Archaeometry **42**, 1 (2000), 61–76. Printed in Great Britain

WHY A KILN? FIRING TECHNOLOGY IN THE SIERRA DE LOS TUXTLAS, VERACRUZ (MEXICO)*

C. A. POOL

Department of Anthropology, University of Kentucky, 211 Lafferty Hall, Lexington, Kentucky 40506-0024, USA

The benefits of one ceramic firing technology over another are not absolute, but depend upon the interaction of multiple environmental, economic and social factors, as well as the specific design of firing facilities. The coexistence of updraft kilns and open firing methods in the Sierra de los Tuxtlas, Veracruz, Mexico, for over 1700 years provides a case-in-point. Evaluation of the performance characteristics of ancient and modern firing technologies in relation to their natural and behavioural contexts offers a more secure basis for understanding this specific historical instance of long-term polymorphism than explanations based in the generalized technological advantages of kilns or their cross-cultural association with intensive modes of production.

KEYWORDS: MESOAMERICA, MEXICO, VERACRUZ, MODERN, PREHISPANIC, ETHNOARCHAEOLOGY, CERAMICS, FIRING, KILN, PERFORMANCE CHARACTERISTICS, TECHNOLOGICAL CHOICE

The answer to the question, 'Why a kiln?', probably seems patently obvious to most archaeologists. In Dean Arnold's (1985, 213) words, 'It is primarily the insulating qualities of the kiln (which prevent heat loss during firing) and the greater control that the potter has over the firing process that makes the kiln a more evolved and more effective innovation for ceramic production than other firing methods.' Frequently cited advantages of kilns over non-kiln methods include protection of the kiln load from wind and rain, attainment of higher maximum temperatures, greater fuel efficiency, and control over the rate of temperature increase (ibid., 213; Gosselain 1992, 246; Rice 1987, 153; Rye 1981, 98; Shepard 1980, 75). So clear are the presumed advantages of kilns that Anna Shepard (1980, 75) wondered that 'In view of the simplicity of building an updraft kiln, it is surprising that crude improvised methods of firing were so widespread among prewheel potters and permanent kilns so rare.'

In some places, however, both kiln and non-kiln firing methods coexist. These cases serve to remind us that the advantages of kilns are not absolute. Mesoamerica is one such area. Until recently, it was thought that updraft kilns were first introduced to the New World by the Spanish in the early sixteenth century as part of a technological complex that included glazing and throwing on the wheel (D. E. Arnold 1985, 218; Foster 1955, 1; cf. Rice 1987, 153). These European methods contrasted with native Mesoamerican traditions, which employed hand-modelling and moulding, slipping and painting, and, it was thought, only open firing methods (Foster 1955, 1). Given these assumptions, it was reasonable for Foster (ibid., 28, and 1967, 103–4) to conclude that contemporary variation in Mesoamerican firing methods resulted largely from differential acculturation to European norms, grounded in differing world views held by specific social and ethnic groups. In particular, traditional indigenous and peasant potters

* Received 9 March 1999, accepted 11 August 1999.

were held to be highly conservative and strongly influenced by community standards emphasizing custom (or *costumbre*) (Reina and Hill 1978, 242) and an 'Image of Limited Good' (Foster 1962, 1965a and 1965b).

As applied to firing technology, Foster's (1955 and 1967) acculturation model is less convincing for regions such as the Valley of Oaxaca and the Sierra de los Tuxtlas, where open and kiln firing methods are used by peasant potters living in different communities less than 30 km apart (P. J. Arnold 1991a; Balkansky *et al.* 1997). Table 1 summarizes ethno-linguistic and technological information for pottery communities in the two regions. Contrary to the implications of Foster's model, kiln firing cuts across the acculturative divide between Spanish-speaking mestizos and speakers of the indigenous Zapotec and Nahuat languages, and, more significantly, open firing is not practised only by less acculturated indigenous potters. Furthermore, with the exception of green-glazed pottery production at Santa María Atzompa, Oaxaca, kiln firing in these areas is not associated with other Spanish-introduced production methods. Archaeology has dealt the final blow to the acculturation model by demonstrating that kilns were used long before the Spanish conquest in both regions (Pool 1990 and 1997a; Santley *et al.* 1989; Winter and Payne 1976).

Drawing on the cross-cultural association of kilns with specialized pottery production, Balkansky *et al.* (1997, 155–6) suggest that variation in firing technology in the Valley of Oaxaca and the Sierra de los Tuxtlas was a consequence of differing production intensities in the modern and ancient contexts alike (cf. P. J. Arnold 1991a; Pool 1997a). Indeed, the data on marketing patterns in Table 1 tend to support this thesis, despite the fact that production is carried out in household contexts in all these communities. Nevertheless, the case of Sehualaca, which produces open-fired pottery for regional exchange in the market of Santiago Tuxtla, shows that kiln firing is not an inevitable outcome of increased production intensity. Rather, choosing a particular firing method involves weighing its advantages and disadvantages with respect to specific requirements for using available resources, organizing labour, and producing the desired range of products. Explanations for the use of kilns based on their cross-cultural association with intensive modes of production or their general technological characteristics fail to capture the complex interaction of these factors and are inadequate to explain any particular historical instance of their adoption. In this paper I use a behavioural approach that seeks to explain formal variation in firing technology as the result of technological choices grounded in the performance characteristics of firing facilities as they relate to their specific natural, social and economic contexts (Schiffer and Skibo 1997).

MODERN AND ANCIENT FIRING METHODS IN THE SIERRA DE LOS TUXTLAS

Philip Arnold (1991a, 51–6) has described contemporary firing methods in the Sierra de los Tuxtlas. In most communities, potters fire their vessels on the ground in open fires (Fig. 1). The ground is first covered with a bed of wood to raise pots off the wet ground, provide for better air circulation and distribute heat more evenly. The potter then places a brick, large sherd or metal stake in the centre of the fuel to support the vessels, which are laid against the support and one another in an overlapping fashion, gradually increasing the size of the firing load. The last layer of vessels typically consists of large, shallow tortilla griddles, or *comales*, which serve to retain heat. About 25 vessels are usually fired in one load.

