	*20.8*	*6.1*	*11.7*	*33.0*	

Site/Sector	**Sample**	**Weight percent (wt%)**													
		Na_2O	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
	VT														
Pyrgos/South	**205a**		4.5	5.7	32.7	2.7	0.2		0.2	1.9	0.2		48.3	3.7	
Pyrgos/South	**131a**		0.4	10.0	38.6	3.8		0.3	0.2	0.6	0.2		43.3	2.6	
Pyrgos/South	**90**		0.5	6.4	41.0	0.6			0.1	1.5			48.1	1.8	
Pyrgos/South	**204a**		2.7	6.5	31.0	3.2			0.2	2.1			51.3	3.1	
Pyrgos/South	**206**		2.2	4.1	30.7	2.0			0.3	5.6			53.0	2.1	
Pyrgos/South	**189**	0.5	6.6	9.7	35.1	0.4	0.2		0.7	6.3	0.3	0.2	37.7	2.1	
Pyrgos/South	**96**		1.2	5.7	44.5	0.5	0.2		0.2	1.6			43.5	2.6	
MEAN		**0.5**	**2.6**	**6.9**	**36.2**	**1.9**	**0.2**		**0.3**	**2.8**	**0.2**	**0.2**	**46.5**	**2.6**	
STDEV			2.3	2.2	5.3	1.4	0.1		0.2	2.2	0.1		5.3	0.7	
Inter RSTDEV			87.3	32.0	14.6	73.4	26.2		73.1	79.4	36.8		11.4	25.7	
Mean Intra RSTDEV			60.0	26.3	20.6	57.0	95.7	*173.2*	58.2	34.2	107.9	173.2	9.9	43.0	

Site/Sector	**Sample**	**Weight percent (wt%)**													
		Na_2O	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
	VT														
Mavroraki	**50**		4.5	7.9	35.6	1.6	0.1		0.1	3.8	0.2	0.2	43.7	2.2	
Mavroraki	**49a**		1.2	9.8	36.5	0.6	0.2		0.2	7.7			41.1	2.8	
Mavroraki	**406a**		1.0	3.2	26.2	7.0	0.0	0.4	0.3	1.8			58.0	1.6	0.5
MEAN			**2.2**	**7.0**	**32.8**	**3.1**	**0.1**	**0.4**	**0.2**	**4.5**	**0.2**	**0.2**	**47.6**	**2.2**	**0.5**
STDEV			2.0	3.4	5.7	3.4	0.1		0.1	3.0			9.1	0.6	
RSTDEV			89.3	48.9	17.3	112.4	103.3		39.5	67.1			19.1	27.1	

Site/Sector	Sample	Weight percent (wt%)													
		Na_2O	MgO	Al_2O_3	SiO_2	SO_3	Cl	P_2O_5	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO
	VT														
Aulaki	**191bisC**		0.8	5.8	59.7	1.3			0.2	1.6	0.1		29.6	0.8	

Table 4.9 Average chemical composition of the Fe-silicate phases of the viscous slags samples, determined by SEM-EDX. All values are given in weight%. The average, the standard deviation and the relative standard deviation are calculated for the major and minor oxides.

Site/Sector	Sample	Weight percent (wt%)									
		Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	FeO	CuO	Total
K-AD Tap-Slags		1.1	1.9	6.2	23.0	5.3	0.6	2.5	0.3	57.0	1.5	99.4
K-AD Furnace-Slags		2.0	2.0	9.8	33.4	1.8	0.8	3.7	0.4	44.1	1.1	99.2

Table 4.10 Average chemical composition of the Fe-silicate phases of the Tap-Slags and Furnace-Slags samples from Kalavassos-Aghios Dhimitrios, determined by SEM-EDX (adapted from Van Brempt 2016).

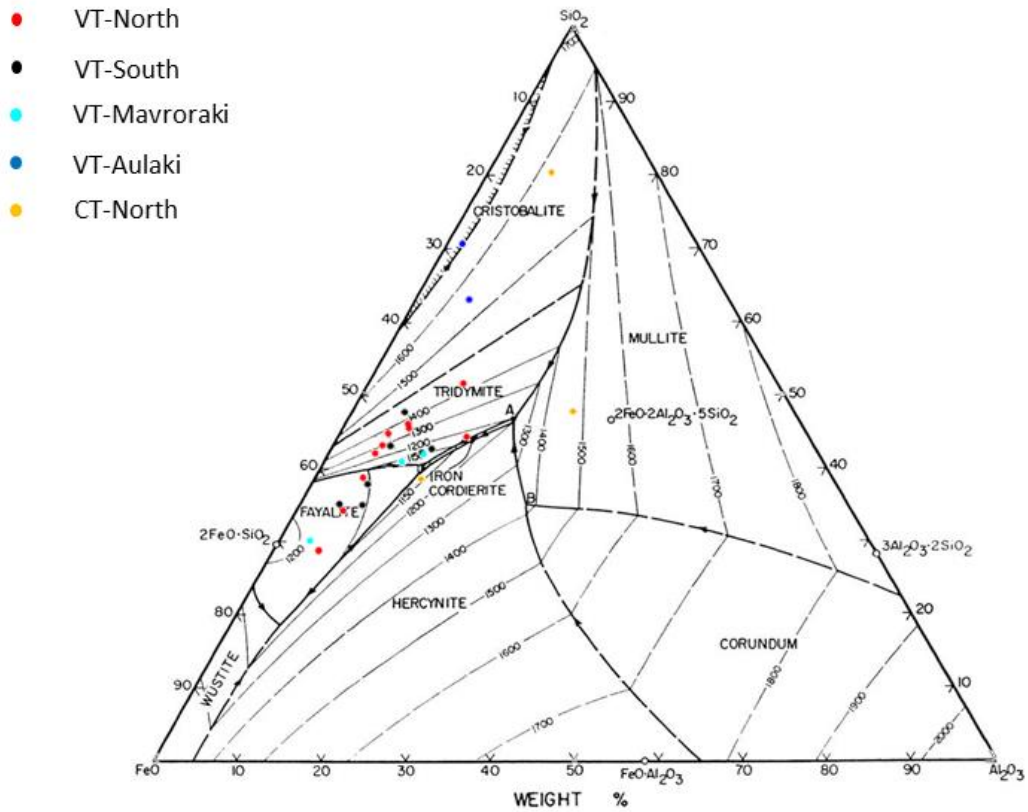


Figure 4.20 Pyrgos-Mavroraki slag samples represented on the SiO_2-FeO-Al_2O_3 ternary phase diagram (adapted from Maldonado and Rehren 2007, Fig. 8, after Muan 1957, Fig. 10)

4.6.2 Type 2: Coarse Slags

I. Microstructural composition

Four samples were selected for microscopic analysis, three from the Northern Sector, where the main smelting activity was supposedly performed, and one from the survey in the Aulaki area.

The products of corrosion identified during the preliminary visual analysis were observed in section as well, following the occasional cracks towards the core that characterise CT slags. Similar to the VT slags, the main bulk of the slag is composed of a dark grey matrix, not dissimilar to the VT slags, usually corresponding with Cristobalite (SiO_2), containing **iron silicates**. Fayalite has been found in blocky-shaped crystals of up to 72 μm, rather than laths. This possibly suggests that this type of slag cooled down slower than the VT.

Euhedral **Iron oxides** crystals and agglomerations were recorded in CT as well, and similarly to the VT, were identified as Magnetite (Hauptmann 2011, p. 195). The presence of Magnetite once again suggests that the metallurgical process was carried out under non effective redox conditions. Considering the redox conditions, it could be suggested that CT slags originated inside the same type of furnace, with the same kind of air-supply, that originated the VT slags, possibly at an earlier stage.

The main differences with the VT slags are relatable to the **iron-copper sulphides** phases content. Prills of metallic copper (type 1) were not found in the three samples analysed. Instead, the presence of bigger Cu/S phases (type 2-3-4-5) is recurrent, often visible to the naked eye in the polished sections. The abundance of large iron-copper sulphide features suggests that the process that originated this slag was probably still at an early smelting stage and its by-products needed to be refined by further smelting cycles.

II. General chemical composition

Following the same protocol, which was used for the VT slags, the general chemical composition was determined with the SEM-EDX, taking three measurements at low magnification (100x) of representative parts of the Fe-silicate phases, within areas of 1.2 by 0.8 mm. The large iron-copper sulphidic phases and the other irregularities were not included in the analysis.

It is difficult to compare this data with the one obtained for the VT, considering that for the latter, a much larger sample was selected to be analysed. However, if we look at the samples from the Northern Sector, we soon realise that there are very slight differences with the VT samples from the same sector. The bulk analysis revealed a higher content in Al e Si and lower levels of Fe. This might be due to the presence of a larger amount of unreacted ore and gangue. This results also in a lower viscosity index of an average of 0.5, which correlates with their external appearance.

Despite what has been observed on a microstructural level, with regard to the abundance of large iron-copper sulphide phases, the amount of Cu detected in the matrix is slightly lower than that recorded in the VT. This is quite unexpected if we consider that, microstructurally, these slags seem to belong to an earlier smelting phase in Pyrgos’s metallurgical process, and therefore they should be richer in Cu, which would not have been efficiently separated from the rest of the slag, due to its high viscosity. This result could be explained by the considerable heterogeneity of the slag and, therefore, in the challenging analytical procedure that might allow some inaccuracy, failing to detect a general representation of the slag, but just some particulars.

The large iron-copper sulphide phases detected in these slags, similarly to the VT slags, but more abundant, are chemically closer to Chalcocite, Covellite and Bornite. The higher content of Al, Si dispersed in the matrix might suggest that the gangue did not reach the same level of “decomposition” reached in VT slags, and together with a higher content of S, it could be the indication that CT slags might belong to a roasting cycle or a very preliminary smelting stage.

Site/Sector	Sample	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	Cl	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO
CT														
Pyrgos/North	**7**		1.9	20.2	37.1	3.6		0.1	12.2	1.0	0.2	20.6	3.1	
Pyrgos/North	**10**			6.8	75.9	4.1	0.5					12.1	0.7	
Pyrgos/North	**17**	0.2	4.3	10.9	33.2	2.8	0.2	1.4	2.4	0.2		42.4	2.0	
MEAN		**0.1**	**2.1**	**12.6**	**48.7**	**3.5**	**0.2**	**0.5**	**4.9**	**0.4**	**0.1**	**25.0**	**2.0**	
STDEV		0.1	2.1	6.9	23.6	0.6		0.8	6.5	0.5	0.1	15.7	1.2	
Inter RSTDEV		173.2	103.6	54.6	48.5	18.0		150.5	133.2	126.8	173.2	62.6	63.6	
Mean Intra RSTDEV		86.8	37.9	39.7	12.2	19.1	112.5	71.5	53.4	19.2	89.2	20.2	57.9	
Site/Sector	**Sample**	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
CT														
Aulaki	191bis B		0.3	0.6	29.9	8.9			0.4			11.9	48.0	

Table 4.11 Average chemical composition of the Fe-silicate phases of the coarse slags samples, determined by SEM-EDX. All values are given in weight%. The average, the standard deviation and the relative standard deviation are calculated for the major and minor oxides.

Chapter 5. The Metalwork at Pyrgos-*Mavroraki*: typology and alloy composition

5.1 Introduction

This chapter intends to contextualise Pyrgos-*Mavroraki*'s metal finds within the wider context of Early/Middle Bronze Age metal production in Cyprus. The first section of this chapter is dedicated to the typological aspects of Pyrgos's metal finds. After a brief summary dedicated to the main typological studies carried out on Cypriot metalwork, Pyrgos's metal types from both the settlement and the cemetery are discussed. To pursue this aim, the objects were divided into four categories: weapons, tools, ornaments and tools of personal ornament. Where possible, useful comparisons from past and more recent discoveries have been included, while a separate paragraph has been dedicated to those objects which could not be framed within the known types and were grouped as "Miscellanea".

The second section of this chapter is dedicated to the chemical compositions of Pyrgos's metalwork. A general overview on metal chemical composition in Early/Middle Bronze Age Cyprus is provided beginning with the meticulous study of Judith Weinstein-Balthazar (1990).

This creates the appropriate background to describe and discuss the chemical compositions of Pyrgos-*Mavroraki* metal artefacts, considering the preliminary study carried out by Giardino et al. (2002), and the analyses included in both old and new unpublished materials from the site. This will allow a better contextualisation of Pyrgos-*Mavroraki*'s material in relation to the existing literature on Cypriot metal typology and will place Pyrgos and its finds within the wider framework of the Early-Middle Bronze Age Cypriot metalwork.

5.2 Pyrgos-*Mavroraki* metal finds in relation to the main Early and Middle Bronze Age metal types in Cyprus

As outlined in Chapter 2, the first evidence of metal artefacts in Cyprus is attested starting from the Middle Chalcolithic. Focussed studies on these early materials were not efficiently undertaken until very recent, when Peltenburg (2011) and successively Kassianidou (2013) and Charalambous (Kassianidou and Charalambous 2019) compiled very accurate summaries of Chalcolithic metalwork. A reconsideration of the metal types belonging to the Philia facies (tab. 5.1) has been included in studies on the topic by Webb and Frankel (1999, p. 31), and, more recently, discussed further by Mina (2014), showing a clear increase in the archaeological record of metal artefacts during this period.

SITE	TYPOLOGY	METALLURGY
Bellapais-*Vounourouthkia*	Settlement/cemetery?	No
Dhenia-*Kafkalla*	Cemetery	- Two copper spiral rings
Episkopi-*Bamboula*	Cemetery	No
Khrysiliou-*Ammos*	Cemetery	No
Kissonerga-*Mosphilia*	Settlement/cemetery	- Metalworking debris - Possible crucibles - Finished objects
Kyra-*Alonia*	Settlement	no
Kyra-*Kaminia*	Cemetery	- Metal knives - Earrings
Marki-*Alonia*	Settlement	- Spiral earrings/hair rings in copper or gold -
Marki-*Davari*	Cemetery	- Copper spiral earring
Marki-*Vounaros/Pappara*	Cemetery	- No
Nicosia-*Ayia Paraskevi*	Cemetery	- Whetstones - Knives - Spiral earrings - Spearhead
Philia-*Drakos B*	Settlement	- No
Philia-*Laksia tou Kasinou*	Cemetery	- Toggle pins - Knives - Spiral earrings - Axe

Philia-*Vasiliko*	Settlement	-
Philia-*Vasiliko/Kafkalla*	Cemetery	- No
Sotira-*Kaminoudhia A and B*	Cemeteries	- Gold and copper spiral earrings - Unforged billet of a knife - Knife
Vasilia-*Kafkallia and Kilistra*	Cemeteries	- Three arm rings - Knife - Razor - Spearhead - Two toggle pins
Vasilia-*Loukkos Trakhonas*	Cemetery	- No
Vasilia-*Alonia*	Cemetery	- Fragmentary metal axe and knife

Table 5.1 Gazetteer of Philia Sites (adapted by Webb and Frankel 1999, pp. 8-13)

The most important works on typology are those of Åström (1957; 1972) for the Middle Cypriot, Catling (1964) and Stewart (1992) who included in their work the artefacts from both the Early and the Middle Bronze Age and finally, the remarkable work of Balthazar (1990) who pointed out the strengths and weaknesses of the previous typological systems. Balthazar extended the selection of the artefacts considered, providing an up-to-date list of recent finds (until 1990), and discussed their chemical compositions, including a meticulous collection of published and unpublished analytical programs.

The main types belonging to the Cypriot Early and Middle Bronze Age metallurgical *repertoire* are relatively limited and uniform. For this reason, the typological systems designed since the beginning of Cypriot archaeology until now, despite the logical improvements due to new discoveries, are all still valid.

It is possible to categorise the types of Cypriot Early and Middle Bronze Age metalwork analysed by the aforementioned scholars into three major groups: weapons, tools and ornaments (which include tools of personal ornament as well). In the following paragraphs, the metal finds from Pyrgos-*Mavroraki* and its cemetery have been categorised and discussed according to the typological studies mentioned above.

5.2.1 Weapons

The most characteristic type of metal object which belongs to this period is the so-called "**hook-tang weapon**". Watkins defined them for the first time with this simple descriptive name focusing on the typical long "hook-tang" on the lower portion of its leaf-shaped blade, and thus avoiding interpretative implications (1976, p. 136; 1981, p. 121).

Åström and Catling, reconfirmed successively by Balthazar (1990, p. 308) and Philip (1991, p. 63), suggested a typological chronology for these artefacts. The gradual development of different features present on these artefacts was considered towards this specific aim. The most evident modification concerned the shape of their shoulders, which went from straight to heart-shaped, angular-heart-shaped, and sloping, leading to the definitions of different types (fig. 5.1).

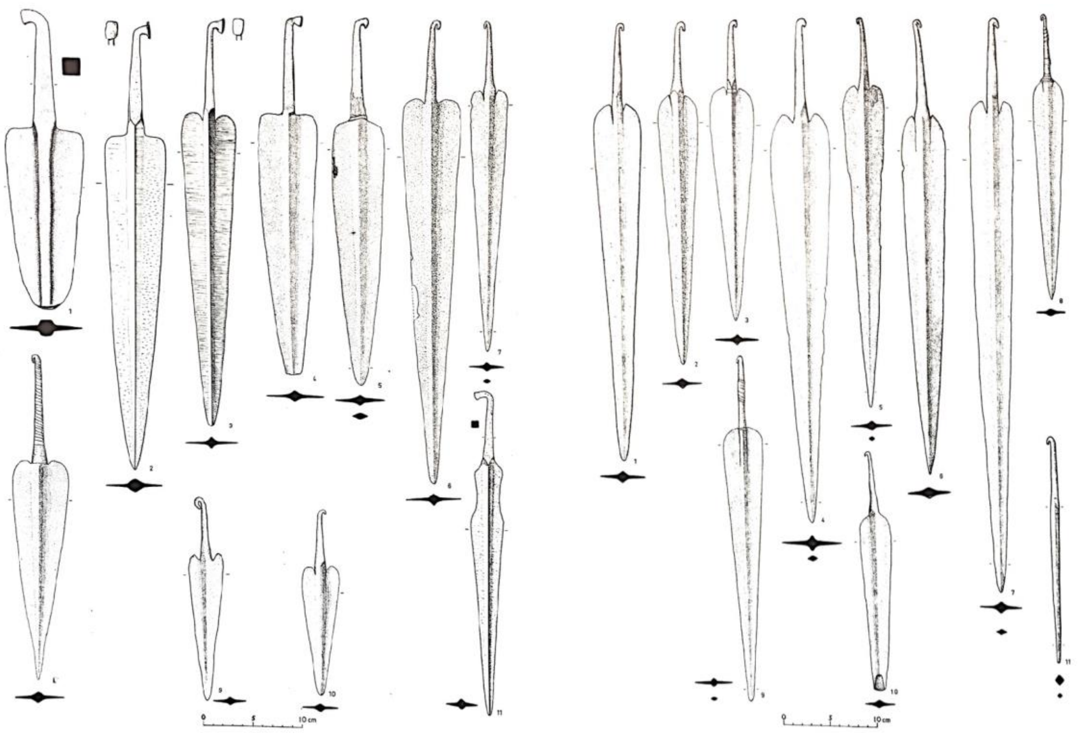


Fig.5.1 Hook-tang weapon types (Catling 1964, figg. 1-2).

In parallel with the shoulder's shape development, a transformation in the shape of the hook-tangs was observed as well. The broader midsections attested in the Philia Facies hook-tang weapons gradually slimmed down and were replaced by sharp midribs.
Likewise, through the time, the hooks and tangs became lighter: the button-shaped terminal is present only in early examples; the early thick tangs with square cross sections eventually being replaced by thinner tangs with round cross sections.
It has been observed that the stylistic transformation was also strictly connected to the way of manufacturing these objects. Using metallography Balthazar examined eighteen hook-tang weapons and was able to establish that they began as rough castings which were subsequently shaped by heavy hammering, annealing and re-hammering (1990, p. 309). It is therefore arguable that the process of "weight-loss", undergone by these weapons, was made possible by the improvement of the earliest Cypriot metallurgists' smiting skills and the discovery of shapes that needed less forging effort. The angular heart-shaped shoulders were cut with a chisel and the tangs were a result of hammering.
Different scholars discussed the use and function of these blades (Schaeffer 1936; Gardner 1937; Philip 1991). One of these artefacts, currently on display as part of the metal collection in the permanent exhibition of the Cyprus Museum, has been hafted as a sword. The haft-replica was based on Gardner's interpretation, who thought that these were the real-size metal weapons which inspired the clay models from *Vounous* tombs (fig. 5.2).

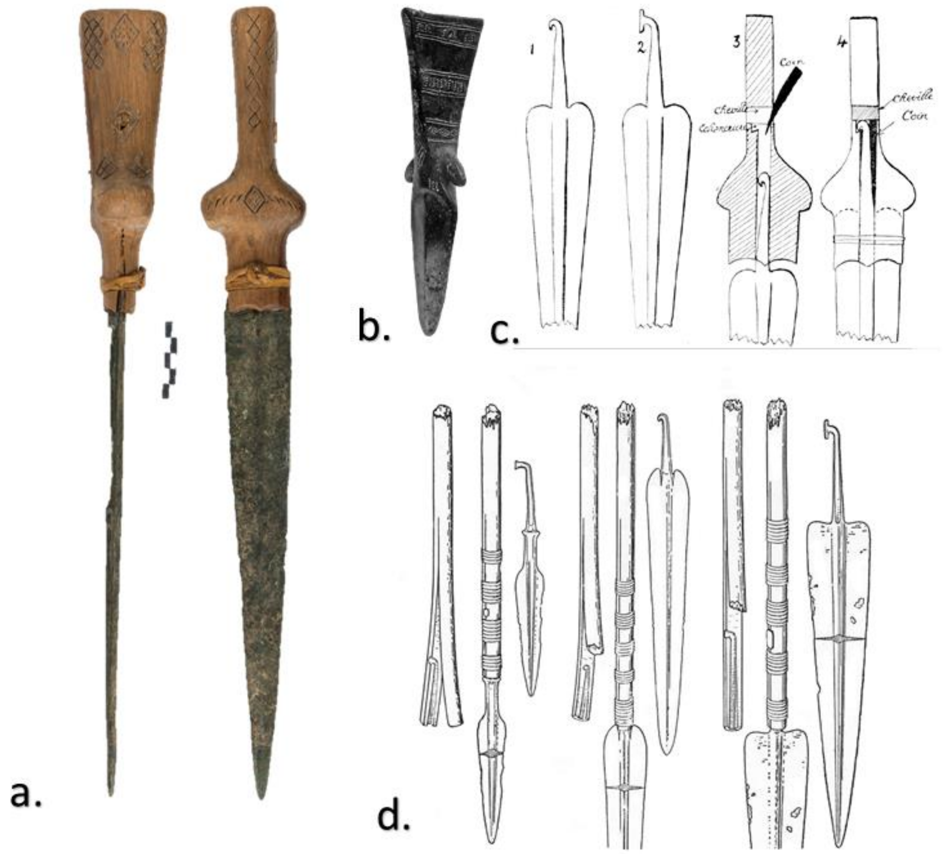


Figure 5.2 Hook-tanged weapons hafting hypotheses: a. HTW hafted as a sword, on display at the Cyprus Museum (DAC©); b. Clay model of HTW from Vounous, on display at the Cyprus Museum (DAC©); c. Hafting hypothesis of HTW interpreted as swords (Gardner 1937, p. 546, fig. 1); d. Hafting hypothesis of HTW interpreted as spearheads (Schaeffer 1936, p. 41, fig. 16).

Shaeffer argued that these blades should be interpreted as spearheads, suggesting a different type of hafting (1936, pp. 41-45, fig. 16). Stewart (1962, p. 245) and Åström (1957, p. 136) distinguished swords (longer than 39cm) from daggers in their typology, but Balthazar remarks her agreement with Schaeffer's interpretation. In addition, the scholar highlighted the fact that Cypriots, being hunters would have certainly used spears and that hook-tang weapons seem to be the most direct predecessor of Late Cypriot socketed spearheads (Balthazar 1990, p. 309). Balthazar specified that during her analyses on more than 200 exemplars, she never found any trace of hafting on their shoulders, but instead she found thongs wrapped around the tangs on 50 of them (1990, p. 310).

No hook-tang weapons were found at Pyrgos-*Mavroraki*'s settlement, while only three of these artefacts were recovered from Pyrgos's E/M BA tombs. We also must consider a possible addition to these: a fourth HTW, which was confiscated from illegal excavations and, according to the Limassol Archaeological Museum's records, was found by a villager in a tomb in the vicinity of Pyrgos (Balthazar 1990, p. 263, Swiny 1986, p. 76). This object, with the DAC inventory number LMRR 520/1, is a pointed blade with high midrib and notched, heart-shaped shoulders. Its tang has a thick, squared section. The point of its blade seems to be bent intentionally, following a ritual practice already attested on the Island (Swiny 1986, p. 76).

The other three artefacts come from certain contexts of Pyrgos's cemetery: number 6 from Tomb 1, number 45 from Tomb 42 and number 1 from Tomb 55 (fig. 5.3).

The first two belong to the same type of LMRR 520/1, with their heart-shaped notched shoulders showing minor differences. While T.42/45 shows a squared section hook-tang similar to LMRR 520/1, T.6/1 has a round section tang. The notches cut in these weapons' shoulders seem to be deeper and more pronounced compared to those ones present on LMRR 520/1. Moreover, T.42/45 is characterised by two long grooves prosecuting from the notches on the shoulders and running parallel to the midrib which extends up onto part of the tang but is less pronounced than LMRR 520/1's high midrib.

T.55/1 belongs to Catling's Type A.1b, with its rounded heart-shaped shoulders, high midrib and round section hook-tang.

Considering the shape of shoulders, midribs and tangs we could argue that T.55/1 is the earliest among the HTW mentioned, while T42/45 is probably the most recent. They are all datable between the EC III – MC I.

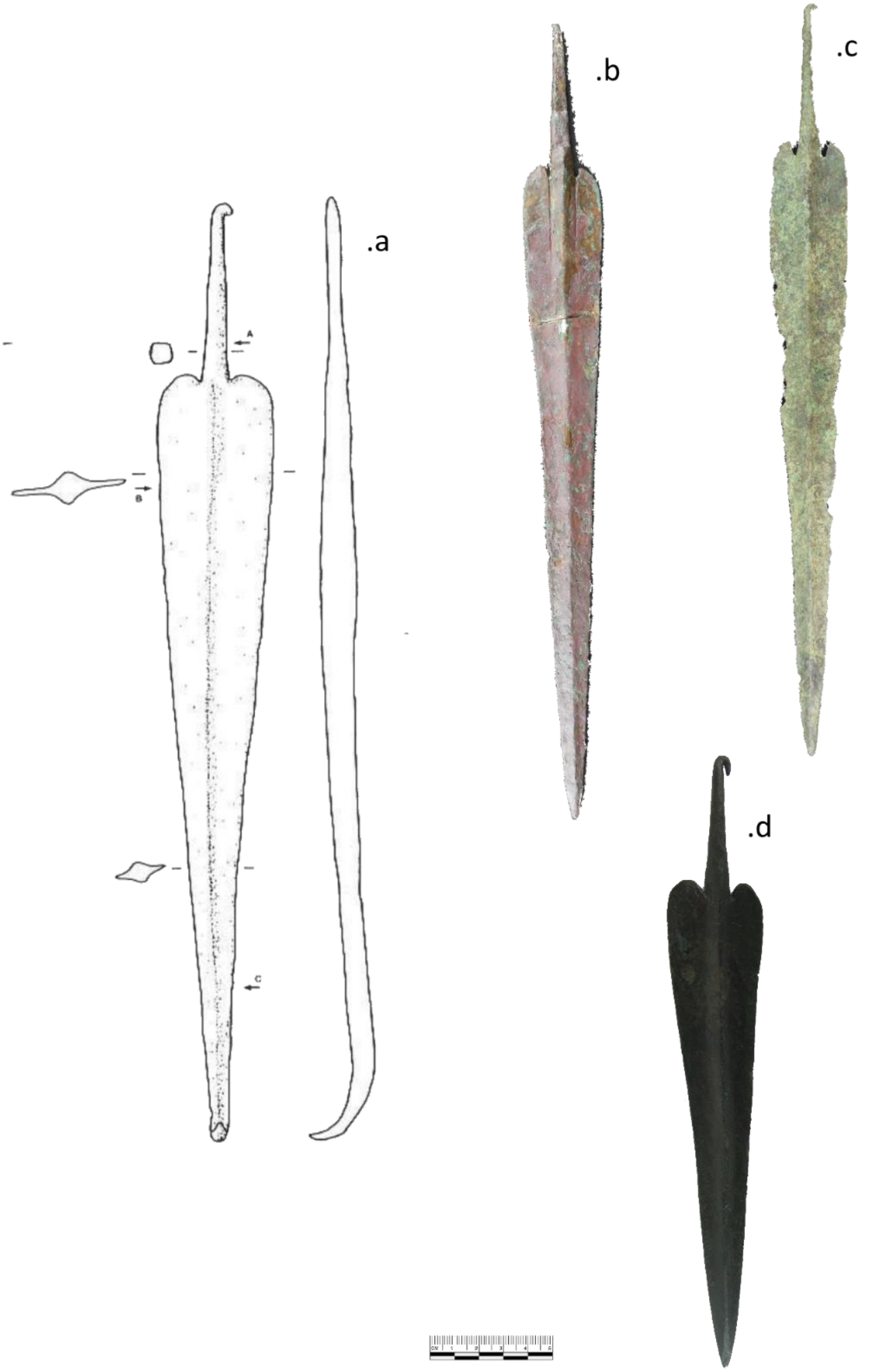


Figure 5.3 HTW from Pyrgos Cemetery: a. LMRR 520/1; b. T42/45; c. T1/6; d. T55/1.

5.2.2 Tools

Another category of metal artefact which could be ascribed both to the weapons and the tools is that one of the **knives**, a term preferred by Balthazar over the term "dagger" suggested by Catling (1964, pp. 59-62). They are characterised by a flat tang or no tang at all, and rivets are used to attach the blade to its handle. Similarly, to the hook-tang weapons, scholars observed a stylistic development in this type of artefact, distinguishing between knives with distinct tangs and knives without tangs and shaped butts instead (Balthazar 1990, p. 324).

Two knives were found in Pyrgos's settlement: M7, a flat-tanged knife with midrib and 610, a tangled knife with round butt and no sign of rivets (fig. 5.4). The first one could be assigned to Catling's Type A2a (1964: 59) and looks similar to the daggers from the so-called "Vasilia Deposit 2" (Webb 1997, p. 73, nn. 334-5; Swiny 2003, p. 383, fig. 8.2 nn. 2/22-23).
The fact that the round-butt knife does not have any rivets, as expected for this type, makes it unusual. Despite the fact that both these knives have been conserved, it seems highly unlikely that a possible trace of rivets could have been missed by the conservators, due to the state of corrosion.

Five knives come from Pyrgos's cemetery, three of them from the same context: Tomb 21 (T.21/29,35,44) and the other two from Tomb 44 (T.44/5) and Tomb 55 (T.55/16) (fig. 5.4).

Figure 5.4 Knives from Pyrgos-Mavroraki and Pyrgos Cemetery: a. T44/5; b. T55/16; c. T21/35; d. T21/44; e. T21/29; f. M7.

The artefacts from the famous Coppersmith Tomb are all tanged knives with rivets on shoulder and tang. T.21/29 was probably restored after the first two rivet-holes pierced on its shoulders failed and a re-hafting was needed. Two new rivets were placed just below the original ones. Evidence of reuse of metal objects is also attested in a needle from Pyrgos-Mavroraki's settlement, where the eyelet was re-pierced under the original one, which probably snapped due to use.

T.21/35 presents a very peculiar surface, where a sort of flowing pattern is visible on the blade's surface. It has been suggested that this could be an unfinished cast (Belgiorno 1997, p. 127), however the presence of two rivets in place on the shoulders and a remaining rivet-hole in the tang undermine this interpretation, leaving no other viable explanation than the effects of bad corrosion.

T.21/44 shows similar flowing patterns towards the point of the blade, but, similarly to T.21/35 the rivets are in place on the shoulders and the trace of a third one on the broken tang is still visible, making unlikely it to be an unfinished object (fig. 5.5).

Figure 5.5 Detail of flowing patterns on T21/35.

T.44/5 is a flat-tanged knife (according to Stewart's typology) or narrow-tanged dagger (according to Catling's typology) with a single rivet hole. It is evident that its blade has been used more on one side than on the other one. Similar knives have been found in Kalavassos Village, Tomb 78 – Cinema Area (n.17) and in Tomb 57 - Panayia Church (n. 33) where similar use-wear observations can be suggested, especially for one shoulder of T.78/17 and for the overall state of T.57/33, which is smaller as a result of its prolonged use (Todd et al 2007: figg. 43.3,5).

Metal tools used in Early/Middle Bronze Age Cyprus can be grouped in seven macro-categories: axes, scrapers, chisels, awls, needles. The largest tools used were the axes, distinguished in flat axes and socketed axes.

Flat axes were classified according to the shape and size of their butts, also considering if these were pierced or not. This is because, as observed by Catling, the only area of the axe unaffected by the forging is the butt, so this is used as a diagnostic feature for categorization. The only Chalcolithic antecedents for flat axes from Cyprus have been found in a fragmentary state at Kissonerga-*Mosphilia* (KM 457, Peltenburg 1998, p. 188-9) and, very recently, at Chlorakas-*Palloures* (571_M1, During et al. 2018, pp. 18-20).

Polygonal butts seem to be a Philia Culture prerogative while pierced butts appear from the Middle Cypriot I-II. Broken butts instead appear soon after, becoming common from Middle Cypriot II-III. This type of tool seems to go out of use in the Late Cypriot period (Balthazar 1990, p. 360).

Due to the total absence of visible traces of binding on any of the axes analysed by Balthazar, it is still unclear how these axes were hafted, if their butts were pierced to facilitate hafting, or if they were hafted at all and maybe simply held in hand instead (Balthazar 1990, p. 360).

From a manufacturing point of view, Balthazar suggested that these objects must have been cast in an open mould, undergoing little subsequent reshaping by hammering. Moulds for this type of object are now known from the two Early/Middle Bronze Age sites of Marki-*Alonia* and Pyrgos-*Mavroraki.* In the two multifaceted moulds from Marki-*Alonia* (S850 and S745, Frankel and Webb 2006, pp. 215-7; fig. 6.7), the shape of pierced-butts flat axes was recognised. A hole was drilled into the mould at the location of the butt, "probably used to support a stick or twig, which would have burnt out when molten copper was poured into the mould, but not before the metal around it had cooled sufficiently to produce a hole in the cast (Frank and Webb 2006, pp. 216-7; Fasnacht and Künzler Wagner 2001, p. 41).

The two clay moulds from Pyrgos-*Mavroraki* are the only ones of their kind from Cyprus, and, similarly to the exemplars from Marki-*Alonia*, they also are characterised by small holes impressed in the area where the axe's butt would have originated.

The larger appearance of these holes as pierced/drilled in the axes, and not as a direct result of casting, might be explained by the possibility that the original hole, left by a wooden- or other material-stick inserted through the mould's hole, would have subsequently been polished, reshaped and possibly enlarged by drilling, in order to remove any casting spill. These finds represent a further confirmation that this type of axe was manufactured at different metallurgical sites in Cyprus during the Early/Middle Bronze Age.

Moreover, Webb and Frankel suggested that these types of artefacts could have been produced as ingots to be stored or traded, rather than be used as actual tools (2006, p. 217), following similar interpretations already argued for the so-called Philia armbands (Webb et al 2006) and the Philia knife-billet from Sotira-*Kaminoudhia* (Giardino et al 2003, p. 391).

A second well known type of axe, which flourished during the Middle Cypriot period, is the **shaft-hole axe**. These objects resemble other prototypes from abroad, which although similar cannot be confused with the Cypriot examples. Two important technological innovations are reflected in these artefacts: they were all made of tin-bronze, differently from the majority of flat-axes usually casted in unalloyed or arsenical copper; secondly, manufacture traces seem to show that they were all cast in closed moulds. Balthazar also highlighted that the all the shaft-hole axes from certain contexts come from central Cyprus. Considering that another category of objects such as the toggle-pins show evidence of closed-mould casting, this might be a technological development that was first achieved in Middle Cypriot in this area of the Island (Balthazar 1990, pp. 372-1).

Despite the discovery of at least four moulds for axes, two of which suitable for the production of the so-called pierced-butt flat axes, no metal artefacts belonging to this type have been found at Pyrgos-*Mavroraki*'s settlement. Instead, two flat axes were found in Pyrgos's cemetery (fig. 5.6). These two examples both come from the same context: the so-called Coppersmith Tomb 21 (T.21/6,27).

Figure 5.6 Axes from Pyrgos Cemetery: a. T21/6; b. T21/27.

T.21/6 is 16.4 cm long and, considering the slight shape/size modifications due to hammering, seems to be quite compatible with the mould 352 from Pyrgos-*Mavroraki*'s settlement (see Ch. 3). However, the hole pierced in this axe's butt is partial and it is not clear if this is due to a sudden malfunction of the mould used (the wooden stick, possibly too small or made of the wrong essence took fire too soon) or for some other reason.

T.21/27 is smaller than that one just described, just 11.2 cm long. It is shaped in the form of a wedge and, considering eventual slight modifications in shape and size due to hammering, might correspond to the mould 1652 from Pyrgos-*Mavroraki*'s settlement.

In general, it is interesting to note that, despite the fact that Pyrgos's finds clearly testify a production of this type of flat axes, the majority of finds for these artefacts is reported in the rich Northern cemeteries, far more distant from the main copper ores outcrops and, therefore, from metallurgical sites. This may be considered one piece of evidence, alongside the others, of metal goods exchange from the Southern to the Northern coast, which could have been a vector towards Northern countries such as Anatolia.

One particular type of tool-blade is the **scraper** (or **razor**), which appeared in the Philia Culture and Early Cypriot period and remained in use until the end of the Middle Cypriot. Scrapers/razors usually appear as rectangular flat blades with smaller rectangular tangs, much rarer are those ones with blunt or pointed butts. Both the corners at the shoulders and close to the bottom are usually rounded. Shoulders have been distinguished as having sloping and straight forms (Catling 1964, p. 67) and blades as long-narrow and short-broad (Stewart 1962, p. 246) but, in Balthazar's opinion, no sharp demarcations really exist (1990, p. 352). From a manufacturing point of view, these objects were roughly cast, and shaped by hammering. Hafting traces were noticed on the base of the tang on the majority of the examples analysed by Balthazar (1990, p. 353). While other scholars interpreted these objects as a personal toiletry-tool, often found in connection with tweezers within the same funerary context, Balthazar, considering the use-wear patterns found on most of these blades, suggests that they could have been used also for other purposes. Similarly, to knives, the earliest scrapers are rivet-less until the Early Cypriot III, through the end of Middle Cypriot, when a single rivet pierced on the tang is used.

No scrapers/razors were found in Pyrgos-*Mavroraki*'s settlement, but among the grave-goods from the Coppersmith Tomb 21, one blade has been interpreted as belonging to this type (n. 37) (fig. 5.11). It is a long rectangular blade (9.9 cm), with a low midrib and distinct shoulders. Its long, flat tang is rectangular in shape as well and equipped with one rivet (Belgiorno 1997, p. 127), which suggests an EC III date. Another object which could be interpreted as a razor is number 6 from Tomb 44 within the same cemetery. It appears as a fragment of a thin, slightly tapering blade with sloping shoulders and a rivet-less tang (Giardino et al. 2002, p. 41).

Another important type of metal tool in Early/Middle Bronze Age Cyprus is the **awl**.
These objects were obtained from an open-mould cast metal bar, subsequently hammered to shape. Awls have a typical square cross section and pointed tangs, and they were hafted in a similar manner to chisels. According to different typological groups, Catling suggested different uses for these objects: by hand, with the aid of a hammer (as pointed out by the plain tops of some exemplars) or with a bow-drill (1964, p. 65).
From a manufacturing point of view, Balthazar suggested that awls were probably cast in an open mould, even if the metallographic analysis on three exemplars seems to suggest that they were cast in a closed environment (a simple sand-mould?) (1990, p. 373).

A particular variant of this objects has been identified as **scraper/awls**, metal objects resembling the broken arm of a tweezer. While other scholars suggested that these were hafted like awls and the broad "blade" used as scraper, Balthazar suggested they could have been hand-handled between the thumb and middle finger and used as a punch or a normal awl (1990, p. 379).

Together with the awls, **chisels** are known in Cyprus since the Middle and Late Chalcolithic. (Peltenburg 2011, pp. 4-5). These tools, as proved by the well-preserved Chalcolithic exemplars, were hafted in bone handles (Peltenburg 2011, p. 7). They usually consist of a long shaft with square or rectangular cross section, tapering butt and flaring cutting edge. It has been suggested that these objects were cast in an open mould and then rehammered in the cutting-edge area (Balthazar 1990, p. 377)

In the field these objects were identified as five chisels, following post-excavation analysis they were determined to be three **awls** with square sections, of which two tang-less (M4, M9, 626), a small **chisel** (606) and what looks more like a **drill** (M8) according to Catling's Type B4b (1964, p. 65), with its cutting edge of just 0.5 cm (fig. 5.7).

Moving to the metal finds from Pyrgos's cemetery, two awls, one with sharp pointed tang and tapering quadrangular pointed haft, was found in Tomb 2a (n. 31). Three larger examples of chisels were also be recovered from Pyrgos's cemetery, Tomb 21 (nn. 26, 30) and Tomb 37 (n.22) all belonging to Catling's Type B4 (1964, p. 65). T.21/26 and T.21/30 both have flaring hammered cutting-edges. T.36/22, the largest of the three with its 18.5 cm length, does not have any trace of use visible to the naked eye, probably buried new and unused as a funerary offer.

Figure 5.7 Awls from Pyrgos settlement and cemetery: a. 626; b. M4; c. T2a/51; d. M9. Drill from Pyrgos-Mavroraki: e. T21/31. Chisels from Pyrgos settlement and cemetery: g. 606; h: T21/30; i. T21/26; j. T36/22.

Looking at earlier contexts, **needles** are the only metal tools (the only other metal objects from this period are ornaments) which have been found in the Middle Chalcolithic site of Erimi (Peltenburg 2011, p. 4) and are now known from the Philia contexts of Marki-*Alonia* (Frankel and Webb 2006, p. 185-6). However, this tool type does not become common throughout the Island until the Middle Cypriot. They consist of long thin circular wire shafts that tend to taper to a point at one end and are hammered flat at the other end, which hosts a small, pierced circular or oval eyelet.

No chrono-typological development is shown for this category of artefacts, other than the later ones recorded by Balthazar (1990, pp. 380-3) that are possibly slightly thinner and longer, and in which, occasionally, the eyelet is almost rectangular, probably obtained using a square cross section awl. This might represent a certain level of residuality, a phenomenon that regarded other simple-shaped tools such as chisels and awls (Kassianidou 2013, p. 237).

Of the twenty-one metal tools found in Pyrgos-*Mavroraki*'s settlement, the most common are **needles** (163-5, 607, 609, 614, 616, 618-9, 621, 627) (fig. 5.8). Most of them come from the Western Sector, a vast 15m x 15m room, where the archaeological remains led the excavator to interpret this space in connection with textile production/processing (Belgiorno 2009, pp. 66-76). Six needles are whole (3 with a broken eyelet), while the remaining are fragmentary. They are very similar in shape to those ones from the EC III-MC I levels at Marki-*Alonia* (Webb and Frankel 2006, figg. 5.27-28).

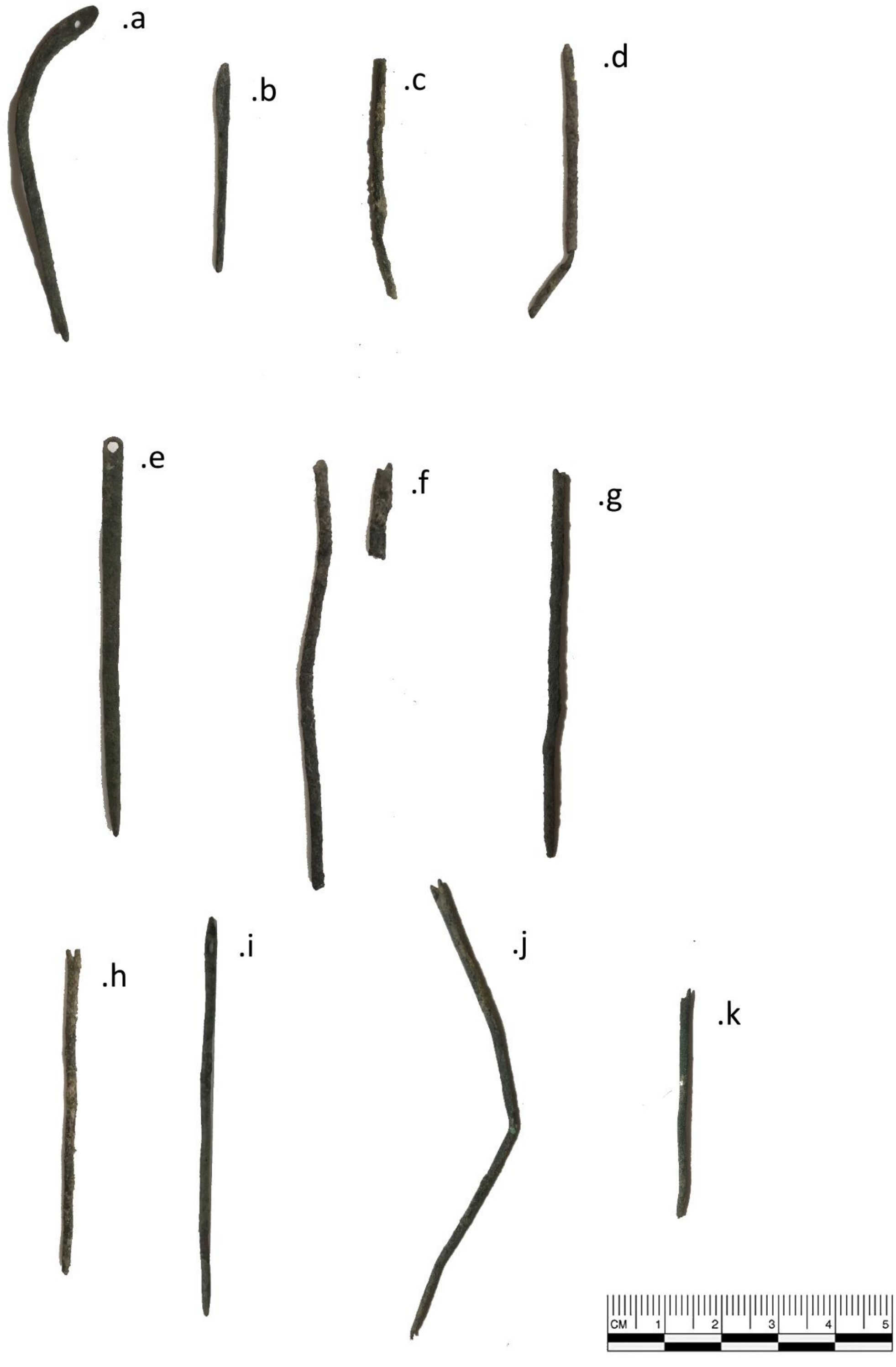


Figure 5.8 Needles from Pyrgos-Mavroraki: a. 164; b. 616; c. 165; d. 619; e. 607; f. 614; g. 163; h. 618; i: 609; j. 621; k. 627.

It is possible to notice that 614 was re-pierced just under the original eyelet, which probably broke due to use. This highlights how important even the smallest metal item was to Pyrgos's ancient inhabitants, who considered preferable to fix the object instead of throwing it away. These needles were probably produced on site as seems to be suggested by 616. This object could be considered as an unfinished item, as its hammered edge is conserved intact and not yet pierced for use.

5.2.3 Ornaments and tools of personal ornament

Balthazar felt that the previous categorisations operated by Åström and Stewart of **pins** included too many shape nuances, possibly going towards the identification of different hands, rather than overall trends. On the other hand, the author was not satisfied with Catling's typology which summarised these objects in just five categories. Therefore, she rethought the previous typologies, proposing a new list of twelve types in her study, based on the shape of their heads (1990, p. 390).

These artefacts were manufactured from the Early Cypriot II or III to the Middle Cypriot III, to be possibly replaced by toggle pins in later periods.

It has been suggested that, similarly to the vast majority of metal artefacts from the Early/Middle Bronze Age in Cyprus, these objects were cast in open moulds and then hammered, annealed and rehammered (Balthazar 1990, pp. 390-1).

Similarly, to pins, a vast series of **toggle pin** types that take into account head-shapes and the position and shape of apertures was suggested. Balthazar, however, summarised the mains typological characteristics of these artefacts as follows.

Toggle pins belonging to the Philia Culture are completely different from the others. Their heads are solid and well-defined, and their apertures are drilled in a round shape.

