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CERAMICS AND CIVILIZATION

Volume VII

The Prehistory & History of Ceramic Kilns

Editor: Prudence M. Rice
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Foreword

This seventh volume of the *Ceramics and Civilization* series continues the efforts of The American Ceramic Society to situate and understand its activities and programs in the broad context of culture, history, and society. Ceramic sherds make up the largest fraction of material objects recovered by archaeologists from prehistoric and historic sites. As a result there is great interest in the inferences that can be developed about design, production, distribution, use, and performance from the objects themselves.

An essential component of the very definition of ceramics is the heat treatment resulting in permanent shapes and useful properties. Thus, every site where ceramics were produced contains the remains of ceramic kilns, some simple, some complex. Many archaeologists believe that too little generally available information on kiln types, construction, and use has led to their underrepresentation in excavation reports. A principal purpose of the present meeting has been to bring together ceramic engineers, ethnographers, ceramic historians, and archaeologists familiar with the normal configurations of ceramic kilns that have been developed in a wide variety of epochs, geographies, and cultures.

The simplest ceramic pots are made with a fast, low-temperature firing accomplished in a variety of configurations with no permanent structure. For larger production and longer firing permanent kilns were constructed in many different designs appropriate for particular fuels, products, raw materials, processes, environments, cultures, and social organizations. For ceramic production at all times and all places, the kiln is an integral component.

We are fortunate that the symposium was mostly organized and this volume edited by Professor Prudence M. Rice, an eminent scholar in the field of archaeological ceramics and Chair of the Department of Anthropology at Southern Illinois University. I extend to her my thanks as Series Editor and as Chairperson of the American Ceramic Society History Committee.

W. David Kingery

PREHISPANIC KILNS AT MATACAPAN, VERACRUZ, MEXICO

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ABSTRACT

Investigations in and around Matacapan, Veracruz, Mexico have identified the remains of 40 circular updraft kilns dating to the Classic period. Excavated firing localities provide information on kiln design and construction materials, fuel types, products, and production scale and context. Built with fiber-tempered mud, the prehispanic kilns are similar in design and construction to those used by traditional potters in the surrounding region today. Fragments of kiln material have been recovered from Late Formative contexts, suggesting technological continuity over two millennia. During the Classic Period, kilns were utilized in contexts ranging from small household industries to large nucleated workshops with little variation in design or construction. At Matacapan, control over firing atmosphere appears to have been a more significant factor in kiln use than climate, fuel efficiency, or production intensity.

INTRODUCTION

Archaeologists and engineers (though not necessarily potters) widely regard kilns as a significant improvement over open fires for firing pottery. The many advantages cited for kilns include better control over firing conditions, the possibility of attaining higher temperatures, more efficient use of fuel, and protection from wind and rain (D. Arnold 1985:213; Rice 1987:161; Rye 1981:98). In addition, Philip Arnold (1991:109-113) has argued recently that by using kilns to protect firing loads from drafts, potters in the Sierra de los Tuxtlas of southern Veracruz conserve the amount of space they allot to firing on their small houselots. The variety of advantages attributed to kilns suggests that the origins of kiln technology may have diverse causes in different settings.