After arranging the vessels, the potter ignites the fuel beneath them and places the remaining fuel, consisting of wood, cattle dung and/or palm leaf stalks, over the pile in a tipi-like structure.

Table 1 *Ethno-linguistic affiliation and firing methods of potting communities in the Valley of Oaxaca and the Sierra de los Tuxtlas*

Community	*Ethno-linguistic affiliation*	*Firing method*	*Forming method*	*Surface treament*	*Market*
Valley of Oaxaca					
Santa María Atzompa[1,2,3]	Mestizo (formerly Zapotec)	Kiln	Coiling, revolving mould	Glazed	Regional
San Bartolo Coyotepec[2,3]	Zapotec	Kiln	Revolving mould	Burnished	Regional
San Tomás Tlapazola[1,3]	Zapotec	Open	Coiling, revolving mould	'Plain'	Local
Ocotlán de Morelos	Zapotec	Kiln	Mushroom mould, coiling	Slipped, painted	Regional
Sierra de los Tuxtlas					
San Isidro Texcaltitan[4]	Mestizo (and Nahuat)	Kiln	Parado[4]	Scraped, smoothed	Regional
Sehualaca[4]	Mestizo	Open	Parado	Scraped, smoothed	Regional
Chuniapan de Abajo[4]	Mestizo	Open	Parado/palmeado[5]	Scraped, smoothed	Local
Bascascaltepec[4]	Mestizo	Open	Palmeado	Scraped, smoothed	Local

[1] Balkansky *et al.* 1997.
[2] Foster 1955.
[3] Shepard 1963; P. J. Arnold 1991a.
[4] In which vessels are modelled from a truncated cone of tempered clay (P. J. Arnold 1991a, 39–42).
[5] In which vessels are moulded on fabric stretched across a basin (P. J. Arnold 1991a, 42–4).

Figure 1 *Open firing at Chuniapan de Abajo in the Sierra de los Tuxtlas. (Photo: author)*

As the fuel burns, the potter tends the fire, occasionally adjusting the fuel, and even adding a piece or two. The entire procedure takes less than two hours, and the vessels are allowed to cool for another hour (ibid., 52).

In contrast, potters in the communities of San Isidro Texcaltitan (P. J. Arnold 1991b) and Francisco I. Madero (Pool, field notes 1987) use simple, circular, updraft kilns to fire their pottery (Fig. 2). The kilns are built of mud mixed with vegetable fibres, rocks and pieces of scrap

Figure 2 *Kiln at San Isidro Texcaltititan in the Sierra de los Tuxtlas. (Photo: author)*

iron. Building a new kiln begins by amassing the materials used in its construction (Pool and Hoag, field notes 1996). Earth is dug from the house lot, grass is gathered from surrounding pastures and water is brought from a nearby stream. Stones and scrap iron are salvaged from the old kiln. The grass is chopped into short pieces with a machete, and mixed with the earth and water by trampling. Construction begins by tracing a circle about 1 m across on the ground. Large stones are placed on the circle, leaving a space for the firebox door, which is capped with a large, flat stone. The potter then proceeds to build up the walls of the kiln by alternating thick coils of mud with smaller stones (Fig. 3). At a height of about 27 cm, larger stones are placed so as to project into the firebox and support the scrap-iron grate. The walls are then finished to a height of about 70 cm, and a large stone support, called an *ombligo*, is placed into the centre of the kiln. The kiln is allowed to dry for several days, then the scrap iron is placed across the supports to form the grate. The actual construction of the kiln takes about two and a half hours.

When pots are fired, the potter removes any debris left over from the previous firing. Large vessels are then placed mouth-downward in the upper firing chamber, and smaller vessels are arranged on top of them. The last items loaded into the kiln are typically the large, flat *comales*, and these are covered with an insulating layer of large sherds. The potter then starts a small fire in the mouth of the firebox to warm the ceramics. Additional wood is then added during the course of the firing, which typically lasts about four hours. Pots are left in the kiln overnight and removed in the morning after the kiln has cooled. About 30 to 50 vessels are typically fired in this manner (P. J. Arnold 1991a, 54–5).

Archaeological investigations conducted during the 1980s in and around the site of Matacapan in the Sierra de los Tuxtlas demonstrated that simple updraft kilns were used to fire pottery by the Early Classic period (AD 300–450), and perhaps as early as the Terminal Formative period (AD 100–300) (P. J. Arnold *et al.* 1993; Pool 1990, 1997a and 1997b; Santley *et al.* 1984, 28, fig. 7; Santley *et al.* 1989). Forty *in situ* prehispanic kilns have been recorded at Matacapan, and fragments of kilns were identified in 55 surface collections from a systematic survey of the site. Excavation of eight of the kilns revealed details of construction which are remarkably similar to the kilns of modern potters in the same region (Fig. 4) (Pool 1997a). The kilns were built directly on the ground surface or partially dug into a sloping bank. As in the

Figure 3 *Building a kiln at San Isidro Texcaltitan in the Sierra de los Tuxtlas. (Photo: author)*

