McDONALD INSTITUTE CONVERSATIONS

Fuel and Fire in the Ancient Roman World

Towards an integrated economic understanding

Edited by Robyn Veal & Victoria Leitch

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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

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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 Commonwealth Forests Chairman (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

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.[1]

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

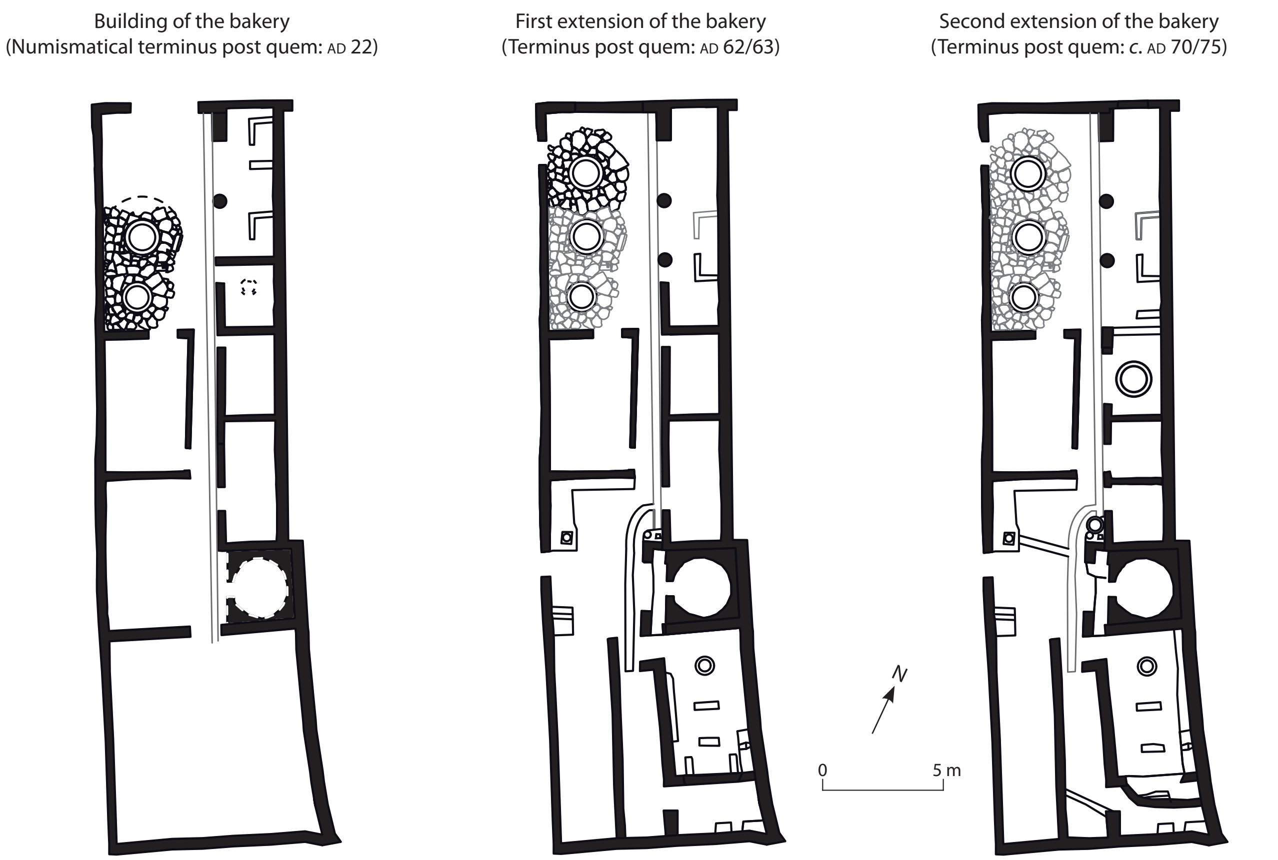

Figure 11.1. *Changes in bakery I 12, 1–2 in Pompeii between its building and the Vesuvius eruption (drawing N. Monteix).*

