



McDONALD INSTITUTE CONVERSATIONS

# Fuel and Fire in the Ancient Roman World

Towards an integrated economic understanding

Edited by Robyn Veal & Victoria Leitch

# Fuel and Fire in the Ancient Roman World





McDONALD INSTITUTE CONVERSATIONS

---

# Fuel and Fire in the Ancient Roman World

Towards an integrated  
economic understanding

Edited by Robyn Veal & Victoria Leitch

*with contributions from*

Jim Ball, H.E.M. Cool, Sylvie Coubray, David Griffiths,  
Mohamed Kenawi, Victoria Leitch, Archer Martin, Ismini Miliaresis,  
Heike Möller, Cristina Mondin, Nicolas Monteix, Anna-Katharina Rieger,  
Tony Rook, Erica Rowan, Robyn Veal, Véronique Zech-Matterne



This book, and the conference upon which it was based, were funded by: the Oxford Roman Economy Project (OxREP), University of Oxford; a private contribution from Jim Ball (former FAO forestry director, and President, Commonwealth Forestry Association); the British School at Rome; and the Finnish Institute of Rome. The editors would also like to acknowledge the support of the McDonald Institute for Archaeological Research, and the Department of Archaeology (University of Sydney).



*Published by:*

McDonald Institute for Archaeological Research  
University of Cambridge  
Downing Street  
Cambridge, UK  
CB2 3ER  
(0)(1223) 339327  
eaj31@cam.ac.uk  
www.mcdonald.cam.ac.uk



McDonald Institute for Archaeological Research, 2019

© 2019 McDonald Institute for Archaeological Research.  
*Fuel and Fire in the Ancient Roman World* is made available  
under a Creative Commons Attribution-NonCommercial-  
NoDerivatives 4.0 (International) Licence:  
<https://creativecommons.org/licenses/by-nc-nd/4.0/>

ISBN: 978-1-902937-91-5

Cover design by Dora Kemp and Ben Plumridge.  
Typesetting and layout by Ben Plumridge.

Edited for the Institute by James Barrett (*Series Editor*).

---

# CONTENTS

Contributors	vii
Figures	viii
Tables	ix
Preface	xi
<b>Introduction</b> Studying fuel and fire through the integration of ecology, economy, technology and culture	1
ROBYN VEAL	
Research approaches	1
Organization of the book	2
Discussion	3
Further thoughts and questions	4
Conclusions	6
<b>Part I        Science and technology of fuel</b>	
<b>Chapter 1</b> The history and science of fire and fuel in the Roman Empire	11
ROBYN VEAL	
Characterizing the importance of fuel in the economy	11
Calorific potential and efficiency of fuel consumption	13
Factors affecting the wood supply	13
Roman fuel consuming activities: wood or charcoal?	17
Pricing and transport	18
Modelling the size of the wood fuel supply	18
History of wood charcoal analysis	19
The reflectance technique: differentiating raw wood and charcoal fuel	19
Conclusion	20
<b>Chapter 2</b> Glass and fuel	25
H.E.M. COOL	
The development of the glass industries	25
Glass chemistry, manufacture and melting temperatures	26
Putting the numbers together	29
<b>Chapter 3</b> Problems in estimating fuels consumed in buildings: fuel requirements of hypocausted baths	35
TONY ROOK	
Simplified calculation of heat loss from buildings	35
Openings	35
Heat requirements of a simplified <i>caldarium</i>	36
Inside temperature	36
The structure of a hypocausted building	37
The fuel consumption of a hypocaust	37
Conclusions	37
<b>Chapter 4</b> Throwing money out the window: fuel in the Forum Baths at Ostia	39
ISMINI MILIARESIS	
The windows of the Forum Baths at Ostia	39
The effects of window glazing	42
Heat study method and initial results	43
Conclusion	47

<b>Part II</b>	<b>Fuel in ceramics making: ancient and modern examples</b>	
<i>Chapter 5</i>	Fuelling Roman pottery kilns in Britain and North Africa: climatic, economic and traditional strategies	53
	VICTORIA LEITCH	
	Kilns	53
	Choice, location and collection of North African fuel	57
	Economic factors	58
	Conclusions	59
<i>Chapter 6</i>	Kilns in a wood-poor environment: traditional workshops in the western delta of Egypt	63
	ARCHER MARTIN	
<i>Chapter 7</i>	Necessity is the mother of invention: the fuel of Graeco-Roman pottery kilns in the semi-arid Eastern Marmarica	71
	HEIKE MÖLLER & ANNA-KATHARINA RIEGER	
	The fuel consumers: pottery production and kilns in the Eastern Marmarica	71
	How to generate biomass	76
	Botanical remains from Wadi Qasaba	80
	Botanical remains from Wadi Umm el-Ashdan	82
	Modern pottery workshops – an ethnoarchaeological approach to fuelling kilns	84
	Conclusion	84
<i>Chapter 8</i>	Continuity of production: kilns and fuel in Egypt and the Mediterranean	87
	MOHAMED KENAWI & CRISTINA MONDIN	
	Hellenistic and Roman kilns: the evidence	87
	Medieval to Early Modern kilns: the evidence	88
	Modern Egyptian kilns in Fayoum	89
	Modern kilns in the Mediterranean	92
	Discussion	95
<b>Part III</b>	<b>Alternative fuels to wood: olive pressings and oil</b>	
<i>Chapter 9</i>	Commercialization of the night at Pompeii	99
	DAVID G. GRIFFITHS	
	Pompeii: a case study	99
	Quantifying consumption	104
	Conclusions	106
<i>Chapter 10</i>	The utility of olive oil pressing waste as a fuel source in the Roman world	109
	ERICA ROWAN	
	The properties of pomace	110
	Quantities generated in the Roman Empire	111
	Consequences of quantity	111
	The case of Lepcis Magna	113
	Rome's challenge and solution	114
	Conclusions	116
<i>Chapter 11</i>	Of olives and wood: baking bread in Pompeii	121
	SYLVIE COUBRAY, NICOLAS MONTEIX & VÉRONIQUE ZECH-MATTERNE	
	Sampling macro-remains	121
	Results of the plant remains study	123
	Interpretation of plant assemblages	124
	Charcoal assemblage	125
	Olive pressing by-products used as fuel	125
	Conclusion	131
<i>Epilogue</i>	Final discussions	135
	ROBYN VEAL & JIM BALL	
	Introduction (Robyn Veal)	135
	Wood fuels in the present-day context, or 'What can the past learn from the present?' (Jim Ball)	135

---

## CONTRIBUTORS

DR ROBYN VEAL

McDonald Institute for Archaeological Research,  
University of Cambridge  
Downing Street, Cambridge, CB2 3ES  
Department of Archaeology, University of Sydney  
Camperdown, NSW 2006, Australia  
Email: rjv33@cam.ac.uk  
Website: www.robynveal.com

DR VICTORIA LEITCH

School of Archaeology and Ancient History,  
University of Leicester  
University Road, Leicester, LE1 7RH  
Email: vl46@le.ac.uk

JIM BALL

Formerly Food and Agriculture Organization,  
Rome  
Email: jbball1@yahoo.co.uk

DR H.E.M. COOL

Barbican Research Associates  
Email: hilary@coolarchaeology.com

DR SYLVIE COUBRAY

INRAP/MNHN, UMR 7209 Archéozoologie,  
Archéobotanique: sociétés, pratiques et  
environnements)  
National d'Histoire Naturelle, Paris  
Email: sylvie.coubray@inrap.fr

DR DAVID GRIFFITHS

Independent researcher  
Email: david.griffiths1973@gmail.com

DR MOHAMED KENAWI

EAMENA Project, School of Archaeology,  
University of Oxford  
Email: mohamed.kenawi@arch.ox.ac.uk

DR ARCHER MARTIN

Independent researcher  
Email: archer.martin@alice.it

DR ISMINI MILIARESIS

University of Virginia, Charlottesville, VA, USA  
Email: iam5f@virginia.edu

DR HEIKE MÖLLER

German Archaeological Institute, Berlin  
Email: heike.moeller@dainst.de

DR CRISTINA MONDIN

Padua University and Asolo Museum  
Email: cristina.mondin@unipd.it

DR NICOLAS MONTEIX

Département d'histoire, Université de Rouen  
1 Rue Thomas Becket, 76130, Mon-Saint-Aignan,  
France  
Email: nicolas.monteix@univ-rouen.fr

DR ANNA-KATHARINA RIEGER

Institute of Classics, University of Graz, Austria  
Email: anna.rieger@uni-graz.at

TONY ROOK

Independent researcher  
Email: tony.rook@virgin.net

DR ERICA ROWAN

Department of Classics, Royal Holloway, University  
of London, London  
Email: Erica.Rowan@rhul.ac.uk

DR VÉRONIQUE ZECH-MATTERNE

CNRS/MNHN UMR 7209 AASPE  
Centre national de la Recherche Scientifique  
UMR 7209 team, Muséum National d'Histoire  
Naturelle, Paris  
Email: veronique.zechmatterne@mnhn.fr



## Figures

1.1	An example of a microphotograph of deciduous oak from Ostia synagogue.	15
1.2	Modern 'smallwood' (or coppice) being taken to market in the Sarno valley, Campania.	16
1.3	Probable fuel types for different activities.	17
4.1	Plan of the modern remains of the Forum Baths at Ostia.	40
4.2	Plan of the modern remains of Room 15.	41
4.3	Plan of the modern remains of Room 16.	41
4.4	Plan of the modern remains of Room 17.	41
4.5	Plan of the modern remains of Room 18.	41
4.6	Plan of the modern remains of Room 19.	41
5.1	Kiln at Oudhna, Tunisia.	56
5.2	Schematic plan of the Leptiminus kiln site.	56
5.3	Kiln at Moknine pottery production site today.	57
6.1	Location map of the production centres discussed.	64
6.2	Pots at Idfina.	65
6.3	Workshop at Idfina with piles of sugar cane pressings and scrap wood and a kiln.	66
6.4	Adding sawdust to a beginning firing at Rahmaneyah.	66
6.5	Adding scrap wood to an ongoing firing at Damanhur.	67
6.6	Ongoing firing with agricultural waste at Gezira Isa.	67
7.1	Map of the Marmarica showing the investigation area. Pottery production sites in the Eastern Marmarica	72
7.2	Natural prerequisites along the coastline in the Eastern Marmarica.	73
7.3	Wadi Qasaba. Trench of the wasters heap. Pressing facility.	74
7.4	Wadi Umm el-Ashdan. Reconstruction of the pottery kiln. Trench of a pottery kiln.	75
7.5	Wadi Umm el-Ashdan. Different agricultural areas in the watershed system.	77
7.6	Wadi Umm el-Ashdan. View on planting mounds as they appear on surface (teleilat el-einab). Wadi Umm el-Ashdan. Excavation of a stone mound.	78
7.7	Archaeobotanical remains from Wadi Qasaba and Wadi Umm el-Ashdan: Wood of a <i>Tamarix</i> sp. Wood of <i>Vitis vinifera</i> .	79
7.8	Archaeobotanical remains from Wadi Qasaba: <i>Hordeum vulgare</i> , <i>rachis</i> , and <i>Triticum aestivum</i> , <i>caryopsis</i> . <i>Triticum aestivum</i> , <i>caryopsis</i> .	80
7.9	Vegetation in the Wadi Umm el-Ashdan and Wadi Kharouba: <i>Salsola</i> and <i>Artiplex Halimus</i> , <i>Chenopodiaceae</i> species. Vegetation in the desert of the Marmarica Plateau: <i>Acacia</i> .	81
7.10	Archaeobotanical remains from Wadi Umm el-Ashdan: <i>Ficus carica</i> , <i>achene</i> . <i>Fabaceae</i> , <i>seed</i> .	83
8.1	Small kilns at Tell Timai in the eastern delta.	88
8.2	Map of the modern production sites mentioned in this chapter.	89
8.3	Kilns and pottery at al-Nazla, Fayoum.	90
8.4	Kilns and pottery at al-Nazla, Fayoum.	90
8.5	Kilns and pottery at al-Nazla, Fayoum.	90
8.6	Pottery produced in Tunis, Fayoum.	91
8.7	Kiln at Tunis, Fayoum.	92
9.1	Number of game days at Pompeii.	101
9.2	The apodyterium at the Forum Baths.	103
9.3	Length of daylight hours for Pompeii, Italy.	105
10.1	Hypothetical divisions of pomace fuel usage in the hinterland of Lepcis Magna.	114
11.1	Changes in bakery I 12, 1-2 in Pompeii between its building and the Vesuvius eruption.	122
11.2	Section view of beaten earth layers in bakery I 12, 1-2 during excavation.	122
11.3	A Pompeiian bakery oven during heating and baking phases.	127
11.4	Distribution plans for <i>Olea europaea</i> and charcoal fragments in bakery I 12, 1-2 during the first and second phases.	128
11.5	Distribution plan for <i>Olea europaea</i> and charcoal fragments in bakery I 12, 1-2 during the last phase.	129
11.6	Oil presses and perfume workshops in Pompeii.	129
11.7	Known villas with trapetum around Pompeii.	130
11.8	Variations of land use for olive trees according to the culture mode and the estimated Pompeiian population.	130

---

## Tables

1.1	<i>Approximate relative heat values of different fuel types, drawn from a range of sources.</i>	13
2.1	<i>Key temperatures in the working of soda-lime-silicate glass.</i>	29
2.2	<i>Fuel consumption recorded by the Roman Glassmakers furnace project.</i>	30
4.1	<i>Room 18 with unglazed windows.</i>	44
4.2	<i>Room 18 with glazed windows.</i>	44
4.3	<i>Room 18 with windows in January on a cloudy day.</i>	45
4.4	<i>Room 18 with both glazed and double-glazed windows.</i>	46
4.5	<i>Room 18 with unglazed, glazed and partially open windows.</i>	46
4.6	<i>Room 18 with unglazed and glazed windows with no shutters, and unglazed and glazed windows with closed shutters.</i>	47
7.1	<i>Botanical finds from the large pottery production site in Wadi Qasaba.</i>	82
7.2	<i>Botanical finds from the area of the settlement in Wadi Umm el-Ashdan.</i>	83
8.1	<i>Calorific value of various natural fuels.</i>	94
9.1	<i>Lighting equipment from ten Pompeiian households.</i>	100
9.2	<i>The ceramic oil lamps from Casa del Chirurgo, Insula VI. 1.</i>	104
9.3	<i>Estimated light fuel consumption for 95 commercial structures, ten households and the Forum Baths.</i>	105
10.1	<i>Domestic uses of pomace.</i>	112
10.2	<i>Quantities of pomace required to heat the water used for one press and then all presses in Rome's hinterland during a single 90-day pressing season</i>	115
11.1	<i>Relative importance of the main species identified.</i>	123
11.2	<i>Fragmentation of the Olea remains: comparison between the concentrations and the occupation levels.</i>	124
11.3	<i>Summarized results of charcoal analysis: absolute, relative and ubiquity frequency of the taxa.</i>	125



---

## Preface

This book arises from a conference held at the British School at Rome, and the Finnish Institute in Rome, in March 2013, entitled *Fuel and Fire in the Ancient Roman World*. The conference represented the first real attempt to try to bridge the gap between ‘top-down’ generalized models about Roman energy consumption (itself, still a relatively new area of research), and research carried out by artefact and environmental specialists. In many ways it exceeded our expectations, although it probably raised more questions than it answered. As fuel is used in many different domestic and industrial contexts, the papers were very heterogeneous; some presenters came from a strong archaeobotanical background, which is a central area for fuel research, while others came from social, technical and economic spheres, opening up the discussion beyond archaeobotany. Some papers presented more ‘qualitative’ rather than ‘quantitative’ results but, as a new research area, this was inevitable and qualitative evaluation can provide the framework for approaching quantitative studies. Nevertheless, useful quantitative beginnings are proposed in a number of papers. Although focused on the Roman period, the research often extended beyond this chronological span, to help contextualize the results.

We gratefully acknowledge the support and assistance of the British School at Rome and the *Institutum Romanum Finlandiae* (Finnish Institute of Rome). In particular we thank Professor Katariina Mustakallio, then director of the *IRF*, for generously hosting the conference lunch on the final day. The financial support of the Oxford Roman Economy Project, through

Professor Andrew Wilson, and a significant private donation from Mr Jim Ball, former President, Commonwealth Forestry Association (administered through the BSR Rickman Fund) allowed speakers’ travel, accommodation and subsistence costs to be covered, as well as a contribution towards publication costs. Professor Wilson and Mr Ball both provided much appreciated moral support and intellectual input, acting as our major discussants. The McDonald Institute for Archaeological Research, through its Conversations series, also helped fund publication. Professor Graeme Barker (McDonald Institute director to September 2014), Professor Cyprian Broodbank (current director), Dr James Barrett (current deputy director) and Dr Simon Stoddart (former acting deputy director) all provided advice and guidance over time. This was much appreciated. Dora Kemp provided initial advice on manuscript preparation, and after her untimely death, Ben Plumridge took over the practical side of production. Maria Rosaria Vairo, then a Masters student of the University of Lecce, and Dana Challinor, a doctoral student at the University of Oxford, provided significant voluntary support during the conference and we thank them both profusely. Robyn Veal would also like to acknowledge the long-term financial and intellectual support of the Department of Archaeology, University of Sydney, through much of her early work on fuel. This led to the opportunity of a fellowship at the BSR, and the idea for this conference. The feedback from reviewers has greatly improved the book.

Robyn Veal & Victoria Leitch





---

## *Introduction*

# **Studying fuel and fire through the integration of ecology, economy, technology and culture**

Robyn Veal

Fuel consumption is an essential aspect of modern economic studies, and a crucial part of GDP, but it has only recently started to receive attention in ancient studies. To understand Roman uses of fuel and fire we must synthesize information from a large range of sources. Base environments, i.e. geology/soils, climate and topography, together with ecological details of plants, help us to understand supply areas for fuel. Ancient economies, populations, societal structures and behaviour help us to understand cultural uses of fuel. Ancient technologies viewed through the lens of modern science help us interpret these activities more fully. The ancient literary and artistic sources, coupled with the burgeoning archaeological (charcoal) evidence, provide direct input from the ancients themselves, and this evidence needs to be evaluated carefully.

Regions and provinces have differing micro-climates, soils and populations, and differing levels of adoption and adaptation of so-called 'Roman' technology and socio-cultural mores. All of these affect fuel supply and consumption. In structuring the conference, we recognized that it would not be possible to have representative papers from all of the geographic regions of the Roman Empire, nor cover the wide arena of nuances in societal structures in the provinces. For this discussion, we wished to focus on fuel-consuming technologies and their individual consumption levels. While social structures and dietary habits help to delineate both industrial and domestic fuel consumption, we have not here explicitly considered domestic consumption, although many charcoal reports for various Roman dwellings exist (for Campania, see Veal 2012, 19–52, 2014, 27–44, 2018, 516–24; Moser et al. 2013, 397–408; Vairo et al. 2015, 71–8). There is an abundance of literature for the rest of the empire as well. Fuel for food production is also not specifically considered in this volume, but see Veal (2017, 32–7).

Jim Ball, in his entertaining view of modern forestry and fuel consumption (Epilogue), notes that domestic round-wood (i.e. 'coppice') consumption exceeds industrial wood consumption in developing countries that are still wood dependent. Projecting modern patterns too forcefully back into the ancient world is inadvisable, but it may be that resolving the quantities and types of fuel used in ancient technology will only signify around half of the volume of fuel consumed; also, separating out domestic and industrial uses is not always easy (discussed below). Archaeological visibility is much greater for urban centres, and for the rich. It will remain a challenge to evaluate fuel consumption of the poorer members of society. Some technologies also leave poor archaeological traces (e.g. glass). Instances where fuel types are less well (or not at all) preserved in the archaeological record, continue to challenge us (such as chaff and oils, which burn to completion) and yet, overall, the data available have increased enormously in the last ten years, and this conference sought to explore and exploit those data.

### **Research approaches**

Speakers from differing national research paradigms were invited, since fuel research is still a relatively new discipline, and approaches vary. Some research centres employ ethnographic comparisons, some focus on socio-cultural background, and others much more on excavation or laboratory methods. All are important, and understanding the range of approaches in their totality is an essential path towards an 'integrated economic understanding' of fuel in the Roman Mediterranean. The study of fuel economics must of necessity include a detailed and diligent approach to: systematic data collection in the field; consistent laboratory techniques for wood identification and estimation of cropping indicators among other

techniques; and placement of the results in the local geological, climatic and historical milieu. The same criteria apply to 'alternative fuels'. In this workshop, charcoal analysts were pushed to move beyond their comfort zones making lists of wood taxa, into the realm of estimating fuel consumption. Specialists in various artefact or technology areas were encouraged to move outside their areas of expertise in classifying and describing their artefacts and technologies, to finding the role that fuel may have played. The majority of the papers approached the topic from a case study basis, providing the beginning of the bridge from 'bottom-up' lists of wood taxa to 'top-down' holistic studies of the economy. Many also included preliminary assessments of fuel quantities.

## Organization of the book

### *Part I – Science and technology of fuel*

The first chapter on the history and science of fuel and fire (Veal), provides some background for the papers which follow. It broadly reviews the factors that impact the production of fuel, its transport and marketing, and its consumption in the Roman period. The second chapter by Cool, on glass and fuel, describes the history of glass-making across time and space, contextualizing those aspects of the technology that expanded in the Roman period. She expertly presents the chemistry and technology involved in glass-making and -working, and estimates the cost of producing one object (in terms of fuel); the calculations lead to an astonishing conclusion. Clearly glass-making, from raw (billet) production to intricate finished articles, uses a very large amount of fuel, and the actual cost does not appear to be factored into their sale prices.

In the third and fourth chapters, fuel in Roman baths is explored using two different and complementary approaches. Miliaresis examines, in a tightly detailed model, how much fuel might be saved through the use of window coverings in the Roman Forum Baths at Ostia. Detailed mathematical analyses allow her to draw conclusions about when and how these potential coverings (whether glass or wooden) could have affected heat retention. She allows for seasonal variation. Rook, conversely, overviews in a broad manner all of the variables needed to estimate the heat required for a *caldarium*, and the types of calculations required. The breadth of these variables is such that he does not (and could not easily) provide detailed calculations, but instead he points the way forward. He notes that one aspect of Roman bathing is that every bath installation is different. Miliaresis' case study is a 'bottom-up' approach, while Rook's is 'top-down.' They complement each other well,

but there is a lot of scope for further work before these approaches can be made to meet in the middle. Another approach to estimating Roman bathing fuel requirements is the building of experimental baths, and the subsequent actual measurement of fuel used. Rook visits this topic briefly in two examples. Heating the baths up from cold takes a very large amount of fuel, while 'topping up' to keep them running does not. This suggests perhaps that Roman baths (at least public ones) were unlikely to be allowed to cool down much overnight when not in use.

### *Part II – Fuel in ceramics making: ancient and modern examples*

The next four chapters read together provide a comprehensive view of fuel used in ceramics kilns through focused case studies. Leitch compares pottery kilns and their fuel in Britain with those of North Africa. Her chapter, more than any other, highlights the fact that fuel use is highly location dependent. The ceramics industry in Britain, producing reasonably similar products, accessed standard deciduous leaf woodlands as its major fuel source. In contrast, in North Africa (with a completely different climate and soils), agricultural residues (particularly olive pressings) and some of the native scrubland were used.

The remaining chapters focus substantially on different sites in Egypt, exploring fuel use in wood-poor areas. Martin, using an ethnographic approach, finds that almost anything to hand that is organic waste is currently used for fuel in modern traditional workshops in the Egyptian delta. This not only includes the expected agricultural residues, but also (modern) broken up wooden pallets. This reminds us that packaging in the Roman world was also probably a good source of fuel. Möller & Reiger's study of the Marmarica valley, northwest Egypt (Ptolemaic to Late Roman periods), examines the archaeological fuel residues. In what is a fairly arid zone, they describe the surprising size and complexity of agricultural production, including vines and olives (with pressings and cuttings used as fuel in both cases). Large numbers of kilns and waster heaps were found. They observe that when olive cuttings went down in numbers, vine cuttings went up (over time). A similar (but opposite) pattern appears for the pressings of each. Seasonal behaviour is thus well reflected, and we can envisage a very busy landscape, despite its lack of water (or rather because of its careful harvesting). Kenawi's examination of modern kilns in Fayoum, now using ancient firing techniques to recreate ancient forms, sees olive residues and other cereal waste being used. In an ethnographic example from Spain, almond shells are added at the end of the

(modern gas-based) firing process to re-create more accurately the colours of ancient cookware. He notes a temperature range of 700–800 °C, and provides us with useful detail on times required to heat up and cool down kilns (sometimes a week to ten days), and estimates of fuel used.

The papers together demonstrate some common features. The ethnographic information from modern kilns operated along ancient lines reveals that little has changed with time. Almost any organic waste can be used as fuel, and agricultural wastes such as olive pressings were preferred (and delivered a high heat value, and little ash, making cleaning easier). Fuel wastes were rarely found in the firing chambers of ancient kilns, but more generally in waster heaps. This phenomenon is also true for baths, metal smelting/smithing and bakeries. Fuel remains are rarely found directly *in situ*. Production facilities are cleaned regularly. Early discoveries of ‘clean’ kilns led archaeologists to bemoan the lack of residues, but we know now to look underfoot for waste trodden into floors, and for rubbish deposits nearby. Indirect firing chambers (with an open ‘floor’ or flu system to separate combustion smoke/vapours from product) use more fuel than direct firing chambers (pots fired on the floor of a kiln with a firing chamber that feeds directly into the area, or more primitively, pots fired in a large covered hole). How much more fuel indirect firing uses, as opposed to direct firing, is an area ripe for study. While production of standard early Republican cookware appeared to use mostly direct kiln strategies, the rise of demand for and supply of increasingly complex and delicate pottery through the Imperial period (thin-walled and red-slip wares), must have led to a far greater increase in fuel consumption than just population growth might suggest. While agricultural residues included the olive and vine wastes already mentioned, wheat chaff and that of (especially) barley were common. Wadis and oases in rural areas provided access to limited arid zone trees, particularly acacia (wattle) types and tamarisk. These two wood genera also appear in a small prehistoric assemblage from Farafara (Veal, unpub.), and at Roman Utica (Veal, forthcoming). While the Sahara may have grown and shrunk over time, the major desert wadi woods appear to have been permanent. Various types of saltbush are used as fuel in a number of sites. These would have functioned as a fuel source that builds temperature quickly (rather like gorse or broom in wetter climes, or wheat/barley chaff in many locations). A good deal of continuous manual effort would have been required to keep a fire stoked, if these ‘inferior’ lower calorific potential fuels were used, compared with kilns in places where wood was

available, for example Britain, northern Europe and parts of southern Europe where rainfall was sufficient for trees (above 400 mm p.a., or so).

### *Part III – Alternative fuels to wood: olive pressings and oil*

Three chapters here focus on olive pressings (pomace) and olive oil as fuel. Griffiths lays out a detailed discussion of lighting in Pompeii (at AD 79), focused on the use of olive oil in lamps (he acknowledges other fuels can be used). This is an innovative study. He argues for lighting both inside and outside, and especially in the baths and entertainment areas at night. He assesses lamp types and potential numbers, and produces some useful preliminary calculations on oil fuel volumes required, based on oil burning rates. Rowan’s chapter explores olive pressings (pomace) as fuel. Rowan, as did Cool, frames her study more widely chronologically, and usefully compares the utility of pomace with wood fuels, including charcoal. Where olives dominate semi-arid and arid zones, olive pomace is found as fuel. Rowan also models her data to calculate the calorific contribution pomace might make to the fuelling of Roman industry. However, pomace is not only used in wood-poor areas. In the last chapter of this section Coubray, Zech-Matterne & Monteix produce a detailed evaluation of fuel used in some Pompeian bakeries, the majority of which is pomace, (with a very small quantity of wood as well). The small number of wood types found differ little from other Pompeian fuel studies.

This pomace, found in Pompeii, a city in a wood-abundant region, raises a number of questions. Where did it come from? How big was olive cultivation in Campania? Data from Veal’s Pompeian fuel studies, and those underway in different locations in Pompeii (D. Challinor, PhD in prep.), and also those from further afield in Campania, have not yet uncovered the use of olive pomace as domestic fuel. It must be pointed out, though, that olive seeds are often very prolific in food assemblages. Murphy (2015) and other researchers, including Rowan, have found a large number of olive seeds in sites in Pompeii and Herculaneum. Murphy (in Pompeii *Regio VI.1*) deduces these are probably food refuse, but does not discount the idea that they could also represent some use of pomace as fuel. Rowan, examining a large Herculaneum drain, believes olive pomace has been used as fuel. More detailed studies of the remains are possibly needed for certainty. Very little olive *wood* has been found archaeologically speaking in Pompeii (very few fragments found in four centuries in four houses/areas in Veal’s studies of 2014 and 2018). Further adding to this puzzle, pollen studies in the region do not show very much olive either in the period (and olive is a



big pollen producer); see, for example, Russo Ermolli et al. (2014, 399–411). A broader landscape study investigating grape and wine production in Campania demonstrates a very high intensity of wine production at AD 79 (De Simone 2017, 23–51). De Simone did find one pile of olive pomace drying out at one large rural villa, but his major finding was that the size and scale of wine production was so high as to suggest its dominance in the landscape. These data are beginning to point to production of wine in Campania on a large comparative advantage basis (over olive). Some olive was obviously grown for local consumption, but not in any great quantity in the first century AD. If Campania (and possibly Latium), due to climate, soil and perhaps price/market advantages, produced a lot more wine than oil in the Imperial period then we must ask just how significant were the imports of olive oil (and preserved olives) from other Italian and provincial regions? This is a topic too large to discuss in much more detail here, except to suggest that perhaps large-scale comparative advantage agriculture was being carried out in some parts of the empire, at least for a short period. It points to a sophistication of agricultural and economic supply that was possibly more organized and advanced than we might have allowed previously. This research continues.

The question of pomace's overall contribution to the ancient economy as a whole remains somewhat open, since volumes of pomace produced can only be estimated from a calculation of oil production, itself only broadly estimable in the empire in any one year. Even today, pomace is a valued fuel, especially in wood-poor areas.

### Further thoughts and questions

*Is the fuel economy strictly related to the agrarian economy?*

An assumption that the fuel economy is strictly related to the agrarian economy might be formed from these chapters, as several of them associate agrarian waste production with ceramics production. However, it should be recalled that the ceramic production sites mentioned here were located in wood-poor areas, and so agricultural waste was the natural (and in some cases, the only) alternative. 'Non-agricultural' trees growing in desert areas (in and around wadis) do appear in small quantities, but these wattles and tamarisks were the dominant (almost the only) woody species in arid zones on the African continent.

So, this statement appears true for wood-poor areas, where the fuel is close to the production area (which is mostly rural, or at best, near a small town). In most cases, fuel and product are intricately connected.

Olive pomace produced in large quantities in the Roman provinces was used to fuel the kilns that made the transport amphorae used to ship olive oil across the Mediterranean. Was this system seasonal? Was this fuel produced in enough quantity that it could be stored, providing a year-round supply? Was the system closed and completely self-sufficient? These are questions that have been posed before, and still remain to be answered. More detailed modelling and more raw data are required. A particular problem that remains is estimating firing frequencies. Modelling fuel requirements for a range of kiln types would also assist, i.e. developing a 'typology' for kilns directed at analysing heat requirements in relation to carrying capacities, and further, ceramics demand in different classes of product.

What about areas that were well wooded, such as Italy? Supply of the olive pomace for the bakeries in Pompeii (Coubray et al.) and olive oil for lamps (Griffiths), and more generally wood and charcoal fuel for larger cities such as Rome, may not necessarily have been so closely tied to their particular agricultural hinterlands. Wider, and more diverse supply arrangements appear probable, if only because of the volumes and distances involved to reach major wood-growing areas. Cities may have demanded a wider range of products (for example, charcoals of varying 'quality', woods of different heat values, woods cut to a particular size (such as kindling), or fragrant woods (for ceremonial purposes)). In one context in the House of the Vestals, very specific woods in a clearly identified ritual deposit represented the fruits and nuts sacrificed, among other unusual woods, as opposed to the 'run of the mill' fuel remains in scattered secondary contexts in the rest of the house (Veal 2014, 27–44). Rome (and even Pompeii) had industrial ceramic kilns on the edge of the city. Late Roman evidence for small-scale metal smelting and smithing in the Roman Forum (under Santa Maria Antiqua (Veal, forthcoming), and elsewhere in the Forum), would have required high-quality charcoal. Rome's requirements for fresh food and flowers pushed larger timber and fuel cultivation further out, all the way to the mountains (and for timber at least, even further across the Mediterranean). Was the raw wood and wood charcoal supply in fact mostly disconnected from other agricultural activities in the case of Imperial Rome? Supplies perhaps arriving independently from a variety of sources? Wood fuel (and other fuels) are seen as 'free' (or nearly free) goods, but was this really true if it was transported a long way to a large city? In the case of pomace in the bakeries, it appears Pompeii did not have a huge number of olive trees growing close to town (or even perhaps many growing in the whole region in the Imperial period, as

discussed above), although olive trees have been found in small numbers in individual gardens. Cereals and other fruits/nuts dominate pollen evidence, and the same fruit and nut trees appear in fuel assemblages, but only in small numbers. The majority of Pompeii's fuel consisted of the range of mostly soft-leaved large trees we would expect including oak (deciduous and only a few instances of evergreen), maple (several types), very few conifers, and much beech.

More broadly, development and expansion of the Roman fuel economy were tied especially to technological advancement and population increase, which themselves were related to the *pax Romana*. Long-term peace facilitated the empire-wide trade and connections that allowed transfers of technological skills. Apart from the *pax Romana* as a prime mover in technological advancement, the fuel economy in any one place is greatly determined by the limits of soils, climate and topography. Areas of poor soils and low precipitation support far fewer tree types for use as fuel. This could be mitigated by good water management in order for agriculture to prosper, but whole forests for fuel use could not be supported by irrigation in arid areas.

#### *Domestic vs industrial consumption*

We have focused here on industrial consumption, (particularly ceramics), although the published reports of Veal relating to Pompeii mostly deal with domestic consumption, and a few other examples were provided earlier in this introduction. One characteristic of note is that elite Roman houses often included industrial or retail spaces (at the front or back of the main house), so separating out 'domestic' and 'industrial' consumption requires careful consideration. The House of the Surgeon in Pompeii housed an iron smithy in one front room (Veal 2018, 516–24). The nature of the charcoal was very different to that found distributed in other parts of the building. It was 'harder' (a higher quality charcoal), more uniform in size, and there were fewer wood types. In other domestic rooms, charcoal remains showed a greater diversity in size and a higher number of wood types. This pattern is observable in other parts of Pompeii (in the area near the Porta Stabia where more modest housing and more light industry existed). Owners/operators of workshops often lived beside or inside their production areas. We have not yet fully explored how separate the fuel supply systems may have been for these differing uses, but in Pompeii 'industrial strength charcoal' would have been charcoalified to a much greater degree to achieve the quality of charcoal required, compared to that used in kitchens. Charcoal production took place in the mountains where wood grew in abundance. Wood was cropped (potentially sorted) and dried prior to

making the charcoal. The dominant wood at Pompeii is beech, which only grew in abundance some 20–25 km away from the city, and only above 600 m (and more commonly probably above 900 m) (Veal 2012, 19–52).

#### *Urban vs rural consumption*

No paper presented at the conference specifically included a direct comparison of urban and rural sites. One example is the work of Maria Rosaria Vairo, who compared charcoals from several sites in Campania (Vairo et al. 2015, 71–8) with charcoals found in one site in Pompeii. Her research shows that rural villas appear to exploit very nearby resources (i.e. self-supply, which is perhaps unsurprising), while urban houses (such as those in Pompeii) appear to utilize much wood from a longer distance (i.e. probable market supply, although ownership of tracts of mountain land by wealthy city dwellers cannot be discounted). Developing work in Rome and Latium shows similar patterns.

#### *Important omissions*

It has been noted that consideration of the domestic fuel supply is not made in any detail in the papers here; however, the reader has been directed to a small selection of typical single site reports. A large range of reports on charcoal analysed in various houses and towns in the empire have been published, too numerous to mention here. We are yet to aggregate these fully, so as to produce a fuller picture of regional and temporal variation.

The conference participants were unable to hear any presentations on lime production or metals, two areas of high fuel consumption. Lime production uses a great quantity of wood in open fires or in kilns. With metals, fuel estimation is difficult due to recycling (as it is with glass), although significant work has been undertaken by Peter Crew in Britain (Crew 2013, 25–50, summarizes his lifetime's work). A further area of omission is cremation: around 750 kg to 900 kg of wood are required to cremate a body, and further wood was used in (usually regular) celebrations when tombs were revisited. One case study provides data from Gaul (Deforce & Haneca 2012, 1338–48); fuels consumed reflected the major woods available in the environment. A further study in Roman Italy also detected a range of fuels probably local to the environment, and also included cultivated types (Caracuta & Fiorentino 2018, 58–68). With detailed historical and population studies, we may be able to approach some estimates of fuel used in this process.

Scientific studies on the quality and types of archaeological charcoal continue, although challenges exist in terms of having charcoal routinely collected (and analysed) in every excavation. More studies on

the *chaîne opératoire* are needed, in particular the end of the process – sales and marketing, and transport (some aspects will be covered in Veal, forthcoming). Fairly consistent patterns in technological advancement are observable throughout the empire (and through time), but we need to assess more closely the relative consumption levels of differing technologies, and come to an understanding of hierarchy of fuel consumption in different locations. Relative population levels, together with expanding urbanization, are core to the assessment of regional fuel consumption. These are areas of scholarship which also require amplification and better integration with case studies of individual houses, and cities.

## Conclusions

The roles of climate and base geological/geographical environment in determining which materials could possibly be selected as fuel in the very different areas of the Roman Empire, must be emphasized. In accumulating and comparing more studies, we must remember that northern European climes were wetter; Mediterranean locations ranged greatly in precipitation levels and some had high fertility. A range of deciduous and evergreen Mediterranean tree types form the basis of most fuel supplies in these areas, typically oaks, maples, hazels, alders, ashes and beech. Conifers were less frequently used (but can also be less well-preserved in the archaeological record). Maquis (lower-growing scrubland, mostly evergreen) dominates in drier areas where soft-leaved deciduous trees fail to thrive in the Mediterranean. Egypt's highly fertile delta area had access to substantial agricultural wastes, and some trees. Trees were also present (and exist now) on mountains, but clearly limited in terms of area. Generally, many sites on the North African continent had very little access to trees, except for low-growing tamarisks and wattles close to wadis (any superior woods available were more probably used in building; and much timber was imported). More recent research on modern colonial ecological history does support the idea there were few trees in the 'real desert', as misplaced colonial efforts to 'replant trees' failed. Subsequent science showed the indigenous nomads who trod lightly in their environment and moved around had the right idea. The trees in the ancient deltas and on mountains possibly originally existed in greater quantities, but how many there were, and how far these travelled to become fuel, we don't yet know. We have a substantial lack of evidence at present in North Africa (especially pollen). Matters started to improve until recent political instability rendered excavation perilous in many places. Many

sites which were dug before this period of political unrest are still in the process of being published. Most North African sites documented to date were almost wholly dependent on agricultural wastes for fuel, often in a circular relationship with the residues or cuttings of the produce being cultivated (olive oil, wine) providing the calorific input. Olive pomace is a fuel that requires a lot more research, starting with a better recognition of it in the archaeology (as opposed to olive food waste). A better understanding of the volumes and nature of olive cultivation in the Roman world (commercial vs small-scale) is needed. Olive wastes are found in every part of the Roman world (wetter and drier regions), but pomace is more frequently found in more arid locations.

We set out with a goal of heading 'towards an integrated economic understanding' of fuel and fire in the ancient Roman world. We hope the conference and the papers reported here have at least brought into clearer view this important economic subject, even though they cover limited territory. There is some way to go before a truly integrated understanding may be achieved. The avenues forward are many: gathering and analysing more fuel remains; running laboratory and experimental archaeological research to increase the amount of information we can obtain from these finds; and fully integrating developing scholarship on technology, population, urbanization and even climate.

## References

- Caracuta, V. & G. Fiorentino, 2018. Plant rituals and fuel in Roman cemeteries of Apulia (SE Italy), in *The Bioarchaeology of Ritual and Religion*, eds. A. Livarda, R. Madgwick & M. Santiago Riera. Oxford: Oxbow Books, 58–68.
- Crew, P., 2013. Twenty-five years of bloomery experiments: perspectives and prospects, in *Accidental and Experimental Archaeometallurgy*, eds. D. Dungworth & R.C.P. Doonan. (Occasional Publication No. 7.) London: Historical Metallurgy Society, 25–50.
- De Simone, G.F., 2017. The agricultural economy of Pompeii: surplus and dependence, in *The Economy of Pompeii*, eds. M. Flohr & A. Wilson. Oxford: Oxford University Press, 23–51.
- Deforce, K. & K. Haneca, 2012. Ashes to ashes: fuelwood selection in Roman cremation rituals in Northern Gaul. *Journal of Archaeological Science* 34, 1338–48.
- Moser, D., E. Allevato, J.R. Clarke, G. di Pasquale & O. Nelle, 2013. Archaeobotany at Oplontis: woody remains from the Roman Villa of Poppaea (Naples, Italy). *Vegetation History and Archaeobotany* 22, 397–408.
- Murphy, C., 2015. *Romans, Rubbish, and Refuse. The archaeological assemblage of Regione VI, insula I, Pompeii*. Oxford: Archaeopress.
- Russo Ermolli, E., P. Romano, M.R. Ruello & M.R. Barone Lumaga, 2014. The natural and cultural landscape of Naples (southern Italy) during the Graeco-Roman and

- Late Antique periods. *Journal of Archaeological Science* 42, 399–411.
- Vairo, M.R., R. Veal & G.F. De Simone, 2015. L'evidenza per l'economia del legno e legna in Campania: i carboni dal nord Vesuvio del tardo antico. *Rivista di Studi Pompeiani* XXIV – 2013, 71–8.
- Veal, R., 2012. From context to economy: charcoal as an archaeological interpretative tool, a case study from Pompeii, 3rd century BC to AD 79, in *More than Just Numbers: The Role of Science in Roman Archaeology*, ed. I. Schrufer-Kolb. (*Journal of Roman Archaeology* Supplementary Series 91.) Portsmouth, RI, 19–52.
- Veal, R., 2014. Pompeii and its hinterland connection: the fuel consumption of the House of the Vestals, c. third century BC to AD 79. *European Journal of Archaeology* 17(1), 27–44.
- Veal, R., 2017. Fuel in ancient food production. *Tijdschrift voor Mediterrane Archeologie (TMA)* 56, 32–7.
- Veal, R., 2018. Fuel and timber in the *Casa del Chirurgo*, in *House of the Surgeon, Pompeii: Excavations in the Casa del Chirurgo (VI 1, 9-10.23)*, eds. M. Anderson & D. Robinson, 516–24.
- Veal, R., forthcoming. *Fuelling Pompeii*. London: Accordia Research Institute.





*Part I*  
**Science and technology of fuel**



---

## Chapter 1

# The history and science of fuel and fire in the Roman Empire

Robyn Veal

The Romans had strong technological skills that were applied to all aspects of life, from public to private domains, and most required the employment of fuel. Architectural advances were facilitated by waterproof cement and the use of higher-level mathematics to build large domes; road and shipbuilding became highly developed; and water management through the construction of large-scale aqueducts fundamentally changed the landscape and the economy. In manufacturing, metals, ceramics and glass, already present in the ancient world well before the Romans, reached new heights of refinement, as well as higher levels of mass production. On an elite domestic level, cooking became both an art and an expression of *otium*. Fashion dictated the demand for the colouring of new fibres, and the production of ornate jewelry and personal effects made of many types of materials. The artisanal classes and the poor also needed wood in its various forms in order to live. Tools were essential on farms, and for use in some industries. Most agricultural activities used wood for stakes, and as fuel for various purposes (such as heating in olive presses, or making lime). Food was sometimes smoked. Everyone needed to keep warm in winter.

All of these processes involved the supply and consumption of fuel and the use and control of fire. Fuel and fire touched the life of every Roman, every day, and yet our exploration of this topic has been fairly limited to date. We have examined the historical sources in the past, but where these are discussed without inclusion of much science (especially ecology and climate), or appropriate use of archaeological evidence, they can lead to quite inaccurate conclusions.<sup>1</sup> As a prelude to the following chapters, the discussion here overviews the relative importance fuel played in the function of the economy, and provides some technical background to the nature of fuel in the Roman Empire.<sup>2</sup>

### Characterizing the importance of fuel in the economy

#### *The ancient GDP*

We are unable to estimate the percentage of the ancient GDP that fuel may have represented, but even in the modern day, fuel has represented somewhere between 10 and 15 per cent of the GDP of the United States (Veal 2013). If we accept the view that agricultural and other parts of the economy were less efficient in Roman times than at present, fuel may have constituted 20 per cent or even more of the GDP. This figure does not imply that the total value of the ancient Roman GDP has been underestimated by scholars, but rather that the finer details of the make-up of the ancient GDP are yet to be fully elucidated.

#### *A survey of major types of fuel in the ancient world: wood and charcoal*

Wood was the most important and commonest fuel in the ancient period, and is observed archaeologically as fuel waste in Europe and most of the Mediterranean, especially where woodland was common. Petroleum-based fuels were little understood, although they were occasionally used when found. We especially know of coal used in the later Roman period in Roman Britain, where it has been found mixed with charcoal, especially for iron smelting (Veal 2012a). Romano-British coal did not come from sub-surface mines, but was mostly recovered from surface deposits. Similarly, pitch and other liquid tarry substances were known in the east but ancient sources do not document these extensively, and proof of their use as fuel cannot easily be detected archaeologically, as they burn to completion.

Both raw wood and raw wood made into charcoal were used for domestic and industrial purposes. When charcoal was consumed, naturally a proportion of raw wood was required to make the charcoal. The

ratio for carrying out this conversion was (and still is in modern developing wood-dependent countries) quite variable, and is based on a number of factors including ambient conditions, skill of the charcoal-maker, and sometimes, intended use of the charcoal.<sup>3</sup> Wood, often cut to measure, was piled into heaps and covered by ash remains from a previous charcoal burn, plant waste and sometimes mud. Alternative means of making charcoal also included making a pit for the wood, and covering it with a metal sheet, or even 'rough' fabrication in a fire, before use in small-scale smelting or smithing operations. The covered stack or pit of wood was then 'charcoalified': in the absence of oxygen, most water and organics are driven off with heat, leaving a mostly carbon-based product (as opposed to combustion, where the presence of oxygen causes complete consumption of the wood to produce heat, ash and water) (Chabal et al. 1999). Production 'efficiency' of charcoal ranged potentially from 4 or 5 kg raw wood to make 1 kg of charcoal, to a very inefficient 10 or even 20 kg raw wood to make 1 kg of charcoal. It is reasonable to expect that skilled Roman charcoal-makers were 'efficient', although to produce charcoal of a very high quality (i.e. high carbon content), long charring was required (thus reducing the resultant charcoal weight, an apparent reduction in efficiency, necessary to increase the carbon content). It appears from work in Pompeii (Veal 2012b, 2014), that charcoals for domestic use<sup>4</sup> were of a moderate quality with some organic volatiles left in the charcoal to facilitate ignition of the fuel in the kitchen, while charcoals used in metal smithing may have been of much higher quality (denser, and with a higher carbon content). These broad observations correlate with modern ones made for wood dependent developing countries (Schenkel et al. 1998), and laboratory work on archaeological charcoal is ongoing.

#### *Non-wood fuels*

Almost anything organic can be used for fuel (or turned into charcoal for that matter). Agricultural wastes of all sorts (mostly in the raw state) were routinely consumed, especially in places where wood was scarce, i.e. any part of the empire where poor soils or poor rainfall predominated, such as Greece, parts of the East, and those parts of Africa furthest away from the coast. One of the first studies on chaff looked at its use in arid and semi-arid zones (van der Veen 1999). Some of the following chapters (Leitch, Martin, Möller & Reiger and Kenawi) elucidate valuable ancient and modern ethnographic examples, especially in the case of ceramic production on the African continent. Even in places where wood was common, non-wood fuels have also been consumed

when available. Of all of these, olive pressings (often referred to as 'pomace'), were the most useful in terms of calorific value (see Coubray et al. and Rowan, this volume). The volume of olive pressings available varied geographically and seasonally, and so while available were precious if used as fuel; they could also be used as animal fodder and even fertilizer (both in limited quantities).

Other examples of non-wood fuels include: seaweed (Griffiths & Harrison 2011); peat, especially in wetter climates – but for an Italian example see Peña (2013); and animal dung, the detection of which in the archaeological record is still a challenge (Lancelotti & Madella 2012). Recognizing animal dung as fuel requires careful attention to field collection of archaeobotanical remains, as well as a recognition of seed assemblages inside the dung. Its use as fuel means less is available for fertilizing soils. Animal bone has also been detected as fuel but more instances are recorded for prehistoric periods (Beresford-Jones et al. 2010; Théry-Parisot 2002). This list is not exhaustive.

#### *Lighting: lamps and torches*

The commonest form of Roman lighting was the oil lamp, which came in a large range of styles and sizes. Olive oil was the main fuel, although other vegetable oils and animal fats were also used. Griffiths (in this volume) focuses on this topic in detail. Evidence ranges from ancient historical records to the numerous archaeological ceramic and less common metal lamps. Indirect archaeological evidence includes hooks in walls and niches in which lamps could be installed, both inside and outside buildings.

In addition to lamps, torches were used. The literary and artistic evidence is summarized by Smith (1875).<sup>5</sup> Torches were 'formed of wooden staves or twigs, either bound by a rope drawn about them in a spiral form... or surrounded by circular bands at equal distances.... The inside of the torch may be supposed to have been filled with flax, tow, or other vegetable fibres, the whole being abundantly impregnated with pitch, rosin, wax, oil, and other inflammable substances.' The Romans knew of phosphorus, and also could make complex torches of sulphur and lime (which burn for longer). These topics have been little studied, beyond the literary and artistic evidence such as the wooden staves and the types of flame depicted. Archaeological preservation would be rare (of the torches themselves), although some buildings in Pompeii appear to have niches and/or iron rings attached outside at a height and location that may suggest their function as part of a lighting installation, as mentioned above. Whether individual cases were for torches or lamps is a matter needing further investigation.

### Calorific potential and efficiency of fuel consumption

Each type of fuel has an intrinsic heat value ('calorific potential'). In general terms, if an 'inferior' fuel is used, more of it will be required, all other factors being equal, than if a 'superior' fuel is used, but caveats apply. Some processes require charcoal as it produces a more continuous heat, providing greater temperature stability, whether for low (such as cooking a delicate custard), or high temperatures (metal-working). Charcoal is essential in some high-heat technological processes (c. 1100 °C) as this temperature is difficult to achieve with raw wood in a consistent manner (for example in iron-smelting and, usually, smithing). The charcoal is also consumed as part of the chemical reaction of reduction in smelting. However, even lower calorific potential fuels have their uses: straw, for example, can be used to help raise the temperature quickly, although it will not produce a sustainable heat. Table 1.1 shows the approximate relative calorific potentials of different fuel types.

We can only estimate relative values because different types of raw or dried peat, wood, pomace, etc., will vary slightly in their calorific potentials. Taking raw wood as our standard value of '1', 'good wood' means a typical hardwood such as oak or ash. 'Charcoal' denotes typical hardwood charcoal. Table 1.1 shows that 'charcoal' is nearly double the heat potential of 'good wood'; that 'olive pomace' is a valuable fuel; and that our modern addiction to fossil fuels is easily comprehended. It should be noted that just as almost any type of organic material can be used as fuel, and most can be made into charcoal, differing organic materials result in charcoal of slightly varying qualities.<sup>6</sup> However, once made into charcoal, calorific potentials of charcoals of different origins do not vary as much as the calorific potentials of their original materials (so, for example, it is not correct to infer that olive pomace, a high calorific fuel, once made into charcoal, will produce a lot more heat than any other type of charcoal).<sup>7</sup>

**Table 1.1.** *Approximate relative heat values of different fuel types, drawn from a range of sources.*

Peat (dried)	0.8
Poultry litter	0.8
'Good Wood' @ 20% moisture content (air-dried)	1
Olive pomace (skin, pips, pulp)	1.3
Charcoal	1.8
Coal (average quality)	2
Oil (fossil fuel) or LPG (liquid petroleum gas)	2.5
Coal (anthracite)	3

Besides heat potential, to understand fuel consumption we also need to understand 'heat yield'. By this we mean the amount of potential heat in a fuel that actually ends up employed in the process intended. Different technological situations differ in their efficiency of fuel use, and of course, the less efficient a process, the more calorific potential is lost to the air (and not applied to the process intended), and therefore the more fuel will be required to get to a particular result. In open fires, about 10 per cent of the calorific potential actually makes it into the food being heated/cooked, or the industrial process being undertaken. Enclosed tripods reach perhaps 30 per cent efficiency (so, moving from the prehistoric to the historic periods, man's approaches to cooking became more efficient by using stone surrounds for fire, and/or tripods of ceramic and then metal). Oven efficiency, depending on the oven, may have ranged from 30–50 per cent;<sup>8</sup> and for kilns, a range of 40–80 per cent may be inferred, depending on the kiln type and build, and in particular whether it was a continuous use kiln (more efficient), or single use.

### Factors affecting the wood supply

A range of factors affected the wood supply, from ambient ecological conditions to land ownership, silvicultural practices, intended cultural uses, transport and pricing. Geology, topography, climate and soils are the base determinants of where different plant types grow. Below appears a summary of these factors. A more detailed discussion may be found in Veal (2013). Italian growing conditions range from coastal and inland flats to steep mountains and islands, with soils enriched by their recent evolution in geological time through volcanic activity. We generalize climate to be 'Mediterranean' (hot dry summers, wet winters), but micro-climates were worse, and better than this, and the provinces varied greatly.

#### Geology

There are radical differences in geology between those parts of the empire located on or near volcanically influenced crusts (e.g. Italy) and those removed from these areas (e.g. Roman North Africa, Egypt and Greece). Italy's fertility has been sung by the ancient writers, and proven in geological and macrobotanical analyses. Egypt's soils and water supply were relatively poor except for those associated with the Nile delta and its seasonal flood. This alluvial area was and is large, making the province the breadbasket of Rome for many years. Outside this area though, in much of the African continent, desert prevailed. Greece has always had mostly poor soils, and in many places,



much less rain than Italy (Rackham 1982). These base ecological conditions created greater challenges for timber provision in Greece (and Egypt), and much timber was imported, although local scrubland and limited woodland seemed to have provided sufficient fuel, which at least in the Greek historical sources was made into charcoal and transported by donkey into town. Greek villagers, however, were noted for sharing cooking facilities (thus saving fuel), rather than always cooking individually at home (Bresson 2016, 72–3).

#### *Topography*

Large mountains block inflowing warm and wet air from the sea. In the case of Italy with its raised central peninsular spine, rainfall is more abundant in the centre, i.e. in the Campanian Apennines (modern range 1000–1700 mm p.a.), than at the coast (modern range 700–1000 mm p.a. on the Campanian coast) (Costantini et al. 2013). Steep inclines can tend to lose topsoil with rainfall, making areas of even apparently fertile soil less suitable for growing anything other than scrub. Steep inclines also influence silviculture practices (see below).

#### *Climate and micro-climate*

Forest growth is greatly affected by climate, but broad regional ‘climate’ characteristics may be quite different to those observable at micro-climate (i.e. local city/state) scales. Variation in the so-called ‘Mediterranean’ climate was (and is) as much as 30 per cent (in terms of precipitation and temperature) from place to place. The Roman ‘warming period’ (c. 150 BC to second century AD) allowed agriculture in more marginal areas, and was a major factor in bringing about economic and agricultural stability at the time (Büntgen et al. 2011; Harper & McCormick 2018; McCormick et al. 2012). Altogether, climate records show a broader stability of climate for the millennium of Roman dominance, than time periods either side of it. However, even within the Roman period, climate varied. Harper & McCormick’s overview of Roman climate is particularly useful in that it explains all of the different proxies that go into estimating past climate, their validity (especially in the Roman period), and the nuances of various results from different areas in the Roman Empire. Data types vary from those which may be resolved broadly (e.g. pollen), to those that can be resolved by decade and even by year (e.g. tree rings). Glacier retreat/advance, speleothems, hydrological changes and many other proxies exist. They reflect the Roman world to a larger or lesser extent, partly depending on distance from the empire (e.g. glaciers were not found in Roman territory but their changes are still a useful correlate for other proxies). We know

ice cores some distance from Rome reflect chemical changes in the metal ages (particularly in the Roman period), due to upper atmospheric long-distance aerial transport of smelting chemical products. This global phenomenon, as well as that of the ocean currents, are large-scale drivers of climate, and lead us to speak of regional and inter-regional climates. Intuitively we understand that in the Mediterranean there is a north/south divide, but the east/west divide is also distinctive, and even sub-regions within an area may vary due to geographical permutations. Climate is now considered at the broadest level to be primarily influenced by solar radiation and volcanic activity. Volcanic and solar radiation ‘forcing’ appear to precede climate changes, which in themselves appear to precede mass population movements and social instability through human history (these were/are not the only drivers of change of course, but socio-economic changes have already been well covered elsewhere in the overall debate).

Volcanoes reduce solar radiation reaching the Earth through the dust and gases that arise from eruptions. Size, frequency and types of eruption (whether highly explosive and producing lots of particulate matter, vs gentle eruptive) determine how much volcanoes may limit sunlight and reduce regional temperatures. Solar radiation is also independently affected by the sun’s own output (solar ‘flares’ increase radiation). Solar changes affect large oceanic currents and upper atmosphere movement and have a subsequent inter-regional bearing. It is notable that we lack sufficient proxies (yet) to be able to say much about Roman North Africa and some parts of the southern Mediterranean. We also have a continuing difficulty of relating climate changes and chronology tightly to archaeological and historical records (and as already stated, we cannot ignore the socio-economic factors of change). A major future challenge is to integrate larger-scale climate changes and smaller patterns of regional weather anomalies into the already well-discussed socio-economic factors.

In ancient studies, when environmental factors are proposed as significant agents in influencing human behaviour, some modern scholars have immediately made accusations of ‘environmental determinism.’ We know now that environment is a large determinant of the base conditions of life. The degree to which natural environmental changes dominate or influence human behaviour cannot easily be ascertained (and vice versa). Hypotheses in this regard have been made in a general sense, but we need more, and more detailed records of all types (Manning 2018). We can generally correlate colder periods (e.g. the Little Ice Age) with drier conditions, and warmer ones generally

with wetter conditions, but this does not always hold (e.g. in the Sahara). Occasionally even in Europe the opposite patterns of expected precipitation apply in small areas.

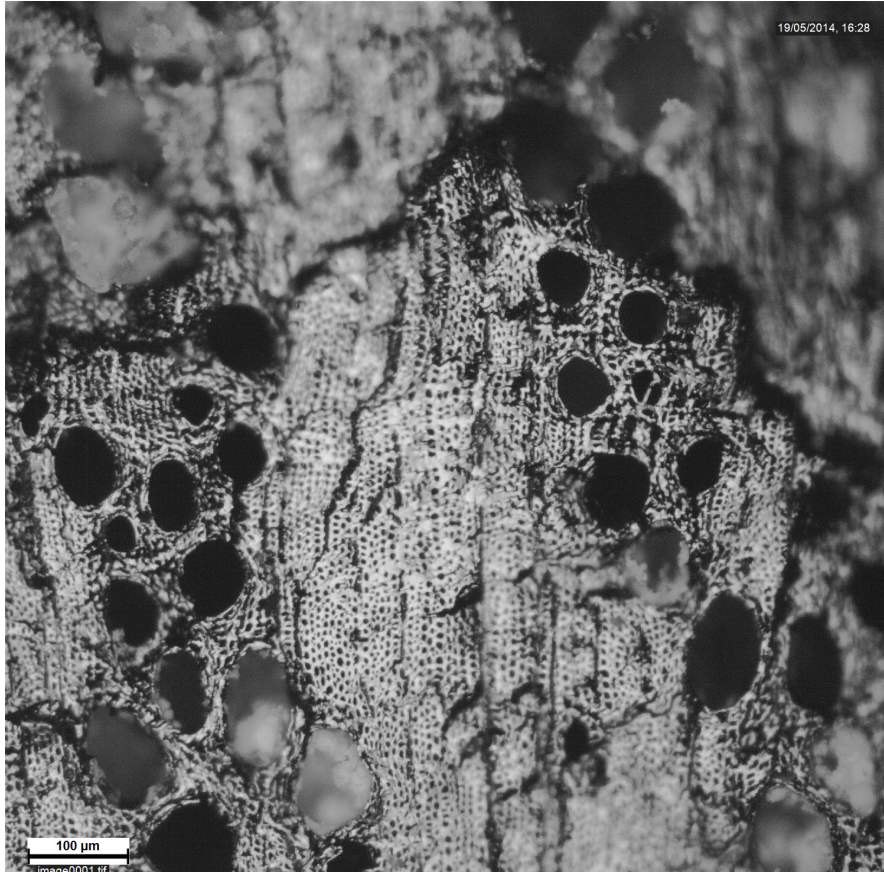
#### *Land ownership and use*

In land use the Romans, as other cultures, could significantly alter fertility by improvements to poorly drained areas (which could then be brought into cultivation), as well as over-exploitation of hilly areas (which resulted in loss of topsoil). Soil fertilization was carried out using animal and plant waste where available, in addition to other strategies such as fallowing, and inter-cultivation of nitrogen fixing crops (especially legumes, such as the famous bean, *Vicia faba*). Land ownership by the emperor, the state and the elite dominated access to forests, with *ager publicus* diminishing over time, presumably making access to fuel by the poor more difficult and/or expensive (although the matter has not been thoroughly explored). Roman emperors valued timber for ship building and construction in particular, especially conifers such as cedar (*Cedrus libani*) and silver fir (*Abies alba*), but these markets and the extent to which they were coveted and protected should not

be confused with the fuel supply, although timber waste can end up as fuel (see for example, Harris 2017; Moser et al. 2016; Veal 2017a, 2017c, 2018).

#### *Silvicultural practice in the Mediterranean*

Silvicultural practice may in part be viewed through characteristics of archaeological charcoal sections (see an example in Figure 1.1, which is a cross section of a young oak branch). From the cross section a charcoal specialist can identify wood structures, the most important of which are tree rings (one for every year of growth), vessels (to conduct water and nutrients from roots to crown) and rays (to conduct water and nutrients from the core to the outer growing edges). Young (small branches) have fewer rings, and smaller vessels, and often sections of whole small branches may be preserved. Observation of many small-medium branches of consistent diameter – suggests (but does not prove) coppicing or other intensive woodland management. Other information is gained from historical sources and preserved artefacts. These together tell us that the Romans used two-man saws, axes and other woodland management tools, much like those of today (except without electricity!) (White 1967, 1975). While ‘coppice’, small diameter, uniformly



**Figure 1.1.** An example of a microphotograph of deciduous oak (cross-section at  $\times 40$ ) from Ostia synagogue (late Roman) (photo Veal).





**Figure 1.2.** Modern ‘smallwood’ (or coppice) being taken to market in the Sarno valley, Campania (photo Veal).

cut wood, is often presumed to be the main source of fuel (Figure 1.2 shows a modern example on the way to market), the steepness of the mountains suggests maintaining fencing for satisfactory coppice production may have been difficult, if not impossible, in mountainous parts of Roman Italy. Strategies such as pollarding (cutting above animal grazing height), or indeed clear felling (and sorting), may have been more common in these areas. These differing arboreal management strategies are sometimes difficult to observe in the archaeological charcoal. Care must be taken not to project common strategies in one country (Roman Britain) with those found elsewhere (Roman Mediterranean), despite significant commonality of wood species. Grove & Rackham (2001) provide a detailed overview of the woodlands of the Mediterranean and the various woodland management strategies in different regions.

There is good evidence that charcoal of different qualities was produced for domestic, as opposed to industrial use. In the House of the Surgeon at Pompeii, strong evidence for a first-century BC smithy attached to the villa was found (structures and iron waste), and the associated charcoal was of a much denser, older wood, compared to that of the remains found elsewhere (Veal 2012b, 27, 2018). This pattern of industrial use was also observed in the charcoals of the Porta

Stabia area (Veal, unpub.). Coppice production (cutting of wood at the base, so multiple stems regrow), dominated in Roman Britain, for example, and across much of Roman Europe. Small diameter woods also dominate assemblages from more arid areas (those of steppe and maquis vegetation types) although these do not always represent coppice production. Maquis woods, whilst scrappier and sometimes difficult to collect (due to spiny or noxious wood characteristics), were of equal, if not greater calorific potential than wood produced from larger-scale coppice production. A detailed overview of the history of wood fuel in the Mediterranean is found in Grove & Rackham (2001).