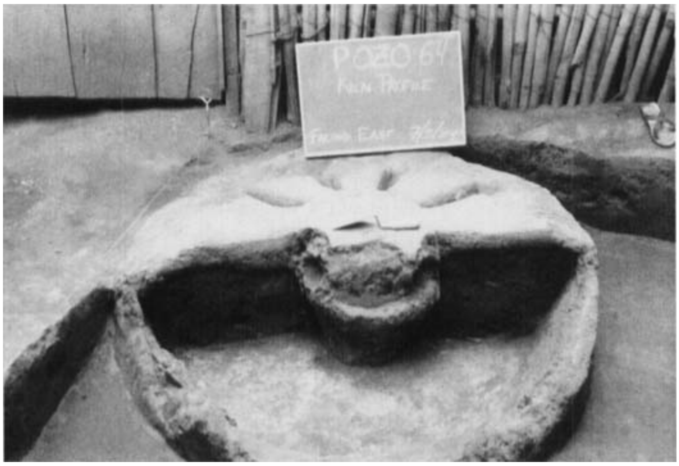

Figure 4 *Classic period kiln at Comoapan locality, Matacapan. (Photo: Philip J. Arnold III, used by permission)*

modern kilns, walls were formed with fibre-tempered mud (adobe) and stones or blocks of consolidated volcanic ash (*laja*). The same adobe was used to form the central supporting post and grate. The firing chambers of the kilns were not preserved, but the amount of adobe fragments surrounding the kilns suggests that the walls projected above the firebox as in the modern kilns. The ancient kilns tend to be larger, on average, than the modern ones, with fireboxes ranging from 109 to 138 cm in diameter, against 85 cm in the modern kilns (ibid.; P. J. Arnold 1991a, 54).

Firing pits and open firing locations have not been identified at Matacapan, but their existence is inferred from firing defects in Coarse Brown ware utilitarian vessels. These vessels, mainly necked jars, exhibit higher frequencies of fire clouds, fire cracks, star-shaped cracks and dunting cracks than the fine-paste serving vessels or Coarse Orange storage jars found in association with the kilns (Pool 1990, table 14, and 1997a, 167). The location of many of the fire clouds on the upper bodies and necks of the storage jars suggest that they are not simply the product of smudging over cooking fires. Together, these defects suggest that Coarse Brown pottery was more often fired in a manner that permitted less control over atmosphere and temperature than the kiln-fired pottery. This inference is supported by the scarcity of kiln fragments in surface collections from areas at Matacapan specializing in the production of Coarse Brown vessels, as compared to their frequency in other production areas of the same site. In Coarse Brown production areas, the ratio of kiln fragments to surface collections is 1 : 10.6, against 1 : 5.45 in other production areas, and the ratio of kiln fragments to total sherds is 1 : 2207.1 against 1 : 336.1 in other production areas (data from R. S. Santley, pers. comm. 1988).

To summarize, archaeological and ethnoarchaeological studies suggest the coexistence of kiln and open firing methods within a small region over a period of some 1700 years, despite changes in the ethno-linguistic affiliation of the inhabitants. Archaeologically, both methods were used contemporaneously in the same site at Matacapan. Ethnographically, modern mestizo potting communities use one or the other technique. Clearly, ethnic diversity and differential acculturation do not explain this persistent coexistence. I will argue below that variation in production intensities also fails to provide an adequate explanation. Rather, to understand this 'balanced polymorphism' in firing technology, we must consider the performance characteristics of kilns and open firings as they relate to the specific natural, social, economic and historical contexts of pottery production in the Sierra de los Tuxtlas. Although it has been applied more often to the products of ceramic manufacture, the behavioural approach outlined by Schiffer and Skibo (1997; Schiffer 1995) also provides a useful framework for investigating technological choice in firing facilities.

SITUATIONAL FACTORS

Situational factors refer to the 'behavioral, social, and environmental externalities that impinge on the activities of an artifact's behavioral chain and are embodied in each activity's specific components' (Schiffer and Skibo 1997, 32). In other words, situational factors encompass those behavioural, social and environmental conditions which are external to the specific set of activities in which an artefact is made and used, but which, nonetheless, condition those activities. In the Tuxtlas case, environmental factors other than the availability of fuel have remained relatively constant since the beginning of the Classic period. Behavioural and social factors, however, have changed dramatically, particularly in the last century.

Environmental factors

Raw materials The raw materials of pottery manufacture include clay, temper, water and fuel. In the western Sierra de los Tuxtlas, tectonic uplift has widely exposed the Concepción Formation, which contains fine-grained calcareous clays with a high kaolin content (Pool and Santley 1992, 208). These clays are preferred by modern potters (P. J. Arnold 1991a, 21), and X-ray fluorescence spectrometry (XRF) has demonstrated that ancient potters used them to manufacture fine-paste service vessels and Coarse Orange jars (Santley and Pool 1992, 218–25). Montmorillonitic clays derived from volcanic deposits are also widespread in the western Tuxtlas, and my XRF analysis suggests that they may have been exploited by ancient potters for Coarse Brown utilitarian vessels.

Primary deposits of mineral tempers in the western Tuxtlas include widespread volcanic ash deposits and the quartz and feldspar sands of the Filisola Formation. Today, the potters of San Isidro temper their clay with Filisola sands, while most potters in the region obtain their temper from stream bed deposits. The composition of stream bed deposits varies with their source material, but generally includes large amounts of volcanic ash. Volcanic ash may also be obtained from primary tephra deposits exposed along stream courses. The Classic period potters of Matacapan favoured volcanic ash for their Coarse Orange jars, but temper constituents in Coarse Brown jars include both volcanic ash, quartz grains and feldspar grains, suggesting an alluvial source (Pool 1990, table 12). The Fine Orange and Fine Grey service wares of Matacapan were not tempered, although they contain minor amounts of calcareous and ochre inclusions.

Water is widely available from numerous streams, lakes and springs throughout the western Tuxtlas, and has been throughout the time period in question. Recent deforestation has in all likelihood had a profound effect on fuel availability, however. San Isidro potters prefer to use firewood for fuel in their kilns, but must obtain it from 10.6 km away, on average (P. J. Arnold 1991a, 25). Potters in other Tuxtlas communities use a mixture of fuels, including firewood, palm leaf stalks and cow dung, travelling average distances of 2.4 to 7.5 km to obtain them (ibid., 25–6, table 6). The natural vegetation surrounding Matacapan in the Classic period consisted of high evergreen forests of tropical hardwoods (Gomez-Pompa 1973). Nevertheless, excavated kilns contain ash and carbonized seeds of the *coyol* palm in addition to wood charcoal, suggesting that the urban population of this site may have caused some local deforestation (Pool 1997a, 163). Cow dung, of course, was unavailable to the ancient potters, and the droppings of the indigenous wild animals, such as deer or tapir, are too widely dispersed to provide a cost-effective alternative to other fuels.