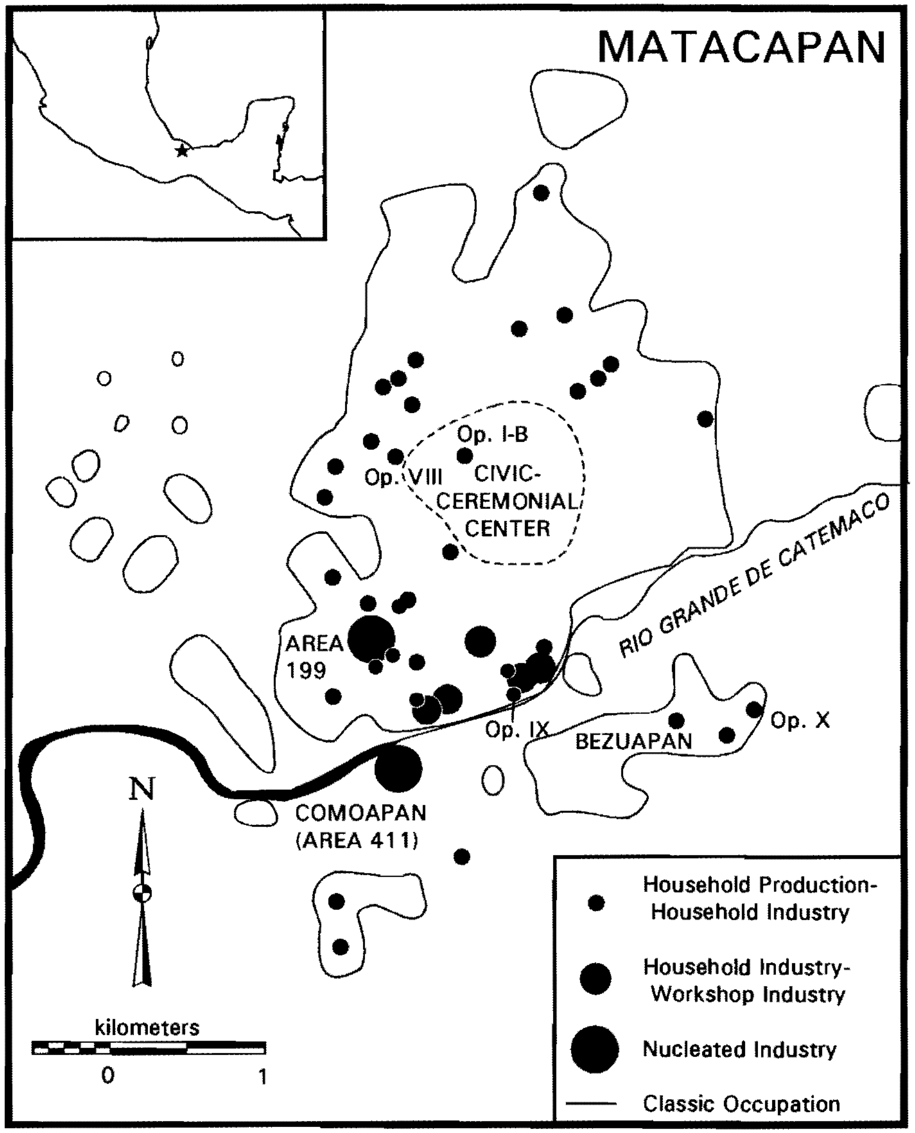

Figure 1. Map of ceramic production areas at Matacapan (redrawn after Santley et al. 1989, with modifications).

Investigations in and around the site of Matacapan, Veracruz, Mexico, provide a case study of the evolution of kiln firing technology in a humid tropical lowland environment (Figure 1). Forty prehispanic kilns have been securely identified at

Matacapan, and the systematic transect survey of the site produced 55 additional surface collections that contained fragments of the fired, fiber-tempered mud used in kiln construction. The ages of the kilns, as determined from their associated ceramics, span the Classic period from A.D. 300 to A.D. 800. Kiln debris recovered from a sealed Late Formative context at the outlying site of Bezuapan suggests that kilns may have been in use by 100 B.C. (Pool 1996). We have found kilns in both domestic and non-domestic contexts, and we interpret kiln contexts as representing a range of production modes that varies from household production to nucleated workshop industries (P. Arnold et al. 1993; Arnold and Santley 1993; Pool 1990:242-248, 322-325, Santley et al. 1989). Previous publications by participants in the Matacapan Project have detailed the overall ceramics production system at Matacapan (Santley et al. 1989), described the nucleated workshop industry in the Comoapan locality (Arnold et al. 1993), identified sources of clay for pottery associated with production areas (Pool and Santley 1992) and discussed the assemblage composition and context of production areas (Pool 1990). In this paper I focus on details of kiln construction and evaluate factors in the origin of kiln technology at Matacapan.

THE CERAMICS PRODUCTION SYSTEM AT MATACAPAN

Forty-two ceramic production areas have been identified at Matacapan. Forty-one of these were identified on the basis of surface collections, and one was discovered in excavation (Santley et al. 1989). Surface indicators of ceramic production consisted of cracked, warped or vitrified ("deformed") waster sherds, kiln construction material ("kiln debris") and high densities of sherds. "High density" was defined as the upper tercile of the distribution of sherd frequencies across the site, or more than 22 sherds per 3 m x 3 m collection square[1] (Pool and Santley 1992:212; cf. Santley et al. 1989:112). These indicators were treated as a polythetic set; a collection had to contain either deformed wasters or both kiln debris and a high sherd density to be counted as a "production square" indicating ceramic manufacture.

Ceramic production areas at Matacapan vary greatly with respect to their context, size, average sherd frequencies, proportion of space devoted to firing activities, and assemblage composition (Santley et al. 1989:115-121). Variation in these parameters suggests differences in scale, intensity, labor organization, and activity segregation from one production entity to another. Monitoring variation among multiple "dimensions of variation" in this manner provides a more precise characterization of ceramic production systems than does pigeonholing them in predefined production modes (Costin 1991:8-18; Pool 1992:277-280). Nevertheless, analysis of variation along these dimensions among the production areas at Matacapan suggests the existence of at least three distinctive production modes, which also correspond to differences in products and reflect the chronological development of the production system. The nomenclature for production modes at Matacapan follows van der Leeuw (1976) and Peacock (1982).

Most of the production areas consist of small groups of 1 to 3 production squares associated with housemounds and domestic refuse or widely dispersed production squares in broad zones of domestic occupation. They exhibit either low average sherd densities or low levels of activity segregation (as measured by the proportion of the area devoted to firing activities), or both (Santley et al 1989:117-118). The characteristics of this group are broadly consistent with small-scale, low intensity domestic production comparable to household production and small household industries in Peacock's (1982) and van der Leeuw's (1976) terminology. These "household production-household industry" areas are widely distributed outside the civic-ceremonial center of the site (Figure 1). Another small production area was identified in excavations (Operation I-B) in a plaza in the civic-ceremonial center of Matacapan. Operation I-B has been interpreted by Santley et al. (1989:108-109, 120-121) as a locus of "tethered" or attached specialist ceramic production for elites, as described in greater detail in the following section.

Five medium to large production areas in the southern part of Matacapan were represented by 4 to 12 production squares and had higher-than-average sherd densities (Figure 1). Although all 5 were associated with domestic occupation, more than 20% of the squares within each production area contained indicators of firing activities. These areas appear to have engaged in ceramic production at a greater scale and intensity than those of the first group, and firing activities appear to have consumed sufficient space to require their segregation from other domestic activities. Depending upon whether labor was organized as a part-time or full-time activity, these areas would represent either large household industries or workshop industries (Santley et al. 1989:118).