#### *Deforestation*

We may infer that as the Roman period progressed from the Republican to the Late Antique period, and sophistication of technology advanced, kiln-based manufacturing processes increased, and fuel efficiency also probably improved. Higher temperatures (and finer control of these) were required to manufacture, for example, red-slip ware (c. 1000–1100 °C) (Cuomo di Caprio 2007, 38).<sup>9</sup> Production of better-quality steels also required closer temperature control, in both smelting and smithing. Concern as to the production of the ‘right’ quality of charcoal became more necessary, as well as provision of sufficient woodland to provide the charcoal. Production of glass reached very sophisticated standards (see Cool, this volume). In all of this consumption, however, except for some localized examples, the Romans did not seem to deforest their empire. A pattern of conservative management of woodlands related to fuel or timber use in peninsular Italy appears to have occurred, despite clearance for agriculture. It is fair to say, though, that we do not have all the data to be entirely sure of this fact yet, and patterns in the provinces vary. Islands were more vulnerable. On the island of Elba, where iron ore was found in such abundance, ore was shipped to the mainland for processing by about the third century BC, as apparently the wood had run out for smelting and working the ore into bars for export elsewhere (Costantini et al. 2013). The Romans appear to have exploited (at times unreasonably) some provincial forests more than those of peninsular Italy. However, even here, climate and soils may have been larger factors in forest cover changes (e.g. in North Africa). These matters are ongoing (and long-term) subjects of investigation. Large-scale deforestation does not show up in the European pollen record until the medieval period (see especially Harris 2011, 2013, 2017). For Italy, a recent summation of a large database of archaeobotanical records for the Holocene (Mercuri et al. 2015) suggests irreversible land transformations

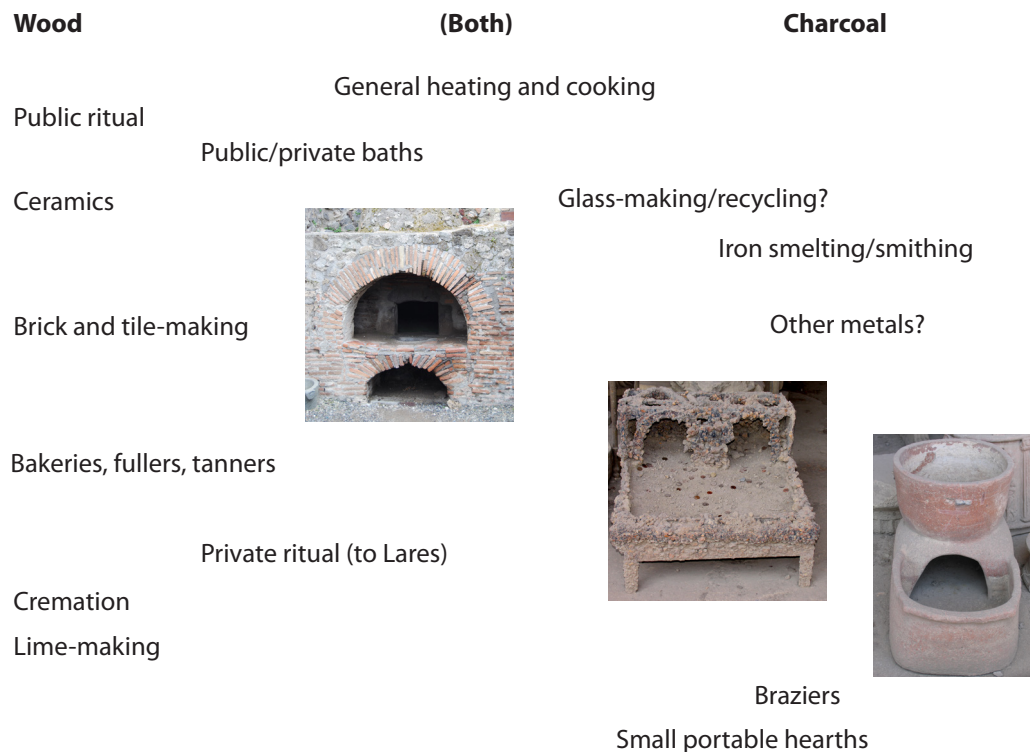
commenced (in terms of tree composition) from the middle Bronze Age, but not necessarily large-scale deforestation. One aspect that has been little studied is carrying capacity. Although Roman fuel consumption was relatively high (cf. other ancient societies), it was probably not high enough to deforest the empire, if total carrying capacity is considered (vs the population). Carrying capacity estimates need to be carried out in conjunction with reconstructing landscape use in more detail (and reconstructing population ranges). There is much work to do.

### Roman fuel consuming activities: wood or charcoal?

Turning to Roman fuel consuming activities, we need to consider which ones used raw wood, and which charcoal. Clearly those that required the use of charcoal were ultimately consuming more forest than those that required raw wood. We know from the historical sources, for example, that braziers used charcoal,<sup>10</sup> and that both charcoal and wood were called for in the kitchen. We don't know in what proportion. Figure 1.3 provides a diagram of the various fuel-consuming processes and their probable fuel type(s).

In some cases we cannot know for sure whether charcoal or wood was used (but see the discussion

on 'reflectance' below). From Figure 1.3, it may be inferred that in general, the hotter and more constant the temperature required, the more probable it is charcoal will have been employed. However, this is not the only consideration. Modern analogies suggest the Pareto (80/20) rule could have applied – that in cities, 80 per cent of fuel was charcoal and 20 per cent was wood (with the reverse ratio in the country).<sup>11</sup> This is understandable with charcoal's more constant burning qualities, and the fact that it burns with little, or no, smoke. Further, it is one-third the weight of raw wood (by volume), and as we have already seen, nearly double the calorific potential. Temperature processes requiring a temperature of 1100 °C appear to need charcoal. Very little archaeological evidence is available for glass-making. We must also differentiate between wholesale raw glass production and glass-working (less heat is required for glass-working, as the already chemically created material only needs to become plastic for working; see Cool, this volume). Few sites have been discovered in the Roman Empire for the former, whilst indirect evidence for the latter is more common. In the case of iron smelting, charcoal is not only required for temperature but also is an intrinsic part of the chemical process. Archaeometallurgists commonly remark that they would also expect charcoal to be used for easier fire control (and in chemical



**Figure 1.3.** Probable fuel types for different activities (figure and photos by Veal).

reduction as well) for lower melting/smelting point metals; however, we do not yet have proof. It is also possible that other fuels were used, and even more probable the further back in time we proceed.

#### *Moderators of fuel consumption*

It is logical that fuel consumption went up with: cooler or wetter (micro-) climate; the predominance of cremation in burial practices; technological advancements (requiring higher temperatures); increased population (increasing domestic and industrial demand); increased urbanization (increasing charcoal consumption); increased wealth (promoting perhaps more profligate use of fuel); and in times of war (when demand is also heavier, not only on the fuel supply for manufacture of weapons, but also for cooking and heating for troops).

Other activities relating to particular social mores that can increase fuel consumption which have not yet been examined in any detail include elaborate funereal feasts; regular re-visitations and celebrations at tombs (both of which are essentially private activities); and elaborate public feast days (state or emperor funded). See, for example, Small (2018) and Veal (2017b).

#### **Pricing and transport**

Cities, in particular large cities like Rome, probably consumed much more charcoal than wood, and had a significant supply system in place. We know from the historical sources, toponyms and logistical analyses that timber for Rome was supplied from as far away as modern-day Umbria.<sup>12</sup> Transport of the lighter charcoal may have been cheaper, but would cause more damage to the charcoal (resulting in ‘fines’ that may not be useful industrially, but are still useful domestically for one purpose or another.) There is little pricing information in the historical sources, except for Diocletian’s Edict (Graser 1959). Notwithstanding the recognized issues with this source, Diocletian shows us that *ligna* (fuel) is clearly differentiated from *materia* (timber). For fuel, kindling was highly prized, and charcoal was more expensive than raw wood fuel, although this can only be discerned from the transport prices of these products (and as in the modern world, transport appears to make up a significant portion of the cost). Non-wood fuels are not mentioned in the Edict.

#### **Modelling the size of the wood fuel supply**

Various approaches to modelling all Roman energy consumption have been made. Those focusing on fuel alone are currently few in number. A useful review

for the Roman period is provided by Malanima (2013). Normally his time period of focus is post Roman to early modern, and so he perhaps underestimates Roman wood fuel consumption, not allowing for the excesses of public bathing and feasting, among other issues; however, the range of his work is highly instructive. For the upper Rhine region, another broad model based more on landscape, archaeobotanical and historical data, examines supplying the Roman Army (van Dinter et al. 2013). This has the advantage of consideration of cultural inputs, but the fuel supply calculations are broad brush (and explicitly exclude bath supply).

A model to calculate the amount of fuel a city might use in a year has been proposed by this author. Initial efforts focused on an individual house (the House of the Vestals) and then Pompeii as a whole.<sup>13</sup> The approach was recently modified for Rome (Veal 2017). Simply put, the estimated population of the city is firstly multiplied by the volume of wood per head consumed (ranges are estimated based on ethnographic data and ancient socio-economic considerations). An adjustment has to be made to account for the amount of wood used in charcoal-making, and then the total is divided by an estimate of forest productivity (again, allowance is made for a range of productivities). Together these provide an estimate for the area needed to grow the wood fuel. Examining the volumes of wood required, and taking into consideration the ecological constraints suggested by the actual wood types identified in archaeological charcoal, we may start to make more informed inferences about possible growth areas. Competition with other agricultural activities must be considered. This model still lacks refinements to include ‘quality’ of charcoal (i.e. how much was ‘industrial’ in nature, or ‘domestic’). It is currently a linear model using a range for each of the variables, which may be applied to other cities where some notion of population and forest productivity ranges may be gleaned from ecological and ancient sources. A refined version employing a Bayesian probabilistic approach that tests the sensitivities of the various variables is under preparation.

Another recently published model (Janssen et al. 2017) also attempts to calculate the fuel consumed within one town. It makes for useful reading in conjunction with the chapters herein, as it focuses specifically on wood consumption in the Roman Baths and for red-slip ware production (but only for these activities). The site is Sagalassos during the second century AD. A Monte Carlo approach is used to account for uncertainties in the variables discussed, and many of the assumptions and ranges of variables seem very appropriate. However, by focusing on bathing and



ceramics, the study can omit considerations of the increased wood required from charcoal consumption since, as the authors argue, these were activities that probably only used raw wood. Their subsequent, although brief inclusion of archaeological charcoal analysis results, and ecological assessment, provide an integrated approach. They conclude that the area required for wood production was high, and close to the maximum space available (for these two activities alone). Pollen records however, do not show large-scale vegetative change. Questions therefore arise about the possibility of the use of non-wood fuels on a significant scale, and/or wood importation perhaps from a nearby region (as is proposed for Pompeii). Finally, we do not yet have enough information to assess the relative size of the consumption of fuel from these two industrial activities, in comparison with every other use of fuel at Sagalassos.

All of these recent attempts to model fuel consumption provide useful input towards progressing our understanding of local and city-wide consumption. They approach the matter more from a 'bottom-up' strategy, and most require refinement to include greater accuracy of variables, in particular, as well as the relative volumes of consumption by different technologies, and the use of charcoal vs raw wood. Adding in 'domestic' consumption is another challenge, and here again we require better refinement of population data than currently is available for most cities.

### History of wood charcoal analysis

Charcoal collection and analysis has been well described in a number of publications,<sup>14</sup> and has been undertaken to some degree or other since the 1940s. Results have mostly been framed in terms of wood lists, and an emphasis on a presumed fuel collection strategy of 'Least Effort' coupled with subsequent inferences about how the proportions of wood identified might relate to the potential environment (Chabal 1992; Shackleton & Prins 1992). An inherent assumption is that 'selection' does not play a big part in the wood fuel collection process. This may be true for prehistoric periods to a large extent (but see Picornell Gelabart et al. (2011)). Work in historical periods suggests city fuel provision had to be more strategic and managed. Increased urbanization (a feature of the Roman period) dictated the necessary cultivation of fresh and perishable goods closer to cities (dairy, most fruits and vegetables, flowers), with less perishable goods being cultivated at further distances. Hence in large (and even smaller) Roman towns we might expect to see evidence of a managed fuel economy. In smaller, rural areas, local supply of available materials might

be expected. Even for the city of Rome at its height, however, there is little epigraphic evidence for mass movement of wood fuel across the Mediterranean (and no archaeological evidence to date). Woods may well have travelled intra-regionally, probably by cabotage, by river, or short distances by road. Exotic woods, when detected archaeologically in low forested areas (e.g. Roman North Africa and Egypt), are thought to represent either construction waste (in very small quantities), or the burning of wooden tools/objects (van der Veen et al. 2011). Timber marketing and transport is a different issue, and Mediterranean movements are documented in literary and epigraphical sources, and archaeologically.

Besides identification, analysis has now moved forward to explore tree ring curves and counts for cropping marks. See, for example, Marguerie (2011), and references therein. Charcoals recovered in dry sieving in excavation, and in the laboratory, are subject to continual breakage; however, this does not seem overall to bias results too much, providing that over-examination of small (<4 mm) fractions does not occur (Chravzev et al. 2014; Chravzev et al. 2011). Charcoal collected from flotation fragments a lot and then often requires subsampling at the microscope. More problematic is the issue that charcoal may only be collected opportunistically (e.g. when sighted), or by targeted analyses (i.e. from hearths or ovens). Systemized random sampling, as well as targeted analyses, are both useful strategies, but consistent collection, through time and space, is the only way to produce representative results. Charcoal is usually ubiquitous in urban environments, but collecting it only from hearths or ovens means sampling of just the last, or last few, burn events. These will be primary, or near primary contexts (which are intuitively preferred by archaeologists and historians). However, to gain a view of the wood fuel supply (or indeed the food supply) over time, collection of material from all types of contexts, including general secondary and refuse deposits is essential (as is preferred by bioarchaeologists and statisticians).

### The reflectance technique: differentiating raw wood and charcoal fuel

We also require much more information as to the proportional use of charcoal vs raw wood. This is a key issue (as is the part non-wood fuels may have played). The reflectance technique is a laboratory procedure borrowed from coal assaying, that relates the 'shininess' (i.e. reflectance) of charcoal to its absolute burn temperature (i.e. the highest temperature to which the charcoal has been exposed). Experimental work



on modern charcoals, and the subsequent creation of calibration curves to relate measured reflectance to temperature, have been completed in the last few years, although for the most part not by archaeologists. See, for example, McParland et al. (2009a). Braadbaart and his colleagues have carried out considerable experimental work in the laboratory in this area (and some limited work on archaeological charcoals) (Braadbaart et al. 2016; Braadbaart & Poole 2008; Braadbaart et al. 2012; Braadbaart et al. 2009). This experimental work is valuable, but we need to extend our examination of archaeological material, and verify that the measures he suggests will aid archaeological interpretation.<sup>15</sup> Some work on archaeological charcoals has produced mixed results to date (McParland et al. 2010; McParland et al. 2009b; Veal et al. 2016).<sup>16</sup>

## Conclusion

This discussion has offered a broad insight into the complexities of the Roman fuel economy, exploring some of the major uses of fuel, and aspects of the science behind charcoal manufacturing and consumption. The chapters that follow examine aspects of particular uses of fuel, using a range of data from ancient historical sources, archaeological and archaeobotanical evidence, ethnographic parallels, and some quantitative modelling. They focus mostly on kiln technologies, as well as some exploration of non-wood fuels. Ultimately, we would like to be able to rank, according to demand, all of the Roman activities that consumed fuel, coupled with chronological and geographical patterns. Modern analogues suggest domestic use outweighed or equalled industrial demand (but we must be careful not to be too free with projecting developing world parallels back into the ancient period). There is much work to do. We are just beginning to unravel fuel in the ancient Roman world, and indeed the ancient world in general.

## Notes

1 Thommen's 2012 work is well regarded by ancient historians, but less so by some archaeologists and scientists. He fails to integrate these areas well enough in his analysis. Hughes wrote in 1994 of Pan's Travail, and we could possibly forgive the lack of scientific and archaeological integration at that time. However, he further defended his position of the Romans being great deforesters in 2011, with a very limited examination of three small case studies (referencing pollen, charcoal and modelling). This restatement showed little understanding of the limits of either palynological or charcoal examination. He refers to models that simplistically incorporate historical data at face value. He does not define 'deforestation', including

all sorts of forest and agricultural cover changes (whereas deforestation is usually defined as permanent removal of any and all trees). He fails to account (even in 2011) for any contribution from soils or climate; or the continuity of change through time of nearly all of the landscape (well before the Romans). Despite writing this 'update' in 2011, the small case studies examined (and most of his references) are from the 1990s. Work has progressed since then. See especially Harris (2013).

- 2 The author's early work in this area, and some subsequent laboratory studies currently in publication, were carried out in the Department of Archaeology, University of Sydney. Some of the ideas expressed in this chapter were presented at a conference in Rome, 'History and Environment in the Ancient Mediterranean', held at the American Academy in Rome and the *Institutum Romanum Finlandiae*, 15–16 June 2011, and hosted by Prof William Harris, and subsequently appeared in Veal (2013). The idea for the conference owes its gestation to those discussions and the ongoing encouragement of Prof Harris, and I thank him for his generosity of time and intellect. I also thank all of the directors of excavations who have invited me to examine their charcoal.
- 3 A small quantitative model, developed for evaluating the fuel economy of Pompeii, may be found at <https://www.robynveal.com/a-quantitative-model-for-the-ancient-fuel-supply-to-pompeii-ad-79.html>
- 4 We can't precisely tell while excavating whether charcoal remains originated from raw wood or charcoal fuel, but a test to assist us to determine this called 'Reflectance' is being trialled. See, for example, McParland et al. (2009a); see also notes 15 and 16, below. Modern data also clearly distinguishes between 'domestic' and 'industrial' charcoals and their differing qualities (see <http://www.fao.org/docrep/x5328e/x5328e0b.htm>; however, this is still developing in archaeological research.
- 5 Found online at the Lacus Curtius site. Bill Thayer curates these pages made up of primary (and secondary) historical sources that are out of copyright. The extended and revised commentaries of Thayer significantly augment older Loeb translations.
- 6 Denser, harder woods tend to make better-quality charcoal for metal smelting and smithing.
- 7 <http://www.fao.org/docrep/x5328e/x5328e0b.htm>, section 10.1.5, provides details of some comparisons between various wood charcoals and other organics.
- 8 <http://www.fao.org/3/ab780e/ab780e04.htm> tells us that ovens in developing countries are usually below 50 per cent heat efficiency for a variety of reasons.
- 9 Cuomo di Caprio (2007) provides a detailed elucidation of firing modalities for all types of ceramics.
- 10 According to Columella, Pliny the Elder and Apicius (Meiggs 1982, 264–70). Meiggs is still the best collation of the ancient sources.
- 11 Otherwise known as the 80/20 rule. Vilfredo Pareto observed that this ratio applied to many economic, financial and natural phenomena. In the case of wood and charcoal it is proposed that the richer citydwellers used 80 per cent charcoal (a more expensive commodity) and 20 per cent wood, while the poorer country-dwellers

- used the opposite quantities of each. Much more research is required to examine this question.
  - 12 For detailed analyses see, for example, Diosono 2008a; Diosono 2008b; also Veal (2017c).
  - 13 <http://www.robynveal.com/a-quantitative-model-for-the-ancient-fuel-supply-to-pompeii-ad-79.html>
  - 14 Leney & Casteel (1975). See also Asouti (2007 and onwards) and Veal (2012b).
  - 15 McParland et al. (2009b) review the previous literature in detail. This work is still in its infancy as researchers have developed calibration curves that can differ by around 150 °C for any one reflectance temperature. Cooperation between laboratories to resolve this issue is required.
  - 16 Neither of these studies prove the method is yet successful for accurately measuring, e.g., the burn temperature of a particular process (in these cases, a hypocaust and Bronze Age cremations). Resolution of the calibration issue is required. In a further study yet to be published, more encouraging results for charcoal obtained from iron slag have been obtained by the author. The method does, however, appear very suitable for discerning charcoal fuel from raw wood fuel and testing is continuing at a number of laboratories.
- ## References
- Asouti, E., 2007 and onwards. Charcoal Analysis Web, University of Liverpool, <http://pcwww.liv.ac.uk/~easouti/>
- Beresford-Jones, D.G., K. Johnson, A.G. Pullen, A.J.E. Pryor, J. Svoboda & M.J. Jones, 2010. Burning wood or burning bone? A reconsideration of flotation evidence from Upper Palaeolithic (Gravettian) sites in the Moravian Corridor. *Journal of Archaeological Science* 37, 2799–811.
- Braadbaart, F., E. Marinova & A. Sarpaki, 2016. Charred olive stones: experimental and archaeological evidence for recognising olive processing residues as fuel. *Vegetation History and Archaeobotany* 5(5), 415–20. <https://doi.org/10.1007/s00334-016-0562-2>
- Braadbaart, F. & I. Poole, 2008. Morphological, Chemical and Physical Changes During Charcoalification of Wood and its Relevance to Archaeological Contexts. *Journal of Archaeological Science* 35(9), 2434–45.
- Braadbaart, F., I. Poole, H.D.J. Huisman & B. van Os, 2012. Fuel, Fire and Heat: an experimental approach to highlight the potential of studying ash and char remains from archaeological contexts. *Journal of Archaeological Science* 39, 836–47.
- Braadbaart, F., I. Poole & A.A. van Brussel, 2009. Preservation potential of charcoal in alkaline environments: an experimental approach and implications for the archaeological record. *Journal of Archaeological Science* 36, 1672–9.
- Bresson, A., 2016. *The Making of the Ancient Greek Economy: Institutions, Markets and Growth in the City-States*. Princeton, New Jersey: Princeton University Press.
- Büntgen, U., W. Tegel, K. Nicolussi, M. McCormick, D. Frank et al., 2011. 2500 Years of European Climate Variability and Human Susceptibility. *Science* 331(4 February), 578–82.
- Chabal, L., 1992. La Représentativité paléo-écologique des charbons de bois archéologiques issus du bois de feu. *Bulletin de la Société Botanique de France* 139(2/3/4), 213–36.
- Chabal, L., L. Fabre, J.-F. Terral & I. Théry-Parisot, 1999. L’Anthracologie, in *La Botanique*, eds. C. Bourquin-Mignot, J.-E. Brochier, L. Chabal, S. Crozat, L. Fabre et al. Paris: Errance, 43–104.
- Chrzavzez, J., I. Théry-Parisot, G. Fiorucci, J.-F. Terral & B. Thibaut, 2014. Impact of post-depositional processes on charcoal fragmentation and archaeobotanical implications: experimental approach combining charcoal analysis and biomechanics. *Journal of Archaeological Science* 44, 30–42.
- Chrzavzez, J., I. Théry-Parisot, J.-F. Terral, A. Ducom & G. Fiorucci, 2011. Differential preservation of anthracological material and mechanical properties of wood charcoal, an experimental approach of fragmentation, in *5th International Meeting of Charcoal Analysis. The Charcoal as Cultural and Biological Heritage*, eds. E. Badal, Y. Carrión, E. Grau, M. Macías & M. Ntinou. Valencia: Saguntum, Papeles del Laboratorio de Arqueología de València, Department de Prehistòria i Arqueologia, 29–30.
- Costantini, E.A.C., M. Fantappiè & G.L’Abate, 2013. Climate and Pedo-Climate of Italy, in *The Soils of Italy*, eds. E.A. C. Costantini & C. Dazzi. Dordrecht: Springer Science and Business Media.
- Cuomo di Caprio, N., 2007. *Ceramica in Archeologia 2. Antiche Tecniche di Lavorazione e Moderni Metodi di Indagine*. Rome: L’Erma di Bretschneider.
- Diosono, F., 2008a. Il commercio del legname sul fiume Tevere, in *Mercator Placidissimus. The Tiber Valley in Antiquity. New Research in the Upper and middle River Valley*, eds. H. Patterson & F. Coarelli. Rome: Edizioni Quasar di Severino Tognon, 251–83.
- Diosono, F., 2008b. *Il Legno. Produzione e Commercio*. Rome: Edizioni Quasar.
- Graser, E.R., 1959. The edict of Diocletian on maximum prices (Appendix), in *An Economic Survey of Ancient Rome. Rome and Italy of the Empire* (Vol. 5), ed. T. Frank. Paterson, New Jersey: Pageant Books, 305–422.
- Griffiths, D. & J. Harrison, 2011. Settlement under the sand. New discoveries in Orkney. *Current Archaeology* 253(April), 12–9.
- Grove, A.T. & O. Rackham, 2001. *The Nature of Mediterranean Europe. An Ecological History*. New Haven and London: Yale University Press.
- Harper, K. & M. McCormick, 2018. Reconstructing the Roman climate, in *The Science of Roman History*, ed. W. Scheidel. New Jersey: Princeton University Press, 11–52.
- Harris, W.V., 2011. Bois et déboisement dans la Méditerranée antique. *Annales HSS, janvier-mars*(1), 105–40.
- Harris, W.V., 2013. Defining and detecting Mediterranean deforestation, 800 BCE to 700 CE, in *The Ancient Mediterranean Environment between Science and History*, ed. W. V. Harris. Boston: Brill, 173–94.
- Harris, W.V., 2017. The indispensable commodity: Notes on the economy of wood in the Roman Mediterranean, in *Trade, Commerce, and the State in the Roman World*, eds.

- A. Wilson & A.K. Bowman. Oxford: Oxford University Press, 211–36.
- Hughes, J.D., 1994. *Pan's Travail. Environmental Problems of the Ancient Greeks and Romans*. Baltimore: John Hopkins University Press.
- Hughes, J.D., 2011. Ancient deforestation revisited. *Journal of the History of Biology* 44, 43–57.
- Janssen, E., J. Poblome, J. Claeys, V. Kint, P. Degryse et al., 2017. Fuel for debating ancient economies. Calculating wood consumption at urban scale in Roman Imperial times. *Journal of Archaeological Science Reports* 11, 592–9. <https://doi.org/10.1016/j.jasrep.2016.12.029>
- Lancelotti, C. & M. Madella, 2012. The ‘invisible product’: developing markers for identifying dung in archaeological contexts. *Journal of Archaeological Science* 39, 953–63.
- Leney, L. & R.W. Casteel, 1975. Simplified procedure for examining charcoal specimens for identification. *Journal of Archaeological Science* 2, 153–9.
- Malanima, P., 2013. Energy consumption in the Roman world, in *The Ancient Mediterranean between Science and History*, ed. W. V. Harris. Leiden and Boston: Columbia Classical Studies Series, 13–36.
- Manning, S.W., 2018. Events, episodes and history: chronology and the resolution of historical processes, in *An Age of Experiment: Classical Archaeology Transformed (1976–2014)*, eds. L. Nevett & J. Whitley. Cambridge: McDonald Institute for Archaeological Research, 119–32.
- Marguerie, D., 2011. Short tree ring series: the study materials of the dendro-anthracologist, in *5th International Meeting of Charcoal Analysis. The Charcoal as Cultural and Biological Heritage*, eds. E. Badal, Y. Carrión, E. Grau, M. Macías & M. Ntinou. Valencia: Saguntum, Papeles del Laboratorio de Arqueología de València, Department de Prehistòria i Arqueologia, 15–6.
- McCormick, M., U. Büntgen, M.A. Cane, E.R. Cook, K. Harper et al., 2012. Climate change during and after the Roman Empire: reconstructing the past from scientific and historical evidence. *Journal of Interdisciplinary History* 43(2), 169–220.
- McParland, L.C., M.E. Collinson, A.C. Scott & G. Campbell, 2009a. The use of reflectance for the interpretation of natural and anthropogenic charcoal assemblages. *Archaeological and Anthropological Sciences* 1, 249–61.
- McParland, L.C., M.E. Collinson, A.C. Scott, G. Campbell & R. Veal, 2010. Is vitrification in charcoal a result of high temperature burning of wood? *Journal of Archaeological Science* 37, 2679–87.
- McParland, L.C., Z. Hazell, G. Campbell, M.E. Collinson & A.C. Scott, 2009b. How the Romans got themselves into hot water, temperatures and fuel types used in firing a hypocaust. *Environmental Archaeology* 14, 172–9.
- Mercuri, A.-M., E. Allevato, D. Arobba, M. Bandini Mazzanti, G. Bosia et al., 2015. Pollen and macroremains from Holocene archaeological sites: A dataset for the understanding of the bio-cultural diversity of the Italian landscape. *Review of Palaeobotany and Palynology* 218, 250–66. <https://doi.org/10.1016/j.revpalbo.2014.05.010>
- Moser, D., O. Nelle & G. Di Pasquale, 2016. Timber economy in the Roman Age: charcoal data from the key site of Herculaneum (Naples, Italy). *Archaeological and Anthropological Sciences*, November. DOI: 10.1007/s12520-016-0406-0.
- Peña, J.T., 2013. Evidence for the Use of Raw Materials for the Manufacture of Black-Gloss Ware and Italian Sigillata at Arezzo and Volterra, in *IMMENZA AEQUORA Workshop. Ricerche archeologiche, archeometriche e informatiche per la ricostruzione dell'economia e dei commerci nel bacino occidentale del Mediterraneo (metà IV sec. a.C. – I sec. d.C.)*. Atti del convegno Roma 24–26 gennaio 2011, ed. G. Olcese. Rome: Edizioni Quasar, 11–116.
- Picornell Gelabart, L., E. Asouti & E.A. Martí, 2011. The ethnoarchaeology of firewood management in the Fang villages of Equatorial Guinea, central Africa: Implications for the interpretation of wood fuel remains from archaeological sites. *Journal of Anthropological Archaeology* 30, 375–84.
- Rackham, O., 1982. Land-use and the Native Vegetation of Greece, in *Symposia of the Association for Environmental Archaeology No. 2*, eds. M. Bell & S. Limbrey. (BAR International Series No. 146.) Bristol, 177–98.
- Schenkel, Y., P. Bertaux, S. Vanwijnsberghe & J. Carre, 1998. An evaluation of the mound kiln carbonization technique. *Biomass and Bioenergy* 14, 505–16.
- Shackleton, C.M. & F. Prins, 1992. Charcoal Analysis and the “Principle of least Effort” – a Conceptual Model. *JAS* 19, 631–7.
- Small, D.B., 2018. An explosion, not revolution: recasting issues in the Greek Iron Age, in *An Age of Experiment: Classical Archaeology Transformed (1976–2014)*, eds. L. Nevett & J. Whitley. Cambridge: McDonald Institute for Archaeological Research, 21–9.
- Théry-Parisot, I., 2002. Fuel Management (Bone and Wood) During the Lower Aurignacian in the Pataud Rock Shelter (Lower Palaeolithic, Les Eyzies de Tayac, Dordogne, France). Contribution of Experimentation. *Journal of Archaeological Science* 29, 1415–21.
- Thommen, L., 2012. *An Environmental History of Ancient Greece and Rome*, Cambridge: Cambridge University Press.
- van der Veen, M., 1999. The economic value of chaff and straw in arid and temperate zones. *Vegetation History and Archaeobotany* 8(3), 211–24.
- van der Veen, M., R. Gale & D. Ubel, 2011. Woodworking and firewood – resource exploitation, in *Consumption, Trade and Innovation: Exploring the Botanical Remains from the Roman and Islamic Ports at Quseir al-Qadim, Egypt*, ed. M. van der Veen. Frankfurt: Africa Magna Verlag, 205–27.
- van Dinter, M., L.I. Kooistra, M.K. Dütting, P. van Rijn & C. Cavallo, 2013. Could the local population of the Lower Rhine delta supply the Roman army? Part 2: Modelling the carrying capacity using archaeological, palaeo-ecological and geomorphological data. *Journal of Archaeology in the Low Countries* 5(1), 5–50.
- Veal, R., 2012a. Examining continuity in landscape exploitation: the Late Roman fuel consumption of Insula IX at Calleva, in *Silchester and the Study of Romano-British Urbanism*, ed. M. Fulford. (Journal of Roman Archaeology Supplementary Series 90.) Portsmouth, RI, 227–45.
- Veal, R., 2012b. From context to economy: charcoal as an archaeological interpretative tool, a case study from Pompeii, 3rd century BC to AD 79, in *More than Just*



- Numbers: The Role of Science in Roman Archaeology*, ed. I. Schrufer-Kolb. (*Journal of Roman Archaeology* Supplementary Series 91.) Portsmouth, RI, 19–52.
- Veal, R., 2013. Fuelling ancient Mediterranean cities: a framework for charcoal research, in *The Ancient Mediterranean between Science and History*, ed. W.V. Harris. Columbia Classical Studies Series, 37–58.
- Veal, R., 2014. Pompeii and its hinterland connection: the fuel consumption of the House of the Vestals, c. third century BC to AD 79. *European Journal of Archaeology* 17(1), 27–44. DOI: <http://dx.doi.org/10.1179/1461957113Y.0000000043>
- Veal, R., 2017a. The environment of Villamagna through time, in *Villa Magna. An Imperial Estate and Its Legacies. Excavations 2006–2010*, eds. E. Fentress, C. Goodson & M. Maiuro. (Archaeological Monograph 23.) Rome: British School at Rome, 50–5.
- Veal, R., 2017b. Fuel in ancient food production. *Tijdschrift voor Mediterrane Archeologie (TMA)* 56, 32–7.
- Veal, R., 2017c. Wood and charcoal for Rome: towards an understanding of ancient regional fuel economics, in *Rural Communities in a Globalizing Economy: New Perspectives on the Economic Integration of Roman Italy*, eds. T. de Haas & G. Tols. Leiden & New York: Brill, 388–406.
- Veal, R., 2018. Fuel and timber in the *Casa del Chirurgo*, in *House of the Surgeon, Pompeii: Excavations in the Casa del Chirurgo (VI 1, 9-10.23)*, eds. M. Anderson & D. Robinson, 516–24.
- Veal, R., L. O'Donnell & L. McParland, 2016. Reflectance: current state of research and future directions for archaeological charcoal: results from a pilot study on Irish Bronze Age cremation charcoals. *Journal of Archaeological Science* 75, 72–81. <http://dx.doi.org/10.1016/j.jas.2016.08.009>
- White, K.D., 1967. *Agricultural Implements of the Roman World*. Cambridge: Cambridge University Press.
- White, K.D., 1975. *Farm Equipment of the Roman World*. Cambridge: Cambridge University Press.





---

## Chapter 2

# Glass and fuel

H.E.M. Cool

Glass can be viewed as coming of age early in the Roman period. For centuries, it had been used as a luxury material to make things such as small perfume containers and items of jewelry. In the Roman period, technological developments meant it became a much more versatile material used for a wider range of functions. As a result, it moved from being a small player in the high temperature industries to being a major one. To understand what the demand on fuel supplies would have been, it is necessary to consider both the chemistry of the glass itself, and the technology being used for production. This paper seeks to summarize what is currently known about this. Although questions relating to where and how glass was made in the Roman period have been research topics that have attracted considerable attention over the past few decades, there are still some very large gaps in our knowledge. One of these is how the industry was fuelled, as there is little hard archaeological evidence about what the fuel or fuels might have been. Courtesy of some interesting experimental work that will be outlined, it is possible to start trying to estimate what the fuel demands may have been.

### The development of the glass industries

The glass industries of the Imperial period were born during the late Hellenistic centuries. Prior to that glass vessels had been made by either the core forming techniques, which were suitable for making small perfume containers, or by using lapidary techniques to grind and polish the desired shape from solid blocks or hollow blanks (see, for example, Grose 1989 and Stern & Schlick-Nolte 1994 for useful summaries). None of these techniques lent themselves to mass production, and glass remained a material only suitable for the luxury end of the market as far as vessel use was concerned.

The change came in the mid second century BC when it was discovered that discs of hot glass could be sagged over formers to produce conical or hemispherical bowls (Grose 1989, 193–4). These are generally referred to as Syro-Palestinian bowls because of the large numbers that have been found in that area, but their distribution spreads across the eastern Mediterranean and into Italy, and there is evidence for manufacture in Rhodes (Triantafyllidas 2003, 136–7). As has been noted in a consideration of those from Israel, these mark the beginning of the perception that glass vessels could be an alternative to pottery (Jackson-Tal 2004, 28), and thus opened the way to their large-scale use. The industries using sagging and manipulating methods of making bowls expanded and grew in the late Republican and early Imperial periods. Their ultimate form was the ribbed bowl (Isings 1957, 17–21 Form 3), known in the Anglophone literature as a pillar-moulded bowl. These are ubiquitous on first century AD sites across the empire, bearing witness to how large the industry must have been.

The more important technological breakthrough in the use of glass came with the discovery of how to blow vessels. Using this technique a much wider range of vessel types, both open and closed, could be produced quickly and in large numbers. The discovery of glass-blowing is generally placed in the middle of the first century BC. The earliest glass-blowing waste that has been discovered comes from Jerusalem, where it was found sealed by a road built by King Herod in 37–4 BC (Israeli 1991). This was not the form of blowing where a gather of molten glass is taken from the furnace and inflated on a blowing iron. Rather, it was the inflation of one end of a pre-formed tube to provide a reservoir for a small unguent bottle. It is probable that experimentation was ongoing during the second half of the first century BC to develop the hot gathering method. Blown glass vessel fragments are rare in the first century BC

but start to appear more regularly during the Augustan period (Grose 1977). It is then found in ever increasing volumes during the Tiberio-Claudian period when it use overtakes that of the sagging industries. Roman Britain is a good example of this. Glass vessels of any sort were extremely rare prior to the Claudian invasion of AD 43. Thereafter glass vessels flooded into the new province and by far the majority were blown. At the fortress and *colonia* at Colchester a snapshot of the vessel use between AD 43 and AD 60/1 has been captured because it was burnt to the ground during the Boudican rising. The extensive city centre excavations revealed a ratio of almost three to one for blown to cast fragments (Cool & Price 1995, 11, Table 1.4).

With blowing, the functions that glass vessels served increased. Glass could be used for both fine tablewares and, possibly more importantly, for utilitarian containers. Columella, writing his treatise on agriculture in the mid-first century AD, urges the bailiff's wife to be sure she has suitable glass storage vessels as well as pottery ones for preservation (*De Re Rustica* XII, iv.4). The impact of glass vessels as a storage medium by the final third of the first century AD is vividly shown by the numbers recovered from the eruption levels at Pompeii. Scatozza Hörich (2012, 36 Tav. B) has usefully tabulated the types present within the 2000 vessels available for study. From this it can be seen that over 50 per cent are unguent bottles and small flasks for the storage of perfumes, bath oil and the like. A further 15 per cent belong to the utilitarian range of storage bottles and jars (Isings 1957, 63–9 Forms 50–1, 81 Form 62). These are the types that the bailiff's wife would have needed. Many of the container forms would have been reusable, but some were literally disposable packaging, as the contents could only have been accessed by breaking the vessel. The elegant blown birds that are such a feature of the northern Italian glass industry of the early to mid-first century AD, for example, needed to have their beaks or tails snapped off before the contents could be extracted (Isings 1957, 24 Form 11 – see, for example, Harden et al. 1987, 95 no. 37).

This increased demand caused a change to the nature and distribution of the glass-working industries. Whereas the sagging industries were most probably based in the eastern Mediterranean and latterly Italy, blowing industries spread relatively rapidly across the whole empire in the early to mid-first century AD. Even in Britain, a newly absorbed province, there is evidence of this. In the decade following the Boudican rising of AD 60/1, which had also destroyed the new foundation at London, a glass-blowing workshop was active in the harbour area once it had been rebuilt (Brigham 1997, 27).

It is possible to trace the spread of the blowing technique because the waste glass that comes from the

ends of the blowing irons (*moiles*) is very distinctive (see, for example, Amrein 2001, 21–33; Price & Worrell 2006, 132–3, colour plates 2–7). Since the fragments became widely recognized for what they were in the 1980s, there has been an ever increasing number of sites where it is known glass-blowing must have been carried out. In the latest publication of excavations in London where such debris has been found, it was noted that, to date, 21 different sites had produced it from contexts ranging from the first to late fourth century (Wardle 2013, 53). Comparable material is not uncommon throughout the rest of the province. On the continent the situation is similar. Over a decade ago it was possible to produce a map of Gaul with over 50 sites with evidence of glass-working (Foy & Nenna 2001, 43), and the number has increased since then. The pattern appears to have been for a widespread and dispersed industry serving local communities with their everyday needs. It can often be noted that where there is *in situ* evidence of glass-blowing which includes the furnaces, it is often located in zones where there were other high-temperature industries such as the manufacture of pottery (Price & Cool 1991, 27; Keily & Shepherd 2005, 154), and so it might be surmised that both industries were calling upon the same fuel supplies.

So far attention has been focused on vessel production, but glass also had an important role in building. Windows must have been regularly glazed given the frequency of window fragments in glass assemblages of all types of sites. The window glass of the first to third centuries AD (known as *latt/glossy*) was made by manipulation and sagging like the earlier bowl tradition. It was not until the fourth century that blown window glass came to be more commonly used (see Allen 2002 for discussion). *Latt/glossy* glass was translucent rather than transparent, but the important thing was that it could allow light into a structure whilst also keeping heat in. For this reason it was a vital element of bath-houses, but it was also a key part in the development of other new forms of architecture from the first century AD onwards (Ward-Perkins 1981, 187 fn 3, 151).

Whilst these would have been the two main uses of glass by volume used, the material also continued to be used for jewelry and had other uses in building such as in *tesserae* for wall and floor mosaics and blocks for *opus sectile*. As can be seen the Roman world was thus quite a voracious user of glass, and the implications of this for fuel use can now be addressed.

### Glass chemistry, manufacture and melting temperatures

To understand the amount of fuel used, it is necessary to consider the ranges of temperatures that would

regularly have to be reached and sustained to make and work glass. The viscosity of glass at particular temperatures varies according to the chemical composition, and so attention has to be given to this. Fortunately for this period that recipe is stable and uniform across the empire.

Technically Roman glass is a soda-lime-silicate. The silica may be thought of as forming the body of the glass and typically contributes about 70 per cent to the recipe. Silica has a very high melting temperature at just under 2000 °C, so a flux was needed to bring the temperature down to a level ancient technology could attain. For Roman glass, and from this point on the term is being used to include the Hellenistic material, that flux was an inorganic soda and averagely contributes c. 20 per cent to the recipe. Lime was also needed to stabilize the end product and added a further six per cent or so to the mix. The remainder of the ingredients are the minor elements, both the naturally occurring ones, such as iron which influences the blue/green colour of natural glass, and ones deliberately added either to colour or decolourize it. Beach sand would normally have included sufficient shell fragments to provide the lime, so for many glass-makers it might have been thought of as a two ingredient recipe. This is naturally a very simplified and brief outline suitable for the purpose of this paper. Further details may be found in Henderson (2000).

When studying glass it is normal to make a distinction between glass-making and glass-working. The former activity takes place in primary installations making glass from the raw ingredients. The latter describes the activity of the glass-blowers, window-makers, bead-makers, etc. Their raw material may often have been chunks of raw glass made in the primary installations but then as now, broken glass was collected for re-use. Collectors of cullet for re-use must have been common in the AD 70s and 80s in Rome, for example, as Martial used the profession as an insult in a poem (*Epigrams* I.41). The recycling of glass in this way must always be kept in mind when assessing how much glass people were using. Pottery *can* be reused when broken, as the make-up levels in buildings, or to make items such as counters, etc., but that may have been an exception. In the case of glass items, recycling was their *normal* fate. This means that in any archaeological assemblage, the number of glass vessels will always appear tiny compared to the amount of pottery ones. This need not imply that glass vessel use was necessarily small when both categories of finds were in active use. There is certainly evidence in Roman Britain that by the later second century, people across all site types and social levels were preferring to drink out of glass, with the

consequence that the volume of pottery cups in use fell (Cool 2006, 149).

Our state of knowledge of the primary installations of the Roman world is minimal. There is a model that suggests much may have been made in the Middle East (Freestone et al. 2002), but physical evidence is, on the whole, lacking. Tank furnaces for primary glass production have been found in the region but these appear to date to the Byzantine era (Gorin-Rosen 2000, 52–6). Traces of primary glass-making installations that may be of Roman date have also been found in the Wadi el-Natrun in Egypt (Nenna et al. 2000, 99–103; Nenna et al. 2005), which is an area that supplied the type of inorganic soda (natron) used in Roman glass-making. Very occasionally semi-reacted batch material has been recovered elsewhere suggesting the manufacture of raw glass, as at York. There the activity is thought to belong to the late second to early third century AD, based on the typology of the glass-melting pots it was associated with (Cool et al. 1999). Elsewhere a case has been made for local production of raw glass in the fourth century glass houses in the Hambach Forest in Germany, based on lead isotope data and other chemical correlations with the local sands (Wedepohl et al. 2003).

Amongst glass scholars the question of whether there was a centralized or dispersed production tends to be a matter of individual belief in the balance of likely probabilities. This is naturally of interest to them, but here the relevance is that it makes it difficult to access fuel requirements in any detail. Some general points, however, can be noted. There are two stages in making raw glass. The sand and soda are mixed together and heated at a relatively low temperature, certainly not exceeding 850 °C. The aim of this is to produce a substance known as frit. The heating causes the two ingredients to react with each other and drives off gasses and impurities. It is a solid-state process. The resulting solid can then be melted to make the glass. This can be done sequentially in the same furnace.

In the absence of any solid archaeological evidence for the Roman period, it is useful to look at the case of one of the primary glass installations that has been excavated in Israel. There at Bet Eli'ezer, near the modern Hedera, a single-period installation of 17 tank furnaces was recovered in 1992 during rescue excavation. Here I draw on the English summary of Gorin-Rosen (2000, 52–4) and the French account in the catalogue to the exhibition *Tout feu tout sable* (Foy & Nenna 2001, 37–8). The former does not date the installation explicitly but notes it is close to a Byzantine settlement; the latter dates the activity to within the sixth to seventh centuries AD.

The individual furnaces were laid out in a neat row side by side. Each consisted of two firing chambers with



a rectangular furnace behind them measuring  $2 \times 4$  m. The excavated evidence, combined with ethnographic observations of raw glass production in India, suggested that here both the fritting and the melting was done in a single operation. The ingredients would have been loaded into the tank, which would have been heated via the firing chambers so that the solid state reaction could take place. The temperature would then have been raised to c. 1100 °C. It was suggested this would take between 10 and 15 days. Each furnace would have produced between eight and nine tonnes of glass. When cold the furnace would have been dismantled and the block reduced to chunks of glass. These would then have been transported for sale to secondary workshops. The furnaces were only used once.

It was suggested that this was a seasonal activity with work starting in the spring to prepare the ground for the furnace, as later in the year it would become too hard to dig. The summer would be spent drying the wood for fuel, making the mud bricks with which to build the furnace(s) and then building it/them. Firing was likely to have been a late summer activity to make best use of the prevailing winds, given that the furnaces would have needed continuous air circulation over the fortnight they would have been fired. Interestingly it was suggested that production ceased at the site because the glass-workers might have run out of sufficient fuel in the area. That the production of raw glass is a very fuel-hungry process can be noted from the experience in the late sixteenth- to early seventeenth-century English glass industry (Charleston 1984, 73–5). At that time there was a major increase in the demand for glass, especially for windows. The State became increasingly alarmed about the inroads in the timber stock that was being made to, literally, fuel this (the State being always anxious about maintaining sufficient stocks of good-quality timber for ship-building and the defence of the realm). In this case the concern led to the move to coal-fired furnaces, which was presumably not an option for many Roman glass-makers. It does, though, provide a vivid illustration of the impact the rise in glass use would have had from the first century AD onwards, as more and more people wanted glass vessels in their kitchens and dining rooms, and glass in their windows.

Much more is known about secondary workshops as many more have been found. Well-published examples include those from Avenches (Amrein 2001) and Kaiseraugst (Fischer 2009), and these give a good idea of the sort of installations to be expected. The furnaces tend to be small and circular with internal diameters generally ranging from 0.5 to 1 m (Amrein 2001, figs. 91–4). There has been some debate about how such small installations could successfully reach

the temperatures needed, but early experimental work showed that if they were provided with a chimney to ensure good air circulation, this is not an issue (Shepherd 1996). Later work has shown the need for chimney can be done away with if the stoke holes are large enough (Taylor & Hill 2008, 250). It seems likely that the glass was often melted and gathered from a suspended tank inside the furnace as tank fragments often occur in deposits of glass-working waste (Keily & Shepherd 2005, 148–51). Being above-ground features, the size of the suspended tanks is difficult to evaluate, but clearly they cannot have filled the interior of the furnaces as otherwise there would not have been sufficient air circulation to maintain the high temperatures. Some authors maintain that the use of crucibles rather than suspended tanks is a fourth-century and later development (Foy & Nenna 2001, 64). The examples of crucibles from widely geographically scattered sites such as York in England, Kaiseraugst in Switzerland and Ptuj in Slovenia suggest they were in use earlier than the fourth century (for references see above and also Lazar 2003). The volumes of glass it would be possible to melt in the glass melting pots found in the Hambach Forest and at York were calculated at 6 l and 0.0125 cubic metres respectively, equivalent to about 15 to 20 kg of glass.

Interestingly on glass-working sites it is extremely rare to find charcoal or the remains of any other fuel. This is an additional difficulty when attempting to assess fuel use by the glass industries. Some of these installations were excavated prior to systematic environmental sampling, so if the evidence had been there it would not have been found. In other cases there is always the possibility that it was recovered but not reported on. Elsewhere it was looked for and not found. A good example of that occurred shortly before the conference from which this book proceeds. An *in situ* glass furnace was excavated in Winchester by Borders Archaeology with the full panoply of environmental sampling and careful excavation. Being at the time ‘fuel-aware’, I specifically enquired about any fuel remains and was told that none had been recovered. The reason for the absence will be returned to in the following section.

Having established the quantities of glass that might have been heated at any one time, it is now appropriate to look systematically at the temperatures that would need to have been achieved and maintained. Table 2.1 summarizes the temperatures required to carry out certain actions with a soda-lime-silicate glass made to the recipe outlined above. It is based on Marianne Stern’s extremely useful experimental work conducted when she was working at the Toledo Museum in the United States (Stern & Schlick-Nolte 1994, 21–4).

**Table 2.1.** Key temperatures in the working of soda-lime-silicate glass (after Stern & Schlick-Nolte 1994, 21–4).

Activity	°C	Activity
Working range	700–1100	
Chunk gathering	505–590	Simple beads
Sagging	625–830	
Fuse to other glass	735–800	Making millefiori blanks
Flatten to disc	830–875	Counters
Draw cane	930–965	Beads; canes for millefiori bowls.
Blowing	970–1020	Blown vessels
Hot gathering	1000–1150	Blanks for monochrome sagged bowls; blown vessels
Annealing point	529	
Melting point	1050–1150	Glass manufacture

The glass will start to melt at 1050 °C but temperatures in excess of that are needed to melt a pot or tank full of glass. The annealing temperature should also be noted. After a glass vessel has been made, it has to cool down slowly in a controlled environment (annealing). It is possible that waste heat from the furnace could have been used if annealing ovens were built on top of the furnace or at the back, but the need to anneal may have been an additional call on the fuel supplies.

As can be seen at the top of Table 2.1, the working range is *c.* 700–1100 °C. Within this range different things can be done at different temperatures. The chunk gathering entry (505–590 °C) is the point at which glass can be picked up and softened directly on a very hot iron. Temperatures in the 600s may thus have been sufficient to produce some monochrome beads. Glass will fuse to other pieces of glass at a minimum temperature of 735 °C, so polychrome decorated beads would have had to be produced at that temperature or higher. Some bead forms in the Roman world were made by drawing out a cane or rod and then chopping it into segments and that would need a higher temperature (930–965 °C). Canes were also an important component of the vessels made by the late Hellenistic and early Imperial industries that used the sagging techniques (Grose 1989, 189–92, 195–7, 247–54, 256–62). Thus the canes would have had first to be made at this temperature and then heated again later as part of the vessel manufacturing process.

From time to time during the Roman period, plano-convex glass counters were popular. Heating chunks of glass to the mid-800s °C and putting them on a surface should have been sufficient to make these as at that temperature the glass will naturally seek a rounded shape and flatten.

At this point it is important to start considering not just the temperatures that need to be reached, but also the length of time it is necessary to work at those temperatures. Here the contribution that the work of Mark Taylor and David Hill has made to our understanding of various processes can be drawn upon. Taylor & Hill are commercial glass-workers who became interested in Roman glass, and in the late 1990s and earlier part of the next decade they concentrated on recreating and selling ‘Roman’ vessels. Experimental work can never prove that an ancient item was made in a particular way; it can only say it could have been. Whilst acknowledging that, it is appropriate to say that I have handled tens of thousands of pieces of Roman glass during my professional life and there have been times when I could not tell the difference between those pieces and their recreations. This has not been the case in the work of some other workers who have attempted to reconstruct working practices. Taylor & Hill’s results are very convincing, and it is reasonable to think we can usefully work with them, as is done below (Taylor & Hill 2003a, 2003b).

For millefiori slumped bowls the individual cold cane segments are packed closely together and heated in a kiln to 575 °C before being transferred into the glory hole of the furnace to be manipulated and fused to a disc. As noted that will require the disc to reach a temperature of 735 °C and the slumping can be carried out in the 625–830 °C range. The manipulation needs repeated reheating in the furnace mouth. The plain ribbed bowls need the furnace to be running at the hot gather temperature as the original blank is made from poured glass. Reheating is regularly needed as the ribs are formed. Taylor & Hill note that it takes between 15 and 20 minutes to create a monochrome ribbed bowl, and almost twice as long to create a millefiori one because of the preliminary fusing of the canes.

Blown glass requires hot gathering so the furnace must be kept at temperatures of over 1050 °C even though it is best blown a lower temperature. Some blown vessels such as the simple unguent bottles must have been very quick to make. The square bottles that are so common during the later first to third centuries, were mould blown and so are more complex, with the larger ones possibly needing two gathers. Taylor (1997) estimates from his experience that an output of five bottles an hour should have been achievable.

### Putting the numbers together

It is possible to make some estimates of fuel consumption courtesy of an experimental Roman glass furnace project that Taylor & Hill ran in 2005 and 2006 (Taylor & Hill 2008). Two glass furnaces of the type found



in the secondary workshops already discussed were reconstructed. One used the suspended tank system, and one used a melting pot. The former failed at an early stage and so the figures presented here are based on the pot furnace, which was successful. The glass-melting pots used were based on the Hambach Forest vessels discussed above. There were two three-week seasons; in the first seasoned wood was used and in the second they had a mixture of seasoned and green wood. Species used included beech, ash, walnut, chestnut and yew. Once up and running the furnaces were stoked day and night, with the night-time temperature being allowed to drop a little below the gathering minimum temperature of 1050 °C. Fuel was weighed and thermocouples used to record temperature. The full article the following summary is based on records a wealth of quantified detail which people concerned with other high-temperature industries and fuel use will no doubt find of great value.

One fact that the work showed was just how long the very high temperatures needed for hot glass gathering had to be maintained even before blowing commenced. Following two days of low temperature drying out, the furnaces were gradually taken up to the working temperature of 1050 °C over two days. The empty glass-melting pots were kept in the furnace running at full temperature for two more days to season them and check for any defects or cracks that might emerge, before being charged with cullet. It was found that the melting of the glass then needed a night/day/night cycle before it was ready to blow – this allows the waste gasses to escape and so ensures that the glass is not full of bubbles. First- to third-century Roman glass is normally of very good quality and often virtually bubble free, so the Roman glass-blowers must have followed this practice.

With regard to the type of timber used, it was found that controlling the temperature was very difficult with green wood, and so seasoned wood must have been preferred. Cordwood up to c. 1.2 m long and 0.15 m in diameter worked very well with the types of stoke holes that have been found on glass furnaces of this type. This size allowed sufficient air to circulate around it as it combusted. It was also found to be easier to adjust the temperature if logs, rather than lump wood, were used.

The project also provided the answer to why it is so difficult to find evidence of fuel at glass-working sites. Spent fuel was removed morning and evening from the furnace, and dumped in an ash pit. Once there it continued to combust at about 600 °C. All that was left in the ash pit at the end of the project was a few buckets-full of ash. During the project some 49 tonnes of timber were consumed, so only to have a

**Table 2.2.** Fuel consumption recorded by the Roman Glassmakers furnace project (data taken from Taylor & Hill 2008, Tables 1 and 2).

	Total weight consumed (kg)	Day – average fuel consumption per hour (kg)	Night – average fuel consumption per hour (kg)
<i>First firing (2005)</i>			
Ash wood	332.25	13.05	13.45
Beech wood	589.25	12.23	15.94
Mixed wood	5362.00	15.92	13.25
Total	6283.50	-	-
<i>Second firing (2006)</i>			
Seasoned wood	6759.75	17.83	15.06
Green wood	420.00	36.14	26.14
50:50 seasoned/green	1220.75	26.52	23.84
Total	8400.50	-	-

few buckets of ash left at the end of the process suggests that it will be normal not to find fuel remains at Roman glass-working sites.

Table 2.2 shows the consumption of fuel used in the pot furnace running at glass gathering temperatures. If we take an average of the day and night fuel consumption of seasoned wood we can work with 15 kg of seasoned fuel per hour; that means that once the furnace gets to 1050 °C, 720 kg fuel would be needed to season the glass-melting pots and then a further 540 kg would be needed for the 36-hour melting process.

If we use the same rate of fuel use we can start to estimate how much timber would be involved in making particular types of vessels. Earlier in the paper estimates of how long it would take to make pillar moulded bowls and prismatic bottles were given. These are amongst some of the commonest Roman glass vessels found. They must have been made in huge quantities given the number that would never have entered the archaeological record because of recycling. Let us assume that a working day is eight hours. Working glass is physically taxing and so that would be a long day. Let us further say that in that day a glass-worker could produce 42 ribbed bowls (8 × 4 per hour) or 50 square bottles (8 × 5 per hour). Furthermore let us assume each of these uses 0.25 kg of glass. Both types vary in size but both can include substantial vessels. So in a charged pot of 20 kg of glass there would be enough material for 80 vessels. Making the bowls would require the furnace running for 32 hours, and making the bottles would require it to run for 30 hours. Both of these assume only one glass-worker and assistant at the furnace. This seems

reasonable because many furnaces are quite small and, given the reheating frequently needed at the mouth of the furnace, two teams might have been in each other's way.

If these assumptions are accepted, there would be a timber consumption of 480 kg for the manufacture of the bowls and 450 kg for the bottles. To both of these figures 1260 kg must be added for seasoning the pot and then melting the glass. So it would need between 21 and 22 kg of fuel to make each vessel. Cast window panes would have needed the same amount as producing them is comparable in time to producing ribbed bowls and they need to be hot gathered (Allen 2012, 105). To this would have to be added the amount of fuel needed to bring the furnace up to running temperature, and that to run the annealing ovens. There is also the amount of fuel needed to make the glass in the first place, but in the absence of knowledge about the size of the installations that is difficult to do. The Bet Eli'ezer furnaces were much larger than the secondary glass-working furnace the experimental figures relate to, and so presumably would have needed a higher input of timber per hour.

There can be no doubt that the glass industries were fuel hungry, but equally there can be no doubt that glass was in everyday use by large numbers of people throughout the empire. So by implication the glass vessels and windows were not luxury goods. Does this give us any insight into how fuel was valued? The Edict on Maximum Prices issued by Diocletian in AD 301 is not without its problems (see, for example, Rathbone 2009, 317–21), but prices for both loads of timber and finished glass artefacts are given. Using these and the fuel estimates proposed above, it is possible to start exploring what the relative cost of the fuel would have been compared to the finished goods. The artefacts we can estimate the fuel needs of (ribbed bowls, bottles and window panes) are all earlier than the Price Edict, but in the absence of any other indication of the cost of fuel and vessels, this one will have to serve.

The Edict sets the rate of the cost of a wagon load of wood at 150 denarii (Graser 1940, 360 XIV.8). The load is set at 1200 lb, so following the equivalent offered by Rathbone (2009, 301) that would represent 3715 kg. The fuel costs for the bowls, bottles and window panes per unit, as calculated above, would be slightly under 1 denarius (excluding the fuel cost for the primary glass manufacture, etc.). The part of the Edict that relates to glass divides it into vessels and window glass, giving four different prices for vessels varying from 13 to 30 denarii per pound for vessels and 6 to 8 denarii per pound for window glass (Barag 2005, 184). We do not know quite what the different

categories of vessels represent or how many you would have got to the pound. Taking all the figures together, they do suggest that the fuel cost for window glass might have represented a higher proportion of the total cost than it would have done for vessels. For the latter it does seem to be quite low. For this fuel-hungry industry, these figures suggest fuel costs would not appear to have been a problem, at least in the later third century and presumably before.

In the absence of hard evidence, this paper has made many assumptions ranging from the working speed of the Roman glass-worker to the reliability of Diocletian's price edict. Some may be reliable, some may not be. The aim has been to bring the glass industries into the equation when considering fuel use in the Roman Empire. To finish it is useful to pose a final question that it may be useful to consider more widely. Were the fuel resources running out in the later Roman period? Were they being consumed faster than they could grow? The question arises because early in the fourth century there is a major change in Roman glass. It goes from being good quality, bubble-free glass in primarily blue/green and colourless shades, to being pale green and full of small bubbles. The reason for this is unknown. It could be aesthetic, for the new glass is attractive and the bubbles catch the light. Equally though, is this a reflection of stress in the fuel supplies? We have seen the length of time a batch has to be heated to drive off the gasses that cause the bubbles. Perhaps if fuel was becoming scarcer and more expensive, this stage could no longer be afforded. It would be most interesting to explore whether other categories of evidence suggest that there might have been problems with fuel supplies at this time, but that is a task for other authors.

### Acknowledgements

I would like to thank the organizers for inviting me to speak at the interesting conference from which this paper arose, and the staff at the British School at Rome for making my stay there a pleasant one.

### Afterword

This paper was written in 2014 and glass scholarship has naturally moved on. An important project was published at about the same time this was written, which would have been referenced had it been available (Degryse 2014). This addresses the theme of where Roman glass might have been made and naturally has important implications for where fuel supplies might have been needed. A more recent note (Taylor 2018) revisits the experimental work used here and indicates

that the fuel consumption figures originally reported on have been confirmed in other experimental glass furnaces.

Degryse, P. (ed.), 2014. *Glass Making in the Greco-Roman World; results of the ARCHGLASS project*. Leuven, Leuven University Press.

Taylor, M., 2018. Reconstructions of Roman wood-fired furnaces. *Glass News* 43 (January), 14–6.

## References

### Ancient sources

Martial. *Epigrams* (Loeb edition translated by W.C.A. Ker, London and New York, 1919).

Lucius Junius Moderatus Columella. *De Re Rustica* (Loeb edition translated by E.S. Forster and E.H. Heffner, London and Cambridge, MA, 1974).

### Modern sources

Allen, D., 2002. Roman window glass, in *Artefacts and Archaeology*, eds. M. Aldhouse-Green and P. Webster. Cardiff: University of Wales Press, 102–11.

Amrein, H., 2001. *L'Atelier de Verriers d'Avenches Aventicum XI*. (Cahiers d'Archéologie Romande 87.) Lausanne.

Barag, D., 2005. Alexandrian and Judean glass in the Price Edict of Diocletian. *Journal of Glass Studies* 47, 184–6.

Brigham, T., 1998. The port of Roman London, in *Roman London Recent Archaeological Work*, ed. B. Watson. (Journal of Roman Archaeology Supplementary Series 24.) Portsmouth, RI, 23–34.

Charleston, R.J., 1984. *English Glass*. London: George Allen and Unwin.

Cool, H.E.M., 2006. *Eating and Drinking in Roman Britain*. Cambridge: Cambridge University Press.

Cool, H.E.M., C.M. Jackson & J. Monaghan, 1999. Glass making and the Sixth Legion at York. *Britannia* 30, 147–6.

Cool, H.E.M. & J. Price, 1995. *Roman Vessel Glass from Excavations in Colchester 1971–85*. (Colchester Archaeol. Rep. 8.) Colchester: Colchester Archaeological Trust.

Fischer, A. 2009. *Vorsicht Glas! Die römischen Glasmanufakturen von Kaiseraugst*. (Forschungen in Augst 37.) Augst: Augusta Raurica.

Foy, D. & M-D. Nenna, 2001. *Tout Feu Tout Sable*. Marseilles: Musées de Marseille / Éditions Édisud.

Freestone, I.C., M. Ponting & M.J. Hughes, 2002. Origins of Byzantine glass from Maroni Petrera, Cyprus. *Archaeometry* 44, 257–72.

Gorin-Rosen, Y., 2000. The ancient glass industry in Israel: summary of the finds and new discoveries, in Nenna (ed.) 2000, 49–63.

Graser, E.R., 1940. The Edict of Diocletian on maximum prices, in *An Economic Survey of Ancient Rome. Vol. V. Rome and Italy of the Empire*, T. Frank. Baltimore: John Hopkins Press, 307–421.

Grose, D.F., 1977. Early blown glass: the western evidence. *Journal of Glass Studies* 19, 9–29.

Grose, D.F., 1989. *Toledo Museum of Art. Early Ancient Glass*. New York and Toledo: Hudson Hills Press.

Harden, D.B., H. Hellenkemper, K. Painter & D. Whitehouse, 1987. *Glass of the Caesars*. London: Olivetti.

Henderson, J., 2000. *The Science and Archaeology of Materials*. London and New York: Routledge.

Isings, C., 1957. *Roman Glass from Dated Finds*. (Archaeologica Traiectina II.) Groningen / Djakarta: J.B. Walters.

Israeli, Y., 1991. The invention of blowing, in *Roman Glass: Two Centuries of Art and Invention*, eds. M. Newby and K. Painter. (Soc. Ant. London Occasional Papers 13.) London: Society of Antiquaries, 46–55.

Jackson-Tal, R.E., 2004. The late Hellenistic glass industry in Syro-Palestine: a reappraisal. *Journal of Glass Studies* 46, 11–32.