Climate Climate can have a significant effect on firing technology, due to the adverse effects of wind and rain (D. E. Arnold 1985, 70–1, 213). Although the peaks of the Tuxtlas occasionally experience freezing temperatures, temperature variability is minimal in the potting communities, which are located in the tropical setting of lower elevations (P. J. Arnold 1991a, 16–18). The Tuxtla mountains create an orographic pattern of rainfall, with annual precipitation ranging from 5000 mm on the mountain peaks to about 1500 mm in their lee to the south-west. Average annual precipitation is less variable in the area of Matacapan and the modern potting communities, ranging from about 2500 mm in San Isidro to about 2000 mm in the more southerly communities (ibid., fig. 3). Rainfall patterns in the area are distinctly seasonal, with average monthly dry season figures of 40 to 54 mm and wet season figures of 256–92 mm in the vicinities of San Andres Tuxtla and Santiago Tuxtla, but the degree of seasonality does not vary greatly from one potting community to another (ibid., table 3).

Behavioural and social factors

Technological choices in firing methods are linked through behavioural chains (Schiffer and Skibo 1997, 29) to a host of other activities involving the manufacture and use of vessels in their social and economic contexts (see, e.g., Pool 1992). Space does not allow an exhaustive consideration of all behavioural and social factors affecting firing methods in the ancient and modern contexts of the Tuxtlas, but I will discuss a few that appear to be most salient. These factors include pottery use, production organization and space management.

The specific uses of pottery condition their forms, surface treatment, decoration and paste composition. Therefore, the users of pottery, be they the potters themselves or non-producing consumers, exert a strong influence on technological choice (Pool 1992, 293). This influence has been documented most often with respect to vessel form (D. E. Arnold and Nieves 1992), particularly in the case of new demands for tourist wares (Neff 1990). Because different pastes, forms and surface treatment may respond differently to the thermal stresses of firing (e.g., Rice 1987, 155–6, 229–32) and because control of the firing atmosphere affects the appearance of ceramics, consumers' choices from among alternative sets of formal ceramic characteristics can indirectly influence producers' selection of firing methods. The ceramic inventory of Classic period Matacapan was exceedingly diverse, with over 40 recognized types and varieties defined on the basis of paste composition, texture and surface treatment, as well as ten basic forms in different sizes and with many minor variations in rim form (Ortiz and Santley 1989; Pool 1990). Nevertheless, most of the pottery produced at the site falls within four broadly defined wares: Fine Orange, Fine Grey, Coarse Orange and Coarse Brown. Fine Orange and Fine Grey wares are untempered and were typically used for serving vessels, including bowls, plates, dishes and specialized ritual forms, including cylindrical tripod jars, *floreros*, and 'cream pitchers'. The Fine Orange vessels were often decorated with slips and paints in red, white, black and orange. Coarse Orange pottery consists primarily of two jar forms, one with a neck and the other with only a folded lip; both were probably used for storage and transport. Coarse Brown vessels include necked jars, often with brushed shoulders, as well as shallow cooking pans, or *cazuelas*, and large basins.

Modern potters produce a greatly reduced inventory, owing to the replacement of traditional pottery by commercially produced ceramic, plastic and metal vessels. The forms of traditional pottery produced today all have utilitarian uses as tortilla griddles (*comales*), large 'toasters' (*tostadores*), bowls (*tecualones*), *cazuelas* for frying, *ollas de maiz* for soaking maize and *ollas de frijol* for boiling (P. J. Arnold 1991a, 62). The pastes used for all forms are heavily tempered and coarsely textured. Temper to clay ratios generally vary between 1 : 1.66 and 1 : 2.66, although one of the two clays used in San Isidro is tempered in a proportion of 1 : 4, due to the presence of organic inclusions that serve as a natural temper (ibid., 38–9, table 16). Although clays and tempers exploited by potters in different communities in the Tuxtlas vary with local resource availability, and most communities exploit two different clays, paste types are not differentiated with respect to different forms (ibid., 20–4).

The organization of production is often cited as a factor influencing firing technology, with gains in the efficiency of production, resulting from reduced frequency of vessel failure or improved fuel-clay ratios, providing the impetus for more intensive producers to adopt kilns (e.g., Balkansky *et al.* 1997, 156). Currently, all ceramic production in the Sierra de los Tuxtlas is conducted by independent households. Production intensity varies among these producing households, with producers in San Isidro and Sehualaca consuming about 2.7 times the amount of clay and engaging in production activities about 1.5 times as frequently as those in Bascascaltepec or Chuniapan de Abajo (P. J. Arnold 1991a, 26–8, 38, tables 7 and 16). Although the San Isidro potters use kilns, the Sehualaca potters do not, suggesting that production intensity is not a determinant factor in kiln use today.

The Classic period ceramic production system of Matacapan embraced a wider variety of production modes than the modern Tuxtlas system. Based on quantities of production refuse, the size of production units, and their association with domestic or public architecture, Middle to Late Classic production units appear to have included independent household industries, independent workshops and nucleated workshop industries, as well as attached specialists (*idem*; Pool 1990, 1994 and 1997a; Santley *et al.* 1989). Although non-kiln firing features have not been identified at Matacapan, the incidence of firing defects and scarcity of kiln fragments in Coarse Brown production areas imply that Coarse Brown vessels were less often fired in kilns than were other wares. All of the Coarse Brown production areas are located in domestic contexts and interpreted as loci of household industries (Santley *et al.* 1989, figs. 2 and 5c). In contrast, kilns and kiln fragments have been found in association with loci representing the full range of production modes, including household industry loci (Pool 1990 and 1997a). As in the modern case, it does not appear that production intensity alone explains the variation in Classic period firing technology.