The exemplars from the Early Cypriot are rare and impossible, according to Balthazar, to force into classes. The contemporary pins' shapes often inspire these unique creations (Balthazar 1990, p. 408).

In the Middle Cypriot period toggle pins were in use for a short period, confined to the specific area of Lapithos and were divided by Balthazar in four classes: button-heads, thickened flattened heads, plain-heads and mushrooms-shaped head. The latter, in some cases, was manufactured separately and successively attached to a plain- or button-shaped head pin. These objects were obtained with the same technique used in pins production: open mould cast of simple shafts, which were then hammered to obtain tips and heads. The apertures were pierced with a chisel, as can be noted by the displacement of material that cause the shafts' swelling around the eyelets. Incised decorations appeared in this period.

A new type of toggle pin appeared at the end of the Middle Cypriot, which, differently from all previous exemplars, was cast using a closed mould. Both its conical head and decorations were moulded in, while the apertures were still obtained by chisel. It is interesting that this type of toggle pin was confined mainly to Central Cyprus, in the same area where the production of shaft-hole axes, and therefore the use of closed moulds, is already attested (Balthazar 1990, pp. 409-410).

Two **pins** were found at Pyrgos-*Mavrorak*i's settlement (fig. 5.9). The most recent one (M3), with a loop-shaped eyelet head, was recovered from the area on the northern limit between the Central and the Eastern Sectors (K5). Considering the context, it seems more appropriate to assign it to the MC III Åström's Type 21 (1957, pp. 144-6), rather than to the Late Cypriot Catling's Type Jc. It is indeed comparable with a specimen from Paleoskoutella Tomb 7 (Gjerstad et al. 1934, p. 435, n. 98). The second pin found at the settlement (608) belongs to an earlier type and is characterised by a convex head with a slight narrowing just underneath it. It was found in the Western Sector and it can be assigned to Åström's Type 7 (1957, pp. 144-6), dated to the EC IIIb-MC I.

Up to now, four pins have been recovered from the tombs of Pyrgos's cemetery.
Two specimens were found in Tomb 6 (nn. 1, 6) and they are both characterised by the same domed, convex head, and a marked narrowing of their shafts just below the rim. They have been dated to the EC II-III (Belgiorno 2019, pp. 124) and can be assigned to to Åström's Type 8 (1957, pp. 144-6). The pin from Tomb 2a (n. 21) has an almost biconical head and its shaft is thinner than T.6/1 and T.6/6. A similar object was found at the site of Episkopi-*Phaneromenoi* in Tomb 7A (n. 10), however its head look more conical than biconical (Todd et al 2007, p. 78, Ph.B4). This pin was already described by Todd et al. (2007, p. 80), who reported by its DAC inventory number LM RR121/21, indicating a general provenance from Pyrgos, without the specification of the tomb.
The last pin recovered from Pyrgos's cemetery was found in Tomb 24. Differently from the ones described above, this pin has a squared section and a plain flattened head. This object could be classified under Catling's Type A1.b. Four pins belonging to the same type have been found at the site of Episkopi-*Phaneromenoi* (Ph.M1 from Tomb 23B and Ph.M29, Ph.M49 and Ph.M58 from the settlement), but one in particular, Ph.M29, matches T.24/2 both in shape and size (Todd et al 2007, p. 79).

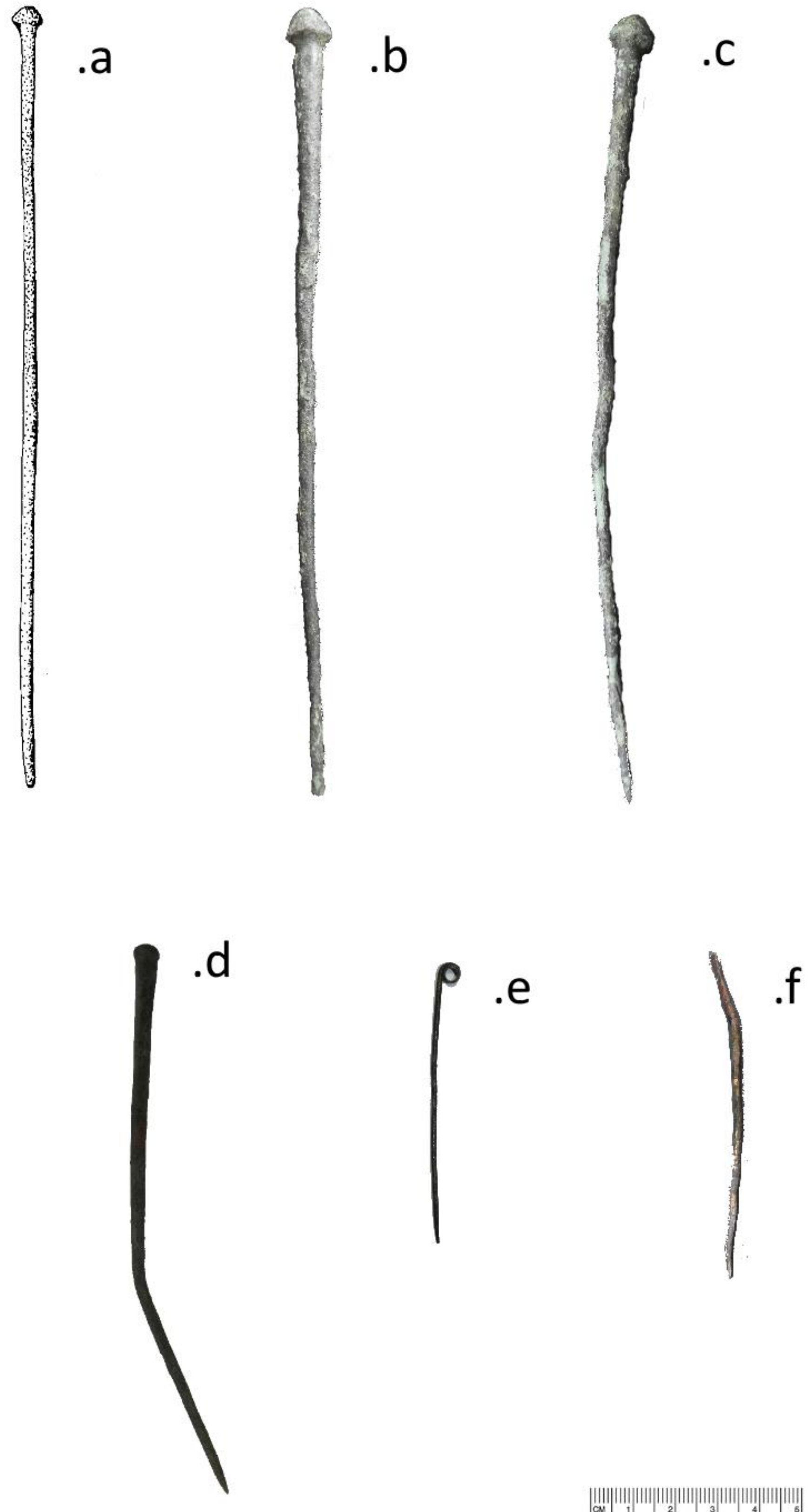


Figure 5.9 Pins from Pyrgos Cemetery: a. T2a/21; b. T6/2; c. T2/1; f. T24/2. Pins from Pyrgos-Mavroraki: d. 608; e. M3.

A general typological class has been dedicated to **rings**, but it includes different types of objects most probably intended for different uses. Even in this case Balthazar suggested her own reinterpretation of earlier typological systems (Catling, Astrom, Stewart), dividing these objects thus: spirals, large closed rings and closed small rings.

Spirals were probably used as earrings or hair rings (Balthazar 1990, pp. 420-1).

Thin **spirals**, obtained rolling tightly flat ribbons of metal, have been found in Chalcolithic funerary contexts such as Souskiou-*Vathyrkakas* and *Laona* (Christou 1989, p. 93, fig. 12.10) and in Bellapais-*Vounous* Site B (Dikaios 1940, pp. 48-49, pl. LX.27). They were found in MC tombs in several sites along the Island (Frankel and Webb 2006: 189) but also in the LC IA burials at Morphou-*Toumba Tou Skourou* (Vermeule and Wolsky 1990, pp. 298, 320, 331, pl. 112) and Ayia Irini-*Paleokastro* (Pecorella 1977, p. 255, fig. 491).

These spirals have been found in different sizes and consequently they have been interpreted as necklace's beads (Frankel and Webb 2006, p. 189) or part of a hair-dress decoration (Astrom 1972, p. 320) Vol. IV Part IB The Middle Cypriot Bronze Age.

A very similar type of artefact has been found used in other manners. It has been recorded how narrow spiral-shaped bindings have been used, probably as a decoration, wrapped around the shafts of EC III-MC II pins, possibly as an imitation of the thread or string used to bind the pin in place (Frankel and Webb 1996, p. 215). Similarly, to how these spirals are found in connection with pins, it has been observed that these objects were also used wrapped around the tangs of HTW (Todd 2007, fig. 43.1-2), possibly to facilitate hafting (Balthazar 1990, pp. 309-10). Frankel and Webb suggested for longer exemplars, such as M10 from Marki-*Alonia*, considering its 5.6cm length, that they might have been used as a "convenient way to store strips of metal sheets" (1996, p. 215).

Two artefacts belonging to this category have been found at Pyrgos-Among the metal objects found at Pyrgos's settlement, there are two specimens (M6 and 620) of copper-based small spirals, a very common object, classified by Åström as Bronze.Spiral.Type 1 (1957, pp. 150-151 fig. 15 nn. 7-8). They appear as spirals of thin flat metal, tightly coiled. These objects have also been found at other Chalcolithic (Souskiou-*Vathyrkakas* and *Laona*) and Early/Middle Bronze Age sites on the Island (Marki-*Alonia*, Kalavassos Village's tombs), but they have also been recorded in a few LC IA sites such as Morphou-*Toumba tou Skourou* and Ayia Irini-*Palaeokastro* (Frankel and Webb 2006, p. 189).

One of the "fossil-guides" which characterise the Philia Facies is indeed a type of personal ornament which has been commonly interpreted as **earrings** or hair rings. They consist of elongated triangular sheets of copper, or occasionally gold (Swiny 2003, p. 376, M6), rolled into spirals. These artefacts have been found at Philia-Laksia tou Kasinou, Kyra-Kaminia, Dhenia-Kafkalla, Nicosia-Ayia Paraskevi, Sotira-Kaminoudhia (in gold), Kissonerga-Mosphilia, Marki-Alonia and Marki-Davari (Webb and Frankel 1999, p. 31). They correspond to Type I identified by Todd et al. in their 'hair ornaments' typology (2007, p. 254).

The most ancient metal artefacts from the settlement of Pyrgos-*Mavroraki* belong to this category. Three **earrings** (or hair rings) of the typical Philia shape were found in the most ancient levels of the site. The first earring (239) was found in the "textiles room". The other two were found interlaced and probably form a pair (622, fig. 5.10). These are not the only finds which date back to the Philia Facies: two pierced annular pendants have also been found at Pyrgos-*Mavroraki* (Carannante 2009, pp. 115-6), as well as a spindle whorl and potsherds all belonging to Philia (Belgiorno 2009: 55).

Todd et al. classified three more types of hair ornaments (2007: 255-6); however, their Type II is of particular interest for this study. This is a new type of **tubular hair rings**, which was produced with the same technique of the Philia examples and appears in gold at the end of EC I and in copper at the end of EC III. They correspond to Catling's Type D3, who mentions examples from Vounous Tomb 164b (n. 39) and Tomb 16 and from Kalavassos, Tomb 5 (1964: 75).

It consists of rectangular or triangular shaped piece of metal sheet, rolled up to form a cylindrical tube. At the upper edge, a pointed loop of flat wire encircling the cylinder allows to wear this object as an earring, threading the wire through a hole in the ear, or as a hair ornament, simply tightening the wire up around the cylinder.

A pair of **tubular hair-rings** (M5), comparable with the type just described, was recovered from deep levels in the "room of perfumes" (Central Sector). They were found in fragments and, after being restored by Andreas Georghiades, DAC Head Conservator at the Cyprus Museum, they measure 7.2 cm in length and about 1.5 cm in diameter, considerably larger in size when compared to Todd's Type I. The specimens from Pyrgos-Mavroraki's are, as far as the writer is aware, the only ones found in a settlement up until now (Belgiorno 2009: 65).

A tubular hair-ring, larger than the pair found at Pyrgos's settlement (9.9 cm in length and 2.5 cm in diameter), has been found in Tomb 37 (n. 5) of Pyrgos's cemetery.

Possible comparisons can be found in a series of fragments from the cemetery of Kalavassos Village (Todd et al 2007: 256).

Another type of **spiral ring** appears at the transition to the Middle Cypriot. It consists of flat ribbons or coils with circular cross-sections, spiralling into rings of usually 2-3 cm in diameter, but ranging up to 8 cm (Balthazar 1990: 420).

A **coil ring** (M1) with a diameter of 1.6 cm was found in the Northern Sector at Pyrgos-Mavroraki, belongs to this type and was probably used as a finger ring. It can be assigned to Catling's Type D1 (1964: 74).

Two unusual pieces of jewellery from Tomb 21 belong to this section but have no direct collocation in the published typology of Early and Middle Bronze Age Cypriot metals. These are a **bracelet** with open ends (n. 60b) and a fragmentary **necklace** made of thin metal sheet-ring equipped with a small rectangular plate-shaped pendant, pierced in the corners (n. 60a). The bracelet shares vague similarities with the armlets from the Philia site of Vasilia, which, however, are composed of a thick rope of metal bent into a circle where the two ends have been hammered, soldered or melted together, closing its shape. Open armlets with overlapping ends were to become more common in the Late Cypriot period (Catling 1964, p. 231).

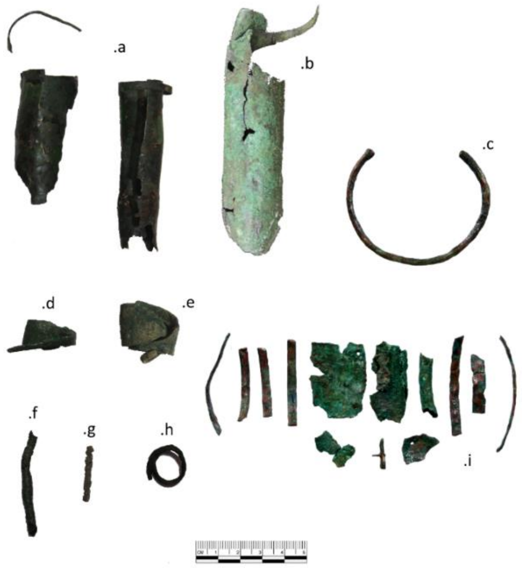


Figure 5.10 Ornaments from Pyrgos-Mavroraki and Cemetery: a. M5; b. T37/5; c. T21/60b; d. 239; e. 622; f. M6; g. 620; h. M1; i. T21/60a.

Finally, I included in this section **tweezers**, as this tool, more than razors/scrapers which could have used for multiple purposes, is strictly connected with personal ornament. These objects were introduced to Cyprus from the Early Cypriot III. They were most probably cast in an open mould in the shape of a long strap of metal, successively reshaped by hammering and bent in a U-shape. Both pinched-spring and open-spring tweezers are found from the Early Cypriot III through the Middle Cypriot III, when a new type of pinched-spring tweezer with a definite angle between the loop head and the arm appeared.

These objects, usually found in tombs together with razors, highlighting the attention of ancient Cypriots paid to their physical appearance and personal style. Stewart suggested that tweezers were used in facial grooming to pull on the beard and facilitate shaving, rather than for plucking hair (Balthazar 1990, p. 384). It would be interesting, however, to investigate more accurately the funerary contexts these objects are usually found through osteo archaeological analyses, in order to verify if these objects can be truly used so widely as a sex indicator.

A single object found Pyrgos-*Mavroraki* has been interpreted by the excavator as a pair of **tweezers** (M3). It appears as a short metal bar with a total length of about 6.8 cm, with a rectangular cross-section towards the edges, which becomes circular in the bent portion. Giardino et al. assigned it to Catling's Type C2b (2002, p. 37), but there is no clear evidence of the pinched spring which characterises Catling's type. Overall, considering the unusual shape and the metallurgical production vocation of the site, the possibility that this object might be an unfinished product belonging to a completely different type of artefact should also be considered.

Three pairs of tweezers were found during the excavation of Pyrgos's MC I-II Tomb 1 and EC III-MC I Tomb 21 (fig. 5.11).

Number 7 from T.1 is a pinched spring tweezer 10 cm long (Belgiorno 2019, p. 15) and belongs to Catling's Type C2b (1964, pp. 68-9). T.21/25 and T.21/41 are both open-spring tweezers and can be classified under Catling's Type C2a (1964, p. 68) but differ slightly in shape. The first one shows narrow long arms with a sensible blade splaying, while the metal strap which composes the second tweezer keeps its rather large diameter along the entire length of the arms with a less pronounced splaying towards the blades (Belgiorno 1997, pp. 125, 127, 140 fig.12).

Figure 5.11 Razors and Tweezers from Pyrgos-Mavroraki and Cemetery: a. T44/6; b. T21/37; c. M2; d. T1/7; e. T21/41; f. T21/25.

5.2.4 Miscellanea

A series of unusual objects or unrecognisable fragments of copper/copper alloy have been found at Pyrgos-*Mavroraki***.** These objects find no link to the types described in the previous paragraph in some cases because of their recognisable later chronology, in others simply due to their unusual shape, their fragmentary status and poor state of conservation.

It is possible to start this list removing those objects which are likely not to belong to the Early/Middle Bronze Age occupation of the site.

Two small **disks** (604 and 611) have been found in the superficial layers 1 and 2 in the area “beyond the road”. They measure 2 cm each in diameter and might be identified as studs or small coins in very poor condition.

A beautiful **arrowhead**, complete and well-preserved, was found in the disturbed levels in the area “beyond the road” and can be dated between the Cypro-Archaic II and the Cypro-Geometric as suggested by strict comparisons with the arrowheads found in Tomb 322 at Amathus (Karageorghis et al. 1992, pp. 65, 84 figg. 7-9, 11).

At last, it is mentioned here a **small fragment** (617) of a bent shaft 3.9 cm long, with circular section, bulbous edges and a small broken branch departing from the centre of its shaft. This was found in a disturbed level of the Southern Sector. It is hard to suggest a reliable interpretation for this item basing it just to a simple autoptic analysis. More accurate metallographic analysis might reveal if this object belonged to a small figurine cast through lost-wax technique or, perhaps, is part of a metal spillage originated during the casting of another object. In case of a casted figurine, it would be possible to recover, under the microscope, evidence of polishing, refining and possibly hammering traces, which would have caused an alteration and distortion of the metal grains' shape, which would not have occurred in the case of a simple incidental spillage.

This list continues moving to other unusual objects which come from certain E/M BA contexts. A small **closed ring** (623, fig. 5.12b), with a diameter of only 0.8 cm, was found in the same area of M1, but its shape finds no coeval comparisons.

Another object which seems to not find any typological comparison has been interpreted as a **leaf-shaped pendant** (612) by the excavator (Belgiorno 2009, p. 66, fig. 2). It consists of a thin flat piece of metal with an ogival shape towards one end. Just below the pointed end, a small notch on both sides has been cut, probably with a chisel, possibly to make the object wearable (fig. 5.12a). The fact that this artefact comes from a disturbed level, opens its interpretation to doubts.

The fragment of an unusual copper-based **hook-shaped tool** was found in the "textiles rooms" (Western Sector). It is a small metal shaft which has been bent twice to obtain an "S" or "Z" shape, and one of the edges has been hammered in the shape of a small spatula with slightly flaring blade (fig. 5.12c). This object has been interpreted by the excavator as a possible tool related to textile production, such as a rug-hook (Belgiorno 2009, p. 68, Belgiorno 2004, pp. 66, 97 fig.37)

Two small fragments of corroded **metal scrap** have been recovered in the Central and Southern Sectors (fig. 5.12d-e).
613 has a triangular shape with its largest side measuring 2.9 cm and an overall thickness of 1 cm, while 603 has a globular shape and measures 1.4 cm in diameter.

Finally, two metal objects, very different in colour and shape from all those ones described until now, were found from Pyrgos-*Mavroraki*'s settlement. 624 is a small flat **fragment of grey metal**, about 4 cm in length and no thicker than 0.3 cm., while 174 appears as a **miniature oxhide ingot**, similar in colour to 624 and missing part of one short side, for a total length of 7.6 cm long and 1.8 cm thick (fig. 5.12g-h).

Figure 5.12 Miscellanea from Pyrgos-Mavroraki: a. 612; b. 623; 166; d. 613; e. 603; f. 617; g. 174; h. 624.

Weapons	Tools	Ornaments/tools of personal ornament	Miscellanea
HTW (C: 3)	Knife (S: 2; C: 5)	Pin (S: 2; C: 4; X: 2)	Disk (S: 2)
	Flat axe (C: 2)	Spiral (S: 2)	Arrowhead (S: 1)
	Scraper/razor (C: 1)	Earring (S: 3)	Amorphous Fragment (S: 1)
	Awl (S: 3; C: 2)	Hairring (S: 3)	Closed ring (S: 1)
	Chisel (S: 1; C: 3)	Coil ring (S: 1)	Scrap (S: 2)
	Drill (S: 1)	Bracelet (C: 1)	Miniature oxhide ingot (S: 1)
	Needle (S: 11)	Necklace (C: 1)	Hook-shaped tool? (S: 1)
		Tweezers (S: 1; C: 3)	Lead scrap (S: 1)
			Leaf-shaped pendant? (S: 1)
Total **3** (C)	**Total 26** (S: 18; C: 13)	**Total 21** (S: 12; C: 9; X: 2)	**Total 11** (S)
TOTAL 68 (S: 41; C: 25; X: 2)			

Table 5.2 Overview of the copper and copper-alloy items from Pyrgos-Mavroraki (S), Pyrgos Cemetery (C) and general provenance from Pyrgos area (X).

5.2.5 Discussion

If we consider the total amount of metal artefacts from the settlement and the cemetery of Pyrgos-*Mavroraki*, we are looking at a total of 68 objects (including a hook-tang weapon presented at the DAC as coming from "a tomb nearby Pyrgos" and two pins from an unspecified location in the Pyrgos area).

The forty-one objects from the settlement include a Cypro-Archaic/Geometric copper arrowhead, a possible bronze stud from level 1 and what looks like a coin in very poor condition, which were soon identified to be late. Four other objects, two needles, a small chisel and a copper drop, were found in the Limassol Museum's storeroom unprovenanced, but, considering the typology of the first three, were identified as coeval with the Early/Middle Bronze Age occupation of the site.

The remaining thirty-three objects were initially divided according to their provenance following the method used in Chapter 4 for the slags (fig. 5.13-14).

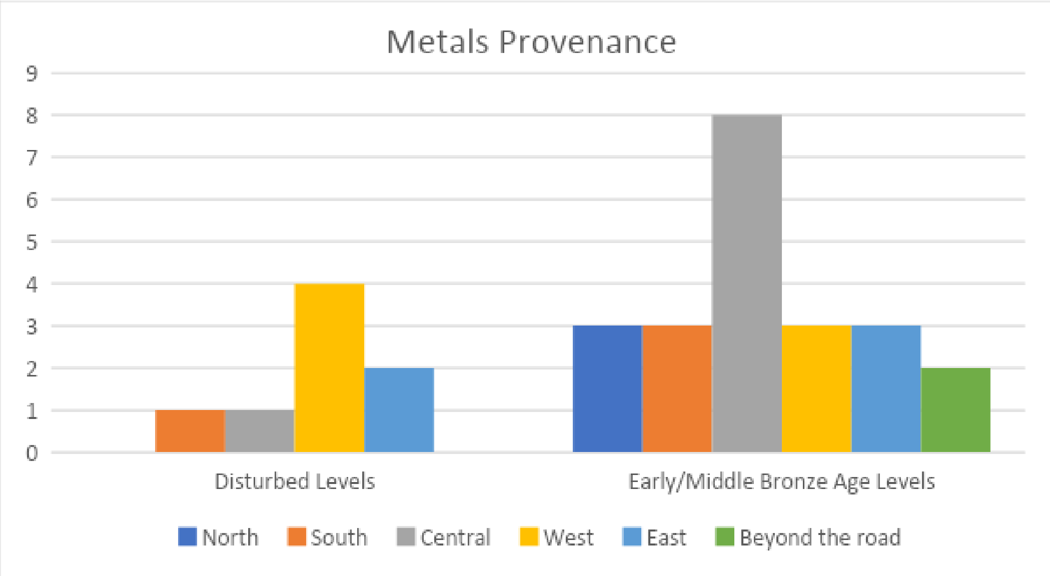


Figure 5.13 Distribution of metal artefacts in Pyrgos's sectors and general stratification.

The bronze stud is the only object which was found on the surface, and it is most likely late, while the arrowhead and the coin came from the "disturbed levels" in the sector "Beyond the Road". The majority of the other eight objects listed as coming from the "disturbed levels" are typologically compatible with the Early/Middle Bronze Age occupation of the site, leaving out just a few of unsure attribution (see Miscellanea). A total of twenty-two objects have been listed from the E/M BA levels.

As expected, no HTWs, usually buried as funerary offering, were found in the settlement, but various tools and objects related to personal ornament were.

Similarly, to HTW, objects of personal ornament are more commonly found as funerary offerings than dispersed individually.

The discovery of nine objects of personal ornaments at Pyrgos-*Mavroraki*, in a settlement context, especially if compared to other coeval settlements such as Marki-*Alonia* and Alambra-*Mouttes*, where these finds are certainly not abundant, seems to reflect the sudden abandonment of the site due to the seismic event mentioned in Chapter 3.

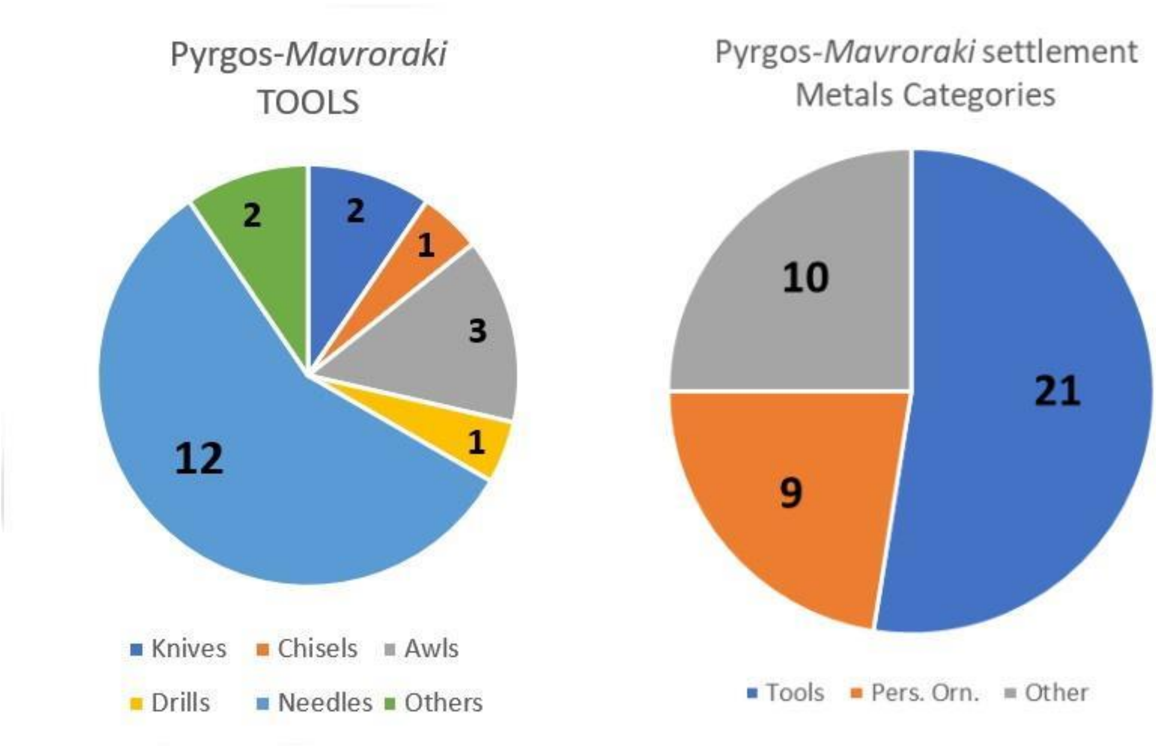


Figure 5.14 Graph showing the amount of metal artefacts belonging to each category and type.

In terms of evident concentrations of specific types, the only possible relevant data is that the majority of needles comes from the Western Sector, adding further evidence towards the interpretation of this area as a space dedicated to the processing and production of textiles.

Some of the objects found at the settlement of Pyrgos-Mavroraki are strictly related to the metal production which took place at the site.

Objects like the needle 616 or the metal bar M2 (previously interpreted as a tweezer) seem to be unfinished items that were lost or abandoned before they could be completed. The two fragments 603 and 613 (and possibly the unclear 617) might be related to smelting and casting processes. The fragment of grey metal, confirmed by pXRF analysis to be lead, could have been used during casting to improve the fluidity of metal.

The miniature grey ingot, which has been confirmed by pXRF analysis to contain both lead and tin, might be evidence of alloying practices carried out on-site.

It is remarkable that just three HTW have been found in Pyrgos's cemetery from sure contexts, with the fourth one collected after confiscation. The five daggers/knives also seem a small number in comparison to wealthy tombs of the coeval Northern cemeteries of Vounous and Lapithos. As well outlined by the excavator, the so-called Coppersmith Tomb 21 with its 13 metal items, certainly represents a unicum in Pyrgos's cemetery (Belgiorno 1997), where just 10 more tombs contained a maximum of two metal artefacts each, despite the fact that many of them are multiple burials.

There might be two different explanations to this phenomenon: the first one being that only a fraction of the metal grave-goods has been effectively recovered and other objects might have been lost due to looting activities. The old excavation notes deposited to Limassol Archaeological Museum do not always explicit if the tombs excavated were found already looted or not. However, Tomb 2a, where 8 individuals were buried at different stages and 59 objects were offered as grave-goods, and for which no signs of looting have been recorded, contained just one pin and an awl.

Another possibility is that the members of the E/M BA Pyrgos's community considered metal more as a precious good for trade than a shiny implement to own, preferring to exchange it with the communities on the Northern coast and possibly even outside the Island for other goods not available in the areas surrounding Pyrgos. To support such a statement more studies dedicated specifically to these problematics should be carried out, possibly involving a new program of isotopic studies both on metal artefacts and metallurgical discard from Pyrgos-*Mavroraki*, in an attempt to reconstruct the ancient itineraries followed by the copper produced at the site.

5.3 Metal composition in Early and Middle Bronze Age Southern Coast Cyprus through the chemical study of Pyrgos-*Mavroraki*'s artefacts

5.3.1 Previous approaches to the study of Pyrgos-*Mavroraki*'s artefacts

Preliminary analyses were carried out and published by Giardino et al in 2002. Five artefacts from the site were analysed by ED-XRF, together with sixteen more objects from Pyrgos's necropolis and three more objects part of the permanent exhibition at the Archaeological Museum of Limassol District: a sword from Pyrgos, one axe from Vassa Argylas and a pin with a general provenance from Limassol.

The authors found that the objects analysed had a diversified chemical composition, from unalloyed copper to arsenical copper and tin-bronze (tab. 5.3).

Pyrgos-*Mavroraki* Settlement								
Sample	**Artefact**	**Composition (wt%±STDEV)**						
		Cu	**Sn**	**Pb**	**As**	**Fe**	**Zn**
M1	Small ring	88.3	10.6	0.4	-	0.7	-
M2	Pin	81.6	16.5	1.0	-	0.9	-
M3	Tweezers (?)[1]	99.3	-	-	0.5	0.2	-
M4	Awl	99.1	-	-	0.2	0.7	-
M5[2]	Hair-rings	83.1	15.6	0.1	0.6	0.5	-
Pyrgos's Cemetery							
Sample	**Artefact**	**Composition (wt%±STDEV)**					
		Cu	**Sn**	**Pb**	**As**	**Fe**	**Zn**
T.2a/51	Awl (A)	97.7	-	-	1.8	0.5	-
T.2a/51	Awl (B)	98.2	-	-	1.4	0.5	-
T.2a/21	Pin	98.4	-	-	1.1	0.5	-
T.21/29	Dagger (A: blade)	95.3	-	0.2	3.8	0.8	-
T.21/29	Dagger (B: rivet)	96.4	-	0.4	2.5	0.7	-
T.21/37	Dagger (A: blade)	84.9	12.4	2.3	-	0.4	-
T.21/37	Dagger (B: rivet)	84.7	11.4	3.4	-	0.5	-
T.21/44	Dagger (A: blade)	87.2	12.2	-	0.1	0.4	-
T.21/44	Dagger (B: rivet)	95.6	3.0	-	0.8	0.6	-
T.21/35	Dagger (A: blade)	82.3	17.0	0.5	-	0.5	-

[1] The authors follow Belgiorno's interpretation of this object as tweezers, but, as already suggested, alternative interpretations cannot be rule out.

[2] This item was mistakenly reported by Giardino et al. (2002, pp. 34, 37) as M6. This inventory number corresponds instead to a small spiral and was not analysed by the authors.

T.21/35	Dagger (B: rivet)	91.2	7.4	-	0.9	0.5	-
T.21/31	Awl	84.5	15.0	0.3	-	0.2	-
T.21/30	Chisel (A)	96.1	0.9	0.2	2.4	0.4	-
T.21/30	Chisel (B)	96.3	0.7	0.1	2.4	0.5	-
T.21/26	Chisel	98.0	-	-	1.3	0.7	-
T.21/6	Axe (A)	96.7	-	0.1	2.6	0.6	-
T.21/6	Axe (B)	97.1	-	0.1	2.1	0.6	-
T.21/27	Axe	98.6	-	-	1.1	0.4	-
T.21/25	Tweezers (A)	94.0	-	0.2	5.3	0.4	-
T.21/25	Tweezers (B)	92.5	-	0.2	6.9	0.5	-
T.21/41	Tweezers	83.8	15.5	0.5	-	0.2	-
T.21/60a	Necklace (rivet)	96.7	1.2	-	1.5	0.6	-
T.21/60b	Bracelet	81.9	16.9	0.8	-	0.5	-
T.44/5	Dagger (A)	96.8	-	0.1	1.9	1.2	-
T.44/5	Dagger (B)	96.5	-	0.2	2.3	1.1	-
T.44/6	Razor	99.9	-	-	0.1	-	-
Pyrgos's Area							
Sample	**Artefact**	**Composition (wt%±STDEV)**					
		Cu	**Sn**	**Pb**	**As**	**Fe**	**Zn**
LM 520/1	Sword (A)	99.6	-	-	0.1	0.3	-
LM 520/1	Sword (B)	99.7	-	-	-	0.3	-
LM 520/1	Sword (C)	99.6	-	-	0.1	0.3	-
LM 1031	Axe (Vassa Argylas)	98.5	-	-	1.2	0.3	-
Km 1881 T.294/20	Pin (Limassol)	95.6	2.9	0.2	0.8	0.5	-

Table 5.3 ED-XRF analyses of metal artefacts from Pyrgos by Giardino et al. (2002, p. 34).

Four objects were found to be made of unalloyed copper, while eight artefacts showed a content of arsenic below 2% with the only exception of the tweezers from Pyrgos Cemetery (T.21/25) that contain a higher amount of arsenic (5.3-6.9%). Considering its irrelevance to the mechanical properties of the alloy, the authors suggest interpreting the low amount of arsenic detected in these objects as evidence of the exploitation of local arsenic/copper ores, present in the Limassol area, at the localities of *Pevkos* and *Laxia tou Mavrou* (Giardino et al. 2002, p. 44). Tin-bronze was identified as the copper alloy used for thirteen of the objects analysed. The daggers 35 and 44 found in Tomb 21, interpreted by the excavator as unfinished objects (Belgiorno 1997, pp. 125, 127), are now reconsidered by Giardino et al. The authors detected a high content of tin and recognised that the corrosion displays possible defects in casting the final object rather than casting billets (Giardino et al. 2002, pp. 39).

It was established that the composition of blades and rivets differs in the artefacts analysed, where a major presence of the alloying element (As or Sn) has been recorded in the blade, very likely to improve the objects' hardness (Giardino et al. 2002, p. 44).

Since these analyses were carried out, more metal objects were found at Pyrgos-*Mavroraki*. Essential information about the manufacture of these objects and their provenance can be provided only through metallography and the analysis of lead and copper isotopes. These methods, however, require physical sampling which was not viable in this case. For this reason, it was decided to proceed with an alternative non-invasive technique, bearing in mind its limitations in regards of possible difficulties in the final interpretation where a thick patina and corrosion are present on the artefacts' surface (Wrobel Nørgaard 2017). Twenty-five new metal artefacts found at Pyrgos have been analysed by hand-held portable X-Ray Fluorescence (HHpXRF) and the objects already analysed by Giardino et al. (2002) have been re-analysed with the same device to achieve a more acceptable level of comparability. Despite the knowledge that comparisons between the data collected during this research and the results published for other coeval sites is not 100% reliable, because different devices and analytical parameters have been used, more general comparative considerations might be suggested.

5.3.2 New pXRF analyses on published and unpublished metal finds: methods

The adoption of HHpXRF has been possible after decades of successful use of lab-based XRF Spectroscopy applied to archaeology using bench-top devices. The construction of this type of device started in 1970s, and since then the size of the equipment has radically decreased, allowing the production of hand-held devices with a readily understood gun-like form. However, the user-friendly shape of these instruments somehow fostered the spread of the common misperception that XRF is as easy as “taking aim and shooting” (Ferretti 2014, p. 1754).

This method is based on the irradiation of the surface to be analysed with an electromagnetic radiation of suitable energy, inducing electronic transitions in the inner shells of its atoms. These transitions result in the emission of X-rays whose energy is characteristic of the element invested by the transitions themselves, whereas the intensity of emission is determined to the elemental abundance in the sample analysed (Ferretti 2014, p. 1754).

This method has two main limitations that need to be addressed. One is that detection of elements with a low atomic number ($Z < 20$) is difficult due to their low photoelectric absorption coefficient, higher degree of internal conversion (Auger effect) and low energy of characteristic radiation. The second limitation is that the penetration of the radiation emitted by the device is limited to a thin layer below the surface: almost the entirety of the analytical information for Cu and Pb and almost half of the information for Sn comes from the first 20 μm of the sample. When it comes to the investigation of ancient metals, it is therefore important to consider that products of corrosion, which usually cover the surface of these artefacts, can sensibly affect the accuracy of the XRF measurements (Ferretti 2014, p. 1754). Superficial phenomena that can occur in metal artefacts such as the Pb migration to the surface of leaded bronzes during the annealing process, or the formation of patina (a corrosion layer which retains the form of the original surface of the object). In the patina, which can reach several tens or hundreds of μm of thickness, Cu corrosion products tend to leave the surface of the object in a wet context as they are more soluble than Sn and Pb, which instead might appear more prominent than the actual alloy core composition analysed by XRF (Ferretti 2014, p. 1756). Therefore, the results provided by XRF measurements should be considered as qualitative and “semi-quantitative”.

This technique involves, therefore, increased sampling uncertainty compared to more invasive techniques, but it has been successfully applied in identifying the major alloyed elements in archaeological artefacts, while tending to overestimate the proportion of secondary metals (Charalambous and Webb 2020, p. 3).

This technique has become very popular over the last few decades and the reason for its success over other techniques, such as Atomic Absorption Spectroscopy or Inductively Couple Plasma Spectroscopy, might be connected to different reasons. Museum curators around the world are becoming more and more reluctant to allow the physical sampling of artefacts (integral or fragmentary), necessary for analyses run by the latter two techniques mentioned, but not for HHpXRF. It is important to highlight, however, that the best conditions to perform XRF analyses on a metal artefact would require the depatination of the superficial spot analysed, to correct the compositional phenomena described earlier and to increase the chances of reliable results (Charalambous and Kassianidou 2014, p. 199; Ferretti 2014, p. 1756). The portability of these devices and the fact that they have been made highly “user-friendly” by the factories also contributed to their success.

Differently from the past, the new software, with which these machines are usually equipped for data collection, now allow a direct and simultaneous conversion of the spectra acquired during the analysis to actual elemental evaluation, extending the use the X-Ray Fluorescence to a larger audience of scholars (even archaeologists and not just material scientists).

Newcastle University’s Bruker Tracer III-SD Handheld X-Ray Fluorescence Spectrometer has been used, in combination with the S1PXRF© software, to manage data acquisition, spectral assignments and computation of concentration through calibration.

This instrument is equipped with a Rhodium target X-Ray tube with a maximum voltage of 30µA at 40kV (15µA at 15kV) and Silicon Drift Detector (SDD). It contains a high-resolution, Peltier cooled, Silicon PIN (Si-PIN) diode detector.

The instrument is factory-calibrated, and it was used with the following settings suggested by the factory for the analysis of copper alloys: 40kV voltage beam, 10μA current range, filter 1(Al-300um/Ti-25um), calibration file Cu1.CFZ.

In most cases, due to their small size, the objects were positioned directly on the detector window and analyses were undertaken in a Bruker bench-top stand.

The measuring time for each spot analysis was 120 secs. The data collected were exported into an Excel spreadsheet to allow further mathematical treatment. The final measurement value for each analysed object is the mean value of three to six measurements conducted on selected areas free from corrosion of each object (Charalambous and Kassianidou 2014, p. 199). It was possible to find suitable corrosion-free areas to undertake just two spot-analyses for each of the following artefacts: PY.615; PY.623; PY.625; only one for PY.165.

5.3.3 Results, comparisons and discussion

In order to make the results of this study comparable to other modern, although chronologically slightly more recent, compositional studies carried out on Cypriot metal objects using the same methodology, the analytical data is presented using tables similar to the ones used by Charalambous and Kassianidou (2014) and Van Brempt (2016).

The five objects previously analysed by Giardino et al. (2002) were re-analysed as part of this study which included thirty-four new artefacts. The results for weight % of Copper, Tin, Lead, Arsenic, Iron and Zinc have been reported normalised (Tab. 5.4).

Pyrgos-*Mavroraki* E/M BA TOOLS							
Sample	**Artefact**	**Composition (wt%±STDEV)**					
		Cu	**Sn**	**Pb**	**As**	**Fe**	**Zn**
M7	Knife	95.6 ± 2.3	1.0 ± 0.2	0.0 ± 3.5	2.7 ± 1.4	0.7 ± 0.4	0.1 ± 0.0
610	Knife	97.2 ± 0.7	0.6 ± 0.1	0.0 ± 1.4	1.3 ± 0.5	0.9 ± 0.2	0.1 ± 0.0
M4	Awl	95.4 ± 4.7	0.3 ± 0.1	0.1 ± 0.3	0.1 ± 0.1	4.0 ± 2.0	0.1 ± 0.0
M9	Awl	88.6 ± 0.3	10.0 ± 0.3	0.0 ± 0.3	0.9 ± 0.1	0.4 ± 0.1	0.1 ± 0.0
626	Awl	93.2 ± 1.5	0.3 ± 0.1	0.0 ± 1.3	1.4 ± 0.5	4.9 ± 0.6	0.1 ± 0.0

M8	Drill	93.6 ± 3.4	0.3 ± 0.2	0.0 ± 6.5	4.9 ± 2.6	1.1 ± 0.3	0.1 ± 0.0
606	Chisel	99.5 ± 0.1	0.2 ± 0.0	0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
163	Needle	86.7 ± 7.0	3.1 ± 0.3	0.0	0.9 ± 0.6	9.2 ± 3.0	0.2 ± 0.0
165	Needle	82.8	1.6	0.5	0.4	14.4	0.2
607	Needle	98.7 ± 3.3	0.5 ± 0.0	0.0	0.5 ± 0.1	0.2 ± 1.5	0.2 ± 0.0
609	Needle	95.0 ± 2.3	1.2 ± 0.1	0.2 ± 0.2	0.2 ± 0.0	3.2 ± 1.1	0.2 ± 0.0
610	Needle	97.2 ± 0.7	0.6 ± 0.1	0.0 ± 1.4	1.3 ± 0.5	0.9 ± 0.2	0.1 ± 0.0
614	Needle	90.2 ± 5.6	1.2 ± 0.1	0.1 ± 0.6	0.3 ± 0.2	8 ± 2.5	0.2 ±0.0
615	Needle	92.1 ± 0.6	0.6 ± 0.0	0.0 ± 0.7	1.6 ± 0.3	5.6 ± 0.5	0.2 ± 0.0
616	Needle	95.0 ± 3.6	0.4 ± 0.1	0.0 ± 0.1	0.6 ± 0.1	3.9 ± 1.3	0.1 ± 0.0
618	Needle	89.8 ± 4.0	5.2 ± 0.5	0.0 ± 0.5	1.2 ± 0.2	3.7 ± 1.3	0.1 ± 0.0
619	Needle	83.3 ± 4.7	2.2 ± 0.4	0.0 ± 5.6	3.5 ± 2.1	11 ± 2.4	0.1 ± 0.0
621	Needle	96.1 ± 4.6	0.6 ± 0.2	0.6 ± 0.5	0.7 ± 0.2	2.5 ± 1.6	0.2 ± 0.0
627	Needle	95.1 ± 3.1	0.7 ± 0.1	0.0 ± 0.4	0.5 ± 0.1	3.6 ± 1.2	0.1 ± 0.0
Pyrgos-*Mavroraki* E/M BA PERSONAL ORNAMENTS							
Sample	**Artefact**	**Composition (wt%±STDEV)**					
		Cu	**Sn**	**Pb**	**As**	**Fe**	**Zn**
239	Earring Philia	94.2 ± 7.7	0.4 ± 0.1	0.2 ± 0.1	0.0	5.1 ± 4.0	0.1 ± 0.0
622	Earrings Philia (pair)	94.7 ± 0.5	0.4 ± 0.0	0.8 ± 0.0	0.0	4.5 ± 0.2	0.2 ± 0.0
M6	Small spiral	72.0 ± 11.6	22.7 ± 9.2	3.3 ± 1.1	0.1 ± 0.0	1.9 ± 0.8	0.1 ± 0.0
620	Small Spiral	93.1 ± 0.5	0.6 ± 0.0	0.4 ± 0.1	0.1 ± 0.0	5.7 ± 0.4	0.1 ± 0.0
M1	Coil ring	77.5 ± 5.8	17.1 ± 1.8	1.3 ± 0.3	0.1 ± 0.1	3.7 ± 1.7	0.3 ± 0.2
M5	Tubular hair-rings (pair)	81.1 ± 3.7	17.6 ± 2.2	0.0 ± 0.7	0.8 ± 0.2	1.9 ± 0.2	0.1 ± 0.0
M3	Pin	78.2 ± 4.9	18.8 ± 2.8	1.1 ± 0.2	0.6 ± 0.1	1.1 ± 0.4	0.1 ± 0.0
608	Pin	98.5 ± 4.9	0.6 ± 0.3	0.0	0.7 ± 0.5	0.1 ± 1.2	0.1 ± 0.0
M2	Tweezers?	96.7 ± 5.4	0.5 ± 0.1	0.4 ± 0.4	0.0 ± 0.1	2.3 ± 2.1	0.1 ± 0.1
Pyrgos-*Mavroraki* MISCELLANEA							
Sample	**Artefact**	**Composition (wt%±STDEV)**					
		Cu	**Sn**	**Pb**	**As**	**Fe**	**Zn**
623	Small closed ring	51.6 ± 3.8	26.6 ± 1.3	0.8 ± 0.0	0.1 ± 0.0	20.5 ± 2.1	0.3 ± 0.0
612	Leaf-shaped pendant	95.5 ± 2.5	0.2 ± 0.0	0.0 ± 0.1	0.2 ± 0.0	3.9 ± 1.1	0.1 ± 0.0
166	Textile hook?	89.8 ± 4.6	0.7 ± 0.2	0.6 ± 0.3	0.0	8.8 ± 1.9	0.2 ± 0.0
624	Lead fragment	0.0	0.0	100.0 ± 1.3	0.0	0.0	0.0
174	Miniaturistic Oxhide Ingot	0.0	29.7 ± 0.0	70.0 ± 0.3	0.0	0.0	0.2 ± 0.0
613	Scrap Metal	16.1 ± 49.1	0.8 ± 0.1	0.7 ± 0.1	0.0	82.3 ± 55.3	0.1 ± 0.0
603	Scrap Metal	79.4 ± 8.2	0.6 ± 0.1	0.5 ± 0.1	0.0	19.4 ± 5.9	0.2 ± 0.0
617	Scrap Metal	94.7 ± 3.1	0.5 ± 0.2	0.2 ± 0.3	0.1 ± 0.1	4.4 ± 1.0	0.1 ± 0.0

604	Stud/ corroded coin	76.2 ± 5.1	17.7 ± 1.5	0.0	3.4 ± 0.2	2.7 ± 0.1	0.0
611	Stud/ corroded coin	82.2 ± 12.4	13.6 ± 1.7	0.0	3.8 ± 0.7	0.4 ± 0.1	0.0 ± 0.1
605	Arrowhead	97 ± 1.8	0.2 ± 0.0	0.0	0.1 ± 0.1	2.5 ± 0.7	0.2 ± 0.0

Table 5.4 Chemical composition of Pyrgos-Mavroraki's metal artefacts, calculated by HHpXRF analysis.