The most intensive level of ceramic production is represented by Area 411 in the modern village of Comoapan and Area 199, both of which are located close to permanent water sources and clay outcrops near the southwestern margin of the site (Figure 1). Both contain discrete clusters of kilns and ceramic dumps distributed over 2 ha. in Area 199 and 4 ha in Comoapan. Average sherd densities exceeded 200 sherds per collection and collections from individual waster dumps yielded more than 1000 sherds. Housemounds occurred within Area 199, but none were detected in Comoapan. Recent building activities may have destroyed housemounds in Comoapan, but domestic residues were also scarce, suggesting that production activities were segregated from domestic occupation, though at what distance is uncertain. The size, intensity, and aggregation of production loci in these two areas suggests that they functioned as nucleated workshop industries (Peacock 1982:9). Separate workshops within such nucleated industries may achieve economies of scale by cooperating in resource procurement and distribution of finished products (Pool

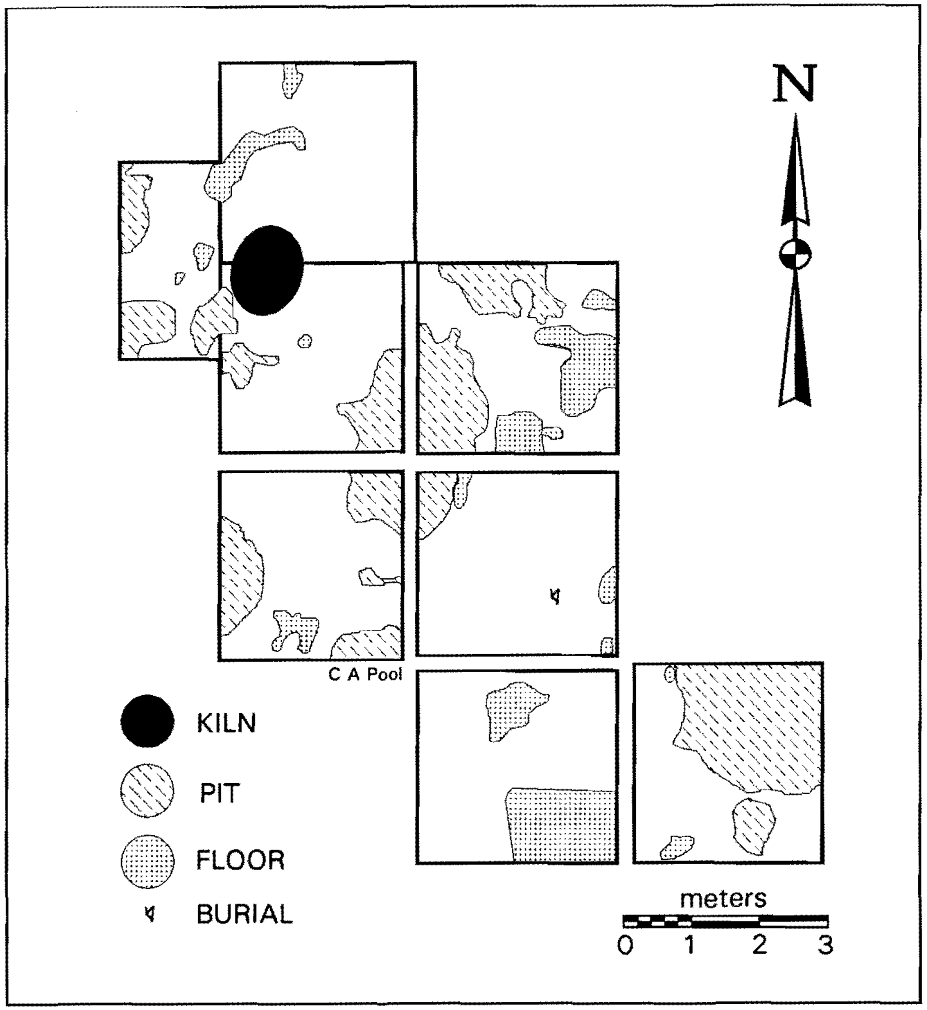

Figure 2. Excavation plan of Operation VIII, Western Locality.

and Santley 1992:214). Alternatively, the Comoapan workshop complex may have functioned as a manufactory under the direction of a general supervisor (Santley et al. 1989:120).

Variation in assemblage composition tends to parallel variation in production mode at Matacapan. Nucleated workshop assemblages are highly skewed towards Coarse Orange jars, while the principal ware in production areas of the large household industry-workshop industry class is Fine Gray. Both of these wares

Table I. Maximum sherd densities in excavated production contexts.

Western Locality (Op. VIII)	838/m³
Central Locality (Op. I-B)	865/m³
Southeastern Locality (Op. IX), Lower Unit	2825/m³
Southeastern Locality (Op. IX), Upper Unit	4650/m³
Comoapan Locality (Op. VI)	5364/m³

become increasingly common after A.D. 550, and Fine Gray is most common between A.D. 650 and 800. Household production and small household industry production areas exhibit greater variation in their ceramic assemblages, but Fine Orange service vessels often constitute the principal ware. Coarse Brown ware (mainly jars) is the most common ceramic in six production areas, all of them interpreted as household or small household industry production. As discussed below, a high incidence of fire clouds on Coarse Brown sherds suggests this ware was fired most commonly without the benefit of kilns, and indeed, none of these six areas yielded kiln debris in surface collections. As kiln debris is one criterion we have used to define production areas, its lack of association with Coarse Brown production has undoubtedly biased our sample against domestic manufacture of this common utilitarian ware. Both Fine Orange and Coarse Brown wares were manufactured throughout the Classic Period. In sum, the more intensive modes of production appear to have developed to meet demand for Coarse Orange jars and Fine Gray serving vessels after A.D. 550, but they coexisted with continued household industry production of Fine Orange serving vessels and probably Coarse Brown jars as well (Pool 1990:332-333).