Philip Arnold (1991a, 109–10) argues that the availability of space is the prime determinant of kiln use in the modern Tuxtlas, because the occupants of smaller house lots have less freedom to move firing facilities so as to mitigate microenvironmental factors, such as wind gusts. House lots of producing households in the kiln-using community of San Isidro have an average exterior area of only 142.27 sq m, while those of communities who use open fires have average exterior house lot areas of 293.35 sq m or more (*idem*, table 29). Excavation at the Late and Terminal Formative site of Bezuapan (Pool 1997b) and analysis of surface distributions of architecture and artefacts at Classic period Matacapan (Killion 1992) indicate that ancient patterns of house lot maintenance paralleled those seen in modern villages of the Tuxtlas. But the ancient house lots appear to have been larger, and the sites less densely setled, than those studied by Arnold. At Bezuapan, the patios alone of two house lots covered 313 and 335 sq m, and surface artefact distributions suggest an average total house lot size of 0.45 ha (Pool 1997b, 62). At its height in the Middle Classic, Matacapan covered 700 ha, with a civic-ceremonial core of 250 ha surrounded by a residential zone of 450 ha (Santley 1994, 251–2). All but one or two of the ceramic production areas are located within this residential zone, and they are widely distributed throughout it. Santley (ibid., 248) estimates the Middle Classic population at 35 000 people. Assuming the widely cited figure of 5.6 persons for average household size in lowland Mesoamerica (e.g., Drennan 1988, 274), the average house lot would have occupied 720 sq m. Even subtracting a generous estimate of 100 sq m for the area covered by houses and ancillary structures, average house lot size at Classic period Matacapan would have been well above that found in the modern potting communities. Killion's study of surface distributions in two parts of the peripheral zone suggests house lots (including space devoted to household gardens and waste disposal) may have been even larger, in the order of 1 to 2.5 ha (estimated from Killion 1992, figs. 6.6 and 6.7). Whichever figure is accepted as the norm, conservation of house lot space does not appear to have been a significant impetus for kiln use in the prehispanic sites.

PERFORMANCE CHARACTERISTICS

The preceding discussion does not exhaust the situational factors that potentially have affected modern and ancient firing choices, but it does provide a starting point for assessing the performance characteristics of kilns and open firings. Here I focus on performance characteristics relating to thermal properties, control of atmosphere, efficiency of raw materials consumption, management of space and construction costs.

Construction costs

Kilns obviously consume more labour and materials in their construction than open fires, but the simple updraft kilns used in the Tuxtlas are not as difficult to build as many archaeologists appear to assume, and the earth, stones and vegetable fibres used in their construction are often available on a producer's house lot. Working together, a producer and her family in San Isidro was able to dig the earth, mix it with vegetable temper and water, and build their kiln in two and three-quarter hours. Ancient potters would also have had to form the adobe support and grate, but this operation could not have added more than an hour to the total labour investment. Shepard's (1980, 75) remark regarding the simplicity of building a kiln is remarkably apropos for the Tuxtlas case. Nevertheless, thermal stresses from repeated firings ultimately destroy the kiln, and in San Isidro it must be rebuilt every six months to two years, multiplying the total cost of kiln construction over the life of a potting household (Juana Chipol, pers. comm. 1996; Philip Arnold, pers. comm. 1992).

Thermal performance characteristics

Thermal performance characteristics of firing facilities include the maximum temperature achieved, temperature variation within the kiln load and the rate of temperature increase. It is possible to reach maximum temperatures above 1000 °C in simple updraft kilns, while open firings seldom reach this level (Rye 1981, 98). Gosselain (1992, 244), however, observes that reported maximum temperature ranges in simple updraft kilns, pit and open firings overlap considerably, with all types achieving temperatures in the range of 600 °C to 900 °C (Gosselain

1992, 244). This observation appears to hold for the modern Tuxtlas case as well. Using flame colour as an indicator, Philip Arnold (1991, 55) estimated maximum temperatures in kilns to be a little above 800 °C and those in open firings to lie between 750 °C and 800 °C. Likewise, refiring experiments on samples of Tuxtlas clays produced colours similar to those of Fine Orange ceramics between 750 °C and 800 °C (Pool 1997a, 165). When higher temperatures were achieved in the ancient kilns, they often produced warped, vitrified and cracked sherds. Thus, the evidence does not support the conclusion that the ability to reach higher maximum temperatures achieved threshold levels favouring the use of kilns for the ceramics produced today or in the distant past in the Tuxtlas.

Both open firings and updraft kilns suffer from uneven distributions of temperature (Gosselain 1992, 244; Rye 1981, 100). Citing studies in which two or more thermocouples were used to monitor the same firing, Gosselain (1992, 244) reports that the amplitude of variation in open firings varied from 100 °C to 500 °C, and variation in updraft kiln firings varied from 5 °C to 350 °C. Mean values of the variations were 240 °C in open firings and 180 °C in updraft kiln firings. Apparently temperature variations can be controlled more effectively in simple updraft kilns, but they seldom are.

Updraft kilns do permit greater control over the rate of temperature increase (Rye 1981, 98). In the 27 studies from different parts of the world examined by Gosselain (1992, 246), open and pit firings required an average of 22 min and 41 min, respectively, to achieve maximum temperature. These figures increased to 60 min and 114 min when sherds were used to separate vessels from the fuel. In contrast, updraft kilns required an average of 259 min to achieve maximum temperature. For the modern Tuxtlas potters, Philip Arnold's observation that open firings were completed in two hours but kilns were fired for four hours suggests a similar pattern with respect to firing schedules. The desirability of controlling heating rate is confirmed by Juana Chipol, a potter of San Isidro, who explained to me that people in her village use kilns because they use firewood and heat the kilns slowly for about one and a half hours, after which they add firewood until the upper portion glows red. She further expressed the opinion that she would not be able to heat the pottery as slowly in an open fire, and that vessels would be likely to break as a result.