The data collected through pXRF presented some peculiar results which, in some cases can be the outcome of an operator error, while other instances require further discussion.

First, it needs to be mentioned that the results recorded for four objects, all belonging to the "miscellanea" category do not seem to be coherent, and the main cause could be the poor state of the artefacts and the impossibility to find a homogeneous de-patinated surface to analyse. These objects are the small, closed ring 623, the fragments of scrap metal 603-613 and the two "studs" 604 and 611.

It must be taken into account that, even though iron content is to be expected in Cypriot copper mostly smelted from iron-copper sulphides, the high percentages recorded for some of the objects analysed seems unusual. This might be explained by the fact that, as indicated by Scanning Electron Microscopy, iron is often present in the smelted metal as iron-copper, iron-copper-sulphide or iron-sulphide particles of slag or unreacted ore (Balthazar 1990, p. 75). Considering that up to 3% Fe was considered by Tylecote as resulting from early smelting processes (1982, p. 97), contents higher than that should be interpreted as inaccurate, possibly due to an incorrect de-patination. The low and constant content of zinc can be seen as characteristic of Cypriot copper-ores (Charalambous et al 2014, p. 213; Craddock 1978, p. 2); similar percentages of zinc have been recorded by Van Brempt in her recent study of Kalavassos-*Ayios Dimitrios*'s metals (2016, p. 288)

Overall, it was possible to observe that the assemblage of metal artefacts from Pyrgos-*Mavroraki* did not include objects in pure unalloyed copper. Most of the objects analysed proved to be, as expected, copper-based alloys containing arsenic and tin in different ratios. Arsenic is very common in Early/Middle Bronze Age metal artefacts from Cyprus. The debate on the intentionality at the base of arsenical coppers is still open (Giardino et al 2003, p. 388). If we consider arsenic contents below 1% as unintentional, it can be observed that the majority of Pyrgos's artefacts can be classified as unintentional arsenical coppers. A constant content of tin usually lower than 2%, can be interpreted as evidence of re-melting of arsenical copper with tin-bronze as a re-cycling practice.

Interestingly, the Philia earrings 239 and 622 were found to lack of any trace of arsenic, while a 0.4% tin content was recorded, evidence of the use of recycled metal. Two of the Philia earrings found at Sotira-*Kaminoudhia* are made of arsenical copper, four of tin-bronze and, exceptionally, two of electrum (Giardino et al. 2003, p. 387-392)

Among the E/M BA objects analysed, eight objects have been found to be made of tin-bronze. Three can be classified as regular tin-bronzes with a maximum tin content of 10%, while the other five, containing up to 22% of tin, are considered high-tin bronzes (Van Brempt 2016, pp. 279-281).

Finally, the small fragment of grey metal 624 was found to be pure lead, while the analyses on the miniature oxhide ingot revealed that to be made of an unusual alloy of lead and tin. It has known that lead was commonly added in antiquity to copper alloys to improve their fluidity during casting. However, lead is not present in Cypriot copper ores and the occurrence of this element in Pyrgos's metals can only be explained with deliberate addition.

Ten of the objects considered for this study show a lead content below 1.0%. This content increases in high tin-bronzes up to 3.3%.

A sort of interdependency between lead and bronze has been highlighted before by Balthazar (1990, p. 74). Similarly, to tin, lead ores are not present in Cyprus, however the existence of many lead or silver-lead rings found in MC tombs proves that this metal was known and used by ancient Cypriot metallurgists (Balthazar 1990, p. 321).

Miniature oxhide ingots, made of unalloyed copper, are known in Late Bronze Age Cyprus from Enkomi, Mathiatis and Alassa (Giumlia-Mair et al. 2011), but the finding of a lead-tin miniature oxhide ingot such as the item 174 from Pyrgos-*Mavroraki* is unprecedented. The miniature ingots from Cyprus have been interpreted as related to the ritual practice, possibly with votive function (Giumlia-Mair et al. 2011, p. 17). This interpretation is based on their unusual size but also due to the presence of Cypro-Minoan signs inscribed on some of them, partly comparable to inscriptions found on two bronze ring-stands from the sanctuary of Myrtou-*Pigades* (Giumlia-Mair et al. 2011, p. 17). If the ritual interpretation argued for the Late Bronze Age miniature ingots is to be adopted for the ingot from Pyrgos, this would suggest an earlier sacred connotation of metallurgical practice in ancient Cyprus.

5.4 Conclusions

Since the Middle Chalcolithic, metal artefacts made their appearance in Cyprus in the form of small pieces of personal ornament and simple tools such as chisels and fishhooks.

In the Early Bronze Age, with the development of the Philia Facies, an increase in metal artefacts has been recovered in Cyprus, with a more varied array of types, some of which will develop during the course of the Middle and Late Bronze Age, such as the characteristic hook-tang weapons.

Using the work of Åström (1957; 1972), Catling (1964), Stewart (1992) and Balthazar (1990) as primary references, part of the 68 metal artefacts from Pyrgos, both from the settlement on *Mavroraki*'s hill and the cemetery, were divided in three main categories: weapons, tools and ornaments/tools of personal ornament. The artefacts were described and compared with finds from coeval Cypriot sites.

The study of this material revealed that the only three hook-tanged-weapons found in this area come from funerary context, while tools and ornaments were found both at the settlement and the cemetery.

The tombs, some of which are multiple burials, resulted not very rich in metal artefacts if compared with the northern cemeteries of Lapithos-*Vrysi Tou Barba* and Ballapais-*Vounous,* with the only exception of Tomb 21, the so-called "Coppersmith Tomb" with 13 metal objects. This phenomenon appears quite surprising considered that the cemetery belongs to a metal-production site. The concept and value attributed to metal artefacts by the members of Pyrgos-*Mavroraki*'s community might have differed from that one shared by the "northern communities". The metal might have been seen more as a valuable material of exchange rather than a prestigious good to be shown as a symbol of power.

A complete publication of Pyrgos's cemetery is needed to explore further its archaeological context and compare it to the contemporary cemeteries of Cyprus.

The discovery of several ornaments in the settlement, usually found as funerary goods, supports the hypothesis that the site underwent to a sudden abandonment due to a disastrous event.

An interesting concentration of needles has been recorded in the Western Sector, where other archaeological finds such as loom-weights and spindle whorls seem to suggest that this area was dedicated to textile production.

Some finds can be interpreted as unfinished objects (616; M2) and some others show evidence of recycling (614), while alloying is confirmed by the presence of a led fragment and a tin-lead miniature oxhide ingot.

Thirty-nine objects from the settlement of Mavroraki were analysed by pXRF. Some of the objects belonging to the “Miscellanea” category resulted suspect due to the poor conditions of the artefacts and the impossibility of analysing a homogeneous de-patinated area.

Overall, none of the objects analysed resulted to be made of unalloyed copper, while both arsenical copper and tin-bronze were confirmed to be the main metals worked at Pyrgos-*Mavroraki*.

The presence of low tin contents in some of the objects, occasionally detected together with arsenic suggests that metal recycling was practised at the site.

This will confirm the complexity of Pyrgos-*Mavroraki*’s metal workshop, where copper smelting is evidenced by the presence of slags, casting, and alloying by the presence of multiple moulds and lead/tin remains and recycling by chemical composition.

Chapter 6. The Experimental Archaeology of Pyrgos-*Mavroraki*

6.1 Introduction

The study of the archaeological context of Pyrgos-*Mavroraki* and the chemical analyses carried out on the metallurgical by-products collected during the excavations, integrated by appropriate comparisons with the relevant coeval metallurgical sites of Cyprus, allowed to formulate some hypotheses about the smelting techniques used at Pyrgos, and possibly, in Cyprus during the Early and Middle Bronze Age.

As part of this research, it is intended to test the validity of these hypotheses through a series of systematic experimental archaeometallurgical trials. It is important to highlight that testing a hypothesis's validity does not mean that it corresponds to the truth, but merely that the principles behind it can be used until another hypothesis characterised by a better set of principles will falsify and replace the old one (Outram 2008, p. 1).

The best way to materially test hypotheses drawn on ancient crafts and their operative processes is experimental archaeology.

Experimental archaeology has been recently defined as "a widely accepted and integrated method in archaeological science" (Paardekooper 2019, p. 7/21), though it was first formalised in 1973 with the publication of John Cole's "Archaeology by Experiment", followed soon after by "Experimental Archaeology" in 1979.

Imitative experiments appear in articles throughout the nineteenth century, but the term "experimental archaeology" seems it has been used for the first time, according to Forrest (2008, p. 62) by Robert Asher in 1961 article published in the American Anthropologist: "If archaeology is taken to be the study of past cultural behaviour, the imitative experiment is the keystone of experimental archaeology" (1961, p. 793).

The validity of an archaeological experiment lies in its capacity to answer to a specific research question (Cunningham et al. 2008, p. v). To do so, it approaches the archaeological record through different actions summarised by Paardekooper (2019, p. 9/21) in five main points:

1. Good research into the primary sources;
2. Set up of a hypothesis which explains certain aspects of the archaeological record or the individuals who were responsible for that record;
3. Test the hypothesis through an action comparable to the action which, presumably, originated the archaeological record. This stage requires an appropriate level of experience within the craft/field under experiment, fitting the research project's geo-chronological framework;
4. The traces left by the experimental action need to be recorded and the data collected need to be documented in a way, fit for purpose;
5. The data produced by the experiment are compared with the archaeological record, comparing a present action with a past action by means of the data both actions produced.

The use of analogy, in this specific case between the experimental action and the presumed archaeological action, is the main theoretical foundation of experimental archaeology, commonly used in other scientific approaches (Lammers-Keijsers 2005, p. 19). Two other important concepts relative to analogy, within the framework of experimental practice, have been outlined by Lammers-Keijsers (2005, p. 20): uniformity and non-ambiguity. An analogy is uniform when the material evidence produced by the experimental action, the object, is identical with the original archaeological data, the source; furthermore, an analogy is unambiguous when no other possible explanations for the occurrence of similarities between the source and objects could be suggested.

This chapter, after an historical overview of Experimental Archaeometallurgy, the specialist field of investigation within experimental archaeology that looks at the *chaîne opératoire* of ancient metallurgy, an evaluation of what can be considered, today, valid guidelines for best practice, will be discussed. After a brief *excursus* dedicated to some preliminary "experiential" experiments carried out on Pyrgos's metallurgy in the past, the chapter showcases the new experimental plan designed as part of this research on the possible reconstruction of Pyrgos-*Mavroraki*'s copper smelting process. The materials, pyrotechnological structures and methods used are accurately described and the data collected during the experiments reported, in order to make the trials presented clear and repeatable.

6.2 Experimental Archaeometallurgy: History of the Discipline and contemporary guidelines for good practice

The application of experimental archaeology has been recognised as an essential methodology of proving theories of archaeometallurgical studies since the end of the nineteenth century (Tylecote and Merkel 1985, p. 3).

The first recorded experiments on copper metalwork are Cushing' s trials, published in 1894. These represented an attempt reconstruct different stages of the *chaîne opératoire* which characterised the ancient Pueblo metallurgy in the Salado Valley, Arizona (1300-1400 AD). The experiment aimed to test the hypothesis that early native American metalwork could have been produced by means of hammering and annealing, utilising simple stone and bone tools, in contrast with the theory that copperwork was imported "by the whites" (Cushing 1894, p. 98). Some trials regarded the preliminary roasting in an open fire of "ore rich in scales or seams of copper too minute to be useful in the native state", followed by a smelting stage carried out in a "kind of subterranean funnel-shaped oven furnace or kiln" (Cushing 1894, pp.

94-95). The details of this experiment such as the quality and quantity of the ore, quality and type of fuel, temperatures reached, dimensions of the reactor, all data which should be carefully recorded in modern experiments, have not been reported in the paper. The author, instead, more in line with his time's common practice, provided a more general archaeological context and relevant ethnographic comparisons.

At the beginning of the twentieth century, more metallurgical experiments were carried out such as the co-smelting trials performed by Gowland, who used copper and tin ore to produce bronze (Gowland 1912), but, again, too few details were published to make the experiments scientifically relevant for modern research (Tylecote and Merkel 1985, p. 4).

The use of ethnographic comparanda in the early archaeometallurgical experiments was based on the erroneous evolutionistic assumption that past and present societies all over the world are following a single technological trajectory, at different stages of progress (Pfaffenberger 1992, in Doonan and Dungworth 2013, p. 1). Ethnographic investigation when included in an interdisciplinary archaeological research project, must be used with caution.

Coghlan, who reported on several experiments of copper-carbonates smelting (malachite), for the first time made a point that natural open fires are not suitable for copper smelting, and he argued that the discovery of metallurgy might have happened in ceramic kilns (1939; 1939/1940).

Sulphidic copper ores (chalcopyrite) were experimentally smelted for the first time by Bohne (1968). After removing the iron-sulphidic metallic copper produced (matte) from the shaft-furnace utilised in the experiment, this was crushed to separate it from the slag, hand-sorted, re-roasted and finally reduced in a simple bowl-shaped furnace lined with clay (Tylecote and Merkel 1985, p. 5). Compared to previous publications, Bohne's trials were recorded in a more accurate manner, recording details such as the building materials and measurements of the furnaces used, the sulphur concentrations measured after roasting and the chemical composition of the products obtained.

The excavations of Beno Rothenberg at the different sites of Timna started a new tradition of experimental work, mainly laboratory based (Tylecote and Boydell 1978; Ghaznavi 1976; Tylecote et al. 1977; 1978; Merkel 1977; Bachman and Rothenberg 1980; Merkel 1985; Tylecote and Merkel 1985; Merkel and McGovern 1989; Merkel and Rothenberg 1999; Rostoker and Sadowski 1980) successfully smelted copper sulphides such as chalcopyrite utilising a crucible, though setting the experiment in a laboratory environment. This demonstrated that ancient metalsmith could have smelted this type of ore, which notoriously necessitates a multiple-steps process to be processed, by using very limited technology, if compared to the more recent shaft-furnaces.

Differently from Bohne's and other scholars' experiments carried out in the 1980s, who often used industrial blower to reach the temperatures needed for smelting, Rehder focussed for the first time on the use of blowpipes, evaluating this technique in contrast with the use of bellows in Pre-Columbian metallurgy (1994).

Archaeometallurgical experiments have been pursued in two different contexts: the laboratory and the field. The fact that laboratory-based experiments were preferred by the earlier generations of academic archaeometallurgists is in line with the research protocol required by experimental archaeology, as a preliminary scientific knowledge of the phenomena studied is indispensable and should be preliminary acquired in a close, controlled environment. The data collected in this manner can be then utilised to design field experiments which will add further variables imposed by an external environment, and the "human" factor provided by the induvial skills of the experimentalists. What has been learned in the lab, can now be taken further, introducing in the "experimental equation" a range of environmental conditions which aim to reflect more accurately "real life" or "actualistic" scenarios (Outram 2008, p. 2).

Since the first imitative trials have been published, important archaeometallurgical sites have been discovered and investigated by the means of experimental archaeology, for a total of more than 100 papers published on this field, including the most recent detailed research, a number which is certainly not exhaustive, but based uniquely on the literature review carried out by the writer and updated to 2019.

Experimental protocols had been designed for almost every step of the metallurgical *chaîne-opératoire*, including the extraction of the ore from the mines (Timberlake 2007), the ore's roasting and smelting (Fasnacht & Senn 2001; Pryce et al. 2007; Girbal 2013; Timberlake 2013; Doonan 1994), the casting, refining and polishing of the final artefact (Barbieri et al. 2015a; 2015b). Another area of investigation within experimental archaeometallurgy is the examination of the last phases of an artefact's biography, such as its use and function, applying experimental archaeology to use-wear analysis to distinguish between traces left by the manufacture and marks originated by a certain use of the object (Dolfini & Crellin 2016; Heeb 2014; O'Flaherty 2007; Molloy 2004).

An effective example of the importance ant the attention gained by experimental archaeometallurgy in modern academia is shown also by the several conferences, workshops and summer schools organised all around the world dedicated to this discipline[1]. One of these events dedicated to experimental archaeometallurgy which gained a great success for a series of reasons is undoubtedly the HMS 2010 conference organized by David Dungworth and Roger C. P. Doonan at West Dean College, Sussex. The proceedings of this conference (Dungworth & Doonan 2013) represent an up-to-date state of the art of this specific field of archaeometallurgy.

The characteristics of every single experimental research protocol depend on different factors among which is essential to remind: the hypothesis to be tested, the specific questions that need to be addressed and the archaeological and analytical data that can be collected and compared to the aim of the experimental inquiry.

---

[1]All the major international conferences dedicated to Archaeometallurgy are usually provided with a specific session dedicated to Experimental Archaeology (Archaeometallurgy in Europe, Historical Metallurgy Society Meetings…etc.) In Italy the Centre for Experimental Archaeology Antiquitates (www.antiquitates.it) has been organizing several international conferences dedicated to different archaeometallurgical topics investigated by experimental archaeology since 2003 (the last one occurred in 2014).

In addition, before engaging in an articulate scientific project, it is not rare to take into consideration pilot experiments, sometimes carried out with the help of "archaeo-technicians". This type of experiment has been defined "experiential", "pre- or pilot experiment" (Cunningham et al. 2008, p. v), "hypothesis-forming" experiments (Richter 1992). Pilot experiments are particularly valuable to identify variables, exploring pre-tests in which the main aim is to gain control over all the factors playing a major role in the final hypothesis-testing experiment (Lammer-Kejers 2005, p. 21).

It could be argued that pilot experiments should be aimed to approach the materials and structures researched with a heuristic attitude. Once relieved by the pressure of systematically collect measurement and data imposed by a strictly defined research protocol, which can be used, but it is not necessary, the researcher can focus on the experience provided by the imitation of an ancient craft/technology, often obtaining precious holistic insights. Another important point to be made is that some of the craft/technologies investigated have long been lost and need to be completely re-learned (e.g., copper smelting).

During this phase of the experimental research, the archaeologists have the opportunity to acquire the technical skills necessary to engage with their experiment, if that is related to a specific craft. For examples, not all archaeometallurgists are skilled metalsmiths, therefore, if their intention is to be the direct agents of their experiments, it will be necessary to approach the material side of the research and gradually familiarise themselves with the craft/technology, object of their study.

Some researchers, instead of engaging with the practicality of the experiment, might prefer to participate as protocol designers and data collectors, seeking for the aid of more skilled craft-people, called in the field of experimental archaeology, "archaeotechnicians" (Hein 2000). Archaeotechnique, the demonstration of ancient technology, is performed by experts, not necessarily academics, but with a good knowledge of the archaeological sources and a highly dexterity in one or more ancient crafts, who dedicate their work to the engagement of the public (Paardekooper 2019, p. 10/21).

6.3 The first "experiential" experiments

Following the excavation of Pyrgos's metallurgical installation in the Northern and Southern Sectors, a series of initial trials, which could be defined as "experiential" experiments or, in the words of Richter, "hypothesis-forming" experiments, were carried out to test, on a very preliminary base, the functionality of two different kinds of furnaces: the bowl-shaped furnace type, found in both Southern and Northern Sectors and a shaft-furnace based on a structure found in square J4 of the Northern Sector and interpreted by the excavator as a possible metallurgical installation (Belgiorno 2009, pp. 79-80). The definition of these initial trials as experiential experiments is preferred in this instance, to distinguish them from the second generation of pilot experiments, which have been carried out according to a research protocol and documented as part of this research.

The first experiments were performed by Mr Angelo Bartoli, founder of the Centre for Experimental Archaeology Antiquitates, in Italy. Bartoli started his experiments on the pit-furnaces in 2006, using as a model for his reconstructions the bowl-furnace found in J7, equipped with the ceramic carburettor/jug. The trials were carried out at Antiquitates between 2006 and 2007, with the main aim to demonstrate that the aforementioned context interpreted as a metallurgical installation characterised by a bowl-shaped furnace equipped with a modified jug, was indeed a special type of reactor fitted with a sort of carburettor (the jug). This would have been used by Pyrgos's metallurgists to fuel the furnace by olive oil instead of charcoal. Following the reconstructions of the excavator who found multiple long channels related to this context and interpreted them as the remains of a "complex ventilation system" based on "pipelines made of organic material, such as leather", functional to the artificial air supply of the furnace (Belgiorno 1998, p. 298), Bartoli used a pair of simple bellows made of leather and wood, connected to the bowl-furnace through a similar set of underground channels (Bartoli and Cappelletti 2009, p. 144).

The use of olive oil as a fuel was argued for two main reasons: 1. the vicinity of the examined metallurgical context to the so-called Olive Press Room and the big pithoi used to store olive oil; 2. The apparent scarcity of charcoal remains within the furnaces' contexts (Bartoli and Cappelletti 2009, p. 144). The dimensions of the original furnace were overall respected in the reconstruction of the experimental one (Bartoli and Cappelletti 2009, p. 146): a truncated cone of clay with a base of 55cm was realised with a combustion chamber of ca.18.5cm in diameter and ca. 22cm in depth (instead of 20cm in diameter and 30cm in depth, Belgiorno 2009, pp. 81-82). The building materials had to be sourced from the local area (Lazio, Central Italy) and, instead of Cypriot ores, a charge of malachite from Congo (480g) was selected for the experimental smelting (Bartoli and Cappelletti 2009, p. 148), despite a few preliminary compositional analyses, carried out by Giardino (2000, pp. 22-23) on Pyrgos-*Mavroraki*'s metallurgical by-products, were already available at the time of the experiment, clearly demonstrating the use of copper sulphides.

Although the temperatures were monitored with thermocouples and the authors claim that a temperature between 1350-1380°C was achieved "in a short time" (Bartoli and Cappelletti 2009, p. 150), these data were not systematically registered. The correlation between temperature/time was not reported, other than a brief mention to the fact that the highest temperature reached was kept for 30 minutes. The authors do not explain what type and how much kindling and wood was used to preheat the furnace; however, it has been reported that a total of 3.25 litres of olive oil were used for the experiment (Bartoli and Cappelletti 2009, p.150). Metallic copper was finally obtained, but the successful outcome was not quantified. In general, this experiential trial was used to prove that it is possible to use a "modest" amount of olive oil as fuel to smelt copper carbonates, while its use in combination with other types of fuel such as horse dung and olive pomace did not produce positive results (Bartoli and Cappelletti 2009, p. 152).

Mr Bartoli tested also the structure found in J4, interpreted as a shaft-furnace, reconstructing a similar reactor on-field at the site of Pyrgos, this time having the opportunity to use local building material (soil and stones) collected from the surroundings and local copper carbonates (Bartoli and Cappelletti 2009, p. 154; Bartoli and Romeo Pitone 2017, pp. 171-172). The furnace was built in the direction of the wind and other than a single blowpipe used just in the furnace preheating phase, the temperature of 850°C was reached without the aid of any artificial air supply. Unfortunately, also in this case, no systematic documentation for the experiment was accurately recorded, none of the experimental furnace-conglomerates obtained during Bartoli's trials were microscopically nor chemically analysed, making of this trial nothing more than another experiential experiment.

6.3.1 Second generation of pilot experiments

Following these initial experiences, supported by the preliminary knowledge gained by Bartoli's trials, the writer planned a new series of pilot experiments, to approach for the first time in person experimental archaeometallurgy applied to ancient Cypriot metallurgy and copper production.

The information provided by Bartoli's trials combined with the data collected from other Early and Middle Bronze Age Cypriot sites, the accurate examination of the extraordinary context offered by Pyrgos-*Mavroraki* with its peculiar metallurgical installation, by-products, artefacts and tools, allowed the formulation of a series of evaluations and hypotheses on the very structure of the *chaîne opératoire* used at this site for the production of copper.

To suggest a possible (re)construction[2] of the different steps which might have characterised the metalwork operations chain used at Pyrgos, the first aspect taken in consideration was the type of ore utilised. As discussed in Chapter 4, slag analyses carried out by Giardino (2000) and Giardino and Rovira (2007) on an unspecified number of samples from Pyrgos-*Mavroraki*, suggested that the main type of copper ore smelted at the site was sulphidic. This preliminary data appears now further confirmed by the compositional analyses carried out as part of this doctoral research. Despite it is generally believed that the smelting of sulphidic copper ores necessitates of an advanced metallurgical knowledge, the general viscosity of the slags, and the amount of metal copper (or sulphur/copper phases) and the type of iron/silicates found trapped in the slag's matrix, suggested a poor control of both the temperature and the reducing atmosphere within the furnace.

These results seem to be consistent with slags from other Cypriot early metallurgical sites and have been connected with a primitive smelting technology based on the use of crucibles heated simple bowl-shaped furnaces (Coleman et al. 1996, pp. 389-390). However, this simple technology is usually found connection with the processing of copper oxides, richer in terms of metal content and much easier to be processed if compared with copper sulphides, which require a multiple-steps procedure to be transformed in metallic copper and would require better control of temperature and reducing atmosphere, conditions which are ideally provided by a more advanced technology, such as the use of shaft furnaces. Much more efficient slags form inside these furnaces and can be easily "tapped" out to free the copper ingot at the base of the furnace. This type of slags has been found, as fragments of a larger circular, convex

[2] Using the word (re)construction, we are aware of the debate highlighted by Reynolds (1999, p. 159: on this problematic term and the impossibility of actually reconstruct the past, but only suggest possible scenarios.

“cake”, such as in the case of the LC site of Kalavassos-Ayios Dhimitrios (Van Brempt 2016).

As already observed, Pyrgos’s slags appear usually as viscous lumps which have originated inside a furnace and do not belong at all to the “tapped” type of slag. The presence of secure shaft furnaces, which would have produced this kind of slag, is anyway not based on incontrovertible data. The best attested type of furnace at the site seems instead to be the bowl-shaped furnace. Before completely removing the possible shaft furnace found in J4 from Pyrgos’s metallurgy equation, a second series of pilot experiments was planned and performed by the writer to test further the shape functionality of this structure considering the technological conditions aforementioned, with the intention to collect some more systematic data on the thermal behaviour of this type of furnace.

A very similar type of furnace was experimented by Bourgarit and Mille (1997), who performed experiments on both roasting and smelting with polymetallic ores containing tetrahedrite, malachite and chalcopyrite compounds, based on the archaeological context of the Chalcolithic site of Cabrières (Hérault, France). As the archaeological slags found onsite showed evidence of having been in contact with furnace-walls made of stone, rather than clay, a 50cm wide oven was built with dolomite blocks and clay mortar at a hight of about 40cm (Bourgarit and Mille 1997, p. 52). No flux was added to the charge and commercial charcoal was utilised as fuel. The roasting process lasted four hours and the same timing was adopted for the following smelting operation. Samples from each step of the *chaîne opératoire* were collected and compared with the metallurgical remains recovered in the archaeological record. In this instance, the experiment showed that the smelting technique investigated has a poor outcome in terms of metallic copper and the remaining copper trapped in the slags, which were particularly viscous, resulted in copper prills too minute to enable their recovery (Bourgarit and Mille 1997, p. 60).

It is important to highlight that this second series of pilot experiments was planned by the writer in 2014 and took place at Antiquitates first, and in 2015 at the Archeosite in Aubechies (Belgium), before the official start of the present doctoral research. The data which informed the experiments were obtained from the available literature on Pyrgos-*Mavroraki*, the amount of which did not drastically change since then in terms of its archaeometallurgy, the experiential data provided by Bartoli's first trials and the aforementioned preliminary chemical analyses published on the slags (Giardino 2000; Giardino and Rovira 2007).

Differently from Bartoli's shaft furnace trial, the writer's pilot experiments were not carried out on-site and, therefore, the use of Cypriot building materials was not possible. In the attempt to remain as faithful as possible to the original structure, both basalt (for the lower circle of blocks) and calcarenite (for the upper circles of blocks) were sourced locally and used to build the furnace, using as mortar silt from the river Tibur. The silt[3] was collected in the area of Orte (Viterbo, Italy) before the rivers crosses the volcanic plateaus, so to imitate the chemical composition of Pyrgos's soil used in the construction of the original furnace (Romeo Pitone 2018, p. 6/13). The basalt was kindly gifted by the company "Basalti Orvieto s.r.l." (Castel Viscardo, Terni, Italy), which consented to collect large blocks directly from the quarry, while the calcarenite blocks were collected from a natural geological deposit identified with the aid of a local geologist, on the way from Umbrian city of Terni to Rieti, in the Lazio region (Italy).

[3] The silt was kindly donated by "Calcestruzzi FANANO di Fanano Lorenzo, Franco & C. s.n.c.", towards which goes our deepest gratitude.

The ore selected for the experiments was Chalcopyrite, bough online from Congo. The ore was pre-treated through roasting. Differently from Bartoli's trials, all the steps of the writer's pilot experiments were recorded and published (Romeo Pitone 2018).
Three different fuels were tested: dry pinewood, olive pomace and olive oil used just as a starter/additive for the other two types of fuel. Both blowpipes and bellows were tested during the pilot experiments as artificial air suppliers. River siliceous sand was used as flux in the ratio of 1:1, in the belief that this might have improved the slag formation.
The poor control over the furnace's internal conditions prevented to keeping constant the temperature and the creation of an efficient reducing atmosphere. As a consequence, the chemical reactions necessary to extract the copper from its ore could not occur inside the combustion chamber, despite a further attempt was made using a pair of leather and wood bellows. The smelting was, therefore, compromised, though the experiment and its negative results provided interesting insights about the process and reactor tested.
The fuel types and size were probably not suitable for the experiment, as well as the very wide and short shape of the shaft-furnace. Although the pilot experiments showed many areas of possible further investigation through variables variation, such as the fuel used or alternative furnace shapes (Romeo Pitone 2018, p/ 7/13).

A series of factors including the structural and functional complexity of the shaft furnace revealed during this second series of pilot experiments, its poor archaeological preservation and, overall, a better knowledge of the comparanda provided by the study of contextual coeval metallurgical sites from Cyprus carried out as part of the present doctoral research, persuaded the writer to (temporary) abandon the experimental study of the shaft-furnace from J4. The absence of tapped slags from Pyrgos-Mavroraki's archaeological record also might weaken the theory that shaft-furnaces were in use at this site, if we consider that this type of slag and furnaces are usually considered related (Van Brempt 2016).

Furthermore, another important factor is absent from the equation shaft furnace/tapped slags: the airflow needed to run a furnace of these dimensions, if we rule out the possibility of wind-powered air supply (Bassiakos and Philaniotou 2007, p. 45), would have required a more powerful artificial air supply than what mouth-powered blowpipes could have ever achieved, as further demonstrated by the present experiment. This would have been possible instead by using bellows, attested in Cyprus in the form of pot-bellows, usually identifiable by two archaeological indicators: 1) characteristic ceramic vessel-shaped implements used as a solid base completed by organic materials such as leather and wood; 2) tuyères, much larger clay nozzles found in Cyprus in different shapes and used to connect the bellows to the furnace. These are easily distinguishable from the earlier clay nozzles used as blowpipe-tips, and, according to Kassianidou (2011, p. 45), they did not appear on the island before the Late Bronze Age (LCI).

6.4 The new research plan and experimental conditions

As stated before, the first generation of pilot experiments carried out by Bartoli, which included the test of bowl-shaped furnaces, were not designed, nor conceived, to keep control of all variables under a strict scientific protocol (Romeo Pitone 2018, p. 7/13). For the sake of scientific research, a new generation of pilot experiments had to be designed, performed and accurately documented keeping the mind open to a heuristic approach in setting up solid foundations for any possible long-term experimental work on the (re)construction of Pyrgos-*Mavroraki*'*s* metallurgy.

Within this framework, it is important to stress on the importance of taking into account all the variables and data collected, because every experiment could give a possible result, which still won't necessarily represent the original context (Thomas 1999, p. 181; Forrest 2008, p. 64), but will certainly achieve refutation of other hypotheses (Shimada 2005: 618).

Bartoli's first series of pilot experiments tested successfully the (re)construction of a bowl-shaped furnace from Pyrgos-*Mavroraki* to smelt malachite using olive oil as fuel and the air supply provided by leather bellows. The third generation of pilot experiments described in the following paragraphs aimed primarily to test two different stages of Pyrgos-*Mavroraki*'s *chaîne opératoire*: 1) the roasting process to desulphurise copper ores such as chalcopyrite and bornite; 2) the smelting process of roasted ores, using a bowl-shaped furnace, using charcoal as a fuel and blowpipes as artificial air supply.

Seldom experimental archaeology has been scientifically applied to test the functionality of this type of furnaces, especially in combination with blowpipes and sulphidic copper ores. An overview of recent literature on the topic is discussed here.

While conventionally archaeometallurgical research has privileged the study of the last stages in the production of copper from copper-rich ores (Renzi et al. 2018; Verly 2017; Radivojevic 2013; Timberlake 2007; 2013; Girbal 2013; Chapman and Chapman 2013; Hanning et al. 2010; Rovira et al. 2009; Catapotis et al. 2008; Pryce et al. 2007; Bourgarit et al. 2002; Lechtman and Klein 1999; Happ et al. 1994; Fasnacht 2009; Fasnacht and Senn 2001), less efforts have been spent towards earlier production steps such as beneficiation and the roasting of the usually less copper-rich sulphidic ores (Doonan 1994, p. 84).

However, considering that this is the type of minerals utilised in the present research, the roasting process plays an important role as the first stage of the new experimental plan. Doonan (1994) investigated the pre-treatment of copper ore and its effects on the smelting process. The first stage of his experiments regarded the crushing of 150kg of sulphidic ore (chalcopyrite from Erzberg, Austria). To facilitate this operation and make the ore more friable, a small series of preliminary roasting experiments was carried out following a quote from Agricola (De Re Metallica, Book VIII). The experimental roasting of a 100g nodule of chalcopyrite was carried out in the lab using a muffle furnace at 700° for 48hrs, allowing a constant flow of air to pass through the mineral in order to create an oxidising environment (Doonan 1994, p. 85). No relevant modifications were noticed in the roasted mineral during the following crushing process, as the oxidising reaction occurred just on the surface of the nodule examined, penetrating no more than 4mm. The oxidised surface showed black and red spots (oxidised iron and copper) and resulted very friable, but not of any use towards the following stages of the experiment (Doonan 1994, pp. 85-86).

After the ore was crushed using a pebble stone hammer, the scholar and his team hand-sorted the mineral dividing it in 5 categories based on the visible chalcopyrite content of the samples: from high-grade chalcopyrite nodules to small fragments measuring less than 2mm (Doonan 1994, p. 87). A roasting rectangular pit 2m long, 0.9m wide and 0.2m deep was constructed and its base was lined with a weighty implement to avoid the admixture of ore and soil and facilitate the ore removal after roasting (Doonan 1994, p.89). two different experimental campaigns were carried out, each one including three experiments characterised by a slightly different combination of variables (Doonan 1994, pp. 90-91).

Doonan’s experiments demonstrated that the beneficiation and roasting operations can be highly variable and so their products can greatly affect the smelting practice. The quality of the matte and the efficiency of the slag produced are predetermined by roasting (1994, p. 95). Following Doonan’s experiments, others included the roasting process of sulphidic ores in their experimental plans (e.g.: Bourgarit and Mille 1999).

While many experiments have been carried out on smelting copper sulphides (or polymetallic ores including copper sulphides) using shaft-furnaces, very few involved the use of a bowl-furnace (Hanning et al. 2010; Timberlake 2007; Bourgarit et al. 2002; Bourgarit and Mille 2001; Bourgarit and Mille 1997; Happ et al. 1994; Rothenberg 1978), despite the viability of this process has been successfully demonstrated since the end of the 1980s by Rostoker et al. (1989).

The field experiments carried out on crucible-smelting of sulphidic copper are mainly based on the system crucible/bowl-shaped smelting and bellows. Bourgarit et al. (2002) experimented the smelting of sulphidic copper ores using domestic U-shaped vessels embedded in a simple hole dug in the earth, using a single hand bellow and a clay tuyere placed above the pot. The archaeological context under investigation was the Chalcolithic (2400-2200 BCE) settlement of Al Claus (Tarn-et-Garonne, France). The aim was to expand the experience gained from the Cabrières experiments, putting in place a systematic experimental survey of the main pyrometallurgical parameters involved. The authors considered three main parameters inferred by archaeological data: ceramic domestic vase (30cm diameter/depth) a smelting reactor, sulphidic copper ores, one-step process…the simplest process. Similarly to Cabrières, a hole in the ground was used to locate the crucible, and after one hour of preheating, one hour of experimental smelting took place. As the experiment regarded a one-step process which aimed to obtain both the desulphurisation of smelting of the ore, different combinations of crucible and tuyere positioning were trialled with the aim to achieve the most suitable oxygenation inside the crucible, necessary for the success of the roasting process. The outcome of the experiment was metallic copper and wastes similar to what was found in the archaeological record. The scholars highlighted that while the smelting of chalcopyrite on its own resulted in matte, a co-smelting of chalcopyrite and malachite produces a better metallic outcome. However the authors argued that chalcopyrite can be smelted on its own, provided enough gaseous oxygen,as opposed to “solid oxygen” provided by malachite ($CuCo_3Cu(OH)_2 \rightarrow 2\ CuO + CO_2 + H_2O$).

As part of a more articulate series of various smelting experiments, including different types of furnaces and copper ores, another attempt at roasting and crucible-smelting chalcopyrite, using a bowl-shaped furnace and leather bellows, was done by Timberlake (2007). The experimental conditions were based on the archaeological evidence from the Chalcolithic (2400-2200 BCE) site of Ross Island (Munster, Ireland). The roasting of cleaned and concentrated ore lasted two and half hours at a temperature of 750° over charcoal, then for a further two hours inside the fire. The roasted ore was then smelted under a thick bed of charcoal for two hours and fifteen minutes, maintaining an average temperature of 1180°C, with occasional peaks over 1300°C. the final product was only a few grams of metallic copper, while the majority of the ore converted into matte (Timberlake 2007, p. 34)

When compared to the experimental conditions selected for the present research, another similar smelting experiment is that one performed by Hanning et al. (2010). As part of their archaeological study of the Copper Age settlement of Zambujal (Torres Vedras, Portugal), the authors aimed to (re)construct part of the *chaîne opératoire* which characterised the copper production onsite, performing crucible-smelting in bowl-shaped furnaces to process five different types of local polymetallic ores, including both copper sulphides and oxides which would have been available to the prehistoric communities (Hanning et al. 2010, p. 291). As no single Chalcolithic settlement in south-central Portugal has been found showing the entire *chaîne opératoire* of primary copper production, the experimental conditions for Hanning's research were based on metallurgical contexts from south-west Chalcolithic Iberia (Hanning et al. 2010, p. 290). In some of the experiments., local natural clay was utilised to produce shallow, rectangular to semi-ovoid crucibles, otherwise natural clay from the shores of Lake Constance, mixed with industrial clay (50% grog) was also used. In some cases, the clay used for crucibles and tuyères was tempered with vegetable (donkey dung) and/or minerals (crushed gneiss or sand). The design of the furnace, an open, stone ringed hearth, was periodically modified from an original structure with a 70cm internal diameter to a downsized version measuring 25x25 cm^2 at the base and 17cm in height, aiming to correct the initial loss of heat and optimise the smelting operation (Hanning et al. 2010, p. 291).

To provide the air-draft necessary to the operation of this furnace, a set of cane/bamboo or steel blowpipes, tipped with clay nozzles, was used. This would have been mouthblown or, in the event of enough volunteers not being available, attached to a hand pump, according to Rehder's studies on this field (1994, p. 348).

Preheating of the furnace was carried out for an hour using an initial charge of wood, followed by charcoal. Each smelting operation involved varying charges of 100-250g of crushed ore, depending on the capacity of the crucible utilised, in some cases mixed with charcoal (Hanning et al. 292). The smelting process varied between 30 minutes to 120 minutes, with an additional 20-76 minutes of "roasting", periodically stirring the crucible contents to assure and even and thorough reaction, an expedient previously adopted by Bourgarit et al. (2002, p. 301). Temperatures were measured and recorded; both the ores and the products of each smelting experiment have been analysed by the means of microscopy, microprobe analysis, X-ray diffraction, X-ray fluorescence, neutron activation analysis and lead isotope analysis (Hanning et al 2010, p. 293).

Hanning's experiments successfully produced metallic copper, demonstrating that the smelting of polymetallic ores, including copper sulphides, could be achieved using blowpipes and a basic shape of furnace. The experiment showed that six blowpipes powered solely by human lungs are necessary to achieve temperatures between 1,000°C and 1,300°C, and maintain them for 45 minutes. Due to the small tip of the clay nozzle and the open shape of the furnace, it was observed that hotter and cooler zones were present in the fire, varying also in relation to the internal or external areas of the crucible. In terms of temperature achievement, it was also observed that, as expected, adverse weather negatively affects the experiment (Hanning et al. 20120, p. 293).

Based on the heuristic approach adopted by Hanning and her team, it could be argued that these trials must be categorised as pilot experiments, used to gain familiarity with the technology investigated, while still systematically collecting different kinds of experimental and analytical data. Other than this heuristic approach, the main similarities which connect Hanning's pilot experiments with those ones carried out as part of the present research have to be considered in the morphological simplicity of the reactor built, the use of mouthblown blowpipes and the inclusion of sulphidic ores in those ones selected for smelting.

Considered that the pilot experiments were aimed to familiarise with the roasting and smelting processes, hence the evident heuristic approach adopted, two more definite research questions to be investigated were outlined as follows:

1) Is it possible to crucible-smelt Fe-S copper ores in Pyrgos-*Mavroraki*'s (re)constructed bowl-shaped furnace, using just blowpipes?

2) What conditions (number of blowpipe-operators, timing, furnace set up amount of fuel utilised) are required to achieve this?

The following paragraphs describe the experimental conditions established to carry out this new series of metallurgical experiment dedicated to Pyrgos-Mavroraki's *chaîne opératoire*. The ore, fuels, flux and technical pottery utilised will be discussed as well as the type of pyrotechnological reactors (re)constructed for the purpose of the present experimental project. The experimental plan included two cycles of sulphidic copper ore roasting (JH-RST I-II), followed by three cycles of crucible-smelting of the roasted ore, two trials of co-smelting adding malachite to the sulphidic roasted ore and, finally, two additional crucible-smelting trials with an increased charge of roasted ore and flux (silicious river sand) in the ratio of 1:1. An experimental diary has been kept reporting comments on each stage of the process. More systematic formal tables were also created to be used on field for the collection of temperatures and fuel additions during the experiments.

The entire experimental plan was carried out at the archaeological open-air museum Jarrow Hall Anglo-Saxon Farm, Village and Bede Museum (Tyne and Wear, UK).

6.4.1 Ores, fuel, flux and technical pottery

In line with the slag analysis reported in chapter 4, the ore selected for the experiment had to be a Cu-Fe sulphide, the most abundant copper ore present in Cyprus. As it was not possible to collect local ores from Cyprus, the mineral had to be sourced commercially. Two initial issues presented when the online hunt for the ore begun: minerals available online are usually selected for specific kinds of market such as that one dedicated to collectors or the more variegated world of natural-based religions and New Age, for which minerals are selected for the spiritual properties attributed to them.

The minerals sold through these media are usually very expensive and are not sold in bulk. Another commercial way to source minerals is the industrial market, which however deals in great quantities (tons) for minimum order, also very expensive and not suitable for an archaeological experiment. Considered these initial difficulties, chalcopyrite was impossible to source in the quantities needed and for the funding available, instead a good example of Mexican bornite was found and purchased. Bornite is often found along with the more common chalcopyrite and it is one of the sulfidic copper ores which can be found in Cyprus. A good sample of high-grade malachite from Congo was also at a local mineral shop[4] in Durham to be co-smelted in the experiments JH-SMLT IV-V.

Commercial siliceous sand was purchased to be used in some of the experiments as flux.

In terms of fuel, pinewood, commercially sourced, in the shape of kindlings, logs and charcoal, was selected for the experiment. Considering that palaeobotanical investigations at Pyrgos-*Mavroraki* focussed mainly on domestic plants and the essences used in the manufacture of cosmetics (Lentini 2009), and no anthracological analyses were published to the writer's knowledge, this appeared the most appropriate choice to resemble the Calabrian

[4] The Rock and Fossil Shop, Durham Market Hall (www.rockandfossilshop.co.uk, last visited Feb. 2021)

Pine found as charcoal in other Cypriot metallurgical contexts (Socratou et al. 2015; Falconer and Fall 2013, p. 112). The use of olive oil, even as fuel additive, was not considered in the research protocol of the present experiments. Given the preliminary nature of these pilot experiments, this decision was taken to reduce the amount of variables within the equation. The use of olive oil as an additive in a bowl-shaped furnace, equipped with a carburettor-jug built on the example of the furnace found in J7, could be material of investigation for future research on Pyrgos-*Mavroraki*'s metallurgy.

The generous amount of crucible fragments found at the site left no doubt about their use at some point of the chaîne opératoire of Pyrgos-Mavroraki, either for smelting or melting. As stated elsewhere, the writer was not allowed to carry out microscopic and chemical analyses on the archaeological crucible fragments, however, the only crucibles' analyses ever published, suggests that they might have been used for smelting (Giardino 2000; Belgiorno et al. 2012). Shapes and dimensions Three clay nozzles from Pyrgos-*Mavroraki* and the relative comparanda from Ambelikou-*Aletri* (Webb and Frankel 2013, p. 180), Alambra-*Mouttes* and Bellapais-*Vounous* (Tomb 119.1; Webb and Frankel 2012, p. 111, Class. XXVIIa, fig. 24.4) were considered for the (re)constructions utilised in this experimental plan.

Four crucibles, similar in shape and dimensions to the example from Ambelikou-*Aletri* (Webb and Frankel 2013, p. 177), were kindly donated by Dr Andrea Dolfini for this project. These were handmade with a mixture of commercial clay for pottery and siliceous sand (ratio 1:1), delivered to the writer already well dried and ready to be baked. Two more crucibles were hand-crafted by the writer, shaped on the dimensions suggested by Cypriot examples such as crucible PYCR.18 (graphic reconstruction in Appendix 2, n.1) from Pyrgos-*Mavroraki*, the possible crucible found in Tomb 4 at Pyrgos's Cemetery (Belgiorno 2019, p. 52) and the crucible with uncertain provenance from Alambra or Kalopsidha (Stewart 1962, p. 234 n.1).

To this purpose, industrial refractory clay mixed with 50% grog was purchased at the “Metal Workshop” of the Fine Arts Department at Newcastle University to (re)construct two crucibles (JH-SMLT I and VI) and 5 blowpipe nozzles (see table 6.1) shaped on those ones found at Pyrgos-*Mavroraki*. Despite, at this stage, technical ceramics were not the focus of this investigation, the technical pottery created for the experiment has been left to dry naturally for two weeks and then baked in an open-fire kiln, imitating one of the simplest ancient techniques to produce pottery (Costa et al. 2019). Two nozzles were dried and baked, two were just dried and the last one was obtained roughly shaping it around the tip of the blowpipe, using fresh clay.

Crucible	**Diameter (cm)**	**Internal Diameter (cm)**	**Walls at rim (cm)**	**Walls at base (cm)**	**Depth (cm)**
JH-SMLT I	10	7.6	1.1	1.8	5
JH-SMLT II	9.7	5.4	1.5	1.9	5
JH-SMLT III	10.4	7.1	1.4	2.1	3.6
JH-SMLT IV	9.9	6.4	1.5	2.7	4.8
JH-SMLT V	9.4	7.2	1	1.5	4.4
JH-SMLT VI	11.6	9	1.5	1.5	4.1
JH-SMLT VII	8	6.5	0.5	0.7	5.3
Nozzles	**Length (cm)**	**Diameter (cm)**	**Internal diameter at base (cm)**	**Internal Diameter at tip (cm)**	**Baked**
N-1					YES
N-2	10	4.3	2.5	0.7	YES
N-3	9.7	4.6	2.1	0.7	NO
N-4	10.1	4.5	2.1	0.7	NO
N-5 (just clay)	10	6	2	0.7	NO

Table 6.1 Experimental technical pottery dimensions.

To host the open-fire kiln, a pit measuring 70x70cm was cut in the ground at a depth of ca. 25cm, based on similar structures found at the Late Neolithic site of Lugo di Grezzana (Verona, Italy) experimented by Costa et al. (2019).

All the artefacts were placed at the centre of the pit and a first wood fire was lit on one side of them at 9:00am, followed by a second fire lit at 9:30am and both fires were kept alive charging fuel until 9:45pm at a constant temperature between 550-670°C.