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 Olea				20,598 (99.50%)
Total other species				107 (0.50%)
Olea europaea	endocarps	228	507	735 (4%)
	half endocarps	246	399	645 (3%)
	fragments	5083	14,135	19,218 (93%)
Cerealia	caryopsis		4	4
Hordeum vulgare	rachis node		2	2
Triticum aestivum/durum	caryopsis		1	1
Bread	fragments	1	3	4
Fabaceae	seed		6	6
Lathyrus cicera/sativus	seed		12	12
Lens culinaris	seed		2	2
Vicia ervilia	seed		1	1
Vicia faba var. *minor*	seed	2	2	4
Vicia sativa	seed	1		1
Corylus avellana	pericarp frag.	2	8	10
Cupressus sempervirens	bract frag.		1	1
Ficus carica	sycone frag.		3	3
Juglans regia	endocarp frag.	1	23	24
Pinus pinea	bract frag.		1	1
Prunus persica	endocarp frag.		1	1
Vitis vinifera	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.

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%	

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 where 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

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 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.

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

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 Pompeiian 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. Pompeiian 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.[2] 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

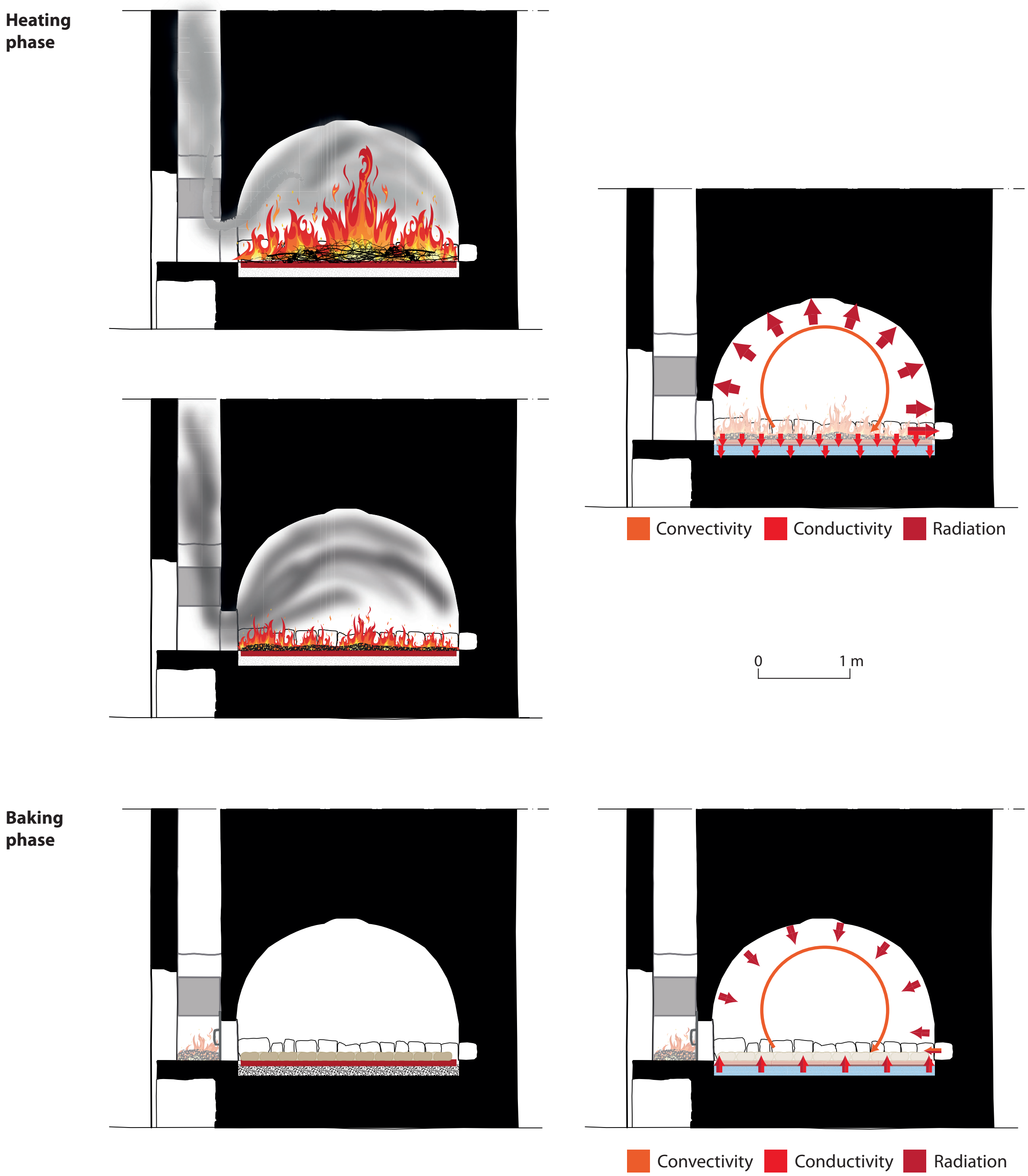

Figure 11.3. *A Pompeiian bakery oven during heating and baking phases. On the left, 'realistic' cross-section; on the right, scheme of thermal exchanges (drawing N. Monteix).*

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.

