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 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

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).[1] 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 × 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; Vitr. *De arch*. II, 9; Plinio *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 conburendi 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 segnio 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, cresciendo troppo il fuoco, gli lavori si piegano e vengan frigni, e cossì non pigniano puoi il bianco. E tengasi il fuoco cossì che la fornace si vegga bianca, cioè tutta infocata; e quando ella harà avuto viccino 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

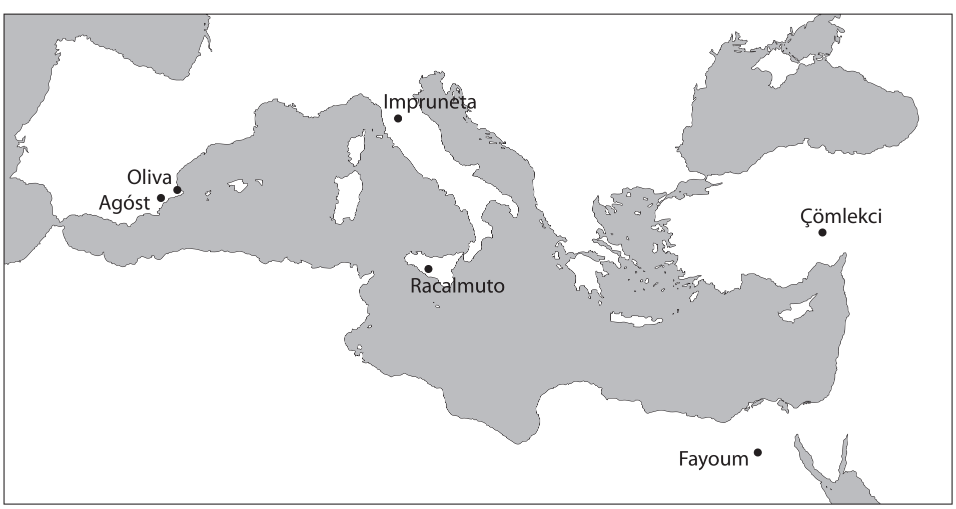

Figure 8.2. *Map of the modern production sites mentioned in this chapter.*

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,[2] 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).[3] 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 are 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), Philoteras (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-Manzaneque 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 àrabe' 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 àrabe' 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 (*Arundo donax*)	15.5 – 16.5	4 – 5%
Cardoon (*Cynara cardunculus*)	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.

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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/

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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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