While the four crucibles made of commercial clay for pottery mixed with sand and the two nozzles endured the high temperatures, the other two crucibles made with industrial clay grog-rich cracked, leaving one of them not usable. It could be argued that a possible reason for this might have been an insufficient dryness, which provoked the remaining humidity present inside the crucible to "explode".

One last grog-rich crucible was instead commissioned to an experimental archaeologist colleague expert in the production of pottery and was used in the last smelting trial (JH-SMLT VII).

A replica of the sandstone blowpipe holder found in J8 at Pyrgos-*Mavroraki* was reproduced in a refractory industrial material; however, once positioned holding the blowpipe's nozzle in connection to the bowl-shaped furnace, it was found not usable for the specific type of reactor, hence it was decided not to use it. Hollow iron rods, 2cm in diameter, were used as blowpipes for two main reasons: 1) the investigation was aimed to monitor the thermal behaviour and functionality of the metallurgical reactor and the ore in a crucible-smelting environment and the study of organic blowpipes was excluded from the variables to be monitored; 2) organic blowpipes made of hollow reeds would have required a quite laborious searching, and the timescale of the experimental plan did not allow it.

6.4.2 Pyrotechnological reactors: roasting bed and bowl furnace

A very basic shape was selected to construct the roasting bed (fig. 6.1). To start with, a flat area of 1x1m was identified onsite and de-turfed, an operation certainly not necessary on the Cypriot bedrock. The aim was to reproduce a flat, calcareous surface imitating the limestone-based soil which characterises Pyrgos-*Mavroraki*, to host a simple open fire.

Figure 6.1 Experimental roasting bed (Jarrow Hall, 17-07-2018).

In the attempt to correct the difference between the soil present at Jarrow Hall and the archaeological soil, a level of limestone gravel, with an average grain-size of 1x1cm and an average thickness of 5cm, was laid to line the squared de-turfed area. Four slabs of sandstone were placed at the centre of this structure and sealed together with a small amount of clay, to facilitate the positioning and recovery of the ore after roasting, trying to avoid any loss during the experiment.

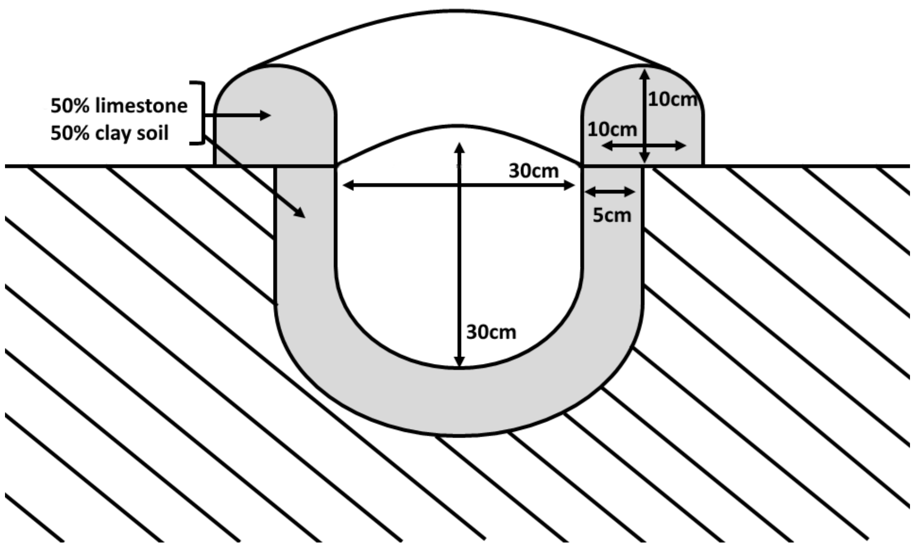


Figure 6.2 Graphic reconstruction of the experimental bowl-shaped furnace.

The (re)construction of the bowl-shaped furnace (fig. 6.2) required the de-turfing of a small circular area of about 50cm in diameter (fig. 6.3-1) where a pit was dug in the ground and lined with a 5cm thick layer of limestone gravel mixed with clay soil collected onsite (fig. 6.3-2), to make the mixture plastic and easier to manipulate and shape. On top of the pit, a short circular rim was built in the shape of a coil with a diameter of 10cm (fig. 6.3-3). As a matter of health and safety, it was decided to line with limestone gravel the remaining de-turfed area surrounding the furnace (fig. 6.3-4), to create an area of respect between the structure and the grass around it. This solution, other than increase the “limestone” environment mimetic of Cypriot soil, proved to be useful also as a clear demarcation of the pit, which, otherwise, would pass quite unnoticed. Finally an wood fire was lit into the furnace to dry it and “bake” it ready for use.

Figure 6.1 Bowl-shaped furnace's construction sequence.

6.5 Roasting

Two cycles of roasting (JH-RST I and JH-RST II) were conducted in sequence, hence they should be considered as a unique experiment, as the same mineral was re-roasted, for a total of twelve hours. The roasting experiments took place on the 19th and 20th of July 2018.

The aim of these experiments was to successfully oxidise and desulphurise the ore, preparing it for smelting. The material effects on the consistency of the roasted ore were also object of attention.

At first, the fire was started with four small pieces of wood kindling, each one weighting ca. 60g. (fig. 6.4-1) and three logs of pinewood were added soon after. The logs utilised during the roasting experiments had an average weight of ca. 500g each. Once the fire was successfully started and burning, 16 small ore chunks with a diameter of about 5cm plus two flakes were centrally located in direct contact with the stone base built in the middle of the roasting bed. A total of 942g was utilised for this experiment. The temperature profile of the experiment is reported in Table 6.2. In this respect, the present research protocol differed from that one designed by Doonan, who processed the ore by crushing in order for it to pass through a 1cm screen (Doonan 1994, p. 86). In the present research, this treatment was reserved to the ore once it had undergone through the first roasting cycle.

The frequency of fuel (pinewood logs) additions depended on the speed to which they consumed inside the fire; however, a certain regularity was observed in the necessity of recharging the roasting bed every 10/15 minutes.

The maximum temperature reached was 830°C, soon after the fire reached the edges of the roasting bed and had to be contained (fig. 6.4-2).

Time	**Temperature °C**	**Fuel Charge (logs)**	**Notes**
9:30		3	Starting fire.
9:41			Fire successfully started and burning.
9:55		4	
10:02		3	
10:12		3	
10:15	784		
10:27	736	4	Ore placed in the middle of the fire.
10:42	720	2	
10:52	718	4	
11:17	750	4	
11:29		7	
11:40	830		
11:48	683	5	
12:05		4	
12:10			The fire reached the edge of the roasting bed.
12:15		5	
12:23	766		
12:27		3	
12:45	661		
12:56		6	
13:00		4	
13:18		4	
13:30	696	5	
13:48		3	
13:57		3	
14:15	730	7	
14:41		4	Last fuel charge added to the fire.
14:50			
15.00	696		

15:11	679		
	Average: 727	**Tot: 87 (ca. 43.5kg)**	

Table 6.2 JH-RST I - Experimental form.

Figure 6.2 JH-RST I.

Four hours after the beginning of the experiment, the addition of fuel stopped, leaving the fire to slowly extinguish (fig. 6.4-3). The temperature's monitoring, collecting data from a spot among the ore chunks at the middle of the roasting bed, started 45 minutes after the fire was lit. Thermal data were recorded by the use of a nickel-chromium thermocouple[5] connected to a hand-held datalogger thermometer. The average temperature maintained during the experiment was 727°C with a minimum of 661°C and a maximum of 830°C. The average environmental temperature measured on the day of the JH-RST I was 23°C. It is worth mentioning that during the entire length of the experiment, a light breeze blew feeding the

[5] Nicrobell D Sheath, 1.5mm diameter x 1000m long.

flames and facilitating an efficient oxygenation of the fire. Following the example described in Doonan 1994 (p. 90), after the last visible flames, the ore mound was raked over with the aim of increasing its exposure to oxygen. Similarly to Doonan's experiment, after the ore was racked over, an increase was noticed in the pungency of the sulphur dioxide emitted by the roasted minerals. When the blocks of roasted bornite were collected, a sulphurous smell was still noticeable and the ore was superficially covered in brick-red and black extended spots, confirming that oxidation took place at a certain extent.

To prepare the ore for a second cycle of roasting (JH-RST II), the chunks of bornite were crushed in smaller grains using a rudimental "stone anvil", which imitated to a certainan extent some of the smallest and most basic stone anvils found at Pyrgos-*Mavroraki*. When crushed, a remarkable increased friability in the roasted ore was noticed if compared to the untreated mineral. To avoid any ore loss, the smaller fragments of roasted bornite were placed in two crucibles and placed, together with the remaining larger chunks, in the same position of the first roasting charge (fig. 6.5)

Figure 6.3 JH-RST II: 1) crushed ore; 2) crucible containing the most minute praticles.

The second roasting experiment involved an ore charge weighting 868g, determining a weight loss in the mineral. If this has been caused by the roasting process or a non-completely efficient recovery from the roasting bed, in this instance has not been ascertained.

A very gentle breeze was noticed, similarly to the previous day, which might have improved the oxygenation of the fire; however, a light rain started towards the end of the experiment. The average environmental temperature measured on the day of the present experiment was 20°C. During JH-RST II, the temperature readings were conducted in a more systematic way, recording thermal data every half an hour, just before adding fuel to the fire (table 6.3).

Time	**Temperature °C**	**Fuel Charge (logs)**	**Notes**
10:10			Starting fire with 4 pieces of kindling.
10:23		7	Fire successfully started and burning.
10:30	930	4	
10:45	928		
10:58	650	4	+ 4 kindling + ore charge
11:13		3	
11:19		4	
11:30	794		
11:43		4	
11:50		4	
12:00	796	5	
12:24		2	
12:30	774	4	
12:43		2	
12:54		4	
13:03	766	5	
13:27		4	
13:36	616	5	
13:51		4	
14:00	746	1	Light rain started.
14:03		3	
14:20		6	
14.33		4	
14:41	693	5	Last fuel charge to the fire.
15:00	728		
15:35	676		
16:00	696		
	Average: 753	**Tot.: 84 (ca. 42kg)**	

Table 6.3 JH-RST II - Experimental form

After both roasting processes, samples for chemical analysis were taken and, in the case of JH-RST II one sample was withdrawn from the top and one from the bottom of one of the crucibles utilised. A first simple autopsy of these samples showed a variation in the levels of oxidation that affected the fragments of ore which were at the bottom of the crucible, compared to those ones withdrawn from the top. The ore collected from the roasting bed after JH-RST II, characterised by an increased friability compared to the state recorded after the previous roasting, was further grinded into a finer grain measuring ca. 5mm (fig. 6.6). A total of 745g of crushed ore was collected, confirming that a further loss of mineral occurred during the process. In case this loss is to be attributed to human error, rather than a chemical reaction, it could be read as a useful insight in the type of material remains (fragments of roasted ore easily lost during the process) that this specific step of the *chaîne opératoire* might have left in antiquity.

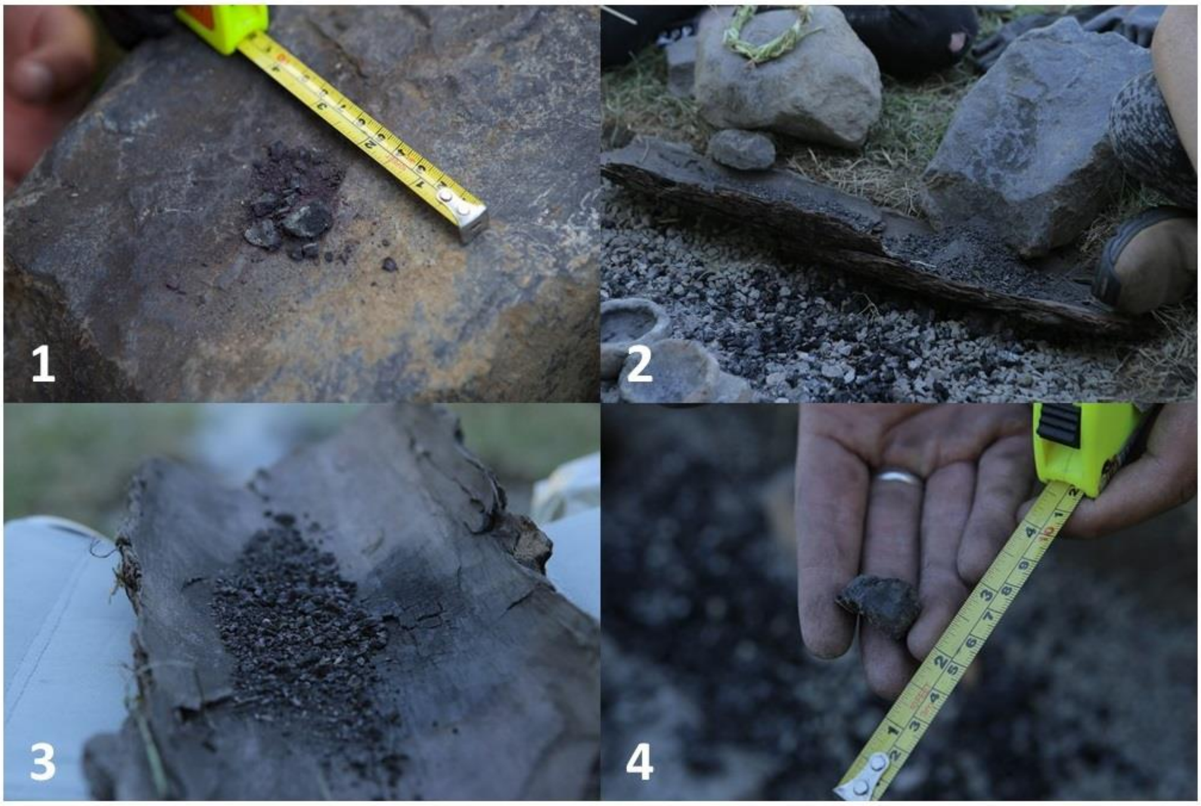


Figure 6.4 Ore crushed after JH-RST II (1-3); sample from the top of the crucible (4).

6.6 Smelting

A series of seven smelting trials was performed as part of this experimental plan. Considering the heuristic approach of these pilot experiments, different variables were trialled, rather than approached systematically. These variables included: different shape, capacity and location inside the furnace of crucibles and nozzles, ore charge composition (JH-SMLT 4 and 5 involved the co-smelting of bornite and malachite), spots within the furnace/crucible from where the thermal data were collected, use of flux and number of blowpipe-operators.

All smelting experiments, though, share some common practice described in the following points:

- before the start of each smelting, a specific amount of ore was weighed out, mainly depending on the capacity of the crucible used. The Ambelikou-*Aletri*-style crucibles are shallower and have a smaller capacity compared to the (re) construction of the deeper crucible #18 (Appendix 2, n.1) from Pyrgos-*Mavroraki*.
- charcoal is crushed with a stone mortar in smaller lumps of about 3/5cm diameter max; a scale and a large bowl used to pour the charcoal into the furnace are positioned in its proximity;
- initially the fire is ignited inside the furnace with pinewood kindling, few logs and few lumps of charcoal;
- for each experiment it has been attempted to maintain a temperature around 1000° for one hour;
- before use, crucible and nozzles were slowly heated on the rim of the furnace, then placed into a bed of coals;
- samples for each experiment were collected and both original ores and their smelting products were analysed using OM and SEM-EDX;
- every experiment has been documented through dedicated forms, pictures and videos.

6.6.1 First, second and third smelting experiments (JH-SMLT I-II-III)

The first three smelting experiments used a charge composed only by roasted bornite, previously processed in JH-RST I-II.

JH-SMLT I (22-07-2018) used a shallow crucible filled with 50g layered with charcoal dust (8g). The environmental temperature was measured at a maximum of 26°C. After the fire was ignited, it took 3 hours and 45 minutes to bring the furnace to temperature. It was established to charge the furnace with 200g crushed charcoal every 15 minutes. After 3 hours and a half from the start of the fire inside the furnace, the use of two blowpipes started, which occasionally increased to three, but these shifts were not properly documented. An alternate blowing procedure was adopted in the attempt to provide the furnace with the most constant air flow possible. This coordination between blowpipe-operators took some time to be perfected.

Once a temperature of 980° was achieved, the crucible was moved from the furnace's rim and embedded into the glowing embers. The temperatures were systematically recorded within the furnace from inside the crucible and outside. After about one hour since the blowpipes started to be operated, it could be observed that the tip of the blowpipe nozzle vitrified after reaching a temperature of 1170°C, and green, orange and blue flames were visible, confirming that a chemical reaction was taking place inside the crucible. While the first thermal readings were recorded from the glowing embers at the bottom of the furnace, after about four hours since the beginning of the experiment, temperatures were started to be recorded both from inside and outside the crucible at an interval of about 15 minutes (table 6.3). At the end of the experiment the crucible was removed from the furnace and left to cool down on a stone slab, to allow sampling. The crucible presented a high level of vitrification which caused the partial collapse of its wall, melting it with the fresh clay-nozzle used on the third blowpipe (fig. 6.7). As this was the first smelting trial, at the beginning of the experiment a large amount of time was lost in logistics.

Time	Temperature °C		Fuel Charge	Notes
10.30				Starting fire with kindling, wood logs, charcoal.
13.00				Crucible placed on the rim of the pit-furnace
14.00				Blowpipes introduced
14.15	980		200g	Crucible in the furnace (temperature calculated at the bottom of the embers)
14.25			200g	
14.35	1150		200g	
	Crucible	Furnace		Temperature calculated on the crucible and outside of it
14.45	870	1000	200g	
15.00	1170	935	200g	
15.08				Nozzle vitrified, charcoal turning white/green, flames turning green/orange and blue outside
15.10			200g	
15.15	1045	1220	200g	Last fuel charge to the fire.
15.30	1220	1042		Last reading before crucible withdrawal.

Table 6.4 JH-SMLT I – Experimental form.

Figure 6.5 JH-SMLT I: 1) vitrified nozzles; 2) nozzle melted with crucible.

JH-SMLT II (23-07-208) replicated almost the same conditions of JH-SMLT I; however, a few modifications were introduced such as the temperatures recording which occurred every 15 minutes since the very beginning of the experiment, the fuel charge interval which was reduced to 10 minutes and the fact that, after about one hour since the beginning of the experiment, the two blowpipes used were reduced to one for health and safety reasons, as one of the operators experienced intense fatigue. According to the thermal readings, the temperature of above 1000°C was achieved in the furnace after about one hour since the beginning of the experiment and it was maintained for almost one hour with just one blowpipe! A temperature of above 1200°C was recorded at the end of process. Despite these extraordinary achievements, it seems unlikely that this process could have been conducted by a single blowpipe operator, as it resulted particularly labour intensive.

Time	**Temperature °C**		**Fuel Charge**	**Notes**
	Crucible	Furnace		
9.56				Starting fire with kindling, wood logs, charcoal; crucible placed on the rim of the pit-furnace
10.50		396		Crucible in the furnace (temperature calculated at the bottom of the embers)
11.00	550	1003		
11.15	880	600	200g	Just one blowpipe; 1 hour is calculated from now for the smelting process.
11.30			200g	
11.45	1100	900	200g	
11.50	1070	950		
12.00	1130/ 1200	1200	200g	Last fuel charge to the fire.
12.15	+1200	+1200		Last reading before crucible withdrawal.

Table 6.5 JH-SMLT II – Experimental form.

While the same experimental conditions adopted for the previous smelting experiments were applied to JH-SMLT III (24-07-2018), a more ambitious set-up for the thermocouples was trialled in the attempt to gain a more in-depth knowledge of the thermal behaviour of different areas within the metallurgical reactor. Four thermocouples were connected to the same datalogger (1-4b), two to a second data logger (1-2a) and a last thermocouple was kept separate as well (1c). Thermocouples 1-2a and 1-2b were positioned around the circumference of the furnace, in the immediate proximity of the crucible, surrounding it; thermocouple 3b was placed in an intermediate area between the crucible and the furnace's wall, while 4b was positioned in direct contact with the furnace's wall (fig. 6.8).

The aim of this set-up was to determine the heat distribution within the furnace's structure and verify the presence of eventual cold spots.

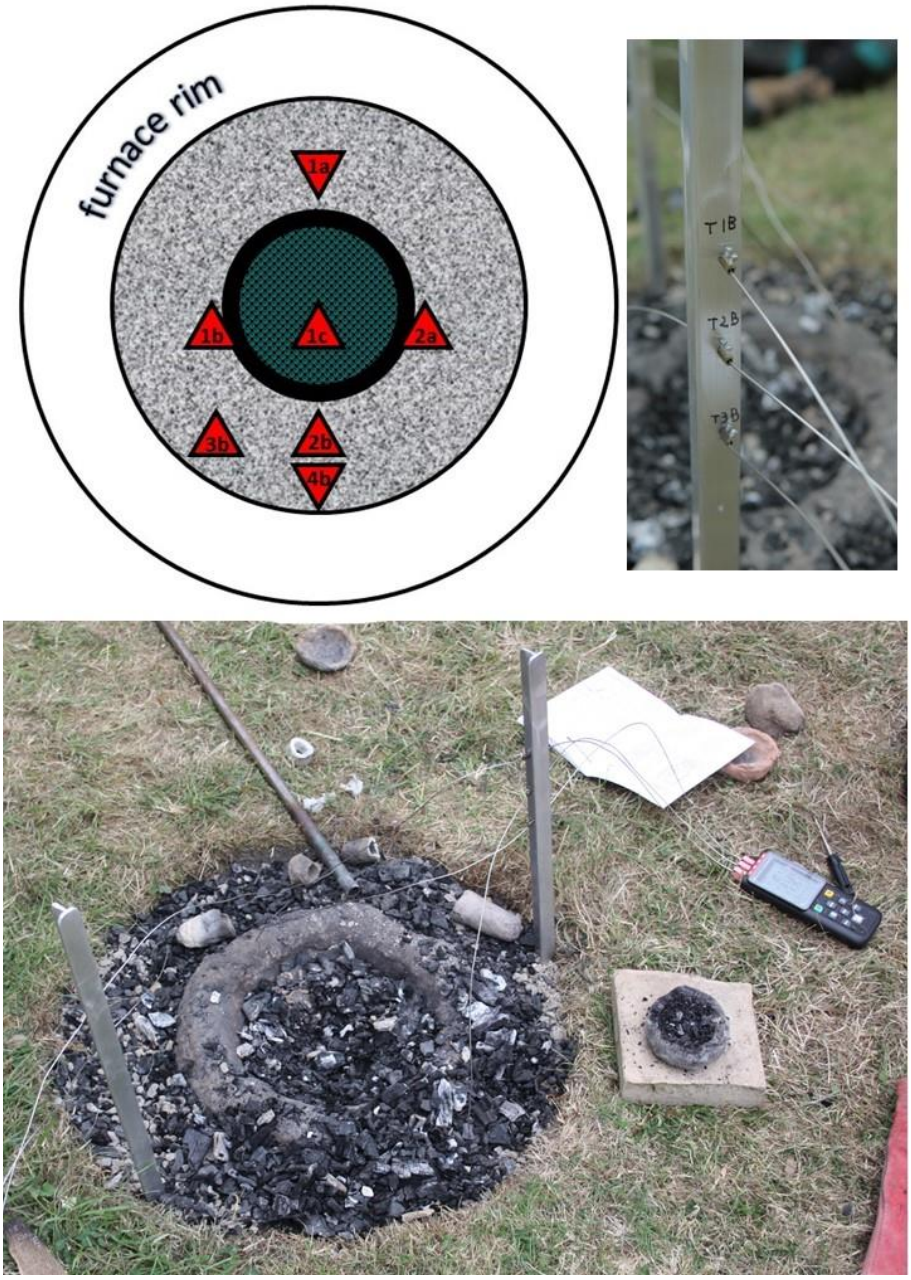


Figure 6.6 Thermocouples set-up used during JH-SMLT III-IV.

The dataloggers were programmed to record temperatures at 5 minutes intervals for a period of two hours. The aim of this was to facilitate the entire operation, allowing the only two blowpipe operators present at that specific experiment to focus on the process without any further distraction caused by the necessity to record temperatures. Another variation to the protocol of the pilot trial regarded the length of time considered for the actual smelting, after achieving the temperature of 1103°C inside the crucible, reduced from one hour to 30 minutes. The average environmental temperature recorded on the day of the experiment was around 20°C.

Unfortunately, an unexpected human error occurred in the process of downloading the data from the dataloggers, and all the readings recorded for this experiment have been lost except for the temperatures collected by thermocouple 1c inside the crucible. For this reason, table 6.5 is limited to the monitoring of the crucible and not many considerations could be withdrawn from this experiment. However, during the process some observations were noted such as the fact that one thermocouple (1a) moved, unnoticed, from its original position, failing to produce accurate readings of the area selected in the protocol. In correcting the eventual displacement of some thermocouples, their relocation caused a general drop in the temperature of the entire furnace, which inevitably must have affected the final outcome of the experiment. After the end of the experiment, when it was possible to recover the crucible, thermocouple 1c was found embedded and fused in its slagged content.

Time	**Temperature °C**		**Fuel Charge**	**Notes**
	Crucible	Furnace		
11.15	315			
11.30	417			
11.45	514		200g	
11.55			200g	
12.00	708			
12.05	1103		200g	Start to operate two blowpipes. 30 minutes are calculated from now for the smelting process
12.15				
12.20			200g	Last fuel charge to the fire.
12.30	1300			Last reading before crucible withdrawal.

Table 6.6 JH-SMLT III – Experimental form.

6.6.2 Fourth and fifth co-smelting experiment (JH-SMLT IV-V)

JH-SMLT IV and JH-SMLT V represent the attempt to conduct a co-smelting mixing the roasted bornite from processed during JH-RST I-II and high-grade malachite.

A ratio of 1:1 was adopted for a total of 100g ore charge (50g bornite + 50g malachite), layered with the usual levels of charcoal dust (8g). The previous unsuccessful thermocouple set-up was replaced with the old one, locating one device just over the crucible's content, avoiding leaving it in place permanently, but only the time to record each individual reading, in the attempt to prevent accidents similar to what experienced during JH-SMLT IV. A second device was embedded in the surrounding glowing embers and the time interval to record the temperature readings was 5 minutes (tab. 6.7).

An actual smelting period of 30 minutes, after achieving a temperature of 1000°C, was kept valid in the protocol of this experiment. Two blowpipes were operated for the entirety of the process. It was observed that at the temperature of 1000°C green flames were visible over the charcoal.

Time	**Temperature °C**		**Fuel Charge**	**Notes**
	Crucible	Furnace		
10.49				Starting fire with kindling, wood logs, charcoal; crucible placed on the rim of the pit-furnace.
11.00			200g	
11.10		390	200g	Start to operate two blowpipes on the ambers in the furnace and prepare the space for the crucible.
11.15		414.3		Crucible in the furnace (temperature calculated at the bottom of the embers).
11.20	345.3	557.2	200g	
11.25	549.3	522.7		
11.30	1000	613	200g	Green flames observed. 30 minutes are calculated from now for the smelting process.
11.35	996.2	633		
11.40	1000	700	200g	
11.45	1000	876		
11.50	1035	807	200g	
11.55	1080	893		
12.00	998	818	200g	Last fuel charge to the fire and last reading before crucible withdrawal.

Table 6.7 JH-SMLT IV – Experimental form.

Figure 6.7 JH-SMLT IV: 1) experimental diary; 2) mixed bornite/malachite charge; 3) two blowpipe-operators; 4) crucible content at the end of the experiment.

JH-SMLT V (26-07-2018) replicated the same experimental conditions of JH-SMLT IV: mixed ore charge, fuel addition (200g charcoal) every ten minutes, a smelting time of 30 minutes after the initial achievement of a temperature above 1000°C, two active blowpipes (table 6.8). However, the crucible was buried in hot colas at an earlier stage of the process (almost at the very beginning), speeding up considerably the operations to reach the required temperature. This also greatly impacted on the ability for the blowpipe-operators to maintain constant the temperature during the smelting, without drops and avodingd the exhaustion experience during previous experiments due to the considerable effort to bring the furnace to temperature. Smelting temperatures were easily maintained within the range of 1090°C/1250°C. Green and blue flames were observed at 1080°C, indicating that reducing conditions were successfully maintained throughout the smelting process.

Time	Temperature °C		Fuel Charge	Notes
	Crucible	Furnace		
9.30				Starting fire with kindling, wood logs, charcoal; crucible placed on the rim of the pit-furnace.
10.05				Crucible in the furnace
10.10				Start to operate two blowpipes.
10.20	341	348	200g	
10.25	830	319		
10.30	1080	301	200g	Green and blue flames observed. 30 minutes are calculated from now for the smelting process.
10.35	1250	309.9		
10.40	1120	325.4	200g	
10.45	1090	350.3		
10.50	1200	355.3	200g	
10.55	1170	357.7		
11.00	1250	357.2	200g	Last fuel charge to the fire and last reading before crucible withdrawal.

Table 6.8 JH-SMLT V – Experimental form.

6.6.3 Sixth and seventh smelting experiment (JH-SMLT VI-VII)

These last two trials were performed to smelt the remaining roasted bornite, using some of the experimental conditions adopted for the previous experiments such as the addition of 200g of crushed charcoal to the fuel the furnace every 10 minutes, recording thermal data every 5 minutes (table 6.9).

The amount of ore to be smelted was increased to 252g, to which 252g of flux (sand; ratio 1:1) and thin layers of charcoal dust (40g) were added.

The thermocouple set-up used for JH-SMLT V was slightly changed for JH-SMLT VI (28-07-2018), keeping one thermocouple in the usual area between the crucible and the furnace walls, while the thermocouple usually positioned on top of the crucible was inserted in a hole drilled at the base of the vessel to monitor the actual internal temperature reached.

As very low temperatures were recorded from both devices, after one hour and 45 minutes, a third thermocouple was added to monitor the top of the crucible, confirming that smelting temperatures were achieved only in that limited area. Nevertheless, once the crucible was removed from the furnace, it was possible to ascertain that no reaction between the two mineral components had happened and the slag which was usually observed as one of the outcomes of the previous experiments was completing missing in this case. The content of the crucible was still recognisable as loose grains of bornite and sand.

Time	**Temperature °C**			**Fuel Charge**	**Notes**
	Crucible base	Furnace	Crucible top		
10.15	18	18		494g	Starting fire with kindling, wood logs, charcoal; crucible placed on the rim of the pit-furnace.
10.30	25	47.1			
10.35	42.9	59.4			
10.40	48.3	65.2			
10.45	57.0	72.5			
10.50	66.6	80.5		200g	Start to operate two blowpipes.
10.55	71.5	79.4			
11.00	80.2	82.8		200g	
11.05	89.3	92.3			
11.10	98.8	95.3		200g	
11.15	118.5	98.5			
11.20	137.1	109.1		200g	
11.25	161.1	118.5			
11.30	181.3	125.2		200g	
11.35	200.1	129.1			
11.40	216.2	134.3		200g	
11.45	227.6	137.8			
11.50	237.2	141.3		200g	
11.55	244.7	143.2			
12.00	250.1	152.3		200g	
12.05	254.5	143.7	1000		3rd thermocouple inserted on top of crucible; 1 hour is calculated from now for the smelting process.
12.10	261.1	150.3	1003	200g	
12.15	266.7	156.4	1062		
12.20	269.8	156.4	1080	200g	
12.25	271.8	153.5	957		
12.30	272.9	153.0	1080	200g	Last fuel charge to the fire.
12.35	273.8	154.6	1030		
12.40	274.1	155.9	1000		Last reading before crucible withdrawal.

Table 6.9 JH-SMLT VI – Experimental form.

Figure 6.8 JH-SMLT VI: 1) crucible recovered from the furnace; 2) content of the crucible consiting of loose grain of unreacted ore and sand.

The same thermocouples set-up used for the previous experiment was kept unmodified for JH-SMLT VII (29-10-2018). A larger crucible was used for this experiment, similar to that one used in JH-SMLT I, based on the archaeological evidence from Pyrgos-*Mavroraki* and "Alambra/Katydhata".

It is worth to point to the fact that this experiment, differently from the previous summer trials, was carried out in autumn with an average environmental temperature of about 8°C. The recording of temperatures started with the second fuel charge (200g crushed charcoal) with an interval of 5 minutes. After 2 hours and 15 minutes, it was decided to reduce the fuel charge from 200g to 100g, establishing the frequency of its addition to the furnace based on observation rather than fixed time intervals. This solution was suggested to improve the heat loss which inevitably occurs when cold fuel is added to the combustion chamber.

Initially the crucible was placed on the rim of the furnace, according to the technique adopted in the previous experiments, then moved, empty, on top of the embers to be further heated. The charge (245g or roasted ore + 50g of siliceous sand layered with ca. 40g of charcoal dust) was added to the crucible only after 1 hour and a half after the fire was lit (table 6.10).

For the first time three blowpipe-operators have been constantly involved in running the furnace, sensibly facilitating the management of temperatures and air draft.

After about 50 minutes the ore charge was added to the crucible, green flames were visible on the charcoal.

Time	**Temperature °C**		**Fuel Charge**	**Notes**
	Crucible	Furnace		
10.30				Starting fire with kindling, wood logs, charcoal; crucible placed on the rim of the pit-furnace.
11.10				
11.20		420		The crucible is moved on the ambers to be further warmed up.
11.30			200g	
11.40	180		200g	
11.45	239			
11.50	226			

11.55	215			
12.00	108		200g	Charge in the crucible[6], a lot of smoke/white steam is observed.
12.05	265			
12.10	470	238	200g	Flames are visible on top of charge.
12.15	548	409		
12.20	550	476		
12.25	553	512		
12.30	575	630	200g	
12.35	592	653	200g	Very dusty charge, hence needed refill
12.40	595	653		
12.45	601	684	100g	Fuel charge is reduced and added when needed.
12.50	621	960	100g	Glimpse of green flames (12.53)
12.55	650	1000	100g	1 hour is calculated from now for the smelting process.
13.00	702	1000		
13.05	777	1000	100g	
13.10	785	1190		
13.15	800	1050	100g	
13.20	812	1200		
13.25	805	1130		
13.30	806	1000	100g	
13.35	792	950		
13.40	787	1050	100g	
13.45	794	1030		
13.50	797	1060	100g	Last fuel charge to the fire.
13.51	804	1240		
13.55	821	1060		Last reading before crucible withdrawal.

Table 6.10 JH-SMLT VII – Experimental form.

6.7 OM and SEM-EDX analysis of Experimental Slags

As part of the present experimental plan, a sample for each experiment was selected for OM and SEM-EDX analysis. However, due to time and logistic constraints relating to the present project, it was not possible to fully process the samples by SEM-EDX, therefore a discussion will be attempted on the observation carried out on the micrographs and the preliminary chemical data recorded.

[6] Suggestion by Dr Yvette Marks, colleague from Sheffield University: charge should be added to the crucible when the ambers are glowing white, and flames coming through can be observed.

The results presented here are limited to assess the efficacy of the roasting, smelting and co-smelting processes and attempt a general comparison with the archaeological remains from Pyrgos-*Mavroraki*.

The chemical analyses of the natural ores represent a bulk composition of homogeneous areas of 1.2 by 0.8 mm, following the same protocol adopted for the analysis of the archaeological slags. The same strategy was adopted for the samples withdrawn from JH-RST I-II. Minor elements have not been reported in the following tables.

In regard to the samples collected from the smelting trials JH-SMLT I-II, the attention was focused to the nature of the copper product obtained. To this purpose, the areas which appeared metallic under OM study were chemically analysed.

An area analysis of the glassy slag-matrix was also carried out for these samples.

The bornite utilised for this experiment before to be roasted, showed a very high content of sulphur (67.6%) and while the sample collected from JH-RST I showed a lower content of this element, suggesting that the roasting process occurred successfully, the sample analysed from JH-RST II showed a higher percentage compared to this last one. The percentage of iron also appeared to reduce after roasting, while the percentage of copper increased, showing a concentration of the metallic phase.

This discrepancy of results might have depended on the analytical protocol followed. The samples were prepared following the same protocol adopted for the archaeological slags. These were cut with a diamond saw, polish polished and mounted in resin. However, to obtain more homogeneity samples for bulk analysis should have been maybe grinded and reduced to powder, and then mounted for chemical analysis. A larger selection of samples, not possible in this instance, would have certainly provided a better picture.

Sample	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	Cl	K_2O	CaO	TiO_2	MnO	FeO	CuO	ZnO
Ore													
JH-EXP.CHAL	0.0	0.0	0.0	0.0	67.6	0.0	0.0	0.0	0.0	0.0	25.3	30.7	0.0
JH-EXP.MAL	0.0	0.0	1.5	3.8		0.3	0.0	0.0	0.0	0.0	0.9	93.4	0.0
Roasting													
JH-RST I	0.0	0.0	0.0	0.0	25.7	0.0	0.0	0.0	0.0	0.0	20.1	32.6	2.2
JH-RST II	0.0	0.0	0.0	0.0	52.5	0.0	0.0	0.0	0.0	0.0	17.7	35.6	

Table 6.11 Ore samples' chemical compositions before and after roasting.

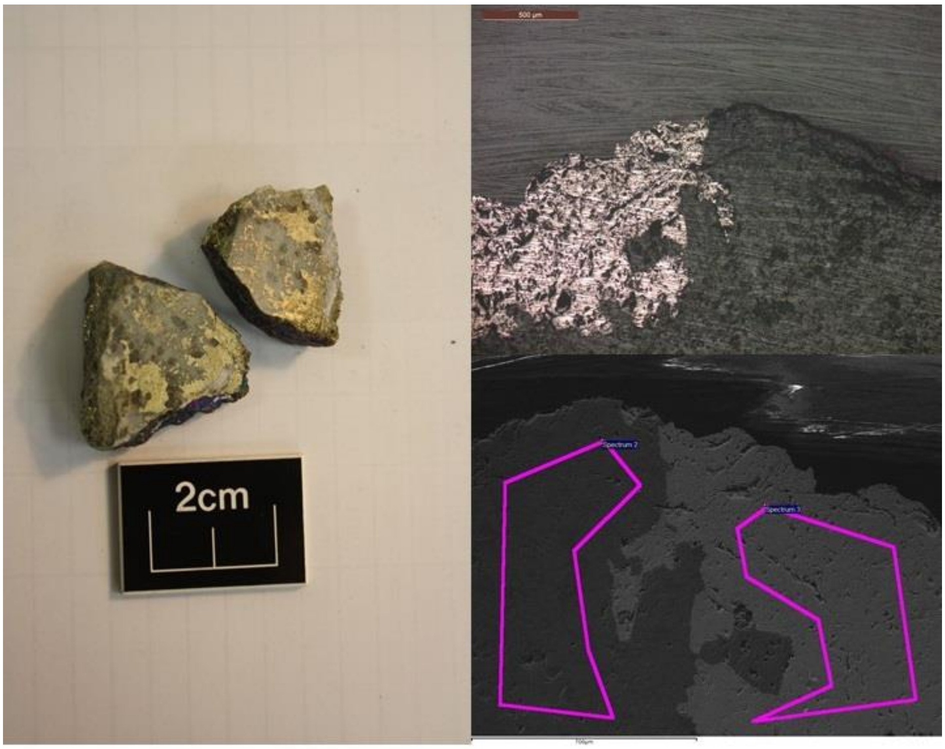


Figure 6.9 Photo and photomicrograph of bornite used for the project. Highlighted the areas analysed with SEM-EDX.

All crucibles were sliced and studied autoptically and by OM.

Only JH-SMLT II, IV and V produced copper prills visible by the naked eye in the sliced crucibles. However, the other crucibles, once sliced, all showed evidence of a FeCuS rich metallic phase, which could be interpreted as matte, and it is comparable with similar phases found in Pyrgos-Mavroraki's slag.

This evidence could suggest that the technique trialled in the present pilot experiments is worth of further research as the experimental smelting by-products resembled chemically, though not in shape, the archaeological ones.

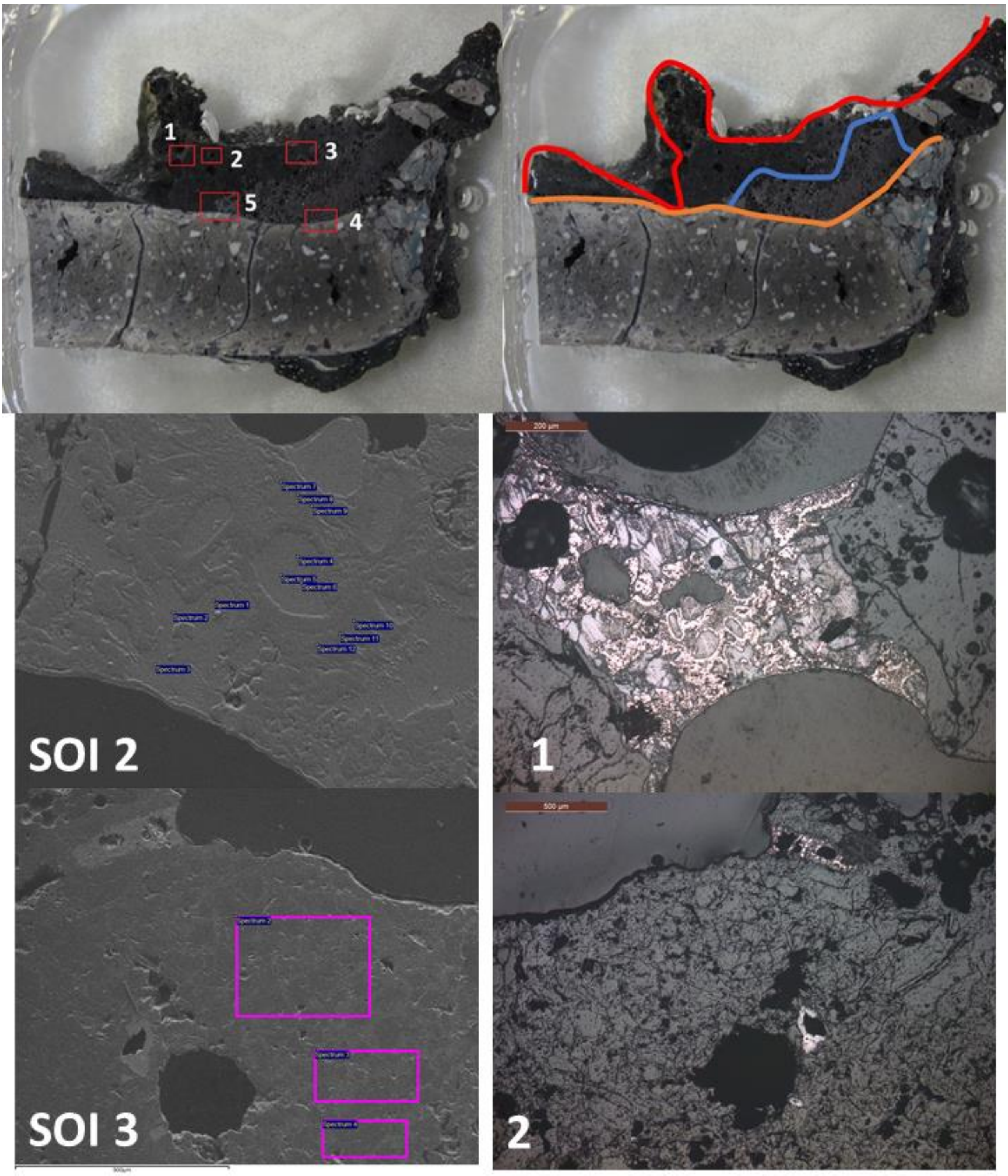


Figure 6.10 JH-SMLT I: sliced crucible, sites of interested analysed. The orange line marks the limit of the crucible which fused together with the ore charge. The blue line marks the limit of a FeCuS metallic phase (matte). The red line marks the limit of the fay

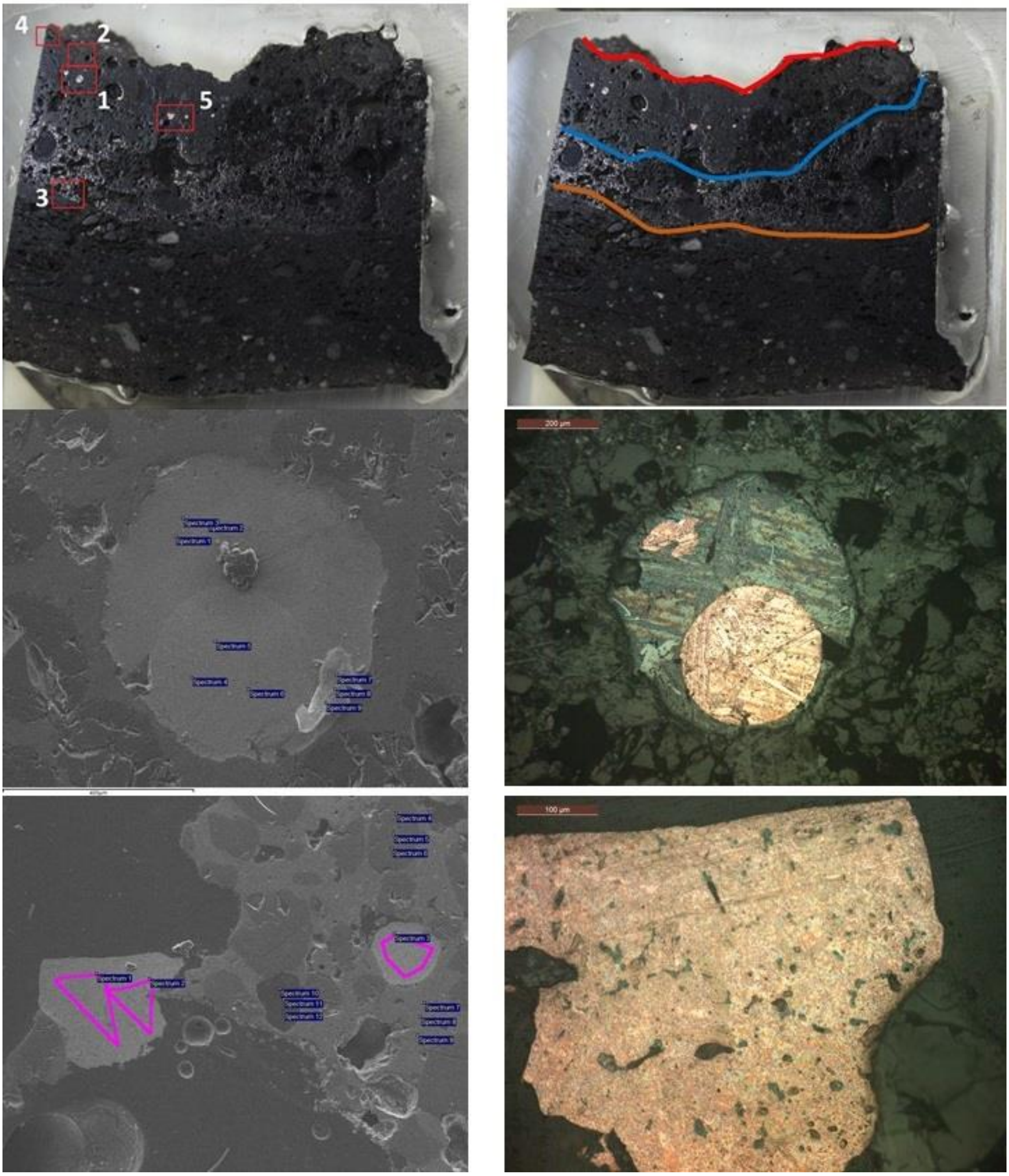


Figure 6.11 JH-SMLT II: sliced crucible, sites of interested analysed. The orange line marks the limit of the crucible which fused together with the ore charge. The blue line marks the limit of a FeCuS metallic phase (matte). The red line marks the limit of the fayalitic slag.

Sample	**Micro**	**Weight percent (wt%) – COPPER-RICH PHASE**													
	/SOI	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl_2O**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
JH-SMLT I	**1/SOI2**	0.0	0.0	0.0	0.0	36.5	0.0	0.0	0.0	0.0	0.0	0.0	11.4	50.3	0.0
		0.0	0.0	0.0	0.0	37.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	49.8	0.0
		0.0	0.0	0.0	0.0	39.7	0.0	0.0	0.0	0.0	0.0	0.0	14.9	43.3	0.0
MEAN						36.8							11.1	50.1	
STDEV						0.3							0.3	0.4	
Sample	**Micro**	**Weight percent (wt%) – SLAG MATRIX**													
	/SOI	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl_2O**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
JH-SMLT I	**1/SOI2**	0.0	11.1	6.9	52.0	0.0	0.0	0.0	0.0	19.3	0.0	0.0	10.7	0.0	0.0
		0.0	11.8	5.5	52.2	0.0	0.0	0.0	0.0	21.0	0.0	0.0	9.5	0.0	0.0
		0.0	12.9	4.5	53.2	0.0	0.0	0.0	0.0	21.3	0.0	0.0	8.2	0.0	0.0
MEAN			11.4	6.2	52.1					20.2			10.1		
STDEV			0.5	1.0	0.1					1.2			0.8		

Table 6.12 Chemical compositions of copper-rich phases identified in samples from JH-SMLT I.