CONTEXTS OF EXCAVATED KILNS

Data on kiln construction at Matacapan derives from excavations in four localities (Figure 1). The Western Locality (Operation VIII) contained the destroyed remains of a single kiln in the patio of a nonelite residence (Figure 2). Three large trash pits and six smaller pits contained a mixture of household refuse and ceramic production residues, including waster sherds. The largest pit was more than 2.25 m in diameter and 2 m deep. Although these pits contained the highest ceramic densities in the Western Locality, the maximum sherd density of 838/m³ was the lowest of all the excavated production localities (Table I). The Western Locality probably represents the remains of small-scale production for the household and limited

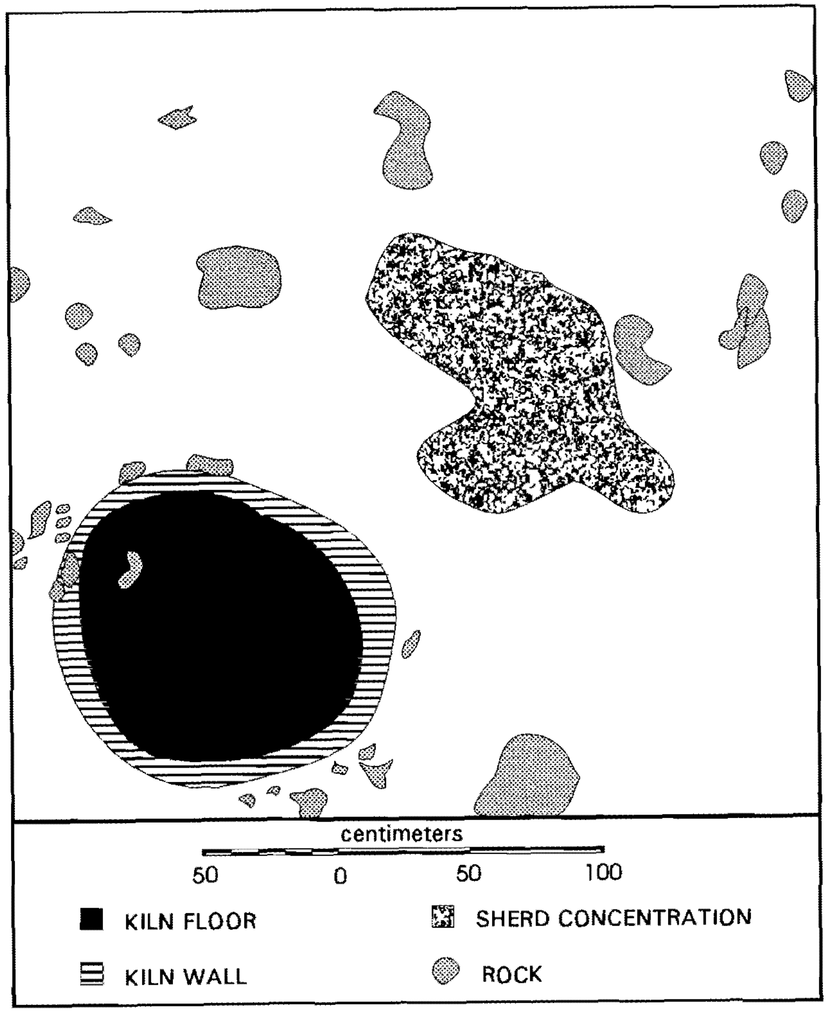

Figure 3. Excavation plan of Operation I-B, Central Locality.

exchange, that is, household or household industry production. Production appears to have focused primarily on Fine Orange serving vessels, and the associated ceramics suggest a date in the Early Classic (A.D. 300-450).

A 3 x 3 m excavation unit in the Central Locality (Operation I-B) uncovered the firebox of a second kiln within a plaza surrounded by pyramids and elite residential mounds (Figure 3). The sherd density of 865/m³ around the kiln only slightly exceeded the maximum sherd density in the Western Locality, but the limited