Control of firing temperature was probably more crucial for Classic period potters in Matacapan, where untempered serving vessels and finely tempered jars made up a large portion of the ceramic assemblage. Gosselain (1992, 257) notes that only coarse pottery can be fired under the rapid heating conditions of open firing, because the open texture of coarse pottery allows steam to escape. In contrast, steam may build up in fine-paste pottery and cause it to shatter. Thorough drying of the vessels reduces this risk, but steam is still produced from the remaining hydroxyl water during the 'water-smoking' stage of firing (Rice 1987, 87, 102–3). Coarsely textured pottery is also more resistant to thermal shock from rapid heating (ibid., 156). These observations coincide well with the inference that the most coarsely tempered vessels at Matacapan, the Coarse Brown jars, were fired in the open (Pool 1997a, 167).

Control of firing atmosphere

Exposure to gusts of wind and contact between pots and fuel make it difficult to control the atmosphere, as well as temperature, in open firings (Rice 1987, 156). This results in uneven colour development and the formation of fire clouds. Carefully positioning fuel and vessels before firing and covering the load with sherds or other non-combustible insulating material can affect the flow of air, but controlling the atmosphere after firing has begun is nearly impossible, and it is particularly difficult to maintain a true oxidizing atmosphere throughout the firing (Rye 1981, 98). Uncovering the vessels while temperatures are still above 600 °C enhances colour development and can help oxidize fire clouds. Where black pottery is desired, this effect can be achieved by smothering the fire with powdered dung or sawdust near the end of the firing, thereby reducing the supply of oxygen to the vessels and depositing a layer of carbon (Rice 1987, 158). For utilitarian vessels, however, and particularly for those that will be used for cooking, even surface colour development will probably not be a significant consideration. In the Tuxtlas, this lack of concern about the formation of fire clouds applies particularly to the pottery produced by modern potters and the Coarse Brown pottery of Classic Matacapan.

Updraft kilns produce more even colours by separating the vessels from the fuel and protecting the load from gusts of wind. Updraft kilns are particularly useful for reducing the incidence of fire clouds in oxidized pottery, although a reducing atmosphere is more difficult to achieve (Rye 1981, 100). Control over the firing atmosphere would have been a particularly important consideration for the production of Fine Orange pottery at Matacapan, as well as the Coarse Orange jars, which are often covered with a white slip and decorated with red paint.

Efficiency of raw material consumption

Choices in firing technology potentially affect the efficiency with which raw materials are consumed in two ways: by reducing the amount of fuel required to fire a certain number of vessels and by reducing firing losses due to cracking, warping, dunting or other defects. Gains in fuel efficiency in updraft kilns are reduced, however, because much of the energy produced is expended in heating the kiln itself and because much heat escapes through the top of the kiln (Rice 1987, 160, 162). In the Tuxtlas, Philip Arnold (1991b, 17) found that open firings produced about 51 usable vessels per *carga* of fuel (about 35 kg), while kiln firings produced only about 32 usable vessels per *carga*. The open firings are, therefore, about 59% *more* fuel efficient than simple updraft kilns in their vessel-to-fuel ratio, using the technology employed today and, we can infer, the similar technology used in the Classic period. Thus, gains in fuel efficiency do not appear to provide an explanation for the adoption of kilns in either the modern or ancient settings.

The Tuxtlas potters who use kilns do appear to achieve lower rates of firing loss than those who use open firing methods, however. Philip Arnold (1991, table 21) reports mean and median firing losses in kilns of 21.0% and 20.0% and in open firings of 31.5% and 27.0%. In other words, the modern kiln-firing potters expend about 25% to 33.3% less clay, temper, water and labour to produce a specified number of pots than those who use open firings. Such gains in efficiency would have been particularly appealing to the more intensive pottery-producing entities identified in Middle and Late Classic Matacapan.

Conservation of space

As discussed above in connection with situational factors, Philip Arnold (1991a, 109–10) argues that by mitigating microenvironmental variations, such as wind shifts, kilns allow potters on small house lots to conserve space. Although this does appear to be one advantage for the modern potters of San Isidro, no such constraints on house lot size appear to have existed in Classic period Matacapan.

DISCUSSION

The foregoing discussion allows us to evaluate the weighting of performance characteristics for different firing technologies with respect to specific situational factors observed in the present and inferred for the past contexts of ceramic production in the Tuxtlas. Table 2 presents these relationships as a *threshold* matrix (Schiffer 1995, 29) which specifies whether or not a technical choice is likely to exceed a threshold value for each performance characteristic, given the kind of pottery produced and the suite of other situational factors described for Classic and modern contexts in the Sierra de los Tuxtlas. It is important to recognize that the choice of any particular design for a firing facility represents a compromise among performance characteristics weighted with respect to different activities or chains of activities. Because the design of Classic period kilns at Matacapan resembles those in current use in the Tuxtlas, performance characteristics in the ancient setting should have been similar to the ethnographic examples. What differ are not the absolute performance characteristics, but the threshold values assigned to them in the context of different sets of situational factors.