Sample	**Micro**	**Weight percent (wt%) – COPPER-RICH PRILL**													
	/SOI	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl_2O**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
JH-SMLT II	**1/SOI1**	0.0	0.0	0.0	6.2	57.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.1	0.0
Blue phase		0.0	0.0	0.0	2.8	60.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.2	0.0
		0.0	0.0	0.0	6.6	57.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.8	0.0
MEAN						36.8								89.6	
STDEV						0.3								2.2	
Orange phase	**1/SOI1**	0.0	0.0	1.1	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.7	0.0
		0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.5	0.0
		0.0	0.0	1.3	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.8	0.0
MEAN				0.5	7.7									92.1	
STDEV				0.8	3.6									3.4	
Sample	**Micro**	**Weight percent (wt%) – COPPER-RICH PRILL**													
	/SOI	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl_2O**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
JH-SMLT II	**5/SOI6**	0.0	0.0	0.6	2.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.5	0.0
		0.0	0.0	0.8	2.8	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.5	0.0
		0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.8	0.0
MEAN				0.0	2.8	0.0								89.5	
STDEV				0.0	0.0	0.0								1.4	
Sample	**Micro**	**Weight percent (wt%) – SLAG MATRIX**													
	/SOI	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl_2O**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**	**CuO**	**ZnO**
JH-SMLT II	**2/SOI2**	0.0	0.0	2.1	10.2	11.0	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	2.1
		0.0	1.5	0.0	29.3	0.0	13.1	0.0	23.8	0.0	0.0	0.0	0.0	1.5	
		0.0	1.1	1.0	26.1	0.0	9.7	0.0	31.3	0.0	0.0	0.0	3.0	1.1	1.0
MEAN			1.3	1.6	21.9	11.0	11.4		20.9				3.0	1.3	1.6
STDEV			0.3	0.8	10.2		2.4		12.1					0.3	0.8

Table 6.13 Chemical compositions of copper-rich phases identified in samples from JH-SMLT II.

6.8 Conclusions

The present research plan based on pilot experiments aimed to gain a preliminary familiarity with the ores, metallurgical reactors, technical pottery, and overall technology which was possible to (re)construct for part of the copper *chaîne opératoire* in use at Pyrgos-*Mavroraki*. As stated earlier on in this chapter, the present work was intended with an aware heuristic approach to the field investigated, however a series of considerations, both experiential and analytical, could be drawn following the experiments performed until now.

Regarding the experiential knowledge gained during the process, it appeared very clear since the beginning of the project that, although the metallurgical technology tested might seem quite primitive to the inexpert eye, it requires a good level of experience, manual capability and familiarity with the different components involved. Despite the fact that the writer followed some preliminary training in ancient metallurgy and performed three series of copper-smelting experiments before the start of this research, it appeared clear that far more practice is needed to gain the expertise necessary to carry out meaningful experimental research in this field.

Looking back to the initial research questions which were up for testing and attempt to provide some preliminary answers.

Although more accurate evaluations can be formulated only following the chemical analysis of the samples withdrawn during the experiments, the majority of the crucibles recovered after the smelting showed highly slagged and vitrified internal surfaces, while no sign of vitrification was noticed on the outside, in perfect accordance with the crucibles recovered at Pyrgos-*Mavroraki*. The only exceptions were the crucibles used in: JH-SMLT I, a large portion of which collapsed and fused with a clay nozzle, and JH-SMLT VI, which did not show any particular vitrification neither on its internal or external walls and no slag formation of any type. It was observed that the vitrification of the crucibles depended mainly by the position of the nozzles during the process.

In the experiment where some sort of chemical reaction occurred, the ore charge fused with the ceramic, making it necessary to break the vessels to extract the smelting products. For each experiment, the small amount of ore/metal fragments left loose inside the crucible were collected onsite, the actual vessel was sawed in a lab environment.

At a first autoptical analysis of the products and by-products collected from the smelting experiments, it was observed that in no case it was possible to recognise morphological similarities with the archaeological slag from Pyrgos-*Mavroraki*. The reasons for this could be several: Pyrgos's crucibles were not used for primary smelting, but possibly to refine the matte produced with a technique different from crucible-smelting.

The nozzles all heavily vitrified, in contrast with what observed on the archaeological finds. It could be argued that the lack of specialistic skills of the blowpipe operators might have influenced on this aspect.

The question "could be sulphidic copper ore smelted in a bowl-shaped furnace using just blowpipes?" has been addressed by the experiments. It was demonstrated that the necessary temperature can be reached even with just one operative blowpipe, though at a great cost in human labour. The ideal conditions to operate the furnace object of these experiments has been provided by three operative blowpipes. However, the use of blowpipes prevents the possibility to talk and interact, and this has led the writer to think that, differently compared to other stages of the operations chain, this step might have been a delicate, quite mysterious process, characterised by the very peculiar, rhythmic sound of controlled human breath.

In regard with the possible timescale of this type of crucible-smelting, it has been demonstrated that the process, once the correct temperature of above 1000°C is achieved, requires a minimum of 30 minutes. The product of such a process is not metallic copper though, but a CuFeS alloy, matte, which needs further processing (re-smelting) to be transformed in metallic copper. As this material was found in many slags from Pyrgos-Mavroraki, it could be argued that its production and refining might have happened onsite.

Chapter 7. Conclusions

7.1 Pyrgos-*Mavroraki* in the framework of Early and Middle Bronze Age Cypriot metallurgy

The first evidence of metal used in Cyprus dates to the Middle Chalcolithic, however, the first secure evidence of actual copper processing is not visible earlier than the Late Chalcolithic at the site of Kissonerga-*Mosphilia*.

A more secure evidence for the production and processing of copper from its ores, accompanied by a remarkable increase in the number of metal artefacts on the island. According to the archaeological record pertaining specifically to the earliest Cypriot copper *chaîne opératoire* examined up to now, the metal was extracted, smelting both oxidised (Alambra-Mouttes) and sulphidic local ores (Kissonerga-*Mosphilia*), using probably the same type of crucibles (Alambra-*Mouttes*, Paramali-*Pharkonia*, Ambelikou-*Aletri*) which were utilised for remelting the copper prills and producing alloys (Kalavassos-*Laroumena*).

Very limited evidence is available for the types of metallurgical reactors and devices for the air supply. Sites such as Alambra-*Mouttes,* Ambelikou-*Aletri* and Politiko-*Troullia* provided limited evidence for the use of crucibles in small stone-lined hearths and pit-shaped furnaces covered in charcoal. The use of resinous wood such as Calabrian Pine might have been preferred by Cypriot coppersmiths. The artificial air supply to operate these types of reactors was provided by blowpipes or simple bellows made of organic material and equipped with clay nozzles such as the unique pieces found at the sites of Ambelikou-*Aletri* and Bellapais-*Vounous*. Another artefact from Alambra-*Mouttes*, previously interpreted as a mould, has been identified by the writer as a clay nozzle for blowpipes.

Onsite melting and casting activities have been testified by clay or limestone moulds found at EC and MC sites such as Marki-*Alonia*, Ambelikou-*Aletri*; Politiko-*Troullia*.

Within this framework, the site of Pyrgos-*Mavroraki*, plays a fundamental role in reinforcing the theories formulated on the base of the relatively small amount of archaeological evidence related to the copper *chaîne opératoire* present in Cyprus during the Early and Middle Bronze Age. The excavations unearthed a vast architectural complex, which hosted several workshops including an olive press, a textile-making workshop, a jewellery workshop, and a perfume 'factory'. Importantly, the complex yielded a great deal of metallurgical installations and residues including ore roasting beds, smelting and casting furnaces, slags, crucibles, moulds, anvils, metalworking tools and bronze artefacts.

The different contexts, described by the excavator in her reports, show that possibly different stages of copper processing were carried out at the site. The vicinity of the site to different copper-ore deposits such as the oxidised outcrops individuated on Mavroraki's hill itself, but also the Cupreous Pyrites in Mazokambos, Ornitha, Manghaleni can be hypothetically seen as the most direct sources for copper ore. While the smelting of oxidised copper ores is straight-forward and easily manageable in a single-step process, sulfidic ores such as Chalcopyrite and Bornite would have required a more complex multiple-steps procedure, involving a preliminary desulfurisation of the ores (roasting) to make the following smelting process possible.

The excavator interpreted the large carbonaceous layers found in the Northern Sector as roasting beds (Belgiorno 1999c, p. 296). However, considering that the ore deposits are all located in areas surrounded by forests, vital fuel supply for the high-consuming roasting activities, it seems too costly in terms of time and energy to transport both ores and fuel charge from the mining areas to the settlement. Once roasted on the mining site, the semi-reduced minerals could have been transported to the site and smelted with the use of charcoal (smelting requires much less fuel than the roasting process, which can last days).

When considering the possible metallurgical furnaces, the present research acknowledged that large circular features were found by the excavator, who interpreted them as tapping shaft-furnaces, however, as their context appears particularly puzzling in relation to a possible metallurgical use, it has been decided not to consider them for the sake of the present research.

The possible shaft-furnace found in J4, preliminary tested by the author before to start the present research, was also discarded. The tapping technology used with the shaft-furnaces is not represented in Pyrgos neither in its slag types (see Ch. 4) neither in the presence of tuyeres, large clay nozzles which would have been attached to leather bellows, a technology which is not attested in Cyprus before the Late Bronze Age (Kassianidou 2011).

The only features found at Pyrgos, considered in these research as possible metallurgical furnaces are therefore the remaining small pits found both in the Northern and Southern Sectors, which represent the most primitive type of metallurgical reactor known in early metallurgy (Zwicker et al. 1985).

Another essential data towards the understanding of Pyrgos's metallurgy is the large amount of crucible fragments. According to the only published SEM-EDX analysis carried out on a crucible from Pyrgos by Giardino (2000), crucibles were used for casting. However, in the absence of a systematic analytical programme on Pyrgos's crucibles to confirm that use of these artefacts was limited to the casting process, it can be argued that crucible-smelting was practiced at Pyrgos-Mavroraki. This theory could be further confirmed by the analyses carried out on the crucibles found at Alambra-*Mouttes* (Gale et al. 1996, pp. 382-383) and provided important data to inform the experimental protocol designed for the present research.

To complete the image of a possible reconstruction for Pyrgos metallurgy, another important component is represented by three clay blowpipe-nozzles found at the site, the highest number ever found in Cyprus in a metallurgical context date to the EC/MC. These objects are usually related with the smelting technology characterised by the combination of pit-shaped furnaces and crucibles (Zwicker et al. 1985). The use of blowpipes and pit-shaped furnaces is further attested at the coeval Cypriot sites of Ambelikou-*Aletri* and, possibly, at Alambra-*Mouttes* (Webb and Frankel 2013, pp.36; 180-181).

Highly specialised metallurgical tools were found at Pyrgos-*Mavroraki*, such as the stone-holders, possibly used to sustain the clay-nozzles or the blowpipes in a certain position onto the pit-shaped furnaces, or the accurately shaped basalt anvils, provided with grooves to possibly facilitate the hammering of hook-tanged weapons and knives. These objects, together with the type of sulfidic copper ore selected for smelting, as confirmed by the analytical work carried out on Pyrgos metallurgical discard, testify a certain level of specialisation in one of the earliest examples of metallurgical *chaîne opératoire* found in Cyprus, making the possibility of a surplus production not impossible. The small ingot of tin found at Pyrgos and various moulds confirm that melting, casting and alloying were practiced at the site.
If Webb and Frankel's suggestion to interpret the pierced-butt flat axes as possible ingots (2006. p. 217) is to be accepted, the finding at Pyrgos of two moulds for this type of object might suggest that the production of metal surplus was part of the common metallurgical practice for the site's metalsmiths. This, in the shape of ingots, could have been traded with other sites on the Island or abroad. Pyrgos-Mavroraki enriches the relative paucity and general condition of early metallurgical remains in Cyprus. EC/MC metallurgy can no longer be interpreted as an indication of a "primitive" or "provincial" copper production or

consumption, destined in this period to fill the needs of village-based communities alone (Gale 1991, p. 46).

The scarcity of metal artefacts from the funerary contexts of Pyrgos seems to contrast with the metallurgical vocation of this site and the richer northern cemeteries. It could be suggested that an economical focus of Pyrgos-*Mavroraki*'s community was to trade the precious goods produced at its workshops, such as jewels, olive oil, essences, including copper and metal artefacts with other groups on the Island and abroad.

If we accept the identification of the Middle Bronze Age country of Alashiya, mentioned by 19th century BCE written sources, with Cyprus, this should lead the interpretation of some of the archaeometallurgical finds from Early and Middle Bronze Age sites on the island.

In terms of the earlier stages of the *chaîne opératoire*, a few more indicators from these periods indicate a gradual increase of interest in this trade network which regards also the exchange of metals copper. The vast and always increasing number of chemical composition analyses available for Cypriot metalwork (Charalambous and Webb 2020), which will be discussed in more detail in chapter 4, confirms the positioning of Cyprus within a wider trade network.

Recent studies have further reinforced the evidence that sees Cypriot metallurgy connected with a wider network since its very beginning (Kassianidou and Charalambous 2019). This picture has been already suggested in the past, using the evidence provided by lead-isotopes analysis, which demonstrated the presence of Cypriot copper outside the island, since the early third millennium BC. This has been shown by the findings from Pella in Jordan (Philip et al 2003), and Aghia Pothia on Crete (Day et al 1998; Stos-Gale and Gale 2003).

The moulds found both at Marki-*Alonia* and Pyrgos-*Mavroraki*, as described in more detail in chapter 3, were used to produce pierced-butt flat axes, interpreted by some scholars as possible axe-shaped ingots (Webb and Frankel 2013, p. 180). The use of copper ingots in MC

Cyprus is further confirmed by the recent (mission 2015) discovery, still unpublished, of two small copper ingots from Alambra-*Mouttes* which the author had the opportunity to view in the storerooms of the Cyprus Museum during his PhD fieldwork. The presence of ingots would suggest a surplus production of copper, which might support the argument towards offsite copper distribution an early interest for either internal (*i.e.*, with other MC settlements) or external trade (*i.e.*, with the regions surrounding Cyprus).

The contacts established between Cyprus and the Eastern Mediterranean and Aegean, which were in place since the beginning of the island's metallurgy, provide the appropriate framework to contextualise the striking fact that the knowledge of sulphidic copper ore smelting and tin-copper alloys developed almost in parallel with other areas of the Eastern Mediterranean.

Charalambous and Webb (2020) recently highlighted further the important role played by Lapithos, and earlier by Vasilia (Webb et al. 2006, p. 283), in the direct involvement of Cyprus with the trade of raw metals conducted along maritime ways which passed between its northern coast and the south coast of Anatolia in the first half of the 2nd millennium BCE. Although it has not been possible to investigate further the northern coast of Cyprus after the Turkish invasion in 1974, looking for the settlements related to this and other cemeteries, it is clear the discrepancy between the evident abundance of prestigious metal grave goods found in the norther burial sites in contrast with the much humbler contexts from the central and southern burials, where the main metallurgical sites for this period have been found on the metalliferous Troodos foothills.

Material from contemporary agricultural villages situated nearer the Troodos copper ore sources indicates the use of more utilitarian copper objects, suggesting that people from these two regions held different social attitudes towards metals during life and after death (Knapp 2013b, p. 26).

Sixty-eight metal artefacts from Pyrgos, both from the settlement on *Mavroraki*'s hill and the cemetery, were divided in three main categories: weapons, tools and ornaments/tools of personal ornament. The artefacts were described and compared with finds from coeval Cypriot sites.

The study of this material revealed that the only three hook-tanged-weapons found in this area come from funerary context, while tools and ornaments were found both at the settlement and the cemetery.

The tombs, some of which are multiple burials, resulted not very rich in metal artefacts if compared with the northern cemeteries of Lapithos-*Vrysi tou Barba* and Bellapais-*Vounous*, with the only exception of Tomb 21, the so-called "Coppersmith Tomb" with 13 metal objects. This phenomenon appears quite surprising considered that the cemetery belongs to a metal-production site. The concept and value attributed to metal artefacts by the members of Pyrgos-*Mavroraki*'s community might have differed from that one shared by the "northern communities". The metal might have been seen more as a valuable material of exchange rather than a prestigious good to be shown as a symbol of power.

A complete publication of Pyrgos's cemetery is needed to explore further its archaeological context and compare it to the contemporary cemeteries of Cyprus.

The discovery of several ornaments in the settlement, usually found as funerary goods, supports the hypothesis that the site underwent to a sudden abandonment due to a disastrous event.

An interesting concentration of needles has been recorded in the Western Sector, were other archaeological finds such as loom-weights and spindle whorls seem to suggest that this area was dedicated to textile production.

Some finds can be interpreted as unfinished objects (616; M2) and some others show evidence of recycling (614), while alloying is confirmed by the presence of a led fragment and a tin-lead miniature oxhide ingot.

Thirty-nine objects from the settlement of Mavroraki were analysed by pXRF. Some of the objects belonging to the "Miscellanea" category resulted suspect due to the poor conditions of the artefacts and the impossibility of analysing a homogeneous de-patinated area.

Overall, none of the objects analysed resulted to be made of unalloyed copper, while both arsenical copper and tin-bronze were confirmed to be the main metals worked at Pyrgos-*Mavroraki*.

The presence of low tin contents in some of the objects, occasionally detected together with arsenic suggests that metal recycling was practised at the site. The tin content in Pyrgos's artefacts and the tin-ingot found at the site, reinforce once again the theory that Pyrgos was somehow involved in the exchange of goods with other settlements in Cyprus and, possibly abroad.

The extent of the interaction between these northern and southern sites within the framework of the early metallurgical industry of Cyprus needs further investigation.

It could be argued that Pyrgos-*Mavroraki* was involved in the wider international trade networks of the time, trading in metal artefacts and copper ingots, through the medium of the northern sites of Lapithos-*Vrysi tou Barba* and Bellapais-*Vounous*, where butt-pierced axes have been found. To reinforce such a theory, lead-isotopes analysis should be performed on both metal remains from Pyrgos-*Mavroraki* and the northern sites.

On a more social aspect, the peculiar coexistence of all these different kinds of artisanal productions, located in different workshops (often open courtyards) within the same buildings at Pyrgos-*Mavroraki*, seems also to refute the old common idea of a guild of metallurgists who used to keep the secrets of their art for themselves (Amzallag 2009, p. 396). Metallurgy was rather a common activity which possibly involved different members of the community, possibly simultaneously involved in different craft-activities, as it is also suggested by the presence of metallurgical activity in several different areas of the site, including the contexts identified by the soundings on *Mavroraki*'s hill and the survey at *Aulaki*.

Different steps of the *chaîne opératoire* could have involved different members of the community, making of copper metallurgy one of the many precious goods produced by the community of Pyrgos-*Mavroraki*.

In this general framework, the pre-industrial early 2nd millennium BC settlement site of Pyrgos-*Mavrorak*i provides further evidence towards the understanding of the metallurgical *chaîne opératoire* characteristic for the Early and Middle Bronze Age in Cyprus.

7.2 Archaeological Science and Experimental Archaeology

As part of this research 1713 slags from the settlement of Pyrgos-*Mavroraki*, 35 slags from four archaeological soundings on *Mavroraki*'s hill and 14 slags collected during the survey carried out South of *Mavroraki* in the *Aulaki* area, were autoptically analysed.

Part of these slags were photographed (836) and categorised in distinct groups of which two resulted the most relevant ones for the sake of the present research: viscous slags (type 1) and coarse slags (type 2). While coarse slags appear as chunky heterogeneous lumps, probably formed inside the furnace as a result of the first step in the smelting process, type 2 usually presents a glossy outer surface that suggests their viscous (or semiliquid) state at the moment of cooling.

Despite the fact that it has been suggested in the past that the mere presence of sulphur in metallurgical slags does not prove that sulphide ores were smelted (Gowland 1899; Koucky and Steinberg 1982b: 278-279), the percentage of Sulphur detected in Pyrgos's slags strongly suggests about the sulphidic nature of the ores smelted/refined in the site, most probably chalcopyrite/bornite, the most common sulphidic copper ore present in Cyprus.

The iron oxides detected in various forms embedded in the matrix of the slags analysed, points out to the poor reducing conditions reached by the ancient metallurgists of Pyrgos. The use of blowpipes and the very simple shape of the reactors used for copper smelting (bowl-shaped furnaces) did not allow the creation of an efficient reducing atmosphere. This is also demonstrated by the high viscosity of the slags, which never reached a fully liquid state.

The fragments of quartz detected during the slag analysis raise the question about an intentional addition of this type of mineral to the charge as a flux. However, it cannot be excluded that fragment of quartz were present in the copper ores as gangue and not efficiently removed during the beneficiation process. The main two main types of slags identified, different in shape and slightly in chemical composition. The coarse slags showed a more inhomogeneous matrix compared to the viscous slags characterised by the presence of a large amount of unreacted material. This inhomogeneity, coupled with a higher content of Sulphur present in the coarse slags might suggest interpreting this type of slags as the by-product of the primary roasting process of the

ores. Waste products similar to the coarse slags analysed in this study were obtained experimentally by Doonan after chalcopyrite roasting (1994: 93). This process could have taken place either in appropriate roasting beds, which, according to the excavator, are identifiable within the Northern Sector, or, more likely, in the same bowl-shaped furnaces used for a multiple smelting process. The primary nodules obtained after roasting could have been successively smelted, originating a more refined, yet still very inhomogeneous, type of viscous slag. The iron-copper sulphides contained in the viscous slags appear more homogeneous and micro-prills of pure copper have been identified embedded in the matrix.

However, considered the abundance of iron-copper sulphidic phases within the slags, it seems arguable that matte was the final product obtained during the smelting operations carried out at Pyrgos-*Mavroraki*. The matte would have been re-melted to obtain copper metal, removing the remaining iron and sulphur components.

The technology used to smelt copper ores at Pyrgos-*Mavroraki*, produced a slightly different type of slags if compared to those ones found at the later site of Kalavassos-*Aghios Dhimitrios*, result of a more mature knowledge of the metallurgical process and therefore of a better control of temperatures and reducing conditions. Finally, it seems relevant to mention that, despite the abundance of crucible fragments in the archaeological record, during this study no melting-slags were identified.

Crucibles might have been used during the smelting process as well, although the size of some coarse slags don't find correspondence with the crucibles' diameters.

However, the metallurgical stages, that follow the ore smelting such as the casting of objects and their further shaping and refining, are testified in Pyrgos-*Mavroraki* by a series of eloquent indicators. Moulds for the casting of flat axes and, possibly, other tools, and varied stone toolset which also includes basalt anvils are unequivocal evidence of metalworking.

The present research plan based on pilot experiments aimed to gain a preliminary familiarity with the ores, metallurgical reactors, technical pottery, and overall technology which was possible to (re)construct for part of the copper *chaîne opératoire* in use at Pyrgos-*Mavroraki*. As stated earlier on in this chapter, the present work was intended with an aware heuristic approach to the field investigated, however a series of considerations, both experiential and analytical, could be drawn following the experiments performed until now.

The archaeological and analytical data collected during the present research pointed to writer to formulate some preliminary considerations and hypothesis on the main characteristics of Pyrgos-*Mavroraki*

’s metallurgical chaîne opératoire.

On the one hand, the archaeological record seemed to point towards the use of a relatively “primitive” smelting technology, using crucibles in small pits dug in the ground and human-operated blowpipes, while, on the other hand, slag analysis indicated that the copper ore smelted at Pyrgos was sulphidic, commonly found in relation to more advanced metallurgical technologies. However, the microstructural study of the slags analysed showed that the technological process that originated them did not allow a very efficient control on temperature’s stability and reducing conditions inside the furnace. These aspects are usually found in connection with the use of simple metallurgical reactors, such as bowl-shaped furnaces and the use of blowpipes.

At Pyrgos, a relatively “primitive” smelting technology such as crucible-smelting and sulphidic copper ore were found combined, belonging to the same metallurgical context. Consequently, as part of the present research, the main theory to be tested by the experiment was the feasibility of smelting sulphidic copper ore in a crucible/bowl-shaped furnace environment, utilising the air-supply provided by blowpipes.

To this purpose, a series of pilot-experiments over eleven days was designed and performed with the specific aim of gaining a preliminary familiarity with the ores, metallurgical reactors, technical pottery and overall smelting technology.

One kg of copper sulphide (bornite) underwent to two roasting cycles for a total length of twelve hours, in the attempt to desulphurise the ore and prepare it for smelting.

The ore, in chunks of ca. 5x5cm, was crushed before and after roasting, noticing that the crushing process required less effort on the roasted mineral. 140 kg of pine wood charcoal was utilised during the roasting process.

After roasting, the ore was further processed undergoing through seven crucible-smelting trials, including 2 co-smelting (roasted bornite and malachite in the ration of 1:1). Almost ten kilograms of charcoal were consumed in total. Considering that once the smelting temperature (over 1000°C) was reached, this was maintained for ca. 30 minutes, it was noticed that the fuel consumption varied from experiment to experiment, from a minimum of 0.8kg to a maximum of 2.2kg of charcoal. More observations on the variables that might have caused such a difference in fuel consumption need to be carried out in the future.

Regarding the experiential knowledge gained during the process, it appeared very clear since the beginning of the project that, although the metallurgical technology tested might seem quite primitive to the inexpert eye, it requires a good level of experience, manual capability and familiarity with the different components involved. Even though the writer followed some preliminary training in ancient metallurgy and performed three series of copper-smelting experiments before the start of this research, it appeared clear that far more practice is needed to gain the expertise necessary to carry out meaningful experimental research in this field.

Looking back to the initial research questions which were up for testing and attempt to provide some preliminary answers.

Although more accurate evaluations can be formulated only following the chemical analysis of the samples withdrawn during the experiments, the majority of the crucibles recovered after the smelting showed highly slagged and vitrified internal surfaces, while no sign of vitrification was noticed on the outside, in perfect accordance with the crucibles recovered at

Pyrgos-*Mavroraki.* The only exceptions were the crucibles used in: JH-SMLT I, a large portion of which collapsed and fused with a clay nozzle, and JH-SMLT VI, which did not show any particular vitrification neither on its internal or external walls and no slag formation of any type. It was observed that the vitrification of the crucibles depended mainly by the position of the nozzles during the process.

In the experiment where some sort of chemical reaction occurred, the ore charge fused with the ceramic, making it necessary to break the vessels to extract the smelting products. For each experiment, the small amount of ore/metal fragments left loose inside the crucible were collected onsite, the actual vessel was sawed in a lab environment.

At a first autoptical analysis of the products and by-products collected from the smelting experiments, it was observed that in no case it was possible to recognise morphological similarities with the archaeological slag from Pyrgos-*Mavroraki.* The reasons for this could be several: Pyrgos's crucibles were not used for primary smelting, but possibly to refine the matte produced with a technique different from crucible-smelting.

The nozzles all heavily vitrified, in contrast with what observed on the archaeological finds. It could be argued that the lack of specialistic skills of the blowpipe operators might have influenced on this aspect.

The question "could be sulphidic copper ore smelted in a bowl-shaped furnace using just blowpipes?" has been addressed by the experiments. It was demonstrated that the necessary temperature can be reached even with just one operative blowpipe, though at a great cost in human labour. The ideal conditions to operate the furnace object of these experiments has been provided by three operative blowpipes. However, the use of blowpipes prevents the possibility to talk and interact, and this has led the writer to think that, differently compared to other stages of the operations chain, this step might have been a delicate, quite mysterious process, characterised by the very peculiar, rhythmic sound of controlled human breath.

In regard with the possible timescale of this type of crucible-smelting, it has been demonstrated that the process, once the correct temperature of above 1000°C is achieved, requires a minimum of 30 minutes. The product of such a process is not metallic copper though, but a CuFeS alloy, matte, which needs further processing (re-smelting) to be transformed in metallic copper. As this material was found in many slags from Pyrgos-Mavroraki, it could be argued that its production and refining might have happened onsite.

7.3 Further Research

This research represents a first attempt to summarise the evidence for copper metallurgy in Early and Middle Bronze Age Cyprus. This systematic preliminary study of the metallurgical evidence from Pyrgos-Mavroraki provided the opportunity to draw a more accurate picture in this regard, confirming further what was partly suggested by the few coeval metallurgical sites of the island.

Despite the general knowledge on the topic might have hopefully slightly advanced due to this research, there are at least three major areas where interesting further research could be carried out.

Considering the great difficulties faced during this project in the interpretation of the rather vague contradicting published reports dedicated to the site, it is clear that the investigation of the site of Pyrgos-*Mavroraki* itself needs further studies. The contexts excavated are still waiting full publication; the lack of a complete dedicated monography on the site which would highlight the stratigraphical sequence and, therefore, an accurate chronology of each context, hindered the present work and will certainly prevent any future research. The full publication of both, the settlement and cemetery of Pyrgos-*Mavroraki* is most desirable. Moreover, if the geophysical prospections carried out in the in the surroundings of the site demonstrated its further extension beyond the limits of the excavated areas, the soundings on

Mavroraki's hill and the surveys carried out at *Aulaki* confirmed that metallurgical remains as well extend beyond the current borders of the area investigated. This data would suggest a prosecution of the archaeological investigation of the area, especially on *Mavroraki*'s hill, which for its elevated position, also exposed to the wind, might have been chosen for the construction of metallurgical structures for smelting.

An accurate GIS study of Pyrgos's area might lead to better informed surveys in the future, looking for superficial metallurgical discard and other sites more specialised in primary production, which might have related to Pyrgos-*Mavroraki*, where the copper *chaîne opératoire* would have been completed with the production of final artefacts and/or ingot for trade.

In terms of the metallurgical finds from the site, the analyses of the metal artefacts from Pyrgos's Cemetery should be completed for all the relative contexts and systematically compared with the northern cemeteries looking for similarities and differences.

An increase in the number of slag-samples, analysed from Pyrgos's contexts, would reinforce and confirm the results obtain in this research.

The slags and metal artefacts from Pyrgos-*Mavroraki* could be subject to a more advanced analytical campaign, including Lead Isotope analysis and Copper Isotope Analysis. These techniques have been primarily focussed on the final artefacts, whit the restrictions imposed by the practices of alloying and recycling.

An extensive survey of the Limassol Forest aimed to identify Early and Middle Bronze Age sites remains would be beneficial to shed light on the exploitation of the arsenical/copper ores, characteristic of this area, by EC/MC communities, with a special focus on the nearby site of Pyrgos.

The study of Pyrgos' crucibles, not possible in the present research, should also be included in future investigations.

I propose the renewed macroscopic and microscopic investigation of the archaeometallurgical remains from other EC and MC sites in Cyprus, such as Politiko-*Troullia* (technical pottery and by-products), Alambra-*Mouttes* (copper bar-ingots), Sotira-*Kaminoudhia* (lumps of ore and slag), Ambelikou-*Aletri* (slag), Kalopsidha-*Site C* (tap-slag) would sensibly contribute enormously to the reconstruction of metalwork in Early and Middle Bronze Age Cyprus.

The series of pilot-experiments carried out as part of this research allow for the design of a more accurate research protocol for a new series of experiments aimed to extend the number of trials, maintaining constant selected variables. The new protocol will profit from the observations made in regard to: 1) the pre-treatment of the ore, 2) the pre-heating of the furnace, 3) the positioning of the crucible inside the reactor, both in terms of location and timing, 4) the positioning of the thermocouples, 5) the size of the fuel inserted in the reactor, 6) the length of the entire process, which, possibly, should be extended from 30 minutes to one hour, after reaching the smelting temperature. It has been observed that adding smaller fuel charges to the furnace, more constantly works more efficiently to maintain constant the temperature inside the reactor.

Once the selection of the most effective conditions observed is made and tested through a first series of more systematic experiments (three trials for each specific set of variables chosen), a second series of experiments should aim to test these conditions using only Cypriot ores and materials. The furnace should be "constructed" in the same type of soil which characterises Pyrgos, highly calcareous and very different from the clayish soil of Jarrow Hall. The ores to smelt should be sourced from Cypriot deposits, which would have been available in the surroundings of the site in the Early and Middle Bronze Age. Following the extensive survey of the Limassol Forest and its ore deposits suggested earlier, it would be particularly interesting to investigate the use of local polymetallic ores and experiment the smelting/production of arsenical copper. This would require an even stricter risk-assessment than what was designed for the present research, involving the use of arsenic, which is a poisonous element. The technical pottery should be baked using local clay, possibly studying and (re)constructing the composition observed in Pyrgos-*Mavroraki*'s crucibles.

An important experimental investigation should regard the crushing, selecting and re-smelting of the matte-rich lumps obtained during the first smelting-process. This new series of re-smelting experiments might highlight the second smelting stage that could have been carried out at Pyrgos-*Mavroraki* and other coeval sites, to produce metallic copper ready for casting and alloying. T

To complete the experimental (re)construction of Pyrgos-Mavroraki's copper *chaîne opératoire*, a new series of pilot-experiments, followed by more systematic experiments, should investigate the last steps of the process. These new trials should test the efficacy of the same bowl-shaped furnace and blowpipes utilised in the present research, once used in casting and alloying processes.

A systematic sampling of the processed ore, by-product and metal produced in each experiment should be carried out and prepared for macroscopical, microscopical and chemical analysis and the results compared with the archaeological samples.

REFERENCES

AJA: American Journal of Archaeology
AntJ: The Antiquaries Journal
BAR: British Archaeological Reports
BASOR: Bulletin of the American Schools of Oriental Research
CCEC: Cahier du Centre d'Études Chypriotes
EJA: European Journal of Archaeology
JAA: Journal of Anthropological Archaeology
JAS: Journal of Archaeological Science
JHS: Journal of Helenic Studies
JMA: Journal of Mediterranean Archaeology
OJA: Oxford Journal of Archaeology
OpAth: Opuscula Atheniensia
RDAC: Report of the Department of Antiquities, Cyprus
SIMA: Studies in Mediterranean Archaeology
SMEA: Studi Micenei ed Egeo-Anatolici

Abedi, A., and Omrani, B., 2015. Kura-Araxes culture and North-Western Iran: New perspectives from Kul Tepe Jolfa (Hadishahr). *Paléorient* vol. 41, n. 1, pp. 55-68.

Addis, A., Angelini, I., Nimis, P. and Artioli, G., 2016. Late Bronze Age copper smelting slags from Luserna (Trentino, Italy): interpretation of the metallurgical process. *Archaeometry* 58:1, 96-114.

A Campo, A. L., 1994. Anthropomorphic Representations in Prehistoric Cyprus: A Formal and Symbolic Analysis of Figurines, c. 3500-1800 BC. SIMA, 109. Paul Åströms Förlag, Jonsered.

Ambert, P., Balestro, F., Laroche, M., Figueroa and Rovira, S., 2014. Technological aspects of the earliest metallurgy in France: 'furnaces' and slags from La Capitelle du Broum (Péret, France). *Historical Metallurgy* 47(1), pp. 60-74.

Ammerman, A.J. and Noller, J.S., 2005. New light on Aetokremnos. *World Archaeology* 37, 533543.

Amzallag, N., 2009. Yahweh, the Canaanite God of Metallurgy? *Journal for the Study of the Old Testament* 33.4, pp. 387-404.

Artioli, G., Angelini, I., Tecchiati, U. and Pedrotti, A., 2015. Eneolithic copper smelting slags in the Eastern Alps: Local patterns of metallurgical exploitation in the Copper Age. *JAS* 63, pp. 78-83.

Asher, R., 1961. Experimental Archaeology. *American Anthropologist*. New Series 63(4), 793-816.

Åström, P., 1957. *The Middle Cypriote Bronze Age*. Lund.

Åström, P., 1966. *Excavations at Kalopsidha and Ayios Iakovos in Cyprus*, SIMA 2. Carl

Bloms Boktryckeri A.-B., Lund.

Åström, P., 1972. SCE IV/1B / The Swedish Cyprus Expedition. Vol. IV/ 1B The Middle Cypriot Bronze Age. Paul Åströms Förlag, Stockholm.

Bachmann, H.-G., 1980. Early copper smelting techniques in Sinai and in the Negev as deduced from slag investigations, in: Craddock, P.T. (Ed.), *Scientific Studies in Early Mining and Extractive Metallurgy*, British Museum Occasional Papers 20. 3rd Edition. The British Museum, London, 103–135.

Bachmann, H. G., 1982a. Copper smelting slags from Cyprus: review and classification of analytical data, in: Muhly, J.D., Maddin, R. and Karageorghis, V. (Eds.), *Early Metallurgy in Cyprus, 4000-500 B.C.* Pierides Foundation, Nicosia, 143–152.

Bachmann, H. G., 1982b. *The Identification of Slags from Archaeological Sites*, UCL Institute of Archaeology Occasional Publication 8. Institute of Archaeology, London.
Bagnall, P.S., 1960. *The Geology and Mineral Resources of the Pano Lefkara-Larnaca Area*, Geological Survey Department Cyprus Memoir No. 5. Authority of the Government of Cyprus, Nicosia.

Bachmann, H. G. and Rotenberg, B, 1980. Die verhüttungsverfahren von site 30. In H.G. Conrad, H.G. and Rothenberg, B. (eds), *Antikes Kupfer im Timna-Tal*. Deutches Bergbau-Museum, Bochum. 215-236.

Balthazar, J.W., 1990. *Copper and Bronze Working in Early through Middle Bronze Age Cyprus*. SIMA 84. Paul Åströms Förlag,
Jonsered.

Bamberger, M., 1996. The working conditions of the ancient copper smelting process, in: Craddock, P.T. and Hughes, M.J. (Eds.), *Furnaces and Smelting Technology in Antiquity*, British Museum Occasional Paper 84. 3rd Edition. The British Museum, London, 151–157.

Barbieri, M. Cavazzuti, C., Pellegrini, L.and Scacchetti F., 2015a. Experiencing Visible and Invisible Metal Casting Techniques in Bronze Age Italy. *EXARC Journal* Issue 2015/3, 1/8-8/8.

Barbieri, M. Cavazzuti, C., Pellegrini, L.and Scacchetti F., 2015a.Experiencing Visible and Invisible Metal Casting Techniques in Bronze Age Italy. In Kelm, R. (ed), Archaeology and Crafts. Experiences and Experiments on traditional Skills and Handicrafts in Archaeological Open-Air Museums in Europe. Husum, 94-102.

Bartoli, A. and Cappelletti, C., 2009. L'archeologia sperimentale applicate alle scoperte di Pyrgos-Mavroraki, Cipro. In Bartoli, A., Belgiorno, M.R., Cappelleti, C. and Lentini, A., Cipro: un sito di 4000 anni fa e l'Archeologia Sperimentale. Viterbo, 121-190.

Bartoli, A. and Romeo Pitone, M., 2017. Experimental Archaeometallurgy at Pyrgos-Mavroraki: the pilot experiments. In Belgiorno, M.R. (ed), Archaeometry and Aphrodite. Proceedings of the seminar 13th Jun 2013, CNR Rome. De Strobel Publisher, 167-169.

Bassiakos, Y. and Catapotis, M., 2006. Reconstruction of the Copper Smelting Process Based on the Analysis of Ore and Slag Samples. In Betancourt, P. (Ed.), *The Chrysokamino Metallurgy Workshop and Its Territory*. Hesperia Supplements vol. 36, pp. 329-353.

Bassiakos, Y. and Philaniotou, O., 2007. Early Copper Production on Kythnos: Archaeological Evidence and Analytical Approaches to the Reconstruction of Metallurgical Process. In Day, P.M. and Doonan, C.P. Doonan (Eds.), *Metallurgy in the Early Bronze Age Aegean*. Oxbow, Oxford, pp. 19-56.

Bayley, J. and Rehren, T., 2007. Towards and functional and typological classification of crucibles, in: La Niece, S., Hook, D., and Craddock, P.T. (Eds.), *Metals and Mines: Studies in Archaeometallurgy*. Archetype Publications, London, pp. 46–55.

Belgiorno, M.R., 1995b. Ricognizione a Pyrgos (Cipro), campagna 1995. Incunabula Graeca, SMEA 36/1, 48-149.

Belgiorno, M.R., 1997a. A Coppersmith Tomb of Early-Middle Bronze Age in Pyrgos (Limassol). *RDAC* 1997, 119-146.

Belgiorno, M.R., 1997b. Limassol-Pyrgos (Cipro), campagna 1997. *SMEA* 39/2, pp. 282-285.

Belgiorno, M.R., 1998. Limassol-Pyrgos (Cipro), campagna 1998. *SMEA* 40/2, pp. 295-313.

Belgiorno, M.R., 1999a. Indagini archeologiche ed archeometallurgiche a Pyrgos: le fornaci del Bronzo Antico e Medio. In La Rosa, V., Palermo, D. and Vagnetti, L. (Eds.), ἐπὶ πόντον πλαζόμενοι. Simposio italiano di Studi Egei dedicato a Luigi Bernabò Brea e Giovanni Pugliese Carratelli. Scuola Archeological Italiana di Atene, Roma, pp. 53-61.

Belgiorno, M.R., 1999b. Preliminary report on Pyrgos excavations 1996, 1997. *RDAC* 1999, 71-86.

Belgiorno, M.R., 1999c. Relazione preliminare campagna di scavo a Cipro, sito di Pyrgos/Mavroraki. Incunabula Graeca, *SMEA* 41/2, 295-311.

Belgiorno, M.R., 2000a. Progetto “Pyrame”: attività 2000. Incunabula Graeca, *SMEA* 42, 331-335.

Belgiorno, M.R., 2000b. Project “Pyrame” 1998-1999: Archaeological, metallurgical and historical evidence at Pyrgos (Limassol). *RDAC* 2000, 1–17.

Belgiorno, M.R., 2002. Rescue-excavated tombs of the Early and Middle Bronze Age from Pyrgos (Limassol). *RDAC* 2002, 1-32.

Belgiorno, M.R., 2004. *Pyrgos-Mavroraki: Advanced Technology in Bronze Age Cyprus*. Theopress Ltd, Nicosia.

Belgiorno, M.R., 2017. *The Perfume of Cyprus: from Pyrgos to François Coty the route of a legendary charm*. De Strobel Publisher, Nicosia.

Belgiorno, M. R., 2008. Lana e olio d’oliva, binomio vincente nell’industria tessile. In Lugli, F. and Stoppiello, A.A. (Eds.), *Proceedings of the 3rd Italian Congress of Ethnoarchaeology,* *Mondaino, 17-19 March, 2004*, BAR International Series 1841. Archaeopress, Oxford, pp. 48-54.

Belgiorno, M.R., 2009. *Cipro all'inizio dell'Età del Bronzo. Realtà sconosciute della comunità industriale di Pyrgos/Mavroraki*. Gangemi, Roma.

Belgiorno, M.R., 2019. Pyrgos (Lm). *The Early-Middle Bronze Age Necropolis from Tomb 1 to Tomb 19*. Scripta Cipria vol. I. De Strobel Publisher, Nicosia.

Belgiorno, M.R., Ferro, D. and Loepp, D.R., 2012. Pyrgos-Mavrorachi in Cypriot metallurgy, in: Kassianidou, V. and Papasavvas, G. (Eds.), *Eastern Mediterranean Metallurgy and Metalwork in the Second Millennium BC*. Oxbow Books, Oxford and Oakville, 26–34.

Belgiorno, M.R. and Romeo Pitone, M. 2017. I pendenti a pettine: simboli viaggianti. In Negroni Catacchio, N. (Ed.), *Preistoria e Protostoria in Etruria Atti XII. Ornarsi per comunicare con gli uomini e con gli Deai. Gli oggetti di ornamento come status symbol, amulet, richiesta di protezione. Ricerche e scavi*. Centro Studi di Preistoria e Archaeologia, Milano, pp. 387-405.

Bohne, C., 1968. Über die Kupferverhüttung der Bronzezeit: Schmelzversuche mit Kupferkieserzen. *Archaeologia Austriaca* 44, 49-60.

Bolger, D.L., 1996. Figurines, fertility, and the emergence of complex society in prehistoric Cyprus. *Current Anthropology* 37, 365-372.

Bombardieri, L. and Graziadio, G., 2019. *Cipro. Preistoria di un'isola mediterranea*. Mondadori Education, Florence.

Bourgarit, D., 2007. Chalcolithic copper smelting. In La Niece, S., Hook, D. and Craddock, P. (Eds), *Metals and mines, studies in archaeometallurgy*. London, pp. 3-14.

Bourgarit, D. and Mille, B., 1997. La metallurgie chalcolithicque de Cabrieres: confrontation des donnees experimentales et archeologiques en laboratoire. Archéologie en Languedoc 21, 51- 63.

Bourgarit, D., Mille, B., Burens, A. and Carozza, L., 2002. Smelting of Chalcopyrite During Chalcolithic Times: Some Have Done It in Ceramic Pots as Vase-furnaces. In Kars, H. and Burke, E. (eds), Proceedings of the 33rd International Symposium on Archaeometry, 22-26 April 2002, Amsterdam. Vrije Universiteit, Amsterdam, 297-302.

Broodbank. C., 2013. *The making of the Middle Sea*. Thames and Hudson, London.

Bronk Ramsey, C., 2017. Methods for summarizing radiocarbon datasets. *Radiocarbon* 59/6, 1809-1833.

Buchholz, H.G., 1959. Keftiubarren und Erzhandel im zweiten vorchristlichen Jahrtausend. *Praehistorisch Zeitschrift* 37, 1–40.

Bucholz, H.G. and Karageorghis, V., 1973. Prehistoric Greece and Cyprus. Phaidon Press, London.

Burger, E., Bourgarit, D., Wattiaux, A. and Fialin, M., 2010. The reconstruction of the first copper-smelting processes in Europe during the 4th and the 3rd millennium BC: where does the oxygen come from? *Applied Physics A* 100:3, pp. 713–724.

Calderoni, G., 2009. Diagrammi di calibrazione per le età convenzionali misurate per il sito di Pyrgos-Mavroraki, Cipro. In Belgiorno, M.R. (Ed.), *Cipro all'inizio dell'Età del Bronzo. Realtà sconosciute della comunità industrial di Pyrgos/Mavroraki*. Gangemi, Roma, pp. 188-193.

Carannante, A., 2009. Analisi Archeomalacologiche nel sito di Pyrgos-Mavroraki (Cipro). In Belgiorno, M.R. (Ed.), *Cipro all'inizio dell'Età del Bronzo. Realtà sconosciute della comunità industriale di Pyrgos/Mavroraki*. Gangemi, Roma, pp. 106-119.

Caskey, J.L., 1971. Greece, Crete, and the Aegean Islands in the Early Bronze Age. In Edwards, I.E.S., Gadd, C.J. and Hammond, N.G.L. (Eds.), *Early History of the Middle East*. Cambridge University Press, Cambridge, pp. 771-807.

Catapotis, M. and Bassiakos, Y., 2007. Copper Smelting at the Early Minoan Site of Chrysokamino on Crete. In Day, P.M. and Doonan, C.P. Doonan (Eds.), *Metallurgy in the Early Bronze Age Aegean*. Oxbow, Oxford, pp. 68-83.

Catapotis, M., Pryce, O. and Bassiakos, Y., 2008. Preliminary results from an experimental study of perforated copper-smelting shaft furnaces from Chrysokamino (Eastern Crete). In Tzachili, I. (ed), Aegean Metallurgy in the Bronze Age. Proceesdings of an International Symposium held at the University of Crete, Rethymnon, Greese, on November 19-21, 2007. Ta Pragmata, Rethymnon, 119-128.

Catling, H.W., 1964. *Cypriot Bronzework in the Mycenaean World*. Clarendon Press, Oxford.

Chapman, D.A. and Chapman, S.G., 2013. Reconstructing and testing the Pentrwyn pit furnaces. Late Bronze Age copper smelting on the Great Orme. Online publication: http://www.ancient-arts.org/pentrwyn%20exp%20report.pdf (visited last time 28th March 2020).

Charalambous, A., 2016. A diachronic study of Cypriot copper alloy artefacts. *JAS Reports 7*, 566-573.

Charalambous, A. and Kassianidou, V., 2012. Appendix V: chemical analyses of metal artefacts from Late Cypriote tombs excavated in the Limassol area, with the employment of pXRF, in: Karageorghis, V and Violaris, Y. (Eds.), *Tombs of the Late Bronze Age in the Limassol Area, Cyprus (17th-13th centuries BC)*. Nicosia: Municipality of Limassol, pp. 300–305.

Charalambous, A. and Kassianidou, V., 2014. Appendix V. Chemical analyses of copper alloy artefacts from Pyla-Kokkinokremos using portable X-Ray Fluorescence, in: Karageorghis, V. and Kanta, A. (Eds.), *Pyla-Kokkinokremos, a Late 13th Century BC Fortified Settlement in Cyprus: Excavations 2010-2011*, SIMA 141. Åströms Förlag, Uppsala, pp. 197–204.

Charalambous, A., Kassianidou, V. and Papasavvas, G., 2014. A compositional study of Cypriot bronzes dating to the Early Iron Age using portable X-ray Fluorescence

Spectrometry (pXRF). *JAS* 46, 205–216.