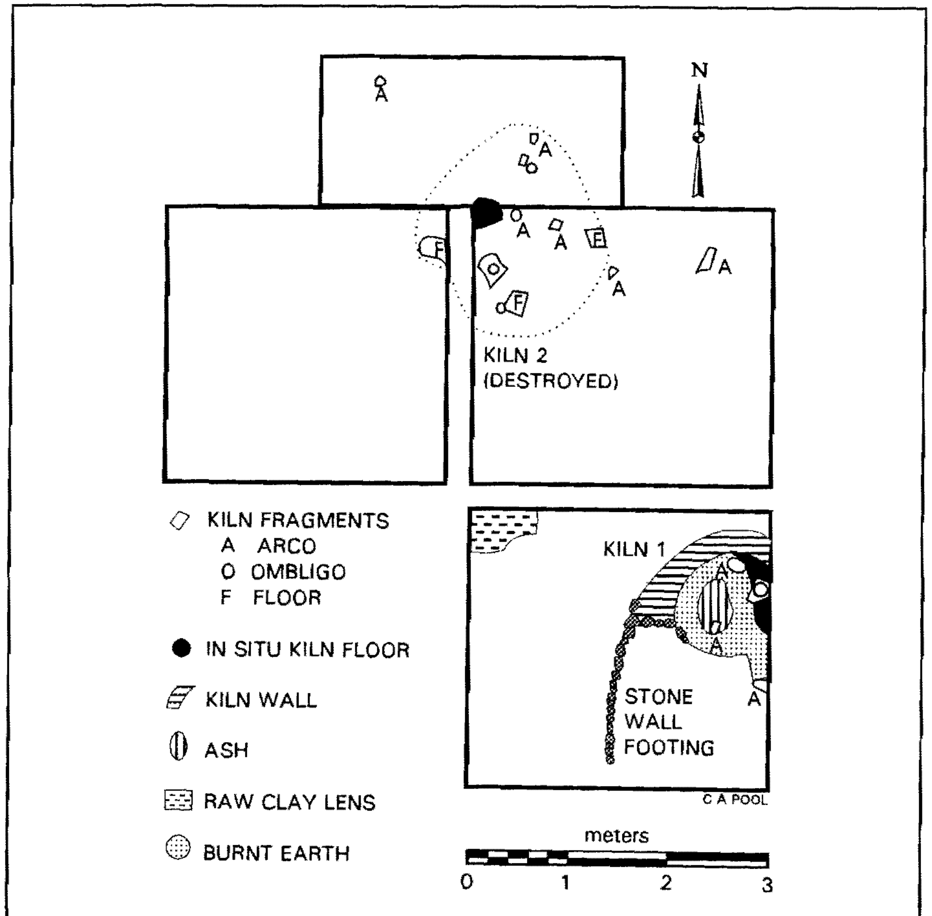

Figure 4. Excavation plan of Operation IX, Southeastern Locality.

exposure produced no household refuse. Waster sherds and pieces of vitrified clay were common, and several small burnishing stones were recovered. Production focused on neckless Coarse Orange jars (30.3% of rim sherds), burnished Brown-slipped Fine Orange serving vessels (21.7%) and Coarse Brown jars (12.0%). Both the Coarse Orange and Brown-slipped Fine Orange types are most common at Matacapan in the late Middle Classic period (A.D. 550-650), but Brown-slipped Fine Orange type comprises less than 2% of the total late Middle Classic assemblage at the site (Ortiz and Santley 1989:Figure 2.8). The context of the central locality, its unimpressive sherd density, and the specialized nature of its assemblage suggest that

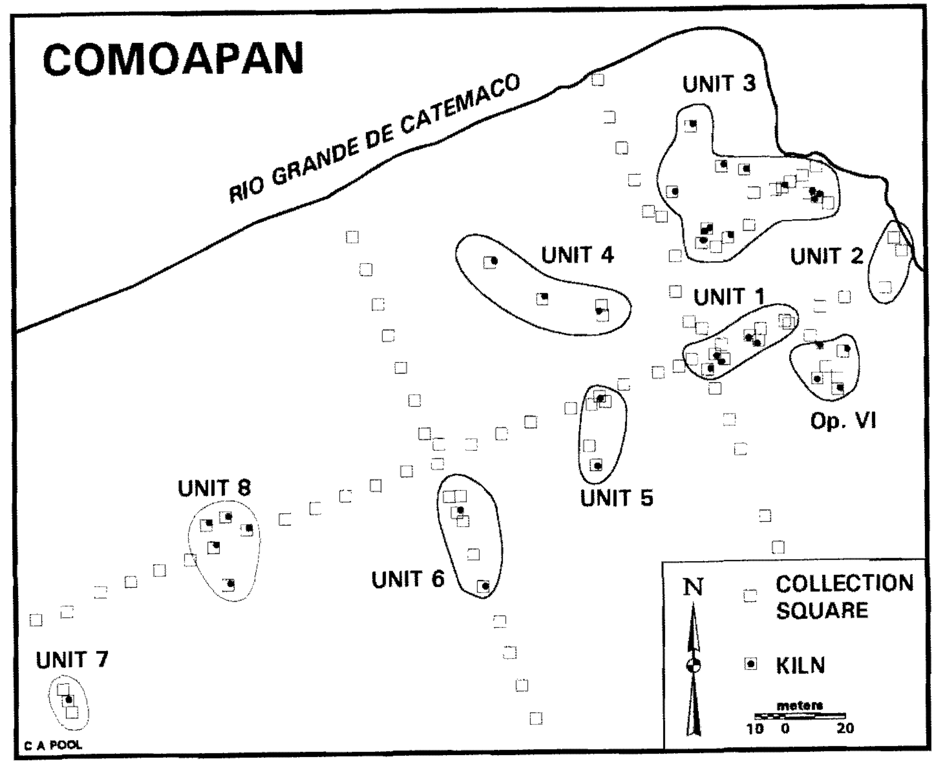

Figure 5. Surface collections, kilns and production units at the Comoapan production locality (after Arnold et al. 1993:Figure 3 and author's field notes).

it served as the workshop of an attached specialist who produced pottery at a relatively small scale for an elite client.