Keily, J. & J. Shepherd, 2005. Glass working in the upper Walbrook valley, in *Roman Pottery Production in the Walbrook valley. Excavations at 20–28 Moorgate, City of London, 1998–2000*, F. Seeley and J. Drummond-Murray. (Molas Monograph 25.) London: Museum of London Archaeological Services, 147–55.

Lazar, I., 2003. Roman glass production in Slovenia, in *Annales du 15<sup>e</sup> Congrès de l'Association Internationale pour l'Histoire du Verre* (New York Corning 2001). Nottingham: AIHV, 78–81.

Nenna, M-D., (ed.) 2000. *La Route du Verre. Ateliers primaires et secondaires du second millénaire av. J.C. au Moyen Âge*. (Travaux de la Maison de l'Orient Méditerranéen 33.) Lyon: Maison de l'Orient Méditerranéen-Jean Pouilloux.

Nenna, M-D., M. Picon, V. Thirion-Merle & M. Vichy, 2005. Ateliers primaires du Wadi Natrun: nouvelles découvertes, in *Annales du 16<sup>e</sup> Congrès de l'Association Internationale pour l'Histoire du Verre* (London 2003). Nottingham: AIHV, 59–63.

Nenna, M-D., M. Picon & M. Vichy, 2000. Ateliers primaires et secondaires en Égypte à l'époque gréco-romaine, in Nenna (ed), 2000, 97–112.

Price, J. & H.E.M. Cool, 1991. The evidence for the production of glass in Roman Britain, in *Ateliers de Verriers de l'Antiquité à la Période Pré-industrielle*, eds. D. Foy and G. Sennequier. Rouen: Association Française pour l'Archéologie du Verre, 23–30.

Price, J. & S. Worrell, 2006. Glass, in *Wroxeter Archaeology: Excavation and Research on the Defences and in the Town, 1968–1992*, eds. P. Ellis & R. White [= Shropshire Archaeological and Historical Soc. Trans 78 (2003)], 129–38.

Rathbone, D., 2009. Earnings and costs: living standards and the Roman economy (first to third centuries AD), in *Quantifying the Roman Economy*, eds. A. Bowman and A. Wilson. Oxford: Oxford University Press, 299–326.

Scatizza Höricht, L.A., 2012. *L'instrumentum Vitreum di Pompei*. Rome: Aracne editrice.

Shepherd, J., 1996. Reconstructing a Roman furnace, *Glass News* 2, 6.

Stern, E.M. & B. Schlick-Nolte, 1994. *Early Glass of the Ancient World 1600 BC – AD 50*. Ostfildern: Verlag Gerd Hatje.

Taylor, M., 1997. On making prismatic Roman bottles. <http://www.theglassmakers.co.uk/archiveromanglassmakers/articles.htm#On> (checked 18 September 2018).

- Taylor, M. & D. Hill, 2003a. The Fusing and slumping process. *Roman Glassworkers Newsletter* 6. <http://www.theglassmakers.co.uk/archiveromanglassmakers/nl6text.htm> (checked 18 September 2018).
- Taylor, M. & D. Hill, 2003b. Ribbed bowls and their manufacture <http://www.theglassmakers.co.uk/archiveromanglassmakers/poster03.htm> (checked 18 September 2018).
- Triantafyllidas, P., 2003. Classical and Hellenistic glass workshops from Rhodes, in *Échanges et commerce du verre dans le monde antique*, eds. D. Foy & M-D. Nenna. (Monographies Instrumentum 24.) Montagnac: Éditions Monique Mergoïl, 131–8.
- Taylor, M. & D. Hill, 2008. Experiments in the reconstruction of Roman wood-fired glassworking furnaces. *Journal of Glass Studies* 50, 249–70. See also <http://www.theglassmakers.co.uk/archiveromanglassmakers/furnace1.htm> (checked 18 September 2018).
- Wardle, A., 2013. The Roman glass, in *Roman and Medieval Development South of Cheapside. Excavations at Bow Bells House, City of London, 2005–6*, eds. I. Howell, L. Blackmore, C. Phillpotts & A. Thorp. (MOLA Archaeological Studies Series 26.) London: London Museum Archaeological Services, 51–7.
- Ward-Perkins, J.B., 1981. *Roman Imperial Architecture*. Harmondsworth and New York: Pelican History of Art.
- Wedepohl, K.H., W. Gaitzsch & A.B. Follmann-Schulz, 2003. Glassmaking and glassworking in six Roman factories in the Hambach Forest, Germany, in *Annales du 15<sup>e</sup> Congrès de l'Association Internationale pour l'Histoire du Verre* (New York Corning 2001). Nottingham: AIHV, 56–61.





---

## Chapter 3

# Problems in estimating fuels consumed in buildings: fuel requirements of hypocausted baths

Tony Rook

In the 1950s, in addition to advising on conventional heating of buildings I did original research on the introduction of domestic electrical underfloor heating.<sup>1</sup> My excavation of the Welwyn Roman baths (published in full in Rook 1986), and my work on the study of Roman domestic baths in Britain (Rook 1975, 1976)<sup>2</sup> led to my publishing a paper (Rook 1978) in which I attempted to calculate approximately the fuel consumption of a small suite of Roman baths, based on the remains excavated at Welwyn. This was intended to be a *ballon d'essai*. Was the suggested reconstruction feasible? Were the assumed conditions correct? Were my naive mathematics satisfactory? Unfortunately, I received no feedback.

Observations at the reconstructed *mansio* baths at Xanten (Rook 1993) strongly suggested that the conditions assumed in my 1978 paper, which were based on published figures for present-day so-called 'Turkish' baths in England, were incorrect. In particular that a maximum temperature of 40 °C could be assumed for the *caldarium*. Since this article was published, more modern studies, particularly of comfort physics, have made a more sophisticated approach possible.<sup>3</sup> So this present paper attempts to show in relatively simple terms how heat loss calculations from buildings are performed now, and also questions some of the basic assumptions I made in the 1978 article and suggests approaches to correcting some of them.

### Simplified calculation of heat loss from buildings

When calculating the heat input required for a building, it is usual to take a total over a long period, such as a year, taking average conditions over the period. The procedure is as follows:

1. Decide on inside temperature
2. Decide on outside temperatures (based on published meteorological tables)

3. Calculate areas of walls, doors, windows and ceiling
4. Determine U-values<sup>4</sup> of these (from published tables)
5. Calculate heat loss = area × U-value × ( $\theta_i - \theta_o$ ) through:
  - a. walls
  - b. doors
  - c. windows
  - d. ceiling
6. Determine ground-loss U-value from floor dimensions and published tables
7. Calculate ground loss  
Loss = U-value × ( $\theta_i - \theta_o$ )
8. Add these to give total conductive heat loss
9. Calculate volume of room
10. Determine the air changes (depends on type of room)
11. Calculate ventilation loss:  
Loss = volume of room × air changes per second × ( $\theta_i - \theta_o$ ) × 0.33
12. Add together the results of steps 4, 6 and 10.

A real situation can be more complicated, e.g. by having a range of temperature differences across walls (into other rooms).

### Openings

Some of the factors involved in calculating heat losses in ordinary buildings, especially heat loss through openings, pose special problems. The example of windows in Roman baths (in this case, the main baths at Ostia) is discussed in detail by Miliareisis in this volume. Whereas an opening that is *efficiently* closed by a door, shutter or by glass (or double glazing) can be treated as a conductivity issue mathematically; problems with U-values; openings without doors,



shutters or glazing, (involving ventilation, either by convection or by wind), cannot accurately be known.

### Heat requirements of a simplified *caldarium*

The case of a hypothetical *caldarium*, where all the walls are lined with all the *tubuli* functioning as chimneys, is illustrated here. No heat is lost through the walls *from the room*. It is lost only through the ceiling, i.e. through heating the roof space. The roof space loses heat through the (usually) tiled roof. The fuel required *to heat the room* can easily be calculated. A difficulty exists, however, with any attempt to estimate the amount of heat lost in the gases leaving the hypocaust.

It is noteworthy that, like most Roman furnaces, those of hypocausts were without grates; the fire burned on the ground. Most of the air entering the system flowed *over* the fire, and there was no inlet air control or outlet damper (as far as we know).

Although radiation must have been important close to the furnace, the transfer of heat further from the fire was mainly achieved by gas flow, which was powered by convection. With a conventional chimney this depends upon its area of cross section, its height and the temperature difference between its bottom and its outlet at the top. In the wall cavities provided by *tubuli* or *tegulae mammatae*, flow was not greatly restricted, and it is probably convenient to think of the furnace as a bonfire. Actual heat transfer was affected by two factors: gases lost heat as they travelled away from the furnace and they were also actually leaving the system. This probably defies theoretical analysis.

There are two additional ways in which heat is lost by the furnace gases: through the walls from the gases in the *tubuli* and as sensible heat in the gases leaving the system to the outside. In my 1978 article an attempt was made to estimate these and hence to calculate the fuel consumption.

### Inside temperature

The calculation of heat loss (and therefore requirement) of a building relies on the assumption of the temperature inside it. In living/working spaces this is comparatively simple. In the cases of the warm and hot rooms of baths, however, *we do not know what conditions were desired*. Clues are provided, however, by the study of thermal comfort.

The temperature a person perceives depends mainly upon:

- Clothing (in a study of baths we may assume that the person is naked)

- The air temperature
- The air velocity
- Humidity (how much water vapour there is in the air)
- Personal metabolism (heat generated by the body)
- Radiation (infrared) in the environment

The thermal conditions in a room are usually measured by fairly simple instruments:

- T – Air temperature measured by an ordinary mercury-in-glass thermometer
- W – The ‘wet-bulb’ temperature, given by a thermometer with its bulb wrapped in a wick and therefore cooled by evaporation. This takes into account both humidity and air velocity
- B – The ‘black bulb’ temperature, read from a thermometer with the bulb inside a hollow, matt-black, copper sphere. This takes into account infrared radiation. It was not considered when I did my earlier work

For an average person who is naked and not taking exercise, and when infrared is negligible, a simplified formula is:

$$0.7W + 0.3T^5$$

The introduction of cavity walls (e.g. employing *tegulae mammatae* or *tubuli*) led to a considerable increase in the radiant heat in rooms. In fact, it probably resulted in the introduction of unglazed, single-glazed and double-glazed windows in some bath rooms, and in ‘sunbathing lounges’ or *cella solaris*, which can be seen (or postulated) in late public baths (Rook 1975, 2005, 2013). The ramifications of these architectural developments are further discussed by Miliareisis in this volume.

Where infrared radiation is significant, a composite ‘wet-bulb globe temperature (WBGT)’<sup>6</sup> can be calculated using the formula

$$WBGT = 0.7W + 0.2B + 0.1T$$

The US military uses this to produce temperature categories for each of which the quantity of physical work and type of clothing are recommended.

(A more sophisticated ‘thermal limit algorithm index’, concerned principally with working conditions, has also now been developed. It uses published experimental studies of human heat transfer and established heat and moisture transfer equations for clothed people doing physical work. Work areas are measured and

categorized based on a metabolic heat balance equation, using dry-bulb, wet-bulb and air movement readings to measure air-cooling power. Instruments are made that measure this directly.)

### The structure of a hypocausted building

The basic idea of a hypocaust, at least at ground level, is so well known as to require no description. Problems arise when a reconstruction is contemplated, because usually insufficient amounts of the structure survive at higher levels. For example:

- How tall was the building? How were the ceiling and roof constructed?
- How large were the windows?
- Were the windows glazed? Double-glazed?
- Were hollow vaults used as flues?
- What sort of chimneys were there?
- What was the ventilation rate?

As with most fires, a hypocaust obtained air by convection and would work only if there were chimneys of some sort connecting the space under the floor to the outside at a higher level. The evolution of these is dealt with in my 1978 paper. Little evidence survives, or has been published or perhaps sought, for what happened at the top of walls that were lined with *tubuli*. I postulated that they all connected to a continuous 'collecting channel' which took the exhaust gases to outlets at the corners of the rooms. A collecting channel of this sort can be seen under a window in the Hadrianic Baths and leading to the chimneys of the 'annex' to the Hunting Baths at Lepcis Magna.<sup>7</sup> In discussions regarding the NOVA reconstruction (Yegül & Couch 2005) this idea was at first fiercely resisted, but an unspecified compromise was tacitly adopted, where only *some* of the *tubuli* were assumed to have been connected to the collecting channel. The reason for this compromise is not clear, and the actual construction was not made public, despite a documentary being filmed.

### The fuel consumption of a hypocaust

A clear error in my 1978 paper, which was not pointed out by anybody, lies in the assumption that for calculations, one can make use of the concept of an *average* temperature of the gases in a hypocaust. The actual conditions are complex. The temperature decreases as the gases flow away from the furnace, since they are losing heat, mainly to the rooms. In addition, their mass and rate of flow are decreasing as more and more are lost up the flues as the distance from the furnace increases. The effect of this is indicated by the inside

surface temperatures that I measured at Xanten. The physics of it probably cannot be theoretically predicted, and experimental reconstruction would be a useful exercise.

Some indication of the scale of the problem can be seen by attempting a description of the combustion process. If wood is the fuel, 1 kg of it requires 6.4 kg of air for complete combustion, and yields about 1.83 kg of CO<sub>2</sub>, 0.52 kg of H<sub>2</sub>O (as a superheated steam) and 5.05 kg of N<sub>2</sub> and about 20 MJ of heat. Damp wood would use some of this heat to evaporate the water, and yield a corresponding quantity of steam. Air-dried wood can contain up to 25 per cent moisture.

Complete combustion of the fuel requires at least 100 per cent excess air: it seems likely that a much larger quantity of air flowed over the fire, and the stoker adjusted the geometry of the fire to ensure that the gases going under the floor were at the optimum temperature: an empirical result. Thus, we cannot know the temperature or mass of the gases entering the hypocaust from the furnace.

Whatever these were, the gases left the 'chimneys' (whatever their form) and took heat with them. 'How much?' is an important question for which we can only estimate possible limits. It is possible to assume an average temperature in this case. In a suite of baths the furnace would have heated at least two rooms, which would make the problem more difficult. It is useful, however, to approximately calculate, for example, the heat lost in the gases leaving the chimneys of a hypothetical hypocaust burning 1 kg of wood per hour.

Thus, for a furnace using five times the theoretical (stoichiometric) quantity of air, with the flue gases leaving the chimneys with an average temperature 100 °C above outside temperature, the heat loss would be 19.4 per cent.<sup>8</sup> Carbon dioxide would be 4 per cent of the gases, assuming that the water vapour/steam has condensed.

Measurements were made in the NOVA baths that were constructed at Sardis.<sup>9</sup> The results, although subject to a number of caveats, were salutary and surprising. It was calculated that only 8 per cent of the (theoretical) heat produced by the combustion of the wood was used!<sup>10</sup>

### Conclusions

To date, we have been able to model various aspects of heating a Roman bath building. The film documentary of the NOVA project that reconstructed a Roman bath at Sardis, and the subsequent work of the coordinators, suggested quite a large loss of heat in the building (only 8 per cent efficiency). Much could be learnt by repeating the exercise of reconstruction,

which also allowed for measurement of gas temperatures as they pass through the system. This would be costly, but it would provide us with a more detailed understanding, at least of one building. However, studying bathing suites in Britain (Rook 1975, 1992) seems to confirm that which is intuitive: every bathing suite was unique, apart from some modularity of plan which is imposed by the dimensions of bipedales used in flooring. There does not appear otherwise to be any standardization of plans and many domestic baths were ‘do-it-yourself’ jobs. Large public baths and their complexity are another thing entirely. Any experimental reconstruction, besides detailed instrumentation, would also need the ability to vary the operation of the flues. At Xanten and at Sardis, I was unable to find a satisfactory configuration of flues, and so in some ways a reconstruction would be hampered until (or unless) archaeology can provide us with more details. Questions also arise as to whether bath furnaces would have been kept burning overnight (probably they would have in most cities), but this too would have varied by demand, climate and fuel availability. Generally speaking, a lot of fuel is required to get a bathhouse up to temperature (from cold), and less fuel is required (per hour) to keep it running. From the point of view of fuel consumption, it would be possible to run a reconstructed bathhouse and observe the fuel used – and to use this data to create a rough model to estimate an annual/per capita basis of fuel consumption for bathing for a small town, and eventually for larger cities.

## Notes

- 1 Unpublished; commercial work for G. Wimpey, Central Laboratories.
- 2 See also Rook (1975).
- 3 See, for example, Parsons (2002).
- 4 U-values measure how effective a material is as an insulator. Thermal performance is measured in terms of heat loss, and is commonly expressed in the construction industry as a U-value (or R-value).
- 5 This formula can also be employed in weather forecasting.
- 6 The wet-bulb globe temperature (WBGT) is a type of apparent temperature used to estimate the effect of temperature, humidity, wind speed (wind chill) and visible and infrared radiation (usually sunlight) on humans.
- 7 Personal observation. See also Rook (2013), fig. 68.
- 8 Assuming that CO<sub>2</sub> is measured *after* water vapour has been condensed, as in Orsat’s apparatus. (The Orsat apparatus consists essentially of a calibrated water-jacketed gas burette connected by glass capillary tubing to two or three absorption pipettes containing chemical solutions that absorb the gases.)
- 9 The full transcript of the film recording the building of the baths may be read at: <https://www.pbs.org/wgbh/nova/transcripts/27rbroman.html>.
- 10 Yegül & Couch (2003) use a Sankey diagram in their figure 4 to demonstrate this (Sankey diagrams are a type of flow diagram in which the width of the arrows is proportional to the flow rate, after a method first documented by Irish engineer Captain Matthew H.R. Sankey, 1853–1925). I am doubtful about the result this diagram represents. Since the temperatures of the exit gases are below 100 °C, some of the heat used to evaporate the water would have been given up in the hypocaust as it condensed, and they omit this consideration in the figure.

## References

- Lucore, S.K., 2009. Archimedes, the North Baths at Morgantina, and Early Developments in Vaulted Construction, in *The Nature and Function of Water, Baths, Bathing and Hygiene from Antiquity through the Renaissance*, eds. C. Kosso & A. Scott. Brill Online, 43–60. <https://doi.org/10.1163/ej.9789004173576.i-538.12>
- Parsons, K.C., 2002. *Human Thermal Environments (2nd Edition)*. London: Taylor and Francis.
- Rook, A.G., 1975. *Aspects of the Design and Operation of Roman Hypocaust Baths in Roman Britain*. Princes Risborough: Shire Archaeology.
- Rook, A.G., 1975. *Aspects of the Design and Operation of Hypocausted Baths in Rural Britain*. M. Phil thesis, unpublished. London: University of London.
- Rook, A.G., 1978. The Development and Operation of Roman Hypocausted Baths. *Journal of Archaeological Science* 5, 269–82.
- Rook, A.G., 1986. The Roman Villa Site at Dicket Mead. *Hertfordshire Archaeology* 9, 79–175.
- Rook, A.G., 1993. How to Fire a Roman Bath. *Current Archaeology* 135, 114–17.
- Rook, A.G., 2002. *The Story of Welwyn Roman Baths (Hertfordshire Histories)*. London: Able Publishing.
- Rook, A.G., 2005. *I’ve Come About the Drains. An Adventure in Architecture*. Welwyn: Able Publishing.
- Rook, A.G., 2013. *Roman Building Techniques*. Stroud: Amberley Publishing.
- Yegül, F.K. & T. Couch, 2003. Building a Roman Bath for the Cameras. *Journal of Roman Archaeology* 16, 153–77.

---

## Chapter 4

# Throwing money out the window: fuel in the Forum Baths at Ostia

Ismini Miliaris

The public baths of the ancient Roman world provide a window into many aspects of Roman life. They served as venues for cleansing, as gathering places, and as inspiration for technological innovations. Baths were frequented daily, and the operation of these facilities impacted both the local surroundings and the greater environment. They varied in size and importance, and some were paid for, and operated, using Imperial funds. The Forum Baths at Ostia, near Rome, are an excellent example of an ancient Roman Imperial bathing complex. Regular and rectangular in their northern sector, the baths contain unique and polygonal rooms in their southern sector. Most of the heated rooms are equipped with grandiose windows facing southwest, several metres high. This study examines the nature of these openings and demonstrates the effect that they had on the consumption of energy in the baths by using a combination of archaeological evidence, ancient literary sources and modern heat-transfer equations.

### The windows of the Forum Baths at Ostia

The Forum Baths at Ostia (Fig. 4.1) are generally accepted as Antonine (AD 138–192), and they probably remained in use until the sixth century.<sup>1</sup> DeLaine (2002, 49) calls them the ‘largest and most sophisticated Ostian building of the second century AD’. Their location next to the Forum enhanced their importance, and their elaborate and opulent decor speaks of their stature within the city. The facility was refurbished many times throughout the centuries, particularly in the Severan period (AD 193–235) and in the fourth century (Cicerchia & Marinucci 1992, 135–9; Poccardi 2001, 164). Excavations began at the baths in 1920 under the direction of Guido Calza, but the site had already been plundered for building material and precious objects.

Panes of glass for windows first came into use during the reign of Augustus, and window glass became

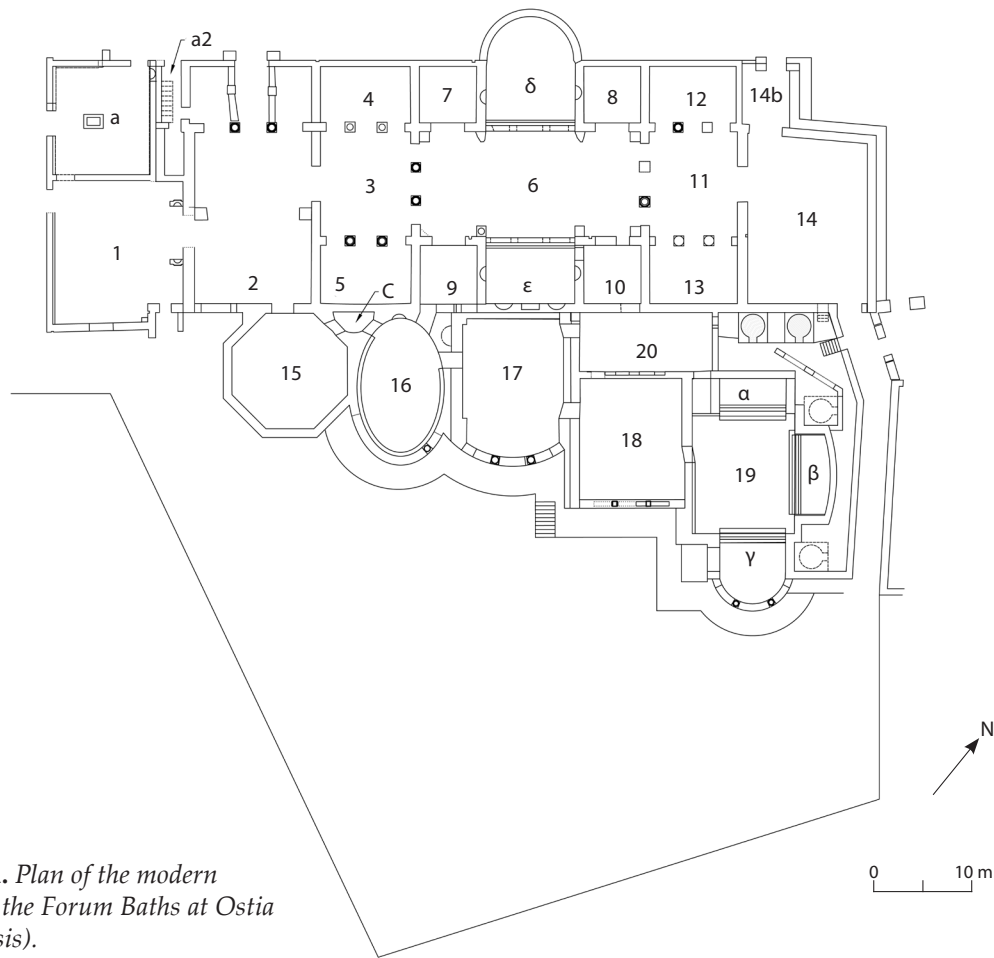
especially popular in the high empire. Sheets of glass that completely fill window spaces are a modern invention.<sup>2</sup> Glass panes were composed of smaller panes that were mounted in windows using either mortar or frames made of wood, stone or metal.<sup>3</sup> Large openings in the Forum Baths were added in the fourth century AD restorations to the *heliocaminus* (Room 15), the sauna (Room 16), the two *tepidaria* on the southern end of the baths (Rooms 17 and 18), and the *caldarium* (Room 19), but it is unclear if similar windows were present in the earlier facility.<sup>4</sup>

The characteristics of these windows have been debated over time, beginning with Thatcher (1956, 170–3). He found no evidence of glazing *in situ* and, unable to accept that glazing could have been present without leaving some trace, he concluded that glass must have always been absent. However, lack of evidence is not proof, and we know that little attention was paid to stratigraphy or small finds in early excavations. Thatcher mentions that enough heat could have been generated to keep the rooms with large unglazed windows at the desired temperatures by having very high temperatures in the floors, and by heating the vaults. Heating the baths to such high temperatures would have consumed more fuel, and there is no evidence *in situ* that the vaults were heated; however, Thatcher’s work on the structure and layout of the baths remains valuable.

Meiggs (1973, 414 n. 2) politely refutes Thatcher’s approach. He points out that the frames for the glass panes could have been wooden, leaving no record. Other scholars have also questioned Thatcher’s theories on the windows of the Forum Baths (Broise 1991, 76–7; Nielsen 1990, 17–18 n. 41; Yegül 1992, 382–3). Leaving the windows unglazed would have wasted a tremendous amount of fuel.

The effects of glazing windows or leaving them open can be understood only through a scientific heat





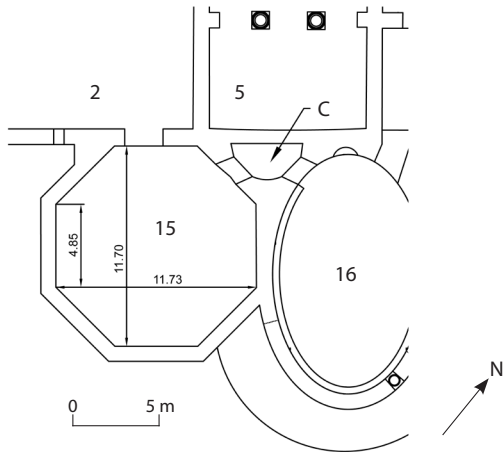
**Figure 4.1.** Plan of the modern remains of the Forum Baths at Ostia (I. Miliareis).

study, which I began as part of my doctoral research on the consumption of fuel in the Forum Baths at Ostia, and have developed further for the purposes of this, and future, studies. The first steps in conducting such a study are: to identify the openings; measure their dimensions; and to determine if there is any evidence to demonstrate whether the openings were closed with glass or some other material. As mentioned above, there are five heated rooms on the southern side of the Forum Baths, which probably had large windows that communicated with the outside. The room furthest to the southwest, Room 15 (Fig. 4.2), has usually been interpreted to be a *heliocaminus*, or sunbathing room.<sup>5</sup> Evidence for windows is present in at least three of the external walls, and there was probably a window in the fourth wall as well. The function of Room 15 as a *heliocaminus* makes it possible that this room had windows that were completely open, allowing for the maximum amount of sunlight to enter the space. Meiggs, Broise and Yegül all agree that this scenario is plausible, since bathers would have been able to get the best tan through windows without glass obstructing the sunlight.<sup>6</sup>

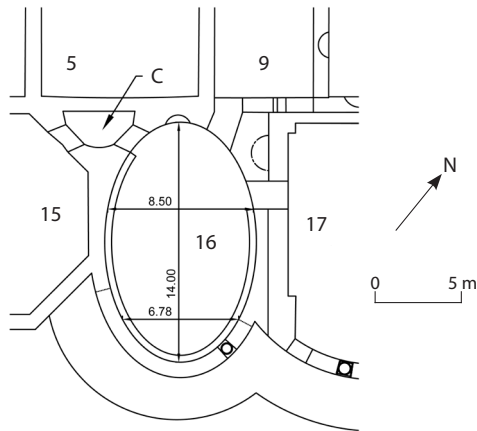
Room 16 (Fig. 4.3) has been identified as a sauna, either a *laconicum* or a *sudatorium*, making it the hottest room of the baths.<sup>7</sup> Minimizing heat loss from this room would have been important. In fact, although Room 16 has been identified as having a large window because of the presence of a column base on its outer wall, I am not convinced that the current configuration of this window is correct, or that a large window was present in this room at all. Early excavation photographs do not show the column base *in situ*, and later photos show an entire column reconstructed on the damaged wall (Cicerchia & Marinucci 1992, 36, fig. 41, 111). Currently there is only a column base in the same location, casting doubt on the entire reconstruction. Under this reconstruction, this window would have been the largest in the entire bathing facility.

The evidence for large openings in Rooms 17, 18, and 19 is more convincing, although these walls were damaged as well. Rooms 17 (Fig. 4.4) and 18 (Fig. 4.5) have been identified as warm rooms, or *tepidaria*; Room 19 has been identified as a hot room, or *caldarium*.<sup>8</sup> The window in Room 17 is formed by two Corinthian columns on a curved wall, which is also a later addition.<sup>9</sup>

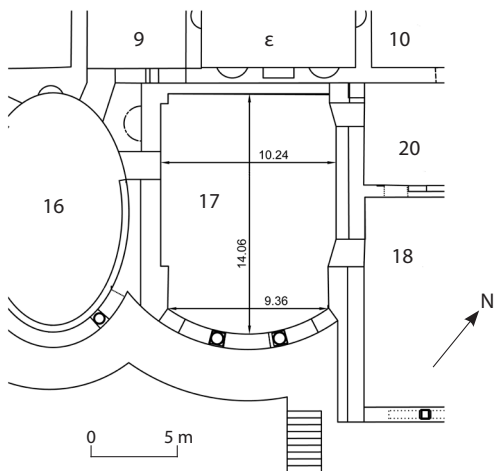




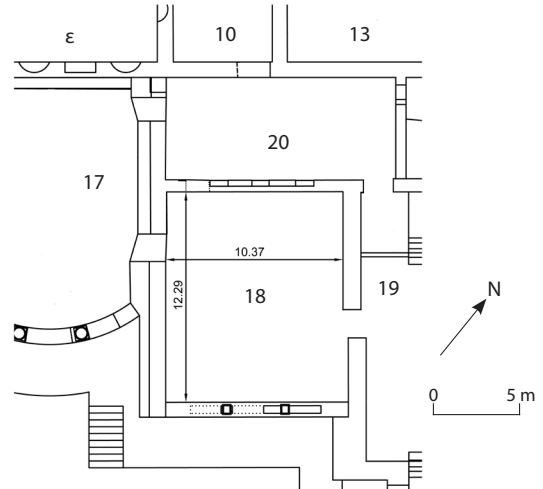
**Figure 4.2.** Plan of the modern remains of Room 15 (I. Miliaresis).



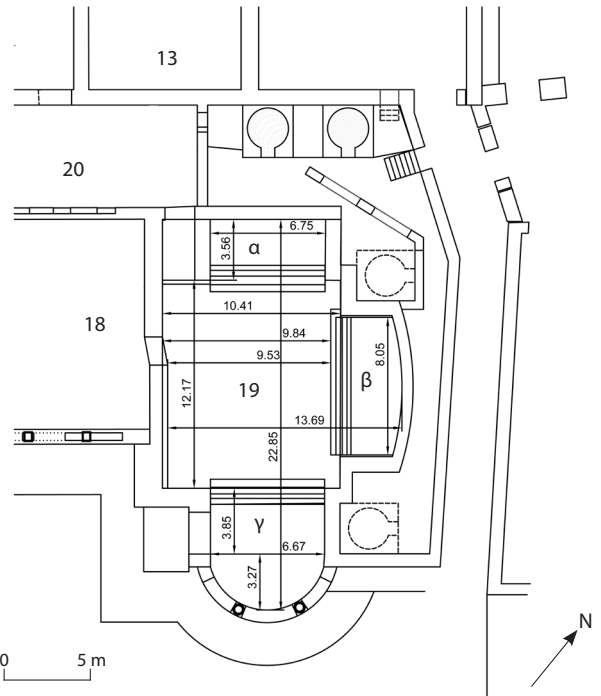
**Figure 4.3.** Plan of the modern remains of Room 16 (I. Miliaresis).



**Figure 4.4.** Plan of the modern remains of Room 17 (I. Miliaresis).



**Figure 4.5.** Plan of the modern remains of Room 18 (I. Miliaresis).



**Figure 4.6.** Plan of the modern remains of Room 19 (I. Miliaresis).

There is no evidence of window frames abutting these columns, making it difficult to draw any conclusions, although Broise (1991, 76–7) finds the evidence for glazing of the windows in Rooms 18 and 19 (Fig. 4.6) irrefutable. The opening in Room 18 is 5.53 m wide in total, and approximately 5 m tall. The double row of holes found along the interior of the Preconnesian marble pilasters demonstrates to Broise that a double-glazed window was supported in this space.<sup>10</sup> Thatcher (1956, 209) instead contends that an ornamental grille was secured by the outer holes, while a movable frame was secured by the inner holes.

A problem must be noted with all the arguments concerning the glazing of Room 18: only one pilaster with its capital, a second capital, part of the architrave, and the cornice were actually recovered at the site. The second pilaster was not found. Moreover, the rectangular capitals of the pilasters were decorated with a marine motif, convincing Cicerchia & Marinucci (1992, 37–8), that these pilasters may actually be part of a modern reconstruction.<sup>11</sup> Calza (1930, 297–8, 301 fig. 13) mentions that only restoring one of the pillars and the associated fragments of architrave and cornice was the better and more scientific option rather than recreating the missing elements in concrete. On-site inspection today, however, illustrates that the second pilaster *was* reconstructed at a later date. The accuracy of this reconstruction and the holes in the two pillars that appear to align perfectly cannot be accepted, due to the tenuous nature of the evidence.

The tripartite window was added to Room 19 in the fourth century AD, according to Broise. The opening is divided by two Corinthian columns and spans a total width of 6.73 m and a height of approximately 5.8 m. Roughly square holes can be seen on the columns, along with traces of mortar on the eastern side of the eastern column. Broise (1991, 74, 76–7, 78) interprets these elements as evidence of a *claustra*, or window screen, similar to one reconstructed at Bosra in the fourth century AD.<sup>12</sup> These columns are unlike any other found in the Forum Baths, both in marble type and size. This variation may be due to the late date of their installation, when large portions of the baths were refurbished using spoliated material. The holes and traces of mortar could be attributed to an earlier function of the columns, rather than attesting to the presence of window glazing. There is another opening on the west side window of the pool in Room 19, also without any clear evidence of glazing.

### The effects of window glazing

Using *in situ* structural remains alone to conclude that the windows of the Forum Baths were glazed is difficult, as has been reviewed. A useful research approach is

therefore to determine scientifically the relative effects of having open vs glazed windows. Windows are very complex moderators of inside temperature, since they are subject to direct, diffuse and reflected heat radiation from the sun, and to heat loss through ventilation, infiltration and conduction. Certain aspects of function must be surmised.<sup>13</sup> Sunlight is an economical way to light and heat rooms, particularly in the Mediterranean, and open windows allow the maximum amount of solar radiation to enter. With completely open windows, however, heat is lost through ventilation. Ventilation refers to air that enters or exits a space, and it is dependent on the temperature difference between the room and the outside.<sup>14</sup>

Glazed windows would have prevented a lot of heat loss, although some heat would still have been lost from improperly sealed junctures between the glass, the frames and the walls. Also, heat is transmitted through glass.<sup>15</sup> The amount of heat exchange depends on the thickness and the translucency of the glass. Although window glass was not recovered from the Forum Baths, extant glass panes have been found in other bathing facilities, e.g. the Suburban Baths at Herculaneum and the baths at Lepcis Magna and Perge.<sup>16</sup> From these data, the glass used in the Ostian baths is assumed to have been approximately 3 mm in thickness.

Glass clarity also affects heat exchange. However, determining the clarity of Roman glass is problematic, since glass fragments in the archaeological record are often iridescent, opaque or greenish in tint.<sup>17</sup> Some of this clouding is due to post-depositional oxidation, although most scholars agree that Roman glass was not as clear as modern glass<sup>18</sup> (and see Cool, this volume). Seneca (*Ep.* 86.11; 90.25) complains about more modern baths by describing windows that were transparent, causing people to ‘roast in the strong sunlight’. Pliny the Younger (*Ep.* 2.17.11) also describes a scene of swimmers bathing in a pool in the private bath of a country villa. The bathers are able to view the sea through the windows from the pool, which Pliny specifically mentions is heated. These descriptions do not clarify if there was glass in the windows or what ‘transparent’ meant to ancient people. For the sake of simplifying comparative calculations in this study, the glass in the Forum Baths is assumed to have been clear.

Other window configurations have also been reconstructed for the Forum Baths at Ostia. For example, Connolly & Dodge (1998, 244) contend that the windows of the Forum Baths were double-glazed, but evidence is lacking. The existence of double-glazed windows in the excavations of the Suburban Baths of Herculaneum is attested (Pappalardo 1999, 237–8). Pappalardo discovered that the windows of the *caldarium*

were closed with two fixed wooden frames, set 10 cm apart. Double-glazed windows separated by a heated space of 10 cm have also been suggested in the Baths of Neptune at Ostia, by Broise (1991, 62–3, 64–5, 69). Since such evidence exists in nearby contexts, it is useful to test the effects of double glazing on the heated rooms of the Forum Baths to provide a complete spectrum of possibilities.

Another scenario worthy of consideration is the possibility of windows being kept partially open with a composite pane of glass. Broise postulates that at least the lower parts of the windows in the Forum Baths could be opened to allow for an outdoor view and for ventilation.<sup>19</sup> Glass panes that could be opened and closed according to the weather and the desires of the bathers would have been ideal, but no evidence exists *in situ* to support such a reconstruction. Testing every possible dimension for a partial opening would be unnecessarily tedious, while testing a half-open window adds an extra scenario to the study.

A final way of reducing heat loss with or without using glass was to add wooden shutters to the windows. Shutters would have decreased the heat lost from open windows through ventilation, although they also would have eliminated much of the heat gain through solar radiation. Closing them on days of inclement weather may have made a significant difference, and at the very least would have helped keep precipitation out. When used in conjunction with glazed windows, they would have protected the glass during stormy weather or from intruders at night, and they would have provided shade in rooms if they got too hot in the summer months. There is no evidence of any shutters in the Forum Bath windows, but such an arrangement can be seen on the windows of the *frigidarium* in the nearby Terme del Invidioso: travertine consoles with round depressions in them for holding the metal hinges of shutters are located immediately outside the opening.<sup>20</sup> The effects of having shutters on the windows of the Forum Baths are therefore included in this study.

### Heat study method and initial results

As part of this study, I have modelled the manner in which heat moved throughout the fabric of the Roman baths using data that included the necessary components of the baths and the appropriate heat transfer equations.<sup>21</sup> This approach has allowed variations to certain factors, like temperature or time of day, in order to understand how these permutations affected the heating system.

To deduce the difference in energy consumption from having windows that are completely open

vs windows that are closed in some way, the various scenarios described above were tested using this model. In this chapter I focus only on Room 18 for the sake of brevity. Room 18 is a *tepidarium*, and the temperature difference between the air in this room and the outside is less extreme than in the *caldarium* or sauna. Therefore, the effect of having unglazed windows was less severe than it would have been in the hotter rooms, where all the results would have been magnified. The ancient outside temperatures and the temperature sustained within the *tepidarium* are not easily determined, but logical values were selected for this study based on a combination of factors: ancient literary sources, modern experimental results and comparative evidence from similar types of facilities.<sup>22</sup> For the average outside temperature at Ostia, 16.67 °C was selected for May/October, 8.06 °C for January and 23.33 °C for August; 28.00 °C was selected as the temperature for the air of the *tepidarium*.<sup>23</sup> Even if these values do not match exactly those of antiquity, (and some assumptions have to be made concerning the fabric of the windows), the comparative nature of this study still demonstrates the difference in energy necessary to operate the baths under the permutations described. In this way, the relative effects of each scenario can be demonstrated. Room 18 was tested under six different conditions: (1) windows with no glass; (2) windows with clear 3 mm thick glass; (3) windows with two panes of clear 3 mm thick glass with a space of 10 cm in between (double-glazing); (4) windows partially (half) covered with 3 mm thick glass; (5) windows with no glass, but with slatted shutters covering them; (6) and windows with clear 3 mm thick glass, and with slatted shutters covering them.

The initial results of this heat study produce some expected and some surprising results. Computations show that having clear glass rather than completely open windows only reduces the amount of solar radiation that enters a room by 14 per cent. Having tinted glass reduces the value by 26 per cent. Roman glass was probably somewhere in between in opacity; therefore, it is concluded that having glass in the windows did not significantly reduce the amount of solar radiation entering the room. Furthermore, on a clear day, solar radiation contributed a great deal of energy to the rooms, with or without glass. Surprisingly, more solar radiation entered the windows of the Forum Baths at noon in January than at any other time. This effect is due to the angle of the sun with respect to the vertical windows. In fact, calculations demonstrate that there was enough energy from the sun entering Room 18 at noon (73,161 kJ per hour gained) to offset completely the effects of ventilation through the open windows (48,216 kJ per hour lost).<sup>24</sup>

Was Thatcher right after all? Could heated rooms have large open windows without the temperature of the room dropping too much, even in winter? The answer is not that simple. The values expressed above are designed for a completely cloudless day, but there were probably not many pristine days in January, and some days were probably stormy and blustery. With the amount of solar radiation dramatically reduced, the heat lost through the open windows may not have been offset enough. More specific tests are necessary to evaluate Thatcher's theory further.

#### *Time of day and 'no glazing' vs 'glazing'*

Time of day is an important factor that must be considered for each season. Martial (*Epig.* 10.48) proclaims that the best time for bathing is the eighth hour of the day, which corresponds to approximately two or three o'clock in the afternoon. The Roman day was composed of two twelve-hour segments: the first began at sunrise and ended at sunset, and the second began at sunset and ended at sunrise. The length of each 12-hour period varied depending on the season and the hours of sunrise and sunset.<sup>25</sup> For the purposes of

**Table 4.1.** Room 18 with unglazed windows. (Shading illustrates hours of the day when sunlight would have been enough to compensate for heat lost.)

Time	May/October				January				August			
	Contr. J/s	Vent. J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Vent. J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Vent. J/s	Tot. J/s	Tot. kJ/hr
6:00 a.m.	0.00	-5997.24	-5997	-21590	0.00	-13393.20	-13393	-48216	2.58	-1718.40	-1716	-6177
7:00 a.m.	1498.55	-5997.24	-4499	-16195	0.00	-13393.20	-13393	-48216	2897.31	-1718.40	1179	4244
8:00 a.m.	4995.08	-5997.24	-1002	-3608	7412.74	-13393.20	-5980	-21530	6777.08	-1718.40	5059	18211
9:00 a.m.	8423.83	-5997.24	2427	8736	14101.86	-13393.20	709	2551	10393.14	-1718.40	8675	31229
10:00 a.m.	11204.47	-5997.24	5207	18746	18175.59	-13393.20	4782	17217	13283.22	-1718.40	11565	41633
11:00 a.m.	13075.18	-5997.24	7078	25481	20322.40	-13393.20	6929	24945	15201.57	-1718.40	13483	48539
12:00 p.m.	13705.19	-5997.24	7708	27749	21083.68	-13393.20	7690	27686	15759.33	-1718.40	14041	50547
01:00 p.m.	13075.18	-5997.24	7078	25481	20322.40	-13393.20	6929	24945	15201.57	-1718.40	13483	48539
02:00 p.m.	11204.47	-5997.24	5207	18746	18175.59	-13393.20	4782	17217	13283.22	-1718.40	11565	41633
03:00 p.m.	8423.83	-5997.24	2427	8736	14101.86	-13393.20	709	2551	10393.14	-1718.40	8675	31229
04:00 p.m.	4995.08	-5997.24	-1002	-3608	7412.74	-13393.20	-5980	-21530	6777.08	-1718.40	5059	18211
05:00 p.m.	1498.55	-5997.24	-4499	-16195	0.00	-13393.20	-13393	-48216	2897.31	-1718.40	1179	4244
06:00 p.m.	0.00	-5997.24	-5997	-21590	0.00	-13393.20	-13393	-48216	2.58	-1718.40	-1716	-6177

**Table 4.2.** Room 18 with glazed windows. (Shading illustrates hours of the day when sunlight would have been enough to compensate for heat lost.)

Time	May/October				January				August			
	Contr. J/s	Cond. J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Cond. J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Cond. J/s	Tot. J/s	Tot. kJ/hr
6:00 a.m.	0.00	-1613.36	-1613.36	-5808.096	0.00	-3473.45	-3473	-12504	2.22	-624.97	-623	-2242
7:00 a.m.	1288.76	-1613.36	-324.6	-1168.56	0.00	-3473.45	-3473	-12504	2491.69	-624.97	1867	6720
8:00 a.m.	4295.77	-1613.36	2682.41	9656.676	6374.96	-3473.45	2902	10445	5828.29	-624.97	5203	18732
9:00 a.m.	7244.49	-1613.36	5631.13	20272.068	12127.60	-3473.45	8654	31155	8938.10	-624.97	8313	29927
10:00 a.m.	9635.84	-1613.36	8022.48	28880.928	15631.01	-3473.45	12158	43767	11423.56	-624.97	10799	38875
11:00 a.m.	11244.65	-1613.36	9631.29	34672.644	17477.26	-3473.45	14004	50414	13073.35	-624.97	12448	44814
12:00 p.m.	11786.46	-1613.36	10173.1	36623.16	18131.96	-3473.45	14659	52771	13553.02	-624.97	12928	46541
01:00 p.m.	11244.65	-1613.36	9631.29	34672.644	17477.26	-3473.45	14004	50414	13073.35	-624.97	12448	44814
02:00 p.m.	9635.84	-1613.36	8022.48	28880.928	15631.01	-3473.45	12158	43767	11423.56	-624.97	10799	38875
03:00 p.m.	7244.49	-1613.36	5631.13	20272.068	12127.60	-3473.45	8654	31155	8938.10	-624.97	8313	29927
04:00 p.m.	4295.77	-1613.36	2682.41	9656.676	6374.96	-3473.45	2902	10445	5828.29	-624.97	5203	18732
05:00 p.m.	1288.76	-1613.36	-324.6	-1168.56	0.00	-3473.45	-3473	-12504	2491.69	-624.97	1867	6720
06:00 p.m.	0.00	-1613.36	-1613.36	-5808.096	0.00	-3473.45	-3473	-12504	2.22	-624.97	-623	-2242



**Table 4.3.** Room 18 with windows in January on a cloudy day. (Shading illustrates hours of the day when sunlight would have been enough to compensate for heat lost.)

Time	January unglazed				January glazed			
	Contr. J/S	Vent. J/S	Tot. J/s	Tot. kJ/hr	Contr. J/S	Cond. J/S	Tot. J/s	Tot. kJ/hr
6:00 a.m.	0.00	-13393.20	-13393	-48216	0.00	-3473.45	-3473	-12504
7:00 a.m.	0.00	-13393.20	-13393	-48216	0.00	-3473.45	-3473	-12504
8:00 a.m.	3706.37	-13393.20	-9687	-34873	3187.48	-3473.45	-286	-1029
9:00 a.m.	7050.93	-13393.20	-6342	-22832	6063.80	-3473.45	2590	9325
10:00 a.m.	9087.80	-13393.20	-4305	-15499	7815.51	-3473.45	4342	15631
11:00 a.m.	10161.20	-13393.20	-3232	-11635	8738.63	-3473.45	5265	18955
12:00 p.m.	10541.84	-13393.20	-2851	-10265	9065.98	-3473.45	5593	20133
01:00 p.m.	10161.20	-13393.20	-3232	-11635	8738.63	-3473.45	5265	18955
02:00 p.m.	9087.80	-13393.20	-4305	-15499	7815.51	-3473.45	4342	15631
03:00 p.m.	7050.93	-13393.20	-6342	-22832	6063.80	-3473.45	2590	9325
04:00 p.m.	3706.37	-13393.20	-9687	-34873	3187.48	-3473.45	-286	-1029
05:00 p.m.	0.00	-13393.20	-13393	-48216	0.00	-3473.45	-3473	-12504
06:00 p.m.	0.00	-13393.20	-13393	-48216	0.00	-3473.45	-3473	-12504

this study, the modern system of hours is used, but in conjunction with both ancient literary accounts and modern meteorological data. In May or October, on a cloudless day, the radiant energy from the sunlight was enough to offset the amount of heat lost through the unglazed windows of Room 18 between 9 a.m. and 3 p.m. Glazing extended the hours to between 8 a.m. and 4 p.m., when heat loss was compensated for by available sunlight. In August, the heat lost through open windows was replaced by enough solar energy between 7 a.m. and 5 p.m., and there was no change in hours by glazing the windows. The hours in January where the sun supplemented enough heat energy were between 9 a.m. and 3 p.m. In all other hours of the day, more heat would have been lost than that which could have been recovered from sunlight, either because of ventilation through open windows, or because of conduction through the fabric of the glass in the *tepidarium*.

As can be seen by comparing Tables 4.1 and 4.2, glazing the windows provided two additional hours of 'free' energy, between 8 a.m. and 4 p.m. for May/October and January. Although the baths were probably open at different hours in each season, as Pliny the Younger suggests (*Ep.* 3.1.8), it is unlikely that they were only open between 9 a.m. and 3 p.m. in January. In fact, a contract concerning the management of a small bath from the mining town of Vipascum, in modern Portugal, mentions that the baths would have to operate every day between sunrise and the seventh hour (12–1 p.m.) for women, and between the eighth hour (1–2.30 p.m.) and sunset for men.<sup>26</sup> If it is assumed that the baths were open to the public

in January from a little after sunrise to a little before sunset, it can be surmised that they opened at 8 a.m. and closed by 5 p.m. These additional hours would have been especially useful in winter, when many bathers may have flocked to the baths simply to warm up.

Some heat would have been stored in the building fabric of the baths, but the Romans did not have solar panels to save the energy generated through solar radiation to be used as desired. Therefore, rather than comparing a daily value of heat lost and gained through unglazed and glazed windows in January, it is more useful to directly compare each hour between 8 a.m. and 5 p.m. on a completely cloudless day: at 8 a.m., 4 p.m. and 5 p.m., heat is lost from the unglazed windows of Room 18 that is not compensated for by solar radiation (21,530 kJ per hour, 21,530 kJ per hour and 48,216 kJ per hour, respectively) (Table 4.3). These quantities are equivalent to a total of approximately 3.5 kg of ash wood for these three hours.<sup>27</sup> Heat is only lost from the glazed windows (for which there is no compensation) at 5 p.m. (12,504 kJ per hour), which is equivalent to approximately 0.6 kg of ash wood. This difference in necessary fuel is significant considering that it would have been incurred every day during the winter months. Also, most of the solar radiation comes from direct sunlight, which would be drastically reduced on a very overcast day. Assuming conservatively that half of the heat energy from the sun would be lost on a cloudy day, then this would result in heat being lost without solar compensation (at all hours of the day) through unglazed windows; there would still be an overall positive heat contribution to Room 18 between 9 a.m. and 3 p.m. with glazed windows.



The total amount of fuel needed to compensate for the net heat loss for each hour between 8 a.m. and 5 p.m. is approximately 11.4 kg of ash wood for unglazed windows and approximately 0.7 kg of ash wood for glazed windows. These results demonstrate that glazing windows, rather than leaving them completely open to the air, would have always conserved fuel.

#### *Double-glazing*

Double-glazing windows, or placing two composite panes of glass separated by a space in the opening of a window, would have been a more expensive and extravagant alternative to closing a window with a single composite pane of glass. This mechanism would have reduced the amount of energy that was lost from a heated space through conduction, but it also would have reduced the amount of solar radiation that entered the room. To numerically illustrate this phenomenon, the windows of Room 18 were compared at 1 p.m. during May/October, January and August (Table 4.4); 1 p.m. was chosen because it formed the original base study conditions, and because it is one of the times of the day when the highest quantity of solar radiation would have entered the rooms.

Computations show that in each season, the amount of energy lost through the glazed windows is reduced by close to 50 per cent when double-glazing is installed, while only 17 per cent of the solar contribution is lost due to the addition of double-glazing. Having double-glazed windows would have been especially beneficial on stormy days or at night, when there was little to no solar contribution to compensate for heat otherwise lost through conduction. The initial extra expense of installing double-glazed windows may well have been worth the fuel that would have been saved over time, although this is a matter for further study.

#### *Partially open*

The ideal scenario for having windows in a heated bathing room is to have units that can be opened or closed as necessary. If there is inclement weather outside, the windows can be closed; if there is too much sunlight streaming in on a summer day, the windows can be opened to allow some of the heat to escape and cool breezes to come in. There is no evidence to support the presence of windows with apertures that could be altered at the Forum Baths, but Pliny the Younger (*Ep.* 2.17.16) describes the windows of a *cryptoporticus* that could be manipulated to block the wind from particular directions on stormy days. He states that on nice days the windows were left completely open. Whether these openings were blocked with glass, or just shutters, is not clear. Assuming that adjustable glazed windows did exist in Roman facilities, it is useful to add this scenario to the study. A further option of a window that cannot be manipulated but is always partly open is also tested here. In this case, the window functions as two separate segments: an unglazed opening and a glazed one. The amount of ventilation and conduction experienced through this window would have varied with the width of the aperture; for the sake of simplicity, the window is tested as being half way open.

The results shown in Table 4.5 logically indicate that having a window in Room 18 that is halfway open to the air would produce gains and losses of energy in between those of completely glazed and unglazed windows. Some days this would be a benefit, and some days it would be a drawback, since the lower the outside temperatures, the more losses that would be incurred by a partially open window. If the window could be closed at will, these losses could be avoided.

**Table 4.4.** Room 18 with both glazed and double-glazed windows.

	May/October				January				August			
	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr
Glazed	11244.65	-1613.36	9631	34673	17477.26	-3473.45	14004	50414	13073.35	-624.97	12448	44814
Dble-glazed	9283.34	-833.31	8450	30420	14428.96	-1532.73	12896	46426	10793.20	-329.27	10464	37670

**Table 4.5.** Room 18 with unglazed, glazed and partially open windows.

	May/October				January				August			
	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr
Unglazed	13075.18	-5997.24	7078	25481	20322.40	-13393.20	6929	24945	15201.57	-1718.40	13483	48539
Glazed	11244.65	-1613.36	9631	34673	17477.26	-3473.45	14004	50414	13073.35	-624.97	12448	44814
Part. open	12159.92	-3417.13	8743	31474	18899.83	-7566.45	11333	40800	14137.47	-1060.46	13077	47077

**Table 4.6.** Room 18 with unglazed and glazed windows with no shutters, and unglazed and glazed windows with closed shutters.

	May/October				January				August			
	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr	Contr. J/s	Loss J/s	Tot. J/s	Tot. kJ/hr
Unglazed	13075.18	-5997.24	7078	25481	20322.40	-13393.20	6929	24945	15201.57	-1718.40	13483	48539
Glazed	11244.65	-1613.36	9631	34673	17477.26	-3473.45	14004	50414	13073.35	-624.97	12448	44814
Unglazed/ shutter	4358.54	-1137.67	3221	11595	6774.40	-2222.45	4552	16387	10134.28	-378.31	9756	35122
Glazed/ shutter	3748.34	-1468.22	2280	8208	5825.99	-2583.95	3242	11671	4357.98	-605.17	3753	13510

### Shutters

Putting shutters outside of both glazed and unglazed windows, which could be closed when the weather was not favourable, would have reduced the heat loss by providing more insulation. This scenario would have been especially useful in winter, when outdoor temperatures were the lowest. Shutters would also have been helpful at night, allowing the heated rooms to retain as much heat as possible for the next day's bathers, thus conserving overall quantities of fuel. For simplicity, only the results for the month of January are discussed here, since they illustrate the most extreme conditions. Shutters formed of slats would have still let some light in, while reducing the surface area of the opening.

As can be noted in Table 4.6, adding shutters to either unglazed or glazed windows would have drastically reduced the amount of heat contribution from the sun at 1 p.m. on a cloudless day (13,075.18 J per second vs 4358.54 J per second for unglazed windows, and 11,244.65 J per second vs 3748.34 J per second for glazed windows). Logically, though, the shutters would only be closed on days when there probably was not much sunshine to exploit. Keeping shutters closed on a sunny day would have only been beneficial if the intent was to reduce the temperature of a room, especially for glazed windows. If the solar contribution is completely removed due to inclement weather or because it is night time, shutters only reduce the heat loss for glazed windows in January by 889.50 J per second (3202 kJ per hour), which is only equivalent to 0.16 kg of ash wood that must be burned to replace the lost heat. In contrast, shutters reduce the heat loss for unglazed windows in January by 10,809.25 J per second (38,913 kJ per hour), which is equivalent to 1.94 kg of ash wood (per hour). These values indicate that shutters were not very helpful in reducing heat loss for glazed windows, although they may have been needed for shade in the summer months. Shutters made a significant difference in reducing heat loss for unglazed windows on days or at times when solar

contributions were negligible, saving almost 2 kg of wood per hour.

### Conclusion

In every case mentioned above, some heat is lost through ventilation that is not replaced by solar radiation from open windows in the span of an entire day. Although sunlight would have made up the difference during certain hours or in certain seasons, the overall computation is still a loss. Covering unglazed windows with wooden shutters reduces heat transfer through ventilation significantly, but a deficit of energy is nevertheless incurred, wasting valuable fuel resources. Thatcher contends that this energy loss can be accounted for within the heating system, but additional fuel is necessary regardless. In contrast, adding glass to the windows, even if it was relatively opaque, would have eliminated these losses (and the need for additional fuel), without significantly affecting the amount of solar radiation entering. There is no way to be sure which choice the Romans would have made, but saving fuel appears probable. The windows of Room 15 could have been left unglazed if sunbathing with full sun was considered essential, but this room could have also been sealed off on days with inclement weather. There is no obvious benefit from having an unglazed window in any of the other rooms, and the numbers computed in this study clearly demonstrate that there were benefits for glazing the windows. The most logical conclusion, therefore, is that most of the windows of the heated rooms of the Forum Baths at Ostia were glazed. Whether or not they employed other useful features, such as window panes or wooden shutters that could be opened or closed at will, is impossible to determine in this case.

### Acknowledgements

This chapter began as part of my doctoral dissertation research, and my initial conclusions were presented

at the 114th Annual Meeting of the Archaeological Institute of America in Seattle, Washington, in January 2013. Thanks are due to the McIntire Department of Art at the University of Virginia and to the Council of American Overseas Research Centers (CAORC) for their financial support, allowing me to carry out extensive research at Ostia, as well as to Angelo Pellegrino and the Ostia section of the Superintendency of Rome. I would also like to thank Carlo Pavolini and Maura Medri for consulting with me about the site, and Tony Rook, Fikret Yegül, Janet DeLaine, Lynne Lancaster, Tahsin Basaran, Massimo Ragazzo, Vasillis Tsiolis and Robyn Veal for sharing their research. Thanks to John J. Dobbins, Tyler Jo Smith, Bernie Frischer, Renee Gondek and Carrie Sulosky Weaver for their editorial suggestions, and to Robert Ribando for his help with the heat transfer aspects.

## Notes

- 1 Bloch (1953, 413–6) and Meiggs (1973, 415) both present detailed discussions of an inscription found in the baths and how it illustrates the likelihood that M. Gavius Maximus was their benefactor. According to Bloch (1953, 416), M. Gavius Maximus died in AD 158 or 159; however, it is possible the work was begun by him and finished after his death. The inscription has not been published in the *Corpus Inscriptionum Latinarum* (CIL). Poccardi (2001, 164) dates the baths specifically to AD 160, as does Pavolini (2006, 106). See also: Becatti (1948, 216); Bloch (1953, 414); Meiggs (1973, 415); Poccardi (2001, 164); Pavolini (2006, 106–9).
- 2 The advent of flat window glass coincides with the opening of the first glass factories in Italy. For more on flat window glass, see Jennings (2015). For more information on the manufacturing of glass in general, see Harden (1961, 48). See also: Gross (1977, 15); Ortiz Palomar & Paz Peralta (1997, 437–8); von Saldern (2004, 2).
- 3 Although few walls survive to heights sufficient to preserve windows, and there is no extant evidence of glass in the Terme del Foro at Ostia, there is material evidence that glass was placed in the windows of some Roman baths: Briggs (1956, 416); Broise (1991, 61–2); Bachman (2008, 118).
- 4 Large windows are also found in the Terme del Filosofo at Ostia. Boersma (1985, 127–8) states that it can be assumed that the large south-facing windows in the two *tepidaria* and in the *caldarium* of the Terme del Filosofo were closed, but he provides no evidence. He also mentions that these rooms were all heated by hypocausts under their floors, but that only the *caldarium* contained any wall heating devices. Boersma also assumes that the windows in the *frigidarium* were glazed. For more on window types in Ostia, see: Packer (1971, 24–7); Calza (1925, 97); Meiggs (1973, 414); Heinz (1983, 102).
- 5 Yegül (2010, 248) defines a *heliocaminus* as ‘A special room for sunbathing believed to have been a part of some Roman baths. These rooms enjoyed a southern or southwestern exposure and received the sun through large, possibly unglazed, windows.’
- 6 Broise (1991, 76); Meiggs (1973, 414); Yegül (1992, 382–3).
- 7 Thatcher (1956, 218) and Pellegrino (2000, 33) identify Room 16 as a *laconicum*, while Meiggs (1973, 414) and Pavolini (2006, 110) identify it as a *sudatorium*. Cicerchia (1992, 35–6, 111, 112–3) also identifies Room 16 as a dry heat *laconicum*, basing his identification on the lack of evidence for any basins, *labra* or water systems. He also mentions that there is no trace in the room of water conduits or *fistulae*. In a contradictory statement, he describes Room 16 in its earliest phase as being almost completely filled by a pool. Yegül (2010, 6) mentions that *laconica* are usually round, but this room is elliptical, making it very unusual.
- 8 Thatcher (1956, 218); Meiggs (1973, 414); Cicerchia & Marinucci (1992, 36–7, 115, 221); Pavolini (2006, 110).
- 9 The southern wall of Room 17 was reconstructed in the modern period primarily using ancient bricks, creating a great deal of confusion. In addition, both pillars that would have formed these windows are missing from the excavation photos and may have been reconstructed incorrectly. There is even the possibility that there were no windows in this wall at all. Cicerchia & Marinucci (1992, 115, 118, 137, fig. 46).
- 10 A similar arrangement of holes can be seen in the large windows of the South Baths at Perge, in Turkey.
- 11 They base their doubts on the fact that two identical marine-motif capitals were found in the area of the *palæstra*, and a more likely reconstruction would be that all four of these elements were derived from one structure. See also Pensabene & Lazzarini (2007, 275).
- 12 The windows of the South Baths at Bosra, in Syria, have been reconstructed as being divided with brick pillars, measuring 0.4 × 0.4 m. These pillars created three openings that were 0.55 m wide, where *claustra* window screens were inserted. Metal hooks and a coating of plaster were used to secure the bricks in place within the screen.
- 13 McQuiston & Parker (1994, 187, 228–9); ASHRAE (2001, 26.10); Çengel (2007, 693).
- 14 McQuiston & Parker (1994, 226); ASHRAE (2001, 26.1); Çengel (2007, 538–9).
- 15 For the sake of simplicity, conduction is only evaluated through the glass, rather than including the conduction through the individual pieces of wood, metal or stone that would have held each pane in place.
- 16 During the AD 79 eruption of Vesuvius, the windows in the *caldarium* of the Suburban Baths at Herculaneum were blown out from the impact of the volcanic flow. A *labrum* that once stood next to a window was also pushed across the room by this violent force, leaving an imprint in the ash. Fragments of double window frames and of glass that had been blown into the *labrum* were found in this ash imprint. These fragments were measured to be 4.5 mm thick. Those from Room Y in the baths at Lepcis Magna, measured between 3 and 4 mm in thickness. See Bartoccini (1929, 60–1); Broise (1991, 62–3, 69); Pappalardo (1999, 237–8).