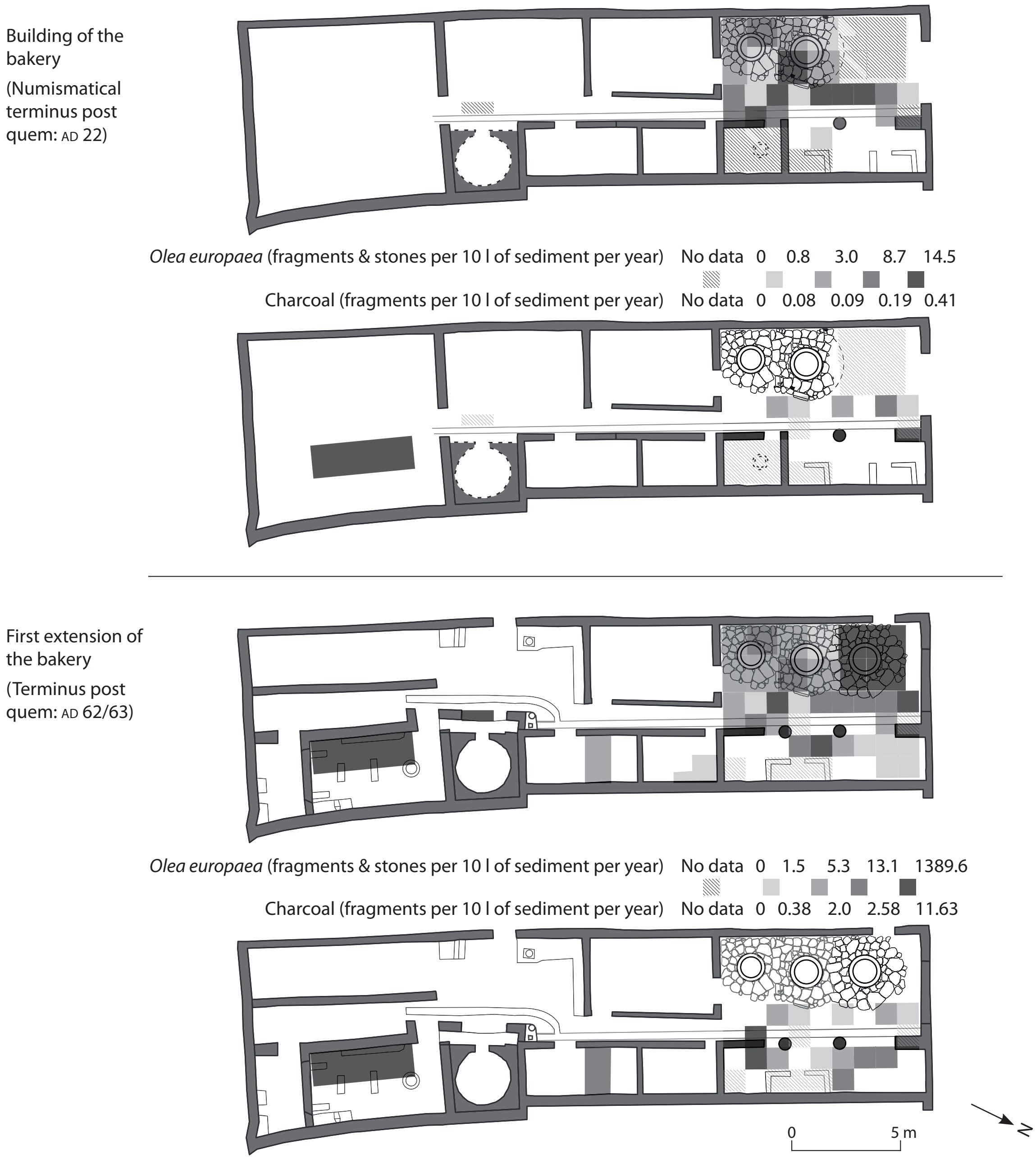

Figure 11.4. *Distribution plans for* Olea europaea *and charcoal fragments in bakery I 12, 1–2 during the first (above) and second (below) phases (drawing N. Monteix).*

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).[3]