With regard to the preparation of the firing facility, open firings have clear advantages over kilns in terms of material and labour costs. In addition, the design of the simple updraft kilns used today and in the past actually consumes more fuel than open firings. Therefore, the decision to build and maintain a kiln must respond to performance characteristics related to other activities that outweigh these economic considerations. For Classic period Matacapan, simple updraft kilns are likely to have exceeded threshold values for producing even surface colours and reducing firing losses to acceptable levels in firing fine-paste and Coarse Orange pottery, by controlling temperature fluctuations, the rate of temperature increase and the firing atmosphere. These performance characteristics would have been heavily weighted for the fine-paste and Coarse Orange wares because their paste textures made them more susceptible to firing loss and because their use contexts and modes of decoration increased the desirability of even surface colour development. The same performance characteristics would have had lower weights in the production of coarsely textured, utilitarian cooking vessels. Therefore, open firings are adequate for producing utilitarian wares in both the modern and ancient cases, and any preference for even surface colours is outweighed by the higher fuel consumption and increased labour expenditures in using, building and maintaining the kilns. Furthermore, because modern potters in the Tuxtlas produce only coarsely textured utilitarian wares and the forms they manufacture are used primarily for cooking, explanations for the modern use of kilns must be sought in factors other than their performance in firing activities. Philip Arnold's ethnoarchaeological analysis of firing technology with respect to the use of space identifies the only clear advantage to the modern Tuxtlas potters of simple updraft kilns over open firings: they allow potters living on small house lots in densely settled communities to manage space better by reducing the need to move the location of firing in response to microenvironmental conditions.

CONCLUSION

For some 1700 years, potters in the Sierra de los Tuxtlas have been able to choose between simple updraft kilns and open fires for making pottery, but their reasons for using kilns have changed. During the Classic period, ceramic vessels were used in a wide range of cooking, storage, serving and ritual activities. Weighing the technical requirements and consumer preferences for different performance characteristics in these multiple activities against the costs of construction, maintenance and resource consumption, potters chose to fire vessels with finer pastes and painted decoration in kilns. Those who confined their production to coarsely textured utilitarian vessels, however, chose the less costly and time-consuming method of open

Table 2 *Threshold performance matrix for simple updraft kilns and open firing in Classic and modern contexts in the Sierra de los Tuxtlas*

		Classic period				*Modern*			
		Fine Paste and Coarse Orange pottery		*Coarse Brown utilitarian pottery*		*Coarse utilitarian pottery*			
						Small house lots		*Large house lots*	
Activity	*Performance characteristic*	*Kiln*	*Open*	*Kiln*	*Open*	*Kiln*	*Open*	*Kiln*	*Open*
Preparing facility	Conserves materials	–	+	–	+	–	+	–	+
	Conserves labour	–	+	–	+	–	+	–	+
Managing house lot space	Conserves space	*	*	*	*	+	–	*	*
Firing	Achieves desired temperature	+	+	+	+	+	+	+	+
	Promotes even surface colours	+	–	*	*	*	*	*	*
	Controls rate of temperature increase	+	–	*	*	*	*	*	*
	Results in acceptable firing loss	+	–	+	+	+	+	+	+
	Conserves fuel	–	+	–	+	–	+	–	+

+: exceeds threshold value.
–: does not exceed threshold value.
*: performance characteristic is unweighted or weighting is ambiguous.

firing. Today, plastics, metals and commercial ceramics have replaced many of the ancient functions of pottery, reducing the products of potters to coarse vessels for cooking and other utilitarian uses. Open firing is an adequate, and in many respects preferable, method for producing such pottery. Were it not for social and environmental conditions favouring denser settlement in some communities, simple updraft kilns might have completely disappeared from the Tuxtlas.

These conclusions carry a caveat for archaeologists interested in the history of technology. Whether a particular technological choice is superior to another is contingent on many factors that relate directly and indirectly to the production of an artefact. In the case of pottery, these include the physical properties of available materials, the abilities, resources and social organization of potters, and the uses for which consumers employ their vessels. Cross-cultural associations and absolute performance characteristics of different technologies can provide clues as to why potters might adopt one technology over another, but by themselves they are insufficient to explain any specific historical instance of technological choice. For each historical case, we need more thorough assessments of the relationship between performance characteristics and their weighting with respect to specific activities in their natural and behavioural contexts. The analysis I offer in this paper is far from complete, but I hope it has helped to demonstrate the utility of this approach.

ACKNOWLEDGEMENTS

Fieldwork at Matacapan and Bezuapan was conducted with the support of the National Science Foundation (grant BNS-8520615) and the H. J. Hienz III Charitable Trust, with the permission of the Instituto Nacional de Antropología e Historia of Mexico. The University of Kentucky generously paid my registration fee for the World Archaeological Congress in Cape Town, South Africa (January 1999). I thank Michael Tite and Bill Sillar for inviting me to participate in the symposium on technological choice. I am also deeply indebted to Juana Chipol and Maximino Toto for allowing me to observe them building their kiln, and to Elizabeth Hoag for her assistance in recording the details of the construction process. Finally, I gratefully acknowledge the helpful comments of Professor Tite, Dr Sillar and, especially, Alexander Livingstone Smith on a draft of this article. Any errors of fact or interpretation are entirely my own.

REFERENCES

Arnold, D. E., 1985, *Ceramic theory and cultural process*, Cambridge Univ. Press, Cambridge.

Arnold, D. E., and Nieves, A., 1992, Factors affecting ceramic standardization, in *Ceramic production and distribution: an integrated approach* (eds. G. J. Bey III and C. A. Pool), 93–113, Westview Press, Boulder, Colorado.

Arnold, P. J. III, 1991a, *Domestic ceramic production and spatial organization: a Mexican case study in ethnoarchaeology*, Cambridge Univ. Press, Cambridge.

Arnold, P. J. III, 1991b, Pottery firing and ceramic ecology in the Tuxtlas Mountains, Veracruz, Mexico, unpubl. manuscript (in the author's possession).

Arnold, P. J. III, Pool, C. A., Kneebone, R. R., and Santley, R. S., 1993, Intensive ceramic production and Classic-period political economy in the Sierra de los Tuxtlas, Veracruz, Mexico, *Ancient Mesoamerica*, **6**, 175–91.

Balkansky, A. K., Feinman, G. M., and Nicholas, L. M., 1997, Pottery kilns of ancient Ejutla, Oaxaca, Mexico, *J. Field Archaeol.*, **24**, 139–60.