- 17 Decolourizers could be added during the glass manufacturing process, to produce a clearer glass. For more information on the process, see Freestone (2015, 30–31).
- 18 Some scholars, such as Esperanza, Palomar & Paz Peralta (1997, 438), assert that Roman glass was not as clear as modern glass. Broise (1991, 61) specifies that ancient glass was ‘translucide, mais non transparent’. See also Harden (1961, 52); Bachman (2008, 119).
- 19 Broise (1991, 61–72 fig. 24) also claims to have identified movable glass panes in the baths at Bosra, in the *apodyterium* and the *tepidarium* of the Forum Baths at Pompeii, and in the Suburban Baths at Herculaneum.
- 20 Broise (1991, 65–72); Ring (1996); Ortiz Palomar & Paz Peralta (1997, 438).
- 21 I was assisted by Kostas Floratos with the development of this model using Microsoft Access software.
- 22 The Romans did not know the numerical value for the temperatures they maintained in the baths. Galileo Galilei invented a rudimentary thermometer in 1593 that was able to measure temperature variations, but it was not until 1714, when Gabriel Fahrenheit created the first mercury device, that quantities of heat could be measured numerically. Tonks (1908, 421) has suggested that ancient Greek potters may have used gold or silver wire to monitor temperatures inside their red and black figure pottery kilns, which had to be precisely regulated in order to produce the desired colour effect. The melting points of both metals (1062 °C for gold, and 961 °C for silver) are just slightly above the temperatures that potters needed to fire these vessels. Rehder (2000, 11–12) conjectures that someone with a ‘practised eye’ would have been able to tell the general temperature within 20 °C by colour. A 20-degree range of error in the baths, however, would have made the difference between having bathers enjoy a hot pool or being cooked alive. See Hasaki (2002, 125–6) on the relationship of bath furnaces to kilns; also Bellis (2012) and Noble (1965, 75).
- 23 The temperature was selected for the *tepidarium* based primarily on a combination of information calculated in previous studies: the measurements collected by Couch (2003, 169, 173–4) in the reconstructed NOVA bath near Sardis (Turkey), and the engineering study conducted by Basaran & Ilken (1998, 4) on the Small Baths at Phaselis (Turkey). The outside temperatures for ancient Ostia were selected based on monthly averages collected between 1961 and 1990 at the meteorological station on the Isola Sacra, adjacent to Ostia, and published in Sadori et al. (2010, 3294). Wind was not included in the calculations for simplicity.
- 24 Joules are a unit for measuring heat, energy or work in the SI system. One joule per second is equivalent to one watt. One joule is equivalent to 0.00094781712 British Thermal Units.
- 25 Calza & Nash (1959, 57); Nielsen (1990, 1); Yegül (1992, 429 n. 28; 2010, 11).
- 26 *CIL* II, 5181 = ILS 6891.20–21.
- 27 For the purpose of this study, ash wood was selected as the primary fuel because of its excellent burning properties and its propensity to grow around the area of (modern) Ostia. We lack published archaeological data at this time.

## References

- ASHRAE, 2001. *2001 ASHRAE Handbook: Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
- Bachman, M., 2008. Lichtvolle Perspektiven. Ein Fensterglasfund aus Bau Z in Pergamon, in *Euergetes: Prof. Dr. Haluk Abbasoğlu’na 65. Yaş Armağanı*, eds. Y. Hazırlayanlar, İ. Delemen, S. Çokay-Kepçe, A. Özdzibay, & Ö. Turak. Antalya: Suna – İnan Kiraç Akdeniz Medeniyetleri Araştırma Enstitüsü, 117–26.
- Bartoccini, R., 1929. *Le Terme di Lepcis (Leptis Magna)*. Bergamo: Istituto Italiano d’Arti Grafiche.
- Basaran, T. & Z. Ilken, 1998. Thermal analysis of the heating system of the Small Bath in ancient Phaselis. *Energy and Buildings* 27, 1–11.
- Becatti, G., 1948. Case ostiensi del tardo impero. *BdA* 33(4), 197–224.
- Bellis, M., 2012. The History of the thermometer. <http://inventors.about.com/library/inventors/blthermometer.htm>.
- Bloch, H., 1953. The name of the baths near the Forum of Ostia, in *Studies Presented to David Moore Robinson*, eds. G.E. Mylonas & D. Raymond. Saint Louis, Missouri: Washington University, 412–8.
- Boersma, J.S., 1985. *Amoenissima Civitas: Block V.ii at Ostia: Description and Analysis of its Visible Remains*. Assen: Van Gorcum.
- Briggs, M.S., 1956. Building construction, in *A History of Technology*, eds. C. Singer, E.J. Holmyard, A.R. Hall & T.I. Williams. New York and London: Oxford University Press, 397–448.
- Broise, H., 1991. Vitrages et volets des fenêtres thermals à l’époque impériale, in *Les Thermes Romains: Actes de la table ronde organisée par l’École française de Rome (Rome, 11–12 novembre 1988)*. Rome: Collection de l’École française de Rome 142, 61–78.
- Calza, G., 1925. *Ostia: guida storico-monumentale*. Milan and Rome: Bestetti & Tumminelli.
- Calza, G., 1930. Restauri di antichi edifici in Ostia. *BdA* 9(2.7), 291–310.
- Calza, R. & E. Nash. 1959. *Ostia*. Florence: Sansoni.
- Çengel, Y.A., 2007. *Heat and Mass Transfer: A Practical Approach* (3rd ed.). New York: McGraw Hill.
- Cicerchia, P. & A. Marinucci. 1992. *Scavi di Ostia. Vol. 11, Le Terme del Foro o di Gavio Massimo*. Rome: Istituto Poligrafico e Zecca dello Stato.
- Connolly, P. & H. Dodge. 1998. *The Ancient City: Life in Classical Athens and Rome*. Oxford: Oxford University Press.
- DeLaine, J., 2002. Building activity in Ostia in the second century AD, in *Ostia e Portus nelle loro relazioni con Roma*, eds. C. Bruun & A.G. Zevi. Rome: Institutum Romanum Finlandiae, 41–102.
- Freestone, I.C., 2015. The Recycling and Reuse of Roman Glass: Analytical Approaches. *JGS* 57, 29–40.
- Gross, D.F., 1977. Early blown glass: the western evidence. *JGS* 19, 9–29.
- Harden, D.B., 1961. Domestic window glass: Roman, Saxon and medieval, in *Studies in Building History*, ed. E.M. Joep. London: Odhams Press Limited, 39–63.

- Hasaki, E., 2002. Ceramic Kilns in Ancient Greece: Technology and Organization of Ceramic Workshops. Ph.D. Diss., University of Cincinnati.
- Heinz, W., 1983. *Römische Thermen: Badewesen und Badeluxus im Römischen Reich*. Munich: Hirmer Verlag.
- Jennings, S., 2015. Flat Glass from Butrint and its Surrounding Areas, Albania, in *Glass of the Roman World*, eds. J. Bayley, I. Freestone & C. Jackson. Oxford and Philadelphia: Oxbow Books, 153–64.
- McQuiston, F.C. & J.D. Parker. 1994. *Heating, Ventilating, and Air Conditioning: Analysis and Design* (4th ed.). New York: John Wiley & Sons, Inc.
- Meiggs, R., 1973. *Roman Ostia* (2nd ed.). Oxford: Clarendon Press.
- Nielsen, I., 1990. *Thermae et Balnea: The Architecture and Cultural History of Roman Public Baths*. Aarhus: Aarhus University Press.
- Noble, J.V., 1965. *The Techniques of Painted Attic Pottery*. New York: Watson-Guptill Publications.
- Ortiz Palomar, M.E. & J.A. Paz Peralta. 1997. El vidrio en los baños romanos, in *Termalismo Antiguo*, ed. M.J. Peréz Agorreta. Madrid: Casa de Velázquez, 437–51.
- Packer, J.E., 1971. *Memoirs of the American Academy in Rome*. Vol. 31, *The Insulae of Imperial Ostia*. Rome: American Academy in Rome.
- Pappalardo, U., 1999. The Suburban Baths of Herculaneum, in *Roman Baths and Bathing: Proceedings of the First International Conference on Roman Baths held at Bath, England, 30 March – 4 April 1992*, eds. J. DeLaine & D.E. Johnston. (*Journal of Roman Archaeology Supplementary Series* 37.) Portsmouth, RI, 229–38.
- Pavolini, C., 2006. *Ostia* (3rd ed.). Rome: Editori Laterza.
- Pellegrino, A., 2000. *Ostia Antica*. Rome: Soprintendenza Archeologica di Ostia.
- Pensabene, P. & L. Lazzarini. 2007. *Ostiensium marmorum decus et decor: studi architetonici, decorativi e archeometrici*. Rome: L'Erma di Bretschneider.
- Poccardi, G., 2001. Thermes et bains de l'Ostie antique, in *Ostia: port et porte de la Rome antique*, ed. J.P. Descoeudres. Geneva: Georg Éditeur, 161–71.
- Rehder, J.E., 2000. *The Mastery and Uses of Fire in Antiquity*. Montreal and Kingston: McGill-Queen's University Press.
- Ring, J.W., 1996. Windows, baths and solar energy in the Roman Empire. *American Journal of Archaeology* 100(4), 717–24.
- Sadori, L., M. Giardini, C. Giraudi & I. Mazzini. 2010. The plant landscape of the imperial harbour of Rome. *Journal of Archaeological Science* 37, 3294–3305.
- Tonks, O.S., 1908. Experiments with the black glaze on Greek vases. *American Journal of Archaeology* 12(4), 417–27.
- Thatcher, E.D., 1956. The open rooms of the Terme del Foro at Ostia. *Memoirs of the American Academy in Rome* 24, 169–264.
- von Saldern, A., 2004. *Antikes Glas*. München: Verlag C.H. Beck.
- Yegül, F.K., 1992. *Baths and Bathing in Classical Antiquity*. New York: Architectural History Foundation.
- Yegül, F.K., 2010. *Bathing in the Roman World*. Cambridge: Cambridge University Press.
- Yegül, F.K. & T. Couch. 2003. Building a Roman bath for the cameras. *Journal of Roman Archaeology* 16, 153–77.



*Part II*

**Fuel in ceramics making:  
ancient and modern examples**



---

## Chapter 5

# Fuelling Roman pottery kilns in Britain and North Africa: climatic, economic and traditional strategies

Victoria Leitch

A comparison of pottery kilns and fuels used at opposite ends of the Roman Empire, enjoying very different climatic and environmental conditions, offers the opportunity to examine the strategies and practicalities involved in the choice, collection and use of fuel. This paper looks at the types of fuel used and the kiln designs and considers questions of economy, scale and tradition.

### Kilns

A kiln is defined as a structure with a chamber that can be closed to raise the temperature, and where the temperature and aeration levels can be controlled. The variety of designs we see in antiquity may have been influenced by the type of fuel used, which would be expected to come from local sources. Looking at modern contexts, we see that in Japan huge Anagama kilns for hundreds of pots fired at up to 1280 °C use seasoned split pine logs from local forests; in south-east Asia and Africa, waste from the harvest is used to fire open bonfire kilns; and in Mexico dried dung is a common fuel. These fuels all require a particular type of kiln design and firebox to make the best use of the heat.

#### *Kilns in Roman Britain*

Starting with Roman Britain, many pottery kilns have been excavated and have been excellently summarized by Vivian Swan in her 1984 publication.<sup>1</sup> Swan also created a useful typology. The kilns were generally a low beehive structure sunk into the ground with a dome roof that was remade over the closely packed pots for each firing. There was no chimney, only an exit hole in the dome, and the fire-mouth was a pit leading to a circular base with a central clay column supporting the chamber floor. By digging a kiln out of the surrounding clay-based soils, the kiln became

a fired pot unit and was probably considered fairly expendable since more than one is usually found at any one site. Known kilns seem to have been built facing different ways, perhaps to maximize the use of different winds.

The origins of Romano-British kilns are debated: were they native or influenced by designs in Roman Gaul? This suggestion arises from the fact that Romano-British pottery was clearly influenced by La Tène Belgic wares, so why not the firing technology as well? Over time, the kilns gradually increased in depth and the area of the furnace chambers and stoke-holes expanded. This is attested from the mid-first century AD, reflecting presumably the impact of the Roman conquest and the new demands of the garrisons.

For the purposes of this paper I will discuss a few typically designed examples that were recently excavated and so have better information on the design and fuels used, and can thus also be used to test the correlation between design and fuel type. In addition, a recent experiment carried out by Beryl Hines with the Suffolk Archaeological Service to reconstruct a Romano-British kiln adds important insights (Hines 2012, 26–38). The reconstructed kiln was based on a Wattisfield-type example (Swan 1984, fig. XVII, 77) found at Barham Quarry, near Ipswich in East Anglia, excavated in 2005, and followed the typical design for a Romano-British kiln, having a smaller hole for the chamber linked by a short trench to a much larger hole for stoking. The kiln is funnel-shaped with a 2 m diameter, a central pedestal, and beyond the stoke hole or firebox, a large stepped stoking pit. The original produced greywares. The reconstruction was carried out at Redewood, Henley, near Barham Quarry. The experiment demonstrated that the best fuel for this design was seasoned sticks. Long thin round pieces of wood are best and achieve a steady rise in temperature to over 800 °C. Half a cord (a ton

of stacked wood 8 × 4 feet/244 cm × 122 cm) of coppice wood is needed to fire a small to medium kiln.

But where did this fuel come from? Traditional coppiced woodland, common in Britain and certainly present at the sites in East Anglia, has been around for centuries, even millennia, and must have been exploited by the Romano-British population. Many trees in Britain are not killed but cut down, and the stumps send up new shoots that usually quickly grow into uniform poles. Among the native woods most observed in the Roman period are: Alder (*Alder glutinosa*), ash (*Fraxinus excelsior*), birch (*Betula pubescens* or *B. pendula*), field maple (*Acer campestre*), hazel (*Corylus avellana*), hornbeam (*Carpinus betula*), lime (*Tilia cordata* or *T. platyphyllos*), oak (*Quercus* spp. – deciduous oaks, there are several possibilities and these can hybridize), willow (*Salix* spp. – as for oak, there are a number of native willows and these can rarely be differentiated in archaeological charcoal), and elm (*Ulmus glabra* or *U. minor*). These are the main coppicing trees. Coppiced woodland is typically cut in a seven- to ten-year rotation, which allows for the production of tall poles (Hines 2012, 33). Fuel was made from faggots – bundles of sticks seasoned for a few months, needing only a simple curved axe (called a ‘billhook’) to cut it. The actual type of timber is not so important; what counts is that the wood is well seasoned and dry, giving the highest calorific value, as most wood types easily reach temperatures over 800 degrees (inside a kiln). Calorific value (heat actually obtained) needs to be differentiated from calorific potential. Different woods have different calorific potentials (and a proxy for this is specific weight at a fixed moisture content; i.e. the denser the wood, the higher its calorific potential). The observed ‘calorific value’, i.e. the heat that is eventually transferred to the pottery, is dependent on kiln design and other ambient issues. Woods can vary greatly in their calorific potential (oak is 50 per cent higher than willow, for instance). Thus, if you have reduced potential, you need more wood (simplistically speaking). Also, the arrangement of the coppiced wood allows for the flow of air through the kiln, vital for efficient combustion (cf., say, sawn timber with flat sides). Thus, this renewable source of coppiced wood was ideal and essential for pottery kilns. This could simply have been local unmanaged wood for small kiln sites or managed woodland for larger workshop industries.

There is evidence in the Roman period at Mucking (Jones & Rodwell 1973) for the use of local wood and the small diameter of the wood suggested the use of faggots, not proper timber. Looking at studies undertaken on charcoal from Romano-British kilns, excavations at the Ellingham kiln revealed charcoal

of oak (*Quercus* spp. deciduous), and alder (*A. glutinosa*) (Bates & Lyons 2003). At Postwick there was maple (*A. campestre*), hazel (*C. avellana*), holly (*Ilex aquifolium*), spindle (*Euonymus europaea*), oak (*Quercus* spp.), gorse/broom (*Ulex* spp.; there are three native gorses and these species cannot be differentiated in charcoal, nor can they be differentiated from broom – *Cytisus scoparius* is the common broom, but several other shrubby plants are also called ‘broom’ in Britain; these are, of course, shrubs, rather than trees), ash (*F. excelsior*), hawthorn (*Crataegus* spp.), apple/pear, rowan/service tree/whitebeam (known collectively as members of the Maloideae family, and generally not differentiable in charcoal), wild cherry, blackthorn (*Prunus* spp., also rarely differentiable), willow/poplar (*Salix* spp./*Populus* spp.), lime (*Tilia* spp.) – all commonly found close to the kilns (Gale 2003). Spelt chaff has also been found in some sites, such as at Stowmarket (Plouviez 1989). Thus, most of the wood in these kilns is from the surrounding area. Gorse is significant as it is highly flammable once dried, and chaff, which burns easily and also provides fast heat, probably came from harvest waste that was shovelled into the kilns as fuel. Neither gorse nor chaff have a ‘high calorific potential’ (or value). Being highly flammable once dried, they are mainly useful for helping build a fire, or giving it a boost to increase temperature quickly: especially useful in ceramic firing, as a specific temperature must be reached for the firing to be successful. However, using chaff or gorse alone as fuel, tons and tons of it would be required. That said, gorse and broom are low-growing, prolific shrubs, and so very available and easy to collect (except for the thorns!); similarly, agricultural chaffs. So, despite the drawbacks and the huge quantities needed, using gorse/broom as fuel may have been quite efficient (i.e. using everything available) and would have helped contribute to the sustainability of more precious wood fuels (for more on this, see Veal, this volume).<sup>2</sup>

At Holm-on-Spalding Moor, west of the Yorkshire moors, there was a substantial pottery production area, which has been well investigated – including excavation of kilns and survey work (Halkon 2002). For example, at Bursea House the kiln follows an Iron Age tradition and matches Swan’s Linwood tradition (Swan 1984, 106), as does the kiln at Hasholme, with large stoking areas. Recent analysis of the pollen and other environmental evidence showed that the area was wooded with an oak-alder forest, and an understorey of hazel. Evidence from the excavation of the Bursea House pottery kilns demonstrates that alder and willow or poplar were used, and thus that woodland management probably took place. It is also

interesting to note that there was an associated iron industry, which took advantage of the local resources, an association that is apparently relatively common in Roman Britain. The link may be to do with fuel resources, though also the grouping of potentially dangerous industrial activities away from domestic areas for safety reasons would have been important.

In summary, coppice wood and harvest waste were probably the fuels used for Romano-British pottery kilns, being readily available, renewable and following a seasonal routine. Coppice is best cut in winter, so early potters probably enjoyed seasonal work, cutting and stacking faggots over winter, digging clay later, and producing pots in the summer, since drying clay (or fuel) during the winter months was almost impossible.

In terms of design, Swan believes there was a direct relationship between the design and the size, type and abundance or scarcity of fuel. For example, the Alice Holt/Farnham twin-flued kilns have a very small opening at the junction of the flue and furnace chamber, probably reflecting the use of fuel with a small diameter (Swan 1984, fig. XVIII, 78). At Hartshill/Mancetter potteries of the second century, the kilns were very large, due to increased demand and probably a desire to conserve fuel resources by having fewer large firings. In terms of wares, for fine wares, kilns with raised floors were essential to protect the vessels from ash and flames (i.e. indirect heat was utilized – these kilns required more fuel than direct heat examples). For instance, the New Forest kilns with high oven-floors and high, short flues may have been designed in this manner to achieve the higher temperatures needed for lustrous wares (compared with coarser wares), by burning bulky bundles of wood (Swan 1984, 75).

Beryl Hines' experiments also demonstrated that typical Romano-British kiln designs worked well with the wood suggested. They also demonstrated the value of a large stoking pit. A clear space in front of the fire-box was important to enable the fuel to be fed easily into the kiln, and as the kiln became hot, space was needed to enable the stokers to escape from the heat of the fire, and, importantly, to allow enough oxygen in to ensure combustion was as efficient as possible. Keeping the fuel and kiln dry was also important in a British climatic context, and shelters could be placed over the stoking pit – as smoke but not flames entered the stoking pit, a shelter could safely be built.

So, fuel for pottery kilns in Roman Britain seems to have been selected for convenience, from the surrounding area, but it was also most probably selected for its calorific potential, and cut in such a way as to permit as efficient combustion as was possible. The

design of the kilns was influenced by the bulk of the fuel and the climate, and the most common designs were indigenous and/or mixed with influences from northern European potteries, but probably were not introduced by the Romans. The Roman conquest was, however, responsible for increased pottery production and thus more pottery kilns.

#### *Kilns in North Africa*

The majority of the kilns in North Africa are up-draught kilns, circular or elliptical in design with a central pillar that supported an upper chamber. The lower chamber dug into the ground was for the fuel and the upper for placing the pottery. It has been suggested that this design travelled from the near east and moved west with the Phoenicians. Similar designs are found in Punic Mozia in western Sicily and as far east as Iran in the first millennium BC. The deep fuel chamber was suitable for olive pit fuel. Lea Stirling has demonstrated that fuel chambers became proportionately deeper in Roman times, which could indicate that different fuel was used by the Romans, or at least that production levels were greater (Stirling 2006). Advances in pottery production also allowed for finer wares with glossy slips, which needed higher firing temperatures, to be mass-produced economically.

North African kilns tend to show a large degree of homogeneity in their design and the placement of the firing chamber. For instance, at Volubilis in Morocco there is a circular kiln with a diameter of 4 m. At Cherchel, on the northern coast of Algeria, two kilns were uncovered about 3 m from one another. One was 2 m in diameter and the other was slightly elliptical in shape with a diameter of  $2.9 \times 3.3$  m. At Oudhna, northern Tunisia, an excavated kiln was placed near two other kilns for which we have a circular outline. The excavated kiln is circular with an internal diameter of 1.75 m, and four arches form the roof, of which two survive. There was no central pillar (Fig. 5.1).<sup>3</sup>

At Sidi Khalifa, a partially excavated kiln is of a similar design to the one at Oudhna. This kiln had an oval firing chamber and a 2 m internal diameter and is late Roman (Ben Moussa 2007, 131). It seems that this design, as for Oudhna, was essentially for late finewares, never for amphorae and only rarely for cookwares. It is significant that this late Roman design was not influenced by the typical Punic kilns with central pillars, though the reasons for this change are not clear.

Major recent excavations at Leptiminus in Tunisia have revealed a complex of kilns, all of which are circular up-draught kilns with a central pillar for supporting the upper chamber, in other words copying the familiar Punic design. The plan in Figure





**Figure 5.1.** Kiln at Oudhna, Tunisia (photo V. Leitch).

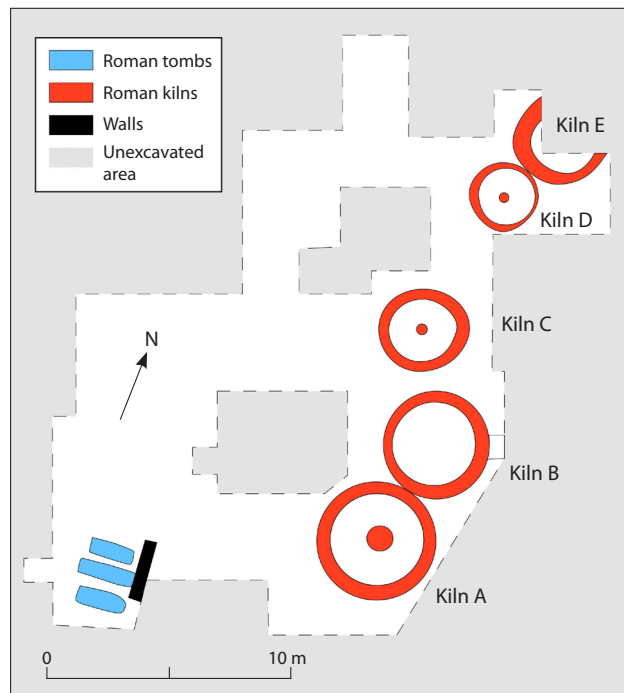
5.2 shows kilns A to E from Site 290, excavated from 1995 to 1998 (Stirling 2001, 220). The earliest excavated kiln F (off the diagram to the north) was filled with waste of a general nature, and gave a date of the mid-first century AD. It has an internal diameter of 2.2 m. Kiln D contained waster material in and around it of cookwares dated to the second to third centuries AD. It has a diameter of 1.9 m. Kiln C was filled with amphorae sherds of the early first century AD with further amphorae wasters outside the kiln of third century AD date. It has a 3.5 m diameter and probably fired amphorae. Kiln A contained wasters of third century amphorae dumped at the bottom and has a 4.9 m diameter. It probably fired amphorae during the second and third centuries AD. Kilns B and E were only partially excavated. The evidence from this complex demonstrates that cookwares were probably fired in a separate kiln from amphorae or finewares but may have been fired with coarsewares, suggesting large-scale and specialized production of these wares, and also that cookware/coarseware kilns were smaller than amphora kilns.<sup>4</sup>

Further east in Libya three kilns were found at a complex at Hai al-Andalus in Tripoli. They were all circular and produced oil and wine amphorae. They are in a rectangular courtyard into which the combustion chambers face. The largest, A, has an internal diameter of 3.66 m and B is 3.10 m in diameter, and both have

central pillars (C was only partially excavated). Wasters from the last phase of production attest to olive oil and wine amphorae production including Tripolitania I and II, and Mau 35s (Faraj Shakshuki & Shebani 1998).

In the western suburbs of Tripoli at Gargaresh, a building complex was found with four kilns by Bakir and his team in the 1960s, perhaps connected to a villa establishment (Bakir 1966–67, 244). ‘Local ware’ of the fourth century is mentioned in the area around the kilns as well as coins of Constantius II (early to mid-fourth century). The kilns are the usual circular type with central pillars. The best preserved example has an internal diameter of 2.65 m.

At Roman Oea in Tripoli there are four circular kilns of fourth century date. They are different sizes and 1–2 m apart. The three smaller kilns are only about 1 m in diameter and the larger 2.3 m. These kilns seem to have produced jugs. At Ain Scersciara on the Tarhuna Plateau of Tripolitania two circular kilns were discovered (Goodchild 1951, fig. 6). The smaller had an internal diameter of 2 m, and the larger 5.5 m. They were up-draught kilns with a perforated oven floor supported by a central pillar. Then at Hadrianopolis on the Libyan coast a large circular kiln was recorded (Jones & Little 1971, 64–7). The internal diameter is 4.8 m with a walled yard or working area in front of the stoke hole.



**Figure 5.2.** Schematic plan of the Leptiminus kiln site (after Stirling 2001, 220).



**Figure 5.3.** Kiln at Moknine pottery production site today (photo V. Leitch).

A comparison to modern kilns near Leptiminus in Tunisia is instructive: at the potters' quarter in Moknine today, the kilns are of the same design and shape as the Punic/Roman ones, and here they are for the production of coarse wares predominantly (Fig. 5.3). Modern kiln builders distinguish three different sizes of kiln: large (5–6 m diameter), medium (3–4 m diameter) and small (2–2.4 m diameter). Most workshops have two kilns of different sizes. See also Möller et al., this volume, for information on kilns in Eastern Marmarica.

#### Choice, location and collection of North African fuel

It is generally assumed that North African kilns were fired by wood fuel, as seen in Roman Britain. In another example, Gaulish potters chose the site of La Graufesenque because of the availability of both clay and wood fuel (Schaad 2007; Vernet 1981), as did

potters at Sallèles d'Aude (Jamet 2001, 266–7). However, the dry climatic conditions in North Africa were not favourable for the cultivation of large forests, and wetland deciduous forests were rare (Schmidt 1997). Meiggs indicates that very few tree varieties could in fact be grown there, except in the mountains (Meiggs 1982, 39–41), and states that 'we hear of massive plantings of olive trees but never of forests' (Meiggs 1982, 373–7). Strabo is sometimes also invoked on this issue: he tells us that in Elba the fuel was totally exhausted due to iron production, emphasizing the lack of fuel and potential consequences of over-use of supplies in the dry southern Mediterranean (Meiggs 1982, 379; Strabo 223; Diod 5.13.1–2). Plains, especially those moving closer to the Sahara, had few trees, except at oases. Roman agriculture was in fact facilitated by the temporary increased rainfall during this period (collected underground). For instance, the planting of olive trees and other crops was possible on previously marginal soils precisely because of this increased water supply, but they did not replace 'trees'. There never were 'trees' in the desertified or marginal areas in Africa, only shrubs, and some trees at oases.<sup>5</sup> Van Zeist et al. did, however, find that in northern Tunisia there was some natural woodland (defined as 'open forest with an undergrowth of brushwood') but in the interior this was more scarce (Van Zeist et al. 2001).<sup>6</sup>

Steve Sidebotham's research in the eastern desert has revealed that the Bedouin today use wood and dung, according to availability, but they are cautious with the use of wood, as it is rare, so they use tamarisk (*Tamarix* sp.) and dead acacia (*Acacia* spp.) wood for charcoal, the commonest woods in an oasis. Dung is only used for cooking fires (Sidebotham et al. 2008, 269, 275).

Returning to antiquity, the Roman Africans needed wood for building programmes and probably also for fuelling baths. Some of this may have been local, but there is evidence that wood was imported: a second- to third-century mosaic in Sousse shows wood being unloaded from a ship, thought by some to have been for construction or for making barrels (Marlière & Torres Costa 2007, 104) but it has been pointed out that on closer inspection it is clear that the wood was not suitable for construction but must be fuel (Meiggs 1982, chapter 12; Wilson 2012, 149). Of course, that is not to say that it was imported from far away, and though it may have come from Italy, it may also have come from the mountains nearer the coast.<sup>7</sup>

In summary, we do not have any accurate information on the rarity of wood in Roman Africa in different locations, nor about volumes imported, and more studies on the African environment, as well as



analyses of pollen and charcoal remains from kilns or baths,<sup>8</sup> could greatly improve this situation. The evidence we do have on the use of alternative fuels certainly opens up the possibility that wood fuel was in short supply in Africa (see also Martin and Möller et al., this volume).

One possible alternative to wood that has been investigated by Van der Veen (1999, 211–24) is the use of chaff and straw, known from arid environments. For example, at Mons Claudianus in the eastern desert of Egypt, chaff and straw were probably imported for use, amongst other things, as fuel for kitchen ovens. During the Libyan Valleys survey, chaff and straw were also found, produced locally and used at the site (and possibly also sold on). There is no evidence yet for the use of chaff and straw for pottery kilns in North Africa (and see above, that chaff and straw do not have high calorific potential so were not ideal for the needs of a pottery kiln), but it is worth considering their use in these wood-poor environments.

Peacock et al. investigated the question of fuel types in Tunisia and found that at Nabeul and Moknine today potters rely on *grignons*, the waste from olive pressing (see Rowan, this volume, for a detailed study on olive pressing waste), and on Djerba they use prunings from date palms and olive trees (Peacock 1982, 25). Furthermore, Fayolle found that modern potters in central Tunisia use animal dung and droppings, and in the Sahel the prickly pear is the ‘combustible numéro un’ along with the wood from olive trees (Fayolle 1992, 98). Ben Lazreg, who assumes there was a lack of wood in Tunisia, indicates that in the Roman period ‘anything that could be burnt as fuel was burnt’, including prunings, pits, seeds and other residue or by-products.<sup>9</sup> Today, in the western delta of Egypt, the situation is similar, with potters using what is available (see Martin, this volume). On Crete, at a modern pottery in the village of Thrapsano, 2.5 tons of olive waste will fuel a kiln with a 2.5 m diameter for 10 hours at 1000 °C. Potters there have apparently been using this fuel for centuries, and this confirms the use of olive pressings in pottery workshops in areas where olive trees, but perhaps not trees for wood fuel, are abundant, such as in Africa.<sup>10</sup>

Looking at the Roman-period evidence, the use of olive pressing waste has been attested at pottery kilns at Acharnes near Athens during the second half of the third century. And olive pressing waste was used as a fuel at the villa de Saint-Michel, Var. At Leptiminus environmental sampling of the Roman layers revealed large numbers of olive stones from olive pressings, which had been intentionally burnt, amongst amphorae wasters, as well as several amphorae full of whole and fragmented carbonized olive stones next to one

of the kilns (Smith 2001, 434; Stirling & Lazreg 2001, 221–7). Similar evidence has been found elsewhere in Roman Africa: at Carthage (Hurst & Roskams 1984, 18–19, 113), and in the bottom of the excavated kiln at Oudha (Barraud et al. 1998, 145), where the link can also be made to the nearby exploitation of olive trees for food production. This burning was essentially to make charcoal for the more efficient use of this waste as fuel.<sup>11</sup> See also Möller et al., this volume, for new analyses of kiln waste in Eastern Marmarica.

### Economic factors

Having established that different fuels were used in different climates and that the fuel type affected the design of the kiln, what can we say about the economy of fuel? Foxhall points out that in ancient Greece olive press cake was thought to be a particularly good fuel for kilns and that Theophrastos mentions the use of prunings for fuel (Foxhall 2007, 82; Theoph., *Hist. Plant.* 5.9.6). An ethnographic study in 1960s Messenia, Greece, demonstrated that potters used whatever was available with a preference for prunings that do not ‘build up a bulky mass of glowing slow-burning charcoal in the combustion chamber as would heavier wood.’ These also have a shorter firing time than brushwood. But others prefer olive pressings that ‘give good heat with little ash and reduces the length of kiln firing time’, so are quicker than prunings (Matson 1972, 219). This is also demonstrated at the modern kiln site of Moknine in Tunisia, where the waste from olive pressings is still used, and the price of this fuel is highly sensitive to the quality and quantity of the annual harvest, as well as the distance between the olive pressing factory and the potters’ quarter, linking the two economically (Hasaki 2006, 16).

Since the archaeological evidence for Roman Africa suggests the use of olive pressing waste was favoured, how did the potters get hold of it, and what was the cost to them? The logical explanation would be that agriculture was linked to ceramic production, in terms of providing amphorae for the agricultural products (and cookwares for extra profit?),<sup>12</sup> but also because waste from vines and olive trees made excellent, available, free (or almost free) fuel. At modern Guellala on Djerba, olive mills are situated adjacent to the kilns, within the same complex.<sup>13</sup> Rice also highlights modern examples in Spain, Bombay and Mexico where ‘potters have effected a symbiosis with other industries, especially agriculture, in order to obtain non-traditional fuels. Thus, not only does agriculture often produce the primary contents of pottery vessels, but its by-products are a major source of raw materials for manufacturing them’ (Rice 1987, 176).

The collection and/or importation of wood and its efficiency compared to the collection and use of olive pressings has clear implications for the economics of production. For instance, at the modern ceramic workshop at Dakhla in Egypt, wood is used, and to collect enough for a single firing requires 24 donkey loads, where two loads take two men five hours to gather (the wood is 8 km from the site) (Henein 1997, 69). Where the wood was imported there are further shipping costs, which can only have been practical in economically vibrant periods when the volume of sea trade made this method of transportation very cheap.<sup>14</sup> So in Africa, where olive groves cover the landscape, presumably olive pressing waste would have been considerably easier to obtain, and therefore cheaper, than wood.

To extend this point, it may be suggested that Africa had an economic advantage over Romano-British and other Mediterranean pottery production sites that used wood fuel. At the Romano-British sites we have investigated, and at La Graufesenque and Lézoux, wood was abundant, and at Sallèles d'Aude potters exploited nearby forests for over three centuries without exhausting them (Chabal 2001, 103–6). The wood itself was probably inexpensive to grow, but it still had to be cut, collected and transported, and we know about special merchants, *lignarii*, who traded wood fuel for profit (Meiggs 1982, chapter 12 and in particular 359), suggesting that it was in fact not always free or readily available.

## Conclusions

This paper has sought to investigate both the fuels used and the driving forces behind the potters' choices of fuel, and to what extent this was purely a climatic and environmental choice, or whether we need also to consider the economic conditions of the Roman Empire. Using examples from two very different peripheral zones of the empire has allowed for an examination of the impact of different fuel types, climate and traditions on kiln design, efficiency and output.

It seems that Romano-British kilns used wood, most probably coppiced wood from the locality, whereas in North Africa, olive pressing waste or other agricultural waste was used. The choice of these materials was clearly connected to the environment and climatic conditions in these two zones. These very different materials nevertheless were chosen for the same reasons – they were the best readily available fuel, were probably (relatively) low cost and allowed for seasonal pottery production. The different kiln designs in these two zones is also probably a reflection of the fuel type used, as well as the climate, with

the Romano-British kilns needing bigger stoking holes and deeper chambers for the more bulky wood fuels and to offer protection against adverse weather conditions. Both also seem to come out of pottery traditions from the pre-Roman period. However, since it is clear from archaeological excavations that pottery production greatly increased in the Roman period in these two zones, how was this achieved? Rather than advances or changes in kiln technology and fuel, potters in the Roman period increased the size and quantity of the kilns, which nevertheless would have required more technical skill, for instance in controlling the higher temperatures needed for finer pottery (such as red-slip ware). It is also possible, as argued above, that one of the reasons for the success of the North African pottery trade was that ultimately olive pressing waste was more efficient and cheaper than wood fuel, allowing for these products to be the most competitive on the Mediterranean market, in competition for instance with Gaulish pottery that was produced using wood fuel. Wood-fuelled Romano-British pottery was not generally exported, but this may have been more to do with having different pottery traditions to the rest of the empire than the economy of wood fuel.

This brief study underlines the importance of combining ceramic and fuel research and their various specialists when looking at questions of fuel and fire in the ancient Roman world. Indeed, this paper has posed more questions than it has answered, and the subject would greatly benefit from much more collaborative work, looking at fuel samples, kiln designs, pottery traditions, ware types, and environmental and political climates, to create a large database of information to examine better the broad conclusions that this preliminary study has suggested.

## Acknowledgements

My thanks go to Robyn Veal for inspiring me to get involved in studies of the use of fuel for firing pottery, and the wider implications for the economy of pottery production.

## Notes

- 1 Swan (1984) is now partly digitized: [http://mapdata.thehumanjourney.net/vgswandb\\_index.html](http://mapdata.thehumanjourney.net/vgswandb_index.html)
- 2 Special thanks to Robyn Veal for the information on gorse and chaff.
- 3 Barraud et al. 1998, 140–6, kiln no. 141 was excavated and traces of two others suggest a similar design (kilns 142 and 143).
- 4 For information on firing temperatures of different wares see Cuomo di Caprio (2007, 38 and 329).

- 5 Robyn Veal, pers. comm.
- 6 Van Zeist, Bottema & Van der Veen (2001).
- 7 Robyn Veal suggested that it may have come from the mountains and thus a coastal voyage rather than a long distance one.
- 8 Robyn Veal (pers. comm.) has studied the huge potential of charcoal for establishing not only the types of wood – or other materials – used, but their calorific value. Veal forthcoming.
- 9 Ben Lazreg 2001, 436.
- 10 The potter at Thrapsano was called Kroutakis.
- 11 Robyn Veal, pers. comm.
- 12 See Brun (2004, 198–231) for evidence of olive oil and wine production in Roman Africa.
- 13 Andrew Wilson, pers. comm.
- 14 See Leitch (2013, 289–90) for arguments about the cost of marine and overland transport in the Roman period.

## References

- Bakir, T., 1966–7. Archaeological News: Gargaresh. *Libya Antiqua* III–IV, 241–4.
- Barraud, D., M. Bonifay, F. Dridi & J.F. Pichonneau, 1998. L'industrie céramique de l'Antiquité tardive, in *Oudhna (Uthina). La redécouverte d'une ville antique de Tunisie*, eds. H.B. Hassen, & L. Maurin. Bordeaux, Paris, Tunis, 139–67.
- Bartoccini, R., 1928. Tripoli, forni per terrecotte. *Africa Italiana* 2, 93–5.
- Bates, S. & A. Lyons, 2003. *The excavation of Romano-British pottery kilns at Ellingham, Postwick and Two Mile Bottom, Norfolk 1995–7*. East Anglian Archaeological Occasional Paper 13. Dereham: Norfolk Museums Archaeology Service.
- Ben Lazreg, N., 2001. A further note on the fuels used in this region, in *Leptiminius report no 2. The East baths, cemeteries, kilns, Venus mosaic, site museum and other studies*, eds. L. Stirling, D. Mattingly & N.B. Lazreg. Ann Arbor: *Journal of Roman Archaeology* supplement.
- Ben Moussa, M., 2007. *La production de sigillées africaines. Recherches d'histoire et d'archéologie en Tunisie septentrionale et centrale*. Barcelona: University of Barcelona.
- Brun, J.-P., 2004. *Archéologie du vin et de l'huile dans l'Empire romain*. Paris: Errance.
- Chabal, L., 2001. Les potiers, le bois et la forêt à l'époque romaine à Sallèles d'Aude (Ier–IIIe s. ap. J.-C.), in *20 ans de recherches à Sallèles d'Aude*, ed. F. Laubenheimer. Paris: Les Belles Lettres, 93–110.
- Cuomo di Caprio, N., 2007. *Ceramica in Archeologia 2, Antiche tecniche di lavorazione e moderni metodi di indagine*. (Studia Archaeologica 144.) Rome: L'Erma di Bretschneider.
- Domergue, C., 1960. Volubilis: un four de potier. *Bulletin d'Archéologie Marocaine* 4, 491–7.
- Faraj Shakshuki, M. & R. Shebani, 1998. The Roman kilns of Hai al-Andalus, Tripoli. *Libya Antiqua* 4, 279–82.
- Fayolle, V., 1992. *La poterie modelée du Maghreb oriental*. Paris: CNRS.
- Foxhall, L., 2007. *Olive cultivation in Ancient Greece: Seeking the ancient economy*. Oxford: OUP.
- Gale, R., 2003. Charcoal, in *The excavation of Romano-British pottery kilns at Ellingham, Postwick and Two Mile Bottom, Norfolk 1995–7*, eds. S. Bates & A. Lyons. East Anglian Archaeological Occasional Paper 13. Norfolk: East Anglia Archaeology, 54.
- Goodchild, R.G., 1951. Roman sites on the Tarhuna Plateau of Tripolitania. *Papers of the British School at Rome* 19, 43–77.
- Halkon, P., 2002. The Roman pottery industry at Holme-on-Spalding moor in its landscape, in *Aspects of industry in Roman Yorkshire and the North*, eds. P.R. Wilson & J. Price. Oxford: Oxbow, 21–34.
- Hasaki, E., 2006. The ethnoarchaeological project of the potters' quarter at Moknine, Tunisia. Seasons 2000, 2002. Unpublished report.
- Henein, N., 1997. *Poterie et Potiers d'Al-Qasr*. Cairo: IFAO.
- Hines, B., 2012. Romano-British kiln building and firing experiments: two recent kilns. *Journal of Roman Pottery Studies* 15, 26–38.
- Hurst, H.R. & S. Roskams, 1984. *Excavations at Carthage: the British Mission I.I. The Avenue du Président Habib Bourguiba, Salammbô. The site and finds other than pottery*. Sheffield: University of Sheffield.
- Jamet, M., 2001. Approche par la modélisation du complexe de potiers de Sallèles d'Aude, in *20 ans de recherches à Sallèles d'Aude*, ed. F. Laubenheimer. Paris, 257–84.
- Jones, G.D.B. & J.H. Little, 1971. Hadrianopolis. *Libya Antiqua* VIII, 53–68.
- Jones, M.U. & W. Rodwell, 1973. The Romano-British pottery kilns at Mucking. *Essex Archaeol Hist* 5, 13–47.
- Leitch, V., 2013. Reconstructing history through pottery: the contribution of Roman N African cookwares. *Journal of Roman Archaeology* 26, 281–306.
- Leveau, P., 1983. Recherches sur les nécropoles occidentales de Cherchel (Caesarea Mauretaniae) 1880–1961. *Antiquités Africaines* 19, 85–173.
- Marlière, E. & J. Torres Costa, 2007. Transport et stockage des denrées dans l'Afrique romaine: le rôle de l'outre et du tonneau, in *In Africa et in Hispania: études sur l'huile africaine*, eds. A. Mrabet & J. Remesal Rodriguez. Barcelona: University of Barcelona, 85–106.
- Matson, F.R., 1972. Ceramic studies, in *The Minesota Messenia Expedition. Reconstructing a Bronze Age regional environment*, eds. M. McDonald and G.R. Rapp. Minneapolis: University of Minnesota, 200–24.
- Meiggs, R., 1982. *Trees and timber in the ancient Mediterranean world*. Oxford: OUP.
- Peacock, D., 1982. *Pottery in the Roman world: an ethnoarchaeological approach*. London: Longmans.
- Plouviez, J., 1989. A Romano-British pottery kiln at Stowmarket. *Proceedings of the Suffolk Institute of Archaeology* 37, 1–12.
- Rice, P., 1987. *Pottery analysis: a sourcebook*. Chicago: University of Chicago Press.
- Schaad, D., 2007. *La Graufesenque (Millau, Aveyron)*. 2 vols. Vol. 1. Aquitania.
- Schmidt, P., 1997. Archaeological views on a history of landscape change in east Africa. *Journal of African History* 38, 393–421.
- Sidebotham, S., M. Hense, & H.M. Nouwens, 2008. *The Redland: the illustrated archaeology of Egypt's Eastern*



- Desert. Cairo & New York: The American University in Cairo Press.
- Smith, W., 2001. Environmental sampling (1990–4), in *Leptiminus report no 2. The East baths, cemeteries, kilns, Venus mosaic, site museum and other studies*, eds. L. Stirling, D. Mattingly & N.B. Lazreg. Ann Arbor: *Journal of Roman Archaeology* supplements, 420–41.
- Stirling, L., 2006. Aspects of Punic and Roman Kiln Design in North Africa. *L’Africa Romana* XVI (4), 2405–17.
- Stirling, L., 2001. A Roman kiln complex (site 290): Preliminary results of excavations, in *Leptiminus report no 2. The East baths, cemeteries, kilns, Venus mosaic, site museum and other studies*, eds. L. Stirling, D. Mattingly & N.B. Lazreg. Ann Arbor: *Journal of Roman Archaeology* supplements, 219–35.
- Swan, V., 1984. *The pottery kilns of Roman Britain*. London: HMSO.
- Van der Veen, M., 1999. The economic value of chaff and straw in arid and temperate zones. *Vegetation History and Archaeobotany* 8(3), 211–24.
- Van Zeist, W., S. Bottema & M. Van der Veen, 2001. *Diet and vegetation at ancient Carthage: the archaeobotanical evidence*. Groningen: Groningen Archaeological Institute.
- Vernet, A., 1981. Un four de la Graufesenque (Aveyron): la cuisson des vases sigillés. *Gallia* 39(1), 26–43.
- Wilson, A.I., 2012. Raw materials and energy, in *The Cambridge Companion to the Roman Economy*, ed. W. Scheidel. Cambridge: CUP, 133–55.



---

## Chapter 6

# Kilns in a wood-poor environment: traditional workshops in the western delta of Egypt

Archer Martin

Discussions of the location of pottery workshops stress the need for good supplies of clay, water and fuel, which are of course the basic elements required to make pottery. It is often taken for granted that fuel normally means firewood. For example, Prudence Rice, who has the most extensive discussion of fuel in the usual manuals, says that wood seems to be the preferred fuel worldwide (Rice 2005, 174) and suggests that the exhaustion of the supply of firewood can lead to the abandonment or displacement of pottery production (Rice 2005, 162). She speaks of other fuels, ranging from dung to sawdust and various agricultural by-products, as non-traditional substitutes to which potters are driven by scarcity of firewood (Rice 2005, 162, 174–6). An older manual dedicated to American archaeology also considers wood to be the normal fuel, although it notes the use of dung and coal, which have certain advantages (Shepard 1956, 77–80). Ninina Cuomo di Caprio spells out what happens during firing in both the second Italian edition of her manual on ceramics in archaeology from the prehistoric to the medieval period in Europe and the Mediterranean and the English version of it (Cuomo di Caprio 2007, 488–501; Cuomo di Caprio 2017, 325–80), but has little to say about fuel, merely that in the ancient world it consisted normally of natural solids – most often wood, but also straw, fruit seeds and other vegetal matter – with data on some fuels (Cuomo di Caprio 2007, 489–90; Cuomo di Caprio 2017, 325, 327–8). In an older article, however, she discusses the properties of various fuels (Cuomo di Caprio 1979). Straw, rich in oxygen, burns very quickly, giving off gases that will themselves burn. Denser fuels, poor in oxygen, burn longer but do not give off gases, thus requiring other fuels to get started. Compact fuels such as olive pressings give off gases but do not favour the circulation of air, hampering combustion and leaving unburnt matter.

Air circulates readily in bundles of twigs and small branches, facilitating combustion. Cuomo di Caprio emphasizes the experience and practical knowledge the kiln-master needs in choosing their fuel according to the structural characteristics of the kiln, its draft, the material to be fired and its stacking, etc. Thus, in spite of the bias in the literature in favour of wood as fuel, alternative fuels could be used in firing pottery.

Various approaches for investigating what fuels may have been employed in ancient kilns can be envisioned. The analysis of the remains from firings in excavated archaeological kilns is obviously a promising method, being the most direct, although it has rarely been carried out (Pichot & Şenol 2014, 230–1 and Pichot & Flaux 2015, 267–8, are an important exception). The exploration of the potential in natural resources of ancient landscapes, although somewhat less direct, is enlightening (see, for example, Rieger & Möller 2011 and in particular Möller & Rieger, plus Leitch, this volume). Ancient sources have little to say about the subject, but writings on early modern firing techniques can also be illuminating for similar ancient establishments (see Kenawi & Mondin in this volume for both ancient and early modern sources). Likewise, examining the practices of modern traditional pottery workshops can be helpful (see Kenawi & Mondin in this volume for modern pottery workshops, particularly in Spain and Italy but also elsewhere).

Egypt is an especially interesting case because it has never been rich in wood, thus necessarily having to develop alternatives. The scarcity of trees in Egypt is often noted in works on ancient and modern Egypt (e.g. Aldred 1961, 55; El Hamamsy et al. 1992, 93–5). The irrigated parts of the country are given over to farm crops – the palm is the main tree there, alongside occasional sycamores and acacias – and the rest of the country is incapable of supporting more than brush. So, while Egypt could and can still produce some wood as

fuel, it is certainly a historically wood-poor country, without forests as a source of firewood. Nevertheless, Egypt has produced pottery in great quantities for millennia. Scholars seem not to have given much thought to the question of what fuel permitted this. For instance, in a major introductory work on ancient Egyptian pottery, the chapter on firing says nothing about the matter (Nicholson 1993). Dealing more widely with energy and fuel, Roger Bagnall says: 'The scholarly literature is remarkably bare of comment...' (Bagnall 1993, 41, note 184). This paper intends to observe traditional workshops still working today in the western delta of Egypt in order to gain insights into how kilns may have been fuelled in ancient Egypt and possibly even in more wooded places.

During the study seasons on the pottery from the German excavation at Schedia in the western delta, visits to traditional pottery workshops in the area were always popular excursions with the participants.<sup>1</sup> The workshops visited are located in four places in the western delta (Fig. 6.1): a cluster at Idfina, an isolated workshop on the outskirts of Disuq otherwise engaged in metal-working, a workshop at Rahmaneyah, a cluster by Damanhur, and a cluster at Gezira Isa near

Dilingat. The workshops all resemble each other in their basic features.

Each single workshop is operated by a master potter along with family members. They are full-time professional operations, although some family members normally engaged in other occupations may be drafted in to help at crunch times. At Idfina, for instance, one workshop was conducted by a man with two of his sons and a brother, while the workshop next-door belonged to his cousin. In one workshop near Damanhur the master potters were an uncle and his nephew, and another was run by brothers. Women were involved only at Gezira Isa and then with the secondary task of unloading a kiln. The workshops are mostly separate from dwellings, although the workshop at Rahmaneyah is located on a street with houses.

The production centres produce a range of coarse vessels (Fig. 6.2). Idfina makes flower pots, dishes for cooking fish or giving water to birds, water jars, etc. Gezira Isa produces especially elements for dovecotes (an important feature of the Egyptian countryside), as well as flower pots and water jars. Damanhur and Rahmaneyah have a larger repertoire including somewhat finer vessels. The only added decoration in any of the



**Figure 6.1.** Location map of the production centres discussed.





**Figure 6.2.** Pots at Idfina (photo Heike Möller).

production centres consists of a whitish slip, mostly applied in bands or wavy lines.

The potters all use clay obtained from fields in the vicinity. They did not indicate any source they preferred, presumably because there is little difference between one place and another in an area formed over the millennia by the deposits from the annual flooding of the Nile. They work exclusively on the wheel. There was no evidence of hand-made or mould-made vessels. They fire in vertical kilns of an approximately conical shape with direct contact between the two chambers (Fig. 6.3). The potters themselves see the distinction between production centres in how much effort the potters put into refining the clay. For instance, the potters at Idfina and Rahmaneyah both emphasized that the latter refine their clay more than those at Idfina.

In fact, the structures for refining clay are the major point in which the production centres differ. Rahmaneyah possesses a complex of settling basins. Similar complexes could be observed in operation at the clusters near Damanhur. In one place, a helper was standing in a vat wet sieving a slurry of clay that was being lead into another vat. In other vats the clay

slurry was left to dry until the surface could be scored and blocks lifted out. At Gezira Isa, the potters merely break up the clay, presumably removing large inclusions by hand. The same happened at Idfina. Neither place has any sort of settling basin. Water comes into play for kneading and treading the clay, mixed with ash from the kilns at Gezira Isa and with dung and sawdust as possible tempers besides ash at Idfina.

The workshops in the cluster near Damanhur also took more pains with the drying process. Each workshop there has covered and open-air areas for drying, and they move the vessels as necessary. At Gezira Isa, on the other hand, there was no provision at all for drying under cover. At Idfina too drying takes place in any available space outdoors. Rahmaneyah has areas for drying both under cover and in the open air, although the impression there was of cramped space and making the best of what was available.

Firings are frequent. At Idfina there can be as many as two or three a week, with some 400 small jars or 200–250 larger ones in each load. They burn fuel only for the first hours – at Idfina, for instance, they said about five, with the possibility of pre-heating the





**Figure 6.3.** Workshop at Idfina with piles of sugar cane pressings and scrap wood and a kiln (photo Heike Möller).



**Figure 6.4.** Adding sawdust to an initial firing at Rahmaneyah (photo Heike Möller).





**Figure 6.5.** *Adding scrap wood to an ongoing firing at Damanhur (photo Archer Martin).*

kiln during loading in order to strengthen the lower layers of pots that have to bear the weight of the vessels above; at Gezira Isa the burning lasts only two hours. The idea appears to be to bring the kiln quickly to a high enough temperature that it will then fire the vessels by radiated heat. After about 24 hours, the kiln is cool enough for the products to be unloaded.

With regard to fuel, all the centres are in agreement. At Idфина we were told specifically that the potters do not like to use gas because it is more expensive than traditional fuel and also because they say a gas-fired vessel will give a bad taste to food cooked in it – so, although the government has forbidden other fuel, they fire with gas only occasionally. Scraps of wood are usually the preferred fuel (Figs. 6.3 and 6.5). The potters buy them from furniture makers. Sawdust is another good fuel (Fig. 6.4), which is the only one used in the workshop at Disuq. In either case, the potters at Idфина and Rahmaneyah estimate that about 150 kg or fifteen wheelbarrow-loads of some

10 kg each are required per firing. The leavings from pressed sugar cane, cuttings from cotton plants and rice husks – that is the waste from common crops in the delta today – were also mentioned as fuel in various places (Figs. 6.3 and 6.6). Sometimes my questioning about fuel came across as amusing, and I was told that if the potters were a bit short of fuel they would lop a branch off a nearby tree or gather some reeds along the canal. In short, obtaining fuel is a non-issue for the potters in the western delta.

The classic account of modern traditional potters in Egypt, based on observations made between 1978 and 1980 (although published nearly 20 years later), concerns Al-Qasr in the oasis of Dakhla (Henry Henein 1997). Obviously, it goes into much greater detail about the potters and their establishments there than is possible here about those in the western delta, but the main lines in the two areas seem to be similar, which suggests that the thoughts prompted by the pottery workshops of the western delta should have wider application. The author reports that the potters of Al-Qasr 35 years ago considered fuel their major



**Figure 6.6.** *Ongoing firing with agricultural waste at Gezira Isa (photo Clemens Bertram).*

constraint (Henry Henein 1997, 69–70). The problem was not, however, its lack of availability. They used tamarisk and salwort (bushy plants that grew especially in the saline areas that received the run-off water from irrigation) and if necessary another less-prized bush. What mattered was the time and effort needed to gather the fuel and transport it to the kilns on donkey back. A potter with a large family to help him and several donkeys could fire once a week, while another could perhaps manage only once a month. It would be interesting to know whether transportation is still so important at Al-Qasr. It seems to have been a more important factor in earlier generations in the delta than at present. I was told that it is easier now that there are motor vehicles and telephones. The former supplement animals for transport, of course. The latter mean that supplies of fuel can be located by calling around rather than going out to scour the countryside.

Such evidence as there is for fuel in ancient Egypt is also in accord with what has been seen among the modern workshops in the western delta. Recent excavations at the amphora-producing site of Akademia in the Mareotid region near Alexandria have shown that rushes constituted the major fuel there, alongside some brush (Pichot & Şenol 2014, 230–1; Pichot & Flaux 2015, 267–8). R.J. Forbes maintains that farm waste played a large part in the fuel economy of ancient Egypt and beyond (Forbes 1966, 14). Roger Bagnall, who dedicates a paragraph to fuel in Roman Egypt, suggests that wood imported from southern Asia Minor, chaff, animal dung and garbage were used (Bagnall 1993, 41). There is papyrological evidence for chaff as fuel for firing pottery at Oxyrhynchus (Hanson 1978), and it is supposed for the operations indicated in the well-known papyri from the same site concerning the leasing of pottery workshops (Cockle 1981, 94). In the Eastern Marmarica along the north-western coast, which had an extensive production of amphorae in spite of its arid or semi-arid nature, a botanical analysis has revealed tamarisk as a fuel, while straw, vine prunings and other agricultural residues, straw, brush and dung are all considered likely fuels (Möller & Rieger 2012, 160–1; Möller & Rieger in this volume).

The example of the modern traditional potters of the western delta shows us several points that are worth bearing in mind with regard to fuel for pottery production in the archaeological sphere:

- It is more than likely that potters in ancient Egypt took advantage of similar sources of fuel to those used today in the western delta. Rice considers that potters' use of fuel derived from

the by-products of other activities, as we see in the delta today, and is typical of the fringes of large urban markets (Rice 2005, 176), but it is not obvious why this could not take place anywhere such by-products are present.

- While firewood may be the preferred fuel in most places around the world, it is perfectly possible to maintain a flourishing and sustainable production of pottery in a wood-poor environment. The availability of firewood is not a prerequisite for pottery production, and its lack does not rule out a region as a possible producer of pottery.
- The activities of a pottery production centre do not necessarily deplete the surrounding natural resources nor have much environmental impact other than putting smoke into the air. There will indeed be cases of potters exhausting a supply of firewood and abandoning or moving production. Potters can, however, find sustainable sources of fuel for their kilns, even over the long term.
- Finally, far from provoking environmental change or even devastation, obtaining fuel for a pottery production centre may leave virtually no footprint in the landscape. Of course, the handicraft and agricultural waste or brush that goes into kilns does not show up elsewhere. Does anyone notice their absence from the scene in modern Egypt though? It would be impossible to perceive the elimination of such items in examining an ancient landscape. The remains of the fires themselves may be the only direct evidence of fuel in the archaeological record.

The observations above concern fuel for potters' kilns. Ancient Egypt needed fuel for other activities too – for heating baths, metal-working and glass-making, for example. Were similar sources to those for kilns used? Bagnall indicates the use of chaff from threshing grain for heating water in baths (Bagnall 1993, 41). Certainly, no more firewood was available for them than for kilns. It is not only pottery specialists who should start asking themselves about fuel.

## Notes

- 1 I am grateful to the Egyptian friends and colleagues who accompanied me and translated on visits to the workshops: Mohamed Kenawi (who went on at my suggestion to make a presentation at the conference on kilns for fine ware in Fayoum), Fady Farid, and in particular Alaa El-Nahas (who as the son of a potter was able to answer many questions). I wish also to express



my thanks to the colleagues and friends from the Schedia Project who took photographs for me during our visits to the workshops: Clemens Bertram and especially Heike Möller (whose presentation at the conference on the ancient kiln sites in the Eastern Marmarica was the companion piece to mine under the joint title of 'Fueling kilns in a wood-poor environment').

## References

- Aldred, C., 1962. *The Egyptians*. London: Thames & Hudson.
- Bagnall, R., 1993. *Egypt in Late Antiquity*. Princeton: Princeton University Press.
- Cockle, H., 1981. Pottery Manufacture in Roman Egypt: A New Papyrus. *Journal of Roman Studies* 71, 87–97.
- Cuomo di Caprio, N., 1979. La cottura della ceramica: I combustibili. *Rei Cretariae Romanae Fautorum Acta* XIX/XX, 236–9.
- Cuomo di Caprio, N., 2007. *La ceramica in archeologia 2. Antiche tecniche di lavorazione e moderni metodi d'indagine*. Rome: L'Erma di Bretschneider.
- Cuomo di Caprio, N., 2017. *Ceramics in archaeology from Prehistoric to Medieval times in Europe and the Mediterranean. Ancient Craftsmanship and Modern Laboratory Techniques*. Rome: L'Erma di Bretschneider.
- El Hamamsy, L.S., M. Jones, D. Hopwood & S.G. Shetler, 1992. Egypt. Physical and human geography, in *The New Encyclopedia Britannica. Macropedia* 18. Chicago: Encyclopedia Britannica, 92–104.
- Forbes, R.J., 1966. *Studies in Ancient Technology* IV. Leiden: E.J. Brill.
- Hanson, A.E., 1978. Chaff and Pottery in the Oxyrhynchite Nome PMich. Inv. 157, in *Le monde grec: pensée, littérature, histoire, documents. Hommages à Claire Préaux*, eds. J. Bingen, G. Cambier & G. Nachtergaeel. Brussels: Éditions de l'Université de Bruxelles, 609–10.
- Henry Henein, N., 1997. *Poterie et potiers d'Al-Qasr. Oasis de Dakhla*. (Institut Français d'Archéologie Orientale – Bibliothèque d'Étude 116.). Cairo: Institut Français d'Archéologie Orientale.
- Nicholson, P., 1993. The Firing of Pottery, in *An Introduction to Ancient Egyptian Pottery*, eds. D. Arnold, & J. Bourriau. (Deutsches Archäologisches Institut Abteilung Kairo, Sonderschrift 17.) Mainz am Rhein: Verlag Philipp von Zabern), 103–20.
- Pichot, V. & C. Flaux, 2015. Les fours à amphores du Haut-Empire du site d'Akadémia (Maréotide): campagne de fouille et carottages 2014. *Bulletin de Liaison de la Céramique Égyptienne* 25, 259–76.
- Pichot, V. & K. Şenol, 2014. The Site of Akademia: The Amphora Workshop of Apol(l)ônios. First Excavation Campaign (July–August 2012). *Bulletin de Liaison de la Céramique Égyptienne* 24, 225–39.
- Rice, P., 2005. *Pottery Analysis: A Sourcebook*. Chicago & London: Chicago University Press.
- Rieger, A.-K. & H. Möller, 2011. Kilns, Commodities and Consumers: Greco-Roman Pottery Production in Eastern Marmarica (Northwestern Egypt). *Archäologischer Anzeiger* 2011(1), 141–70.
- Shepard, A.O., 1956. *Ceramics for the Archaeologist*. (Carnegie Institution of Washington Publication 609.) Washington, DC.



---

## Chapter 7

# Necessity is the mother of invention: the fuel of Graeco-Roman pottery kilns in the semi-arid Eastern Marmarica

Heike Möller & Anna-Katharina Rieger

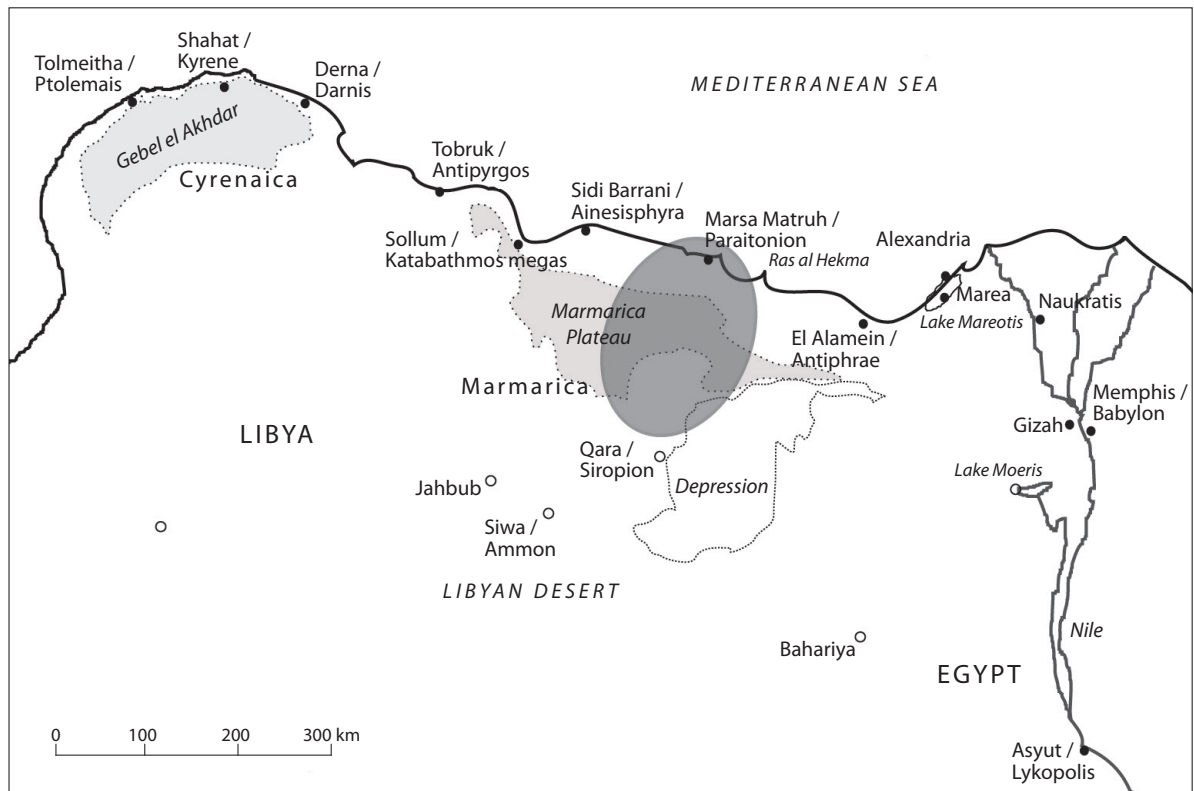
Pottery production is a resource-intensive industry, in antiquity as today, because it requires clay and water for making the pots and fuel for firing them. When we find a pottery production site in a resource-poor environment, the first question that arises is 'How were these requirements met?' The Eastern Marmarica, situated at the northern fringe of the Libyan Desert (Fig. 7.1), represents exactly such a case: in this semi-arid environment, a large number of ancient pottery production sites have been found, dating from Ptolemaic to Roman or, possibly, Late Roman times. This paper focuses on investigating how the potters there obtained the necessary materials for production, and in particular the fuel required.

