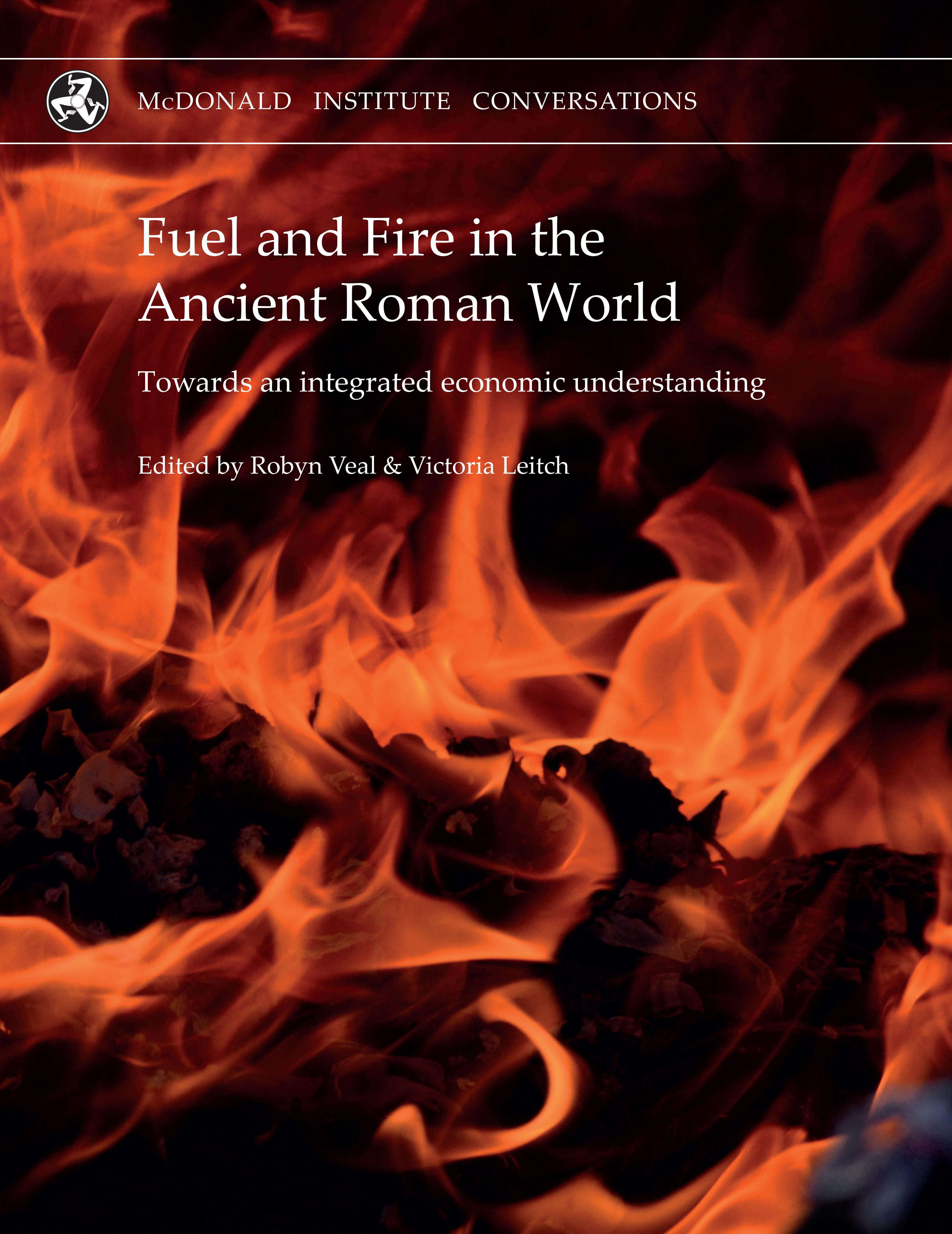
McDONALD INSTITUTE CONVERSATIONS

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,
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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 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.[1] 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).[2]

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 firebox 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 × 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).[3]

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.[4]

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.

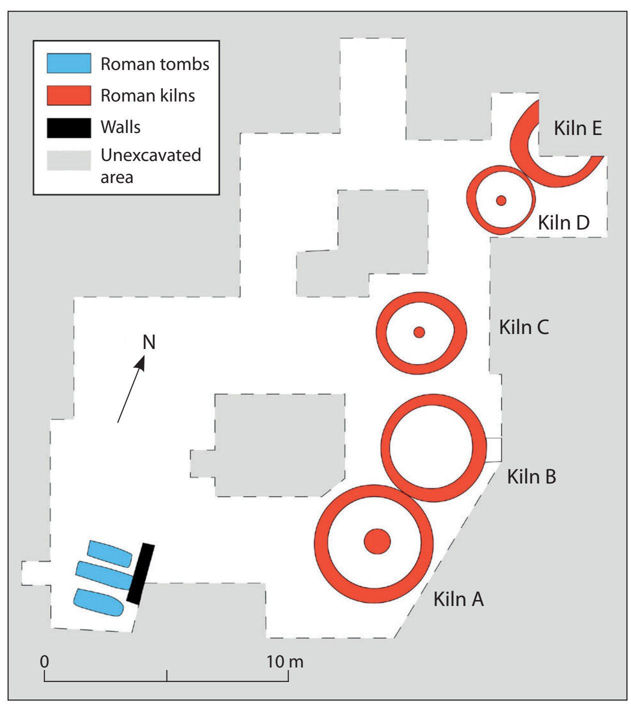

Figure 5.2. *Schematic plan of the Leptiminus kiln site (after Stirling 2001, 220).*

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.[5] 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 was scarce (Van Zeist et al. 2001).[6]

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.[7]

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,[8] 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.[9] 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.[10]

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.[11] 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?),[12] 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.[13] 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.[14] 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.

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Notes

1 Swan (1984) is now partly digitized: 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.

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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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