Drennan, R. D., 1988, Household location and compact versus dispersed settlement in prehispanic Mesoamerica, in *Household and community in the Mesoamerican past* (eds. R. R. Wilk and W. Ashmore), 273–93, Univ. New Mexico Press, Albuquerque.

Foster, G. M., 1955, *Contemporary pottery techniques in southern and central Mexico*, Middle American Res. Inst., Tulane Univ., Publications, **22**, Tulane Univ., New Orleans.

Foster, G. M., 1962, *Traditional cultures and the impact of technological change*, Harper and Row, New York.

Foster, G. M., 1965a, Peasant society and the image of limited good, *American Anthropologist*, **67**, 293–315.

Foster, G. M., 1965b, The sociology of pottery: questions and hypotheses arising from contemporary Mexican work, in *Ceramics and man* (ed. F. R. Matson), 43–61, Aldine, Chicago.

Foster, G. M., 1967, Contemporary pottery and basketry, in *Handbook of Middle American Indians: Vol. 6, Social anthropology* (ed. M. Nash), 103–24, Univ. Texas Press, Austin.

Gómez-Pompa, A., 1973, Ecology of the vegetation of Veracruz, in *Vegetation and vegetational history of northern Latin America* (ed. A. Graham), 73–148, Elsevier, Amsterdam.

Gosselain, O. P., 1992, Bonfire of the enquiries. Pottery firing temperatures in archaeology: what for?, *J. Archaeol. Sci.*, **19** (2), 243–59.

Killion, T. W., 1992, Residential ethnoarchaeology and ancient site structure: contemporary farming and prehistoric settlement agriculture at Matacapan, Veracruz, Mexico, in *Gardens of prehistory: the archaeology of settlement agriculture in greater Mesoamerica* (ed. T. W. Killion), 119–49, Univ. Alabama Press, Tuscaloosa, Alabama.

Neff, H., 1990, Culture contact and ceramic evolution: examples from Mesoamerica, in *The changing role of ceramics in society: 26,000 B.P. to the present* (ed. W. D. Kingery), 159–82, Am. Ceram. Soc. Ceramics and Civilization ser., **5**, Westerville, Ohio.

Ortiz Ceballos, P., and Santley, R. S., 1989, La cerámica de Matacapan, unpubl. manuscript on file, Department of Anthropology, Univ. New Mexico, Albuquerque, New Mexico.

Pool, C. A., 1990, *Ceramic production, resource procurement, and exchange at Matacapan, Veracruz, Mexico*, unpubl. Ph.D. dissertation, Department of Anthropology, Tulane Univ. (University Microfilms International, Ann Arbor).

Pool, C. A., 1992, Integrating ceramic production and distribution, in *Ceramic production and distribution: an integrated approach* (eds. G. J. Bey III and C. A. Pool), 275–313, Westview Press, Boulder, Colorado.

Pool, C. A., 1994, Compositional standardization of pastes and intensity of production at Matacapan, Veracruz, Mexico, unpubl. paper presented at the 93rd annual meeting of the Am. Anthropological Ass., Atlanta, Georgia.

Pool, C. A., 1997a, Prehispanic kilns at Matacapan, Veracruz, Mexico, in *The prehistory and history of ceramic kilns* (eds. W. D. Kingery and P. R. Rice), 149–71, Am. Ceram. Soc., Westerville, Ohio.

Pool, C.A., 1997b, The spatial structure of Formative houselots at Bezuapan, Veracruz, Mexico, in *Olmec to Aztec: settlement patterns in the ancient Gulf lowlands* (eds. B. A. S. Stark and P. J. Arnold III), 40–67, Univ. Arizona Press, Tucson.

Pool, C. A., and Santley, R. S., 1992, Middle Classic pottery economics in the Tuxtla Mountains, southern Veracruz, Mexico, in *Ceramic production and distribution: an integrated approach* (eds. G. J. Bey III and C. A. Pool), 205–34, Westview Press, Boulder, Colorado.

Reina, R. E., and Hill, R. M. II, 1978, *The traditional pottery of Guatemala*, Univ. Texas Press, Austin.

Rice, P. R., 1987, *Pottery analysis: a sourcebook*, Univ. Chicago Press, Chicago.

Rye, O. S., 1981, *Pottery technology*, Taraxacum, Washington, DC.

Santley, R. S., 1994, The economy of ancient Matacapan, *Ancient Mesoamerica*, **5**, 243–66.

Santley, R. S., Arnold, P. J. III, and Pool, C. A., 1989, The ceramics production system at Matacapan, Veracruz, Mexico, *J. Field Archaeol.*, **16**, 107–32.

Santley, R. S., Ortiz Ceballos, P., Killion, T. W., Arnold, P. J. III, and Kerley, J. M., 1984, *Final field report of the Matacapan Archaeological Project: the 1982 season*, Latin American Inst. Res. Pap., **15**, Univ. New Mexico, Albuquerque.

Schiffer, M. B., 1995, Social theory and history in behavioral archaeology, in *Expanding archaeology* (eds. J. M. Skibo, W. H. Walker and A. E. Nielsen), 22–35, Univ. Utah Press, Salt Lake City.

Schiffer, M. B., and Skibo, J. M., 1997, The explanation of artifact variability, *Am. Antiquity*, **62**, 27–50.

Shepard, A. O., 1963, Beginnings of ceramic industrialization: an example from the Oaxaca Valley, in *Notes from a Ceramic Laboratory (Carnegie Inst. Washington, Washington, DC)*, **2**, 1–24.

Shepard, A. O., 1980 edn., *Ceramics for the archaeologist*, Carnegie Inst. Washington Publications, **609**, Washington, DC.

Winter, M., and Payne, W. O., 1976, Hornos para cerámica hallados en Monte Alban, *Boletin del Instituto Nacional de Antropología e Historia*, **16**, 37–40.