The Eastern Marmarica region is predominantly covered by steppe, with little and variable precipitation; vegetation consists of shrubs and grasses extending across the tableland south of the coastal strip. Only along the coastline, with its Mediterranean climate, is it possible to grow trees and crops (Fig. 7.2). On the tableland, agricultural activity is only possible due to elaborate practices of water and soil harvesting (Vetter, Rieger & Nicolay 2009). In Graeco-Roman times, these systems were operated by a rural population that was able to produce a surplus of agricultural goods. The pottery production attested in the region supplied the need for transport and storage vessels as well as for common wares (Rieger & Möller 2011; Möller 2015). But where did the water to process the clayey soil come from? How were the kilns fired, and what kind of fuel was available to the ancient potters? Archaeological and archaeobotanical analyses, as well as ethnoarchaeological parallels found in modern pottery production in Egypt, have been applied to help understand what kind of fuel made pottery production in this resource-poor environment possible (a comparable approach is made by Kenawi & Mondin in this volume).

### **The fuel consumers: pottery production and kilns in the Eastern Marmarica**

More than 55 pottery production sites were active between Ptolemaic and Roman times in the surveyed area and attest to a considerable demand (Rieger & Möller 2011, 144–7; Fig. 1). Judging by the size of the pottery waster heaps, pottery production in the Eastern Marmarica reached a very high output at some sites. A peak of production may be verified in the second to fourth century AD (Rieger & Möller 2011, 161–65 and table 1; Möller 2015). Consequently, over time, huge amounts of fuel for firing the kilns were needed. It is almost impossible to make accurate calculations as to the output and number of vessels produced. However, the sheer number of kiln sites producing within the same time period shows that the potters in the Eastern Marmarica produced vessels on a scale comparable to the region around Lake Mareotis (Empereur & Picon 1998). We can assume that the activity of the pottery workshops was most probably seasonal, as occurs today at Egypt's modern pottery sites. Then, as now, production likely coincided with harvesting and harvest processing times. During these periods, it is probable that a kiln was filled and fired every week (see also Martin, this volume, for information on modern pottery production in Egypt as a comparison). The large kilns, the dimensions of which are known in two cases – Wadi Qasaba, see below, and Bir Abu Sakran – have an estimated capacity of 350 amphorae. Thus, by firing every week, a workshop could produce about 1400 amphorae in a month. How many months a year a workshop and its kiln were in use is impossible to know but it is unlikely that they were active throughout the entire year.

At two of the pottery production sites in the Eastern Marmarica, the kiln and the waster heap have been excavated in order to examine the details of the



### Eastern Marmarica Survey

Pottery production sites  
between Ras Abu Laho  
and Ras al Hakma  
A.-K. Rieger / H. Möller



#### Ecological zoning

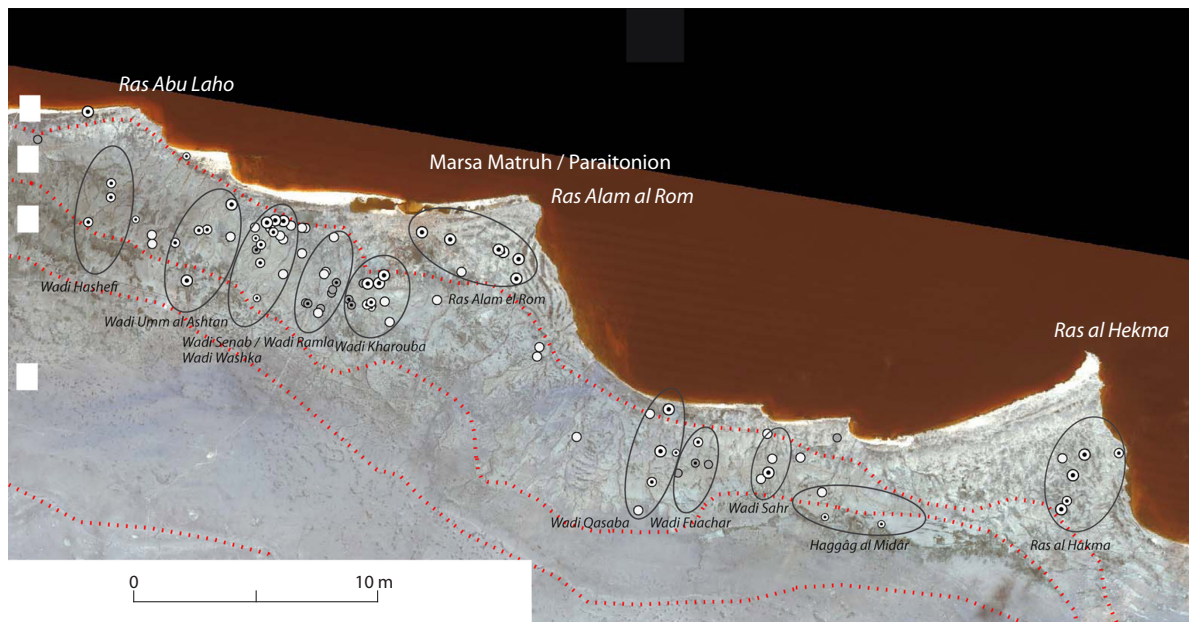
- 1 coastal plain
- 2 northern tableland
- 3 premarmarican plain
- 4 full desert margin

#### Pottery production sites (surveyed)

- large-scale production site
- medium-scale production site
- small-scale production site
- greyish areas

#### Pottery production sites (unsurveyed)

- production site (unsurveyed)
- greyish areas (unsurveyed)



**Figure 7.1.** Above: Map of the Marmarica showing the investigation area (after Rieger, Möller, Valtin & Vetter 2012, Fig. 1). Below: Pottery production sites in the Eastern Marmarica (after Rieger & Möller 2011, Fig. 2).





**Figure 7.2.**  
*Natural prerequisites along the coastline in the Eastern Marmarica. Above: Wadi Kharbouba; below: Wadi Umm el-Ashdan (photos A.-K. Rieger, O. Klammer).*

production process and the applied technology as well as to clarify the chronology of the vessels that were produced and the lifespan of the workshop.

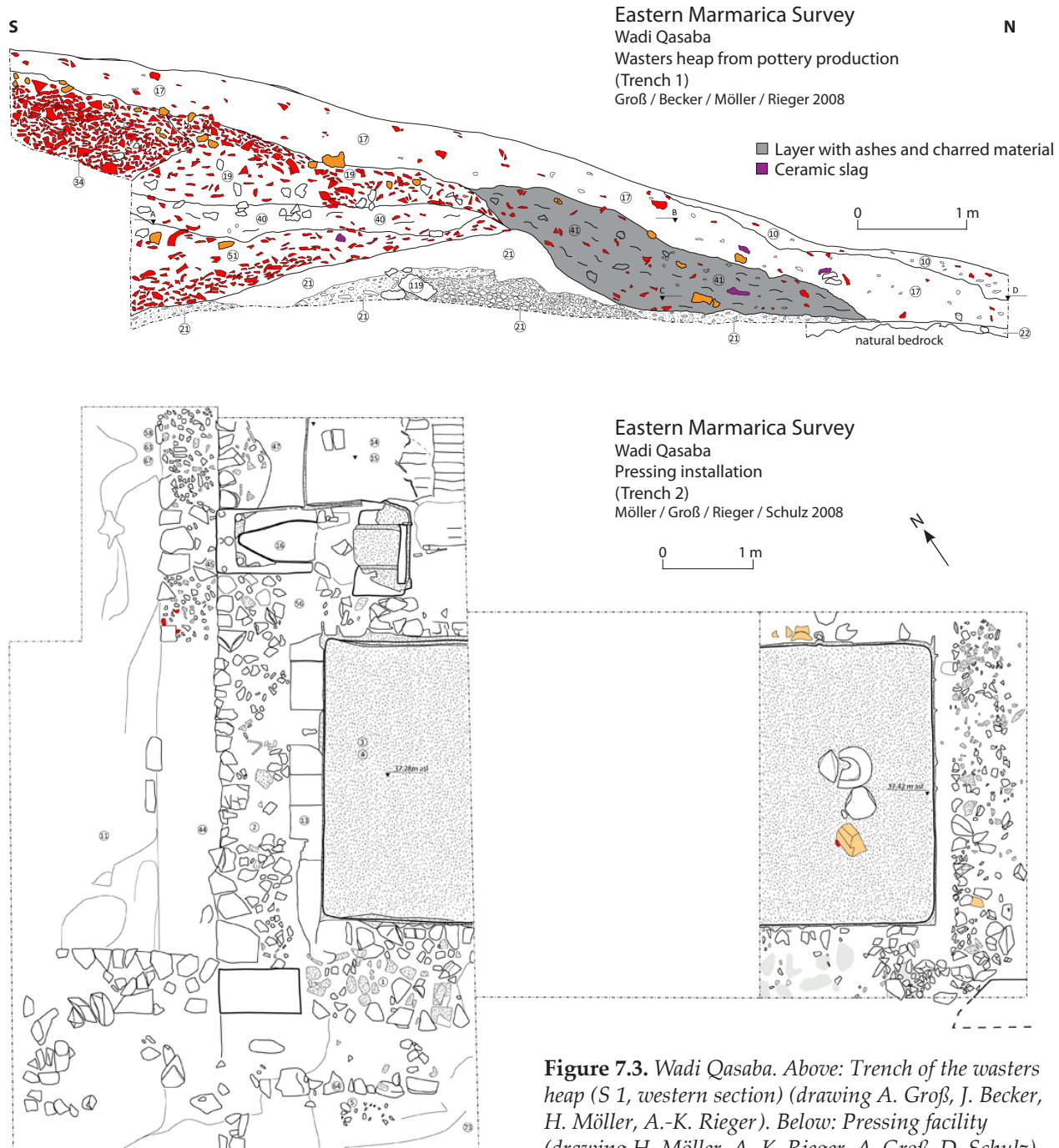
#### *Wadi Qasaba*

Wadi Qasaba is situated 28 km east of Marsa Matruh. This site is a relatively large pottery production area and lies 4 km south of the coast, between the branches of the wadi, and is embedded in a settlement (Rieger & Möller 2011, 154–7). The finds at the site confirm that the settlement and the pottery production site were in use between the end of the second century AD and the fourth century AD. The bean-shaped mound of wasters rises up to 3 m above the ground and it is a prominent feature in the landscape (Fig. 7.3, above). It contains mostly wasters, sherds and slugs of amphorae and some common wares. The kiln itself, sunk into the ground, was discovered ‘leaning’ against the waste heap and

could be reconstructed as an up-draught kiln (Rieger & Möller 2011, 154–5; Möller 2015). This kind of kiln is frequently used in Egypt (El-Ashmawi 1998; Majcherek & Shennawi 1992; Dixneuf 2011) and elsewhere (Bonifay 2004). It is constructed in a chimney form, with an upper and lower chamber separated by a stacking platform providing indirect heat and protecting the product from smoke. This construction, combined with being set deep in the ground, provides a high thermal efficiency (Bourriau, Nicholson & Rose 2000), a technical requirement for pottery production on a more sophisticated level. The size of the kiln (the inner diameter of the stacking platform measures c. 5.5m) and the huge quantity of wasters, indicate pottery production on a large scale. Along with some common wares, mainly amphorae – type AE 3 (recently Dixneuf 2011, 97–128) and AE 3–6 (Möller 2015) – were fired. About 100 m northeast of the potter’s workshop, a facility for producing liquids, most

probably wine, was discovered (Fig. 7.3, below). Two large basins measuring c.  $5.5 \times 2.5$  m are preserved, one of which has been excavated. They lie behind a spouted stone leading to a collecting vat, where fermentation and settling took place. The excavated basin is preserved to a height of 0.2–0.3 m and is lined with waterproof plaster. Judging by its position, it was used as a treading floor. It inclines by about 3.5 per cent towards the northern side, where one would expect the collecting vat.

The facility is comparable to wine presses found around Lake Mareotis (Empereur 1993; Rodziewicz 1998). In the Eastern Marmarica, presses were found mainly near pottery production sites. The close spatial relationship is due to an organizational relationship between the products that each facility provides, both the vessels and the wine (e.g. Ruffing 2001, 58; for the ecological conditions and favourable wine growing areas, see below). The enormous output of vessels and



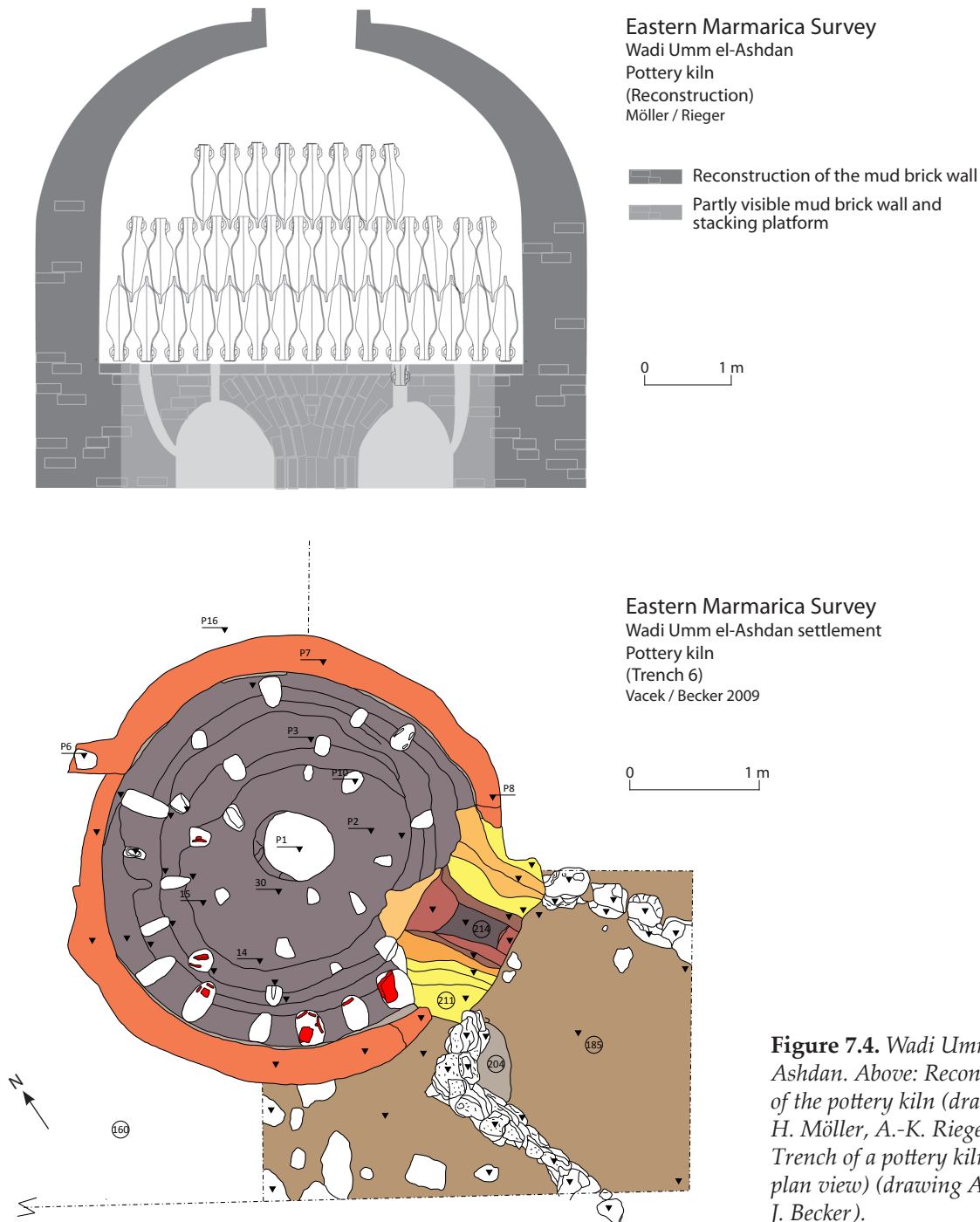
**Figure 7.3.** Wadi Qasaba. Above: Trench of the wasters heap (S 1, western section) (drawing A. Groß, J. Becker, H. Möller, A.-K. Rieger). Below: Pressing facility (drawing H. Möller, A.-K. Rieger, A. Groß, D. Schulz).



the size of the pressing facility at Wadi Qasaba both attest to the considerable economical potential of this semi-arid area. In this case, the high demand for raw materials required to produce such a great number of vessels proves the rather unexpected agricultural capacities in the Marmarica and vice versa. The ancient agricultural system also answers, in part, the question of what fuel can be used in a desert-like region, as is discussed later.

#### *Wadi Umm el-Ashdan*

A smaller kiln site was investigated in the Wadi Umm el-Ashdan, a settlement at the western branch of the wadi, 16 km west of Marsa Matruh. Eight small kilns were active in the settlement itself during the Roman period (Rieger & Möller 2011, Tab. 1, no. 38 and 158–9); there was also a larger kiln, adjacent, not discussed here. A possible reconstruction is provided of the style of the small kilns (Fig. 7.4, above). Complementing and



**Figure 7.4.** Wadi Umm el-Ashdan. Above: Reconstruction of the pottery kiln (drawing H. Möller, A.-K. Rieger). Below: Trench of a pottery kiln (S 6, plan view) (drawing A. Vacek, J. Becker).

contrasting the examination of the large workshop/kiln complex at Wadi Qasaba discussed above, these small kilns demonstrate production on a completely different scale. Their output was clearly much lower than that of the Wadi Qasaba complex, probably covering only the demands of the el-Ashdan inhabitants. It remains unclear what kind of pottery was produced in these small kilns, since they were used as dumps after they were abandoned. The small number of pottery wasters does not indicate a specific type of pottery, but if for local consumption, the pottery was probably mainly common wares, such as for food preparation, as well as tablewares for daily use. However, many amphorae are among the find materials.

Of the eight kilns, the one chosen for a detailed investigation is only 3.5 m in diameter (Fig. 7.4, below) and was probably active in the second and third century AD, as can be inferred from the finds of AE 3 and table- and cooking ware (Rieger & Möller 2011, 163; Möller 2015). Still a (smaller) up-draught kiln, it also differs slightly in design from the one at Wadi Qasaba, as it has a differently built stacking platform. The production site does not have huge waster heaps. Only areas with a mixture of sediment and sherds attest to the activity of the kiln. The greyish colour of the deposit may be the result of cleaning the firing channel that leads south from the firing chamber (Fig. 7.4, below). However, a layer or accumulation of charred material, as in the case of Wadi Qasaba, could not be identified. Consequently, only general assumptions can be made about how the Wadi Umm el-Ashdan small kilns were fired.

### How to generate biomass: agricultural waste and natural vegetation as fuel supply for pottery workshops

Pursuing the question of how to fuel a kiln in a resource-poor environment leads to the more general question of what organic and combustible material can we expect to find there, i.e. what potential biomass existed. Since the natural vegetation, as already mentioned, is limited to shrubs and grasses and produces a few trees only along the coastal strip, the woody plant biomass is insufficient to meet the fuel requirements of the kilns. Fuel has to be augmented by other means when it is needed on a larger scale. Especially on the northern tableland, agricultural activity is feasible due to an elaborate system of water and soil harvesting. The ancient settlements, such as Wadi Qasaba or Wadi Umm el-Ashdan, relied on the areas that became cultivable by these improvements to the pre-existing ecological conditions. Thus, not only life based on agriculture became possible, but also the amount of available organic material required for firing the kilns also increased.

### *Agricultural production on the northern tableland*

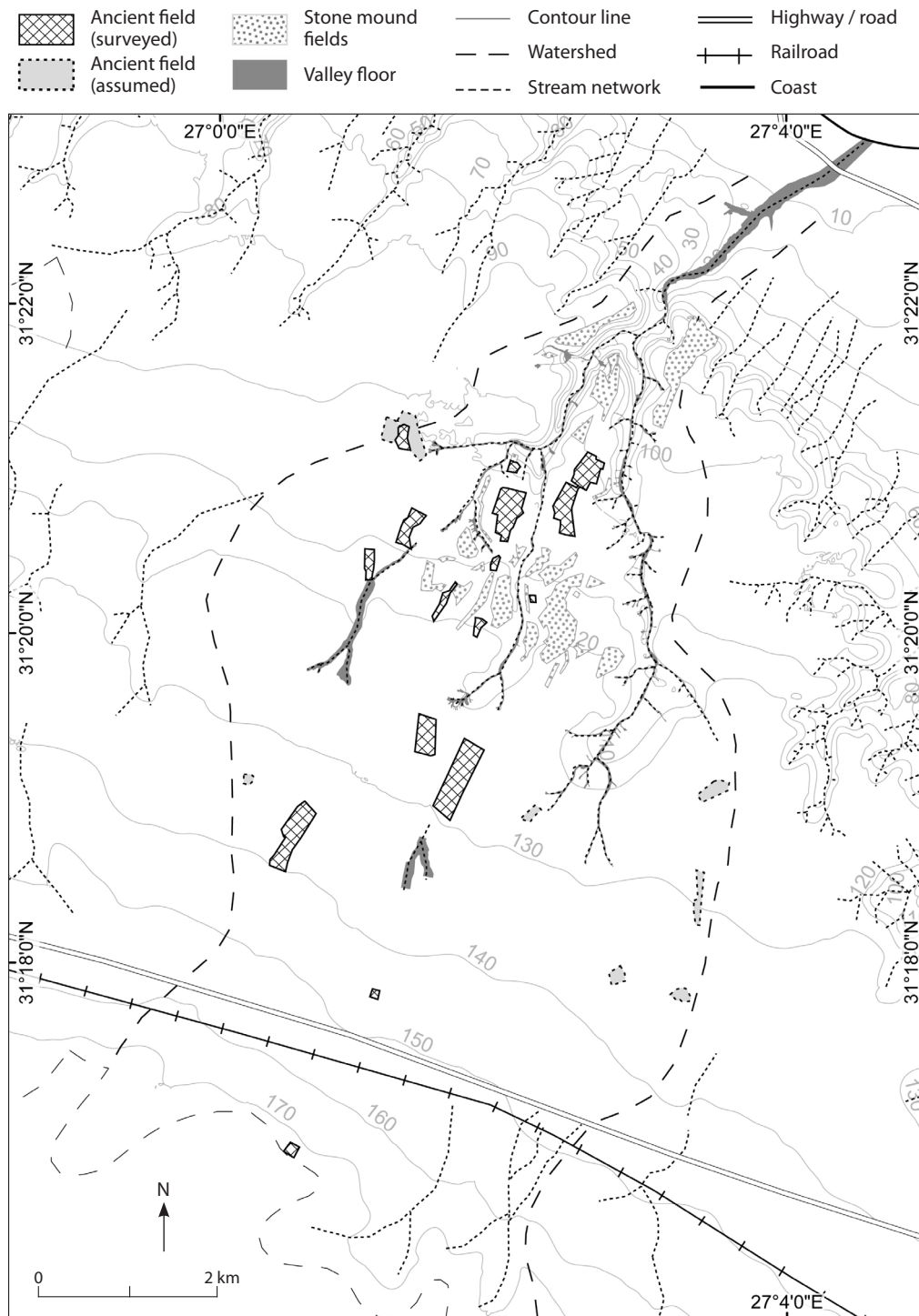
Three different types of cultivable land can be distinguished depending on the water and soil harvesting installations and run-off conditions: embanked fields (*kurum*); planting mounds (*teleilat el-einab*); and terraced fields. Their installation in ancient times was ascertained by OSL-dating of the accumulated soil layers behind man-made walls, embankments and bunds (Vetter, Rieger & Nicolay 2009, 12–7, fig. 16), whereas the close-by Graeco-Roman settlements (as at Wadi Umm el-Ashdan) or sherd scatters along the embankments or bunds provided archaeological evidence that the fields were used in antiquity.

The installation of tableland fields goes back to the second millennium BC (dated by the OSL method). They were more or less continuously active until the middle of the first millennium AD, and the earliest wadi terraces could be dated to the beginning of the first millennium BC (again by the OSL method). Tableland fields and wadi terraces are still in use today; only the stone-covered mounds represent an agricultural innovation that is no longer used. The estimations discussed below on the size of the ancient agricultural areas, their field capacities and possible crops are based on pedological and hydro-geographical analyses in the Wadi Umm el-Ashdan watershed. These estimations are supplemented by textual evidence and botanical research. Firstly, these assumptions serve as an approach to understanding the economic potentials and bases of livelihood of the people on the northern fringe of the Eastern Marmarica in antiquity. Secondly, they give an idea of how much biomass could be produced in the region.

#### 1. Embanked fields (*kurum*)

Embanked fields are a specific feature of dry-farming in the Marmarica. The unique morphological layout of the region, with its slightly sloping tableland, allows the installation of fields, not only in the run-in zones (where the water has to be contained), but also in the run-off zones (Vetter, Rieger & Nicolay 2014, 45) (Fig. 7.5). The characteristics of the *kurum* increase the amount of available water and the soil depth, so that the cultivation of barley becomes possible, although the Arabic name actually implies the cultivation of grapes. According to the only preserved papyrus from the region, barley seems to have been the second most important crop in the fields of the Marmarica. The papyrus refers to an area a little further west of the investigated area (*P. Marm.*, Norsa & Vitelli 1931; Rieger 2017), where more than a quarter (26.5 per cent) of all taxed agricultural areas are barley fields. Furthermore, in the Roman period, taxation of the cereal crops of the region took place in Paraitonion, modern Marsa Matruh, as we learn from a papyrus from Oxyrhynchus (POxy 9, 1221). This





**Figure 7.5.**  
Wadi Umm el-Ashdan. Different agricultural areas in the watershed system (map A. Nicolay).

information confirms once more that crops were cultivated in the region. The area of the *kurum* in the Wadi Umm el-Ashdan system amounts to almost 1 sq. km, which corresponds to c. 2 per cent of the area within the watershed system (51 sq. km). If we assume a yield of c. 400 kg per ha (10,000 sq. km) (cf. Müller-Mahn 1989, 55), an annual yield of 40 tons of barley was possible

on the fields close to the village.<sup>1</sup> The crop provided the basic carbohydrate requirement of the daily diet, in combination with some wheat and vegetables (see below). However, not only the grain itself was used but the chaff and straw as well. After threshing, the remains were an important resource, which was used as animal fodder; as temper for mud bricks; or as fuel.

## 2. Planting mounds (*teleilat el-einab*)

Numerous stone-covered mounds, spread across the entire tableland, are still visible today. This phenomenon is comparable to other semi-arid or arid regions, but their function is highly contested. Each with a diameter of 1–2 m, they cover an area of 3 to >6 sq. m. Their height does not exceed 0.5–0.8 m (Fig. 7.6). Each mound is enclosed by a circle of stones that

is set into the ground. This feature makes them clearly an anthropogenic construction. Their fill consists only of unconsolidated sediment mixed with pieces of local limestone (Fig. 7.6). These cobble-sized stones are also used for neatly covering the mounds. The mounds, 7–15 m apart, are spread out close to scarps but also scattered over the level ground between the wadi branches (Fig. 7.5). In some cases, they seem



**Figure 7.6.** Wadi Umm el-Ashdan. Above: View of planting mounds as they appear on surface (*teleilat el-einab*) (photo A.-K. Rieger). Below: Excavation of a stone-covered mound (photo A. Nicolay).

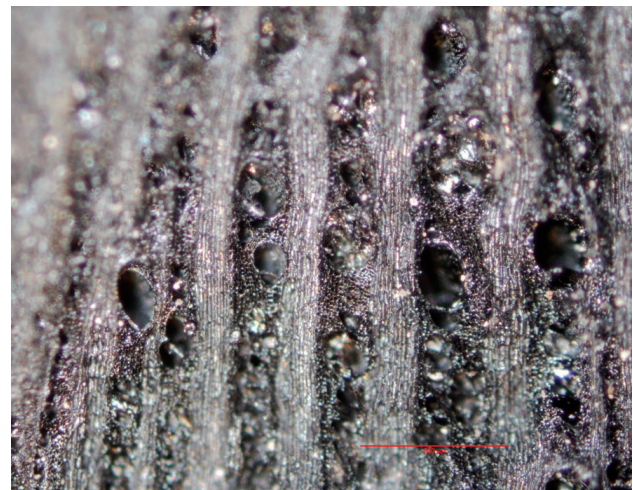
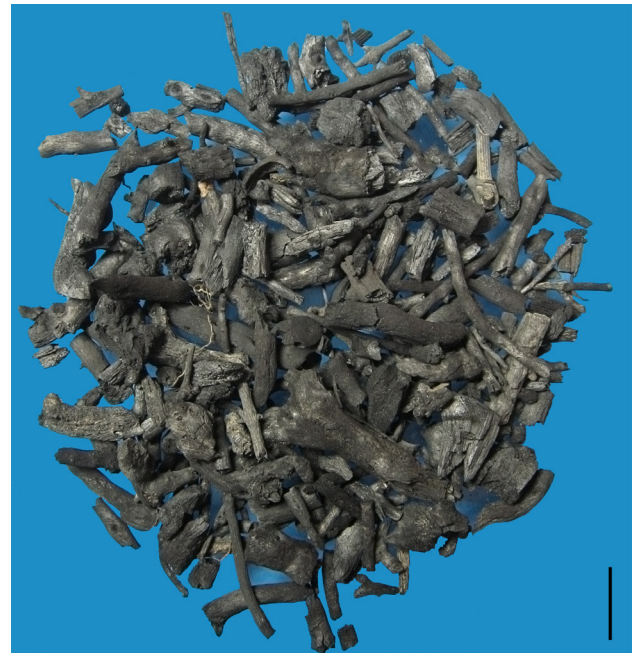


to be placed in a line, but mostly they are randomly distributed, in contrast to the many examples of lined-up mounds consisting only of stones in the Negev.

In the Negev, the opposing explanations are that they functioned either as dew traps and were used as planting mounds, or that the stones were simply collected to clean the ground and thus facilitated the run-off (facilitating the run-off: Evenari, Shannon & Tadmor 1982, 127–30, Mazor 2001, 340; dew traps: Crawford 2008, 93–4, Lightfoot 1997, 210–12). Using satellite images, more than 1450 of these mounds can be counted in the watershed system of Wadi Umm el-Ashdan. They cover an area of 186,000 sq. m (0.18 sq. km), the equivalent of 0.45 per cent of the land within that wadi system (Fig. 7.5).

Although we do not have any data on the amount of water available for planting and the soil conditions in the stone-covered mounds, there is convincing evidence that they were used as planting mounds. In particular, we can assume a quite substantial viticulture in the region of the ancient Marmarica. Two ancient texts attest to viticulture and wine. The first source is Strabo (*Geog.* 17.1.14), who talks about the quality of Libyan wine produced west of Lake Mareotis, in comparison to wine from the Mareotis region itself. The second source is the *P. Marm.* (Norsa & Vitelli 1931; Rieger 2017): almost half of the agricultural regions mentioned in a type of tax list are vineyards. Furthermore, the text states that there are ἀμπελικαὶ δία χέρσου ἀρουραὶ (col. 1, l. 8), which means that a vineyard is planted on infertile land. Some areas of viticulture are bordered by wadi valleys (νάπη; col. 10 and 11, several lines). This description may apply to the planting mounds as we see them on the otherwise useless tableland in the northern parts of the Marmarica. The texts about viticulture, which are geographically rather vague, match the archaeobotanical evidence from the investigated area: wood from *Vitis vinifera* was found in the Roman layers of the settlement at Wadi Umm el-Ashdan (see below, and Fig. 7.7), so that most likely grapes were cultivated in the Eastern Marmarica. Bush vine or low-trained vines (as grown today on the islands of Santorini or Lanzarote) were feasible, because they grow close to the ground and thus would avoid the strong winds of the tableland.

Although the mounds themselves are easily counted, it is difficult to estimate their yield in grapes, because this depends on the plant variety and the precise climatic, hydro- and pedological conditions, which cannot be easily estimated. But assuming only two vines per mound, a huge amount of organic, combustible material would have become available over the year. Dead wood, cuttings and leaves accrued every season. Apart from these plant remains, there



**Figure 7.7.** Archaeobotanical remains from Wadi Qasaba and Wadi Umm el-Ashdan. Above: Wood of a *Tamarix* sp. (scale 1 mm) (photo A. G. Heiss). Below: Wood of *Vitis vinifera* (scale 500  $\mu$ m) (photo V. Asensi Amorós).

were also grape pressings. Both these agricultural ‘waste’ products helped to cover the demand for fuel.

### 3. Terraced fields

A common and widespread way of farming in semi-arid or arid regions is to use water and soil harvesting systems established along wadi incisions. Lateral and cross dams form sediment traps, creating terraces of soil able to hold the run-off from the slopes (Fig. 7.5). Analogies to other semi-arid or arid regions can be found in

Tripolitania, Jordan and the Negev (Vetter & Rieger 2019; Evenari, Shannon & Tadmor 1982; Gilbertson & Chrisholm 1996). Figure 7.5 shows where water and soil harvesting walls of presumably ancient date could be measured in Wadi Umm el-Ashdan, allowing for a reconstruction of the ancient field system. The field areas generated by lateral and cross-sectional terracing were calculated according to the still visible height of the dams. These calculations tend to be minimum estimations, since the walls may have lost their upper stone layers.

Although we do not know how far the village plots of the Wadi Umm el-Ashdan settlement extended towards the north, we can estimate the terraced fields that were cultivated. The escarpment, where the tableland slopes down to the coastal plain, could possibly represent the natural border of the Wadi Umm el-Ashdan settlement. Adding up all wadi fields in this area, the cultivable land generated in the main wadi bed, at the tributaries and on their slopes covered 320,000 sq. m (0.32 sq. km), which is less than 1 per cent of the wadi system (a third of the slopes and wadi beds are terraced; Fig. 7.5).

Due to the relation between run-off zone and target area (Vetter, Nicolay & Rieger 2014), water and soil accumulated, making the terraces in the valleys capable of supporting tree cultures, such as fig, olive, almond and pomegranate. In addition, wheat, which needs more than 300 mm p.a. precipitation, could be grown in these plots. Garden cultures with legumes and vegetables were also possible. Since remains of figs and wheat are preserved (see below) and mentioned in the *P. Marm.* text (Norsa & Vitelli 1931; Rieger 2017) on the northern tableland, we can assume their cultivation in the main wadi and the small tributaries with their terraced fields. Assuming an area of 100 sq. m for one fig tree, for example, up to 3200 trees could have been grown. As in the case of barley or vines, they produced biomass, and their dead leaves, cuttings and dry branches could be used for firing kilns.

These three methods of growing crops and trees on the northern tableland show how floral and small woody biomass could be generated through agricultural exploitation of the region. The botanical macro-remains from the two sites where kilns were excavated give a glimpse of the indigenous and anthropogenic vegetation and, thereby, of the material that is likely to have been burnt in these workshops.<sup>2</sup>

### Botanical remains from Wadi Qasaba

Due to the semi-arid environment in the northern parts of the Eastern Marmarica, botanical remains are likely to be preserved mostly in charred form. Two pieces

of wood and some pieces of sub-fossil/dry remains were found in the region of the northern tableland. Remains of charred wood, seeds and fruits were floated from soil samples (mesh size 0.5 mm) and two pieces of sub-fossil/dry wood were found preserved in the soil. Charred particles and pieces reflect only partially the plants expected in the ancient layers, since some plants burn completely, whereas others become un-diagnostic due to poor preservation. All samples contained few, and only poorly preserved, remains, due to the ecological and archaeological preservation conditions. During the excavation of the kiln at Wadi Qasaba, the firing chamber was reached, but no charcoal was found. However, the trenches in the waster heaps brought to light thick layers of it and provided charred botanical remains (Fig. 7.3). These contexts can be interpreted as deposits from cleaning out the firing chamber, and they provide quite detailed information on the fuel deposited on the waster heap after the firings. Other remains were found in the area where slag has been dumped and on the kiln's stacking platform. In the grape pressing facility, *Hordeum vulgare* and *Triticum aestivum* (Fig. 7.8) as well as synanthropic plants, such as *Plantago* sp., *Malva parviflora* and Cyperaceae (sedge), were discovered as components of the available biomass.



**Figure 7.8.** Archaeobotanical remains from Wadi Qasaba. Above: *Hordeum vulgare*, rachis. Below: *Triticum aestivum*, caryopsis. (Scale 1 mm; photos A. G. Heiss.)





**Figure 7.9.** Above: Vegetation in the Wadi Umm el-Ashdan and Wadi Kharouba: *Salsola* and *Artiplex Halimus*, *Chenopodiaceae* species (photo A. Nicolay). Below: Vegetation in the desert of the Marmarica Plateau: *Acacia* (photo H. Möller).

Besides the rather scattered and small pieces of charred organic material in the layers of the wasters' heap (trenches 1 and 3), fairly homogeneous charcoal samples, consisting of *Tamarix* sp. (tamarisk) and a large number of seeds from the *Chenopodiaceae* (weed) family, were also present. Tamarisk, an indigenous plant, is the only tree that was used as fuel, as far as can be deduced from the botanical remains. It occurred in the ash layer of the wasters' heap (from the cleaning of the firing chamber) and on top of the stacking platform of the kiln. Tamarisk is still a common tree in the Nile valley as well as in the depressions and wadi of the steppe or desert landscape in Mediterranean Africa and Asia

(Thanheiser 2011, 82) (Fig. 7.7). The tree grows in the coastal zone of arid Eastern Marmarica where it apparently was an endemic plant also in antiquity, as the finds in Wadi Qasaba suggest. *Salsola* spp. (saltworts) as well as *Artiplex* spp. (saltbush/orach), are two shrub genera native to Egypt and examples are still found in the steppe zone of the northern tableland. These belong to the family of *Chenopodiaceae*, present among the finds from Wadi Qasaba (Fig. 7.9). Finds of saltwort at Abar el-Kanayis on the Marmarica Plateau to the south and at Wadi Umm el-Ahsdan confirm the existence of this type of shrub in antiquity (see below, and Rieger, Möller, Valtin & Vetter 2012, 140). Their use as

**Table 7.1.** Botanical finds from the large pottery production site in Wadi Qasaba (WQ S 1, 3, 4), the workshop (WQ S 9) and the wine press (WQ S 2); ch=charred and sd=sub-fossil/dry.

	Taxa / family		Number of remains	Trench/context	Preservation	Analysis by
Finds from wasters heap and kiln	<i>Tamarix nilotica</i>	Tamarisk	5	S 1, 40	ch	U. Thanheiser
	Apiaceae	Umbelliferous plants	1	S 1, 40	sd	U. Thanheiser
	Asteraceae	Daisy family	1	S 1, 40	ch	U. Thanheiser
	Asteraceae	Daisy family	1	S 1, 40	sd	U. Thanheiser
	Chenopodiaceae	Goosefoot family	1	S 1, 40	ch	U. Thanheiser
	Lamiaceae	Labiata	4	S 1, 40	sd	U. Thanheiser
	Chenopodiaceae	Goosefoot family		S 1, 41	ch	A. Fahmy
	Fabaceae <i>Trifolium</i> -type	Clover	3	S 3, 56	ch	U. Thanheiser
	Caryophyllaceae	Broomrape, bedstraw	1	S 3, 56	ch	U. Thanheiser
	<i>Malva parviflora</i>	Mallow	1	S 3, 56		
	<i>Portulaca oleracea</i> s.l.	Portulaca / hogweed	1	S 3, 56	ch	U. Thanheiser
	Cerealia		1	S 3, 56	ch	U. Thanheiser
	<i>Chenopodium murale</i>	Nettle-leaved goosefoot	1	S 3, 56	ch	U. Thanheiser
	<i>Typha</i> sp.	Reed mace, bulrush		S 3, 56	ch	A. Fahmy
	<i>Tamarix</i> sp.	Tamarisk		S 4, 128	ch	A. Fahmy
Finds from workshop and wine press	<i>Triticum aestivum</i> s.l./ <i>durum</i>	Breadweed, durum	1	S 9, 1007	ch	U. Thanheiser
	<i>Hordeum vulgare</i>	Barley	7	S 2, 67	ch	U. Thanheiser
	Asteraceae	Daisy family	3	S 2, 67	ch	U. Thanheiser
	Cyperaceae	Sedge family	3	S 2, 67	ch	U. Thanheiser
	Poaceae	Grass family	1	S 2, 67	ch	U. Thanheiser
	<i>Plantago</i> sp.	Plantain	3	S 2, 67	ch	U. Thanheiser
	<i>Chenopodium album</i>	White goosefoot	1	S 2, 67	ch	U. Thanheiser
	<i>Malva</i> cf. <i>parviflora</i>	Mallow	1	S 2, 67	ch	U. Thanheiser

charcoal in a comparable environment is attested by finds at Quseir el-Qadim on the Red Sea coast (Van der Veen 2011, 220–1).

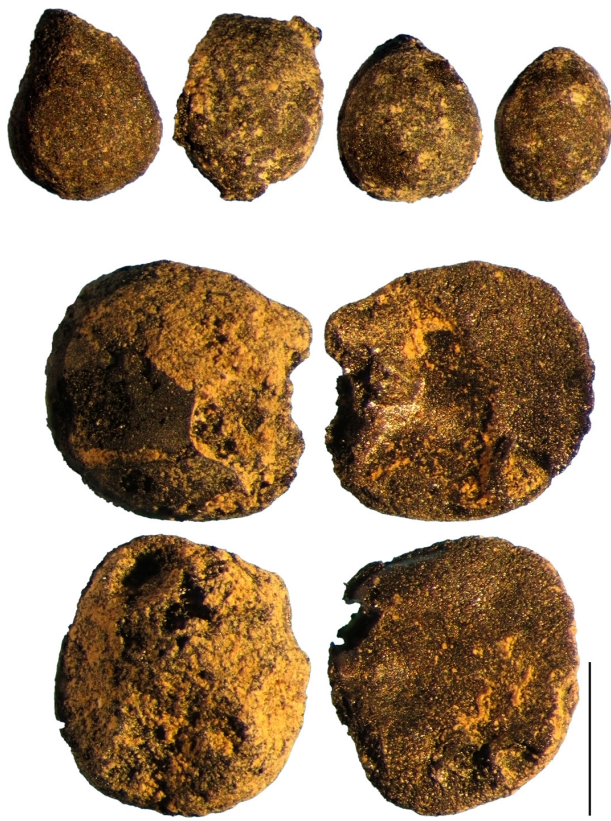
Other plant remains represent a rather scattered picture of the common segetals (weed types growing within grain crops). The occurrence of *Typha* sp. seems to be exceptional in a dry environment, but this hydrophilic plant, especially the salt-tolerant species, can grow in sebkhas and salt marshes close to the sea as well as beside ponds in the wadi beds (for example Wadi Umm el-Ashdan). Since fragments of cereals were found among the ashes in the waster heap and the adjacent workshop building (as well as in the pressing installation, Fig. 7.8), we can assume that agricultural residues and plants taken from the vegetation of the surroundings were burnt. The quite large wine press close to the kiln suggests that grapes were processed here. Although no remains of woody grapevines or grapes were found, cuttings from the grapevines in the area as well as the pressings produced by the wine press could have been used as fuel for the kiln.

The archaeobotanical results not only indicate that the vegetation pattern in Graeco-Roman times was similar to today, but also that, as we have seen in Wadi Qasaba, the semi-arid to arid ecological conditions and the resource-poor environment in antiquity are reflected in the mixed and sometimes meagre material available for firing a kiln.

#### Botanical remains from Wadi Umm el-Ashdan

In the settlement of Wadi Umm el-Ashdan, less information could be discovered. The ashes from the firing channel of the small kiln did not yield any identifiable remains. The ashes brushed out from cleaning the kiln produced only unidentifiable bits of charred plants; however, they did contain calcined pieces of snail shell.<sup>3</sup> Snail shells are present in many ancient contexts in the Eastern Marmarica (Pöllath & Rieger 2011, 169–70; Rieger & Möller 2012, 21, 25), since snails were part of the diet. Their occurrence could mean that every available waste was used for firing the kiln, but they may also just be refuse, because this kiln was





**Figure 7.10.** Archaeobotanical remains from Wadi Umm el-Ashdan. Above: *Ficus carica*, achene. Below: *Fabaceae*, seed. (Scale 1 mm; photos A. G. Heiss.)

later used as a dump. Although plant remains from the kiln are lacking, we can reconstruct the organic material that was produced in the area of Wadi Umm el-Ashdan through the botanical remains from other contexts of the settlement. Charred parts of figs (*Ficus carica*) and legumes (Fabaceae, cultivated species) were found in the fill of one of the circular structures (trench S 4) dated to Ptolemaic times by the ceramic evidence (Fig. 7.10). *Phoenix dactylifera* (date palm) occurs in one context. Grain, as found at Wadi Qasaba, is not present among the finds from Wadi Umm el-Ashdan, which may be due to the small number and volume of samples. However, the cultivation of barley is highly plausible on the embanked fields close to the settlement (Fig. 7.5).

Some synanthropic as well as indigenous plants are preserved. Among the latter, even shrubs and trees occur. Saltwort, and *Acacia* sp. (type of wattle), represent the native shrub and tree vegetation of the northern tableland and the northern Marmarica Plateau (Fig. 7.9). Saltwort was certainly used for fuelling the kilns, as the samples from Wadi Qasaba have shown. The occurrence of charred *Acacia* may indicate that this wood was used for the same purpose (Thanheiser 2011, 87 with table 3, dealing with the possible utilization of these plants in the prehistoric Dakhleh Oasis). Some unexpected finds consisted of pieces of Pinaceae (possibly *Pinus sylvestris*) wood. Pines are difficult to differentiate, but in the case of high altitude European groups, some are distinguishable to species level. They are preserved as sub-fossil/dry remains and were used

**Table 7.2.** Botanical finds from the area of the settlement in Wadi Umm el-Ashdan (UA S 4, 8, 10, 12, 14); ch=charred and sd=sub-fossil/dry.

Taxa / family		Number of remains or weight	Trench/context	Preservation	Analysis by
<i>Vitis vinifera</i>	Vine		S 14, 909	ch	V. Asensi
<i>Vitis vinifera</i>	Vine		S 14, 913	ch	V. Asensi
<i>Vitis vinifera</i>	Vine		S 12, 612	ch	V. Asensi
<i>Salsola</i> sp.	Salsola		S 12, 607	ch	V. Asensi
<i>Pinus</i> cf. ( <i>sylvestris</i> )	Scotch pine / Baltic redwood	15.5 g	S 10, 313	sd	V. Asensi
<i>Phoenix dactylifera</i>	Date palm		S 8, 514	ch	A. Fahmy
<i>Cedrus</i> sp.	Cedar	56.5 g	S 8, 580	sd	V. Asensi
<i>Salsola</i> sp.	Salsola		S 8-7, 768	ch	V. Asensi
<i>Acacia</i> cf. <i>nilotica</i>	Acacia	1	S 8, 531	ch	V. Asensi
<i>Salsola</i> sp.	Salsola		S 8, 531	ch	V. Asensi
<i>Ficus</i>	Fig tree	4	S 4, 86	ch	U. Thanheiser
<i>Plantago</i>	Plantain	1	S 4, 86	ch	U. Thanheiser
<i>Malva</i> sp.	Mallow	1	S 4, 86	ch	U. Thanheiser
Poaceae	Grass family	4	S 4, 86	ch	U. Thanheiser
Fabaceae <i>Trifolium</i> -type	Clover	3	S 4, 86	ch	U. Thanheiser
Fabaceae (cult)	Clover	2	S 4, 86	ch	U. Thanheiser

at least in one case for a sarcophagus or wooden box in a burial in the ancient settlement of Wadi Umm el-Ashdan. A piece of *Cedrus* sp. (cedar) was found in a basin. These conifers are not indigenous to Egypt. Their wood was imported and, therefore, an expensive commodity, most likely not intended to be used for fuelling kilns in the first place.

More important for the question of fuel provision, however, are three pieces of charred grapevine (*Vitis vinifera*, Fig. 7.7). They were discovered in the circular structures, which are most probably dovescotes, and in a house context. These remains clearly confirm the assumed function of the stone-covered mounds as *teleilat el-einab* (planting mounds). The great number of grapevines producing wood and other residue means that there was plenty of material available for firing the kilns on the northern tableland. These results match the pedological and hydrological data, and the reconstruction of the dry-farming system in the region as described above.

### Modern pottery workshops – an ethnoarchaeological approach to fuelling kilns

Pottery production in Egypt is still carried out today, although it is not nearly as widespread as it was in the last century. The production is concentrated along the Nile valley, the delta region (Redmunt & Morgenstein 1996; Koehler 1996; Ballet & von der Way 1993; Kenawi 2012), modern Cairo (van As, Duistermaat, Groot et al. 2009), and the Fayoum and the Eastern Oasis (e.g. Dakhla: Henry Heinen 1997; see Kenawi & Mondin this volume). Visits by the authors to modern kiln sites in the western delta in recent years helped not only to understand the process of pottery production itself but also clarified questions concerning the raw materials, such as water, clay and fuel, their processing and the work sequence.

Interviews with the potters showed that the choice of fuel is quite random (see also Martin in this volume). However, the potters rely on some basic materials, especially scraps of wood and sawdust. This seems to be the preferred fuel, along with by-products from processing agricultural goods, seasonal agricultural waste from plants, such as sugar cane and rice, or any other kind of combustible material. It is plausible that the way in which modern potters collect any accessible fuel could have also been adopted in the ancient sites. Woody plants, fodder plants, straw and chaff, remains from the pruning of grapevines and fig trees, pressings from grapes, and animal dung and droppings; whatever was regionally and seasonally available was used as fuel. This model of an ad hoc fuel supply does not preclude the possibility that fuel was imported to

the site from elsewhere. Since our reconstruction of the agricultural production allows to assume a surplus agricultural economy in this region, we can relinquish the idea that tons of wood were needed to fuel the kilns in the Eastern Marmarica.

In agreement with the assumed mixed fuelling of the kilns, there is no correlation between the spatial distribution of pottery workshops in the Eastern Marmarica and the availability of a certain kind of fuel. Rather, easy access to the raw materials of water and clay is the criterion for choosing the location for a kiln. This is the same pattern we observe in modern pottery production sites.

### Conclusion

Our approach to understanding the fuel that was used for Graeco-Roman pottery production in the semi-arid environment of the Eastern Marmarica has been two-fold. On an archaeological micro-scale, ash deposits from pottery kilns were analysed, whereas on an archaeological macro-scale environmental reconstruction was undertaken with bio- and geo-archaeological methods to understand the ecological conditions and agricultural activities as local providers of plant biomass suitable for firing.

The Eastern Marmarica is an almost desert-like environment with little vegetation. Nevertheless, the 55 pottery production sites consumed considerable amounts of fuel that somehow had to be procured. While the evidence is insufficient to determine the frequency of firing processes in the workshops, we know that many of them produced wares contemporaneously, and over a period of some centuries. Botanical macro-remains in ash layers of excavated kiln sites in Wadi Qasaba reveal that a mixture of different plants was burnt. Besides indigenous trees and shrubs, the by-products of agricultural procedures, such as remains from pruning, and grape pressings, as inferred from the location of the wine press, are likely to have been burnt, even though this kind of fuel is not of the highest quality. At the settlement of Wadi Umm el-Ashdan, the reconstruction of the anthropogenic environment that allowed agricultural production suggests considerable capacities for the cultivation of trees (fig, palm), shrubs (grapevine), cereals (barley) and vegetables/legumes were achieved. The overall increase of biomass, attained by the water and soil harvesting systems utilized, not only provided the food supply for the inhabitants but also increased the available fuel, since agricultural residues of any kind can be burnt.

The investigation of available fuels and the ethnoarchaeological study of modern kiln sites in the western



delta suggests that fuel choice today is also rather random and subject to the varying supply of seasonal agricultural wastes, as well as to the natural vegetation available in the surroundings. The disadvantages of this kind of mixed fuel (being of lower calorific potential), compared to a homogeneous one, can be compensated by more efficient kilns or by limiting the kind of pottery to be fired. The up-draught kilns found in the Eastern Marmarica had a high thermal efficiency. Their design made the control of the firing atmosphere far less problematic, and high temperatures could easily be reached (cf. Bourriau, Nicholson & Rose 2000). Furthermore, the ceramics produced (common wares and transport amphorae) did not need to be fired in an oxidizing/reducing atmosphere, so that exact temperatures and specific proportions of oxygen and carbon monoxide in the firing chamber do not have to be managed.

The varying fuel material, sometimes of inferior quality and lower calorific value, suited the production process and products of the Marmarican workshops. The problem of how to fire a kiln in an environment deficient in wood seems to have been overcome through a variety of sources, and sufficient amounts of fuel were in fact at hand for potters and other fuel consumers in the Eastern Marmarica (Leitch, this volume).

### Acknowledgements

We express our warmest thanks to the German Research Foundation for funding the Eastern Marmarica Survey, directed by Anna-Katharina Rieger, and to the Gerda Henkel Foundation for the PhD-fellowship granted to Heike Möller. The Supreme Council of Antiquities gave permission and substantial support to our work in the Marmarica. At the IFAO, Cairo, we met open doors to use the Laboratoire. The reconstruction of the ancient agricultural system in the region was only possible through the work and competence of the physical geographers Thomas Vetter and Alexander Nicolay. Thanks are also due to Ingrid Keller for reviewing our text.

### Notes

- 1 We base the calculations here on a lower yield than in Vetter, Rieger & Nicolay (2009, 20), where the supposed average yield is taken from numbers of recent crops.
- 2 We are deeply indebted to Prof. Ursula Thanheiser (VIAS, University Vienna), who participated in our project in 2009. She came to this remote region, which offers few botanical remains, with truly scientific curiosity. She made the botanical analyses on location. Andreas G. Heiss (VIAS University Vienna) provided the photographs. Other samples were sent to the IFAO, Cairo,

and analysed by Dr. Ahmed Fahmy, to whom we are deeply grateful. For analysing the wood samples with a high degree of competence we express our gratitude to Dr. Victoria Amoros (Xylodata Paris).

- 3 See Note 2.

### References

Abbreviations:

IFAO: Institut Français d'Archéologie Orientale

CEAlex: Centre d'Études Alexandrines

- El-Ashmawi, F., 1998. Pottery kiln and wine factory at Burg el-Arab, in *Commerce et artisanat dans l'Alexandrie hellénistique et romaine*, ed. J.Y. Empereur. (Bulletin de Correspondance Hellénique Supplément 33.) Athens: École Française d'Athènes, 55–64.
- van As, A., K. Duistermaat, N. Groot, et al., 2009. The Potters of Fustat (Cairo) in 2008: A preliminary report. *Leiden Journal of Pottery Studies* 25, 5–30.
- Ballet, P. & T. von der Way, 1993. Exploration archéologique de Bouto et de sa région (époques romaine et byzantine). *Mitteilungen des Deutschen Archäologischen Instituts Kairo* 49, 1–22.
- Bonifay, M., 2004. *Études sur la céramique romaine tardive d'Afrique*. Oxford: BAR.
- Bourriau, J., P.T. Nicholson & P. Rose, 2000. Pottery, in *Ancient Egyptian Materials and Technology*, eds. P. T. Nicholson & I. Shaw. Cambridge: Cambridge University Press, 121–48.
- Crawford, R.M.M., 2008. *Plants at the Margin. Ecological Limits and Climate Change*. Cambridge: Cambridge University Press.
- Dixneuf, D., 2011. *Amphores égyptiennes. Production, typologie, contenu et diffusion (III<sup>e</sup> siècle avant J.-C. – IX<sup>e</sup> siècle après J.-C.)*. (Études Alexandrines 22.) Alexandria: CEAlex.
- Empereur, J.-Y., 1993. La production viticole dans l'Égypte ptolémaïque et romaine, in *La production du vin et de l'huile en Méditerranée*, eds. M.-C. Amouretti & J.-P. Brun. (Bulletin de Correspondance Hellénique Supplément 26.) Athens: École Française d'Athènes, 39–47.
- Empereur, J.-Y., & M. Picon, 1998. Les ateliers d'amphores du Lac Mariout, in *Commerce et artisanat dans l'Alexandrie hellénistique et romaine*, ed. J.-Y. Empereur. (Bulletin de Correspondance Hellénique Supplément 33.) Athens: École Française d'Athènes, 75–91.
- Evenari, M., L. Shannon & N. Tadmor, 1982. *Negev – The Challenge of a Desert*. Yale: Harvard University Press.
- Gilbertson, D.D. & N.W.T. Chrisholm, 1996. ULVS XXVIII. Manipulating the desert environment. Ancient walls, floodwater farming and territoriality in the Tripolitanian pre-desert of Libya. *Libyan Studies* 27, 17–52.
- Henry Henein, N., 1997. *Poterie et potiers d'Al-Qasr. Oasis de Dakhla*. (Bibliothèque d'Étude 116.) Cairo: IFAO.
- Kenawi, M., 2012. Pottery from the Western Delta of Egypt. *Rei Cretariae Romanae Fautores ACTA* 42, 309–17.
- Koehler, E.C., 1996. Archäologie und Ethnographie. Eine Fallstudie der prädynastischen und frühzeitlichen Töpfereiproduktion von Tell el-Fara'in – Buto. *Cahiers de la céramique égyptienne* 4, 133–44.

- Lightfoot, D.R., 1997. The Nature, History, and Distribution of Lithic Mulch Agriculture: An Ancient Technique of Dryland Agriculture. *Agricultural History Review* 44, 206–22.
- Majcherek, G. & A. el-Shennawi, 1992. Research on Amphorae Production on the Northwestern Coast of Egypt. *Cahiers de la céramique égyptienne* 3, 123–36.
- Mazor, E., 2001. Millennia of sustained desert agriculture in the Central Negev versus highly preserved ecosystems inside the makhteshim, in *The Makhteshim Country – Laboratory of Nature*, eds. B. Krasnov & E. Mazor. Sofia: Pensoft Publishers.
- Möller, H., 2015. *Ptolemäische und römische Keramik in der antiken Marmarica – Nordwestägyptens Wüstenrandgebiet als Produktionsort und Mittler*. PhD thesis. University of Freiburg im Breisgau.
- Möller, H., A.-K. Rieger & T. Vetter, forthcoming. Locally made pottery along the routes of the Libyan Plateau in Greco-Roman times – first results of petrographical observations on calcareous clay-fabrics in the Eastern Marmarica. *Cahiers de la Céramique Égyptienne* 10.
- Müller-Mahn, H.-D., 1989. *Die Aulad 'Ali Zwischen Stamm und Staat*. (Abhandlungen Anthropogeographie Institut für Geographische Wissenschaften 46.) Berlin: Reimer.
- Norsa, M. & G. Vitelli, 1931. *Il Papiro Vaticano Greco 11. Registri fondiarii della Marmarica*. (Studi e Testi 53.) Vatican City: Biblioteca Apostolica Vaticana.
- Pöllath, N. & A.-K. Rieger, 2011. Insights in diet and economy of the Eastern Marmarica faunal remains from Greco-Roman sites in northwestern Egypt (Abar el-Kanayis, Wadi Umm el-Ashdan and Wadi Qasaba). *Mitteilungen des Deutschen Archäologischen Instituts Kairo* 69, 163–84.
- Redmount, C.A. & M.E. Morgenstein, 1996. Major and Trace Element Analysis of Modern Egyptian Pottery. *Journal of Archaeological Science* 23, 741–62.
- Rieger, A.-K. & H. Möller, 2011. Kilns, Commodities and Consumers – Greco-Roman Pottery Production in the Eastern Marmarica (Northwestern Egypt). *Archäologischer Anzeiger* 2011(1), 141–70.
- Rieger, A.-K. & H. Möller, 2012. Northern Libyan Desert Ware: new thoughts on 'Shell-tempered Ware' and other handmade pottery from the Eastern Marmarica (north-west Egypt). *Libyan Studies* 43, 11–31.
- Rieger, A.-K., H. Möller, S. Valtin & T. Vetter, 2012. On the route to Siwa: The Roadhouse of Abar al Kanayis on the Marmarica-Plateau. *Mitteilungen des Deutschen Archäologischen Instituts Kairo* 68, 135–74.
- Rieger, A.-K., 2017. Text and landscape: the complementarity of the Papiro Vaticano Greco 11 R (PMarm) to landscape-archaeological results from the arid Marmarica (NW-Egypt/NO-Libya). *Topoi. Orient-Occident* 21(1), 105–46.
- Rodziewicz, M., 1998. Classification of Wineries from Mareotis, in *Commerce et artisanat dans l'Alexandrie hellénistique et romaine*, ed. J.-Y. Empereur (Bulletin de Correspondance Hellénique Supplément 33.) Athens: École Française d'Athènes, 27–36.
- Ruffing, K., 2001. Einige Überlegungen zum Weinhandel im römischen Ägypten (1.-3. Jh. n. Chr.). *Münsterische Beiträge zur antiken Handelsgeschichte* 20/1, 55–80.
- Thanheiser, U., 2011. Island of the Blessed: 8000 Years of Plant Exploitation in the Dakhleh Oasis, in *Windows on the African Past: Current Approaches to African Archaeobotany*, eds. A. Fahmy, S. Kahlheber & A. C. D'Andrea. Frankfurt: Africa Magna Verlag, 79–90.
- Van der Veen, M. 2011. *Consumption, Trade and Innovation: Exploring the Botanical Remains from the Roman and Islamic Ports at Quseir al-Qadim, Egypt*. Frankfurt: Africa Magna Verlag.
- Vetter, T., A.-K. Rieger & A. Nicolay, 2009. Ancient Rainwater Harvesting System in the north-eastern Marmarica (north-western Egypt). *Libyan Studies* 40, 9–23.
- Vetter, T., A.-K. Rieger & A. Nicolay, 2014. Disconnected contributing areas and adapted ancient watershed management in the semi-arid north-eastern Marmarica (NW-Egypt). *Geomorphology* 212, 41–57.
- Vetter, T. & Rieger, A.-K. (eds.), 2019. Water harvesting as a key for understanding adapted ancient livelihoods in an arid environment – Approaches to dryland archaeology in the Eastern Marmarica (NW-Egypt). *Journal of Arid Environments*, Special Issue, Ancient water and soil management in arid areas of Western Asia and NE-Africa.

---

## Chapter 8

# Continuity of production: kilns and fuel in Egypt and the Mediterranean

Mohamed Kenawi & Cristina Mondin

There are numerous pottery and brick manufacturing sites in Egypt that date back to the Hellenistic and Roman period. However, these sites have not received much attention archaeologically and little information exists in the ancient sources to tell us about the production processes or the fuels used. This paper, therefore, seeks to use studies of medieval and modern kilns in Egypt and the Mediterranean to further our understanding of ancient kiln technology and fuel use.

The sites are mainly located in places where the raw material was readily available, such as along the river Nile and in its delta, along the Mediterranean coast and in the oases. The clay came from the alluvial deposits of the river Nile or from marl plateaus that crumble naturally through rain and wind. The availability of fresh water, and fuel obtained from plants growing in fertile soil, were also among the factors that determined the location of the kilns. Due to the scarcity of wood in such an environment, other types of fuel were used.

### Hellenistic and Roman kilns: the evidence

In this geographical context, there were many pottery installations in the Hellenistic, Roman and late Roman periods. It seems that in Roman times, especially along the western Egyptian Mediterranean coast (Eastern Marmarica), there was an increase in pottery production (Rieger & Möller 2011, 144; and see their chapter in this volume). This followed patterns in the Mareotic region (Empereur & Picon 1998, 75–91). This is true especially for the production of amphorae, which were used as shipping containers for the export of wine, olive oil, fruit and cereals. In some sites, there was no separation in production: the same kilns produced amphorae, common wares for domestic use, and in many cases bricks and tiles as well.

Unfortunately, most of these production sites have only been identified by surveys, and few have been excavated in detail. Rieger & Möller in this volume importantly add to the previously published corpus (Kenawi 2014).<sup>1</sup> Other excavated kilns include Kom al-Dahad near to al-Dilingat (Coulson & Wilkie 1986, 65–74); Buto/Tell el-Fara'in, about 80 km to the south-east of Alexandria (Charlesworth 1972); Wadi Qasaba 28 km east of Marsa Matruh (Rieger & Möller 2011); and Kom Umm al-Athel in Fayoum (Rossetti 2011, 239–62; Tocci 2011, 263–76). These are in addition to those located in the Mareotic region.

These kilns are vertical and almost always have mud brick walls that are baked into red brick with the first firing of the kiln. In most cases, the design is round or oval with an underground combustion chamber. The holed floor is supported by arches that start from the walls of the combustion chamber. In the larger kilns, the floor is supported by a central pillar. Intact firing chambers have never been found, but where the chambers are better preserved, they have the shape of a frustum (or truncated cone). The kiln diameters vary: a large kiln excavated in Wadi Qasaba has a diameter of 5.5 m; a medium-size kiln at Wadi Umm el-Ashdan (near the Marmarica Plateau – west of Marsa Matruh) has a diameter of 3.3 m; and small kilns with a diameter of about 2 m have been identified for instance at Buto/Tell el-Fara'in (Hartung & Ballet 2009, 83–190).