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

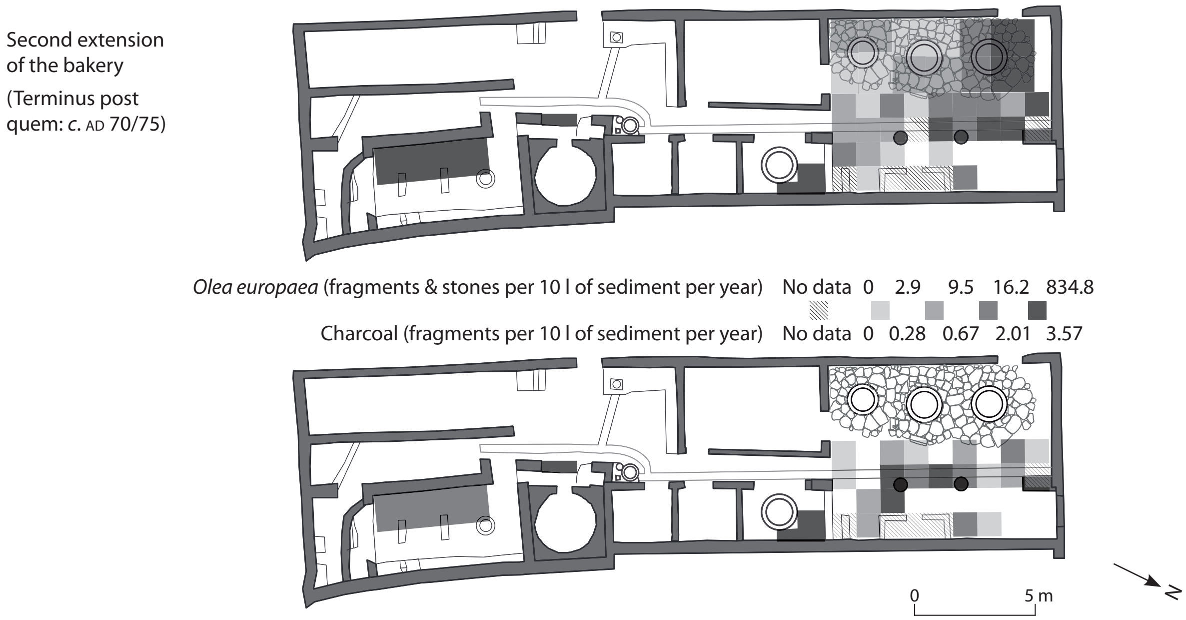

Figure 11.5. *Distribution plan for* Olea europaea *and charcoal fragments in bakery I 12, 1–2 during the last phase (Drawing N. Monteix).*