Excavations in the Southeastern Locality (Operation IX) encountered the remains of two kilns associated with a stratigraphically superimposed series of waster dumps to the east of a nonelite residential mound (Figure 4). The lower waster dumps contained approximately equal amounts of Fine Gray (40.3%) and Fine Orange rim sherds (37.2%). The upper dump contained substantially more Fine Gray rim sherds (61.5%) and fewer Fine Orange rim sherds (11.5%). Sherd densities in the upper dump were higher (at 4650/m^3) than in the lower dump (2825/m^3). The changes in the prevalence of wares and the densities of sherds may reflect the development of a late Middle Classic household industry into a Late Classic workshop specializing in Fine Gray production.

The largest and most specialized of the Matacapan production localities covers about 4 ha within the modern village of Comoapan. Survey discovered 36 kilns

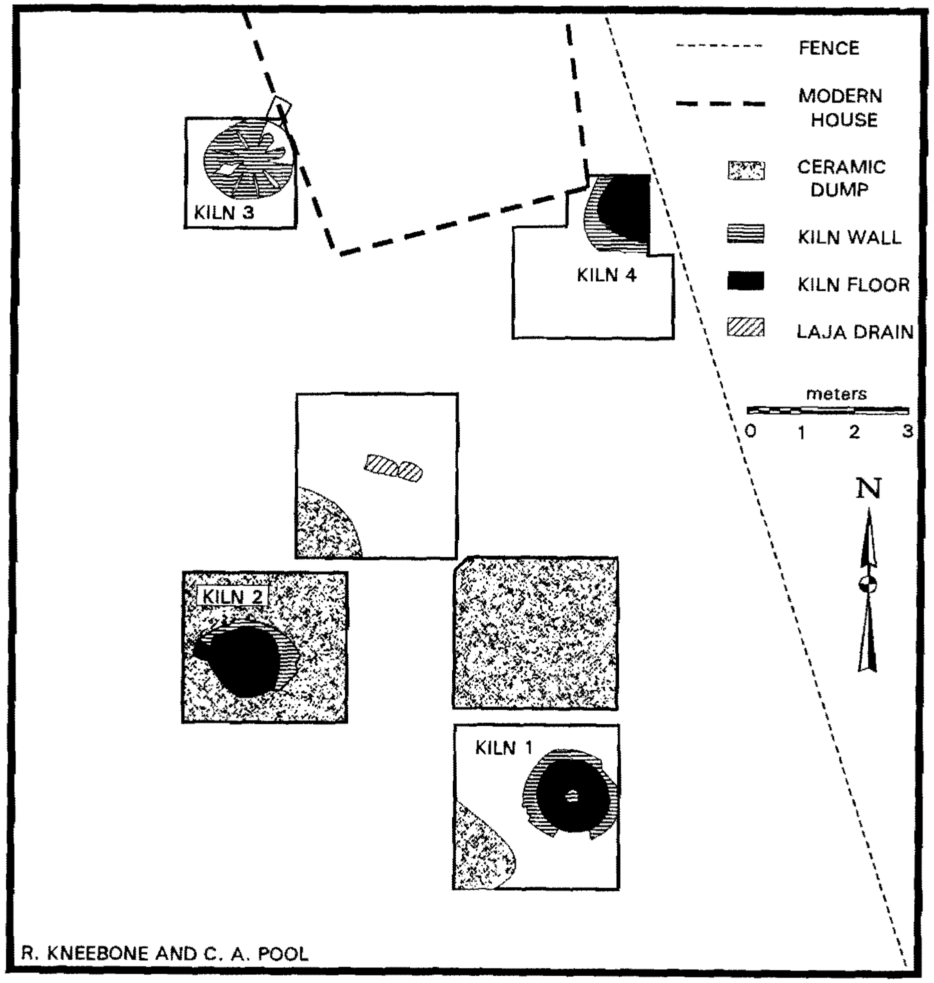

Figure 6. Excavation Plan of Operation VI in the Comoapan Locality (after Arnold et al. 1993:Figure 4 and author's field notes).

associated with waster dumps exposed in the streets and patios of the village (Figure 5). Four of these kilns were excavated in Operation VI (Figure 6). Ceramic densities in the waster dump associated with the excavated kilns attained 5364/cu m. Coarse Orange jars with and without necks comprised 63.4% of all excavated rims in Comoapan. Domestic refuse and residential architectural features were absent from the Comoapan production complex, suggesting that potters lived at some remove from their workshops. The spatial extent, high ceramic densities, high level of

Figure 7. Modern kiln, San Isidro Texcaltitan, Municipio of San Andres Tuxtla, Veracruz, Mexico. Photo by author.

product specialization and lack of evidence for household occupation within the Comoapan locality suggest large scale specialized production in a nucleated workshop industry (Arnold et al. 1993; Pool 1990:247).

KILN CONSTRUCTION

At Matacapan, the identification of features as kilns relies on evidence for intensive heating, association with production residues and failed kiln loads, and similarity in materials and form with kilns used by contemporary potters in the Sierra de los Tuxtlas (P. Arnold 1991:54-56, 145). Although most potters in the Tuxtlas use open fires, the potters of San Isidro Texcaltitan, in the *municipio* of San Andrés Tuxtla, fire pottery in small, cylindrical, double-chambered updraft kilns (Figure 7).