In most of these contexts there is little information regarding the fuels used for firing the kilns. A few chemical analyses have been carried out in Egypt on the vegetal remains found in the Hellenistic and Roman kilns. One example of such a study comes from the site of Wadi Qasaba, where a sample of wood, found among the ashes and waste materials, was analysed (Rieger & Möller 2011, 160–1, and in this volume). It is a fragment of tamarisk, a type of tree or shrub common in arid lands of the Mediterranean basin. Another





**Figure 8.1.** *Small kilns at Tell Timai in the eastern delta.*

example is the recent excavation in the eastern delta at Tell Timai (ancient Thmuis), where a series of small kilns of around  $2 \times 2$  m have been discovered (Fig. 8.1). The type of production was unclear, but the fuel used to fire the kilns was identified as mainly charcoal and the remains of olive stones.

If there is little information from the archaeology, the data from ancient texts is equally scarce. Indeed, few published Egyptian sources mention the process of working with clay and fuel. Papyri that deal with the production process of pottery tend to be leases and legal documents. In particular, two texts discovered at Oxyrhynchus, one dated to AD 156 and the second to AD 243, deal with the production of amphorae and common wares. The technical information reported in the texts mainly relates to the typology of the clay and to the shape of pots produced. In the description of the production process, the only fuel that is mentioned is straw (Cockle 1981, 94).

There are also many Roman sources (for example Cato *Agr. cult.* 28, 1; Vitruvius *De arch.* II, 9; Pliny *Nat. hist.* XVI, 18–19, 76) that talk of wood during Roman times, but there is little information relating to fuel. The most ancient treatises give in-depth descriptions of the wood used in buildings but only cursorily mention types used for heating. Some information on the types of fuel, described in general terms, can be found within *Digesta*.

This collection of passages by classical jurists was put together by Justinian and promulgated in AD 534. The Ulpian passages quoted in book 32 deal with the terminology: the distinction between the *materia* used for building and *lignum* used as fuel (*'Materia est, quae ad aedificandum fulciendum necessaria est, lignum, quidquid comburendi causa paratum est'* Dig. 32.55pr.). It also points out that *'...omnia ligna pertinere, quae alio nomine non appellantur, veluti virgae carbones nuclei olivarum, quibus ad nullam aliam rem nisi ad comburendum possit uti: sed et balani vel si qui alii nuclei...'* (Dig. 32.55.1). That is to say, branches, coal, olive stones, seeds, acorns and other similar kinds of fruit stones that clearly have no other use, are mentioned as fuel. Ulpian, however, does not specify which type of combustion these types of fuel were used for (see also Leitch, this volume, for other examples from Roman North Africa).

### Medieval to Early Modern kilns: the evidence

Roman sources do not give us much information about fuel. Further detail comes instead from more recent texts. For this reason, it is worth discussing these as well as modern sites that still use traditional techniques of production. Only regions that were formerly part of the Roman Empire will be considered.

More detailed descriptions of fuel come from



some Renaissance treatises, which speak explicitly of the fuel used in kilns for pottery and bricks in central and northern Italy, for example. The first firing for common wares, before making white glazed ware, was explained by Cipriano Piccolpasso in c. 1500: ‘...con il nome di Iddio, pigliasi un pugno di paglia, con il segno della croce accendasi il fuoco, il qual con legnie ben secche vengasi inalzando pian piano per insino alle 4 ore, e dipuoi crescasi; però con avvertimento, perché, se bene non vi sono lavori feniti, crescendo troppo il fuoco, gli lavori si piegano e vengano frigni, e cossi non pigniano puoi il bianco. E tengasi il fuoco cossi che la fornace si vegga bianca, cioè tutta infocata; e quando ella harà avuto vicino a dodici ore di fuoco dorebbe, secondo la ragione, esser cotta’ (Piccolpasso ed. 1976, 128–9, 131). In describing the ignition of the fire, Piccolpasso mentions using straw. The pre-heating phase lasted for four hours, with wood being used in addition to straw. The stoker introduced fuel and kept the fire burning for 12 hours. The description states that the fire must constantly be kept at very high temperatures, but does not specify the type or the size of wood being used.

Vannoccio Biringuccio (1540, 146) from Siena described the firing in the same way as Piccolpasso. However, he specified that in order to feed the fire, *scope* (besoms), sorghum and other brushwood *secche* and *dolci* (dry and softwood) might have been used.

A fifteenth-century lease from the territory of Bolsena (Italy) established the rules regarding the use of land for brick production. The contract allows for the exploitation of the clay pits, the possibility of building kilns and other useful buildings, as well as the use of wood. Regarding wood, it is specified as: ‘*lignia comburenda sint minuta et ramos arborum incidat at non troncones a pede*’ (Cortonesi 1986, 305–6), thin wood and tree branches smaller than a foot.

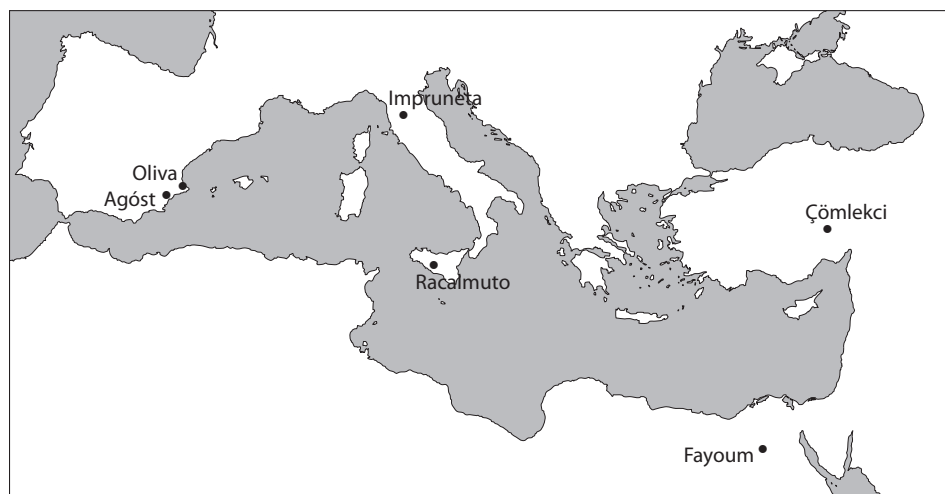
In sources from the sixteenth century in Rome, fuel is mentioned very often among archival documents

containing the census of the properties of the potters. It is not explicit what type of tree species was used, but they are called *fascine*, i.e. bundles of brushwood or small branches from the pruning of fruit trees, vines, etc. From other texts, it transpires that the supply of bundles was not a problem, even in the city. In a judicial act from AD 1542, it is stated that 300 bundles are needed to fire a pottery batch (Güll 2003, 90–1; Pesante 2010, 215).

Regarding the timing of the firing, in a document dated to AD 1756 from the territory between Orvieto and Viterbo (Italy), is the following passage: ‘*Noi sottoscritti... attestiamo che cocendosi nelle fornaci delle nostre botteghe, ad uso di piattaro, li piatti ruzzi, il foco per ogni cotta delli medesimi durerà a farsi e stare acceso per lo spazio di circa ad ore quattordici e quando si cuociono novamente detti piatti rozzi di buono, cioè maiolicati, vi vuole dieci ore di fuoco di più e secondo la qualità della legna, mentre questi piatti maiolicati si cuociono in altra fornace più grande e non in quella ove si cuociono li piatti rozzi, ma per altro il fuoco è temperato sempre, e nella stessa maniera di ambedue le cotture, né è più gagliardo, né più assiduo l’un fuoco dall’altro.*’ Therefore, in a kiln of unspecified size, firing common wares took about 14 hours. For the majolica, the second firing required 10 more hours than the first in a different and larger kiln. The text also specifies that the firing time depended on the kind of wood used. Furthermore, for both productions, the fire needed to be of equal intensity and constant (Güll 2003, 100–1; Pesante 2010, 213–15).

### Modern Egyptian kilns in Fayoum

The technical characteristics of clay have been known to mankind from ancient times. Furthermore, techniques of processing and firing pottery or bricks in a non-industrial production context have not undergone



**Figure 8.2.** Map of the modern production sites mentioned in this chapter.



**Figures**  
**8.3–8.5.** *Nazla,*  
*Fayoum, kilns*  
*and products.*



any real innovations over time and the process has come down to us almost unchanged. Non-industrial or handicraft ceramic or brick production entails the use of raw materials from the surrounding territory, a pottery wheel or wood mould to make bricks, and the use of natural fuel kilns. The fuel is usually available from within a short distance. Less important are the shapes produced; these have always been subject to change due to fashion, the opening of new commercial markets and the requirements of customers (Schütz 1996, 97). In the following excursus, modern manufacturing facilities that use firing systems similar to those identified at Hellenistic and Roman archaeological sites will be discussed (Fig. 8.2). Bearing the characteristics of handicraft work mentioned above in mind, these modern sites will be compared to ancient ones in order to understand better the techniques of firing and to examine the types of fuel used.

After recent land reclamation projects in the oasis of Fayoum,<sup>2</sup> a number of pottery and brick manufacturing plants came into existence. The abundance of raw materials from the surroundings of Lake Qaroun facilitated the building of numerous workshops. In particular, there are two centres where this kind of production is more developed, the first being in the village of al-Nazla and the second in a nearby village called Tunis.

At al-Nazla, which is near Yousef al-Sedik, there is a spot known locally as 'the kingdom of pottery'. Local medium-quality production of an unusual type of common ware is currently being undertaken, with these pots being used in pigeon towers. The pigeon towers are built with bricks, wood and raw clay, and the ceramic vessels are inserted into the walls of the towers as nests. The kilns for this type of pottery have a long history: they are usually quite similar to those in the delta and they have been in use for several hundred years. Locals say that they have been learning and working their craft for many generations, going as far back as the Middle Ages. More local traditional forms are also being produced at al-Nazla (Figs. 8.3–8.5).<sup>3</sup> Fuels used in these types of kilns include every kind of combustible material: rubbish, remains of food, straw, animal dung, remains of woodworking, etc. Kilns used for firing the pottery reach a maximum temperature of around 700 °C; they are vertical and circular in shape and built with mud bricks and cobblestones and coated with clay. They are between 2 and 3 m high, the combustion chamber is cylindrical and the firing chamber is in the shape of a frustum. The firing floor has a diameter of about 2 m, and the firing chamber is accessible through a door, which is walled off during the firing phase. The upper part of the firing chamber is open; in an arid climate, it is not

necessary to cover the pottery during the firing phase. The efficacy of the firing process is relatively poor and pots produced in this way are weak. They are first left to dry in the sun for a few days and are then put in the firing chamber, which is above the ground, while the combustion chamber is underground.

Some 10 km away from al-Nazla there is another village that was able to improve its local economy and transform its quality of life in the space of 25 years – this is the village of Tunis, founded 30 years ago in the western border of Fayoum by a small group of farmers who settled there to look after farms created through new land reclamation projects. The arrival of a potter, who built the first modern kiln in order to produce Egyptian fine ware and started a pottery school, transformed the life of the whole village. Today, there are around 25 kilns in the village that produce high-quality ceramics that are sold in the Red Sea region, Cairo and abroad in Paris and Rome. The forms and the high quality of ceramics produced in Tunis are typical of the Hellenistic and Roman pottery in shape but with a glaze, similar to Coptic and Islamic medieval pottery (Fig. 8.6). This choice of forms is possibly related to the fact that the new potters gathered a considerable quantity of rims and bases from the nearby Hellenistic, Roman and medieval archaeological sites of Dionysias (Papi et al. 2010), Philoteris (Davoli 1997) and Euthemeria (Davoli 1997). In the new workshops, the craftsmen use the remains of ancient rims and bases to make the same forms from the past but as modern productions, which are also painted in a similar way to medieval examples. We thus have here a combination and imitation of different periods in a single production.



**Figure 8.6.** Pottery production from Tunis, Fayoum.

There are two types of kiln in use at Tunis: traditional and electrically operated (Fig. 8.7). The former is rapidly disappearing and has been replaced by the latter. Modern electric kilns (or even gas ones) may also use traditional fuel. The traditional kilns are generally small and can only produce around 40 to 60 pots at a time. Discussion with local workers has revealed that the main difficulty lies in controlling the heating. The use of small kilns and their firing methods appears to follow a traditional model that has been in use in Egypt since the Hellenistic period. The kilns are vertical with two small rooms, an underground combustion chamber and an above-ground firing chamber. The chambers are not connected together, but as in ancient times they are separated by a holed floor built with locally made red bricks. The fuel used in Tunis is different from that in al-Nazla village. In Tunis there is a greater emphasis on producing a type of fire that burns well and does not damage the product. In particular, they use halfa grass (*Desmostachya bipinnata*), a type of perennial plant that grows naturally all over Egypt. This grass has no



Figure 8.7. Tunis kiln in Fayoum.

economic usage and during the firing it is burnt in huge quantities. Nevertheless, this is not the only type of fuel: remains of rice plants, oil pressing, olive stones and sometimes, according to availability, remains of small trees are also used. These fuels leave very little ash and other debris in the combustion chamber, which makes the latter easier to clean after the firing process. However, using fuel that burns quickly makes it necessary to continuously feed the fire to ensure a constant heat. Given the type of fuel used, we can certainly confirm the continuity of usage of these natural materials as fuel from ancient Egypt until today in this region.

### Modern kilns in the Mediterranean

It is also worthwhile discussing comparisons with other craft production facilities still active or recently abandoned in the Mediterranean basin (Fig. 8.2). Agóst is a small town located in the hinterland of Alicante in Spain. A flourishing production of common and glazed ware has existed here from the second half of the 1700s, in the 'alfarerie' (which means both a workshop and shop for selling pottery). The pottery in Agóst is made with local clay, the so-called 'barro blanco' (the clay contains a high percentage of calcium oxide and calcium carbonate and a low percentage of iron, silica and alumina, which gives it a white colouring). The manufacturing techniques have gone through three evolutionary stages (Mondin & Rodríguez-Manzanque y Escribano 2010, 67). The first stage commenced with the beginning of production at the end of the eighteenth century and continued to the end of the nineteenth century. The organization was simple: the production facilities were built inside homes turned into workshops, and public kilns were used for the firing. The second stage dates back to the early twentieth century. This period witnessed an increase in demand for the pottery produced; the consequence was the expansion of existing workshops and the creation of new laboratories. Workers became independent in the firing process too. The third phase, which started in the 1980s, continues up to today. A fall in production has resulted in a reduction in the number of workshops. Even today in Agóst, traditional 'wood' kilns are named 'horno árabe' and used for firing common ware (Schültz 2006, 77–9). These kilns are vertical, with a rectangular design, a single combustion chamber and two or three firing chambers, one above the other. The fuel used varies: the craftsmen do not mention preferred tree varieties but use all types of fuel that can be procured at zero or very low cost. For firing, they use tree bark and waste material from other manufacturers, such as wooden crates, pallets, brushwood, wood shavings,



etc. Solid wood is less commonly used because it is more expensive and has a slower combustion rate than chopped-up wood. The fuel must be dried before being used and consequently requires a large storage area. In the Ágost production sites, there are two places for storing fuel: the first is outdoors, in the backyard next to the road and the kilns, while the second is a covered room immediately in front of the combustion chamber. The first area has easy access for transportation vehicles, such as wagons in the past and trucks today, and is used to dry the wood in the sun. The second storeroom is conveniently situated close to the combustion chamber and is used in the last stage of the fuel's drying process, before the lighting of the fire. In the case of the 'horno árabe' kiln, with two or three firing chambers, the high flame stage is about 96 hours according to Schültz (2006, 124–9). Stokers continuously add fuel and constantly monitor both the fire in the combustion chamber and the temperature of the vessels being fired. The firing is controlled through openings in the roof of the final firing chamber. The craftsmen wait about a week after stopping the fire before opening the doors to extract the vessels.

In Oliva, Spain, near Denia and the Almadrava Roman production site (Gisbert Santonja 1995), a traditional brick works was still active in 2009. A particular type of 'Roman' tile and brick was manufactured here for the restoration of some Pompeiian houses. In this case, we cannot call this 'craft' production since much of the process has been mechanized. However, we can observe some aspects that are still influenced by ancient craft methods. These include the use of wooden moulds, the laying down of the bricks on the ground for drying, and also the use of natural fuel for firing. The vertical kiln has a rectangular combustion chamber, and the holed floor is supported by arches that form a barrel vault. The fuel normally used is natural gas, but natural fuel is added during firing for bricks used in the restoration of ancient buildings. In this case, the natural fuel is the residue of agricultural production, in particular almond shells. The almond shells are added directly inside the firing chamber, through the smoke and steam output chimneys. The addition of solid fuel, the material that was traditionally employed in this kind of production, in the firing phase serves to create smoke and flames that give a more natural colour to the bricks.

In Impruneta, near Florence in Italy, the production of bricks and large pottery vessels, such as *pithoi* and *conche*, began as early as the Middle Ages. The kilns that are still used today are vertical, with the same characteristics as those described by Piccolpasso. The firing starts with the heating phase,

which lasts a day and a night. In this initial phase, the fire is lit and fed with bundles of dry branches, leaves and wood chips. When the fire is started, the stoker will insert bundles and logs continuously as part of the second phase. In the next phase, the fire is fed with dried wood for two to three days to maintain the temperature. The last stage involves firing on an open flame. The fire is revived with bundles of wood in order to heat it one last time before cooling. The cooling phase lasts two or three days. (Casprini Gentile & Hamad 2008, 72–6).

In Racalmuto, near Agrigento in Sicily, the Martorelli family has been producing bricks and above all tiles, named 'canali' since the beginning of the eighteenth century, and continue to do so today. Indeed, the business of the Martorelli brothers, named 'I vecchi', continued to produce tiles until 2005. Now their nephew Calogero Martorelli and his son have begun a new brick production enterprise, Il Canale. Until the closure of the traditional manufacturing workshop, the brothers Martorelli continued to prepare the clay with bare feet, sun-drying the bricks in the courtyard and baking them in a vertical kiln mainly fuelled by olive residues. The production process remained unchanged until a few years ago, and the workshop has remained in its original location near the public fountain. The Il Canale company has mechanized the phase of clay preparation, but the firing process and the kiln are unchanged. The Martorelli family kilns are entirely buried. The combustion chamber has a circular design (2.20 m high). The holed floor (with a diameter over 3.50 m) is supported by arches that form a dome. The firing chamber is 3.30 m high and ends inside a building with a roof 2 to 3 m high. During the firing process, the bricks inside the kiln are covered with the waste from the previous firing session. The main fuel used consists of olive production residues. Other kinds of residues from agricultural production, such as the leftover product from pruning olive trees, are also used. For the large brick kilns, the firing phase usually lasts between 18 and 24 hours (the fluctuation of hours depends on the type of material being fired: the thin and irregular tiles bake more quickly, while thick and compact bricks need more time). Furthermore, for large kilns such as these, the cooling phase is much longer. In Racalmuto, workers start to empty the furnace from above only three or four days after the fire has been extinguished, but it can take up to 10 days to get to the holed floor. At Il Canale, for a mixed batch of bricks and tiles with this type of kiln, about 40 quintals (1 quintal = 100 kg) of olive residues are required. The olive residues must be dried before being used, so that they contain the least possible amount of moisture; this is so that they

produce heat very quickly and release as little water vapour as possible. For this reason, before being used, olive residues are crammed under canopies that are ventilated, but protected from the rain.

The craftsman Tahtir Ergüleç in Çömlekci (South Cappadocia, Turkey) is dedicated to the production of pottery. He has a small workshop where he works alone. The workshop is embedded within a domestic context and Tahtir has adapted the space accordingly. His pottery production is a family tradition that has been passed down through at least four generations of craftsmen, with the profession being handed down from father to son. In this context, the same craftsman manages the kiln. The kiln is completely underground, and has a circular base with a diameter of 1.5 m. The combustion chamber is 1 m high and uses natural fuel, while the firing chamber is in the shape of a frustum and is 2 m high. The pots positioned in the highest part of the firing chamber are protected by waste fragments from the previous batch. The craftsman's sons are not directly involved in the pottery production but are shepherds. This enables them to provide the fuel for the kiln: sheep and goat dung mixed with straw. The arid climate of the region allows the fuel to dry quickly in the sun and it is then collected outdoors in front of the combustion chamber. Because of the small size of the kiln, the combustion phase is short; it takes about an hour and a half. At the end of the firing stage, the vessels placed on the high part of the

firing chamber may already be taken out, one hour after the fire is extinguished. More time, however, is required to empty the lower part of the firing chamber.

Modern examples of brick and pottery production that use natural fuels for heating offer some interesting hints about the fuel used in the ancient craft productions mentioned above. In particular, they provide us with useful data regarding the relative calorific values of different tree species, that is the amount of thermal energy developed by the combustion of 1 kg of fuel, under specific conditions (see also Veal, this volume, for a detailed discussion). The values in Table 8.1 also include the energy produced through the condensation of water vapour. The data were derived from a number of studies commissioned by the Italian government in relation to the study of biomass, including: 'Biomasse ed energia' 2011, one output of the Biomasse Enama project (funded by Mipaaf, and coordinated by the Commissione tecnica biomasse Enama; and Vademecum delle Fonti Rinnovabili); and 'Energia da biomassa', an education campaign covering renewable energy, and energy savings and the efficiencies (sponsored by the Ministry of Economy and the Ministry of Environment and Land Protection.)

In the context of firing with natural fuel, the presence of residual ash is also significant. Craftsmen who light and supervise natural fuel kilns prefer to use tree species and dried raw material that produce little

**Table 8.1.** Calorific value of various natural fuels (because this value also takes into account the dampness content in the fuel, the data must be considered indicative).

Fuel	Lower calorific value (MJ/kg)	Ash
Straw (wheat, barley, oats, rye)	17 – 19.5	2 – 10%
Vine branches	13.5 – 18.5	2 – 5%
Olive tree	16.5 – 18.5	5 – 7% (branch); 1.5 – 2% (wood)
Fruit tree branches	18 – 18.5	10 – 12%
Wood (humidity 0%)	18	E.g.: Silver fir 2.2%; pine 0.10%; ash tree 0.30%; oak 0.15%
Wood (humidity 50%)	9	Varies, depending on tree species, tree age, trunk thickness, etc.
Sawdust and wood shaving (humidity 15–20%)	11.5 – 14	0.3 – 5%
Bark (humidity 15–20%)	19	3.8%
Common reed ( <i>Arundo donax</i> )	15.5 – 16.5	4 – 5%
Cardoon ( <i>Cynara cardunculus</i> )	15 – 16	5 – 10%
Almond shells	17.5 – 18	5.5%
Hazelnut shells	19.5	1%
Peach stones	16.5 – 17.5	0.5%
Olive stones (humidity less than 6%)	20 – 21	1%
Olive stones (humidity more than 10%)	17	≤ 4%
Olive residues	15.5 – 18	2 – 12.5%
Pellets (fir, beech)	18.5 – 20	0.4 – 0.5%

ash. This is due to the fact that during firing, excess ash can stifle the flame and reduce the oxygen levels, which, of course, are fundamental for combustion. Indeed, the drier the fuel, the faster the combustion and consequently the higher the temperature reached. This leads to the production of a smaller amount of residual ash. Using fuels that produce little ash also reduces the time and resources spent cleaning the kiln (see also Cuomo di Caprio 1979, 236–7).

Among the different types of natural fuels taken into account, olive stones are the fuel with the most favourable calorific value and amount of remnant ash in the combustion chamber at the end of the firing. Olive stones are the preferred natural fuel even today. Charcoal and peat are unsuitable for firing because they usually each produce a relatively small flame. Peat has a medium to low calorific value, and a strong flame is crucial for reaching the high temperatures necessary for firing pottery. Even solid wood (in this location) is considered an unsuitable fuel as it is expensive and generally burns slowly. Instead it tends to be used in the construction of buildings (Emiliani & Corbara 1999, 358).

## Discussion

With regards to the Hellenistic and Roman archaeological sites in Egypt and elsewhere, there is little information about the fuels used in kilns for the production of pottery and bricks. There are very few sites where fuel residues have been found within kilns, or where traces of fuel in depots have been analysed. However, where this has been carried out, it has been shown that several tree types were used: pine, fir, oak, poplar, birch, holm-oak, olive, etc. In addition to these tree types it is also reported that straw, reeds, fruit shells, olive stones, pine cones and animal dung were used (for example: Swan 1984, 6–7; Le Ny 1988, 28; Marty 2003, 280; Carre et al. 2005, 106; Carre et al. 2006, 267; *La Graufesenque I* 2007, 28; Manacorda & Pallecchi 2012, 99–101). In Egypt, the sites mentioned above mainly produced amphorae destined especially for the wine trade. Agricultural production at the time flourished and much of its by-products served as cheap fuel for the kilns. The most commonly used fuels were vine branches, olive and fruit branches, straw, as well as the scrub that characterizes the Mediterranean maquis.

We can infer from Renaissance sources, modern ethnographies, and from archaeological studies, those tree types that were of secondary importance in the production of kiln fuels. Sources and ethnographic studies also suggest that any material that burned quickly and produced a lot of heat in small

quantities was the preferred fuel. Such fuel was cheap and readily available as it came from the recycling of agricultural and livestock by-products. While the speed of burning forced workers to tend to the fire constantly, this has been, until recently, the preferred fuel of craftsmen.

Finally, we also have very little information regarding the quantity of fuel used for firing. As mentioned above, at the modern Racalmuto production site in Sicily an estimated 40 quintals (4000 kg) is the amount of fuel needed to fire bricks in a large kiln. In a document from AD 1542, we learn that 300 bundles were used for firing pottery, but in that case, the size of the kiln was not specified. In present-day Italy, a faggot of 30–40 cm in diameter, made up of branches and pruning debris and tied together, weighs from 8 to 10 kg; 300 bundles could therefore correspond to about 24–30 quintals of fuel. Modern studies have compared the different types of fuel: under the same calorific value conditions 32 quintals of wood or derivatives (bundles) were equivalent to 20 quintals of olive stones, and 23 quintals of shells of almonds, hazelnuts, pine nuts, and stones of peaches, plums, apricots or cherries. So, the 40 quintals used to fire bricks in the kiln of Racalmuto would correspond to about 64 quintals of wood or derivatives, and are thus equal to 640–800 bundles.

It is therefore reasonable to assume that the furnace described in AD 1500 was smaller than that in Racalmuto, since we must take into account that the kiln in Rome produced pottery. As is noted even in Renaissance sources (Biringuccio 1540, 146), pottery firing is faster than that of bricks, because there is more space in the firing chamber for the passage of hot air between the materials being fired. Another factor is the difference in thickness between pottery and bricks (with pottery being thinner). However, these considerations are only suggestions that highlight the large quantity and variety of natural fuel that could have been available to manufacturers of ceramics and bricks, especially in large production workshops manufacturing amphorae destined for trade.

## Acknowledgements

We would like to thank Rawyia Abdel Qadir, Hakim, and Evelin Burre from Tunis village in Fayoum, Egypt; Aude Simoney for providing information regarding the kilns of Buto; the Director of the Alfareria Museum in Ágost, José María Rodríguez y Escribano Manzaneque, and the Director of the Archaeological Museum of Denia, Josep A. Gisbert Santona; the craftsmen Severino Boix Arques, Roque Martínez, Miguel Mollá Mirá, Juan Pedro Mollá Gomis and Tomás Román Beneyto from



Ágost, Tahtir Ergüleç from Çömlekci and Raqyia abdel Qadri. Finally, we would like to thank Sarah Norodom from Oxford University for revising a draft of this paper.

## Notes

- 1 In 2012 excavation of one of the major amphora kilns in the Mareotic district commenced (Empereur 2012).
- 2 Land reclamation projects in Fayoum have three different phases. The first was conducted during the Middle Kingdom to create new spaces for cultivation. The second and the most major land reclamation was conducted in the Ptolemaic period when the large space of Lake Qaroun dried up and hundreds of settlements were founded. The third phase was started by the British occupation of Egypt in 1881 and is still in progress today to reclaim the lands and fields which were covered by sand desert in the last centuries. The extent of cultivated land in Fayoum remains less than that of the Ptolemaic period.
- 3 <http://nazlapottery.wordpress.com/about/decoration-based-product/>

## References

- Biringuccio, V., 1540. *De la pirotechnia*, ed. A. Caguro, 1977. Milan.
- Carre, M.B., V. Kovačić, A. Marchiori, G. Rosada & F. Tassaux, 2005. Lorun-Loron (Poreč-Parenzo, Istria). Un complesso costiero di età romana nell'agro parentino: la campagna di ricerca 2004. *Histria Antiqua* 13, 99–118.
- Carre, M.B., V. Kovačić, A. Marchiori, G. Rosada & F. Tassaux, 2006. Lorun-Loron, Poreč-Parenzo, Istria. Una Villa Maritima nell'agro parentino: la campagna di ricerca 2005. *Histria Antiqua* 14, 261–81.
- Casprini Gentile, L. & L. Hamad, 2008. *La terracotta dell'Impruneta. Sapere antico e lavoro moderno*. Florence: Edifir.
- Charlesworth, D., 1972. Tell el-Fara'in Egypt: An Industrial Site in the Nile Delta. *Archaeological Institute of America* 25, 44–7.
- Cockle, H., 1981. Pottery Manufacture in Roman Egypt: A New Papyrus. *Journal of Roman Studies* 71, 87–97.
- Cortonesi, A., 1986. Fornaci e calcare a Roma e nel Lazio nel basso medioevo, in *Scritti in onore di Filippo Caraffa*. Anagni: ISALM, 277–307.
- Coulson, W.D.E. & N.C. Wilkie, 1986. Ptolemaic and Roman Kilns in the Western Nile Delta. *Bulletin of the American Schools of Oriental Research* 263, 61–75.
- Cuomo di Caprio, N. 1979. La cottura della ceramica: i combustibili, in *RCRF* 19/20, 236–9.
- Emiliani, G.P. & F. Corbara, 1999. *Tecnologia ceramica. La lavorazione. Volume II*. Faenza: Gruppo Editoriale Faenza Editrice.
- La Graufesenque I, 2007. *La Graufesenque (Millau, Aveyron) Condatomagos une agglomération de confluent en territoire Rutène II<sup>e</sup> s. a.C. – III<sup>e</sup> s. p.C.*, ed. D. Schaad, vol. I. Cantabria: Santander.
- Empereur, J.Y., 2012. *Été 2012. Akademia: la fouille de l'atelier d'amphores d'Apollônios*. <http://www.amphoralex.org/fouilles/akademia.php>.
- Empereur, J.Y. & M. Picon, 1998. Les ateliers d'amphores du lac Mariout, in *Commerce et artisanat dans l'Alexandrie Hellénistique et Romaine*, BCH suppl. 32, 75–91.
- Gisbert i Santonja, J.A., 1995. L'Almadra, o la presentació al gran públic d'un conjunt arqueològic, in *Espai obert. Revista d'assaig i investigació (Comarques Centrals Valencianes)* 2, 105–16. Corredor/20.
- Güll, P., 2003. *L'industrie du quotidien. Production, importations et consommation de la céramique à Rome entre XIV<sup>e</sup> siècle*. Rome: École française de Rome.
- Hartung, U. & P. Ballet et al., 2009. Tell el-Fara'in – Buto. 10. Vorbericht, in *Mitteilungen Des Deutschenarchäologischen Institutsabteilung Kairo*. Walter de Gruyter GmbH & Co. KG, Berlin/New York, 83–190.
- Kenawi, M., 2014. *Alexandria's Hinterland: Archaeology of the Western Nile Delta*. Oxford: Archaeopress.
- Le Ny, F., 1988. *Les fours de tuiliers gallo-romains. Méthodologie. Etude technologique, typologique et statistique. Chronologie*. Documents d'archéologie Française 12. Paris: Maison des sciences de l'homme.
- Manacorda, D. & S. Palleschi (eds.), 2012. *Le fornaci romane di Giancola (Brindisi)*. Bari: Edipublia.
- Marty, F., 2003. L'atelier de potier gallo-romain de Sivier (Istres, Bouches-du-Rhône). *Revue Archéologique de Narbonnaise* 36, 259–82.
- Mondin, C. & M.J. Rodríguez-Manzanque y Escribano, 2010. La ceramica artigianale di Agost (Spagna); alcune considerazioni strutturali sugli impianti produttivi. *Atti XLII Convegno Internazionale della Ceramica Fornaci. Tecnologie e produzione della ceramica in età medievale e moderna*. Savona, 67–76.
- Pesante, L., 2010. Il ciclo di produzione della ceramica nel Lazio settentrionale in età moderna. Documenti vecchi e nuovi. *Atti XLII Convegno Internazionale della Ceramica Fornaci. Tecnologie e produzione della ceramica in età medievale e moderna*. Savona, 209–218.
- Piccolpasso, C. & G. Conti (eds.), 1976. *Li tre libri dell'arte del vasaio*. Florence: All'insegna del Giglio.
- Rieger, A.-K. & H. Möller, 2011. Kilns, Commodities and Consumers: Greco-Roman Pottery Production in Eastern Marmarica (Northwestern Egypt). *Archäologischer Anzeiger* 2011(1), 141–70.
- Rossetti, I., 2011. Lo scavo del settore E e del settore F del complesso Produttivo (BSE 352), in *Bakchias 2009–2010. Rapporto preliminare della XVIII e XIX campagna di scavi*, eds. P. Buzi & E. Giorgi. Imola, 239–62.
- Schütz, I., 2006. *Agost/Alicante, ein Töpferzentrum in Europa, Bamberger Beiträge zur Europäischen Ethnologie*, 8, Bamberg.
- Swan, V., 1984. *The Pottery Kilns of Roman Britain*. London: Royal Commission on Historical Monuments.
- Tocci, M., 2011. Il complesso produttivo (BSE 352): Lo scavo dell'area occidentale, in *Bakchias 2009–2010. Rapporto preliminare della XVIII e XIX campagna di scavi*, eds. P. Buzi & E. Giorgi, Imola, 263–76.

*Part III*

**Alternative fuels to wood:  
olive pressings and oil**





---

## Chapter 9

# Commercialization of the night at Pompeii

David G. Griffiths

The ancient economy is a subject with a long history of lively debate for scholars of the Classical World. The dynamic nature of the ancient city provided opportunities for large numbers and a wide variety of financial transactions, acting as *foci* for local, regional and long-distance trade and exchange of goods and services. These factors have long been known and scholars have made great strides in advancing our understanding of the complexities of the ancient economy, however, the concept of a ‘nocturnal economy’ has not previously been considered. While the majority of economic activity takes place during daylight hours, especially in pre-industrial societies, the presence of large quantities of lighting devices at most Roman urban centres in the Mediterranean (e.g. the Athenian Agora (Howland 1958; Perlzweig 1961), Carthage (Deneauve 1969), Corinth (Slane 1990), Delos (Bruneau 1965), and especially at Pompeii (Pavolini, 1977; Conticello de’ Spagnolis 1988, 25; Allison 2004, 6)) suggests extensive levels of after-dark activities.

### Pompeii: a case study

The domestic consumption of artificial light at Pompeii seems to have been on a relatively large scale at the time of the eruption in AD 79 (Griffiths 2018). The presence of lighting devices in many commercial premises suggests that a nocturnal economy was a feature of urban living in this ancient city. Domestic and commercial nocturnal activities were facilitated by the provision of artificial light from lighting devices including oil lamps, lanterns, torches and fire baskets. While the devices themselves played an essential role in the provision of artificial light, perhaps the most important component was an affordable and reliable source of light fuel. The main fuel for lighting during the Roman period was olive oil, but other vegetable oils were also used, such as castor and rapeseed, along

with animal fats (Neuberger 1930, 242; Forbes 1958, 120; Kimpe et al. 2001, 87–95; Eckardt 2011, 182–3).

The catastrophic destruction of Pompeii and Herculaneum in AD 79 by the eruption of Mount Vesuvius provides scholars with a rich source of archaeological and epigraphic evidence that has significantly enhanced our understanding of Roman urban living in southern Italy in the first century AD. The unparalleled number of well-preserved structures, some with their decorations and contents *in situ*, provides significant potential for the study of countless aspects of daily life, and evidence from the famous site of Pompeii forms the basis of this paper. The more recent sub-floor surface excavations have recovered invaluable evidence for the growth and development of the city from its earliest origins (e.g. the Anglo-American Project in Pompeii (AAPP), the Via Consolare Project, and the Pompeii Archaeological Project: Porta Stabia).

This paper will utilize archaeological evidence from both the AD 79 eruption levels and the sub-floor surface stratigraphic deposits at Pompeii to consider the primary issues for a nocturnal economy, and will address commercial ramifications for the consumption of artificial light:

- The domestic consumption of artificial light;
- The nocturnal economy – e.g. after-dark commercial activities;
- The production of lighting equipment;
- The agrarian economy – the production and supply of olive oil for light fuel.

The first two issues relate to the consumption of artificial light in domestic and commercial settings, specifically: why Pompeians required lamplight; what they actually did once the sun had set; and whether there were financial benefits to trading after dark. The third and fourth issues focus on the practical aspects

of provisioning artificial light: the manufacture of lighting devices and associated equipment; and olive cultivation and transportation of oil for light fuel.

#### *The domestic consumption of artificial light*

While substantial quantities of artefacts have been recovered from volcanic deposits (where archaeological excavations were taken down to the floor surfaces at the time of the AD 79 eruption), few were recorded with accuracy, and only a small number have been published. Many artefacts were recovered from houses, most of which contained numerous lighting devices (lamps and lanterns) and related apparatus (e.g. hanging chains and lampstands) (Allison 2004; 2006). The abundant evidence for the domestic consumption of artificial light suggests that the night was certainly not a time of inactivity in Pompeian households (Griffiths 2014; 2016; 2018).

There are a number of issues to consider when using AD 79 artefact assemblages from Pompeii: for example, the removal of items (especially, one may assume, lamps and lanterns) by people fleeing the city during the eruption, and the lack of accurate excavation, recording and publication strategies for areas excavated between the seventeenth and early twentieth centuries (Allison 2007, 271). Despite these caveats, the material remains do have significant potential to address aspects of social, cultural and economic life in the city. Allison's seminal studies of artefact assemblages from Pompeian houses were the first to systematically analyse the material based on functional characteristics within their use contexts. Of the 30 Pompeian households in Allison's (2004) study, lighting equipment from 10 properties (Table 9.1) suggests that the regular and extensive consumption of artificial light in domestic settings was common (see also Griffiths 2018). In total, 242 lighting devices

were recovered, many found and recorded in their original locations (at least at a room level); if we also consider Eckardt's (2002) analysis of the known lighting devices from Roman Britain, some 2000 objects, then the importance of the Vesuvian sites in the study of nocturnal activities in the Roman world is significant.

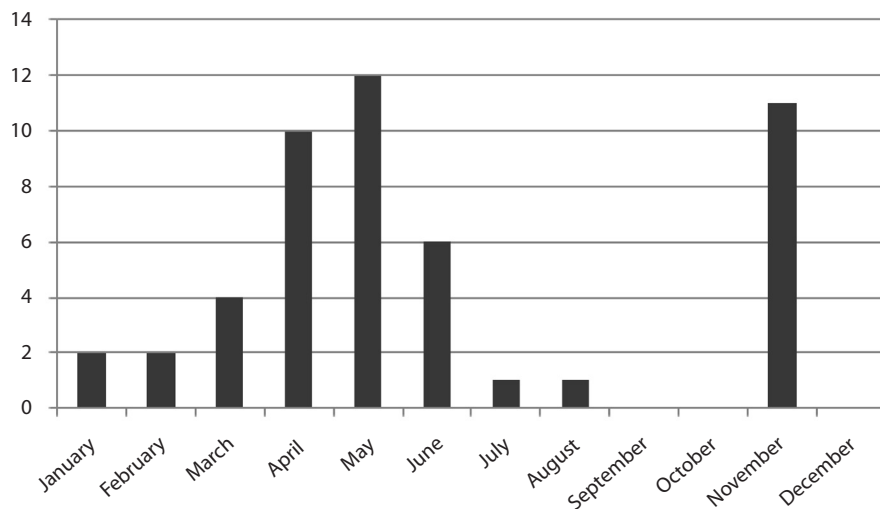
#### *The nocturnal economy*

Space prevents a full discussion of all the complexities of the Roman economy; however, one may consider factors which may have influenced nocturnal commercial activity. For Pompeii, in addition to the abundant permanent commercial enterprises providing goods and services to the inhabitants of the city, temporary and seasonal factors also played a part in driving commercial activity: market days, festivals, entertainment and seasonal agricultural activities attracted visitors and temporarily increased the population, probably for many days at a time. By the first century AD, Pompeii had witnessed dramatic changes in the urban economic landscape, with many commercial structures converted from small-scale industry and production to retail (e.g. Jones & Robinson 2007, 389–406).

Numerous lighting devices have been found *in situ* in many commercial properties at Pompeii (e.g. Spano 1919, 22–3; Allison 2006, 154, 249; Eckardt pers. comm.), suggesting that the use of artificial light helped facilitate trade and exchange once the sun had set. One of the defining features of Imperial Roman urbanism was the quantity and variety of permanent commercial structures for the production and retail of goods and services. These permanent structures were a significant change from the majority of past Greek and Early Roman commerce, which primarily took place in the Agora and the Forum. This shift changed the urban landscape and the way that social interactions and commercial transactions were practiced, and

**Table 9.1.** *Lighting equipment from ten Pompeian households.*

Property	Location	No. of lighting devices	Ceramic %	Metal %	Potential no. of flames
Casa della Ara Massima	VI 16, 15	30	90	10	31
House I 10, 8	I 10, 8	10	100	0	12
Casa del Principe di Napoli	VI 15, 8	6	50	50	6
Casa dei Ceii	I 6, 15	14	86	14	14
Casa del Fabbro	I 10, 7	17	71	29	19
Casa degli Amanti	I 10, 11	10	90	10	10
Casa dell'Efebo	I 7, 10–12	35	100	0	57
House VIII 5, 9	VIII 5, 9	41	100	0	41
Casa di Julius Polybius	IX 13, 1–3	31	90	10	31
Casa del Menandro	I 10, 4	48	92	8	50
<b>Total</b>		<b>242</b>			<b>271</b>



**Figure 9.1.** Number of game days at Pompeii (after Cooley & Cooley 2004).

their location (DeLaine 2005, 29); however, the use of *fora* and other open spaces for commerce continued throughout the Roman period.

#### *Markets, games, festivals and theatre*

Markets, games, festivals and other entertainments were held on a regular basis at Pompeii, with epigraphic evidence suggesting that markets were held weekly, with stallholders moving between towns on set days (Cooley & Cooley 2004, 159–60). There was a wide range of entertainment options available to the inhabitants of, and visitors to, Pompeii, including gladiatorial shows and games, theatres, and those of a more personal nature, such as bathing and a visit to a brothel (Cooley & Cooley 2004, 44–82; Parslow 2007, 212–23). Games and religious festivals played an important role in the socio-economic lives of the inhabitants of Pompeii, with significant investment made in providing permanent structures for these to take place (Coarelli 2002, 74–109; Parslow 2007, 212–23; Small 2007, 184–211).

The amphitheatre had a seating capacity of around 24,000 (Cooley & Cooley 2004, 46), more than adequate to accommodate all of the inhabitants of Pompeii and visitors from other towns and the surrounding countryside (Parslow 2007, 215). The two theatres could accommodate 3000 and 1000 people respectively. Epigraphic evidence suggests that games alone took place throughout the year on at least 49 days (Fig. 9.1), with April, May and November having at least 10, 12 and 11 respectively (Cooley & Cooley 2004, 41, Fig. 4.1).

While most regular events such as markets and games would have taken place during the day, the population of Pompeii would have temporarily increased on a regular basis with many visitors probably staying for a number of days. The increased commercial

opportunities during these times must have been significant, with inns, taverns and bathing establishments bustling with customers, and with much activity taking place after the sun had set.

#### *Hospitality, shops and workshops*

##### *Taverns and inns*

Visitors to Pompeii were serviced with a range of accommodation options, some offering food and drink, and shelter for their animals, for overnight or longer stays (DeFelice 2007, 474–86). DeFelice (2007, 483) identified c. 145 hospitality structures at Pompeii, and a possible further 47. We know from epigraphic, historical and archaeological evidence that taverns in the Roman world were popular places at night. A graffito by a group of late-night drinkers at a tavern in Pompeii, the *seribibi universi*, notes their support for a political candidate (CIL IV, 581). One may safely assume that inns would have certainly been used at night, given their role in providing overnight accommodation, with many serving food and drink.

##### *Retail and industry*

In addition to the many hospitality premises at Pompeii, shops and workshops also formed a major part of the urban landscape. While these premises were primarily commercial, many also functioned as residences for staff and/or slaves and their families (Pirson 2007, 468). Many of these structures had mezzanines and upper floors that were used for storage and as living quarters. The shop fronts and doorways were often fully closed when the premises were shut for business, and during these times access to natural light and ventilation would have been only through small windows above the doorway. The separation of work

and living space at ancient Pompeii was often fluid, and commercial premises provided approximately 40 per cent of the housing units in the city (Pirson 2007, 468). As the urban centre of Pompeii became more densely populated, with the construction of all types of structures intensifying throughout its history, living units generally became smaller (Pirson 2007, 469). By the first century AD, many domestic dwellings began to incorporate commercial activity, sometimes within the house itself, but often converting rooms that fronted onto the street into shops and workshops (e.g. Casa del Chirurgo, Insula VI. 1, Jones & Robinson 2007, 401).

The evidence for the positioning of lamps and lanterns upon shop and bar counters near to the street, and also hanging outside structures at Pompeii, indicates that some commercial premises were trading after the sun had set (e.g. Spano 1919, 21–3; Allison 2006, 154 and 249; Eckardt pers. comm.). McGinn (2002, 10–11) notes literary sources commenting that brothels were identified by lamps hanging outside their doors, and that they probably used more lamps than other structures, even during the day. Spano (1919, 21–3) calculated that the 95 commercial premises (shops/workshops/bars) along two stretches of road (between the Porta Marina and the Forum, and from the Forum part-way along the Via dell'Abbondanza), would have had a minimum of three lighting devices each, and suggested a potential minimum of 285 lamp flames. While it is difficult when using early excavation records to identify exactly which objects came from which structure, how many there were, and their position, one may conclude that many inns and bars had sufficient lighting equipment to illuminate not only the internal space, but also to showcase goods for sale during the dark hours.

#### Public baths

The Roman bathing experience was considered as essential component of civilized life (Koloski-Ostrow 2007, 224). At Pompeii there were at least four sets of public baths which were paid for, maintained and run by the city's officials: the Forum Baths, the Stabian Baths, the Central Baths and the Suburban Baths (Koloski-Ostrow 2007, 224–56). In addition, there were at least three other privately owned public bath suites: the Palaestra/Sarno Baths, the Praedia of Julia Felix and the Republican Baths (Koloski-Ostrow 2007, 224). Bathing establishments were a ubiquitous part of urban centres and were one of the defining features of Roman civilized living. While individual establishments may have differed in architectural design, the general format was broadly similar: a sequence of rooms that included a vestibule, *frigidarium*, *apodyterium*, *tepidarium* and *caldarium*, often surrounding a *palaestra* (Koloski-Ostrow 2007, 228).

The design of bath houses was focused on keeping the various rooms required for the acts of bathing at the required and constant temperature (see also Miliaresis and Rook, this volume). The inconsistencies of natural light and its effects on temperature meant that it was generally restricted in most parts of the bath suite. This resulted in many areas being dark, even during the day, and therefore requiring consistent and controlled levels of artificial light.

In the *apodyterium* and *tepidarium* of the Forum Baths, there was evidence for glass window panels set in bronze frames, which could pivot to open and close to regulate temperature. There was also a light-well in the south wall of the *apodyterium* (Fig. 9.2), below which was a niche for a lamp, which still appears blackened by soot from the flame (Mau 1899, 163). A vaulted *caldarium* was entered through Corridor 'e'; this small room had windows in the *scala* to the south, and also a niche for a lamp. At the southern end of the *tepidarium* there was a large light-well, angled at approximately 45 degrees to direct sunlight into the main area of activity in this space. Directly below the light-well stands a large brazier (still visible today), the burning coals of which would have provided a subtle glow in addition to heating the room. This room was highly decorated and there were many individual niches set into all four walls, separated by architectural ceramics, in the form of Atlantes, to hold up the cornice above (Mau 1899, 199). These niches have often been described as 'lockers' for bathers' personal belongings, but Spano (1919, 154) notes that many were for the placing of lamps, with some having (now missing) sliding convex glass panes to protect the flame from the damp environment.

On entering the Forum Baths, and in order to move between the suites of rooms and the *palaestra*, one had to use the many long, narrow corridors, which had very little access to natural light, and must have been lit artificially (even during the day). Some 500 lamps were found in Corridor 'e' (Gell 1837, 94); while this large quantity would have been more than sufficient to illuminate this dark space, many were probably placed there for storage at the time of the eruption. In total, 1328 lamps were recovered from the Forum Baths (Gell 1837, 94), certainly more than was necessary to illuminate the whole building complex; they would have required significant quantities of olive oil for fuel.

Artificial light played an important role Roman bathing practices. A visit to the baths at Pompeii offered a wide range of activities to facilitate the demands of bathers. In addition to the physical practice of personal hygiene, there were opportunities for other activities, both for leisure and commerce, such as eating and drinking, engaging with prostitutes, social interaction





**Figure 9.2.** *The apodyterium at the Forum Baths.*

with friends and associates, and attending to business. Bathing establishments often supplied a range of activities and services directly to their customers, including libraries, restaurants, theatres and shaded walkways (Koloski-Ostrow 2007, 255).

In order for the continued operation of the baths, significant and continuous financial outlay was required for resources: wood, charcoal and olive pomace to fuel the furnace (Wilson 2012, 149–51); a constant and reliable water supply; staff for running the establishment; a large number of lighting devices; and vast quantities of olive oil for lamp fuel. At the time of the eruption at Pompeii there was evidence for 1328 lamps at the Forum Baths and over 1000 at the Stabian Baths. The presence of lighting equipment in large quantities suggests that the users of these bath suites consumed artificial light on a very large scale.

#### *The production of lighting equipment*

The production and trade of everyday objects have received much attention in studies of the Roman economy (Mac Mahon 2005). Roman lighting equipment was manufactured in a range of materials including ceramic, metal (bronze, iron and even gold), stone and sometimes glass; however, the majority of Roman

lighting equipment was manufactured in clay. There is evidence for the production of ceramic oil lamps at Pompeii, with the remains of two pottery workshops within the city walls (the first, at Insula I. 20. 3, where lamps and lamp moulds were found, and the second, at Insula II. 3. 9), and one small workshop just outside the Porta Ercolano (Cerulli Irelli 1977, 53–72; Peña & McCallum 2009, 57–79). The presence of large quantities of ceramic oil lamps from most excavations at Pompeii suggest that these were the predominant type of lighting equipment used in the city.

Table 9.2 presents the ceramic oil lamps recovered from excavations of stratigraphic levels from over 300 years of domestic occupation at Casa del Chirurgo, Insula VI. 1. A total of 56 (by estimate vessel equivalents or EVEs) ceramic oil lamps were found, and there was a clear change over time in their quantities.

Until the final quarter of the first century BC, we see the number of lamps was consistently low. Between c. 25 BC and c. AD 15/25 there was a dramatic increase in the number of lamps found in the Casa del Chirurgo archaeological deposits, suggesting a significant increase in the consumption of artificial light during this period. From c. AD 25 until AD 79 there was a gradual reduction in the amount of lighting

**Table 9.2.** *The ceramic oil lamps (by EVEs) from Casa del Chirurgo, Insula VI. 1.*

Phase	Chronology	Lamps
Pre-Surgeon	c. 300–150 BC	3
1	c. 150–100 BC	4
2	c. 100–25 BC	3
3	c. 25 BC–AD 15/25	22
4	c. AD 15/25–62	14
5	c. AD 62–79	10
<b>Total</b>		<b>56</b>

equipment. However, fewer lamps does not necessarily mean a decrease in the consumption of artificial light, as once a lamp had been manufactured it potentially had a long use-life; therefore, after the initial ‘surge’ in the number of lighting devices between c. 25 BC and AD 15/25, fewer new lamps would be needed, with existing lamps fuelled by a constant supply of olive oil.

High-status objects are considered here to be items such as elaborately formed or unusual ceramic oil lamps (e.g. with characteristics including multiple nozzles, large decorative shields, or of a size significantly larger than the ‘standard’ types – c. 50–100 mm in diameter); ceramic lamps with a lead glaze; and metal (generally bronze but sometimes iron) lamps and associated equipment (such as lampstands). While there is evidence from workshops in Pompeii where metal objects were produced (Pirson 2007, 466), there are no specific indications for the manufacture of metal lighting equipment. Objects recovered from a workshop outside the Porta Vesuvio in the nineteenth century included an under-life-size statue of an *ephebe* that had been adapted for use as a lampstand and that was undergoing repair (Pirson 2007, 467).

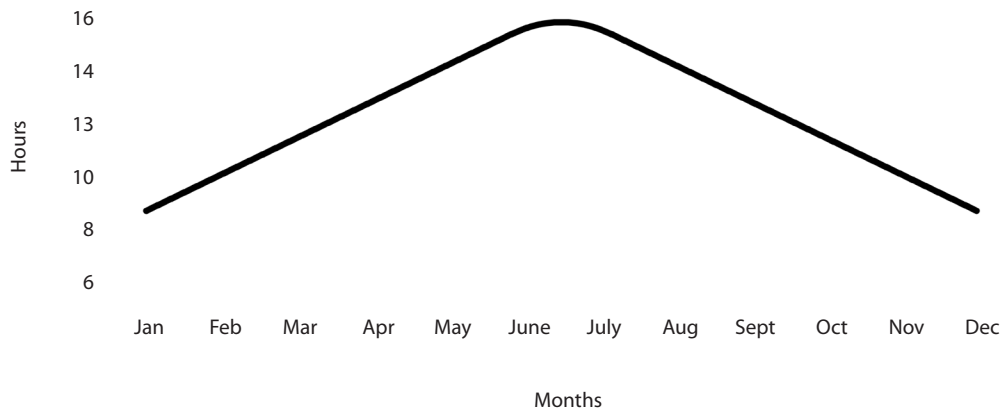
If we consider the domestic assemblages from 10 properties (Table 9.1), around nine per cent of the lighting equipment was manufactured in metal. The nature of the deposition of these assemblages, through the burial of the town with volcanic debris from the eruption of Vesuvius, was significantly different from that of the sub-floor surface assemblages at Insula VI. 1 (AAPP). Of the c. 560 diagnostic lamp fragments recovered from sub-surface-level excavations at seven properties in the insula, none may be considered elaborate, and there were no metal items associated with lighting (Griffiths 2016). The absence of metal lighting equipment is likely due to the extensive recycling of metal items during the Roman period, rather than these items not being used in the years prior to the eruption. Collection of damaged and broken metal objects for recycling was common in the ancient world; in addition, these items were significantly more

robust, and not as easily damaged, broken and discarded, and therefore do not enter the archaeological record in the same way as ceramic waste. These factors certainly contributed to the formation of artefact assemblages at Pompeii. I have already mentioned the removal of valuable personal objects as people fled the city, especially lighting devices to guide their way through the dark periods during the eruption. This factor has potentially had a significant impact on the quantity of high-status objects (especially metal) in the archaeological record.

### Quantifying consumption

It is widely accepted that agricultural production in the Roman Imperial period witnessed unparalleled expansion and growth, and was certainly a major component of the ancient economy (e.g. Bowman 2013; Marzano 2013). This growth coincides with the substantial growth of urban living in many areas of the Mediterranean. Centres often had populations of many thousands of individuals and, for example, at the height of the Roman Empire there were over 431 cities in Italy with populations of around 2–3000; empire-wide, there were around 2000 such cities (Jongman 2007, 501). The presence of large quantities of amphorae (many for olive oil) at almost all Roman Mediterranean urban centres, provides firm evidence for the consumption of olive-based products on a large scale. The cultivation of olives, and their trade, exchange, transportation and consumption (as fruits and oils), played an important role in many aspects of daily life in the Mediterranean, especially during the Roman period (Mattingly 1988a, 1988b). In addition to olive oil consumption for food, and light fuel, it was a key ingredient for personal hygiene products (such as perfumes and oils). Mattingly (1988a) notes that the consumption of olive oil (per capita) in the ancient world has been underestimated, especially in terms of its use as light fuel (1988b, 159). This is certainly an area of the ancient economy that requires further attention with more refined statistical models for quantifying consumption. While it is not possible to provide a model for the whole of ancient Pompeii’s light fuel consumption in this discussion, the data presented below highlight the potential for this type of quantitative approach.

An estimated burn-rate of c. 15 ml per hour (based on experimental research undertaken by the author; Griffiths 2016) forms the basis of the following model for fuel consumption in selected areas of Pompeii. A standard ‘burn event’, i.e. the time required before refuelling, is based on a ‘typical’ ceramic oil lamp (with one nozzle and a fuel capacity of 30 ml) consuming



**Figure 9.3.**  
*Length of daylight  
hours for Pompeii,  
Italy.*

fuel at a rate of 15 ml per hour. Therefore, one 'burn event' would last for two hours and consume 30 ml of olive oil.

For example: one 'typical' ceramic lamp 'burn event' would consume 15 ml of olive oil per hour, or 30 ml per event per day  $\times$  365 days = approx. 11 l per annum

This rate of 30 ml per lamp per day is highly speculative, as it is impossible to know for certain how much light was consumed every day, and how many lamps were lit at any one time, nor the number of times a lamp was refilled. Also, the number of daylight hours changes throughout the year, with longer days in the summer and shorter in the winter (Fig. 9.3).

Therefore, there would have been distinctly seasonal consumption patterns for artificial light. Even so, the figures presented in Table 9.3, while being simplistic and highly speculative, do provide crude estimates for the scale of the consumption of olive oil for lamp fuel in the city.

If one utilizes the evidence for known lighting devices presented in this paper – 285 lamp flames from 95 shops/workshops/bars (Spano 1919, 21–3), 242 (271 flames) from 10 Pompeiian houses (Allison 2004) and 1328 lamps (it is unknown how many had multiple nozzles) from the Forum Baths (Gell 1837, 94) – then we may begin to estimate the scale of lamp fuel consumption for a very small portion of Pompeii (Table 9.3).

The commercial structures had an average of three lamp flames, consuming an average of approximately 90 ml per day or 32.85 l per year. The 95 structures presented in Table 9.3 were only a small proportion of the total number of commercial properties at Pompeii, but they consumed 3139 l (or approximately 41.8 Dressel 20 amphorae) of olive oil per year as light fuel. The 10 households consumed approximately 2920 l per year (or 38.9 Dressel 20 amphorae). Even though the sample of houses is very small, one begins to gain an impression of the huge quantities of olive oil that would have been consumed in the illumination of domestic spaces at Pompeii. The 1328 lamps from the Forum Baths would have consumed approximately 14,527 l of oil annually (or 193.7 Dressel 20 amphorae). It is conceivable that light fuel consumption for the Forum Baths may have been significantly greater, with bath houses being generally dark spaces that would have required large quantities of artificial light even during the day, as articulated above.

While the data presented in Table 9.3 arises from a very small proportion of structures within the city, the quantities of olive oil for light fuel are significant. The entire city, with over 1600 structures, would have consumed vast quantities of olive oil for light fuel. If we consider that there were 431 large towns/cities (with populations of between 2000 and 3000 inhabitants), plus the metropolis of Rome, then the consumption of light fuel for Imperial Italy would have been enormous.

**Table 9.3.** *Estimated light fuel consumption for 95 commercial structures, ten households and the Forum Baths.*

Sample	No. of lamp flames	No. of litres per hour	No. of litres per day	No. of litres per year	No. of Dressel 20 amphorae (est.)
95 commercial structures	285	4.3	8.6	3139	41.8
10 households	271	4	8	2920	38.9
Forum Baths	1328	19.9	39.8	14527	193.7
<b>Total</b>	<b>1884</b>	<b>28.2</b>	<b>56.4</b>	<b>20586</b>	<b>274.4</b>

## Conclusions

As can be seen in Tables 9.1 and 9.3, by the time of the eruption of Vesuvius in AD 79, most houses in Pompeii were consuming artificial light on a significant scale. Domestic activity was not restricted once the sun had set, and the ability of ancient Pompeians to extend the day, and continue with social interactions, had a significant impact on their daily lives. A nocturnal economy developed at Pompeii with, presumably, affordable and reliable supplies of lighting equipment and fuel enabling commercial enterprises to extend the working day without the need for structural expansion. Artificial light enabled businesses to maximize trading hours on days when the population would have significantly increased, e.g. for festivals, games, markets, electoral events. It is not unreasonable to infer that on such days the buying and selling of goods and services was buoyant and continued into the night. Many visitors would have required overnight accommodation. Sustenance and entertainment in bars, restaurants and the public baths would have continued into the night; and at least some shops and workshops would have continued to trade beyond sunset.

The public baths at Pompeii were large consumers of artificial light. The main time of day for bathing was in the late afternoon and in to the evening, as Vitruvius (*de Arch.* 10. 11) suggests, and the presence of large quantities of lamps in both the Stabian and Forum Baths supports this. One may assume that the surrounding commercial premises would have been open and trading well into the night, to take advantage of the human traffic to and from the baths. If we consider that Pompeii had a minimum of nine bathing establishments in AD 79, with varying capacities for facilitating large numbers of bathers, then the opportunities for after dark commercial activities directly related to the business of cleanliness and hygiene would have been significant. Light, both natural and artificial, would have been tightly controlled in bath houses. At least one of the public baths had its origins in the second century BC (the Stabian Baths), with others built, repaired and upgraded up until the destruction of the city. Koloski-Ostrow (2007, 127) suggests that four establishments (Stabian, Forum, Central and Suburban) were publicly owned, and that the local government invested significant funds for their construction and operation. Presumably the fuel supply for these came from public funds, or from euergetism.

The evidence suggests that there was a significant increase in the production of ceramic oil lamps between c. 25 BC and c. AD 15/25 to satisfy the demand for the consumption of artificial light at Pompeii. Producing lighting equipment added to the repertoire of ceramic

goods produced by potters, and their manufacture utilized similar techniques and they were fired in the same kilns as other ceramic products. By the time of the eruption, around nine per cent of lighting devices in domestic settings were made from metal; substantially more expensive than ceramic products, these high-status objects would certainly have been an expression of wealth and status.

While it is very difficult to estimate what proportion of the olive oil supplied to Pompeii was used for light fuel, one may start to make crude estimates for the scale of consumption based on the number of lamps present in specific contexts. The data from Pompeii is ideally suited for this type of study, and the figures presented in Table 9.3 highlight the large quantities of light fuel consumed in a small proportion of domestic and commercial structures.

Some questions arise. In the case of olive oil, was the growth in the consumption of artificial light (through a general increase in wealth and prosperity) one of the driving factors for the extensive expansion and dramatic increase in the scale of production? Or, alternatively, could the increase in agricultural surpluses, especially following 'bumper' harvests, have driven olive oil prices down, making the burning of foodstuffs for light a regular and affordable experience? It is probable that both these hypotheses are correct, as market-orientated urban economies would have been fluid, with the scale of agricultural production dependent on a number of factors. Abundant and poor harvests (as well as demand) influenced commodity prices. The consumption of olive oil for light fuel had significant economic implications, both for agrarian and non-agrarian economic environments.

While all of the main issues of night-time activity and a Pompeian nocturnal economy outlined in this paper are significant, the most important aspect was the affordability of olive oil for fuel. The dramatic expansion of olive production during the Roman period greatly influenced many people's lives, from agricultural workers to the organizations and individuals involved in the processing and transportation of produce, and the many thousands of retailers in urban centres throughout the Mediterranean (Mattingly 1988). The consumption of artificial light had a significant impact on a personal scale, allowing individuals to extend their days and partake in more social, leisure and commercial activities. The commercialization of the night was only possible through the reliable and affordable supply of lighting equipment and, more importantly, olive oil for light fuel. Once established, the nocturnal economy, in addition to the social and cultural changes brought about by artificial light, played an important role in Roman urban living and the ancient economy.