Charalambous, A. and Webb, J. M., 2020. Metal procurement, artefact manufacture and the use of imported tin bronze in Middle Bronze Age Cyprus. JAS 113, pp. 1-13.

Coghlan, H. H., 1939. Some Experiments on the Origin of Early Copper. *Man* 39, 106-108.

Coghlan, H. H., 1939/1940. Prehistoric Copper and some Experiments in Smelting. *Transactions of the Newcomen Society* 40, 49-65.

Coleman, J.E., 1977. *Kephala: A Late Neolithic Settlement and Cemetery*. Keos I. American School of Classical Studies, Princeton.

Coleman, J.E., Barlow, J.A., Mogelonsky, M.K. and Schaar, K.W., 1996. *Alambra, a Middle Bronze Age Settlement in Cyprus: Archaeological Investigations by Cornell University 1974-1985*, SIMA 118. Paul Åströms Förlag, Jonsered.

Constantinou, G., 1982. Geological features and ancient exploitation of the cupriferous sulphide orebodies of Cyprus, in: Muhly, J.D., Maddin, R. and Karageorghis, V. (Eds.), *Early Metallurgy in Cyprus, 4000-500 B.C*. Pierides Foundation, Nicosia, pp. 13–24.

Constantinou, G., 2007. Contribution of the geology to the early exploitation of the cupriferous sulphide deposits of the Skouriotissa mining district, in: Kling, B. and Muhly, J.D., *Joan Du Plat Taylor's Excavations at the Late Bronze Age Mining Settlement at Apliki Karamallos, Cyprus*, SIMA 94:1. Paul Åströms Förlag, Sävedalen, pp. 337–345.

Constantinou, G., 2012. Late Bronze Age copper production in Cyprus from a mining geologist's perspective, in: Kassianidou, V. and Papasavvas, G. (Eds.), *Eastern Mediterranean Metallurgy and Metalwork in the Second Millennium BC*. Oxbow Books, Oxford and Oakville, pp. 4–13.

Constantinou, G. and Panayides, I., 2013. The mining geology of Cyprus with special reference to Ambelikou *Aletri*. In Webb, J. and Frankel, D. (Eds.), *Ambelikou Aletri. Metallurgy and Pottery Production in Middle Bronze Age Cyprus*, SIMA 138. Åströms Förlag, Uppsala, pp. 11-23.

Costa, A., Cavulli, F. and Pedrotti, A., 2019. I focolari, forni e fosse di combustione di Lugo di Grezzana (VR). *IpoTESI di Preistoria* 12, 27-48.

Craddock, P.T., 1980. The composition of copper produced at the ancient smelting camps in the Wadi Timna, Israel, in: Craddock, P.T. (Ed.), *Scientific Studies in Early Mining and Extractive Metallurgy*. British Museum Occasional Papers 20. London: The British Museum, pp. 165–173.

Craddock, P.T., 1986. Appendix I. Report on the composition of bronzes excavated from a Middle Cypriot site at Episkopi Phaneormoneoi and some comparative Cypriot Bronze Age metalwork. In Swiny, S. (ed.) The Kent State University Expedition to Episkopi Phaneromenoi. Paul Åströms Förlag, Nicosia, pp. 153-158.

Craddock, P.T., 2000. From hearth to furnace: evidences for the earliest metal smelting technologies in the Eastern Mediterranean. *Paléorient* 26, 151–165.

Crewe, L., 1998. Spindle Whorls: A study of form, function and decoration in prehistoric Bronze Age Cyprus. SIMA 149. Paul Åströms Förlag, Lonsered,

Crewe, L., 2007. *Early Enkomi: regionalism, trade and society at the beginning of the Late Bronze Age on Cyprus*, BAR International Series 1706. Archaeopress, Oxford.

Crewe, L., 2010. Rethinking Kalopsidha: from specialisation to state marginalisation. In Maguire, L.C. and Bolger, D. (Eds.) *The Development of Pre-State Communities in the Ancient Near East. Studies in Honour of Edgar Peltenburg*. Oxbow Books, Oxford, pp. 63-71.

Crewe, L., 2017. Interpreting Settlement Function and Scale during MC III–LC IA Using Old Excavations and New: Western Cyprus and Kisonerga (Kissonerga) Skalia in Context. In Pilides, D. and Mina, M. (Eds.) *Κυπριακά – Forschungen zum Antiken Zypern Studies on Ancient Cyprus Vol. 2,* Holzhausen Der Verlag, Wien, pp. 140-152.

Çukur, A. and Kunç, Ş., 1989. Analyses of Tepecik and Tülintepe Metal Artifacts. *Anatolian Studies* 39, 113-120.

Cullen, T. and Wheeler, E.C., 1986. The ceramics. In Todd, I. (Ed.) *The Bronze Age Cemetery in Kalavasos Village. Vasilikos Valley Project I*. SIMA 71(I), Åströms Förlag, Göteborg, pp. 128-158.

Cunningham, P., Heeb, J. and Paardekooper, R., 2008. *Experiencing Archaeology by Experiment*. Oxbow, Oxford.

Cushing, F. H., 1894. Primitive Copper Working: An Experimental Study. *American Anthropologist* 7(1), 93-117.

Day, P.M., Wilson, D.E. and Kiriatzi, E., 1998. Pots, Labels, and People: Burying Ethnicity in the Cemetery of Aghia Photia, Siteias. In Braningan, K. (Ed.), *Cemetery and Society in the Bronze Age Aegean*. Sheffield Studies in Aegean Archaeology I, Sheffield, pp. 133-149.

Delgado Raack, S. and Rish, R., 2008. Lithic perspectives on metallurgy: an example from Copper and Bronze Age South-East Iberia. In Longo, L. and Skakun, N. (Eds.) *"Prehistoric Technology" 40 years later: Functional Studies and the Russian Legacy. Proceedings of the International Congress, Verona (20th-23rd April 2005)*, B.A.R., IS 1783, Archeopress, Oxford (2008), pp. 235-252.

De Re Metallica, Georgius Agricola, Translated from the First Latin Edition of 1556. Online publication: https://www.gutenberg.org/files/38015/38015-h/38015-h.htm (visited on the 28th March 2019).

Dikaios, P., 1945. Archaeology in Cyprus, 1939-45. *JHS* 65, 104.

Dikaios, P., 1946. *Early Copper Age discoveries in Cyprus, 3rd millennium BC copper mining*. Illustrated London News (2 March 1946), 244-245.

Dikaios, P., 1960. A conspectus of architecture in ancient Cyprus. *Kypriakai Spoudai* 24, 3-30.

Dikaios, P., 1961. *Sotira*. University Museum, University of Pennsylvania, Philadelphia.

Dimopoulou, N., 2012.Metallurgy and metalworking in the harbour town of Knossos at Poros-Katsambas. In Kassianidou, V. and Papasavvas, G. (Eds.), Eastern Mediterranean Metallurgy and Metalwork in the Second Millenium BC. Proceedings of the International Conference in honour of James D. Muhly. Oxbow books, Oxford, pp. 135-141.

Dobres, M. A., 1999. Technology's Links and Chaînes: The Processual Unfolding of Technique and Technician. In: Dobres, M.-A. and Hoffman, C. R. (eds.), *The social dynamics of technology: Practice, politics, and world views*. Smithsonian Institute Press, Washington, 124-146.

Dolfini, A. and Crelli, R.J., 2016. Metalwork wear analysis: The loss of innocence. *Journal of Archaeological Science* 66, 78-87.

Doonan, R. C. P., 1994. Sweat, fire and brimstone: pre-treatments of copper ore and the effects on smelting techniques. *The Journal of the Historical Metallurgy Society* 28:2, 84–97.

Doonan, R. C. P. and Dungworth, D., 2013. Experimental archaeometallurgy in perspective. In Doonan, R. C. P. and Dungworth, D. (eds), *Accidental and Experimental Archaeometallurgy*. Historical Metallurgy Society Occasional Publication No 7, London, 1-10.

Dothan, T. and Ben-Tor, A., 1983. *Excavations at Athienou, Cyprus 1971-1972*, QEDEM 16. Hebrew University of Jerusalem, Jerusalem.

du Plat Taylor, J., 1952. A Late Bronze Age settlement at Apliki, Cyprus. *AntJ* 32, 133–167.

During, B., Klinkenberg, V., Charalambos, P., Kassianidou, V., Souter, E., Croft, P. and Charalambous, A. (2018). Metal artefacts in Chalcolithic Cyprus: new data from Western Cyprus. *Mediterranean Archaeology and Archaeometry* 18/1, 11-25.

Eliades, N.,-G.H., Aravanopoulos, F.P.A. and Christou, A.K., 2018. Mediterranean Islands Hosting Marginal and Peripheral Forest Tree Populations: The Case of Pinus brutia Ten. In Cyprus. Forests 2018, 9, 514-539.

Falconer, S.E. and Fall, P.L., 2013. Household and community behaviour at Bronze Age Politiko-Troullia, Cyprus. *Journal of Field Archaeology* 38/2, 101-119.

Falconer, S.E., Fall, P.L., Hunt J. and Metzter, M.C., 2010. *Agrarian settlement at Politiko Troullia, 2008*. *RDAC* 2010, 183-198.

Fall, P.L., Falconer, S.E., Horowitz, M., Hunt, J., Metzger, M.C. and Ryter, D., 2008. Bronze Age settlement and landscape of Politiko *Troullia*, 2005-2007. *RDAC* 2008, 38-41.

Fasnacht, W., and Künzler Wagner, N., 2001. Appendix 1: stone casting moulds from Marki-*Alonia*, in: Frankel, D. and Webb, J.M., Excavations at Marki-*Alonia*, 2000. *RDAC* 2001, 38–41.

Fasnacht, W., 2009. 7000 Years of Trial and Error in Copper Metallurgy – in One Experimental Life. In Kienlin, T.L. and Roberts, B.W. (eds), *Metals and Societes. Studies in honour of Barbara S. Ottaway*. Verlag Dr. Rudolf Habelt GMBH, Bonn, 395-399.

Fasnacht, W., and Senn, M. 2001. Experimental copper smelting at Agia Varvara-Almyras. A contribution to the controversy of ancient iron production in Cyprus. *RDAC* 2001, 129-133.

Ferretti, M., 2014. The investigation of ancient metal artefacts by portable X-ray fluorescence devices. *Journal of Analytical Atomic Spectroscopy* 29, pp. 1753-1766.

Forrest, C., 2008. The Nature of Scientific Experimentation in Archaeology: Experimental Archaeology from the Nineteenth to the mid Twentieth Century. In Cunningham, P., Heeb, J. and Paardekooper, R. (eds), Experiencing Archaeology by Experiment. Oxbow Books, Oxford, pp.

Frankel, D., 2000. *Migration and ethnicity in prehistoric Cyprus: technology as habitus*. *EJA* 3, 167-187.

Frankel, D., 2005. *Becoming Bronze Age. Acculturation and enculturation in third millennium BC Cyprus*. In Clarke, J. (Ed.), *Archaeological Perspectives on the Transmission and Transformation of culture in Eastern Mediterranean*. Levant Supplementary Series 2, 18-24.

Frankel, D. and Bolger, D.L., 1997. On Cypriot Figurines and the Origins of Patriarchy, *Current Anthropology* 38, 1, 84-86.

Frankel, D. and Webb, J.M., 1996. *Marki Alonia. An Early and Middle Bronze Age town in Cyprus. Excavations 1990-1994*. SIMA 123:1. Paul Åströms Förlag, Jonsered,

Frankel, D. and Webb, J.M., 2001. Excavations at Marki-Alonia, 2000. *RDAC* 2001, 15–44.

Frankel, D. and Webb, J.M., 2006. *Marki Alonia. An Early and Middle Bronze Age settlement in Cyprus. Excavations 1995-2000*. SIMA 123:2. Paul Åströms Förlag, Sävedalen.

Gale, N.H., 1989. Archaeometallurgical studies of Late Bronze Age ox-hide copper ingots from the Mediterranean Region, in: Hauptmann, A., Pernicka, E. and Wagner, G.A. (Eds.), *Old World Archaeometallurgy*. Selbstverlag des Deutschen Bergbau-Museums, Bochum, pp. 247–268.

Gale, N.H., 1991. Metals and metallurgy in the Chalcolithic period. *BASOR* 282, 37–61.

Gale, N.H., 1999. Lead isotope characterization of the ore deposits of Cyprus and Sardinia and its application to the discovery of the sources of Copper for Late Bronze Age oxhide ingots, in: Young, S.M.M., Pollard, A.M., Budd, P. and Ixer, R.A. (Eds.), *Metals in Antiquity*, BAR International Series 792. Archaeopress, Oxford, pp. 110–121.

Gale, N.H., 2009. A response to the paper of A. M. Pollard: What a long, strange trip it's been: lead isotopes and archaeology. In Shortland, A.J., Freestone, I.C. and Rehren, T. (Eds.), *From Mine to Microscope: Advances in the study of Ancient Technology*, Oxbow, Oxford, pp. 191-196.

Gale, N.H., 2011. Copper oxhide ingots and lead isotope provenancing, in: Betancourt, P.P. and Ferrence, S.C. (Eds.), *Metallurgy: Understanding How, Learning whY. Studies in Honor of James D. Muhly*, Prehistory Monographs 29. INSTAP Academic Press, Philadelphia & Pennsylvania, pp. 213–220.

Gale, N.H. and Stos-Gale, Z.A., 1989. Some aspects of Cypriote metallurgy in the Middle and Late Bronze Age. In Laffineur, R. (Ed.), Transition: Le Monde Egeen du Bronze Moyen et Bronze Recent. Aegaeum 3. Universite de Liege, Liege, Belgium, 251-256.

Gale, N.H., Stos-Gale, Z.A. and Fasnacht, W., 1996. Appendix 2. Copper and copper working at Alambra, in: Coleman, J.E., Barlow, J.A., Mogelonsky, M.K. and Schaar, K.W. (Eds.), *Alambra, A Middle Bronze Age Settlement in Cyprus: Archaeological Investigations by Cornell University 1974-1985*, SIMA 118. Paul Åströms Förlag, Jonsered, pp. 359–426.

Gass, I.G., MacLeod, C.J., Murton, B.J., Panayiotou, A., Simonian, K.O. and Xenophontos, C., 1994. *The Geology of the Southern Troodos Transform Fault Zone*, Geological Survey Department Cyprus Memoir No. 9. Geological Survey Department, Nicosia.

Georgakopoulou, M., 2007. Metallurgical Activities within Early Cycladic Settlements: the Case of Daskaleio-Kavos. In Day, P.M. and Doonan, C.P. Doonan (Eds.), *Metallurgy in the Early Bronze Age Aegean*. Oxbow, Oxford, pp. 123-134.

Georgakopoulou, M., 2013. Metal Artefacts and Metallurgy. In Renfrew, C., Philanioutou, O., Brodie, N., Gavalas, G. and Boyd, M. J. (Eds.) The sanctuary on Keros and the origins of Aegean ritual practice: the excavations of 2006–2008 Volume I, Oxbow, Oxford, pp. 667-692.

Georgakopoulou, M., Bassiakos, Y. and Philantoniou, O., 2011. Seriphos surfaces: a study of copper slag heaps and copper sources in the context of Early Bronze Age Aegean metal production. *Archaeometry* 53,1, 123-145.

Georgakopoulou, M. and Rehren, T., 2013. Report on the analyses of metallurgical samples from Ambelikou Aletri, in: Webb, J.M. and Frankel, D. (Eds.), *Ambelikou Aletri. Metallurgy and Pottery Production in the Middle Bronze Age Cyprus*, SIMA 138. Åströms Förlag, Uppsala, pp. 197–199.

Georgiou, G., 2017.The Political Division of a Culturally Unified Island: The Case of Early and Middle Bronze Age in the Northern Part of Cyprus. In Pilides, D. and Mina, M. (Eds.) *Κυπριακά – Forschungen zum Antiken Zypern Studies on Ancient Cyprus Vol. 2*, Holzhausen Der Verlag, Wien, pp. 114-126.

Ghaznavi. H.A., 1976. M.Sc. thesis, University

Giardino, C., 2000. Prehistoric copper activity at Pyrgos. *RDAC* 2000, 19–32.

Giardino, C., Gigante, G.E. and Ridolfi, S., 2002. Archaeometallurgical investigations on the Early-Middle Bronze Age finds from the area of Pyrgos (Limassol). *RDAC* 2002, 33-48.

Giardino, C., Gigante, G.E. and Ridolfi, S., 2003. Appendix 8.I. Archaeometallurgical studies. In Swiny, S., Rapp, G. and Hersher, E. (eds), Sotira Kaminoudhia: An Early bronze Age Site in Cyprus. Cyprus American Archaeological Research Insititute Monograph 4. American Schools of Oriental Research, Boston, pp. 385-396.

Giardino, C. and Rovira, S., 2007. Pyrgos-Mavroraki (Cyprus): copper smelting slag of the beginning of the Second Millennium BC. In *Proceedings of the 2nd International Conference of Archaeometallurgy in Europe 2007*, file 153 (digital pubblication PDF), pp.1-8.

Girbal, B., 2013. Experimenting with the bowl furnace. In Dungworth, D. and Doonan, R.C.P. (eds*), Accidental and Experimental Archaeometallurgy*. Historical Metallurgy Society Occasional Publication No 7, London, 83-92.

Given, M. and Knapp, A.B., 2003. *The Sydney Cyprus Survey Project: Social Approaches to Regional Archaeological Survey*, Monumenta Archaeologica 21. UCLA Cotsen Institute of Archaeology, Los Angeles, California.

Goren, Y. Bunimovitz, S., Finkelstein, I. and Na’Aman, N., 2003. The location of Alashiya: new evidence from petrographic investigation of Alashiyan Tablets from El-Amarna and Ugarit. *AJA* 107:2, 233–255.

Gowland, W., 1899. The Early Metallurgy of Copper, Tin, and Iron in Europe, as illustrated by Ancient Remains, and the Primitive Processes surviving in Japan. *Archaeologia, or, Miscellaneous tracts relating to antiquity* 56, Society of Antiquaries of London, pp. 267-322.
Gowland, W., 1912. The Metals in Antiquity. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland* 42, 235-287.

Greenfield, H.J., 2010. The Secondary Products Revolution: the past, the present and the future. *World Archaeology* 42, 29-54.

Hadjisavvas, S., 1992. *Olive oil processing in Cyprus. From the Bronze Age to the Byzantine period*, SIMA 99. Paul Åströms Förlag, Nicosia.

Hanning, E., Gauß, R. and Goldenberg, G., 2010. Metal for Zambujal: experimentally reconstructing a 5000-year-old technology. *Trabajos de Prehistoria* 67(2), 287-304.

Happ, J., Ambert, P., Bourhis, J.R. and Briard, J., 1994. Premiers essais de métallurgie expérimentale à l'archéodrome de Beaune à partir des minerais chalcolithiques de Cabrières (Hérault). *Bulletin de la Société préhistorique française* 91(6), 429-434.

Hauptmann, A., 1989. The Earliest Periods of Copper Metallurgy in Feinan, Jordan, in: Hauptmann, A., Pernicka, E. and Wagner, G.A. (Eds.), *Old World Archaeometallurgy*, Der Anschnitt 7. Selbstverlag des Deutschen Bergbau-Museums, Bochum, pp. 119–135.

Hauptmann, A., 1997. Feinan. In Meyers, E.E. (Ed.), *The Oxford Encyclopedia of Archaeology in the Near East*, Oxford University Press, New York, pp. 310-311.

Hauptmann, A., 2007. *The Archaeometallurgy of Copper: Evidence from Faynan, Jordan*. Springer-Verlag, Berlin & Heidelberg.

Hauptmann, A., 2011. Slags from the Late Bronze Age metal workshops at Kition and Enkomi, Cyprus, in: Betancourt, P.P. and Ferrence, S.C. (Eds.), *Metallurgy:*

Understanding How, Learning whY. Studies in Honor of James D. Muhly. INSTAP Academic Press, Philadelphia, Pennsylvania, 189–202.

Hauptmann, A., 2014. The investigation of archaeometallurgical slag, in: Roberts, B.W. and Thornton, C.P. (Eds.), *Archaeometallurgy in Global Perspective: Methods and Syntheses*. Springer, New York, Heidelberg, Dordrecht and London, pp. 91–105.

Hauptmann, A., 2020. *Archaeometallurgy – Material Science Aspects. Springer*, Cham.

Hauptmann, A., Maddin, R. and Prange, M., 2002. On the Structure and Composition of Copper and Tin Ingots Excavated from theShipwreck of Uluburun. *BASOR* 328, pp. 1-30.

Heeb, J., 2014. *Copper Shaft-Hole Axes and Early Metallurgy in South-Eastern Europe: An Integrated Approach*. Archaeopress. Oxford.

Heeb, J. and Ottaway, B. S., 2014. Experimental Archaeometallurgy. In Roberts, B.W. and Thornton, C.P. (Eds.) Archaeometallurgy in Global Perspective. Springer, New York, pp. 161-192.

Hein, W., 2000. "Es recht zu machen jedermann..." Archäo-Technik zwischen Authentizität und Machbarkeit. In Kelm, R. (ed), *Vom Pfostenloch zum Steinzeithaus. Albersdorfer Forschungen zur Archäologie und Umweltgeschichte*. Albersdorf, 177-185.

Hellbing, L., 1979. *Alasia Problems*, SIMA 57. Paul Åströms Förlag, Göteborg.

Herscher, E., 1997. Representational relief on Early and Middle Cypriot pottery. In Karageorghis, V., Laffineur, R. and Vandenabeele, F. (Eds.) Four Thousand Years of Images on Cypriote Pottery. Proceedings of the Third International Conference of Cypriote Studies, A.G. Leventis Foundation and University of Cyprus, Nicosia; Vrije Univesiteit Brussel, Brulles; Université de Liege, Liege, pp. 26-36.

Horejs, B., Mehofer, M. and Pernicka, E., 2010. Metallhandwerker im frühen 3. Jt. v. Chr. – Neue Ergebnisse vom Çukuriçi Höyük. *Instanbuler Mitteilungen* 60, pp. 7-37.

Humphris, J., Martinón-Torres, M., Rerhen, T. and Reid, A., 2009. Variability in single smelting episodes – a pilot study using iron slag from Uganda. *JAS* 36, 359-369.

Hundt, H.J., 1988. Einige Bemerkungen zu den Älterbronzezeitlichen Tondüsen. *Slovenska Archeologia* 36(1), pp. 99-104.

Karageorghis, V., 1958. Chronique des fouilles et découvertes archéologiques à Chypre en 1958. *Bulletin de correspondence hellénique* 83(1), pp. 336-361.

Karageorghis, V., 1964. Chronique des fouilles et découvertes archéologiques à Chypre en 1963. Bulletin de Correspondence Hellénique 88(1), pp. 289-379.

Karageorghis, V., 1965. Chronique des fouilles et découvertes archéologiques à Chypre en 1964. Bulletin de Correspondence Hellénique 89(1), pp. 231-300.

Karageorghis, V., 1971. A deposit of Archaic terracotta figures from Patriki, Cyprus, *RDAC* 1971, pp. 27-36.

Karageorghis, V., 1983. Chronique des fouilles et découvertes archéologiques à Chypre en 1982. Bulletin de Correspondence Hellénique 107(2), pp. 905-953.

Karageorghis, V., 2002. *Early Cyprus: Crossroads of the Mediterranean*. Getty Publications, Los Angeles, California.

Karageorghis, V., Picard, O. and Tytgat, Chr., 1992. La Nécropole d'Amathonte, Tombes113–367, VI: Bijoux, armes, verre, astragales et coquillages, squelettes. Études Chypriotes 16. Department of Antiquities of Cyprus/École Française d'Athènes, Nicosia.

Karageorghis, V. and Kassianidou, V., 1999. Metalworking and recycling in Late Bronze Age Cyprus – the evidence from Kition. *OJA* 18, 171–188.

Karydas, A.G., 2007. Application of a portable XRF spectrometer for the non-invasive analysis of museum metal artefacts. *Annali di Chimica* 97, 419–432.

Kassianidou, V., 2003. Archaeometallurgy: data, analyses and discussion, in: Given, M. and Knapp, A.D., *The Sydney Cyprus Survey Projects: Social Approaches to Regional Archaeological Survey*. Monumenta Archaeologica 21. UCLA Cotsen Institute of Archaeology, Los Angeles, California, pp. 214–227.

Kassianidou, V., 2008. The formative years of the Cypriot copper industry, in: Tzachili, I. (Ed.), *Aegean Metallurgy in the Bronze Age*. Ta Pragmata Publications, Athens, 249–267.

Kassianidou, V., 2011. Blowing the wind of change: the introduction of bellows in Late Bronze Age Cyprus, in: Betancourt, P.P. and Ferrence, S.C. (Eds.), *Metallurgy: Understanding How, Learning Why. Studies in Honor of James D. Muhly*, Prehistory Monographs 29. INSTAP Academic Press, Philadelphia, Pennsylvania, 41–47.

Kassianidou, V., 2012. Metallurgy and metalwork in Enkomi: the early phases, in:

Kassianidou, V. and Papasavvas, G. (Eds.), *Eastern Mediterranean Metallurgy and Metalwork in the Second Millennium BC*. Oxbow Books, Oxford & Oakville, pp. 94–106.

Kassianidou, V., 2013a. Metals, in: Peltenburg, E. (Ed.), *ARCANE II: Cyprus*, ARCANE - Associated Regional Chronologies for the Ancient Near East and the Eastern Mediterranean Vol. 2. Brepols, Turnhout, 231–249.

Kassianidou, V., 2013b. Mining landscapes of prehistoric Cyprus. *Metalla* 20, 36–45.

Kassianidou, V., 2013c. The production and trade of Cypriot copper in the Late Bronze Age. An analysis of the evidence. *Pasiphae* VII, 133–146.

Kassianidou, V. and Knapp, A.B., 2008. Archaeometallurgy in the Mediterranean: the social context of mining, technology, and trade, in: Blake, E. and Knapp, A.B. (Eds.), *The Archaeology of Mediterranean Prehistory*. Blackwell Publishing, Oxford, pp. 215–251. 439

Kassianidou, V. and Charalambous, A., 2019. Chapter 16. Chemical analyses of copper objects and faience beads using portable X-Ray Fluorescence. In Peltenburg, E., Bolger, D.

and Crewe, L. (Eds.) Figurine Makers of Prehistoric Cyprus. Settlement and Cemeteries at Souskiou. Oxbow, Oxford, pp. 279-352.

Keswani, P.S., 1994. The social context of animal husbandry in early agricultural society: ethnographic insights and an archaeological example from Cyprus. *JAA* 13, 255-277.

Keswani, P.S. 2004. *Mortuary Ritual and Society in Bronze Age Cyprus*. Monographs in Mediterranean Archaeology 9. Equinox, London.

Keswani, P.S., 2005. Death, prestige, and copper in Bronze Age Cyprus. *AJA* 109, 341-401.

Knapp, A.B. 1986. Production, exchange, and socio-political complexity on Bronze Age Cyprus. *OJA* 5:1, 35-60.

Knapp, A.B. 1990. Production, location and integration in Bronze Age Cyprus. *Current Anthropology* 31, 147-176.

Knapp, A.B. 1993. Social complexity: incipience, emergence and development on prehistoric Cyprus. *BASOR* 292, 85-106.

Knapp, A.B. 1996. The Bronze Age economy of Cyprus: ritual, ideology and the sacred landscape, in: Karageorghis, V. and Michaelidis, D. (Eds). *The Development of the Cypriot Economy from the Prehistoric Period to the Present Day*. Nicosia: Leventis Foundation, pp. 71-106.

Knapp, A.B. 2001. Archaeology and ethnicity: a dangerous liaison. *Archaeologia Cypria* 4, 29-46.

Knapp, A.B., 2003. The archaeology of community on Bronze Age Cyprus: Politiko "Phorades" in context. *AJA* 107, 559–580.

Knapp, A.B., 2008. *Prehistoric and Protohistoric Cyprus: Identity, Insularity, and Connectivity*, Oxford: Oxford University Press.

Knapp, A.B., 2011. Cyprus, copper, and Alashiya, in: Betancourt, P.P. and Ferrence, S.C. (Eds.), *Metallurgy: Understanding How, Learning Why. Studies in Honor of James D. Muhly, Prehistory Monographs*. INSTAP Academic Press, Philadelphia, Pennsylvania, pp. 249–254.

Knapp, A.B., 2013a. *The Archaeology of Cyprus: From Earliest Prehistory through the Bronze Age*. Cambridge University Press, Cambridge.

Knapp, A.B., 2013b. Revolution Within Evolution: The Emergence of a 'Secondary State' on Protohistoric Bronze Age Cyprus. *Levant* 45(1), pp. 19-44.

Knapp, A.B. and Kassianidou, V., 2008. The archaeology of Late Bronze Age copper production: Politiko Phorades on Cyprus, in: Ünsal, Y. (Ed.), *Anatolian Metal IV*, Der Anschnitt Beiheft 21. Deutsches Bergbau Museum, Bochum, 135–147.

Knox, D., 2013. Figurines and figurative vessels at Early Cypriot Bellapais Vounous. In Knapp, A.B. and Webb, J.M. (Eds.), *Stewart JBR. An Archaeological Legacy*, SIMA 139, Paul Åströms Förlag, Uppsala, pp. 47-57.

Koucky, F.L. and Steinberg, A., 1982. The ancient slags of Cyprus, in: Muhly, J.D., Maddin, R. and Karageorghis, V. (Eds.), *Early Metallurgy in Cyprus, 4000-500 B.C.* Pierides Foundation, Nicosia, pp. 117–141.

Koucky, F.L. and Steinberg, A., 1989. Metallurgical studies: ancient mining and mineral dressing on Cyprus, in: Stager, L.E. and Walker, A.M. (Eds.), *American Expedition to Idalion, Cyprus 1973-1980*, Oriental Institute Communications 24. The University of Chicago, Chicago, Illinois, pp. 275–327.

Kronz, A. and Keesmann, I., 2007. Fayalitische Schmelzsysteme – Ein Beitrag zur vorneuzeitlichen Eisen- und Buntmetalltechnologie im Dietzhölzetal. In: Das Dietzhölzetal-Projekt. Archäometallurgische Untersuchungen zur Geschichte und Struktur der mittelalterlichen Eisengewinnung im Lahn-Dill-Gebiet (Hessen). Marie Leidorf Rahden,Westf.

Kuijpers, M.H.G., 2018. A Sensory Update to the Chaîne Opératoire in Order to Study Skill: Perceptive Categories for Copper-Compositions in Archaeometallurgy. *Journal of Archaeological Method and Theory* 25, pp. 863-891.

Lammers-Keijsers, Y. M. J., 2005. Scientific experiments: a possibility? Presenting a general cyclical script for experiments in archaeology. EuroREA 2/2005, 18-24.

Lechtman, H. and Klein, S., 1999. The Production of Copper–Arsenic Alloys (Arsenic Bronze) by Cosmelting: Modern Experiment, Ancient Practice. *Journal of Archaeological Science* 26, 497-526.

Lehner, J.W. and Yener, K.A., 2014. Chapter 20 Organization and Specialization of Early Mining and Metal Technologies in Anatolia. In Roberts, B.W. and Thornton, C.P. (Eds.) Archaeometallurgy in Global Perspective. Springer, New York, pp. 529-557.

Lentini, A., 2009. Tra Archeologia e Archeometria, Archeologia e Paesaggio Naturale: Indagini archeobotaniche e fisico-chimiche. In Belgiorno, M.R. (Ed.), Cipro all'inizio dell'Età del Bronzo. *Realtà sconosciute della comunità industriale di Pyrgos/Mavroraki*. Gangemi, Roma, 129-187.

Lentini, A., 2015. The Biodiversity of Cyprus Island, *Journal of Environmental Science and Engineering* B 4, 125-131.

Lentini, A. and Belgiorno, M.R., 2011. Archaeobotanical investigations at Pyrgos-Mavroraki (Cyprus), preliminary results. In Δημητρίου, A. (Ed.), Πρακτικά του Δ΄ Διεθνούς Κυπρολογικού Συνεδρίου, Λευκωσία 29 Απριλίου-3 Μαΐου 2008 (2 τόμοι, A1-A2), Society of Cypriot Studies, Lefkosia, 573-588.

Leroi-Gourhan, A., 1964. *Le Geste et la Parole. I, Technique et langage*. Albin Michel, Paris.

Levy, T.E. and Shalev, S, 1989. Prehistoric Metalworking in the Southern Levant: Archaeometallurgical and Social Perspectives. *World Archaeology* 20, 350–372.

Liu, S., Rehren, T., Chen, J., Xu, C., Venunan, P., Larreina, D. and Martinón-Torres, M., 2015. Bullion production in imperial China and its significance for sulphide ore smelting world-wide. *JAS* 55, 151–165.

Lucas, L., 2012. Economy and Interaction: Exploring Archaeobotanical Contributions in Prehistoric Cyprus, PhD thesis. University College London.

Lucas, L., 2014. *Crops, Culture and Contact in Prehistoric Cyprus*. Archaeopress, Oxford.

MacKenzie, I.R. and Adams, A.E., 1994. *A Colour Atlas of Rocks and Minerals in Thin Section*. Manson Publishing, London.

Maldonado, B. and Rehren, T. 2009. Early copper smelting at Itziparátzico, Mexico. *JAS* 36, 1–9.

Manning, S.W., 1993. Prestige, distinction and competition: the anatomy of socio-economic complexity in 4th-2nd millennium B.C.E. Cyprus. *BASOR* 292, 35-58.

McGuire, J.D., 1892. Materials, apparatus and processes of the aboriginal lapidary. American Anthropologist 5, pp. 165-176.

Mellink, M.J., 1991. Anatolian Contacts with Chalcolithic Cyprus. *BASOR* 282/283, 167-175.

Merkel, J.F., 1977. *Neutron activation analysis of copper to examine Timna as an ore source during the Chalcolithic and Early Bronze Ages in Israel*. M.Sc. University of Minnesota.

Merkel, J.F., 1985. Ore beneficiation during the Late Bronze/Early Iron Age at Timna, Israel. *MASCA Journal* 3(5), 164-168.

Merkel, J.F., 1990. Experimental reconstruction of Bronze Age copper smelting based on archaeological evidence from Timna, in: Rothenberg, B. (Ed.), *The Ancient Metallurgy of Copper, Researches in the Arabah 1959-1984.* Institute for Archaeo-Metallurgical Studies, London, pp. 78-122.

Merkel, J.F. and McGovern, P.E., 1989. Experience with Refractories in reconstruction copper smelting experiments based upon archaeo-metallurgical evidence from Timna. In McGovern, P.E. and Notis, M.R. (eds), Cross-Craft and Cross-Cultural Interactions in ceramics. Ceramics and Civilization IV, American Ceramic Society,Westerville, 217-234.

Merkel, J.F. and Rothenberg, B., 1999. The Earliest Steps to Copper Metallurgy in the western Araba. In Hauptmann, A., Pernicka, E., Rehren, T. and Yalçin, Ü. (Eds.) *The Beginnings of Metallurgy*. Der Anschnitt, Beiheft 9, Deutsches Bergbau-Museum Bochum, pp. 149-165.

Merrillees, R.S., 1984. Ambelikou-Aletri: a preliminary report. *RDAC* 1984, 1–13.

Milton, C., Dwornik, E. Finkelman, R.B. and Toulmin III, P., 1976. Slag from an Ancient Copper Smelter at Timna, Israel. *J Hist Metall Soc 10*, pp. 24–33.

Mina, M., 2014. Forging identities: metallurgical technology and embodied experiences in the Philia period. In J. M. Webb (Ed.) *Structure, Measurement and Meaning: Insights into the Prehistory of Cyprus: Studies in Honour of David Frankel.* SIMA 143, Paul Åströms Förlag, Uppsala, pp. 229-243.

Molloy, B., 2004. Experimental combat with Bronze Age weapons. Archaeology Ireland 18(1), 32-34.

Morton, H and Wingrove J., 1969. Constitution of Bloomery Slags. Part I: Roman. *J Iron & Steel Inst 207*, pp. 1556–1564

Morris, D., 1985. *The Art of Ancient Cyprus*. Phaidon Press, Oxford.

Morton, H, and Wingrove, J., 1972. Constitution of Bloomery Slags. Part II: Medieval. *J Iron & Steel Inst 210*, pp. 478–488.

Muhly, J.D., 1991. Copper in Cyprus: the earliest phase. In Mohen, J.P. (Ed.) *Découverte du Métal*. Picard, Paris, pp. 357-374.

Murrillo-Barroso, M., Martinó-Torres, M., Camalich Massieu, M.D., Martín Socas, D. and Molina González, F., 2017. Early metallurgy in SE Iberia. The workshop of Las Pilas (Mojácar, Almería, Spain). Archaeological and Anthropological Science 9(7), pp 1539–1569.

O'Flaherty, R., 2007. A weapon of choice: experiments with a replica Irish Early Bronze Age halberd. *Antiquity* 81, 423-434.

Ottaway, B.S., 2001. Innovation, production and specialization in early prehistoric copper metallurgy. *European Journal of Archaeology* 4(1), pp. 87-112.

Outram, A.K., 2008. Introduction to experimental archaeology, *World Archaeology* 40(1), 1-6.

Overback, J.C. and Swiny, S., 1972. *Two Cypriot Bronze Age Sites at Kafkallia (Dhali)*. SIMA 33. Paul Åströms Förlag, Göteborg.

Palmieri, A. M. 1980. Studio Sedimentologico Del Saggio Profondo Di Coppa Nevigata (Gargano), *Quaternaria* XXII (2), 301-313.

Paardekooper, R., 2019. Experimental Archaeology: Who Does It, What Is the Use?. *EXARC Journal* Issue 2019/1, 1/21-21/21.

Panayiotou, A., 1980. Cu-Ni-Co-Fe sulphide mineralization, Limassol Forest, Cyprus. In Panayiotou, A. (Ed.), Ophiolites. Proceedings International Ophiolite Symposium Cyprus 1979, pp.102-116.

Pantazis, T.M., 1967. *The Geology and Mineral Resources of the Pharmakas-Kalavasos Area*, Geological Survey Department Cyprus Memoir No. 8. The Republic of Cyprus, Nicosia.

Papanicolau, K., 2012. Appendix VII. Erimi-*Pitharka*: a Late Bronze Age settlement in the Kourion area. In Karageorghis, V. and Violaris, Y. (Eds.) *Tombs of the Late Bronze Age in the Limassol area, Cyprus (17th-13th Centuries BC)*, Municipality of Limassol, Nicosia, pp. 310-318.

Pecorella, P.E., 1977. *Le Tombe dell'Etá del Bronzo Tardo della Necropoli a Mare di Ayia Irini "Paleokastro"*. Biblioteca di Antichitá Cipriote 4. Consiglio Nazionale delle Ricerche, Istituto per gli Studi Micenei ed Egeo-Anatolici, Roma.

Peltenburg, E. (Ed.),1982. Early Copperwork in Cyprus and the Exploitation of Pircolite: Evidence from Lemba Archaeological Project. In Muhly, J.D., Maddin, R. and Karageorghis, V. (Eds.), *Early Metallurgy in Cyprus, 4000-500 B.C*. Pierides Foundation, Nicosia, pp.41-61.

Peltenburg, E., 1993. Settlement discontinuity and resistance to complexity in Cyprus, ca. 4500-2500 B.C. *BASOR* 292, 9-23.

Peltenburg, E., 1998. *Lemba Archaeological Project, Cyprus. Vol. II.1B (Part 1)*. Occasional Paper 19, University of Edinburgh, Edinburgh.

Peltenburg, E., 2011. Cypriot Chalcolithic metalwork, in: Betancourt, P.P. and Ferrence, S.C. (Eds.), *Metallurgy: Understanding How, Learning whY. Studies in Honor of James D. Muhly*, Prehistory Monographs 29. INSTAP Academic Press, Philadelphia, Pennsylvania, pp. 3–10.

Peltenburg, E., Bolger, D.L., Croft, P., Goring, E., Irving, B., Lunt, D.A., Manning, S.W., Murray, M.A., McCartney, C., Ridout-Sharpe, J.S., Thomas, G., Watt, M.E. and Elliott-Xenophontos, C., 1998. Lemba Archaeological Project, Volume II.1A: Excavations at Kissonerga-*Mosphilia*, 1979-1992, SIMA 70:2. Paul Åströms Förlag, Jonsered.

Peltenburg, E., Bolger, D.L., Croft, P., Goring, E., Irving, B., Lunt, D.A., Manning, S.W., Murray, M.A., McCartney, C., Ridout-Sharpe, J.S., Thomas, G., Watt, M.E. and Elliott-

Pfaffenberger, B., 1992. Social anthropology of technology. *Annual Review of Anthropology* 21, 491-516.

Philip, G, 1991. Cypriot bronzework in the Levantine world: conservatism, innovation and social change. *JMA* 4, 59-107.

Philip, G., Clogg, P.W., Dungworth, D. and Stos S, 2003. Copper metallurgy in the Jordan Valley from the third to the first millennia BC: chemical metallographic and lead isotope analysis of artefacts from Pella. *Levant* 35, 71-100.

Pollard, M., 2009. What a long, strange trip it's been: lead isotopes and archaeology. In Shortland, I.C., and Rehren, T. (Eds.), *From Mine to Microscope: Advances in the study of Ancient Technology*, Oxbow, Oxford, pp. 181-189.

Portillo, H., Zuluaga, M.C., Ortega, L.A., Alonso-Olazabal, A., Murelaga, X. and Martinez-Salcedo, A., 2018. XRD, SEM/EDX and micro-Raman spectroscopy for mineralogical and chemical characterization of iron slags from the Roman archaeological site of Forua (Biscay, North Spain). *Microchemical Journal* 138, pp. 246-254.

Pryce, T.O., Bassiakos, Y., Catapotis, M. and Doonan, R.C., 2007. 'De Caerimoniae' technological choices in copper-smelting furnace design at early bronze age Chrysokamino, Crete. *Archaeometry* 49(3), 543-557.

Quezel, P., 1979. Les Ecosystemes Forestiers Crétois et Chypriotes. *Revue Forestière Française* XXXI (5), 440-450.

Radivojević, M., 2013. Archaeometallurgy of the Vinča culture: a case study of the site of Belovode in eastern Serbia. Historical Metallurgy 47(1), 13-32.

Radivojević, M., Rehren, T., Pernicka, E., Šljivar, D., Brauns, M. and Borić, M., 2010. On the origins of extractive metallurgy: new evidence from Europe. *JAS* 37, 2275-2787.

Rehder, J.E., 1994. Blowpipes versus Bellows in Ancient Metallurgy. *Journal of Field Archaeology* 21(3), 345-350.

Renfrew, C. 1972. *The Emergence of Civilisation*. Oxbow, Oxford.

Renfrew, C., Boyd, M. and Bronk Ramsey, C., 2012. The oldest maritime sanctuary? Dating the sanctuary at Keros and the Cycladic Early Bronze Age. Antiquity 86, Issue 331, pp. 144-160.

Renzi, M., Georgakopoulou, M., Peege, C., Fasnacht, W. and Rehren, T., 2018. Technology of Copper Smelting at Agia Varvara-Almyras. In Peege, C., Della Casa, P. and Fasnacht, W. (eds), Aghia Varvara-Almyras. An Iron Age copper smelting site in Cyprus. Archaeopress, Oxford, 269-294.

Richter, P.B., 1992. Experimentelle Archäologie: Ziele, Methoden und Aussage-möglichkeiten. *Experimentelle Archäologie, Bilanz 1991*. M. Fansa. Oldenburg, Isensee Verlag. Beiheft 6, 19-49.

Romeo Pitone, M., 2018. Experimental Archaeometallurgy of Early-Middle Bronze Age Cyprus: Pilot Experiments of Copper Smelting at Pyrgos-Mavroraki. EXARC Journal Issue 2018/3, 1/13 – 13/13.

Rostoker, W. and Sadowski, M., 1980. The carbon reduction of fully oxidized chalcopyrite (copper) ores. *Journal of the Historical Metallurgy Society* 14(1), 38–42.

Rostoker, W., Pigott, V.C. and Dvorak, J.R., 1986. Direct reduction to copper metal by oxide-sulfide mineral interaction. *Archaeomaterials* 3, 69–87.

Rothenberg, B., 1978. *Chalcolithic Copper Smelting*, Archaeo-Metallurgy IAMS Monograph Number One, London.

Rothenberg, B. (Ed.), 1990. *The Ancient Metallurgy of Copper*. Institute for Archaeo-Metallurgical Studies, London.

Rothenberg, B., 1996-97. Researches in the Southern Arabah 1959-1990. Summary of Thirty Years of Archaeo-Metallurgical Field Work in the Timna Valley, the Wadi Amram and the Southern Arabah (Israel). *Arx* 2-3, 5-42.

Rothenberg, B., Blanco-Freijeiro, A., 1981. Studies in Ancient Mining and Metallurgy in South-West Spain. *Metal in History I*. Inst Archaeo-Metall Studies, London.

Rovira, S., Montero Ruiz, I. and Renzi, M., 2009. Experimental Co-smelting to Copper-tin Alloys. In Kienlin, T.L. and Roberts, B.W. (eds), Metals and Societes. Studies in honour of Barbara S. Ottaway. Verlag Dr. Rudolf Habelt GMBH, Bonn, 407-414.

Runnels, C.N. and van Andel, T.H., 2009. Trade and the origins of agriculture in the eastern Mediterranean. *JMA* 1, 83-109.

Şahoğlu, V., 2005. The Anatolian Trade Network and the Izmir region during the Early Bronze Age. *OJA* 24, 339-361.

Scheel, B., 1989. *Egyptian metalworking and tools*. Shire, Aylesbury.

Shabel, C., 2000. Frankish Pyrgos and the Cistercians. *RDAC* 2000, 349-360.

Shalev and Northover 1987. Chapter 4 – Chalcolithic metal and metalworking from Shiqmim. In Levy, T. (Ed.), *Shiqmim I. Studies Concerning Chalcolithic Societies in the Northern Negev Desert, Israel (1982-1984)*. BAR International Series 356, Oxford, pp. 357-371.

Sherratt, A.G., 1981. Plough and pastoralism: aspects of the Secondary Products Revolution. In Hodder, I., Isaac, G. and Hammond, N. (Eds.), *Pattern of the Past: Studies in Honour of David Clarke*. Cambridge University Press, Cambridge, pp. 261-305.

Sherratt, A.G., 2007. Diverse origins: regional contributions to the genesis of farming. In College, S. and Connolly, J. (Eds.), *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*. Left Coast Press, Walnut Creek, pp. 1-20.

Shimada, I., 2005. Experimental Archaeology. In Maschner, H.D.G. and Chippindale, C. (eds), *Handbook of Archaeological methods*. Altamira Press, Lanham, 603-642.

Scott, D.A., 2014. Metallography and microstructure of metallic artefacts, in: Roberts, B.W. and Thornton, C.P. (Eds.), *Archaeometallurgy in Global Perspective: Methods and Syntheses*. Springer, New York, Heidelberg, Dordrecht & London, pp. 67-89.

Shugar, A.N. and Mass, J.L. (Eds.), 2012. *Handheld XRF for Art and Archaeology*. Leuven University Press, Leuven.

Socratous, M.A., Kassianidou, V. and Di Pasquale, G., 2015. Ancient slag heaps in Cyprus: the contribution of charcoal analysis to the study of the ancient copper industry. In Hauptmann, A. and Modarressi-Tehrani, D. (Eds.), Archaeometallurgy in Europe III. Proceedings of the 3rd International Conference Deutsches Bergbau-Museum Bochum, June 29 – July 1, 2011, Bochum, 377-384.

South, A., 2012. Tinker, tailor, farmer, miner: metals in the Late Bronze Age Economy at Kalavassos. In Kassianidou, V. and Papasavvas, G. (Eds.), *Eastern Mediterranean Metallurgy and Metalwork in the Second Millennium BC*. Oxbow Books, Oxford and Oakville, 26–34.

Spiegelman, M., 2006. Investigating the faunal record from Bronze Age Cyprus: diversification and intensification. In McCarthy, A. (Ed.), *Island Dialogues: Cyprus in the Mediterranean Network*. University of Edinburgh Archaeology, Occasional Paper 21, pp.119-129.

Steel, L., 2004. *Cyprus Before History. From the Earliest Settlers to the End of the Bronze Age*. Duckworth, London.

Steel, L., 2009. Exploring regional settlement of Cyprus in the Late Bronze Age: the rural hinterland, in: Hein, I. (Ed.), *The Formation of Cyprus in the 2nd Millennium B.C.: Studies in Regionalism during the Middle and Late Bronze Ages*. Denkschriften Der Gesamtakademie 52. Verlag der Österreichischen Akademie der Wissenschaften, Wien, pp. 135–145.