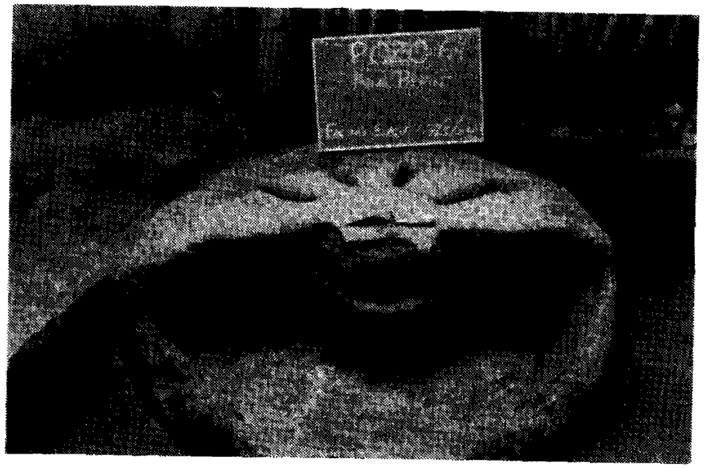

Figure 8 Prehispanic Kiln 3 in Operation VI, Comopan Locality. Photograph by Philip J. Arnold III (Arnold et al. 1993: Figure 6).

The walls of the kilns are built of alternating layers of fiber-tempered mud (adobe) and small stones raised on a foundation of irregular stones placed directly on the ground surface. A removable covering of plastic or tar paper supported by four poles protects the kiln from rain. Access to the firebox is through a small opening topped by a rough stone lintel. A stone called the *ombligo* set in the center of the firebox supports a grate of scrap metal and large sherds. As described by P. Arnold (1991:54), 30 to 40 vessels are loaded into the firing chamber through the open top of the kiln. Large and enclosed vessels (*cazuelas* and *ollas*) are loaded first, smaller *tecualones* and *maceteras* form the second level, and flatter *comales* are placed on top to help retain heat. The top of the kiln is then closed off with large sherds, but no mud or clay is used to cap the load. The high temperatures achieved in the firebox create a vitrified interior surface on the lower walls of the kiln, but the upper walls and exterior surfaces are less highly fired. P. Arnold (personal communication 1991) reports that the kilns last up to three years before they must be rebuilt.

The best-preserved of the prehispanic Matacapan kilns follows a similar design. Kiln 3 in Operation VI in the Comoapan locality was built with puddled fiber-tempered adobe walls set directly on the ancient ground surface (Figure 8). An adobe post in the form of an inverted truncated cone was set in the center of the kiln. This *ombligo* supported a grate formed by 9 trapezoidal plano-convex adobe *arcos* arranged radially about the *ombligo* and cemented to it with daubed adobe (Figure 9). The outer ends of the *arcos* were set on the firebox wall. On the northeast side of the kiln, a tunnel-like entrance 30 cm high, 30 cm wide, and 50 cm long provided access to the fire chamber. A large basalt stone blocked the entrance to this stoking tunnel. All surfaces within the firebox were highly vitrified, to the point that drops of slag formed on the underside of the arcos and ran down the firebox walls. The walls of the upper chamber were no longer intact, but the unsmoothed exterior ends of the arcos may indicate the area of their articulation with the firebox.

The interior walls of the firebox sloped outward from a diameter of 113 cm at the floor to 149 cm at the base of the arcos, 35 cm above the firebox floor. The original exterior dimensions of the kiln are somewhat less certain, as is the thickness of the walls, because the exterior surfaces of the walls were less highly fired. The remaining fired portion of the firebox walls were between 11 and 24 cm thick, and the exterior diameter varied from 145 to 172 cm.

Table II presents data on the dimensions and construction techniques of all excavated kilns at Matacapan. These data indicate that Comoapan Kiln 3 was fairly typical, but that construction techniques and dimensions varied even within the excavated Comoapan workshop. Kiln 1 was also built directly on the ground surface, but stones were incorporated into the foundation of the adobe walls. In contrast, the fireboxes of Kilns 2 and 4 were partially excavated into the sloping ground surface, perhaps primarily to provide a level floor. Firebox mouths in the excavated Comoapan workshop were oriented to the northeast, west, and southeast, not with regard to the prevailing northerly winds, but on the downslope sides of the kilns, possibly to prevent flooding of the firebox due to rainwater runoff. Although temporary coverings may have protected the kilns from falling rain, no postmolds or other evidence for such structures were encountered in the Comoapan excavations.

Elsewhere in Matacapan, the badly destroyed kiln in the Western locality was built directly on a natural surface of consolidated volcanic ash (*laja*). Pieces of this material and stones were incorporated into the adobe walls, only a small fragment of which was intact.

In the Southeastern Locality, Kiln 1 was partly excavated into a steep slope. The collapsed firing chamber walls and front wall of the firebox were made of adobe, but again, stones appear to have been incorporated in the construction of the kiln. In addition, small stones appear to have been used for the footing of the perishable walls of a small structure in front of the kiln. The adobe ombligo and arcos of the kiln were found collapsed in the firebox. Kiln 2, which lay higher in the excavation, was badly destroyed by plowing but appears to have been built directly on a former ground surface. The adobe ombligo and arcos were scattered around a small intact portion of the vitrified firebox floor.

The kiln in the central locality is unusual in that the firebox consisted of a shallow pit. Stones and fragments of fired adobe on the margins of this pit represent the base of the firing chamber walls.