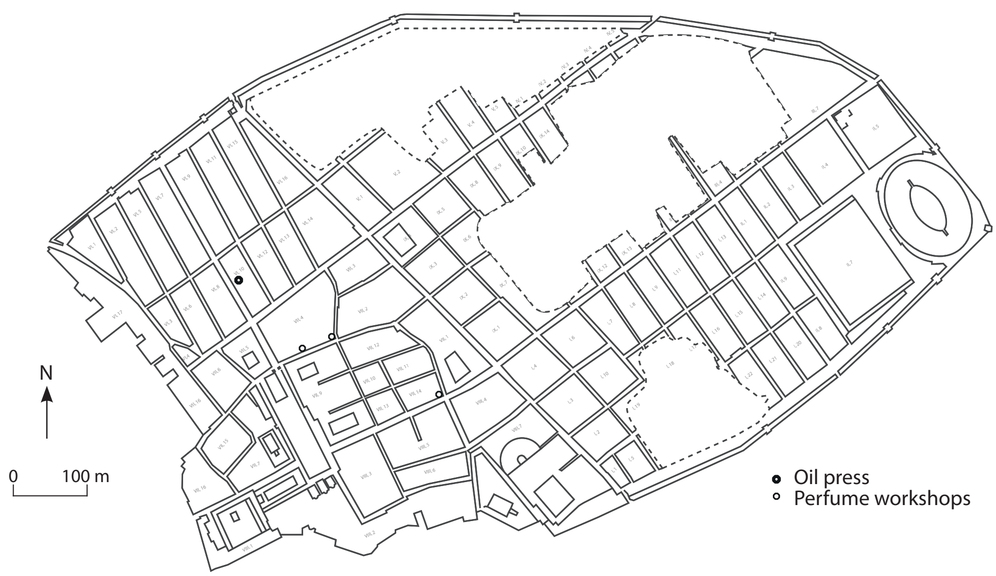

Figure 11.6. *Oil presses and perfume workshops in Pompeii (drawing N. Monteix).*