Steinberg, A. and Koucky, F.L., 1974. Preliminary metallurgical research in the ancient copper industry, in: Stager, L.E., Walker, A.M. and Wright, G.E. (Eds.), *American Expedition to Idalion, Cyprus. First Preliminary Report: Seasons of 1971 and 1972,* BASOR Supplementary Studies No. 18. American Schools of Oriental Research, Cambridge & Massachusetts, pp. 149–178.

Steinberg, A. and Koucky, F.L., 1982a. III. Metallurgical Studies. A. Ancient mining and mineral dressing on Cyprus. In Stager, L.E. and Walker, A.M. (Eds.), *The American Expedition to Idalion, Cyprus 1973-1980*. Oriental Institute Communications 24, The Oriental Institute, Chicago, pp. 275-304.

Steinberg, A. and Koucky, F.L., 1982b. The Ancient Slags of Cyprus. In Muhly. J.D., Maddin, R. and Karageorghis, V. (Eds.), Early Metallurgy in Cyprus, 4000-500 B.C..Pierides Foundation, Nicosia, pp. 117-137

Stewart, J.R., 1962. The Early Cypriote Bronze Age. In Dikaios, P. and Stewart, J.R. (Eds.) *Swedish Cyprus Expedition IV.IA*, Swedish Cyprus Expedition, Lund, pp. 205-401.

Stewart, J.R., 1988. Corpus of Cypriot Artefacts of the Early Bronze Age Part I. SIMA 3/1. Paul Åströms Förlag, Göteborg.

Stewart, J.R., 1992. *Corpus of Cypriote Artefacts of the Early Bronze Age*, Part 2. SIMA III:2. Paul Åströms Förlag, Jonsered.

Stollner, T., 2014. Humans approach to resources: Old World mining between technological innovations, social change and economical structures. In Hauptmann, A. and Modarressi-Tehrani, D. (Eds.) Archaeometallurgy in Europe III, Bochum, pp. 63-82.

Stos-Gale, Z.A., 2001. Minoan foreign relations and copper metallurgy in Protopalatial and Neopalatial Crete. In Shortlant, A. (Ed.), *The Social Context of Technological Change in Egypt and the Near East, 1650-1550 BC,* Oxbow, Oxford, pp. 195-210.

Stos-Gale, Z.A. and Gale, N.H., 2002. . In Bartelheim, M., Pernicka, E. and Krause, R. (Eds.), *The Beginnings of Metallurgy in the Old World*. Verlag Marie Leidorf GmbH, Radhen, pp. 277-302.

Stos-Gale, Z.A. and Gale, N.H., 2009. Metal provenancing using isotopes and the Oxford archaeological lead isotope database (OXALID). *Archaeological and Anthropological Sciences* 1, 195–213.

Stos-Gale, Z.A. and Gale, N.H., 2010. Bronze Age metal artefacts found on Cyprus - metal from Anatolia and the Western Mediterranean. *Trabajos de prehistoria* 67:2, 389–403.

Stos-Gale, Z.A., Maliotis, G., Gale, N.H. and Annetts, N., 1997. Lead isotope characteristics of the Cyprus copper ore deposits applied to provenance studies of copper oxhide ingots. *Archaeometry* 39, 83–123.

Stewart, J.R., 1962. The Early Cypriote Bronze Age. In Dikaios, P. and Stewart, J.R. (Eds.), *Swedish Cyprus Expedition IV.IA*, Swedish Cyprus Expedition, Lund, pp. 205-401.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W, Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van Der Plitch, J. and Spurk, Marco, 1998. INTCAL98 Radiocarbon Age Calibration, 24,000-0 cal BP. *Radiocarbon* 40/3, 1041-1083.

Swiny, S., 1980. Bronze Age gaming stones from Cyprus. *RDAC* 1980, 54-78.

Swiny, S., 1986. *The Kent State University Expedition to Episkopi* Phaneromeni. SIMA 74 (2). Paul Åströms Förlag, Göteborg.

Swiny, S., 1989. From round house to duplex: a reassessment of prehistoric Cypriot Bronze Age society. In Peltenburg, E.J. (Ed.), *Early Society in Cyprus*. Edinburgh University Press, Edinburgh, pp. 14-31.

Swiny, S., 2003. The Metal. In Swiny, S., Rapp, G. and Herscher, E. (Eds.) 2003. *Sotira Kaminoudhia. An Early Bronze Age Site in Cyprus*, Cyprus American Archaeological Research Institute Monograph Series Volume 4. American Schools of Oriental Research, Boston, pp. 369-384.

Swiny, S., 2008. Of Cows, Copper, Corners, and Cult: The Emergence of the Cypriot Bronze Age. *Near Eastern Archaeology* 71 (1/2), pp. 41-51.

Swiny, S. and Mavromatis, C., 2000. Land behind Kourion: results of the 1997 Sotira Archaeological Project Survey. *RDAC* 2000, 433-452.

Swiny, S., Rapp, G. and Herscher, E. (Eds.) 2003. *Sotira Kaminoudhia. An Early Bronze Age Site in Cyprus*, Cyprus American Archaeological Research Institute Monograph Series Volume 4. American Schools of Oriental Research, Boston.

Timberlake, S., 2007. The use of experimental archaeoloöy/archaeometallurgy for the understanding and reconstruction of Early Bronze Age mining and smelting technologies, in: La Niece, S., Hook, D. and Craddock, P. (Eds.), *Metals and Mines: Studies in Archaeometallurgy*. Archetype Publications, London, pp. 27–36.

Timberlake, S., 2013. From ore to artefact: smelting Alderley Edge copper ores and the casting of a small copper axe. In Doonan, R. C. P. and Dungworth, D. (eds), *Accidental and Experimental Archaeometallurgy*. Historical Metallurgy Society Occasional Publication No 7, London, 135-142.

Thomas, D.H., 1999. *Archaeology: Down to earth*. Harcourt Brace College Publishers, New York.

Todd, I.A., 1986. *The Bronze Age Cemetery in Kalavasos Village. Vasilikos Valley Project I.* SIMA 71(I), Åströms Förlag, Göteborg.

Todd, I.A., 1988. The Middle Bronze Age in the Kalavassos area. *RDAC* 1988, 133-140.

Todd, I.A. (Ed.), 2007. *Vasilikos Valley Project II: Kalavassos Village tombs 52-79*. SIMA 71:11. Åströms Förlag, Sävedalen.

Todd, I.A., 2013. The Field Survey of the Vasilikos Valley III: Human Settlement in the Vasilikos Valley. SIMA 71:12. Åströms Förlag, Uppsala.

Tylecote, R.F., 1971. Observations on Cypriot copper smelting. *RDAC* 1971, 53–58.

Tylecote, R.F., 1980b. Summary of results of experimental work on early copper smelting, in: Oddy, W.A. (Ed.), *Aspects of Early Metallurgy*, British Museum Occasional Paper 17. British Museum, London, pp. 5–12.

Tylecote, R.F., 1982. The Late Bronze Age: copper and bronze metallurgy at Enkomi and Kition, in: Muhly, J.D., Maddin, R. and Karageorghis, V. (Eds.), *Early Metallurgy in Cyprus, 4000-500 B.C.* Pierides Foundation, Nicosia, 81–103.

Tylecote, R.F., 1985. Copper working at Kition, in: Karageorghis, V. and Demas, D. (Eds.), *Excavations at Kition: V. The Pre-Phoenician Levels, Part I.* Department of Antiquities, Cyprus, Nicosia, p. 430.

Tylecote, R.F., 1992. *A history of metallurgy*. 2nd Edition. The Institute of Materials, London.

Tylecote, R.F., Ghaznavi, H.A. and Boydell, P.J., 1977. Partitioning of trace elements between the ores, fluxes, slags and metal during the smelting of copper. *JAS* 4, 305–333.

Tylecote, R.F. and Boydell, P.J., 1978. Experiments on Copper Smelting based on early furnaces found at Timna. In Rothenberg, B. (ed), Chalcolithic Copper Smelting, Archaeo-Metallurgy IAMS Monograph Number One, London, 27-49.

Tylecote, R.F. and Merkel, J.F., 1985. Experimental smelting techniques: achievements and future, in: Craddock, P.T. and Hughes, M.J. (Eds.), *Furnaces and Smelting Technology in Antiquity*, British Museum Occasional Paper 48. 3rd Edition. The British Museum, London, pp. 3–20.

Unthank-Salkield, L., 1987. A technical history of the Rio Tinto mines: some notes on exploitation from pre-Phoenician times to the 1950s. The Institution of Mining Metallurgy, London.

Van Brempt, L., 2016. *The production and trade of Cypriot copper in the Late Bronze Age. From ore to ingot: unravelling the metallurgical chain*. PhD Thesis, University of Cyprus.

Van Brempt, L. and Kassianidou, V., 2016. Facing the complexity of copper-sulphide ore smelting and assessing the role of copper in south-central Cyprus: A comparative study of the slag assemblage from Late Bronze Age Kalavassos-*Ayios Dhimitrios*. *JAS.Reports* 7, pp. 539-553.

Verly, G., 2017. The smelting furnaces of Ayn Soukhna: the excavations of 2013, 2014 and 2015. In Montero Ruiz, I. and Perea, A. (eds), Archaeometallurgy in Europe IV. CSIC, Madrid, 143-157.

Vermeule, E. and Wolsky, F.Z., 1990. *Tomba tou Skourou: A Bronze Age Potter's Quarter on Morphou Bay in Cyprus*. Harvard University Press, Cambridge, Massachusetts.

Voskos, I. and Knapp, A.B., 2008. Cyprus at the end of the Late Bronze Age: crisis and colonization or continuity and hybridization?, *AJA* 112, 659-684.

Watkins, T.F., 1976. Wessex without Cyprus: “Cypriot daggers” in Europe, in J.V.S. Megaw (Ed.), *To Illustrate the Monuments. Essays on Archaeology presented to Stuart Piggott*, Thames and Hudson, London, pp. 135-143.

Watkins, T.F., 1981. Levantine bronzes from the collection of the Rev. William Greenwell, now in the British Museum, *Levant* 13/1, pp. 119-155.

Webb, J.M., 1997. *Corpus of Cypriote Antiquities. 18: Cypriote Antiquities in Australian Collections I,* SIMA 20, Paul Åströms Förlag, Jonsered.

Webb, J.M., 2012. Kalopsidha: 46 years after. SIMA Volume 2. In Webb, J.M. and Frankel, D., *Studies in Mediterranean Archaeology: Fifty Years On*, SIMA 137, Åströms Förlag, Uppsala, pp. 49-58.

Webb, J.M., 2015. Identifying stone tools used in mining, smelting, and casting in Middle Bronze Age Cyprus. *Journal of Field Archaeology* 40:1, 22–36.

Webb, J.M., 2016. Anthropomorphic Figures from Middle Bronze Age Cyprus: Who or What do they Represent? *Iris, Journal of the Classical Association of Victoria, New Series*, 29, 5-21.

Webb, J.M. and Frankel, D., 1999. Characterizing the Philia Facies: material culture, chronology, and the origin of the Bronze Age in Cyprus. *AJA* 103:1, 3–43.

Webb, J.M. and Frankel, D., 2006. *Marki Alonia. An Early and Middle Bronze Age settlement in Cyprus. Excavations 1995-2000*. SIMA123(2), Paul Åströms Förlag, Sävedalen.

Webb, J.M. and Frankel, D., 2007. Identifying population movements by everyday practice: the case of 3rd millennium Cyprus. In Antoniadou, S. and Pace, A. (Eds.), Mediterranean Crossroads, Pierides Foundation, Oxbow, Athens, Oxford, 189-216.

Webb, J.M. and Frankel, D., 2008. Fine ware ceramics, consumption and commensality: mechanisms of horizontal and vertical integration in Early Bronze Age Cyprus. In L. A. Hitchcock, R. Laffineur and J. Crowley (eds), DAIS. *The Aegean Feast*. Aegaeum 29Université de Liège, University of Texas. Liège, Austin, 287-295.

Webb, J.M. and Frankel, D., 2011. Hearth and home as identifiers of community in mid-third millennium Cyprus. In Karageorghis, V. and Kouka, O. (Eds), *On Cooking Pots, Drinking Cups, Loomweights and Ethnicity in Bronze Age Cyprus and Neighnbouring Regions*, Leventis Foundation, Nikosia, 29-42.

Webb, J.M. and Frankel, D., 2013a. *Ambelikou Aletri. Metallurgy and Pottery Production in Middle Bronze Age Cypru*s, SIMA 138. Åströms Förlag, Uppsala.

Webb, J.M. and Frankel, D., 2013b. Cultural regionalism and divergent social trajectories in Early Bronze Age Cyprus. *AJA* 117:1, 59–81.

Webb, J.M., Frankel, D., Stos, Z.A. and Gale, N., 2006. Early Bronze Age metal trade in the Eastern Mediterranean. New compositional and Lead Isotope evidence from Cyprus. *OJA* 25, 261–288.

Webb, J.M., Frankel, D., Eriksson, K. and Hennessy, J.B. (Eds.) 2009. *The Bronze Age Cemeteris at Karmi Paleolana and Lapatsa in Cyprus. Excavations by J.R.B. Stewart*. SIMA 136, Åströms Förlag, Göteborg.

Wright, G.R.H., 1992. *Ancient Building in Cyprus*. Handbuch der Orientalistik 7. Abteilung, Kunst und Archaeologie. I Band, Der Alte Vordere Orient. 2B/7/1 and 2B/7/2. Brill, Leiden.

Wrobel Nørgaard, H., 2017. Portable XRF on Prehistoric Bronze Artefacts: Limitations and Use for the Detection of Bronze Age Metal Workshops. *Open Archaeology* 3, pp. 101-122.

Xenophontos, C., 2003. *Lemba Archaological Projects, Cyprus III:1. The Colonisation and Settlement of Cyprus: Investigations at Kissonerga-Mylouthkia, 1976-1996.* SIMA 70:4. Paul Åströms Förlag, Sävedalen.

Yazawa, A., 1974. Thermodynamic considerations of copper smelting. *Canadian Metallurgical Quarterly* 13, pp. 443–453.

Yon, M., 2000. A Trading City: Ugarit and the West. Near Eastern Archaeology 63, No. 4, pp. 192-193.

Zachos, K.L., 2007. The Neolithic Background: A Reassessment. In Day, P.M. and Doonan, C.P. Doonan (Eds.), *Metallurgy in the Early Bronze Age Aegean*. Oxbow, Oxford, pp. 168-206.

Zachos, K.L. and Douzougli, A., 1999. Aegean metallurgy: how early and how independent? In Bentacourt, P.P., Karageorghis, V., Laffineur, R. and Niemeier, W-D. (Eds.), *Meletemata: Studies in Aegean Archaeology Presented to Malcolm H. Wiener as he Enters his 65th Year.* Vol. I. Aegeum 20, Liège, pp. 959-968.

Zohary, M. 1973. *Geobotanical Foundation of the Middle East. vols. 2.* Swets and Zeitlinger, Amsterdam.

Zwicker, U., 1982. Bronze Age metallurgy at Ambelikou-Aletri and arsenical copper crucible from Episcopi-Phaneromeni, in: Muhly, J.D., Maddin, R. and Karageorghis, V. (Eds.), *Early Metallurgy in Cyprus, 4000-500 B.C.* Pierides Foundation, Nicosia, pp. 63–68.

Zwicker, U., 1985. Investigation of samples from the metallurgical workshops at Kition, in: Karageorghis, V. and Demas, D. (Eds.), *Excavations at Kition: V. The Pre-Phoenician Levels, Part I.* Department of Antiquities, Cyprus, Nicosia, pp. 403–429.

Zwicker, U., 1992. Nondestructive and other investigations on objects of the Archaeological Museum Nicosia, in: Ioannides, G.C. (Ed.), *Studies in Honour of Vassos Karageorghis.* Society of Cypriot Studies, Nicosia, pp. 165–177.

Zwicker, U., Rollig, H. and Schwarz, U., 1972. Investigations on prehistoric and early historic copper-slag from Cyprus (preliminary report). *RDAC* 1972, 34–45.

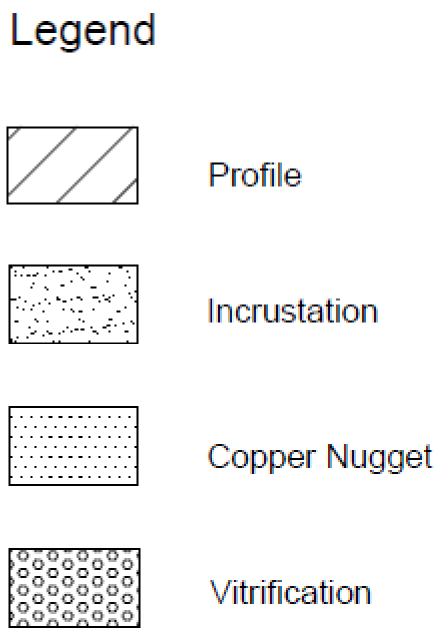
Zwicker, U., Grembler, E. and Rollig, H., 1977. Investigations on copper-slags from Cyprus (second report). *RDAC* 1977, 309–316.

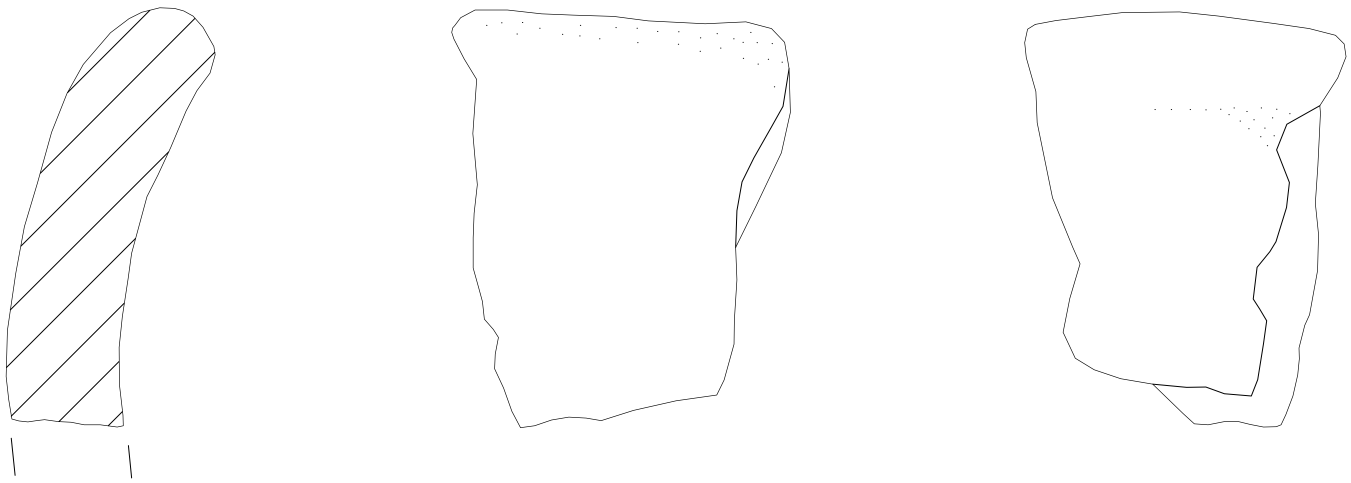
Zwicker, U., Constantinou, G., Buchmolz, H.G. and Karageorghis, V., 1981. Investigation on ore, flux and crucible slag from prehistoric copper smelting at Ambelikou (Cyprus). *Revue d'Archéométrie* 1. Actes du XXe symposium international d'archéométrie Paris 26-29 mars 1980 Volume III., pp. 331-340.

Zwicker, U., Greiner, H., Hofmann, K-H. and Reithinger, M., 1985. Smelting, refining, and alloying of copper and copper alloys in crucible furnaces during prehistoric up to Roman times. In Craddock, P.T. and Hughes, M.J. (Eds.), Furnaces and Smelting Technology in Antiquity. British Museum Occasional Paper 48, British Museum, London, pp. 103-115.