## References

- AAPP Archive. Unpublished archive from the excavations at Insula VI. 1, Pompeii, conducted by the Anglo-American Project in Pompeii between 1994 and 2007.
- Allison, P.M., 2004. *Pompeian Households: An Analysis of the Material Culture*. Monograph 42. Los Angeles: The Cotsen Institute of Archaeology, University of California.
- Allison, P.M., 2006. *The Insula of the Menander at Pompeii. Volume III: The Finds, A Contextual Study*. Oxford: Clarendon Press.
- Allison, P.M., 2007. Domestic spaces and activities, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 269–78.
- Bailey, D.M., 1975. *A Catalogue of the Lamps in the British Museum: Vol. I. Greek, Hellenistic, and Early Roman Pottery Lamps*. London: British Museum Publications.
- Bailey, D.M., 1980. *A Catalogue of the Lamps in the British Museum: Vol. II. The Italian Lamps*. London: British Museum Publications.
- Bailey, D.M., 1988. *A Catalogue of the Lamps in the British Museum. Vol. III: Roman Provincial Lamps*. London: British Museum Publications.
- Bailey, D.M., 1996. *A Catalogue of the Lamps in the British Museum: Vol. IV, Lamps of Metal and Stone, and Lampstands*. London: British Museum Press.
- Bowman, A. & A. Wilson (eds.), 2009. *Quantifying the Roman Economy: Methods and Problems*. Oxford: Oxford University Press.
- Bowman, A. & A. Wilson (eds.), 2011. *Settlement, Urbanization, and Population*. Oxford: Oxford University Press.
- Bowman, A. & A. Wilson, 2013a. Introduction: Quantifying Roman Agriculture, in *The Roman Agricultural Economy. Organization, Investment and Production*, eds. A. Bowman & A. Wilson. Oxford: Oxford University Press, 1–33.
- Bowman, A. & A. Wilson (eds.), 2013b. *The Roman Agricultural Economy: Organization, Investment, and Production*. Oxford: Oxford University Press.
- Bruneau, P., 1965. *Les Lampes. Exploration Archeologique de Delos faite par l'ecole Francaise D'Athenes: Fascicule XXVI*. Paris: E. De Boccard.
- Cerulli Irelli, G., 1977. Una officina di lucerne fittili a Pompeii, in *L'instrumentum domesticum di Ercolano e Pompei nella prima eta imperiale, Quaderni di cultura materiale*, ed. A. Carandini. Rome: L'Erma di Bretschneider, 53–72.
- Coarelli, F., 2002. Pompei, in *Pompeii*, ed. F. Coarelli. New York: Riverside Book Company.
- Conticello De' Spagnolis, M. & E. De Carolis, 1988. *Le Lucerne Di Bronzo Di Ercolano E Pompeii*. Rome: L'Erma di Bretschneider.
- Cooley, A.E. & M.G.L. Cooley, 2004. *Pompeii: A Sourcebook*. London: Routledge.
- De Albentiis, E., 2002. Economics and Industry, in *Pompeii*, ed. F. Coarelli. New York: Riverside Book Company, 110–39.
- DeFelice, J., 2007. Inns and taverns, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 474–86.
- DeLaine, J., 2005. The commercial landscape of Ostia, in *Roman Working Lives and Urban Living*, ed. A. Mac Mahon & J. Price. Oxford: Oxbow Books, 29–47.
- Deneauve, J., 1969. *Lampes de Carthage*. Paris: Centre National de la Recherche Scientifique.
- Eckardt, H., 2002. *Illuminating Roman Britain*. Montagnac: Editions Monique Mergoil.
- Eckardt, H., 2011. Heating and Lighting, in *Artefacts in Roman Britain: their purpose and use*, ed. L. Allason-Jones. Cambridge: Cambridge University Press, 180–93.
- Finley, M., 1985. *The Ancient Economy*. London: Penguin.
- Forbes, R.J., 1958. *Studies in Ancient Technology*. Leiden: E. J. Brill.
- Gell, W., 1837. *Pompeiana: the topography, edifices and ornaments of Pompeii, the result of excavations since 1819*. London: L.A. Lewis.
- Griffiths, D.G., 2014. Licht ins Dunkle bringen: Künstliche Beleuchtung in Pompeji, in *Antike Welt* 1/2014. Germany: Philipp von Zabner, 10–40.
- Griffiths, D.G., 2016. The Social and Economic Impact of Artificial Light at Pompeii. Unpublished thesis, University of Leicester.
- Griffiths, D.G., 2018. Household Consumption of Artificial Light at Pompeii, in *The Oxford Handbook of Light in Archaeology*, eds. C. Papadopoulos & G. Earl. Oxford: Oxford University Press.
- Howland, R.H., 1958. *The Athenian Agora: Results of Excavations conducted by the American School of Classical Studies at Athens, Volume IV. Greek Lamps and their Survivals*. New Jersey: Princeton.
- Jones, R. & D. Robinson, 2007. Intensification, heterogeneity and power in the development of insula VI. I, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 389–406.
- Kimpe, K., P.A. Jacobs & M. Waelkens, 2001. Analysis of oil used in late Roman oil lamps with different mass spectrometric techniques revealed the presence of predominantly olive oil together with traces of animal fat. *Journal of Chromatography A* 937(1–2), 87–95.
- Koloski-Ostrow, A.O., 2007. The city baths of Pompeii and Herculaneum, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 224–56.
- Mac Mahon, A. & J. Price (eds.), 2005. *Roman Working Lives and Urban Living*. Oxford: Oxbow Books.
- Marzano, A., 2013. *Agricultural Production in the Hinterland of Rome: Wine and Olive Oil*. Oxford: Oxford University Press.
- Mattingly, D.J., 1988a. Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman empire. *Journal of Roman Archaeology* 1, 33–56.
- Mattingly, D.J., 1988b. Olea mediterranea? *Journal of Roman Archaeology* 1, 153–61.
- Mattingly, D.J. & J. Salmon (eds.), 2001. *Economies Beyond Agriculture in the Classical World*. London: Routledge.
- Mau, A., 1899. *Pompeii: its life and art*. New York: Macmillan and Co.
- McGinn, T.A.J., 2002. Pompeian brothels and social history, in *Pompeian Brothels, Pompeii's Ancient History, Mirrors and Mysteries, Art and Nature at Oplontis, and the Herculaneum 'Basilica'*, eds. T. McGinn, P. Carafa, N. de Grummond, B. Bergmann & T. Najbjerg. (Journal of Roman Archaeology Supplementary Series 47.) Portsmouth, RI, 7–46.

- Neuberger, A., 1930. *The Technical Arts and Sciences of the Ancients*. London: Methuen.
- Parslow, C., 2007. Entertainment in Pompeii, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 212–23.
- Pavolini, C., 1977. Le lucerne fittili del Museo Nazionale di Napoli, in *L'instrumentum domesticum di Ercolano e Pompei nella prima età imperiale, Quaderni di cultura materiale*, ed. A. Carandini. Rome: L'Erma di Bretschneider.
- Peña, J.T. & M. McCallum, 2009. The production and distribution of pottery at Pompeii: A review of the evidence; part 1, production. *American Journal of Archaeology* 113(1), 57–79.
- Perlzweig, J., 1961. *The Athenian Agora: Results of Excavations conducted by the American School of Classical Studies at Athens, Volume VII. Lamps of the Roman Period: First to Seventh Century After Christ*. New Jersey: Princeton.
- Pirson, F., 2007. Shops and industries, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 457–73.
- Slane, K.W., 1990. *Corinth: Results of Excavations Conducted by The American School of Classical Studies at Athens. Volume XVIII, Part II, The Sanctuary of Demeter and Kore: The Roman Pottery and Lamps*. New Jersey: Princeton.
- Small, A.M., 2007. Urban, suburban and rural religion in the Roman Period, in *The World of Pompeii*, eds. J.J. Dobbins & P.W. Foss. London and New York: Routledge, 184–211.
- Spano, G., 1919. *La Illuminazione Delle Vie Di Pompei*. Napoli: R. Università e della R. Accademia di Archeologia.
- Vitruvius, 1914. *The Ten Books on Architecture*. Cambridge: Harvard University Press.
- Wilson, A., 2012. Raw materials and energy, in *The Cambridge Companion to the Roman Economy*, ed. W. Scheidel. Cambridge: Cambridge University Press, 133–55.

---

## Chapter 10

# The utility of olive oil pressing waste as a fuel source in the Roman world

Erica Rowan

Olive oil, with its multitude of uses, was an enormously important product in the Roman world and consequently was produced in huge quantities. It functioned primarily as a foodstuff for consumption and cooking, and also as a fuel for lamps and a cleanser for the body. High in calories, fats and vitamins, olive oil was a crucial source of energy for the less wealthy members of Roman society (Rowan 2018a; USDA 2013). Yet the main by-product of olive oil production, olive pressing waste, commonly referred to in English as pomace, is mildly toxic and the waste water even more so (Doymaz et al. 2004, 213; Mekki et al. 2006, 1420; Ruggeri et al. 2015, 630–1). Fortunately, the chemical composition of pomace means that it can be converted into an energy efficient fuel resource. The use of pomace fuel to cook and heat within domestic properties as well as to fire kilns and bread ovens has changed little since antiquity, and it is the focus of discussion in this paper (Attom & Al-Sharif 1998, 220; Cuomo di Caprio 2007, 490; Niaounakis & Halvadakis 2006, 15; Rowan 2015a).

The Roman Imperial period (first to fourth centuries AD) and the early twenty-first century are both eras in which significantly greater olive oil production took place than in the preceding centuries (Azbar et al. 2004, 210; Doymaz et al. 2004, 214; Mattingly 1988a, 33–4; Warnock 2007, 45–57). Thus, the challenge of simultaneously removing and exploiting this resource is still pertinent. There has been a considerable quantity of contemporary research into the properties and uses of pomace (Alkhamis & Kablan 1999; Arvanitoyannis & Kassaveti 2008, 470; Attom and Al-Sharif 1998; Azbar et al. 2004, 210; Benavente & Fullana 2015; Canet et al. 2008; Doymaz et al. 2004; Karapinar & Worgan 1983; Masghouni & Hassairi 2000; Mekki et al. 2006; Niaounakis & Halvadakis 2006; Nuhoglu & Malkoc 2009; Ruggeri et al. 2015). Similarly, there has been a growing interest in the use of pomace fuel in antiquity

among both archaeobotanists and the wider scholarly community (Barfod et al. 2018; Bourgeon et al. 2018; Margaritis & Jones 2008a,b; Monteix 2009, 331; Rowan 2015a; Wilson 2013, 260; Coubray et al., this volume). Large deposits of highly fragmented carbonized olive stones often signify the presence of pomace fuel waste in the archaeological record. While deposits of this type have been found throughout the Mediterranean and Middle East, few deposits from Roman sites, compared to Bronze Age and Hellenistic sites, have thus far been found (Rowan 2015a). Increased archaeobotanical sampling during excavations has begun to balance out these numbers and new evidence from Roman sites such as Utica (Tunisia) has been uncovered in recent years (Barfod et al. 2018; Bourgeon et al. 2018; Rowan 2015b, 2018b).

Research into both modern and ancient alternative fuel sources has now reached the point where it is possible to assess the consequences and benefits of increased olive oil production during the Roman period. How did the Romans deal with the large quantities of pomace generated each year and what was the potential impact of this increased production? In other words, what did it mean to have more olive pressing waste and yet more available fuel? What impact did this have on fuel-consuming activities such as ceramic production, building construction and domestic heating and cooking? In the absence of modern technology such as cabinet driers and electric fans, the Romans were limited in the number of applicable techniques regarding pomace disposal and use (Doymaz et al. 2004). Already there exists a set of scientific and historical parameters that constrain us. The following discussion will present these parameters and attempt to estimate the impact that pomace fuel use had on both rural and urban activities. Case studies will focus on building construction, olive oil production and domestic dwellings in Rome and Lepcis Magna.

### The properties of pomace

Olive oil is produced by first crushing the olives and then pressing the resultant paste. Pomace, the paste that remains in the baskets after pressing, is composed of olive skin, flesh, stones (endocarps) and seeds (embryos). Pomace contains between 3.5 and 12 per cent oil and 20–30 per cent water to give it an overall moisture content of 25–55 per cent (Karapinar & Worgan 1983, 185; Mekki et al. 2006, 1419). These percentages do not change whether or not a traditional non-mechanized press (screw press, beam press, etc.) or a modern press (the application of hydraulic pressure) is used. Modern presses simply reduce pressing time because the equipment can exert more pressure on the press bed (Mattingly 1988b, 182). Thus, pomace produced in the Roman period would have contained the quantities of oil and water listed above. When the traditional press system is used, the proportion of olive oil to pomace generated during pressing does not vary to any significant degree. Every tonne of olives pressed generates 200 l (184 kg<sup>1</sup>) of olive oil, 450 l of waste water, and 350–400 kg of pomace (Niaounakis 2011, 414).

This rough 2:1 ratio of pomace to oil production means that millions of kilograms of pomace are generated each pressing season. Scientists and engineers have struggled to find alternative uses for pomace as its chemical properties do not make it readily usable as an agricultural product in an untreated form (Attom & Al-Sharif 1998, 220). Pomace has a pH of 5.33, making it acidic (Hepbasli et al. 2003). The majority of the toxic chemicals are contained within the stones and when they are broken during crushing, the chemicals are released into the paste (Azbar et al. 2004, 210). According to Cato the Elder (*Agr.* 37.2.), pomace could be used to fertilize olive groves but, as he rightly noted, it was too acidic to fertilize cereal crops. In olive groves, the acidity has the beneficial effect of enhancing soil potassium levels while simultaneously suppressing grass growth and controlling harmful parasitic nematode populations (Boz et al. 2010, 292; García-Ruiz et al. 2012, 804). Alternatively, the pressing waste can also be fed to animals, although always mixed with other forms of fodder as pure pomace is too difficult to digest (Karapinar & Worgan 1983, 185). Consequently, pomace cannot be used as fertilizer or fodder on a large scale and even today its primary use is as a fuel (Attom & Al-Sharif 1998, 220; Jauhainen et al. 2005, 512).

The large quantity of oil remaining in the pomace after pressing makes it an ideal fuel. Before it can be used as fuel, however, the moisture content must be reduced. Traditionally, pomace is left in the sun to dry

and the water content decreases through evaporation. Although there is currently a great deal of research into the most time efficient techniques for drying pomace, in many areas of Turkey and Jordan sun-drying is still the dominant method (Doymaz et al. 2004, 214; Göğüs 2006; Vega-Gálvez 2010; Warnock 2007, 51). Once the moisture has been reduced to 5–6 per cent the pomace is ready to be used as a fuel (Akgun & Doymaz 2005, 455). It is important to note that drying pomace does not reduce the amount of oil regardless of the duration of drying or the external temperature (Doymaz et al. 2004, 216–18; Karapinar & Worgan 1983, 185). In the absence of any modern heating or drying technologies such as rotary driers, the fastest way to sun-dry pomace is to reduce the thickness of the paste by spreading it out on the ground (Doymaz et al. 2004, 216–18; Karapinar & Worgan 1983, 185). The formation of the dried pomace into usable units varies by country in the modern world. In Jordan the pomace is traditionally rolled into 8–12 cm balls, while in Turkey it is pressed into briquettes (Akgun & Doymaz 2005, 456; Warnock 2007, 48–51).

The burning properties of pomace make it suitable for both domestic and industrial purposes. Although the calorific value of pomace will vary somewhat based on the ratio of stones to pulp, Doymaz et al. (2004, 218) have determined that on average it has a calorific value of between 21.129 and 22.020 MJ/kg. While this is lower than the average calorific value of charcoal (30.77298 MJ/kg), pomace can burn with a more consistent temperature for a longer period of time than charcoal (depending on the temperature required). Ethnographic work in Thrapsano, Crete, has shown that kilns using pomace can reach up to 1000 °C.<sup>2</sup> Consequently, pomace is a highly desired fuel for use in pottery kilns and in Turkey it is used in bakeries to heat the ovens. Similar to charcoal, it also burns with an odourless and smokeless fire, making it a suitable fuel for domestic cooking and heating (Brun 2003, 183). In Jordan and Israel it is used in small stoves to heat homes during the winter and in Morocco to heat baths (Ait Baddi et al. 2004; Warnock 2007, 51).

Archaeobotanical evidence in the form of carbonized olive stones from sites around the Mediterranean has demonstrated that pomace was used throughout antiquity for domestic heating and cooking (Haggis et al. 2011; Hoffman 1981, 1982; Margaritis & Jones 2008a; Sarpaki 1999; Rowan 2015a). Based on the evidence from sites in Tunisia, Cyprus and Italy, evidence for the use of pomace fuel in industrial activities includes heating the water used in olive oil production as well as fuel for pottery kilns (Haggis et al. 2011; Hoffman 1981, 1982; Margaritis & Jones 2008a; Sarpaki 1999; Rowan 2015a). During the Roman period, in addition to its



more traditional uses, pomace began to be utilized in a wider range of production activities (Rowan 2015a). There is evidence from Pompeii for its use in bread ovens (see especially Coubray et al., this volume); from La Garde (France) for heating of the baths; and from Carthage for lime production (Brun et al. 1989, 126; Ford & Miller 1976, 183–7; Monteix 2009; Monteix et al. 2012). There is also good evidence from Israel and Jordan for the late antique use of pomace fuel in glass production (Barfod 2018; Fischer 1999, 896, 903).

### Quantities generated in the Roman Empire

It must be stated that any calculations regarding the quantities of olive oil and pomace generated within the Roman Empire each year are estimates.<sup>3</sup> Similarly, the quantities of olive oil generated in a particular region or even on a particular farm can never be anything more than educated guesses due to the patchiness of the archaeological record (and the variation in productivity from farm to farm). Nevertheless, in the absence of any prior syntheses and discussions of pomace fuel use within the Roman world, an examination of the estimated quantities acts as a starting point, enabling us to more precisely consider the impact of this alternative to wood fuel on Roman domestic and industrial activities.

According to Mattingly, the Roman Empire was capable of producing between roughly 543 million and 1.09 billion litres of olive oil annually.<sup>4</sup> These quantities of oil equate to between 951 million and 1.91 billion kg of pomace.<sup>5</sup> While small quantities of oil were no doubt produced wherever it was climatically suitable to grow olives, the main centres of production were Spain and North Africa. Mattingly has calculated that the territory of Lepcis Magna could have produced 15 million litres of oil per year, resulting in 26.25 million kg of pomace (Mattingly 1988a, 47). If the territories around Oea and Sabratha are added then the region's total oil output may have been as much as 30 million litres, thus resulting in the generation of 52.2 million kg of pomace (Hitchner 2002, 77; Marzano 2013, 92). Similarly large quantities of oil were produced in Spain. Based on evidence from Monte Testaccio, Garnsey & Saller (1987, 58) have estimated that 55,000 Dressel 20 amphora containing 4 million litres of Baetican olive oil were imported into Rome on an annual basis. A quantity of 7 million kg of pomace would have been generated at this level of production. De Sena believes that this number is too low, as Garnsey & Saller have not taken into account the ceramic evidence from other parts of Rome and Ostia. De Sena therefore suggests that 10–12 million litres were imported from Baetica per annum during

the second century AD, which would have resulted in the generation of between 17.5 million and 21 million kg of pomace (De Sena 2005, 8).

Although not an area of major olive oil production, Rome's hinterland must also be considered. This region has been roughly defined as the areas close enough to the city in which fresh fruit, vegetables and dairy products could be imported and sold (De Sena 2005, 4; Marzano 2013, 87–8). De Sena (2005, 4) examined the archaeological evidence for farms and presses from an area of approximately 5000 sq. km around Rome, encompassing modern day Lazio and stretching 64 km upriver from Rome and 48 km along the consular roads. Marzano (2013, 89–90) has done a similar study of oil and wine presses, examining a 5500 sq. km semi-circle around the city, which includes Centumcellae, Falerii Novi, Praeneste and Antium. Unfortunately, the archaeological evidence for oil presses is scant: Marzano (2013, 89) identified only 61 oil and 84 oil or wine presses. Nevertheless, De Sena (2005, 8) has concluded that the area was densely populated with farms and he estimates that Rome's hinterland could have produced roughly 9.7 million litres of olive oil per year.<sup>6</sup> This quantity of oil would have resulted in a pomace output of approximately 17 million kg.

The production capacity of a single press varies considerably based on its size. According to Brun (1987, 279–81), presses of a similar size to those at La Garde, France, could produce 1500–2000 l of oil per year. The much larger Tripolitanian presses, based on Mattingly's calculations, could generate 6900–13,800 l of oil per pressing season (Marzano 2013, 99; Mattingly 1988b, 185). At the minimum of 1500 l and the maximum of 13,800 l, each pressing season would result in an output of between 2625 and 24,150 kg of pomace per press. This calculation assumes only one press per site; thus far the archaeological evidence has suggested that one press was usual for the hinterland of Rome, but in the Gebel Tarhuna region to the southwest of Lepcis Magna, 67 per cent of 146 farm sites had two or more presses and 39 per cent had three or more presses up to a maximum of 17 (Ahmed 2010, 117–19; Hobson 2012, 141; Marzano 2013, 90; Oates 1953).<sup>7</sup> Using Mattingly's Tripolitanian range of press output estimates, a farm with three presses would have generated 36,225–72,450 kg of pomace per year.

### Consequences of quantity

The generation of so much pomace each year, often within discrete areas, presented the producers with both challenges and benefits. It was a challenge because this acidic substance could not simply be left

to accumulate and decay on its own year after year without occupying and effectively sterilizing sections of land.<sup>8</sup> It was, however, an economic opportunity as it was a product that could be sold on to potters, bakers, glass-makers and so forth. It is difficult to know whether or not the Romans regarded pomace in such dichotomous terms but it is clear that the generation of so much pomace throughout the Roman world promoted its utility as a fuel. The quantities created on an annual basis, especially in highly concentrated areas of production such as North Africa and Spain, often went beyond the needs of even a large farm and thus pomace was distributed and used more broadly.

In the more arid areas of the empire there were numerous opportunities in which to use pomace, especially in the absence of a steady supply of charcoal. Although the kilns have not yet been excavated, it is almost certain that the ARS pottery production sites in inland Tunisia used pomace to fuel the kilns (Hobson 2015; Leitch 2010, 2011; Lewit 2011, 319–20; Rowan 2015a, 2018b; Wilson 2012, 150). Since the ceramics were destined for overseas shipment, it is highly unlikely that the olive groves were planted in this inland region for the specific purpose of exploiting pomace as a fuel source. In other words, the pomace was just a beneficial by-product of olive oil production. Yet the movement of the pottery production inland indicates that the economic benefits of pomace fuel must have outweighed the high cost of transport (Lewit 2011, 320).<sup>9</sup> The firing of the ceramic kilns solved the problem of pomace build-up while at the same time exploiting a large and steady fuel supply in an area with little natural woodland.

Similarly, the large Tunisian and Libyan cities, such as Carthage, Utica, Lepcis Magna, Sabratha and Oea, would have been able to utilize readily the large quantities of pomace being generated in their respective hinterlands (Mattingly 1995, 7–11; WMO 2014).<sup>10</sup> The archaeological evidence from each individual site regarding pomace production and its uses is patchy due to the unevenness of the excavated areas. There has been little survey or excavation work done for the hinterlands of Carthage and Utica and there are no estimations of the number of presses or output of olive oil. The sites, however, have been extensively sampled for archaeobotanical remains (Rowan 2015b, 2018b; Stewart 1984, 257; van Zeist 1994, 325). Large quantities of carbonized olive stones have been found in Carthage and Utica in contexts associated with pottery and lime production, indicating pomace fuel use. Although dating to late antiquity, there is also evidence from Carthage for the use of pomace fuel in domestic contexts (Hoffman 1981, 1982). The areas around Lepcis Magna, Sabratha and Oea, conversely, have

been well surveyed and, as stated above, hundreds of presses have been identified (Ahmed 2010; Barker 1996; Mattingly 1985, 1988a, 35–8, 1989; Oates 1953; Schörle & Leitch 2012). Unfortunately no archaeobotanical work has, as yet, been undertaken for Lepcis Magna, Sabratha and Oea. Nevertheless, combined, the existing material from all five of these sites demonstrates that wherever detailed work has been done, evidence for olive oil production and pomace use has been found.

It is therefore possible to suggest that pomace was used throughout the North African cities for a multitude of domestic and industrial functions. Pomace fuel to fire kilns and bread ovens would have been easily purchased from nearby farms. A closer examination of the domestic uses, especially if exploited by the majority of the urban population for heating and cooking, suggests that domestic activities could have made a significant and essential contribution to the reduction of the pressing waste generated in the hinterland, thereby also significantly reducing pressure on woodland resources.

New population estimates based on city size per hectare have been generated for three of the North African cities mentioned above: Lepcis Magna (90,000), Sabratha (10,850) and Carthage (300,000) (Wilson 2011, 176–84).<sup>11</sup> Ethnographic work by Warnock (2007, 51) has shown that 0.416 kg of pomace will provide heat for a single hour when put into a portable furnace. Table 10.1 indicates pomace consumption if each individual used a small portable furnace for one or two hours every day for a year.

The time estimates simply serve as an example as pomace use could be distributed within domestic contexts in a multitude of ways. If used solely for heating, each time estimate assumes that every person would have three or six hours of heat per day during the coldest winter months (December–March) (WMO 2014). Alternatively the time estimates could relate to the time spent cooking, as the furnace or other heating implement, for example a brazier, could serve as a cooker and heater. While it is obvious that not every person would light their own individual furnace (e.g. young children), taking into account the whole population reduces the problem of houses in which multiple rooms were heated at the same time.<sup>13</sup>

**Table 10.1.** Domestic uses of pomace. Calculations are as follows:  $0.416 \times 365 \text{ (days)} \times \text{population}$ .<sup>12</sup>

	Lepcis Magna (90,000)	Sabratha (10,850)	Carthage (300,000)
One hour	13,665,600 kg	1,647,464 kg	45,552,000 kg
Two hours	27,331,200 kg	3,294,928 kg	91,104,000 kg

### The case of Lepcis Magna

As Table 10.1 indicates, even limited domestic usage of pomace in Lepcis Magna would have halved the roughly 26.25 million kg of pomace generated each year.<sup>14</sup> Additional urban usage might have included the city's large bath complexes, the Hadrianic, Eastern, Hunting and so-called Unfinished baths. Such urban usage of pomace was vital because even if half of the pomace was retained by the rural community, the majority of the rural uses of pomace (heating the water for olive oil pressing, fertilizing the olive groves and feeding livestock), required only a minimal amount of pomace.

It was the amphorae kilns associated with the rural farms around Lepcis Magna that would have consumed the majority of the leftover pressing waste (Ahmed 2010, 248–52; Mattingly 1988c). It is estimated that between 300,000 and 1 million litres of Tripolitanian olive oil was shipped to Rome each year (De Sena 2005, 8; Mattingly 1993, 153). Regardless of the exact volume, thousands of amphorae had to be produced to ship the oil.<sup>15</sup> Thus, similarly to the Tunisian ARS pottery production sites, the importance of the relationship between pomace and kiln firings, in terms of both consuming and exploiting the pomace, cannot be underestimated.

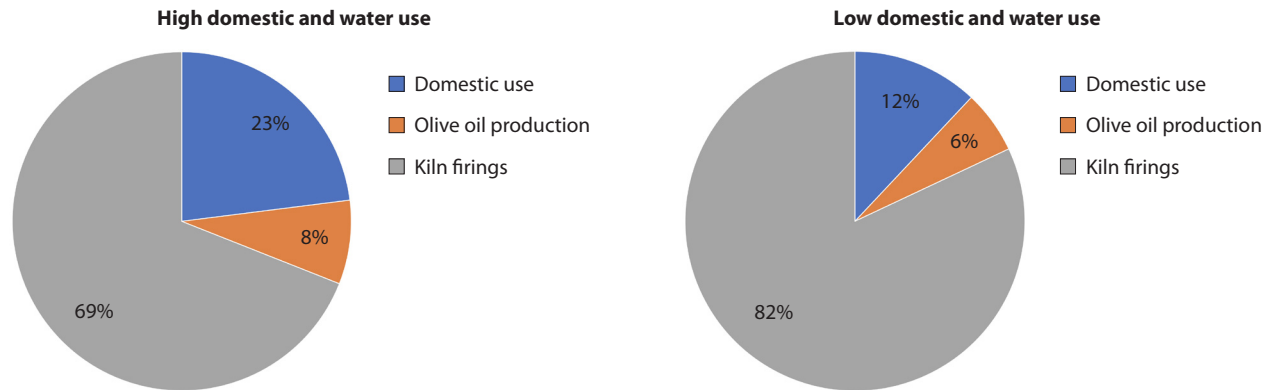
In light of the significance of the kilns, it is useful to hypothesize an example of rural pomace use. Lepcis Magna had a hinterland of 3000–4000 sq. km (Mattingly 1995, 230). Unfortunately there are no estimates for the rural population and thus we will have to use a single villa/press site as an example. Based on the detailed mapping of small concentrated areas during the Kasserine and UNESCO Libyan Valleys surveys, Mattingly (2011, 81–4) has estimated that the population of a villa/press site or a major settlement was 30 people. The oileries on the Tarhuna plateau, classified as farms having five or more presses, are concentrated on the eastern side of the plateau and it has been argued that they were part of the territory of Lepcis Magna (Ahmed 2010, 116–17). Thus the rural villa used in this example will be a press site with 30 residents and five presses. The presses of the Tarhuna plateau were extremely large and Ahmed (2010, 225–32) has calculated that each one could press one tonne of olives during a single pressing session.<sup>16</sup> If 350 kg of pomace are generated during each pressing, and assuming a 90-day pressing season at maximum capacity, then the five presses on the farm would produce 157,500 kg of pomace each winter. If three-quarters of the pomace was shipped into Lepcis for various urban uses, 39,375 kg would remain for use by the 30 people living at the villa.

In terms of cooking and heating, the villa's inhabitants would have had the same requirements as the urban dwellers. If each individual heated/cooked for one or two hours a day then 4555 kg or 9111 kg of pomace would be required. At a press site, an additional fuel requirement would be to heat the water during olive oil production. The traditional press method utilizes 100–120 l of water for every tonne of olives pressed (Azbar et al. 2004, 215). Following Wilson's estimation of the energy required to heat water, where there is a heat transfer efficiency of 25 per cent, 5.6–6.72 kg of pomace would be required to heat the water needed for one pressing (Wilson 2012, 149–50).<sup>17</sup> Since pressing takes place in the winter, this estimate assumes that the temperature of the water must be raised from 10 °C to 80 °C.<sup>18</sup> Over a 90-day pressing season this activity would consume between 504 and 604.8 kg of pomace per press for a total of 2520–3024 kg. The other two primary rural uses, as fertilizer and fodder, are almost negligible as only a small quantity of pomace can be used on the olive trees, and when used as fodder it must be heavily mixed with other materials (Ait Baddi et al. 2004, 39; Arvanitoyannis & Kassaveti 2007, 281). In sum, during a yearly cycle, at the minimum and maximum usages for heating/cooking and water heating, between roughly 27,240 and 32,300 kg would be left over for kiln firings.

The Tarhuna plateau survey has found that pottery kilns were usually associated with or located near to properties with evidence for large-scale olive oil production (Ahmed 2010, 252). Whole carbonized olive stones were found in the one excavated kiln, which tentatively suggests the use of pressing waste as their primary fuel source.<sup>19</sup> The average diameter of the 14 kilns measured was 3.65 m (Ahmed 2010, 271). Ethnographic evidence from Crete has shown that 2500 kg of pomace is needed to fire a kiln 2.5 m in diameter at 1000 °C for ten hours.<sup>20</sup> Ethnographic evidence from the Ballâs Pottery Project along with papyrological evidence from Egypt suggests that approximately 500–700 amphorae could be fired within a single kiln of 4.5 m in diameter, with each firing taking three to four hours (Gallimore 2010, 171–4; Nicholson & Patterson 1989). Since the Tarhuna kilns are larger than the kiln on Crete we can estimate that 3000 kg of pomace would be required for a single ten-hour firing or 1200 kg for a four-hour firing. The remaining pomace then, if used as the exclusive fuel source, would be sufficient for 22 to 27 firings of 500 amphorae each.<sup>21</sup> At the lower end of the scale of production (following Gallimore's method), that would result in roughly 9900 amphorae, with, at the upper end, a maximum of 12,150 amphorae, assuming 10 per cent of the firings end up as wasters (Gallimore 2010, 174).<sup>22</sup>

Depending upon the level of domestic usage, anywhere between 69 and 82 per cent of the pomace





**Figure 10.1.** *Hypothetical divisions of pomace fuel usage in the hinterland of Lepcis Magna.*

was available for amphorae production. All the figures, of course, are only estimates, but as Figure 10.1 shows, the quantities required for each rural activity could easily be manipulated. If additional kiln firings were required, then fewer rooms could be heated or other fuel sources such as dung could be used within the villa.

This exercise has demonstrated that, if three-quarters of the pomace was sent to Lepcis Magna, there was still enough pomace left in the rural areas to ensure sufficient fuel sources for the required domestic and industrial activities. At the same time, however, this exercise has shown the importance of Lepcis, and presumably other North African cities, as consumers, for if the cities did not use pomace then the countryside would be struggling to handle the thousands of kilograms of this toxic waste that would be left to ferment each year.

### Rome's challenge and solution

The cities and the kilns, at least in North Africa, were by far the largest consumers of pomace. Yet what if large quantities of olive oil were produced in an area where there was little pottery production? This question must be asked of Rome and its hinterland. An estimated 9.7 million litres of olive oil and thus 17 million kg of pomace were produced in Rome's hinterland on an annual basis, yet there is no evidence for amphora kilns within this area (De Sena 2005, 8).<sup>23</sup> How and where would the millions of kilograms of pomace be used?

The simple answer is that the excess pomace was used both in Rome and the countryside. Rome had the largest urban population of any city in the empire and consequently greater fuel requirements than even the largest North African cities.<sup>24</sup> Heating the Imperial baths and numerous smaller local baths would have required considerable amounts of fuel,

as would firing the bread ovens each day. The large and almost continuous Imperial construction projects would also have consumed significant amounts of fuel. The building of temples, baths, fora and aqueducts required the production of enormous quantities of lime and brick, both of which had to be produced in nearby kilns (DeLaine 1995, 559–60; Fontana 1995). For example, firing the 4,814,000 *bessales* (bricks) used in the construction of the Baths of Caracalla would have required 2166.3 tonnes of wood, and that is just one of the three types of bricks used in the baths (DeLaine 1997, 116–18, 124, 126).<sup>25</sup> In terms of domestic fuel requirements, even if only half of the population of Rome required one hour of fuel for heating and cooking per day, that would mean fuel needs 5.5 times greater than the entire population of Lepcis Magna. It is interesting to note, however, that despite Rome's high fuel requirements, there is no evidence for deforestation within the area or even the entire Italian peninsula during the Roman period (Grove & Rackham 2001, 174; Kaplan et al. 2009, 3029). The much wetter and more wooded Italian landscape, compared to North Africa, would have ensured a regular supply of charcoal and it was no doubt the primary fuel source used within the city. Veal has recently estimated Rome's total fuel requirements, and in order to avoid deforestation one must entertain the notion that the charcoal and wood supply were supplemented by alternative sources (Veal 2017, 397–9). Pomace, a product generated locally and on a useful scale, has to be regarded as a highly plausible option.

Extremely little archaeobotanical sampling has been done within Rome and as yet there are no confirmed cases of pomace use. Consequently, pomace use within the city must, at this point, be regarded as no more than highly probable. Yet there is ample evidence from elsewhere in the empire that pomace fuel was used in the same domestic and industrial activities



that took place within and near Rome (Rowan 2015a). At Pompeii, the discovery of thousands of carbonized fragments of olive endocarp from two bakeries indicates that pomace fuel was used to heat the bread ovens (Monteix 2009; Coubray, this volume). There is evidence for its domestic use at Herculaneum in the form of carbonized olive fragments from the Cardo V sewer (Rowan 2014). At Utica, fragmented carbonized olives stones were recovered from the bottom of multiple ceramic kilns and one large lime kiln, while from La Garde there is evidence that the villa's baths were heated with pomace fuel (Brun et al. 1989, 126; Rowan 2018b). This widespread use of pomace needs to be taken into account and if Rome's hinterland was producing at least moderate quantities of olive oil, it is difficult to imagine that neither the rural nor urban populations took advantage of this energy source. Despite the absence of physical material from Rome, it will be useful to examine a hypothetical division of rural and urban pomace use for Rome and its hinterland in a manner similar to that undertaken for Lepcis Magna.

The population of Rome's hinterland has been estimated to have been approximately 250,000. This figure has been determined rather arbitrarily based on the estimated population of Roman Italy, and may in fact be too high (De Sena 2005, 6–8). Nevertheless, let us suppose that the rural population kept half of the pomace produced in the hinterland each year and therefore had 8.5 million kg to utilize for a range of activities.<sup>26</sup> Similar to the hinterland of Lepcis, one of the rural uses would have been to heat the water used to press the olives.<sup>27</sup> Marzano's survey of Rome's hinterland has shown that it was typical for a farm or villa to have only one olive press. She hypothesizes that each press could produce 9200 kg (10,000 l) of oil during a 90-day season (Marzano 2013, 90, 99). This quantity of oil equates to a production capacity of roughly 112 l of oil per day and the pressing of 555.5 kg of olives. At this rate, 87,300 press cycles were required to produce the estimated 9.7 million litres total production. If each cycle utilized 50–60 l of water, then heating the water would have consumed between 356,000 and 427,000 kg of pomace (Table 10.2).<sup>28</sup>

Domestic heating and cooking could easily have used up the remaining 8.1 million kg of pomace. The

large population of Rome's hinterland would have made up for the absence of fuel-consuming kilns. Domestic use also would have prevented a build-up of this toxic material, a crucial factor in an area with such a high land value. If we apply the same rural domestic heating and cooking fuel quantities of Lepcis Magna to the hinterland of Rome, then 37.96 million kg of pomace would be required to provide each individual with an hour of heat every day for one year. Not even the entire quantity of pomace generated in the hinterland (17 million kg) could have supplied Rome's rural population with enough energy. However, these calculations assume that pomace was the only fuel in use, which, of course, is untrue. What these numbers instead suggest is that pomace accounted for a small to moderate percentage of the total fuel used by each individual.<sup>29</sup> Yet if the rural population of Rome could easily have used all the available pomace, why would some of it be shipped into the city?

Within the city of Rome, fuel-related activities differed from those in the hinterland and consequently the ratio of fuel types was different. As stated above, fuel was required in bath buildings, bakeries, domestic residences and during building construction.<sup>30</sup> The majority of these activities, especially bread production and domestic cooking, required far more charcoal than raw wood.<sup>31</sup> In her model of fuel use in Pompeii, Veal (2009, 200) adopts the division of urban fuel use as 80 per cent charcoal and 20 per cent wood and the opposite for the countryside. Although charcoal has a much higher calorific content than dried wood (19 MJ/kg compared to 30 MJ/kg), its production consumes large quantities of wood (Francescato et al. 2008, 22). It can require between 4 and 7 tonnes of wood to produce one tonne of charcoal (Veal 2009, 200–1). Since pomace burns at a high and consistent temperature and with little smoke, it is often used as a charcoal alternative or supplement. In other words, pomace can be used almost anywhere charcoal is employed. Even as a small percentage of total fuel use, the exploitation of 8.1 million kg of pomace – what was effectively cheap fuel – by the city of Rome would have taken some of the pressure off the wood and charcoal industries. Moreover, although probably inexpensive, the sale of pomace would have generated some additional income

**Table 10.2.** Quantities of pomace required to heat the water used for one press and then all presses in Rome's hinterland during a single 90-day pressing season, assuming that 100–120 l of water are required to press 1 tonne of olives (after Azbar et al. 2004, 215).

	Quantity of oil	Quantity of olives	Quantity of hot water required	Quantity of pomace fuel for heating the water
Daily (single press)	111.11 l (102.2 kg)	555.55 kg	55.55–66.67 l	4.08–4.9 kg
Seasonally (single press)	10,000 l (9200 kg)	50,000 kg	5000–6000 l	367.2–441 kg
Seasonally (all presses)	9.7 million l (8.9 million kg)	48.5 million kg	4.8–5.8 million l	356,187–427,774 kg

for local farmers.<sup>32</sup> Using 19 MJ/kg as the calorific value of oven-dry raw wood, 8.95 million kg of raw wood would have to be burnt to match the energy present in 8.1 million kg of pomace. This quantity of wood, when converted into forested area, equates to 8952.6 hectares (89.52 sq. km), assuming a low productivity value of 1 tonne/hectare (Veal 2009, 202). The exploitation of the total 17 million kg of pomace is the equivalent to burning 18,789 hectares or 187.89 sq. km of woodland each year. Near Rome, this land could have been used to produce agricultural and horticultural goods, raise livestock or produce timber for use by the city. Thus, even if the archaeobotanical material is still missing, the city's high charcoal demands make it almost certain that pomace was exploited as a fuel source within Rome.

## Conclusions

Unavoidably produced but intentionally exploited as a by-product of olive oil production, it is clear from the growing body of archaeobotanical evidence that pomace was an important and widely utilized fuel source within the Roman Empire. As a toxic waste it had to be removed from the land. The popularity of certain goods and activities within the empire, many of which necessitated the consumption of vast quantities of fuel, meant that there were numerous avenues for pomace use and it was surely welcomed as an inexpensive source of energy. As the above discussion has shown, it is unlikely that any region of the Roman Empire suffered the consequences of having an overabundance of unused pomace.

The objective of this chapter has not been to establish precise quantities of pomace use within the Roman Empire. Instead, the goal has been to suggest ways in which pomace could have been utilized in different geographical areas and what that would have meant for the various fuel-consuming industries. I have tried as best as possible to ensure that all ecological and archaeological parameters have been considered. The numbers are estimates and the models serve simply to suggest new ways of thinking about the exploitation and importance of various fuel resources within the Roman Empire. How important was pomace? In the arid regions of North Africa, for example, pomace exploitation may have been the only way that the thousands of amphorae required for olive oil export could have been produced. How did rural and urban pomace use differ? How much was sent to the cities and how much was retained for rural activities? Again, the 50/50 split presented here for Rome is only a suggestion. Is the exploitation of multiple fuel sources the way that the Romans avoided large-scale

deforestation while at the same time maintained high rates of production, trade and construction throughout the Roman world? (Erdkamp 2016; McConnell et al. 2018). This chapter has raised more questions than it has answered, but it is hopefully only the beginning of a new area of investigation.

In summary, pomace was important. Although used in different ways and for different purposes, agricultural by-products may have been just as important as cultivated agricultural products in the ancient world. Further work will no doubt help to clarify and quantify the use of pomace within the Roman Empire. At the moment, however, it is hoped that this chapter has raised awareness of the importance of incorporating alternative fuels into our models of Roman economic activities.

## Notes

- 1 l of olive oil = 0.92 kg. (Marzano 2013, 99).
- Jean-Pierre Brun, pers. comm. 20 March 2014.
- The amount of olive oil and pomace generated on an annual basis will also fluctuate based on the quality of the harvest, as olive trees vary considerably in their annual yield.
- Mattingly (1988a, 34) estimates a total output of 500,000–1,000,000 metric tonnes of oil. When converted into litres (1 l of oil = 0.92 kg), the precise quantities are 543,478,260.89 l and 1,086,956,521.73 l.
- Or 951,000 and 1.91 million tonnes. All estimates use the ratio of 350 kg of pomace for every 200 l of olive oil produced.
- The accuracy of this number is debatable as he estimates that the density of presses, at least in the Ager Faliscus, was similar to the areas of peak North African production where there is one press every 2 sq. km. (Hitchner 2002; Mattingly 1988b).
- The farm with 17 presses was quite exceptional as the next highest number of presses at a single farm was nine.
- The specific challenge with pomace is that the high levels of phytotoxic chemicals present in the waste will kill the vegetation beneath it. Wet pomace is more harmful because it also contains some of the waste water, which is far more toxic than the paste itself. In the Aydan region of modern Turkey, piles of pomace are left to dry next to the presses in large gravel or paved outdoor areas. Moreover, pomace does not biodegrade quickly and although the stones would have been broken, they would not have been crushed or ground and consequently they would take years to fully decompose (Cayuela et al. 2007, 1985; Martin 1992, 99).
- The oil produced on these farms was transported to the coast in skins in order to reduce shipping costs.
- <http://worldweather.wmo.int/en/home.html>. There was more rainfall at Carthage and Utica than the Tripolitanian cities, but large tracts of forest would still have been scarce except near the deltas and coast, and on the mountains.

- 11 The population of Sabratha is an average of Wilson's estimates.
- 12 Calculations are as follows:  $0.416 \times 365(\text{days}) \times \text{population}$ .
- 13 This would occur especially in homes that had their own kitchens, as cooking and heating would then be separate activities.
- 14 Although it must be kept in mind that pomace would not be the only fuel in use and fuels such as charcoal and dung would also be exploited.
- 15 The ceramic evidence from Rome, primarily Monte Testaccio, and Ostia attests to the production of this large quantity of amphorae (De Sena 2005, 2).
- 16 Each tonne pressed produces 200 l of oil.
- 17 The specific heat capacity of water is 4.2 kJ. At this rate it would take 420–504 kJ to raise 100–120 l of water one degree. The lower energy value of pomace of 21 MJ/kg, as calculated by Doymaz et al. 2004 has been used here.
- 18 Descriptions of traditional press methods always state that hot but not boiling water is used, thus the selection of 80 °C.
- 19 Ahmed (2010, 267–70) argues that the stones are evidence for pomace fuel. However, in the vast majority of cases in which archaeobotanical evidence for pomace fuel has been found, the olive stones are highly fragmented (Rowan 2015a).
- 20 Jean-Pierre Brun, pers. comm. 20 March 2014.
- 21 It is highly unlikely that pomace was used on its own. Chaff is often used to start the fire.
- 22 The Ballas Pottery Project found that 5–10 per cent of the vessels fired were wasters.
- 23 Liquid products, such as olive oil and wine, were transported the short distance into Rome in barrels or skins and there was no need to make amphora on a large scale.
- 24 Alexandria and Carthage, the two biggest cities in North Africa, had estimated populations of only 500,000 and 300,000 respectively, while the traditional population estimate for Rome during the period in question here is one million (Wilson 2010, 184–7).
- 25 According to DeLaine, 2,020,000 *bessales* were used in the construction of the foundations and substructure while 2,794,000 were used in the central block. She has calculated that it requires 0.45 tonnes of wood to fire 1000 *bessales*.
- 26 The large population of Rome's hinterland meant that rural fuel requirements would be higher than Lepcis Magna and so half, instead of only a quarter remains in the countryside.
- 27 Pliny (HN 15.6) also recommends heating the press room with pomace.
- 28 These calculations are identical to the Lepcis Magna calculations in that there would be a 25 per cent heat transfer and the water would have to be heated from 10 °C to 80 °C.
- 29 Without more information on all types of fuel used, it is impossible to estimate precise percentages.
- 30 This list is not complete and fuel was required for other activities such as metal- and glass-working.
- 31 Bread is baked by first heating the oven to a high temperature. The fuel is then raked out, the loaves inserted and the metal door shut, allowing the retained heat to bake the bread. It would therefore be difficult and inefficient to use raw wood to heat the ovens. Moreover, at Pompeii and Ostia, there is no space within the relatively small bakeries to store the quantities of raw wood required. Domestic cooking, even in wealthy homes, was done using tripods or small portable braziers and ovens. Large ovens were not used and thus compact fuel sources, such as charcoal or pomace, were the more probable types of fuel that could fit beneath the tripods or in the small ovens (Veal 2012, 26–7).
- 32 Alternatively, wealthy landowners could have used the pomace to heat their own houses in Rome.

## References

- Ahmed, M., 2010. *Rural Settlement and Economic Activity: Olive Oil and Amphorae Production on the Tarhuna Plateau during the Roman Period*. Ph.D. diss., University of Leicester.
- Ait Baddi, G., J. Antonio Alburquerque, J. González, J. Cegarra & M. Hafidi, 2004. Chemical and spectroscopic analyses of organic matter transformations during composting of olive mill wastes. *International Biodeterioration & Biodegradation* 54, 39–44.
- Akgun, N.A. & I. Doymaz, 2005. Modelling of olive cake thin-layer drying process. *Journal of Food Engineering* 68, 455–61.
- Alkhamis, T.M. & M.M. Kablan, 1999. Olive cake as an energy source and catalyst for oil shale production of energy and its impact on the environment. *Energy Conversion and Management* 40, 1863–70.
- Arvanitoyannis, I.S. & A. Kassaveti, 2007. Current and potential uses of composted olive oil waste. *International Journal of Food Science & Technology* 42, 281–95.
- Arvanitoyannis, I.S. & A. Kassaveti, 2008. Olive oil waste management: treatment methods and potential uses of treated waste, in *Waste Management for the Food Industries*, ed. I.S. Arvanitoyannis. Burlington (MA): Elsevier, 453–552.
- Attom, M.F. & M.M. Al-Sharif, 1998. Soil stabilization with burned olive waste. *Applied Clay Science* 13, 219–30.
- Azbar, N., A. Bayram, A. Filibeli, A. Muezzinoglu, F. Sengul & A. Ozer, 2004. A review of waste management options in olive oil production. *Critical Reviews in Environmental Science and Technology* 34, 209–47.
- Barford, G.H., I.C. Freestone, A. Lichtenberger, R. Raja & H. Schwarzer, 2018. Geochemistry of Byzantine and Early Islamic glass from Jerash, Jordan: typology, recycling, and provenance. *Geoarchaeology* 33(1), 1–18.
- Barker, G., 1996. *Farming the Desert*. 2 Vols. London: UNESCO publishing, Department of Antiquities (Tripoli) and Society for Libyan Studies.
- Benavente, V. & A. Fullana, 2015. Torrefaction of olive mill waste. *Biomass and Bioenergy* 73, 186–94.
- Bourgeon, O., C. Pagnoux, S. Mauné, E.G. Vargas, S. Ivorra et al., 2018. Olive tree varieties cultivated for the great Baetic oil trade between the 1st and the 4th centuries AD: morphometric analysis of olive stones from Las Delicias (Ecija, Province of Seville, Spain). *Vegetation History and Archaeobotany* 27(3), 463–76.



- Boz, Ö., D. Ögüt & M.N. Doğan, 2010. The phytotoxicity potential of olive processing waste on selected weeds and crop plants. *Phytoparasitica* 38, 291–98.
- Brun, J., 1987. *L'oléiculture Antique en Provence. Les Huileries du Département du Var*. Paris: Editions CNRS.
- Brun, J.P., G. Rogers, P. Columeau, M. Thinon & M. Gérard, 1989. La villa gallo-romaine de Saint-Michel à La Garde (Var). Un domaine oléicole au Haut-Empire. *Gallia* 46, 103–62.
- Brun, J.P., 2003. *Le Vin et L'Huile dans la Méditerranée Antique: Viticulture, Oléiculture et Procédés de Transformation*. Paris: Errance.
- Canet, R., F. Pomares, B. Cabot, C. Chaves, E. Ferrer, M. Ribó & M.R. Albiach, 2008. Composting olive mill pomace and other residues from rural southeastern Spain. *Waste Management* 28, 2585–92.
- Cayuela, M., P. Millner, J. Slovin & A. Roig, 2007. Duckweed (*Lemna gibba*) growth inhibition bioassay for evaluating the toxicity of olive mill wastes before and during composting. *Chemosphere* 68, 1985–91.
- Cuomo di Caprio, N., 2007. *Ceramica in Archeologia 2: Antiche Tecniche Di Lavorazione E Moderni Metodi Di Indagine. Nuova Edizione Ampliata*. Rome: L'Erma di Bretschneider.
- DeLaine, J., 1995. The supply of building materials to the city of Rome, in *Settlement and Economy in Italy 1500BC to AD1500*, ed. N. Christie. (Oxbow Monograph 41.) Oxford: Oxbow, 555–62.
- DeLaine, J., 1997. *The Baths of Caracalla: A Study in the Design, Construction, and Economics of Large-scale Building Projects in Imperial Rome*. (Journal of Roman Archaeology Supplementary Series 25.) Portsmouth, RI.
- De Sena, E.C., 2005. An assessment of wine and oil production in Rome's hinterland: ceramic, literary, art historical and modern evidence, in *Roman Villas around the Urbs: Interaction with Landscape and Environment: Proceedings of a Conference at the Swedish Institute in Rome, September 17–18, 2004*, eds. B.S. Frizell & A. Klynne. Rome: Swedish Institute in Rome, 1–15.
- Doymaz, I., O. Gorel & N. Akgun, 2004. Drying characteristics of the solid by-product of olive oil extraction. *Biosystems Engineering* 88, 213–19.
- Erdkamp, P., 2016. Economic growth in the Roman Mediterranean world: An early good-bye to Malthus? *Explorations in Economic History* 60, 1–20.
- Fischer, A., 1999. Glass production activities as practised at Sepphoris, Israel (37 BC–AD 1516). *Journal of Archaeological Science* 26, 893–905.
- Fontana, S., 1995. Un impianto per la produzione della calce presso Lucus Feroniae (Roma), in *Settlement and Economy in Italy 1500BC to AD1500*, ed. N. Christie. (Oxbow Monograph 41.) Oxford: Oxbow, 563–70.
- Ford, R.I. & N. Miller, 1976. Paleoethnobotany I, in *Excavations at Carthage 1976 Conducted by the University of Michigan IV*, ed. J.H. Humphrey. Tunis: Cérès Productions, 181–7.
- Francescato, V., Antonini, E. & L.Z. Bergomi, 2008. *Wood Fuels Handbook*. Legnaro: AIEL-Italian Agriforestry Energy Association. Available from [http://www.aebiom.org/IMG/pdf/WOOD\\_FUELS\\_HANDBOOK\\_BTC\\_EN.pdf](http://www.aebiom.org/IMG/pdf/WOOD_FUELS_HANDBOOK_BTC_EN.pdf)
- Gallimore, S., 2010. Amphora production in the Roman world. A view from the papyri. *Bulletin of the American Society of Papyrologists* 47, 155–84.
- García-Ruiz, R., M.V. Ochoa, M.B. Hinojosa & B. Gómez-Muñoz, 2012. Improved soil quality after 16 years of olive mill pomace application in olive oil groves. *Agronomy for Sustainable Development* 32, 803–10.
- Garnsey, P. & R. Saller, 1987. *The Roman Empire: Economy, Society, and Culture*. London: Duckworth.
- Gögüs, F. & M. Maskan, 2006. Air drying characteristics of solid waste (pomace) of olive oil processing. *Journal of Food Engineering* 72(4), 378–82.
- Grove, A. & O. Rackham, 2001. *The Nature of Mediterranean Europe. An Ecological History*. New Haven: Yale University Press.
- Hadjisavvas, S., 1996. An introduction to olive oil production in Cyprus, in *Olive Oil in Antiquity: Israel and Neighbouring Countries from the Neolithic to the Early Arab Period*, eds. D. Eitam & M. Helzer. Padua: Sargon, 63–75.
- Haggis, D.C., M.S. Mook, R.D. Fitzsimons, C.M. Scarry, L.M. Snyder & W.C. West III., 2011. Excavations in the archaic civic buildings at Azoria in 2005–2006. *Hesperia* 80, 1–70.
- Hepbasli, A., R.C. Akdeniz, F. Vardar-Sukan & Z. Oktay, 2003. Utilization of olive cake as a potential energy source in Turkey. *Energy Sources* 25, 405–17.
- Hitchner, R.B., 2002. Olive production and the Roman economy: the case for intensive growth in the Roman empire, in *The Ancient Economy*, ed. W. Scheidel & S. von Reden. Edinburgh: Edinburgh University Press, 71–86.
- Hobson, M.S., 2012. *The African Boom? Evaluating Economic Growth in the Roman Province of Africa Proconsularis*. Ph.D. diss., University of Leicester.
- Hobson, M.S., 2015. The African Boom: The Origins of economic growth in Roman North Africa, in *Ownership and Exploitation of Land and Natural Resources in the Roman World*, eds. P. Erdkamp, K. Verboven & A. Zuiderhoek. Oxford: Oxford University Press, 207–33.
- Hoffman, E.S., 1981. Palaeoethnobotany II: plant remains from Vandal and Byzantine deposits in three cisterns, in *Excavations at Carthage, 1977, Conducted by the University of Michigan*, Vol. VI, ed. J.H. Humphrey. Ann Arbor: University of Michigan Press, 259–68.
- Hoffman, E.S., 1982. Paleoethnobotany III: charcoal analysis from Vandal and Byzantine deposits in two cisterns, in *Excavations at Carthage, 1978, Conducted by the University of Michigan*, Vol. VII, ed. J.H. Humphrey. Ann Arbor: University of Michigan Press, 193–200.
- Holloway, R.R., 1975. Buccino: The early bronze age village of Tufariello. *Journal of Field Archaeology* 2, 11–71.
- Jauhainen, J., I. Martin-Gullon, J.A. Conesa & R. Font, 2005. Emissions from pyrolysis and combustion of olive oil solid waste. *Journal of Analytical and Applied Pyrolysis* 74, 512–17.
- Kaplan, J.O., K.M. Krumhardt & N. Zimmermann, 2009. The prehistoric and preindustrial deforestation of Europe. *Quaternary Science Reviews* 28, 3016–34.
- Karapmar, M. & J.T. Worgan, 1983. Bioprotein production from the waste products of olive oil extraction. *Journal of Chemical Technology and Biotechnology* 33, 185–88.



- Leitch, V., 2010. *Production and Trade of Roman and Late Roman North African Cookwares*. Ph.D. diss., University of Oxford.
- Leitch, V., 2011. Location, location, location: characterizing coastal and inland production and distribution of Roman African cooking wares, in *Maritime Archaeology and Ancient Trade in the Mediterranean*, eds. D. Robinson & A. Wilson. Oxford: Oxford Centre for Maritime Archaeology, 169–96.
- Lewit, T., 2011. Dynamics of fineware production and trade: The puzzle of supra-regional exporters. *Journal of Roman Archaeology* 24, 313–32.
- Margaritis, E. & M. Jones, 2008a. Olive oil production in Hellenistic Greece: The interpretation of charred olive remains from the site of Tria Platania, Macedonia, Greece (fourth–second century BC). *Vegetation History and Archaeobotany* 17, 393–401.
- Margaritis, E. & M. Jones, 2008b. Crop processing of *Olea europaea* L.: an experimental approach for the interpretation of archaeobotanical olive remains. *Vegetation History and Archaeobotany* 17, 381–92.
- Martin, D.L. & G. Gershuny (eds.), 1992. *The Rodale Book of Composting: Easy Methods for Every Gardener*. Emmaus (PA): Rodale Press.
- Marzano, A., 2013. Agricultural production in the hinterland of Rome: wine and olive oil, in *The Roman Agricultural Economy: Organization, Investment and Production*, eds. A. Bowman & A.I. Wilson. Oxford: Oxford University Press, 85–106.
- Masghouni, M. & M. Hassairi, 2000. Energy applications of olive-oil industry by-products:—I. The exhaust foot cake. *Biomass and Bioenergy* 18, 257–62.
- Mattingly, D., 1985. Olive oil production in Roman Tripolitania, in *Town and Country in Roman Tripolitania: Papers in Honour of Olwen Hackett*, eds. D.J. Buck & D.J. Mattingly. (BAR International Series 274.) Oxford, 27–46.
- Mattingly, D.J., 1988a. Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman Empire. *Journal of Roman Archaeology* 1, 33–56.
- Mattingly, D.J., 1988b. Megalithic madness and measurement. Or how many olives could an olive press press? *Oxford Journal of Archaeology* 7, 177–95.
- Mattingly, D.J., 1988c. The olive boom: oil surpluses, wealth and power in Roman Tripolitania. *Libyan Studies* 19, 21–42.
- Mattingly, D.J., 1993. Maximum figures and maximizing strategies of oil production? Further thoughts on the processing capacity of Roman olive presses, in *La Production du Vin et de l'Huile en Méditerranée = Oil and Wine Production in the Mediterranean Area*, eds. M.C. Amouretti, J.P. Brun & D. Eitam. Athens: Ecole Française d'Athènes, 483–98.
- Mattingly, D.J., 1995. *Tripolitania*. London: Batsford.
- Mattingly, D., 2011. Calculating plough-zone demographics, in *Settlement, Urbanization, and Population*, eds. A. Bowman & A.I. Wilson. Oxford: Oxford University Press, 76–96.
- McConnell, J.R., A.I. Wilson, A. Stohl, M. Arienzo, N.J. Chellman et al. 2018. Lead pollution recorded in Greenland ice indicates European emissions tracked plagues, wars, and imperial expansion during antiquity. *Proceedings of the National Academy of Sciences*, May 2018: 1–6.
- Mekki, H., M. Anderson, E. Amar, G.R. Skerratt & M. Ben-Zina. 2006. Olive oil mill waste water as a replacement for fresh water in the manufacture of fired clay bricks. *Journal of Chemical Technology and Biotechnology* 81, 1419–25.
- Monteix, N., 2009. Pompéi, *Pistrina*: recherches sur les boulangeries de l'Italie romaine [2008]. *Mélanges de l'école française de Rome* 121, 322–35.
- Monteix, N., S. Zanella, S. Aho, R. Macario & E. Proudfoot. 2012. Pompéi, *Pistrina*, *Chronique des activités archéologiques de l'École française de Rome* [En ligne], Italie du Sud, mis en ligne le 19 décembre 2012. <http://cefr.revues.org/328>
- Niaounakis, M., 2011. Olive-mill wastewater in antiquity. Environmental effects and applications. *Oxford Journal of Archaeology* 30, 411–25.
- Niaounakis, M. & C.P. Halvadakis, 2006. *Olive Processing Waste Management: Literature Review and Patent Survey* (2nd ed.). Oxford: Elsevier.
- Nicholson, P.T. & H.L. Patterson, 1989. Ceramic technology in Upper Egypt: a study of pottery firing. *World Archaeology* 21, 71–86.
- Nuhoglu, Y. & E. Malkoc, 2009. Thermodynamic and kinetic studies for environmentally friendly Ni (II) biosorption using waste pomace of olive oil factory. *Bioresource Technology* 100, 2375–80.
- Oates, D., 1953. The Tripolitanian gebel: settlement of the Roman period around Gasr ed-Dauun. *Papers of the British School at Rome* 21, 81–117.
- Rowan, E., 2014. *Roman Diet and Nutrition in the Vesuvian Region: A Study of the Bioarchaeological Remains from the Cardo V Sewer at Herculaneum*. Ph.D. diss., University of Oxford.
- Rowan, E., 2015a. Olive oil pressing waste as a fuel source in antiquity. *American Journal of Archaeology* 119(4), 465–82.
- Rowan, E., 2015b. The archaeobotanical remains from Utica (Tunisia). Unpublished excavation report.
- Rowan, E., 2018a. Olives and olive oil, in *Diet and Nutrition in the Roman World*, eds. C. Holleran & P. Erdkamp. London: Routledge, 129–39.
- Rowan, E., 2018b. Sustainable fuel practices in Roman North Africa. *Interdisciplinaria Archaeologica* 9(2), 147–56.
- Ruggeri, B., F. Battista, M. Bernardi, D. Fino & G. Mancini, 2015. The selection of pretreatment options for anaerobic digestion (AD): A case study in olive oil waste production. *Chemical Engineering Journal* 259, 630–39.
- Sarpaki, A., 1999. What did they produce?, in *Minoans and Mycenaeans: Flavours of Their Time*, eds. Y. Tzedakis & H. Martlew. Athens: Kapon Editions, 35–43.
- Schörle, K. & V. Leitch, 2012. Report on the preliminary season of the Lepcis Magna Coastal Survey. *Libyan Studies* 43, 149–54.
- Stewart, R., 1984. Carbonized seeds, in *Excavations at Carthage: The British Mission. 1,1. The Avenue du President Habib Bourguiba, Salammbô. The Site and Finds Other than Pottery*, eds. H.R. Hurst & S. Roskams. Sheffield: Sheffield University, Department of Prehistory and Archaeology, 257.

- U.S. Department of Agriculture, Agricultural Research Service, 2013. *USDA National Nutrient Database for Standard Reference*. Release 26. Nutrient Data Laboratory Home Page. Available from <http://ndb.nal.usda.gov/>
- van Zeist, W., 1994. Botanical remains, in *Excavations at Carthage: The British Mission. 1,1. The Avenue du President Habib Bourguiba, Salammbô. The Site and Finds Other than Pottery*, eds. H.R. Hurst & S. Roskams. Sheffield: Sheffield University, Department of Prehistory and Archaeology, 325.
- Veal, R., 2009. *The Wood Fuel Supply to Pompeii Third Century BC to AD 79: An Environmental, Historical and Economic Study Based on Charcoal Analysis*. Ph.D. diss., University of Sydney.
- Veal, R., 2012. From context to economy: charcoal as an archaeological interpretative tool, a case study from Pompeii, 3rd century BC to AD 79, in *More than Just Numbers: The Role of Science in Roman Archaeology*, ed. I. Schrufer-Kolb. (*Journal of Roman Archaeology Supplementary Series* 91.) Portsmouth, RI, 19–52.
- Veal, R. 2017. Wood and charcoal for Rome: towards an understanding of ancient regional fuel economics, in *The Economic Integration of Roman Italy*, eds. T.C.A. de Haas & G.W. Tol. Leiden: Brill, 388–406.
- Vega-Gálvez, A., M. Miranda, L.P. Díaz, L. Lopez, K. Rodriguez & K. Di Scala, 2010. Effective moisture diffusivity determination and mathematical modelling of the drying curves of the olive-waste cake. *Bioresource Technology* 101(19), 7265–270.
- Warnock, P., 2007. *Identification of Ancient Olive Oil Processing Methods Based on Olive Remains*. Oxford: Archaeopress.
- Wilson, A.I., 2012. Raw materials and energy, in *The Cambridge Companion to the Roman Economy*, ed. W. Scheidel. Cambridge: Cambridge University Press, 133–55.
- Wilson, A.I., 2013. The Mediterranean environment in ancient history: perspectives and prospects, in *Ancient Mediterranean Environment between Science and History*, ed. W.V. Harris. Leiden: Brill, 259–76.
- World Meteorological Organization, 2015. *Tunis-Carthage*. Updated 31 July 2014. Available from <http://world-weather.wmo.int/en/city.html?cityId=243>

---

## Chapter 11

### Of olives and wood: baking bread in Pompeii

Sylvie Coubray, Nicolas Monteix  
& Véronique Zech-Matterne

Since 2008, the 'Pistrina' project, funded by the École française de Rome and the Centre Jean-Bérard, has been re-studying bakeries in order to define the evolution from domestic bread-making to commercial baking. Pompeii has been used as a first case-study because of the numerical importance of bakeries throughout the urban space: bread ovens with an internal diameter equal or superior to 1 m and/or milling equipment have been found in 42 houses.<sup>1</sup>

Four of these bakeries have been excavated. During this process, excavated beaten earth floors were sampled in order to study the botanical remains. It rapidly became clear that in each of the studied bakeries the majority of the preserved fragments were olive stones, either trapped in the spaces between basalt stones around the mills or in the beaten earth floors in use in AD 79. Additionally, concentrations of stones were recovered in front of, or close to the ovens, in I 12, 1–2 and VII 1, 25.46–47. The limited results obtained in VII 12, 13, Via degli Augustali, where problems of conservation restricted the sampling to 10 l, and in IX 3, 1920, located in the western part of the Via degli Augustali, where pavements linked with the bakery were either built over them or were heavily damaged (Monteix et al. 2011, 311–13), will not be used. Instead, the two other examples do show interesting and diverging patterns in fuel use. The bakery inserted in the so-called Domus Sirici (VII 1, 25.46–47) may not have been in use for a commercial purpose in the final phase: on stylistic dating, from AD 70/75 until the eruption, the mills were removed due to a significant change in the house layout (Monteix et al. 2011, 308–11, 2012, 21–3). Despite these changes, the oven would have been kept in use for domestic purposes – or perhaps as a commercial bakery without grinding facilities – as suggested by the fuel evidence. Our main case study, both for understanding the evolution of a bakery and for its fuel use is the bakery situated in I 12, 1–2. After

its first construction – after AD 22, most probably in the early 30s – it then grew in two successive phases, first after the AD 62/63 earthquake and later during the 70s. For each of these phases, a rotary mill was added (Monteix 2016; Fig. 11.1). In the mill-room, the changes only occurred on the east side of a south–north drain, producing a major disruption in the stratigraphy. On the west side, we could not distinguish soils through a continuous succession of beaten earth layers formed by fuel residues and ashes (Fig. 11.2); on the east side, each change showed clear chronological horizons. Despite this stratigraphic contrast between the eastern and western side, we laid down a 1-m grid in order to collect as precisely as possible – within stratigraphic units – charcoal and vegetal remains.