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

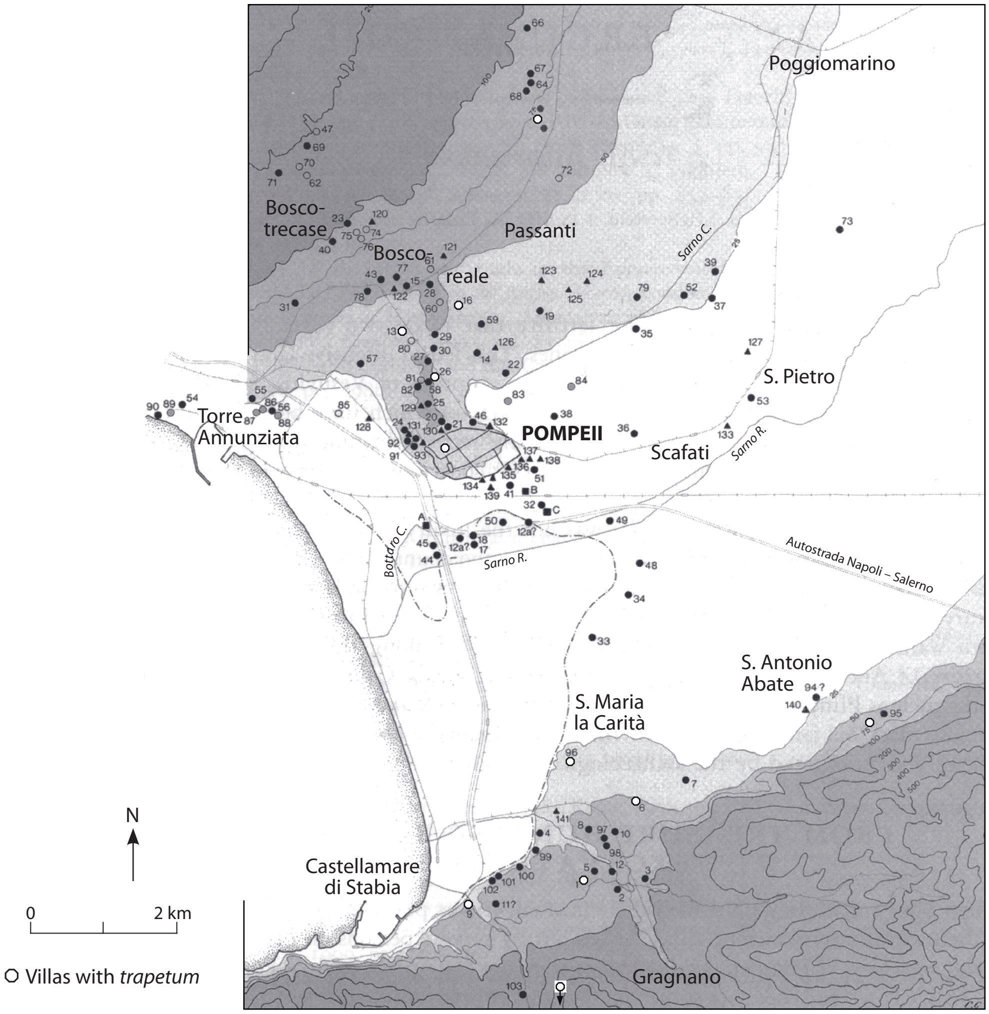

Figure 11.7. *Known villas with* trapetum *around Pompeii (map base from Kockel 1985, fig. 23 – data N. Monteix).*

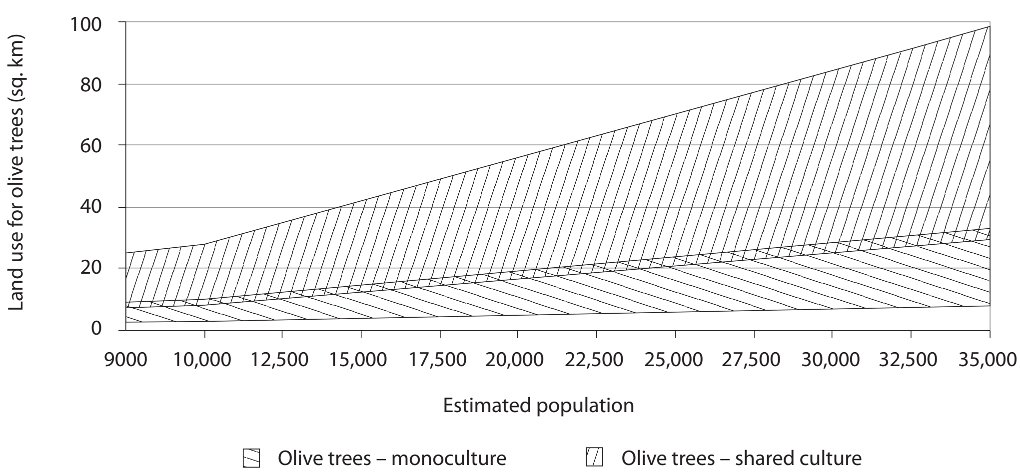

Figure 11.8. *Variations of land use for olive trees according to the culture mode and the estimated Pompeiian population (N. Monteix).*

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 Pompeiian 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; Mastroroberto & 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'araire 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, Egypte 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. Duday, 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.

Mastroroberto, M. & G. Bonifacio, 2002. Ricerche archeologiche nell'*ager stabianus*, in *Stabiae: storia e architettura. 250º 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. Matterne 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. Maï 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. Duday, S. Lepetz, D. Joly & T. Lind. (Collection de l'École française de Rome 468.) Rome: École française de Rome, 1401–31.

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.

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