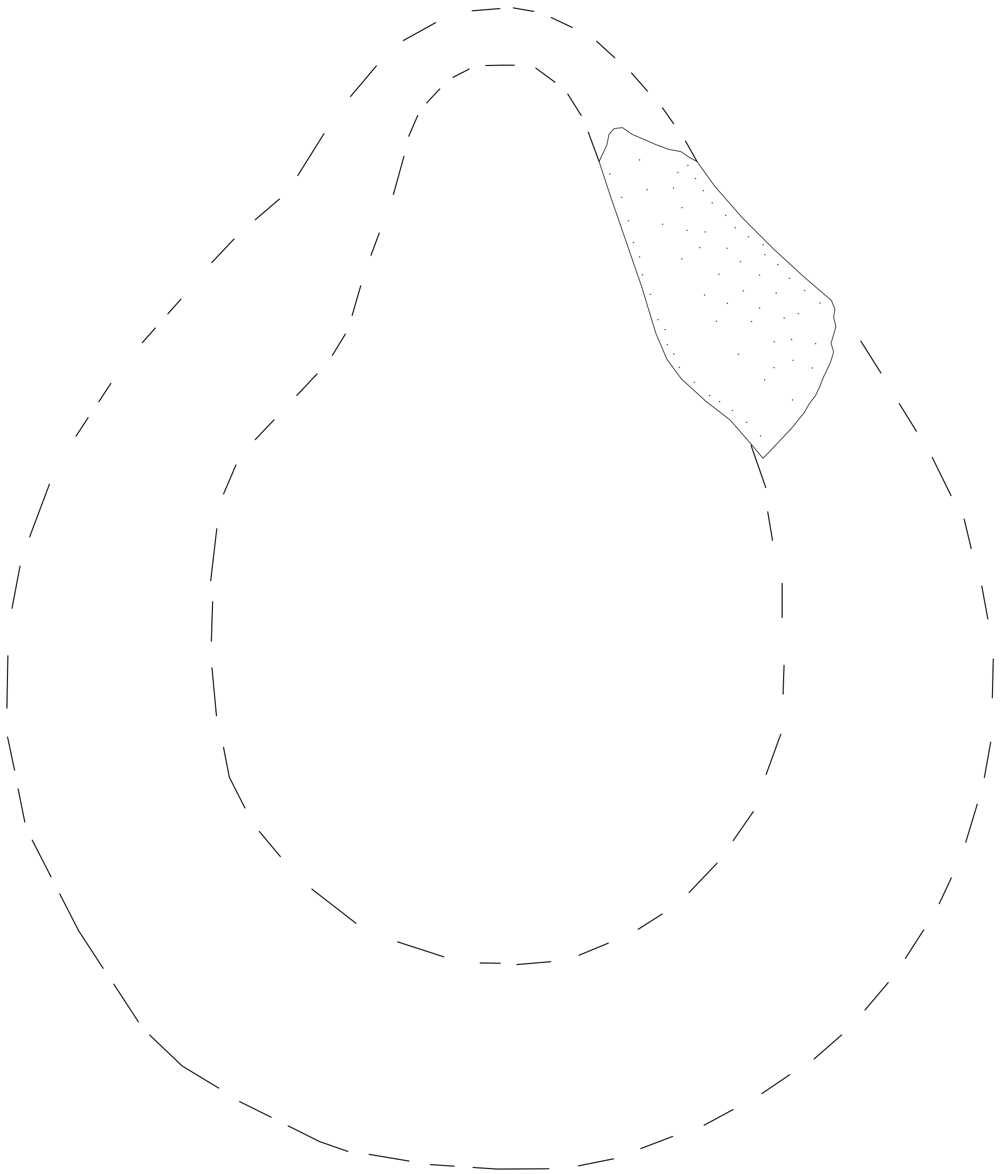
Appendix 1

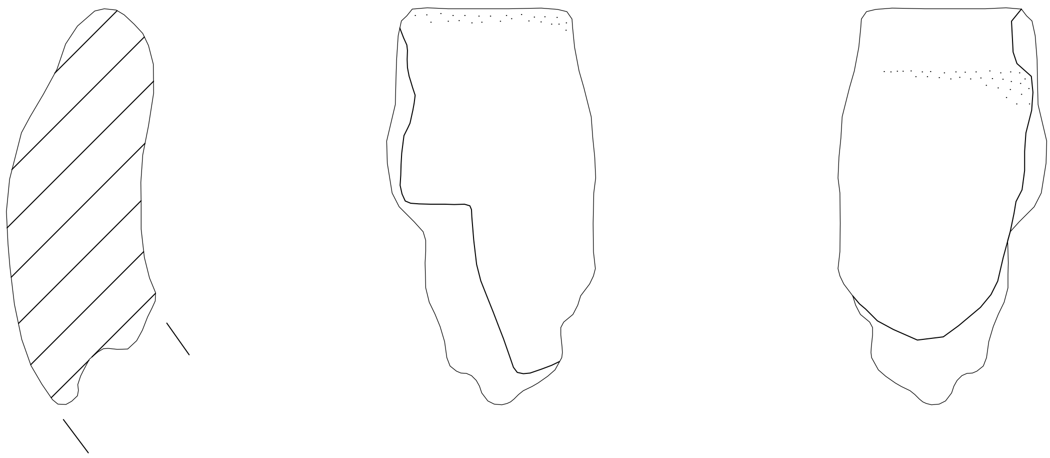
Tables of drawings



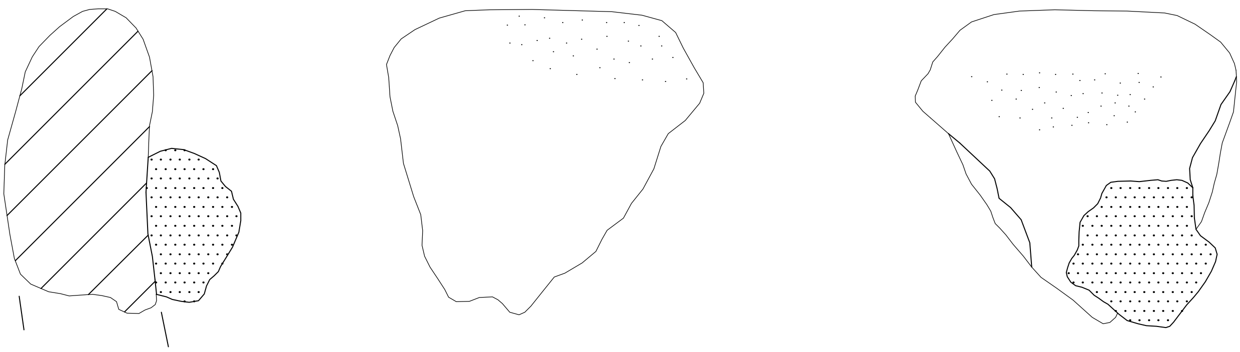


1

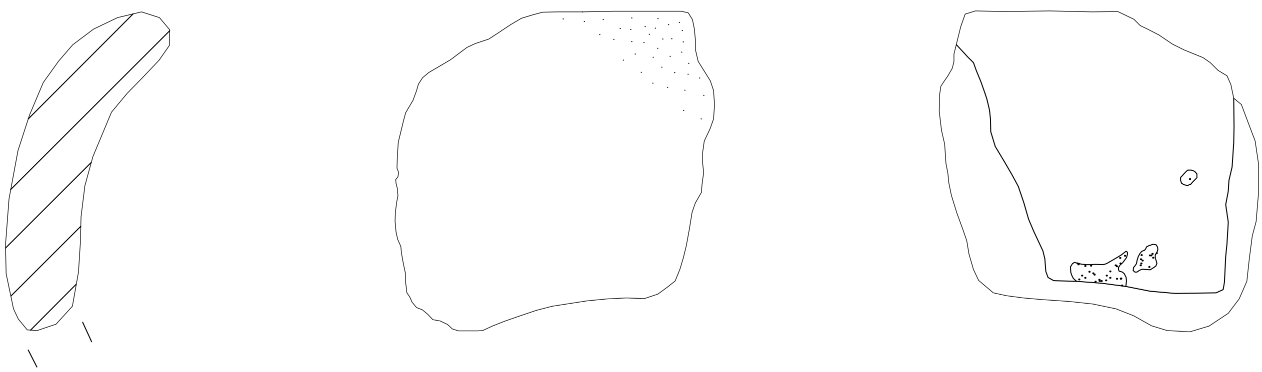




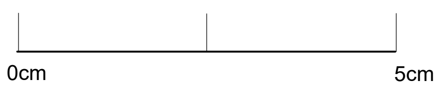
2

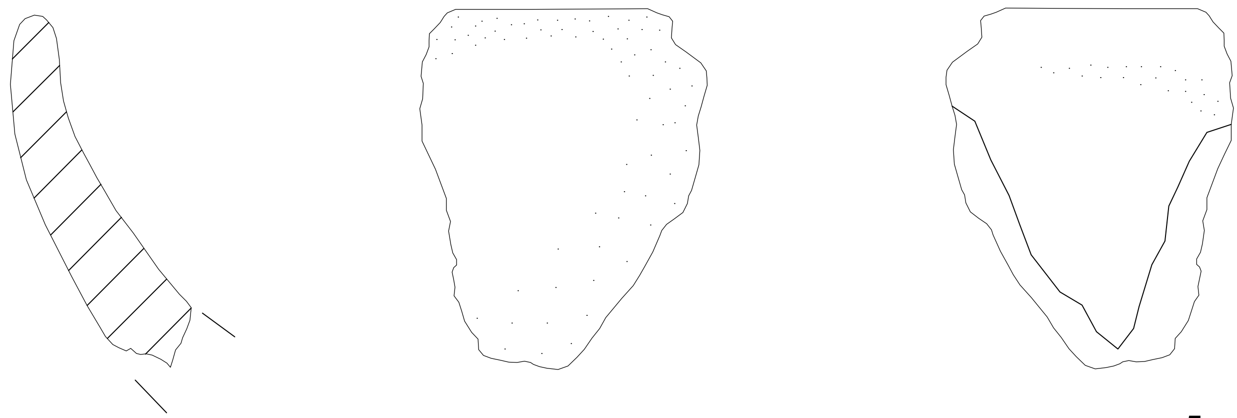


3

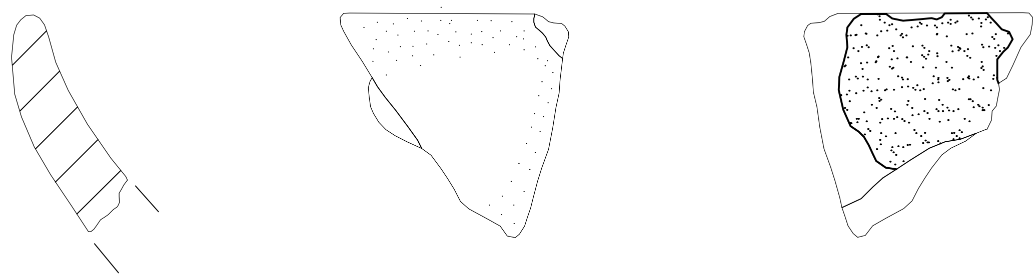


4

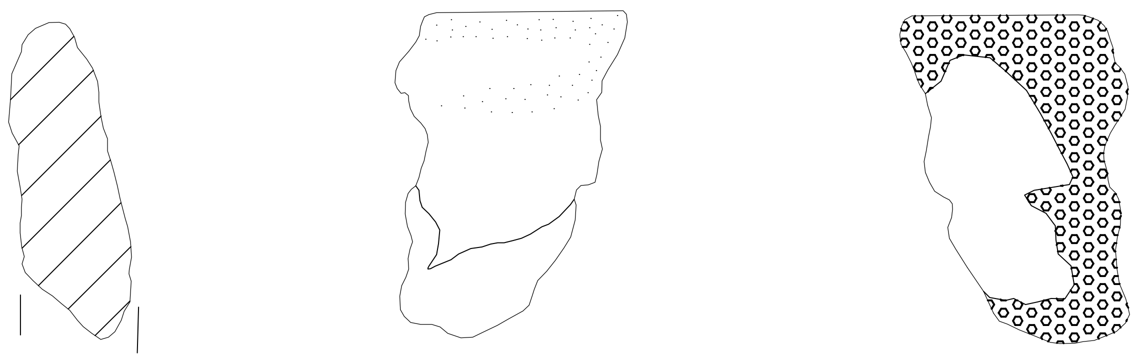




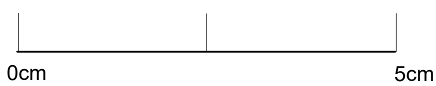
5

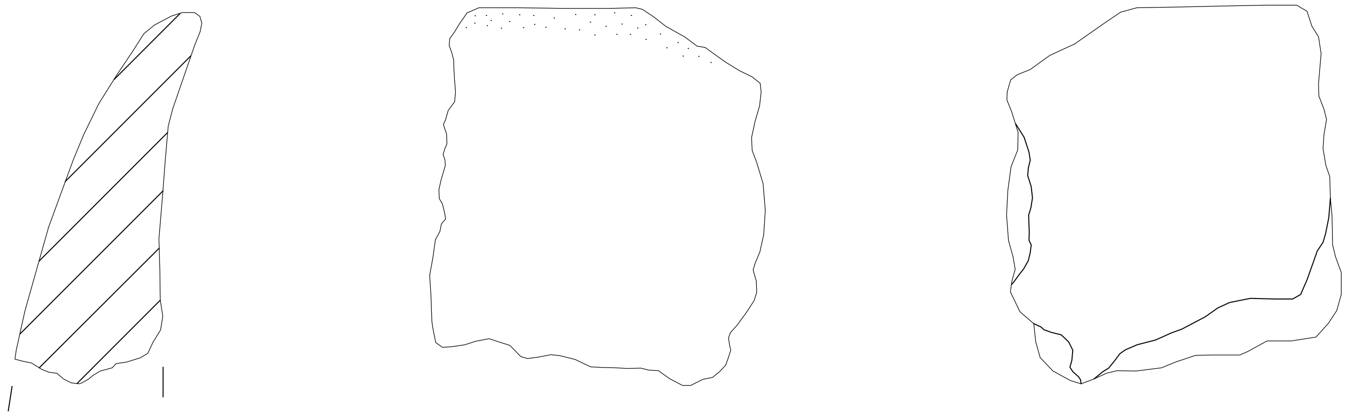


6

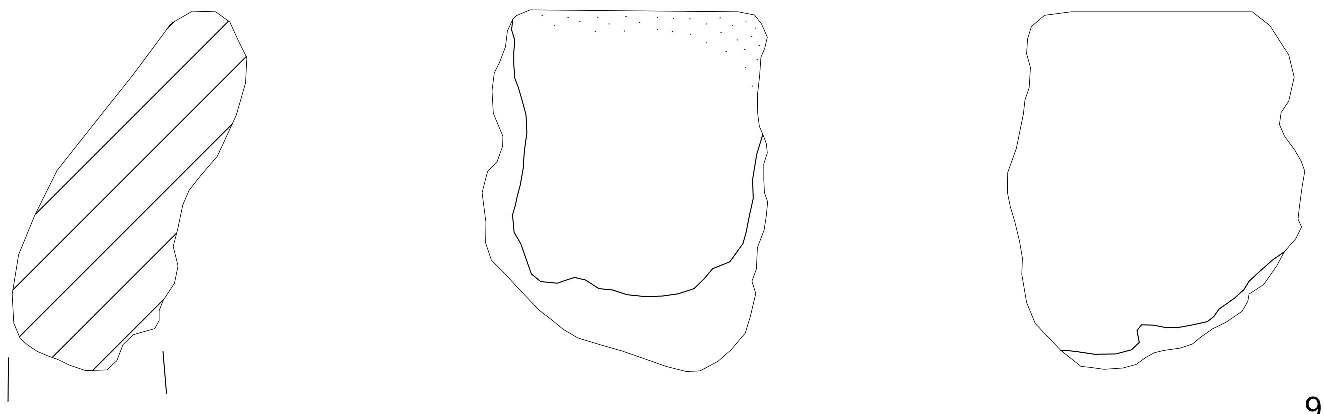


7

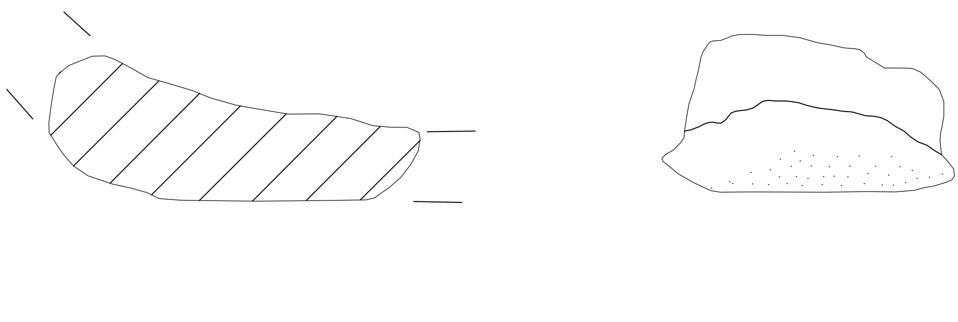




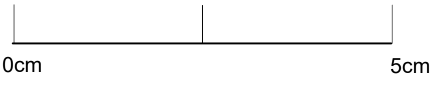
8

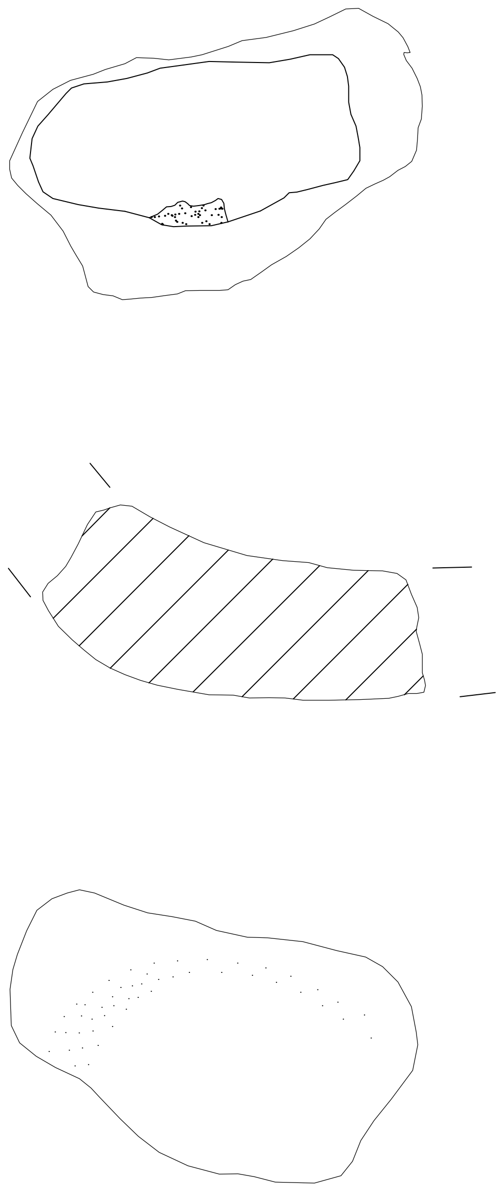


9

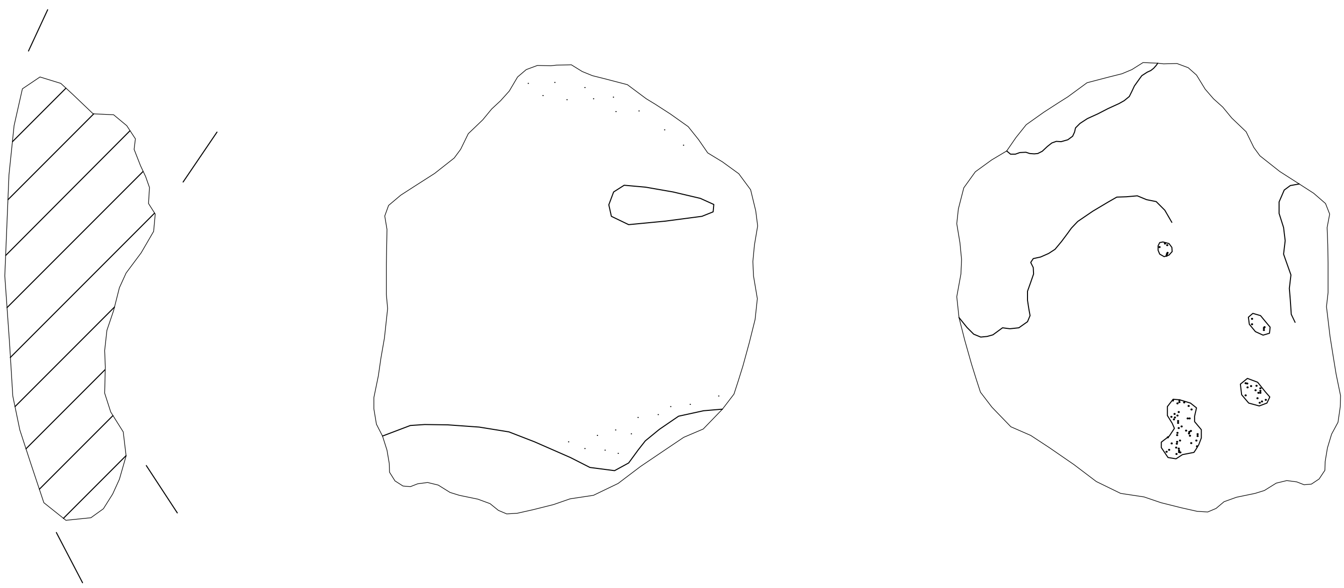


10

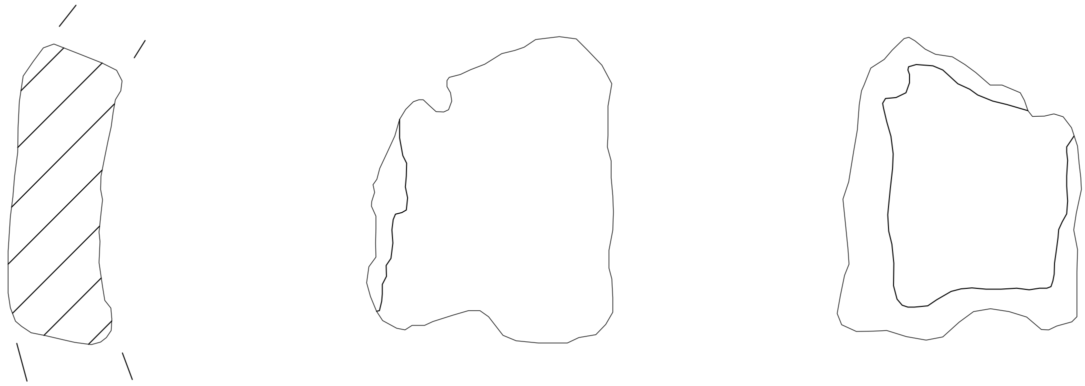




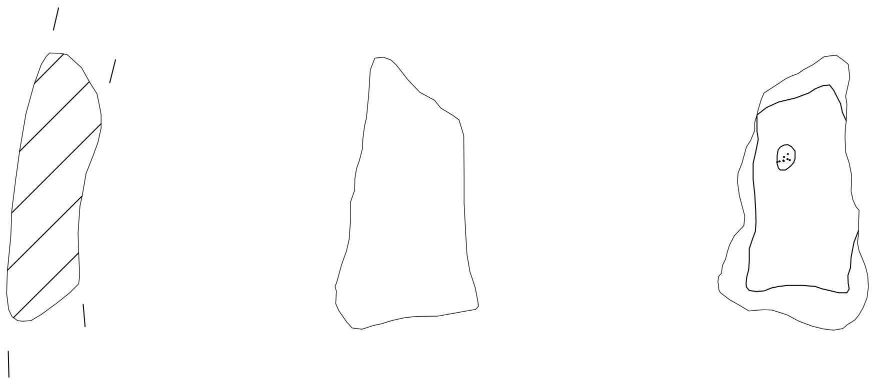
11



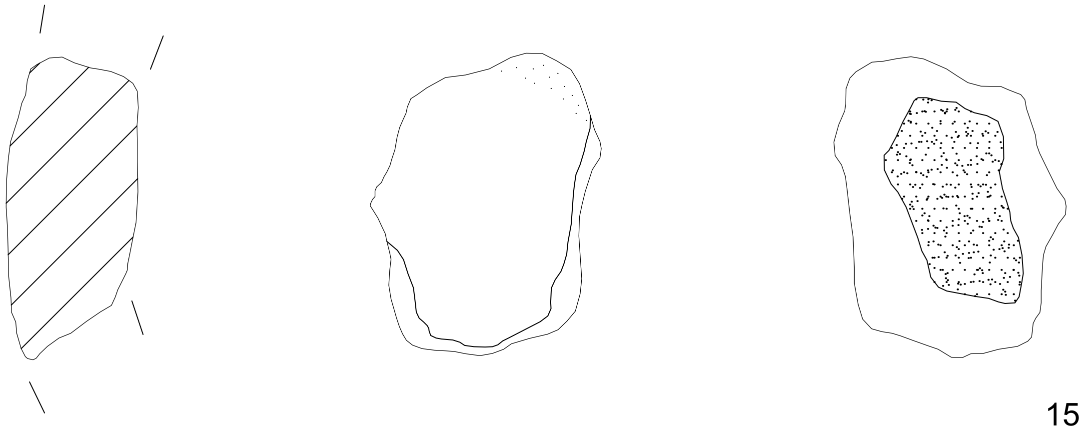
12



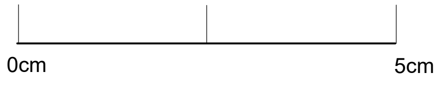
13

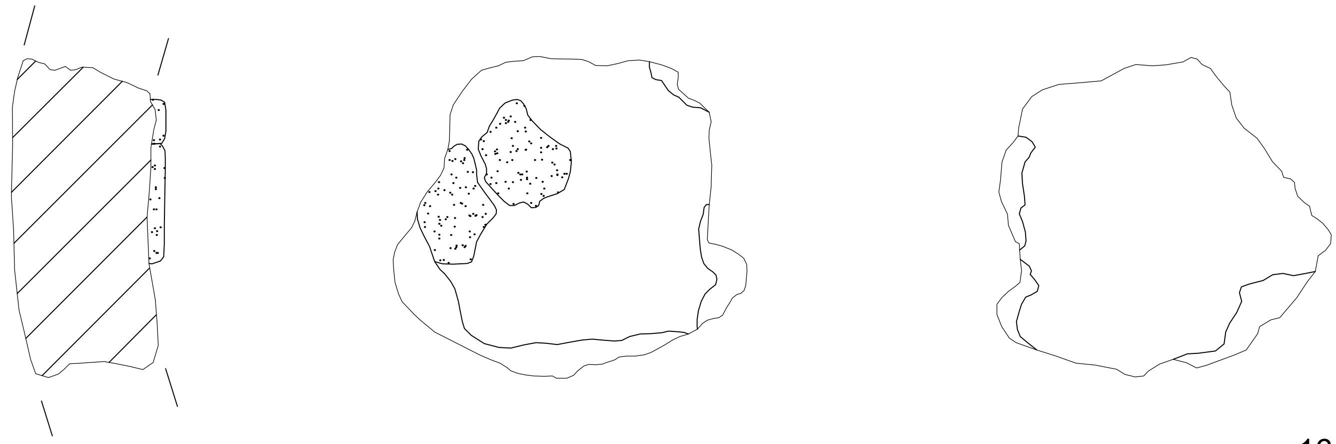


14

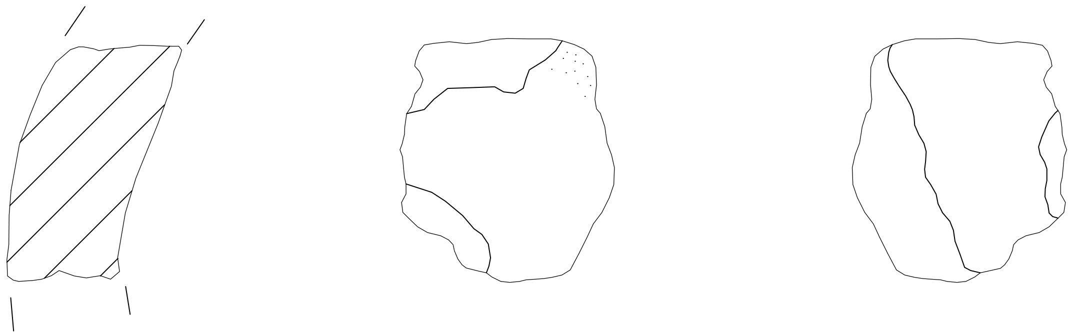


15

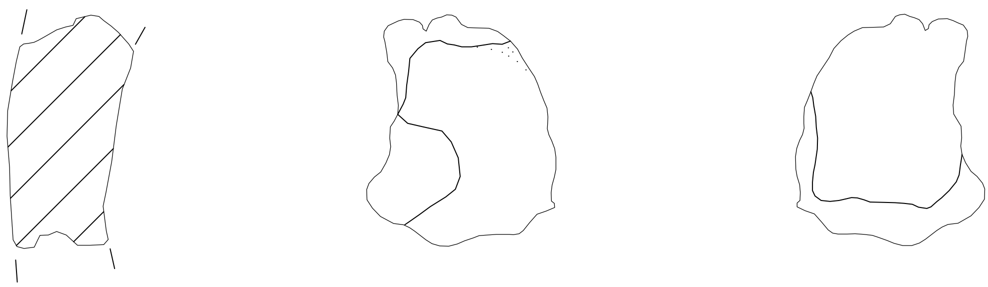




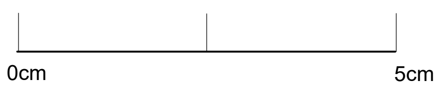
16

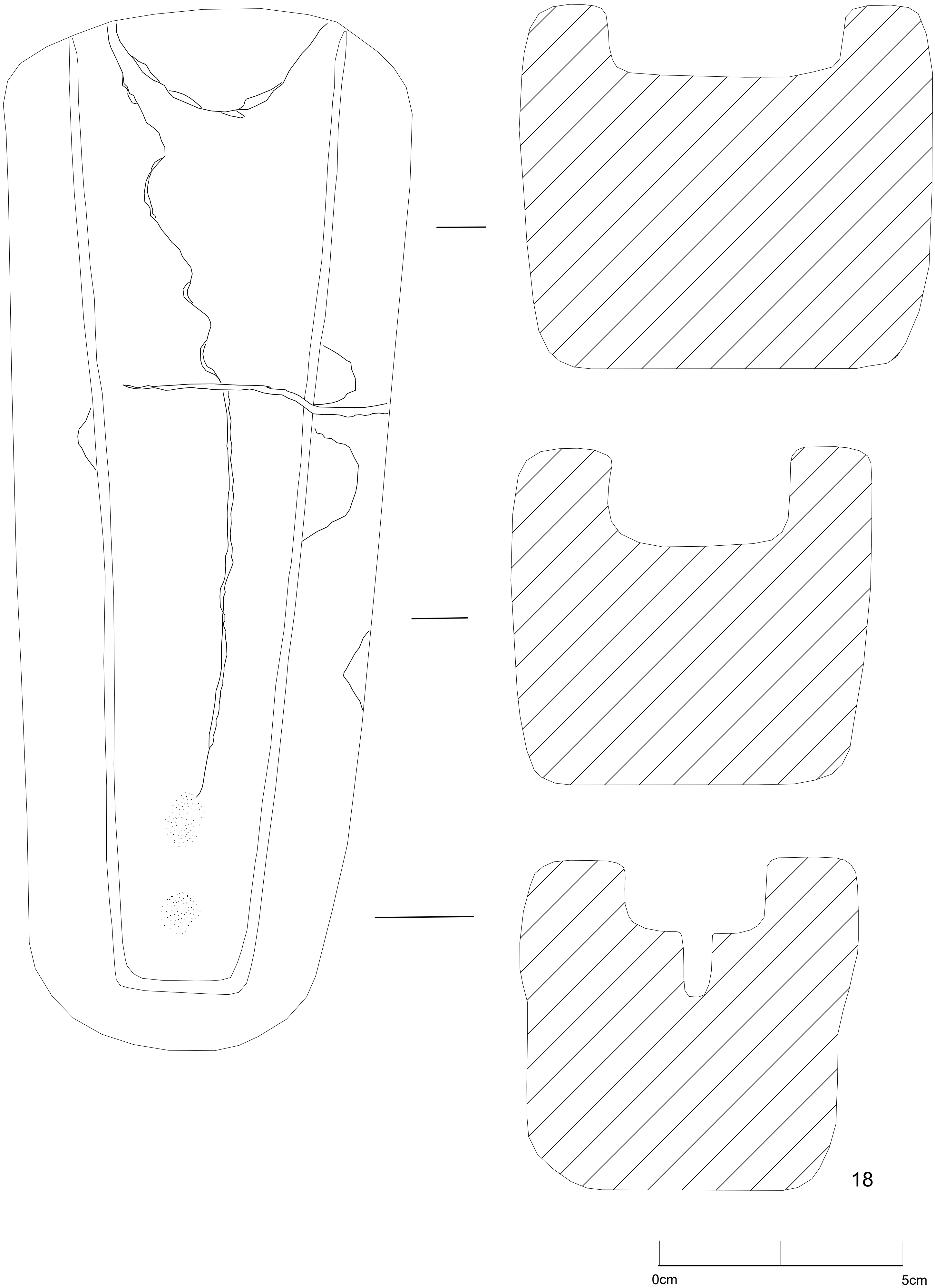


17a

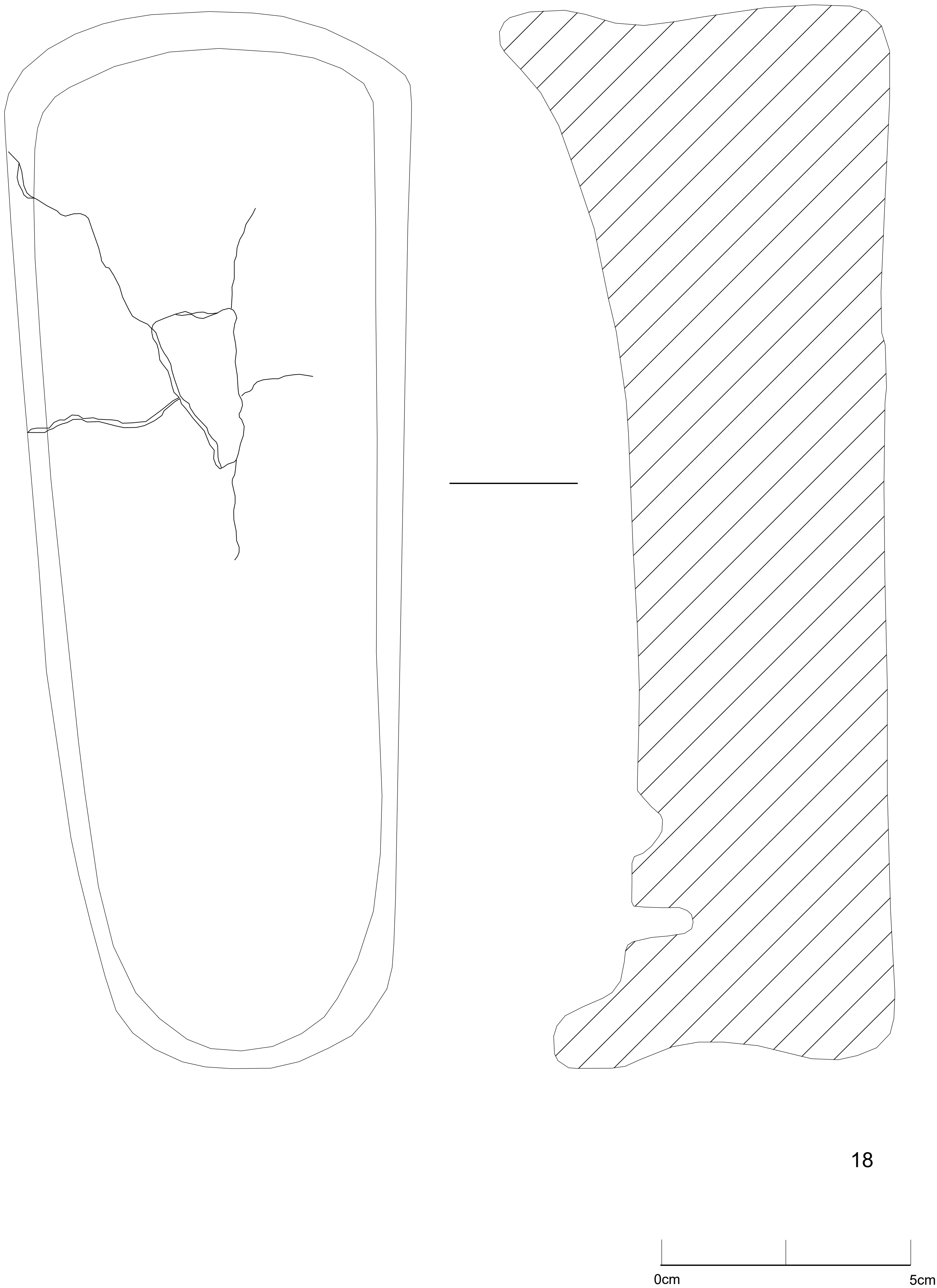


17b

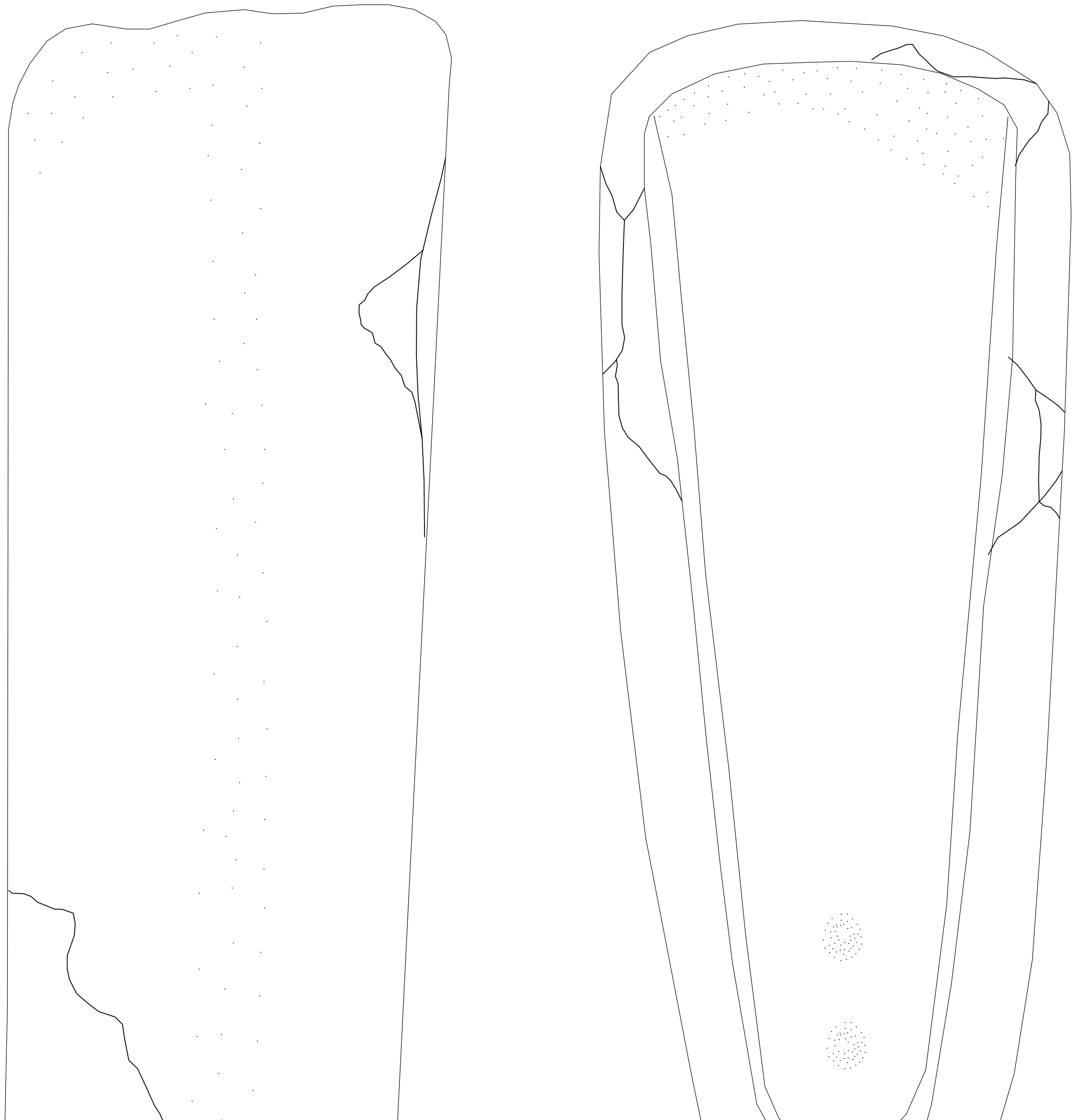




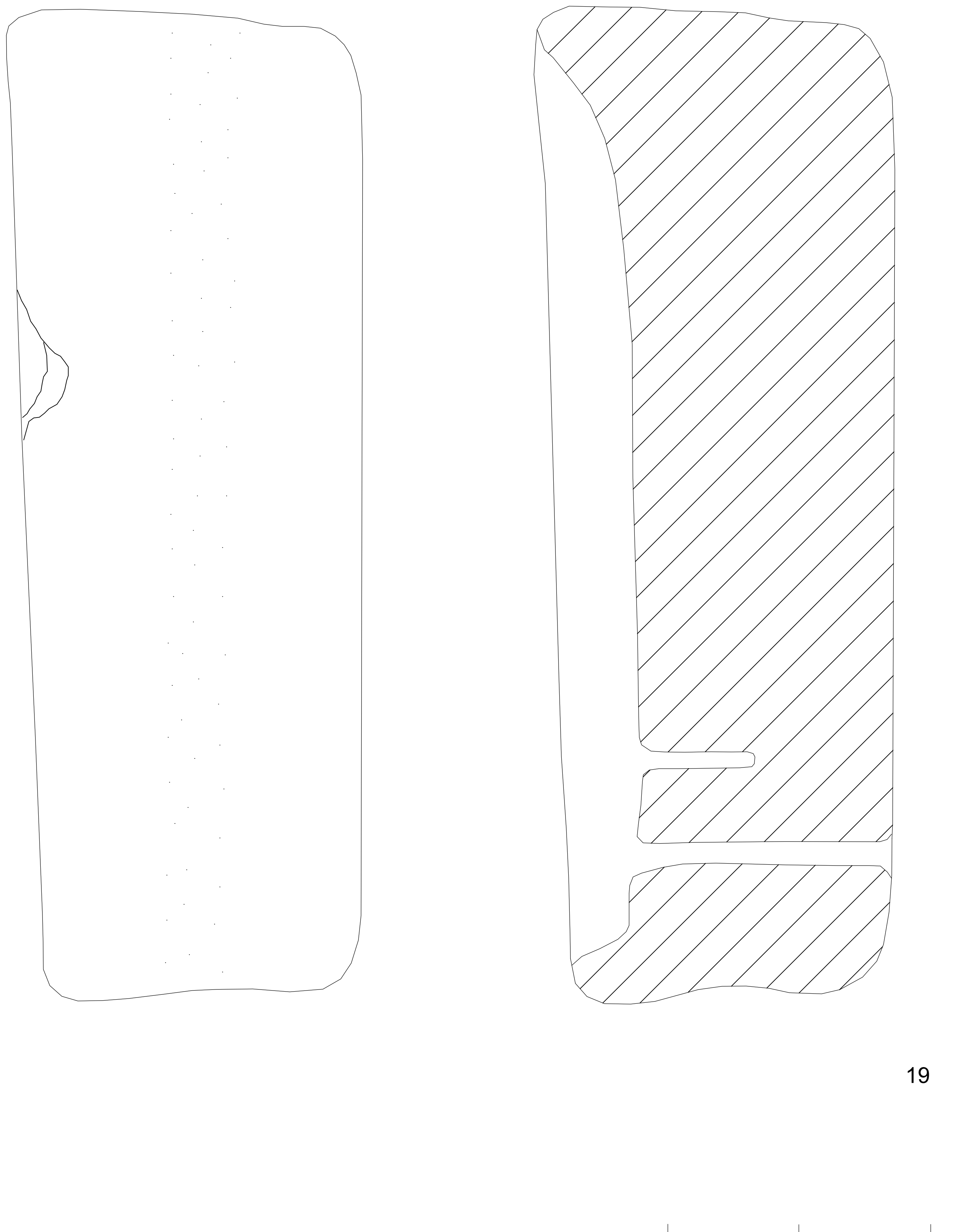
18



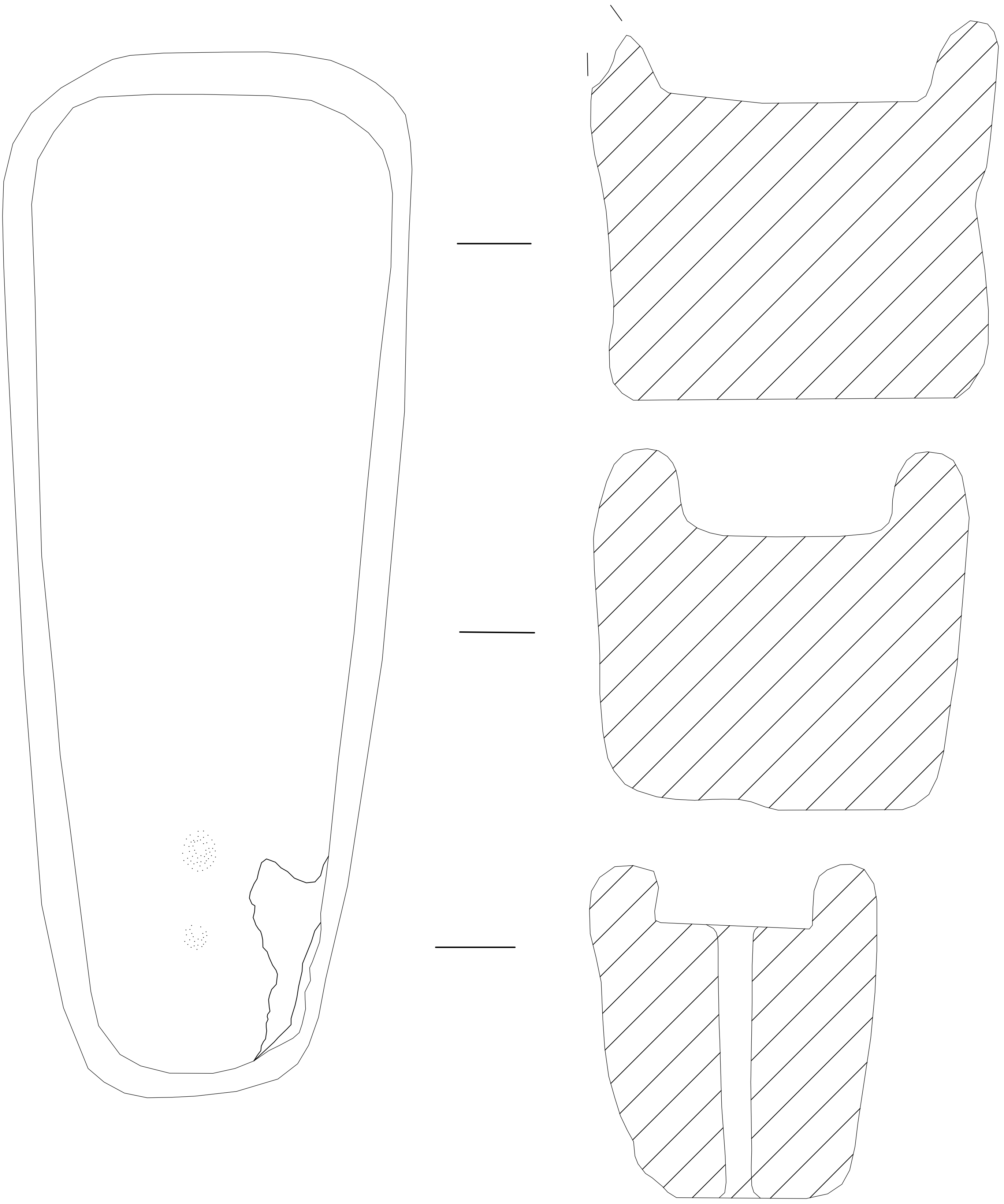
18



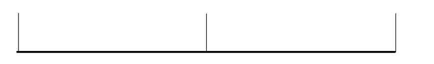
19

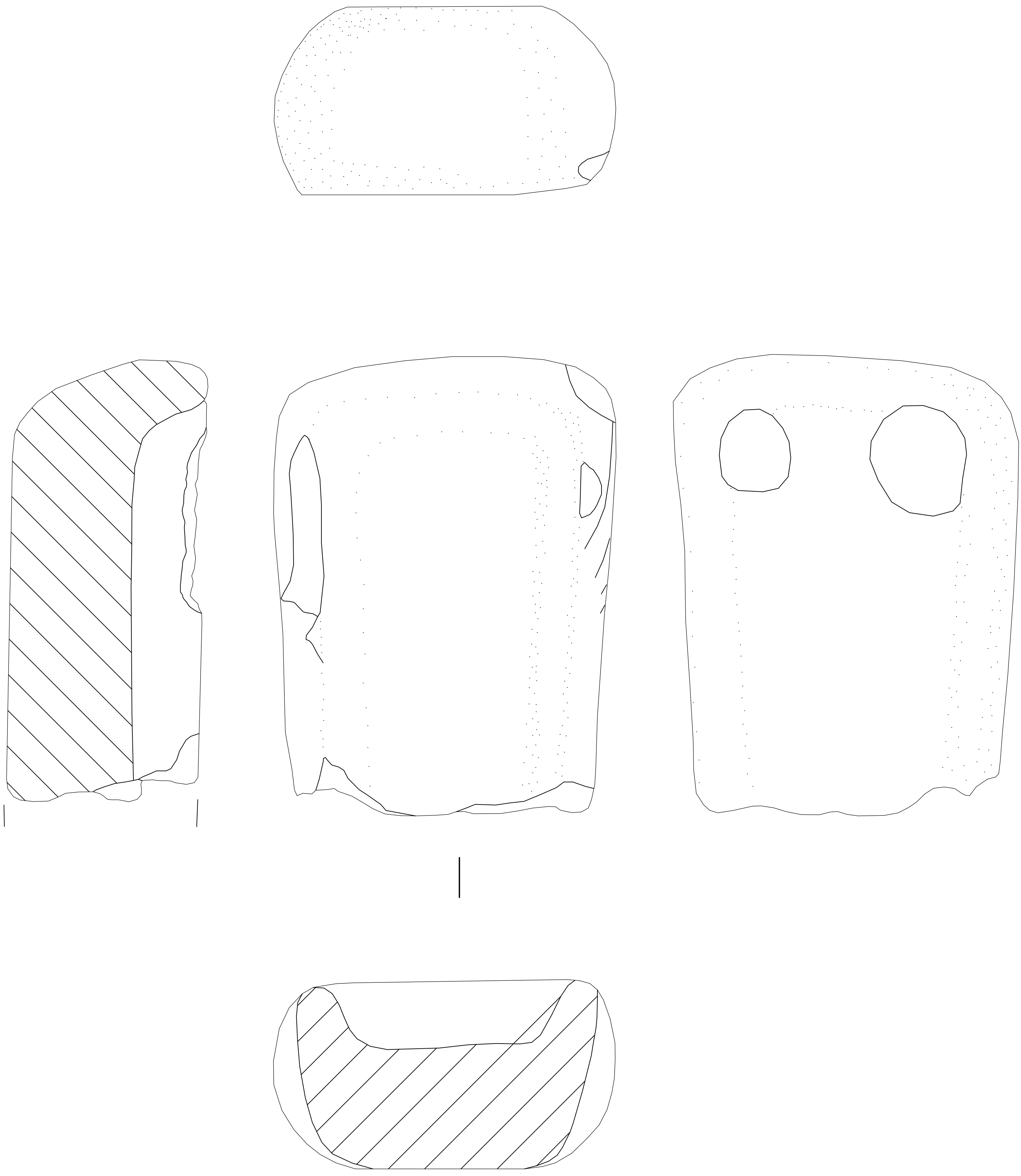


19

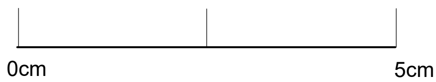


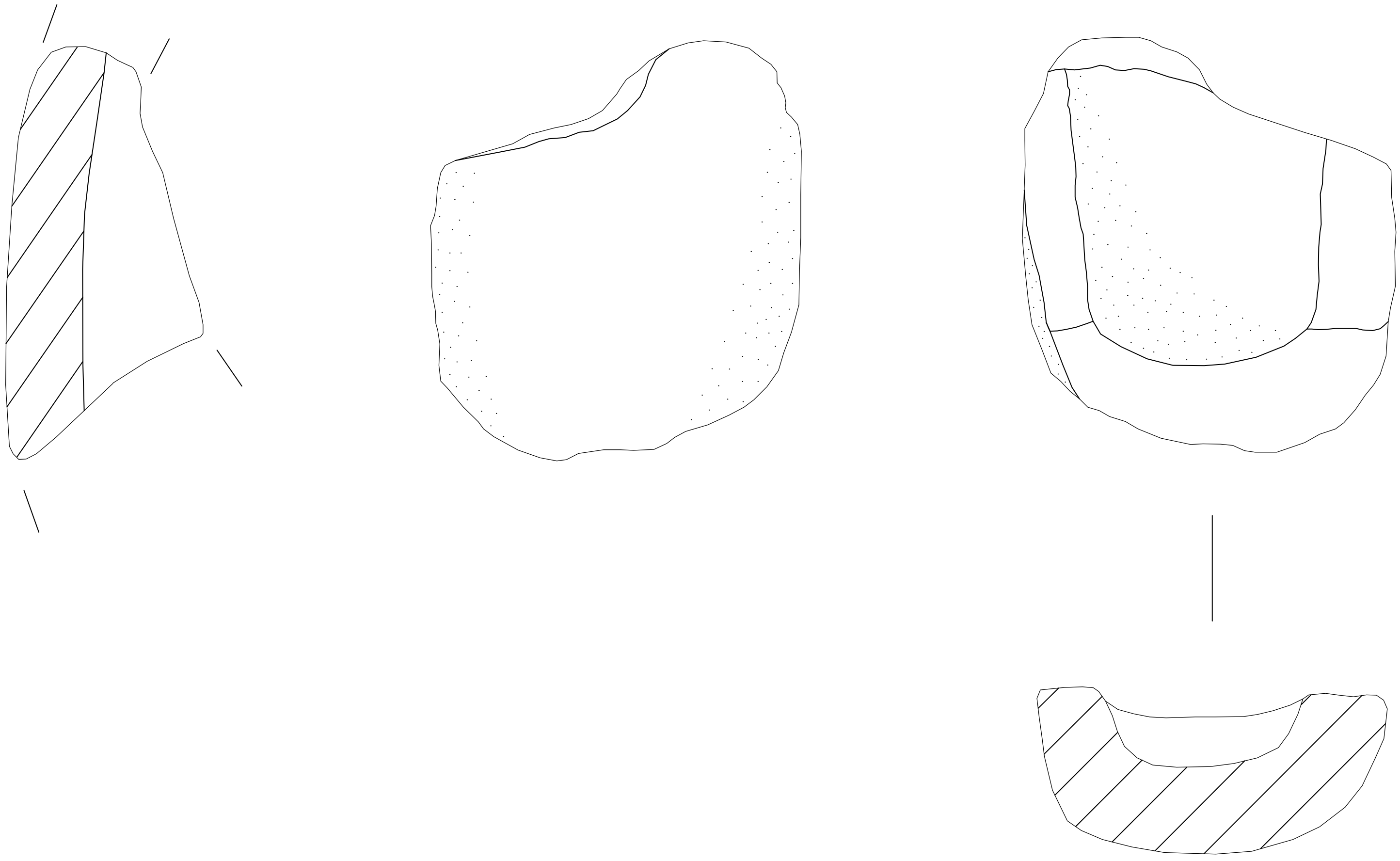
19



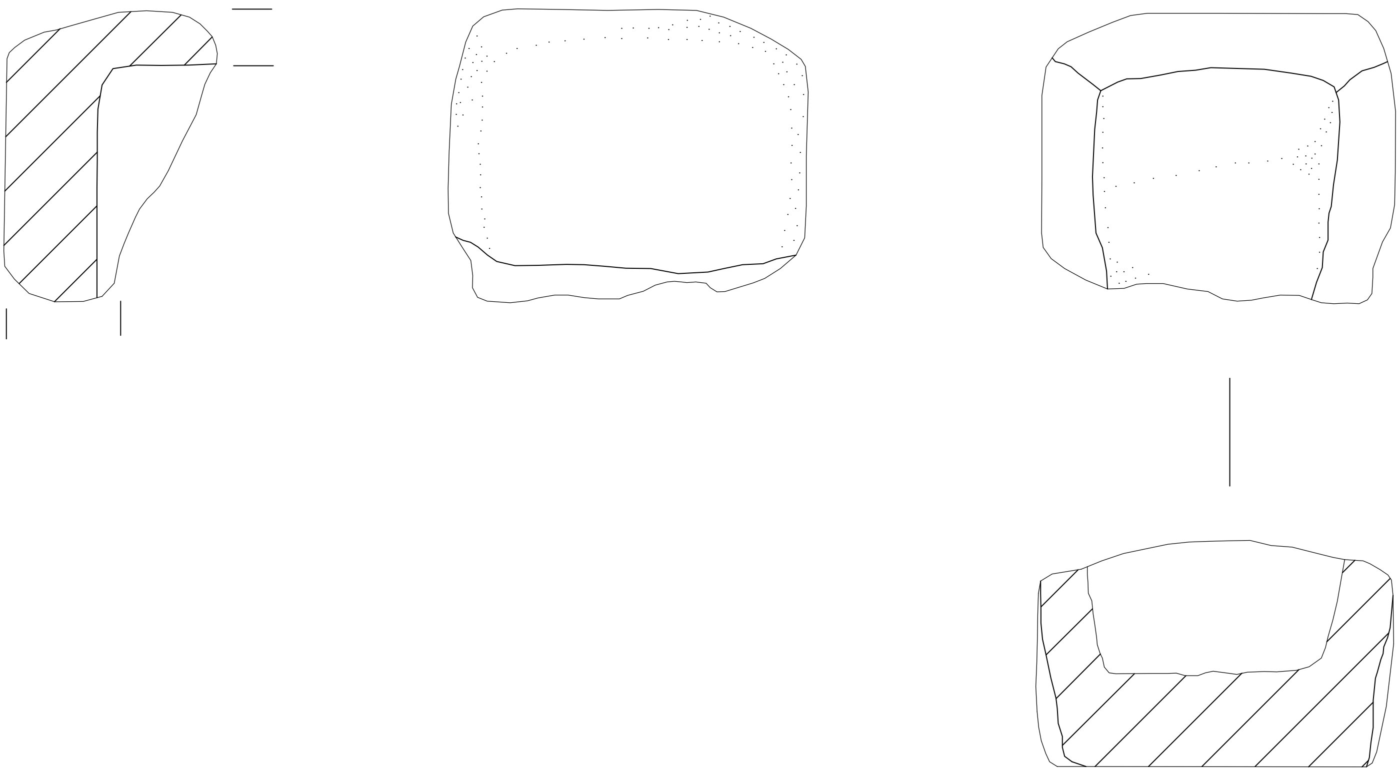


20

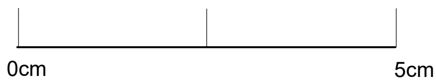


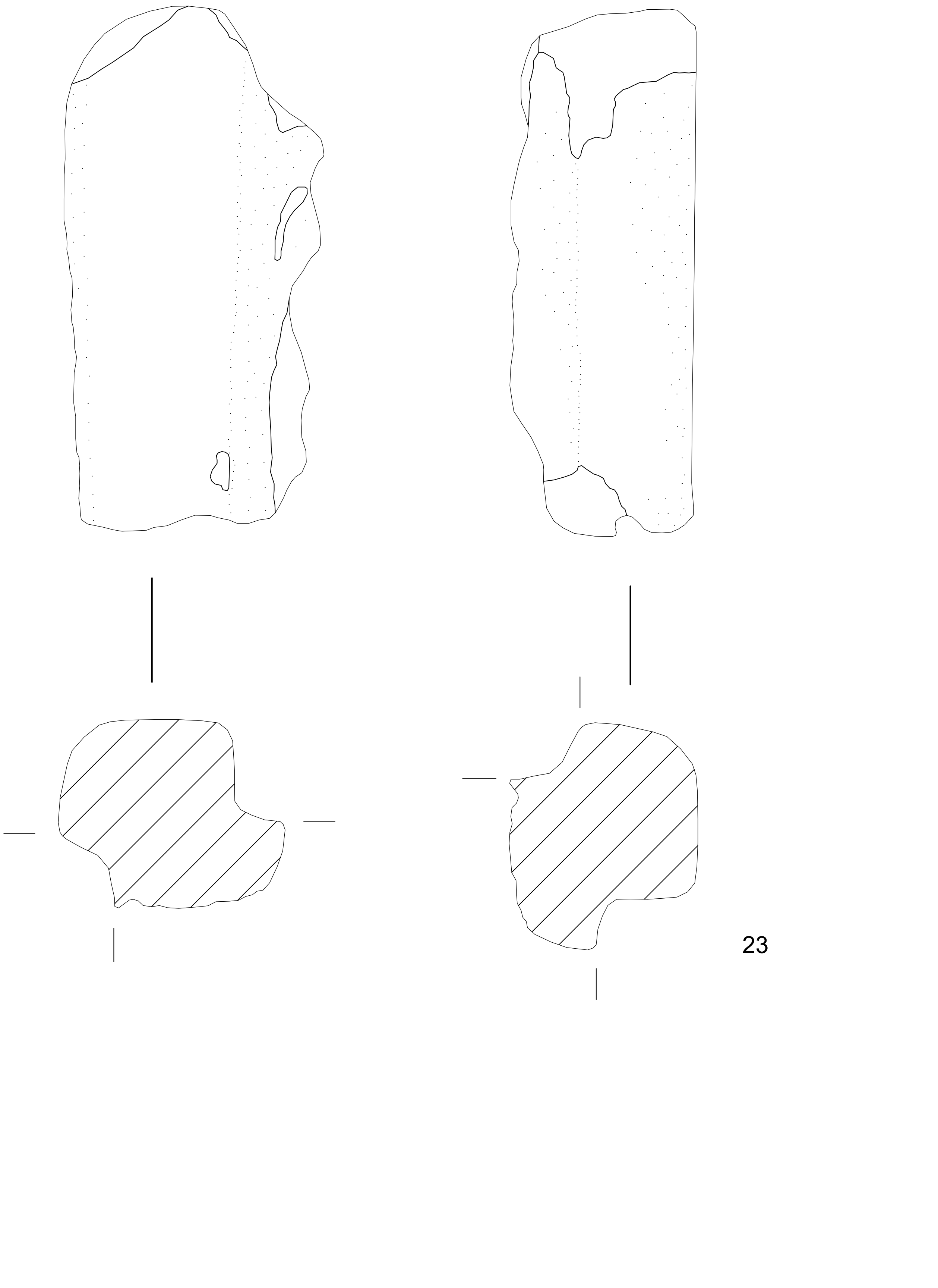


21

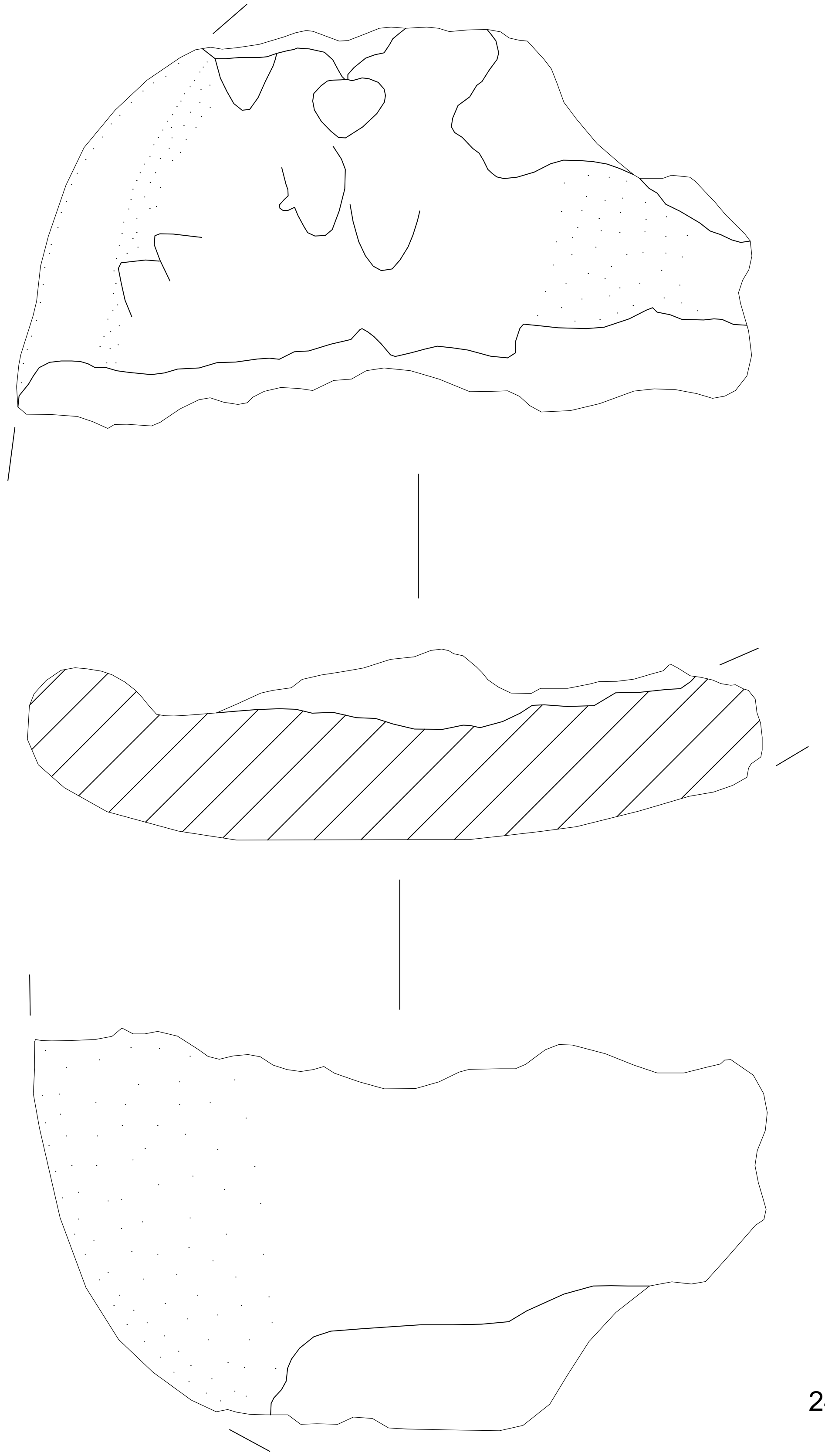


22

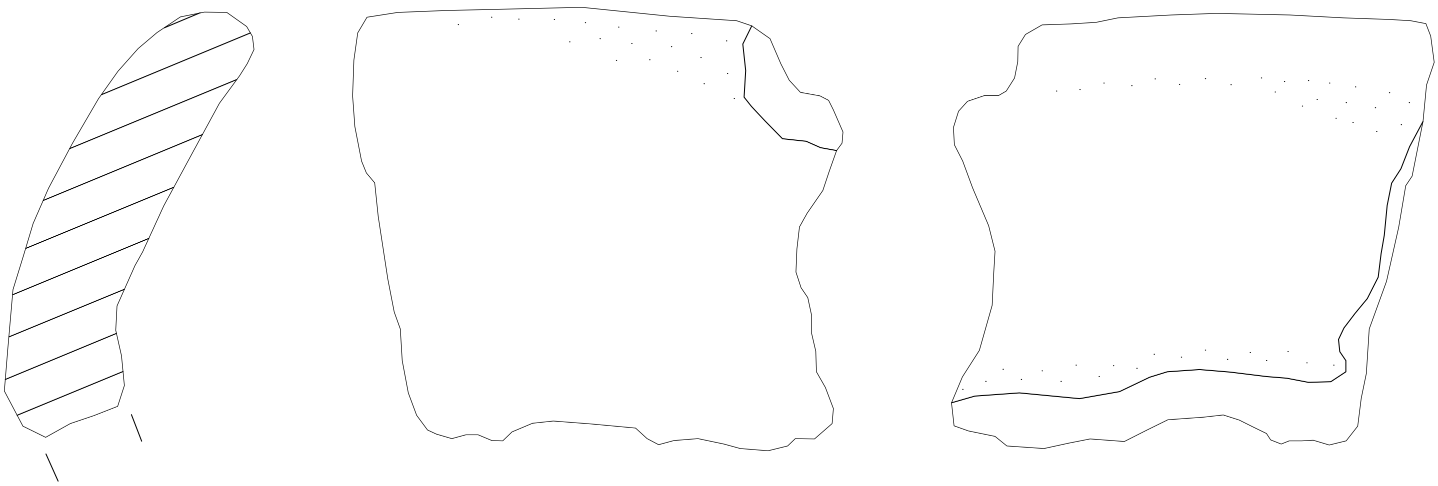




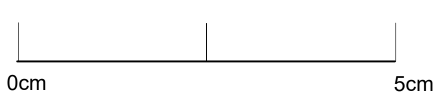
23

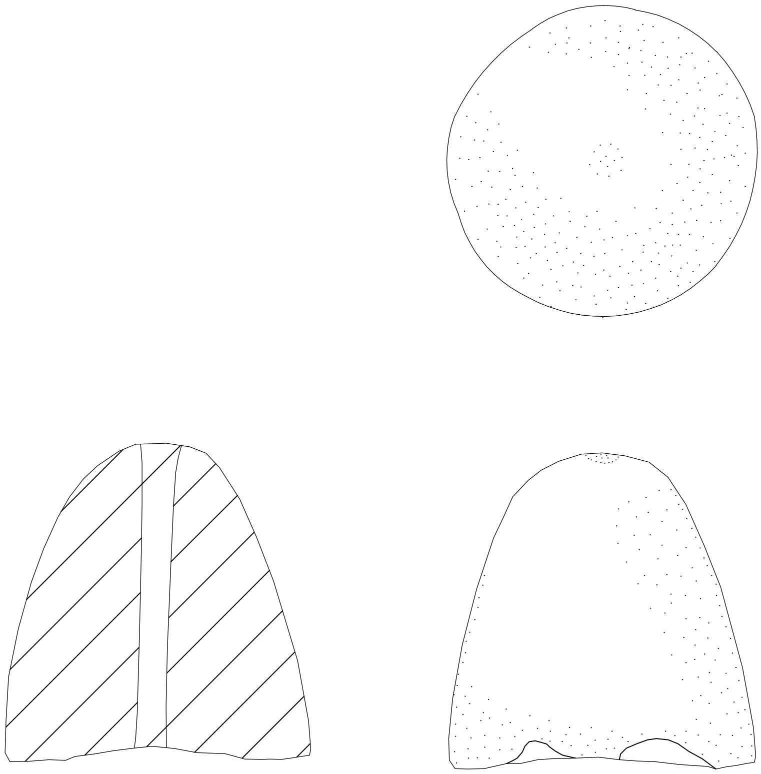


24

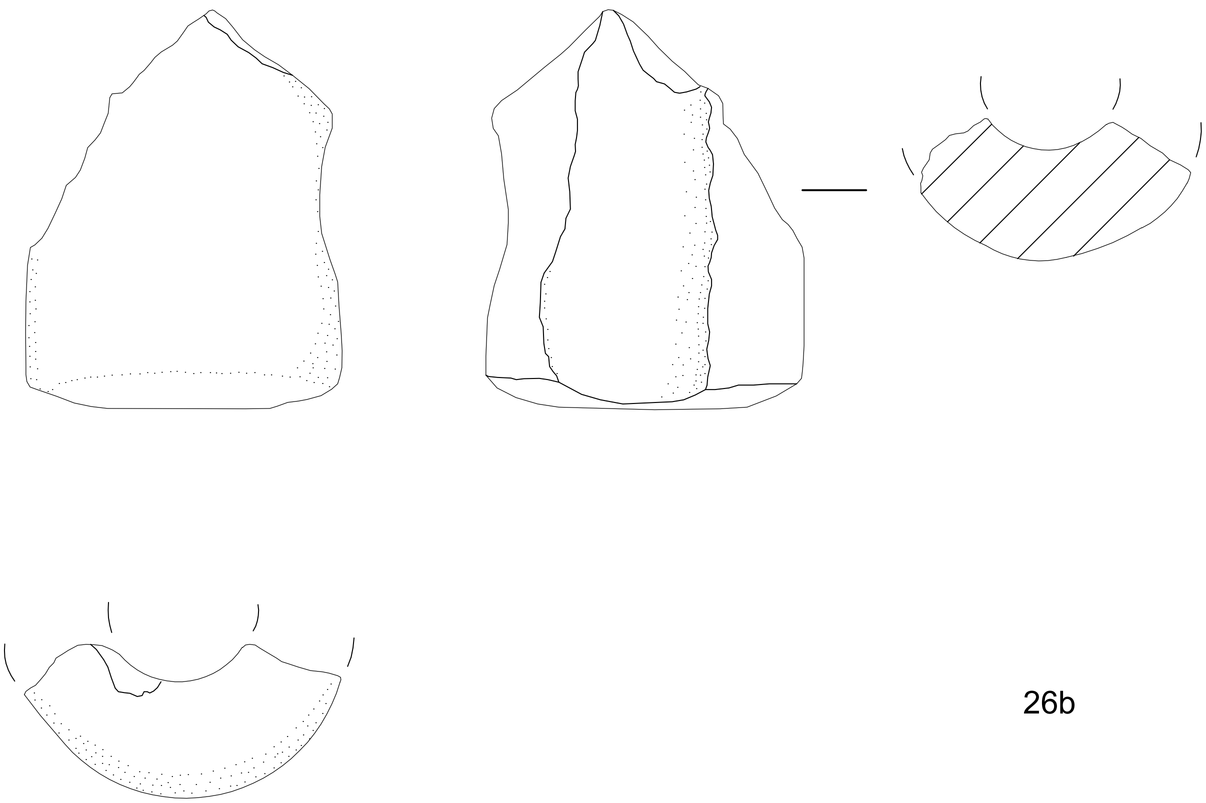


25

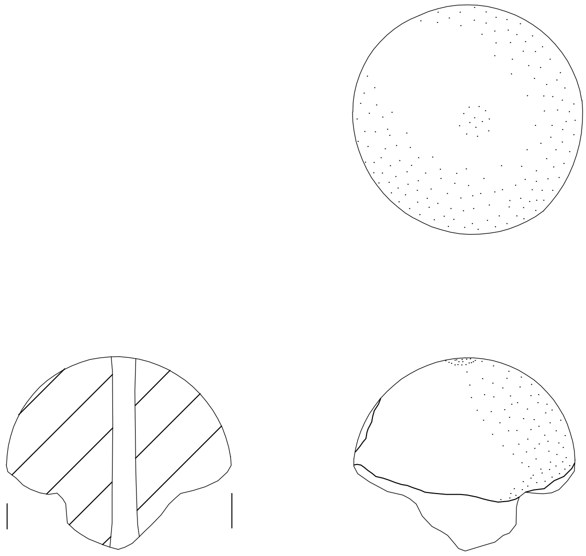




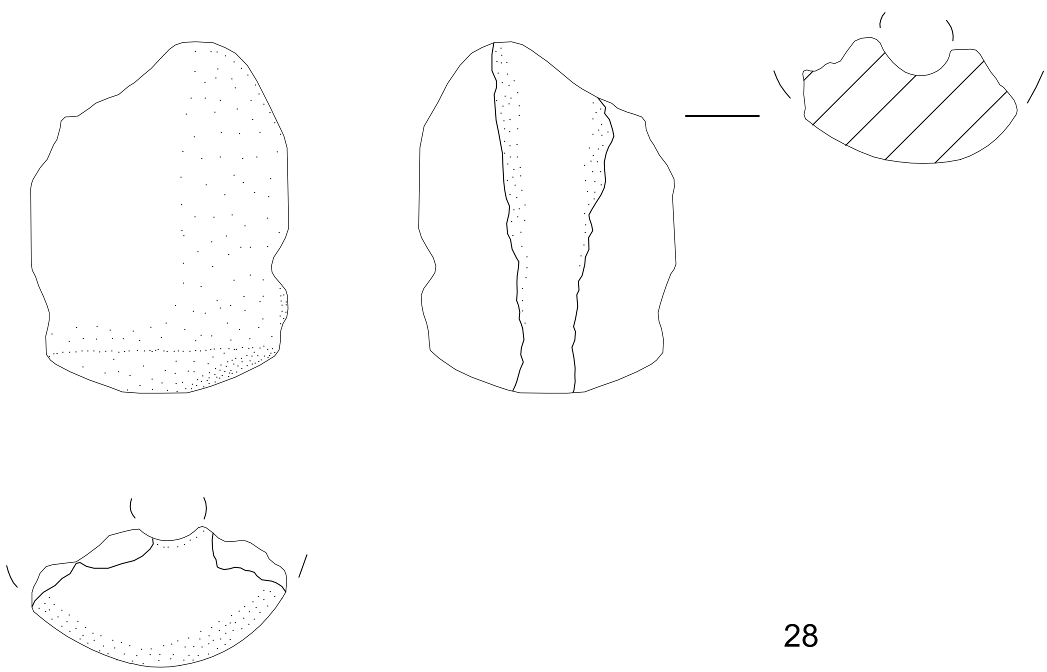
26a



26b



27



28

0cm 5cm