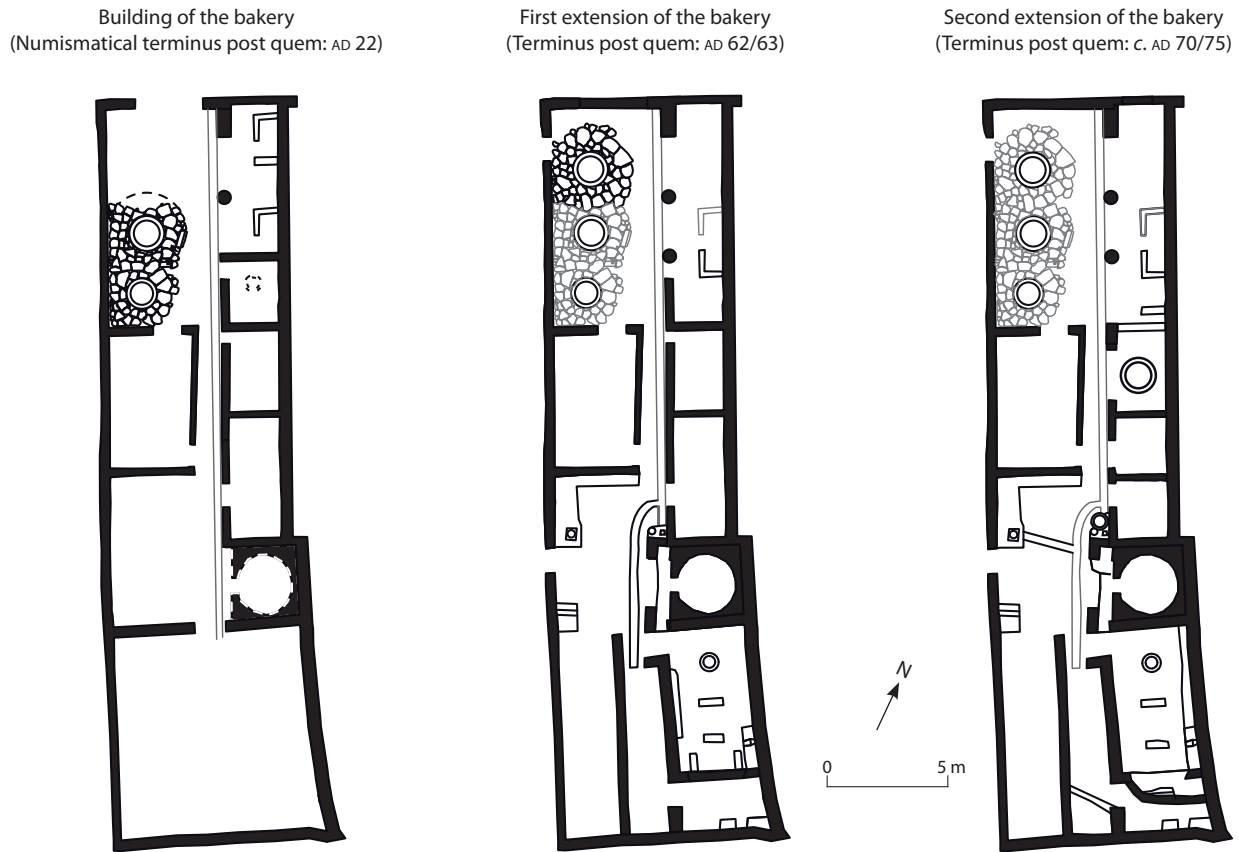
#### Sampling macro-remains

The sampling focused mainly on I 12, 1–2 and VII 1, 25.46–47, the former located at the end of the Via dell'Abbondanza, opposite to the Forum, and the latter situated close to the crossroads between the Vie dell'Abbondanza and Stabiana. In total, 267 samples representing 1818 l of raw sediment were systematically collected: 1525 in I 12 and 293 in VII 1, 25.46–47. When the sample volume is unknown, a value of 5 l has been arbitrary attributed.

Water sieving was carried out systematically on site, using 2 mm and 0.5 mm mesh sieves. The sieved samples were open-air dried. Sorting was practiced on site as well, under a stereomicroscope, at magnifications from 10 to 60.

The charcoal assemblage examined for this study was recovered mainly from 98 samples from bakery I 12, 1–2. Only 60 samples were positive. A few samples from bakery VII 1, 25.46–47 helped complete the list of taxa. In the laboratory, anatomical characteristics of wood preserved by charring were observed under





**Figure 11.1.** Changes in bakery I 12, 1–2 in Pompeii between its building and the Vesuvius eruption (drawing N. Monteix).



**Figure 11.2.** Section view of beaten earth layers in bakery I 12, 1–2 during excavation. These layers would have been created between c. AD 30 and 79 (photo N. Monteix / courtesy Soprintendenza Archeologica di Pompei).



a compound microscope, equipped with a reflected light. Identifications were achieved via the comparison of the archaeological material with modern reference material and the descriptions provided by specialized literature (Schweingruber 1990; Vernet 2001).

Most of the material comes from occupation levels, which were entirely sorted, but ashy pits discovered at the foot of the ovens and pit dumps also contained plant remains. These concentrations of seeds and charcoals, directly associated with the use of the ovens, represented 13 assemblages. For seed and fruit analyses, a sub-sampling of 5 cl of the 2 mm mesh sieving residues was applied to these concentrations. The sub-samples were all sorted for counting.

### Results of the plant remains study

Subsequently, identifications of the fruit and seeds were made and the total amount of remains established for each species (Table 11.1). All recovered plant remains were preserved by carbonization, with the exception

of six mineralized grape pips, found in the occupation levels of I 12, 1–2. Some 35 samples did not produce any remains at all, representing a volume of 178.2 l (about 10 per cent). The total number of remains (NTR) is 20,705 items, the main part of which – 15,141 items – comes from the bakery I 12, 1–2.

20,598 carbonized items were identified as *Olea europaea* endocarps (crushed olive stones, pits and kernels). *Olea* dominates the plant spectrum with 99.5 per cent of the totality of the seeds and fruit remains. The olive stones are well preserved, despite the fact that they are very fragmented. The edges appear smooth and rounded, although recent fragmentation causes sharp breaking. The complete kernels have been sorted for geometric morphometric analysis and sent to the CBAE laboratory, Montpellier, France (J.-F. Terral). 518 charred pits were processed (134 for bakery I 12, 1–2 and 384 for VII 1, 25.46–47). Geometric morphometrics and statistical analyses were applied to this material to determine the characteristics of the olive varieties used in the ovens (Blanchet 2016). Archaeological

**Table 11.1.** Relative importance of the main species identified (data V. Zech-Matterne).

		VII, 1–25	I 12, 1–2	Total
Total volume (litres)		293	1525	1818
NTR		5564	15,141	20,705
TOTAL <i>Olea</i>				20,598 (99.50%)
Total other species				107 (0.50%)
<i>Olea europaea</i>	endocarps	228	507	735 (4%)
	half endocarps	246	399	645 (3%)
	fragments	5083	14,135	19,218 (93%)
<i>Cerealia</i>	caryopsis		4	4
<i>Hordeum vulgare</i>	rachis node		2	2
<i>Triticum aestivum/durum</i>	caryopsis		1	1
Bread	fragments	1	3	4
Fabaceae	seed		6	6
<i>Lathyrus cicera/sativus</i>	seed		12	12
<i>Lens culinaris</i>	seed		2	2
<i>Vicia ervilia</i>	seed		1	1
<i>Vicia faba</i> var. <i>minor</i>	seed	2	2	4
<i>Vicia sativa</i>	seed	1		1
<i>Corylus avellana</i>	pericarp frag.	2	8	10
<i>Cupressus sempervirens</i>	bract frag.		1	1
<i>Ficus carica</i>	sycone frag.		3	3
<i>Juglans regia</i>	endocarp frag.	1	23	24
<i>Pinus pinea</i>	bract frag.		1	1
<i>Prunus persica</i>	endocarp frag.		1	1
<i>Vitis vinifera</i>	pip		29	29
Undetermined	seed		1	1

specimens were confronted to a modern reference model consisting of 42 domestic and 15 wild populations, for a total amount of 1558 pits including 1258 cultivars and 300 oleasters. These references have been gathered in a wide geographical area including Greece, France, Italy, Croatia, Cyprus, Syria, Lebanon, Tunisia and Morocco. All these varieties were reclassified in ten morphotypes by hierarchical ascending classification to distinguish correctly one variety to the others. Although olive remains are so numerous and so well preserved, it is amazing to note that the total amount of the *cerealia* reaches only 7 items and that only one single grain of wheat was retrieved.

Thirteen other taxa were noted: fruit remains mainly from hazelnut tree, cypress, fig tree, walnut, umbrella pine, peach tree and grapevine, as well as pulses (grass pea, lentil, bitter vetch, celtic bean, common vetch). Except for *Olea*, the total amount of other species represents all together 107 remains and 0.5 per cent of the total number of items. These species were present in both bakeries.

### Interpretation of plant assemblages

Considering the low representation of species other than olives, and their scattered distribution in the archaeological levels, they can probably be interpreted as consumption leftovers from the daily meals of the bakery workers. Three species could come from another source: cypress and stone pine cone bract scales, as well as peach endocarps may represent the residues of domestic burnt offerings, as scales are not edible and peaches were still rare and expensive at this time (Sadori et al. 2009). The three species form part of the funeral deposits of a number of tombs and pyre residues in the necropolis of the Porta Nocera (Zech-Matterne & Derreumeaux 2013).

The prominence of olive stones within the plant remains raises the question of their use. Fragmentation of the stones appears systematic, but to confirm this first point, the material coming from the occupation levels and from the concentrated areas was compared

to the bakery VII 1, 25.46–47. Ten samples from concentrated assemblages and 28 from dispersed refuses were examined, for a total amount of 5557 *Olea* remains (Table 11.2):

- In the concentrated assemblages, the complete stones represent 4 per cent of the total of 4379 remains and the fragments 91 per cent. Fifteen per cent of the fragments are longer than 5 mm.
- In the soil levels, the complete stones reach about the same percentages (3 per cent) and the number of fragments is a little bit higher, with 95 per cent of the total (1178 remains). Most of the fragments are between 3 and 5 mm.

The results do not differ significantly, so whether we consider the concentrations of kernels found in the pits located beneath the ovens as a primary use residue or a direct refuse after the heating of the oven, fragmented olive stones were always in the majority. Such considerable quantities of olives and the systematic fragmentation of the stones indicates that we are not dealing with food residues. On the contrary, with reference to experimental results (Margaritis & Jones 2008), the fragmentation of the olive kernels is not due to cooking or heat exposure, with an oxidizing or reducing atmosphere: even at the highest temperature (450 °C), all stones remain intact or eventually split open, taking on an ashy appearance and brittle structure, but they don't fragment. Consequently, the fragmentation took place before carbonization. This suggests the recovery of the by-products of oil pressing as a potential fuel.

Geometric morphometrics brought new outcomes that helped to characterize the olive assemblage (Blanchet 2016). The results did not display any difference between the two bakeries, in terms of diversity or morphotypes. The ovens were thus supplied with pomace probably obtained from the same varieties of olive. Geometric morphometrics enabled us to highlight a dominant morphotype (no. 5, and subtypes 5.1 and 5.2) constituted by many domestic varieties originating from both the eastern and western Mediterranean. This morphotype gives a picture of the complex history of the olive tree domestication process characterized, under human influence, by the spread from east to west of selected forms put in contact with local forms. The domestication of the olive tree is indeed multi-located, consisting of a primary centre located in the Near East and many secondary centres all over the Mediterranean. Phoenicians as well as Etruscans, Greeks and Romans alternately relayed the dispersal of olive cultivation. In addition, only a few stones were attributed to the morphotype

**Table 11.2.** Fragmentation of the *Olea* remains: comparison between the concentrations and the occupation levels (data V. Zech-Matterne).

10 concentrations VII 1, 25.46–47			
endocarps	half endocarps	fragments	Total
188	225	3966	4379
4%	5%	91%	
28 circulation levels and refuses VII 1, 25.46–47			
40	21	1117	1178
3%	2%	95%	

2 (wild type). Consequently it is quite possible that fuel consisted only of residues from domestic olives. Predominance of domestic varieties in the two bakeries could perhaps be explained by the fact that domestic trees produce more oil than wild ones. It could thus be easier to obtain bigger quantities of pomace from plantations of domestic trees than from the wild or even cultivated wild trees.

### Charcoal assemblage

The evidence acquired so far (Table 11.3) testifies to the use of a wide range of woody plants, with a minimum of 19 species for 362 charcoal fragments analysed. The absolute number of charcoal fragments and their relative frequency are the two parameters usually chosen

**Table 11.3.** Summarized results of charcoal analysis: absolute, relative and ubiquity frequency of the taxa (data S. Coubray) (x = presence).

Taxon name	Count	Taxon per cent	Ubiquity (n = 60)
<b>I 12, 1–2</b>			
<i>Fagus sylvatica</i>	207	57.7	70%
<i>Carpinus/Ostrya carpinifolia</i>	36	10	30%
<i>Quercus</i> (decid.)	20	5.6	22%
<i>Acer</i> spp.	20	5.6	15%
<i>Juglans regia</i>	1	0.3	1%
<i>Corylus avellana</i>	16	4.5	6%
Rosaceae Prunoideae	5	1.4	8%
Rosaceae Maloideae	2	0.6	3%
<i>Cornus</i> sp.	2	0.6	3%
<i>Quercus</i> (evergr.)	4	1.1	5%
Cistaceae	3	0.8	5%
<i>Rhamnus/Phillyrea</i>	1	0.3	1%
<i>Arbutus unedo</i>	2	0.6	3%
<i>Ulmus/Celtis</i>	2	0.6	1%
<i>Fraxinus</i> sp.	7	1.9	10%
<i>Salix</i> sp.	3	0.8	5%
Coniferae	5	1.4	3%
<i>Pinus</i> spp.	6	1.7	3%
<i>Juniperus</i> spp.	13	3.6	5%
indeterminate	4	1.1	
<b>TOTALS</b>	<b>359</b>	<b>100</b>	
bark fragments	3	0.8	
<b>VII 1, 25</b>			
<i>Vitis vinifera</i>	x		
<i>Arundo donax</i>	x		

to quantify taxa in charcoal analysis. The criterion of ubiquity of taxa in different samples and archaeological features is commonly used to complete the frequency results and to verify the distribution of the different species in the various archaeological structures. In this way we avoid an over-representation due to charcoal fragmentation.

The taxonomic spectrum identified includes plants from diverse biotopes – (i) highland forest, (ii) gardens and orchards, (iii) riparian woodland and (iv) Mediterranean mixed oak forest – thus suggesting that different areas were exploited as sources of fuel wood. The most important wood identified was beech (*Fagus sylvatica*), which constituted 57.7 per cent of the fuel supply and is evenly distributed among the samples (70 per cent of the samples). The major wood types of fuel supply (beech, hornbeam, maples and deciduous oaks) represent 79 per cent of the total, supplemented by a large variety of taxa. Some analyses performed on samples from bakery VII 1, 25.46–47 complete the list with giant cane (*Arundo donax*) and grapevine (*Vitis vinifera*).

The total of small branches represents 24 per cent of the charcoal assemblage. Even if the use of both shrubby and arboreal species is recorded and the fact that small sized wood is easily obtained from the first, we observed that beech provided a large amount of the smaller pieces. The temperature required for heating the oven can be obtained by using any type of wood, dense or light, if it is healthy and sufficiently dry. The temperature reached during combustion depends more on the mass and shape of the fuel wood than on the wood species used (Chabal 1999; Théry-Parisot 2001). However, in Pompeii, the taxonomic variety and the range of diameters used may reflect not only the existence of an opportunistic organization of supply, using all the available resources from different environments, even recycling pruning remains, but also a more complex wood market.

### Olive pressing by-products used as fuel

Solid residues of olive pressing (named *grignons* in French) comprise the epidermis, pulp residues, stone fragments and kernels. This was widely used all around the Mediterranean, in antiquity as well as nowadays, as a fuel. It has a good heating power despite its variation according to its composition (4780–5015 Kcal/kg = 20–21 MJ/kg = 5.5–5.8 kWh/kg; Mata-Sánchez et al. 2013). It is easily available, as a by-product from oil factories (Rowan 2015). Other traditional uses are fodder (if mixed with twigs and leaves, and after the elimination of the stones) but also soil improvement (mainly the water residues, the so-called ‘amurca’ (Nefzaoui 1991, 106–7).

The implements used for olive oil extraction and pressing were probably not very elaborate in a domestic context, but we can presume that the *trapetum* could have been used in a more collective environment such as in the Roman city of Pompeii, where mill fragments have been recovered. Cato, Columella, Varro and Pliny describe the steps required to obtain oil and Pliny recommends the use of oil residues as fuel (NH 15.22). Crushing the olives does not spoil the quality of the oil, as the seeds contain from twelve to eighteen per cent of an oil with the same chemical properties as the flesh itself.

The collection and use of pressed olive residues as fuel has been established for different situations. It occurs mainly as an opportunistic procedure to make the by-products profitable, or to replace wood in semi-arid environments (together with dung, chaff and threshing waste). However, this does not necessarily indicate wood shortage. The practice of supplying domestic hearths and later collective baths and ovens with olive residues seems to be an ancient one around the Mediterranean and was already in use at the palatial settlement of Tel Yarmouth, Israel, during the early Bronze Age (3500–2000 BC) (Salavert 2008).

In Pompeii, when it was possible to clean or excavate bakeries with beaten earth floors, olive stones were observed and sometimes sampled. From these observations, we formulated the hypothesis that the ovens in Pompeian bakeries mainly used oil extraction by-products as fuel and only occasionally wood. To test this hypothesis, we decided to take a closer look at the construction techniques for building the ovens and how they worked. Pompeian baking ovens are generally built on a square base, 70–80 cm high, above which a dome-shaped baking chamber is added, directly on the base. The first row of the base is always made of lava stones. The oven floor, where loaves are placed to be baked, is made of tiles or square bricks set on a 10–40 cm thick layer of sand that covers the masonry base of the oven (Monteix 2016). Ethnographic examples (Adam & Varène 1980, 46–50 min.) and excavation results (Fig. 11.3) suggest how they functioned. The fire was started with twigs placed in the mouth of the oven and progressively pushed towards its end. Small pieces of wood were then added to fuel the fire. When it had properly started, olive stones were added as fuel. During this pre-heating phase, the high thermal efficiency of the basalt ring set around the base allowed for huge amounts of energy to be stored, while the sandy layer just under the tile floor stopped heat from escaping from the base, thanks to its low heat conductivity, and thus kept it for further radiative heat transfer. Once the oven was ‘whitened’ (c. 550 °C), it was no longer fuelled until it reached a

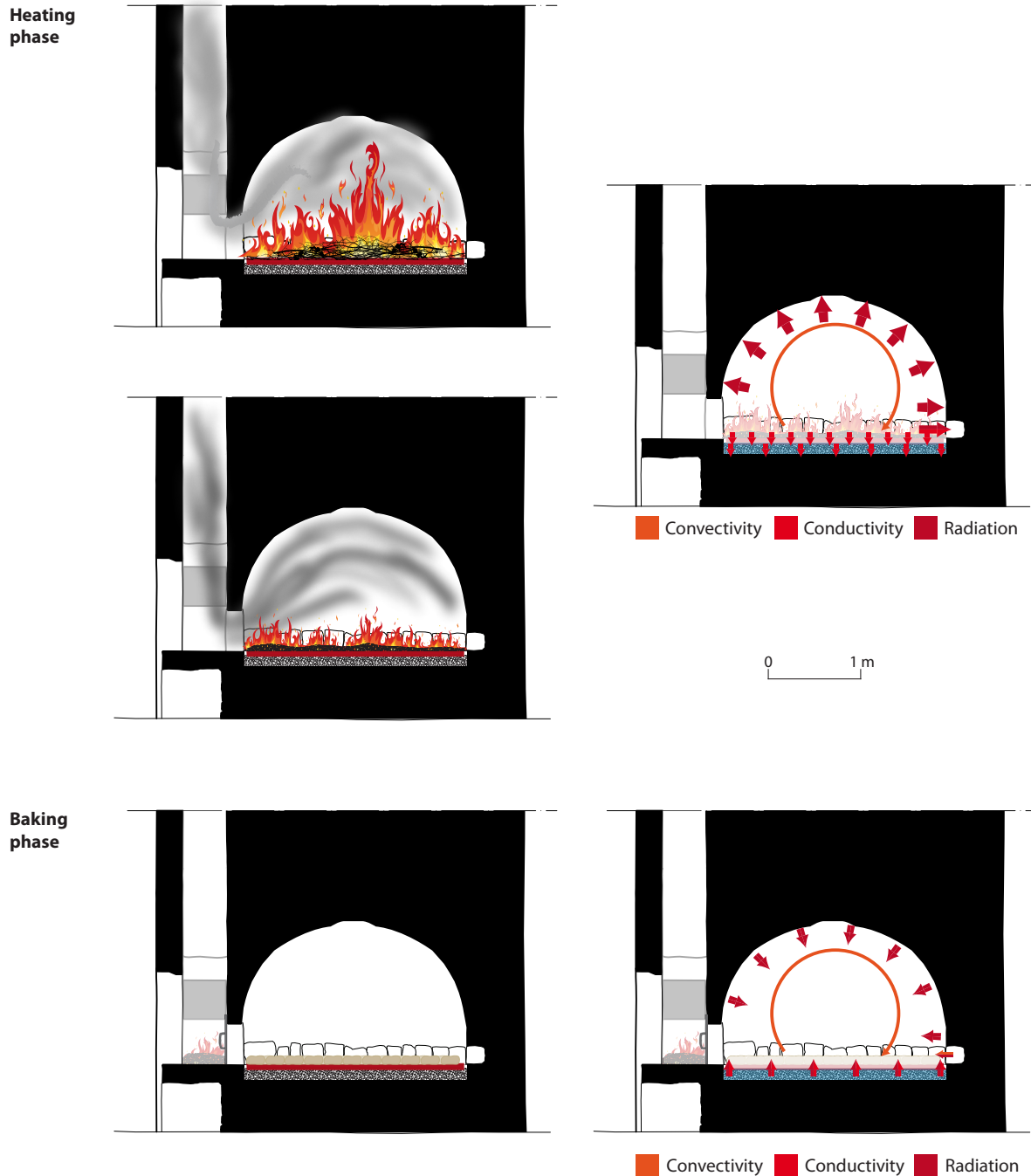
good temperature (c. 250–300 °C). Then all of the fuel was taken away and either stocked in a nearby vessel, such as an amphora or a reused and upturned mill, or used to heat the water boiler set in the oven. Leavened dough loaves were then inserted, the iron door shut, and the baking process started. During this phase, both the basalt ring and the floor slowly release their internal heat by radiative and convective heat transfer, at the same height as the loaves.

Even if both the architectural structure and the building materials help us with this reconstruction, one question remains: how and why stones, charcoal and ashes formed piles away from the oven? In order to answer this, we attempted to look at concentrations over time in the mill-room. Before this, problems and biases linked with the excavation must be underlined. Firstly, the northbound drain, in which the uppermost concentration of stones and half-stones was collected, was repaired many times and none of these repairs resulted in a proper and tight cover. In AD 79, it was filled with loose earth, rich with olive fragments and stones. While the density of fragments is almost equal to the average found in the bakery, the density for complete or half-stones per 10 l of sediment is more than three times higher in the drain.<sup>2</sup> The only explanation for such a density would be that those stones and half-stones were lost in front of the oven, where the drain with its broken cover passes, and then slipped away in the canal and sat there.

It is important to remember that the three identified phases are of unequal length (c. 32, 8 and 9 years) and that the data set collected is more precise but less complete on the east side, due to the many changes that occurred in this part of the milling room. In order to partially compensate the use of phases as a time unit when collecting fragments, we calculated per year averages for the fragments. Such a statistical mean helps us to understand the assemblages for each phase and allows a comparison from one phase to another, despite the loss of a ‘true’ absolute number of fragments and the use of per year fragment averages. On the distribution plans (Figs. 11.4 and 11.5), deposits are expressed in fragments per 10 l of sediment per year, inserted in the 1-m grid. For each phase, both sets of charcoal and olive stone fragments are divided into quartiles.

No clear pattern in concentration emerges, except a late and very narrow concentration in front of the oven. We should emphasize that no beaten earth floors survived in the oven room, most probably because of works carried out on the drain not long before the eruption. Were the ashes – and part of the not completely consumed remaining fuel – spread incidentally all around the working spaces? Observing





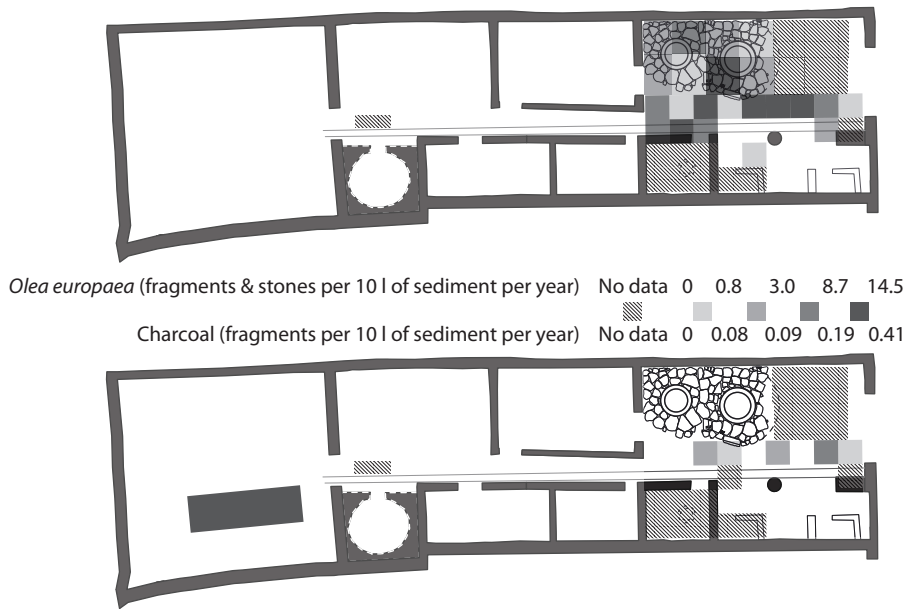
**Figure 11.3.** A Pompeiian bakery oven during heating and baking phases. On the left, ‘realistic’ cross-section; on the right, scheme of thermal exchanges (drawing N. Monteix).

the pattern of the remains, it seems quite unlikely. We could instead imagine an intentional spreading of the ashes, perhaps as an insect repellent, as suggested by Pliny (e.g. *NH* 18.73).

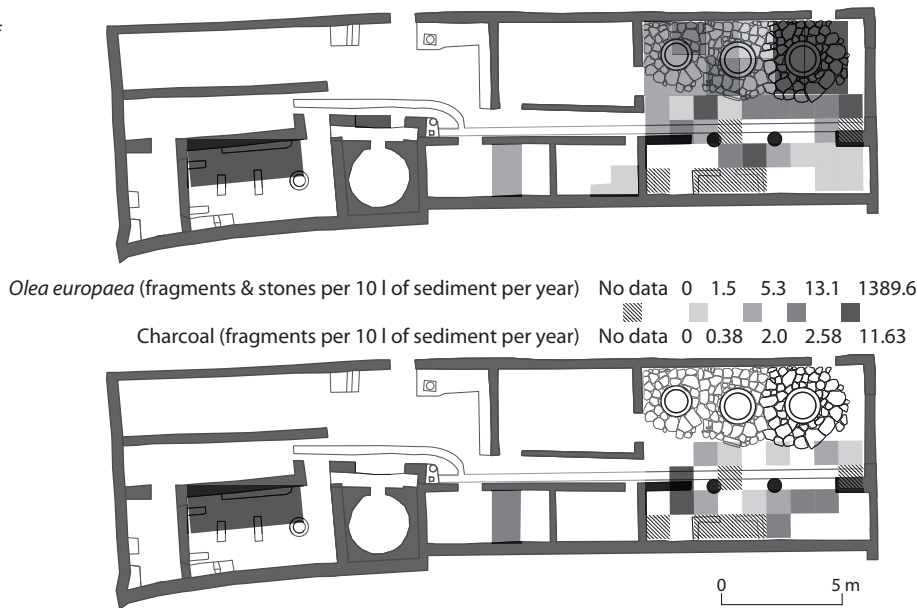
Moving away from hypothetical explanations, as a methodological test, the sampling of vegetal and

carbonized remains with a grid was relatively unsuccessful. Simply choosing samples and sieving would have been sufficient and clearly less time and energy consuming. Beyond such practical matters, excavating bakeries did emphasize the use of olive stones as an important fuel resource.

Building of the  
bakery  
(Numismatical  
terminus post  
quem: AD 22)



First extension of  
the bakery  
(Terminus post  
quem: AD 62/63)



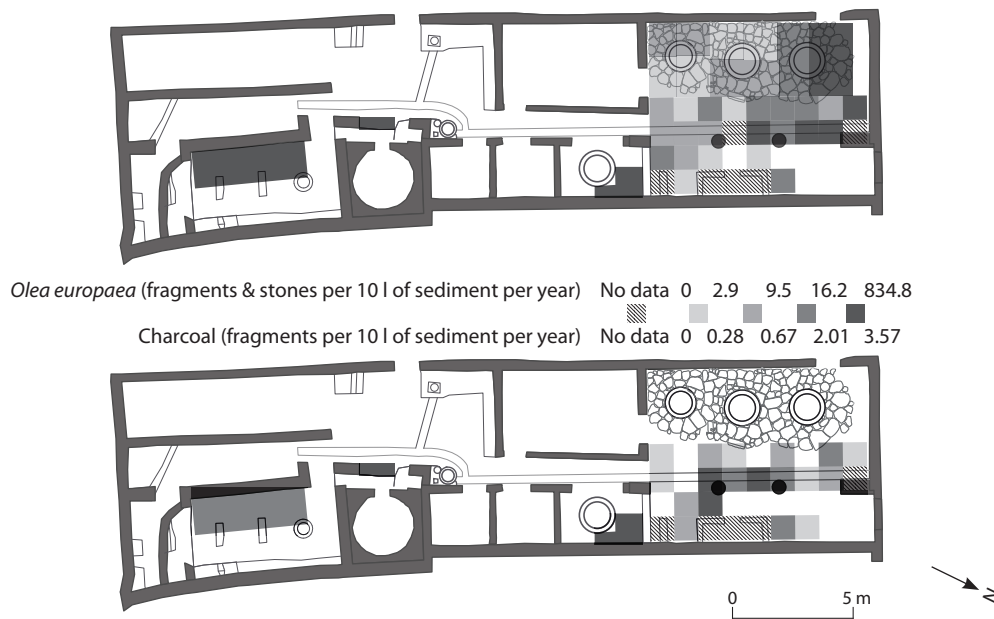
**Figure 11.4.** Distribution plans for *Olea europaea* and charcoal fragments in bakery I 12, 1–2 during the first (above) and second (below) phases (drawing N. Monteix).

This type of fuel could have come from the city itself, where oil factories or other productive activities implying the pressing of olives to obtain quantities of oil did exist in AD 79, though only a few as far as we know. Among shops and workshops with identifiable remains, three perfume workshops – situated in VII 4, 24–25, in VII 4, 31.51 [?] (Brun & Monteix 2009, 123–8) and in VII 14, 4 (Giordano & Casale 1992, 13–14) – and one oil factory in the house VI 10, 6, with all of

the proper material, from *trapetum* to press (Benedetti 2006, 153–4), are actually known within the city walls (Fig. 11.6). Outside the latter, within Pompeii's hinterland and surroundings, evidence for oil pressing has been confirmed through the presence of *trapeta* remains (Fig. 11.7).<sup>3</sup>

Understanding the extent of oil production in the Pompeian hinterland is, however, very difficult as it relies on the random discoveries of ancient villas and

Second extension  
of the bakery  
(Terminus post  
quem: c. AD 70/75)



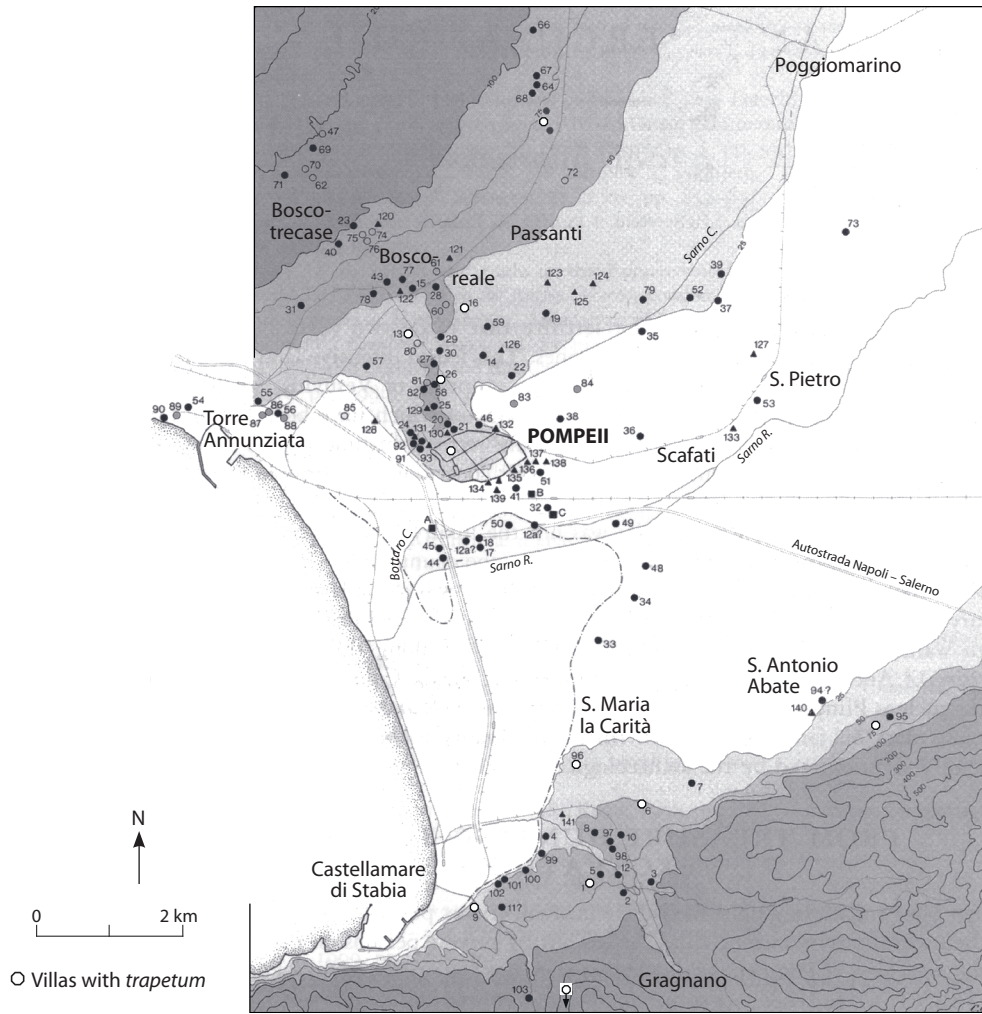
**Figure 11.5.** Distribution plan for *Olea europaea* and charcoal fragments in bakery I 12, 1–2 during the last phase (Drawing N. Monteix).



**Figure 11.6.** Oil presses and perfume workshops in Pompeii (drawing N. Monteix).

presses and *trapeta* within these premises. Despite these gaps in our knowledge, the distribution map reveals two main areas, both of them situated less than 100 m above sea level: the first to the north of Pompeii, the second around the hypothetical settlement of Stabiae. If local oil production cannot be questioned, the area of land on which it was extended raises many questions. Using estimated yields for olive trees (Amouretti & Brun 1993, 553–5), a hectare of olive trees would

have produced between 199 and 925 l of oil per year, taking into account a 10 to 20 kg per year growth and a specific weight of 0.914 kg/l. To this one to five ratio we must add the great fluctuations in population estimates at Pompeii. Recent studies suggest from 9000 (Flohr 2017) to 15,000 (Veal forthcoming). Despite the vivid debate around such an important factor, a wider perspective on oil production is needed; an estimate of 25,000 people has been proposed for the wider area



**Figure 11.7.** Known villas with trapezium around Pompeii (map base from Kockel 1985, fig. 23 – data N. Monteix).



**Figure 11.8.** Variations of land use for olive trees according to the culture mode and the estimated Pompeian population (N. Monteix).



of 'Pompeii and its hinterland' (De Simone 2017). Using an 18.5 l per year and per person consumption (Amouretti 1986, 182–3), the variations in quantifying population amplify yield estimates: olive trees could thus cover from 1.8 sq. km (lowest population, highest yield) to 32.6 sq. km (highest population, lowest yield) (Fig. 11.8), if one imagines that Pompeii and its surroundings were self-sufficient for oil, which was probably not the case as imported oil amphorae coming from North Africa (Panella 1977) and Spain (Manacorda 1977) demonstrate, suggesting in fact a low level of local production. Those estimates need to be considered as mere mathematic exercises and, in any case, only perhaps uppermost figures.

One important question relates to the circumstances leading to the use of olive pressing by-products. Was it a common habit or was it more specifically linked with wood shortage? The analysis of wood charcoal sheds some light on this question, but we should remember that the use of olive stones as fuel seems to have been in operation all around the Mediterranean, and over a very long period of time. They were used to heat domestic and craft ovens/hearths but also baths and houses (Amouretti 1993, 472–3; Bouchaud 2014; Brun 2003, 159) from the Bronze Age to the Islamic period and up until today. The advantages of using the olive residues could be their availability in large quantities, notably in the city where several craft activities could generate this kind of by-product, as well as their own qualities as fuel. Even if we do not know whether olive stones were sold or not, they were surely not wasted.

The reconstruction of wood management supports such theories. Studies of charcoal assemblages carried out over the last few years (Coubray 2013; Veal & Thompson 2008; Veal 2009, 2014) show similar patterns in the distribution of fuel, whatever the context. The major taxa – beech, oaks, hornbeams and maples – are always well represented in the charcoal assemblages, with an increase in diversity through time, especially in the first century AD. This phenomenon could be explained in part as the result of the Sullan colonization in 80 BC implying a reorganization of the territory (Veal 2014, 37). However, the strong link between the city of Pompeii and its hinterland seems to remain stable, contradicting any suggestion of wood shortage in the first century AD. From a regional perspective, current anthracological investigations in the city of Cumae in Campania (S. Coubray, unpublished data) give us the opportunity to outline the wood trade on a large scale – in which Pompeii could have played an important role, especially with respect to beech wood. Around the first century AD, we observe an important quantity of beech in the charcoal

assemblage, however nowadays this species is not present in the surroundings of the archaeological site and the pollen signal is weak or absent (Vecchi et al. 2000, 78). Beech wood suddenly disappears from the assemblages during, or at the end, of the first century AD in a striking correlation with the Vesuvius eruption. Such a disruption might be explained by the rupture of a trade route and supply centre. Ongoing isotopic analyses on modern vegetation around the archaeological site of Cumae and on archaeobotanical remains from the different occupation levels of the city will, in future, shed new light on trade systems (Coubray et al. 2013; Fiorentino et al. 2015, 221).

## Conclusion

The study of the macro-remains (seeds and charcoals) recovered from soils and occupation levels preserved in two bakeries of Roman Pompeii has allowed us to discuss the nature of the fuel used to bake bread there. In combination with the archaeological observations made on the ovens, we have reached a better understanding of their functioning.

Despite using a very large sample and the fine sieving of about two tons of sediment, charcoal remains appear rather poor and the diversity of the plant remains, seeds and fruits, somewhat limited: olives represent by far the main component. Crushed olive stones represent 99.5 per cent of the assemblages and have been interpreted as olive oil pressing by-products, intended to be reused as fuel. These kinds of waste residues have been largely and commonly considered as a very valuable fuel all over the Mediterranean. Charcoal assemblage studies indicate stability in the wood supply of the city.

Several questions remain. What were the relations between oil factories and bakeries, the modes of transport and storage of crushed olive residues, the general organization of the fuel supply, whatever its nature? To answer these questions, we need to look more broadly at the surrounding countryside as well.

## Notes

- 1 Within the 42 ovens acknowledged until now, only 6 to 7 may not have been for commercial purposes and amongst them at least 4 were out of use in AD 79. One must also underline that some of the supposed commercial ovens might not have been in use in AD 79.
- 2 Density in the drain: 8.4 half-stones for 10 l of sediment; 11.2 stone/10 l. Average density in the bakery: 2.7 half-stones/10 l; 3.5 stones/10 l.
- 3 Known *villae* with identified *trapeta* remains on the Pompeian territory: La Pisanella (Boscoreale; VR 13); Fannius Synistor (Boscoreale; VR 16; Brun 2004, 21–2);

Villa di Civita Giuliana (Proprietà Brancaccio; VR 26; Della Corte 1921; Oettel 1996, 227); Boccia al Mauro (Terzigno; villa 6; Cicirelli 1995). Known *villae* with identified *trapeta* remains on the Stabian territory: Casa di Miri (Stabia, VR 1; Brun 2004, 20–21); Villa rustica di Capella degli Impisi (Gragnano; VR 6; Miniero 1988, cat. no. 49, 238–9); Villa rustica in località Ogliaro (Gragnano; VR 9; Miniero 1988, cat. no. 57, 238–239); Villa rustica di Santa Maria la Carità (Petraro, proprietà Gargiulo, VR 96, Miniero 1988, cat. no. 13, 238–9); Olevano (Pimonte; Miniero 1988, 254–5); Villa dell’area 167 (Sant’Antonio Abate; Mastroberto & Bonifacio 2002).

## References

- Adam, J.-P. & P. Varène, 1980. *Construire et vivre à Pompéi*. Meudon: SERDDAV (CNRS Images).
- Amouretti, M.-C., 1986. *Le pain et l’huile dans la Grèce antique. De l’aire au moulin*. (Annales littéraires de l’Université de Besançon 328.) Paris: Les Belles Lettres.
- Amouretti, M.-C., 1993. Les sous-produits de la fabrication de l’huile et du vin, in *La production du vin et de l’huile en Méditerranée*, eds. M.-C. Amouretti & J.-P. Brun. (Bulletin de correspondance hellénique. Supplément 26.) Athens: École française d’Athènes, 463–76.
- Amouretti, M.-C. & J.-P. Brun, 1993. Les rendements, in *La production du vin et de l’huile en Méditerranée*, eds. M.-C. Amouretti & J.-P. Brun (Bulletin de correspondance hellénique. Supplément 26). Athens: École française d’Athènes, 551–62.
- Benedetti, C., 2006. La casa VI 10, 6, in *Rileggere Pompei. 1, L’insula 10 della Regio VI*, eds. F. Coarelli & F. Pesando (Studi della Soprintendenza archeologica di Pompei 12.) Rome: L’Erma di Bretschneider, 119–60.
- Blanchet, C., 2016. *Analyse morphométrique de noyaux d’olive carbonisés du site archéologique de Pompéi (79 AD)*, mémoire de Master 1 CEPAGE Stage d’initiation à la recherche – UE HMBE 276, ISEM, Montpellier, sous la direction de J.-F. Terral, 13 p., annexes.
- Bouchaud, C., 2014. Gestion et utilisation des combustibles végétaux dans les structures thermales. Études carpologiques et anthracologiques de cinq thermes des époques byzantines et omeyyades au Proche-Orient, in *25 siècles de bains collectifs en Orient, Proche-Orient, Égypte et péninsule Arabique*, eds. M.-F. Boussac, S. Denoix, T. Fournet & B. Redon. IFAO Collection: Etudes Urbaines 9, 595–610 (article 34).
- Brun, J.-P., 2003. *Le vin et l’huile dans la Méditerranée antique: viticulture, oléiculture et procédés de transformation* (Collection des Hespérides). Paris: Errance.
- Brun, J.-P., 2004. *Archéologie du vin et de l’huile dans l’Empire romain* (Collection des Hespérides). Paris: Errance.
- Brun, J.-P. & N. Monteix, 2009. Les parfumeries en Campanie antique, in *Artisanats antiques d’Italie et de Gaule. Mélanges offerts à Maria Francesca Buonaiuto*, ed. J.-P. Brun. (Archéologie de l’artisanat antique 2.) Naples: Centre Jean Bérard, 115–33.
- Chabal, L., L. Fabre, J.-F. Terral & I. Théry-Parisot, 1999. L’anthracologie, in *La botanique* (Archéologiques). Paris: Errance, 43–104.
- Cicirelli, C., 1995. Comune di Terzigno. Località Boccia al Mauro. *Rivista di studi pompeiani* 7, 183–5.
- Coubray, S., 2013. Combustibles, modes opératoires des bûchers et rituels. L’analyse anthracologique, in *Fouille d’un quartier funéraire de la nécropole romaine de Porta Nocera (2003–2007)*, eds. W. Van Andringa, H. Duda, S. Lepetz, D. Joly & T. Lind. (Collection de l’École française de Rome 468.) Rome: École française de Rome, 1433–49.
- Coubray, S., G. Fiorentino, F. Longobardi, V. Zech-Matterne & G. Casiello, 2013. New light on ancient foodstuff gathering at Cuma (south Italy) by stable isotopes in plant remains, in *16th Conference of the International Work Group for Palaeoethnobotany*. Thessaloniki: Valamoti SM, 121.
- Della Corte, M., 1921. Altra villa rustica, esplorata dal sig. cav. Carlo Rossi-Filangieri nel fondo di Raffaele Brancaccio nella stessa contrada Civita-Giuliana (Comune di Boscoreale), nei mesi da gennaio a marzo dell’anno 1903. *Notizie degli scavi di Antichità*, 423–26.
- De Simone, G.F., 2017. The agricultural economy of Pompeii, in *The Economy of Pompeii*, eds. M. Flohr & A. Wilson. (Oxford Studies in the Roman Economy.) Oxford: Oxford University Press, 23–51.
- Fiorentino, G., J.P. Ferrio, A. Bogaard, J.L. Araus & S. Riehl, 2015. Stable isotopes in archaeobotanical research. *Vegetation History and Archaeobotany* 24(1), 215–27.
- Flohr, M., 2017. Quantifying Pompeii? Inequality, consumption and the Pompeian Economy, in *The Economy of Pompeii*, eds. A. Wilson & M. Flohr. (Oxford Studies in the Roman Economy.) Oxford: Oxford University Press, 53–84.
- Giordano, C. & A. Casale, 1992. *Profumi, unguenti e acconciature in Pompei antica*. Rome: Bardi.
- Kockel, V., 1985. Archäologische Funde und Forschungen in den Vesuvstädten I. *Archäologischer Anzeiger*, 495–571.
- Manacorda, D., 1977. Anfore spagnole a Pompei, in *L’Instrumentum domesticum di Ercolano e Pompei nella prima età imperiale*. (Quaderni di cultura materiale 1.) Rome: L’Erma di Bretschneider, 121–33.
- Margaritis, E. & M. Jones, 2008. Crop processing of *Olea europaea* L.: an experimental approach for the interpretation of archaeological olive remains. *Vegetation History and Archaeobotany* 17(4), 388–92.
- Mata-Sánchez, J., J.A. Pérez-Jiménez, M.J. Díaz-Villanueva, A. Serrano, N. Núñez-Sánchez & F.J. López-Giménez, 2013. Statistical evaluation of quality parameters of olive stone to predict its heating value. *Fuel* 113, 750–6.
- Mastroberto, M. & G. Bonifacio, 2002. Ricerche archeologiche nell’ager stabianus, in *Stabiae: storia e architettura. 250° anniversario degli scavi di Stabiae 1749–1999*, eds. G. Bonifacio & A.M. Sodo. (Studi della Soprintendenza archeologica di Pompei 7.) Rome: L’Erma di Bretschneider, 153–61.
- Miniero, P., 1988. Ricerche sull’Ager Stabianus, in *Studia Pompeiana & classica in honor of Wilhelmina F. Jashemski. 1. Pompeiana*, ed. R.I. Curtis. New Rochelle: A.D. Caratzas, 231–92.
- Monteix, N., 2016. Contextualizing the operational sequence: Pompeian bakeries as a case-study, in *Urban Craftsmen*

- and Traders in the Roman World, eds. A. Wilson & M. Flohr. (Oxford Studies in the Roman Economy.) Oxford: Oxford University Press, 153–82.
- Monteix, N., 2013. Cuisiner pour les autres. Les espaces commerciaux de production alimentaire à Pompéi. *Gallia* 70(1), 9–26.
- Monteix, N., S. Aho, A. Coutelas, L. Garnier, V. Matterné Zeck & S. Zanella, 2011. Pompéi, «Pistrina»: recherches sur les boulangeries de l'Italie romaine. *Mélanges de l'école française de Rome* 123(1), 306–13.
- Monteix, N., S. Aho, L. Garnier, C. Hartz, É. Letellier & S. Zanella, 2012. Pompéi, Pistrina. *Chronique des activités archéologiques de l'École française de Rome*.
- Nefzaoui, A., 1991. Valorisation des sous-produits de l'olivier, in *Fourrages et sous-produits méditerranéens*, eds. J.-L. Tisserand & X. Alibés. (Options Méditerranéennes. Série A. Séminaires Méditerranéens 16.) Zaragoza: CIHEAM, 101–8.
- Oettel, A., 1996. *Fundkontexte römischer Vesuvvillen im Gebiet um Pompeji: die Grabungen von 1894 bis 1908*. Mainz: Verlag Philipp von Zabern.
- Panella, C., 1977. Anfore tripolitane a Pompei, in *L'Instrumentum domesticum di Ercolano e Pompei nella prima età imperiale*. (Quaderni di cultura materiale 1.) Rome: L'Erma di Bretschneider, 135–49.
- Rowan, E., 2015. Olive oil pressing waste as a fuel source in Antiquity. *American Journal of Archaeology* 119(4), 465–82.
- Sadori, L., E. Allevato, G. Bosi, G. Caneva, E. Castiglioni et al., 2009. The introduction and diffusion of peach in ancient Italy, in *Plants and Culture. Seeds of the Cultural Heritage of Europe*, eds. J.-P. Morel & A.M. Mercuri. (Studio, tutela e fruizione dei Beni Culturali 3.) Bari: Edipuglia, 45–61.
- Salavert, A., 2008. Olive cultivation and oil production in Palestine during the Early Bronze Age (3500–2000 BC). The case of Tel Yarmouth, Israël. *Vegetation History and Archaeobotany* 17, 53–61.
- Schweingruber, F.H., 1990. *Anatomie europäischer Hölzer: ein Atlas zur Bestimmung europäischer Baum- Strauch- und Zwergstrauchhölzer*. Bern: Haupt.
- Théry-Parisot, I., 2001. *Économie des combustibles au Paléolithique: expérimentation, taphonomie, anthracologie*. (Dossier de documentation archéologique 20.) Paris: CNRS Éditions.
- Veal, R., forthcoming. Roman Campania: evidence for a wetter micro-climate and implications for the agricultural economy. *Antiquity*.
- Veal, R., 2009. *The Wood Fuel Supply to Pompeii Third Century BC to AD 79. An Environmental, Historical and Economic Study Based on Charcoal Analysis*. Ph.D. thesis, University of Sydney.
- Veal, R., 2014. Pompeii and its hinterland connection: the fuel consumption of the House of the Vestals (c. third century BC to AD 79). *European Journal of Archaeology* 17(1), 27–44.
- Veal, R. & G. Thompson, 2008. Fuel Supplies for Pompeii. Pre-Roman and Roman charcoals of the Casa delle Vestali, in *Charcoals from the Past. Cultural and Palaeoenvironmental Implications*, eds. G. Fiorentino & D. Magri. (BAR International series 1807.) Oxford: Archaeopress, Hadrian Press, 287–97.
- Vecchi, L., C. Morhange, P.-F. Blanc, J.-P. Goiran, B.T. Mai et al., 2000. La mobilité des milieux littoraux de Cumes, Champs Phlégréens, Campanie, Italie du Sud. *Méditerranée* 94(1), 71–82.
- Vernet, J.-L. (ed.), 2001. *Guide d'identification des charbons de bois préhistoriques et récents: Sud-Ouest de l'Europe, France, péninsule ibérique et îles Canaries*. Paris: CNRS Éditions.
- Zech-Matterne, V. & M. Derreumeaux, 2013. Macrorestes végétaux dans les pratiques funéraires. L'apport de la carpologie, in *Fouille d'un quartier funéraire de la nécropole romaine de Porta Nocera (2003–2007)*, eds. W. Van Andringa, H. Duda, S. Lepetz, D. Joly & T. Lind. (Collection de l'École française de Rome 468.) Rome: École française de Rome, 1401–31.





---

## Epilogue

### Final discussions

Robyn Veal & Jim Ball

#### Introduction Robyn Veal

The conference was greatly enhanced by many lively discussions, both during the proceedings and over coffee, lunch and dinner. The closing discussion was led by Professor Andrew Wilson, who presented a brilliant synthesis of the conference as well as ideas for future directions.

This conference and the papers reported here have helped shed light on an important economic subject, for which there is much scope for further work. We appeal to all archaeologists to recognize the importance of collecting environmental remains, especially charcoal. Scientific studies on the quality and types of archaeological charcoal are developing fast, and so collection of all organic remains through both excavation and flotation is essential.

The study of fuel economics in the Roman or indeed in any ancient world is at a pivotal point. In time, with new research, it may be possible to synthesize regional patterns of supply and consumption for the Mediterranean. Alongside the economic view, we also need to describe in more detail the organization of the social and industrial structures that underpinned the fuel economy. This *chaîne opératoire* was something we hoped to find in this conference, but it was realized only in part, and this remains an important area for future research. Finally, quantitative modelling, in particular Bayesian modelling, could provide a useful way to examine fuel consumption patterns more accurately, taking into account the differing reliability of variables in different locations; and developing a feel for which variables were the most important in a particular locale through sensitivity analysis. This work has only just begun.

The Roman world is, of course, only one large consumer of fuel over around a millennium. Scholarship has not yet provided sufficient data to evaluate

the rest of the world's fuel consumption through time (although various pre- and proto-historic peoples have received detailed attention in case studies, notably at Gordion and Çatalhöyük). It would be useful to note how we might proceed for other geographic zones and historical time periods. The Chinese Song Dynasty (tenth to thirteen centuries) comes to mind as one culture similar to Imperial Rome in terms of population and technological advancement. In this period, the Song moved from firing kilns with wood to firing them with coal (a feat not repeated until the nineteenth century in the west with the introduction of the blast furnace). The relevance of studying ancient fuel remains appears to have become more important today as we consider the modern-world problems of pollution and climate change; and the potential of pelletized wood (at perhaps 70 per cent of the calorific value of coal)<sup>1</sup> as a part of our fuel future. This use of wood is in contrast to keeping the trees in the ground to facilitate carbon storage. Forest cultivation for fuel, carbon storage (and timber) then must be considered in light of land/space competition for growing food.

Finally, in closing, our second discussant, Jim Ball, former head of the FAO Forestry department, gave us an entertaining and interesting picture of some present-day forestry data relating to fuel studies, especially those in developing countries. His presentation is provided here in summarized form.

#### Wood fuels in the present-day context, or 'What can the past learn from the present?' Jim Ball

The studies of ancient fuel use we have heard at this conference may offer a framework for connecting ancient fuel use to that of more recent times. However, as a modern-day forester, I offer here some insights that may be of interest to those carrying out future research into ancient fuel use. As part of the FAO

(Food and Agriculture Organization) of the United Nations, the FAO Forestry Department concerns itself with forests and their growth, protection and expansion economically. The department's main role is the collection of data in the sector, as well as offering advice to countries in relation to the management of their forests including all aspects of the production and use of wood fuel, charcoal and non-wood forest products. Here I offer some information on wood fuel and charcoal production from a global perspective. Much of the information originates from FAO Forestry research, and many publications are available online.<sup>2</sup>

### *The global context*

Putting wood fuels, of which charcoal is one, into a global context there are a number of variables:

- When wood or charcoal is used in a stove, for example, the former wastes more energy than the latter. 1 kg of air-dried wood, when burned, gives around 280 Kcal of energy (depending on the species), while 1 kg charcoal gives 420 Kcal, or over 40 per cent more (however, we must consider how much wood was used to make the charcoal – and this varies!)
- Global consumption of wood fuel for domestic use in 2011 was 1.87 billion m<sup>3</sup> (billion being one thousand million), which is even more than industrial roundwood, which was 1.5 billion m<sup>3</sup>.
- In 2010, the value of the charcoal trade in Tanzania was \$US650 million/year.
- Presently, African Commonwealth countries use 0.6 m<sup>3</sup> fuelwood/head/year in the home, which is five times more than industrial wood. In Sudan, we estimated 0.88 m<sup>3</sup>/head/year.
- There are few estimates of the disaggregation of firewood and charcoal, but a guesstimate from Sudan in the 1980s was that charcoal was 44 per cent of total fuelwood demand.
- The price of wood and charcoal fuel is an important component of the cost-of-living index in several African countries.

### *Efficiency of conversion of raw wood into charcoal*

- Today's traditional earth kilns, which I presume are similar to those used by the Romans, have a conversion efficiency of 20–30 per cent, depending on the skill of the operator, and the sort of incentive they had (i.e. around 3 to 5 kg, more-or-less, of moist wood are used to make 1 kg of charcoal). Experienced operators in Sudan can achieve 30 per cent, inexperienced workers in Brazil 18–20

per cent. This conversion efficiency is calculated from standing trees, measured over-bark, through felling, cross-cutting, burning, and loading into sacks or trucks. Since much of the charcoal evidence presented in this conference suggests the use of coppice, or small woods (in a presumably sustainable way) in the Roman period, we need to use caution in making direct comparisons.

- Roman slaves may have had little incentive to be efficient, but if the charcoal burners were self-employed they had every reason to be as efficient as possible.
- Efficiency may also be improved by removing bark and by using saws (7.5 per cent loss) and not axes (15 per cent loss).

### *Transport and 'fines'*

In Sudan charcoal is transported by truck over hundreds of kilometres, resulting in the production of a lot of 'fines,' i.e. charcoal that has broken down into dust. These are usually disposed of as waste, and in Sudan amount for up to 20 per cent of the total amount of charcoal transported. I can't imagine that transport in bulk by un-sprung Roman ox-cart produced fewer fines, although river or sea transport would have been smoother. 'Harder' woods (i.e. those often with a higher specific gravity) are more resistant to abrasion.

### *Landlords and charcoal*

In Nigeria during the oil boom of the mid-1970s, many people came to the towns from the countryside and rented accommodation. Landlords didn't want their house walls knocked around by firewood and insisted in the terms of the rental contract that the tenant use charcoal. Was there a similar situation at the height of the Roman Empire?

### *Wood properties: Uganda and Sudan*

Despite the fact that denser woods make better charcoal from the point of view of heat, and length of burn, the method is to clear fell all of the trees in a gap and burn them all, as opposed to a selection-based felling, which from a forester's point of view could in some situations be silviculturally preferable, since some cover would be retained over the soil. From the charcoal burner's point of view, they may have preferred to have a mixture of tree species, since some burn easier than others, in order, for example, to start the fire. These soft species would likely have been consumed entirely, and thus would be poorly represented in archaeological charcoal.

### *Transport of wood and charcoal*

Transport in modern-day Africa is usually in sacks of charcoal for small-scale use, or else by the small parcel in the market. Only large-scale industrial users transport wood fuel in bulk. Long-distance transport adds considerably to the cost – and sometimes one wonders if more energy is used in the transport of the fuel than is carried!

### *Processing*

Air-drying in the sun of pots, bricks or wood for charcoal burning would have presumably been an important factor in reducing wood fuel use in Mediterranean countries, as it is today in many African countries.

### *Modern silviculture*

Human intervention in forest management to influence the frequency of a particular tree species is more prevalent today. Two examples are of interest. The first is chestnut (*Castanea sativa*) which, beginning in Roman times, was an important foodstuff and became increasingly cultivated. The second is European silver fir (*Abies alba*), which appears to have been consumed for construction in the Roman period, so much so, that numbers diminished over time. Later, regeneration

was encouraged by Benedictine monks from the seventeenth century at Vallombrosa near Florence (and possibly elsewhere) because of high demand for naval masts. Good prices were obtained for this wood.

### *Ironing*

How did the Romans iron clothes? By banging a charcoal iron down while ironing, one's house staff could make sparks shoot out of a charcoal iron in Kenya and produce a fine speckled effect of little burns on one's shirt!

### **Notes**

- 1 Thran et al. (2017). See also Food and Agriculture Organization (2011), and subsequent years.
- 2 [www.fao.org/forestry/en/](http://www.fao.org/forestry/en/)

### **References**

- Food and Agriculture Organization, 2011. *Energy Grows on Trees: Global forest institutions highlight vital role of forests to cope with future demands for bioenergy, but call for balanced approaches*. [http://www.iufro.org/download/file/7804/5018/forest-bioenergy-cpf111107\\_pdf/](http://www.iufro.org/download/file/7804/5018/forest-bioenergy-cpf111107_pdf/)
- Thran, D., D. Peetz & K. Schaubach, 2017. *Global Wood Pellet Industry and Trade Study*. IEA Bioenergy: Task 40. [http://task40.ieabioenergy.com/wp-content/uploads/2013/09/IEA-Wood-Pellet-Study\\_final-july-2017.pdf](http://task40.ieabioenergy.com/wp-content/uploads/2013/09/IEA-Wood-Pellet-Study_final-july-2017.pdf)





# Fuel and Fire in the Ancient Roman World

The study of fuel economics in the Roman, or indeed in any ancient world, is at a pivotal point. New research in archaeological science, the ancient economy, the ancient environment, and especially, the increasing collection of bio-archaeological datasets, are together providing a greatly enriched resource for scholars. This volume makes a first attempt to bridge the gap between 'top-down' generalized models about Roman energy consumption with the 'case study' detail of archaeological data in the Mediterranean. The papers here are the work of scholars from a variety of disciplines: from archaeobotanists and historians to archaeologists specialising in social, technical and economic fields. A more nuanced view of the organization of the social and industrial structures that underpinned the fuel economy arises. Although focused on the Roman period, some papers extend beyond this era, providing contextual relevance from the proto-historic period onwards. Much exciting interdisciplinary work is ahead of us, if we are to situate fuel economics more clearly and prominently within our understanding of Roman economics, and indeed the ancient Mediterranean economy.

## Editors:

**Robyn Veal** is a researcher at the McDonald Institute for Archaeological Research, and a Quondam fellow at Hughes Hall, University of Cambridge. At the time of writing she was an honorary research fellow at the University of Sydney, and spent time as a Raleigh Radford fellow at the British School at Rome. She works with a number of international excavation teams as an environmental archaeology advisor and charcoal specialist.

**Victoria Leitch** has a D.Phil from the University of Oxford on the production and trade of Roman North African cooking wares. She currently works as the Publications Manager for the Society for Libyan Studies.

*Published by the McDonald Institute for Archaeological Research,  
University of Cambridge, Downing Street, Cambridge, CB2 3ER, UK.*

The McDonald Institute for Archaeological Research exists to further research by Cambridge archaeologists and their collaborators into all aspects of the human past, across time and space. It supports archaeological fieldwork, archaeological science, material culture studies, and archaeological theory in an interdisciplinary framework. The Institute is committed to supporting new perspectives and ground-breaking research in archaeology and publishes peer-reviewed books of the highest quality across a range of subjects in the form of fieldwork monographs and thematic edited volumes.

Cover design by Dora Kemp and Ben Plumridge.

ISBN: 978-1-902937-91-5