Table II. Kiln Dimensions[1] and Construction

Locality	Interior Diameter	Exterior Diameter	Firebox Depth	Firebox Volume	Wall Thickness	Construction
Bezuapan (Op. X)	--	--	--	--	--	adobe wall fragments
Western (Op. VIII)	120	--	--	--	--	surface kiln, adobe, laja and stones
Central (Op. I-B)	109	126	40	0.37	12	semisubterranean, adobe and stones
Comoapan (Op. VI)						
Kiln 1	138	171	27	0.40	21	surface kiln, adobe and stones
Kiln 2	125	--	44	0.54	22	partly dug into slope, adobe
Kiln 3	131	158	35	0.47	18	surface kiln, adobe
Kiln 4	> 122	--	30	--	21	partly dug into slope, adobe
Southeastern (Op. IX)						
Kiln 1	109	--	46	0.43	20	partly dug into slope, adobe and stones
Kiln 2						destroyed, adobe ombligo, arcos, wall
San Isidro (Modern)[2]	85	104	27	0.15	--	surface kilns, adobe, stones, and scrap iron

[1]Dimensions are averages in cm of maximum and minimum measurements, except firebox volumes, which are in m^3.
[2]Averages from P. Arnold 1991:54.

Kiln dimensions are remarkably consistent across time and production context (Table II). Average interior firebox diameters range from 109 to 138 cm, and firebox depths range from 27 to 46 cm. These figures also provide estimates of total firebox volume (including the central ombligo) of 0.37 cu m to 0.54 cu m. The attached specialist workshop in the Central Locality and the unattached workshop of the Southeastern Locality contained the smallest kilns, and the nucleated industry workshop in Comoapan contained the largest kiln, but overall, the excavated kilns do not exhibit consistent variations with production mode, principal products, or chronological period.

The distinctive material employed in kiln construction serves as a good indicator of kilns in surface contexts. As opposed to daub used in house construction, the adobe used in kilns at Matacapan invariably was tempered with vegetable fibers, lacks impressions of poles or saplings, and exhibits either vitrification on one surface or differential firing in cross-section as a result of repeated exposure to high heat on the interior surface. On occasion, specific parts of the kiln, such as the ombligo or the arcos, can be identified in surface collections. Where the ground surface has not been disturbed by plowing, as in the streets and yards of Comoapan, the walls of the kilns' firebox appear as a circle of fired adobe. Evidence of the usefulness of these criteria for identifying kilns is provided by the discovery of *in situ* kilns in the Western and Southeastern localities, where the location of Operations VIII and IX were chosen because of the presence of kiln debris in surface collections.

FUEL

The best information on the fuel employed in the Matacapan kilns comes from Kiln 1 in the Southeastern Locality. The firebox of this kiln contained a light fibrous ash similar to that produced by burning palm leaf stalks, a common fuel for firing pottery in the Tuxtlas today (P. Arnold 1991:25-26). Carbonized seeds of the *coyol redondo* palm (*Acrocomia mexicana* or *Scheelea liebmanii*) recovered from the firebox and the area in front of this kiln confirm the burning of palm, although it is not clear whether the seeds were used intentionally for fuel or included incidentally. In the fireboxes of other kilns at Matacapan, charcoal is scarce, and a similar fibrous ash is typically present, suggesting that palm may have been the generally preferred fuel.

The use of palm is somewhat surprising because its open structure and low specific gravity make palm a notoriously poor fuel. Palm burns rapidly and has a low heating value as compared to hardwoods such as those of the genera *Albizia*, *Guarea*, *Malmea*, *Pterocarpus*, and *Trichilia*, which are found in the high evergreen *selvas* (forests) of the Sierra de los Tuxtlas, and which are widely used for fuel in Central America (Gómez-Pompa 1973:111; Jones and Pérez 1981; Jones and Otavalo 1981). Previously I have argued that the use of palm in kilns at Matacapan resulted from competition between pottery production and cooking for hardwood fuel (Pool 1991). Today in the similar environment of the Nicoya Peninsula, the consumption of fuel averages 2.1 kg per person per day on small *fincas*, where it is used primarily for cooking (Jones and Otavalo 1981). Based on conservative estimates of population and generous estimates of pottery demand, I calculate that total domestic fuel consumption at Matacapan over the course of the Middle Classic would have exceeded 365,230,000 kg, while pottery production for the same population would have consumed a maximum of 7,750,000 kg of fuel, or about 2.1% of domestic fuel consumption.

As the growing population of Matacapan placed increasing pressure on the surrounding evergreen selvas for agricultural land and cooking fuel, potters may have opted for palm as a less efficient but adequate fuel, near at hand, that was not suitable for cooking, as many contemporary potters in the Tuxtlas do today. Today two palm species are widely called "coyol" in Mexico, *Scheelea liebmanii* and *Acrocomia mexicana*. Both produce "branches" that die and can be removed without harming the tree. Moreover, both produce edible seeds, their fronds provide thatch for roofing material and their spathes are sometimes used as containers (Coe and Diehl 1980:92). Describing uses of *Scheelea liebmanii*, Coe and Diehl (1980:92) report that inhabitants of southern Veracruz eat the young sprouts, the heart, and the seeds, drink the juice of the trunk, prepare cooking oil from the seeds, and make a soap by burning the seeds and mixing the ashes with lard. Protected or cultivated stands of these palms in Matacapan would therefore have provided several economic advantages, only one of which would have been fuel for pottery production.

DISCUSSION: WHY KILNS AT MATACAPAN?

Returning to a theme expressed in the opening line of this paper, although archaeologists and engineers extol the virtues of kilns, their advantages are by no means universally appreciated by traditional potters, many of whom make not only serviceable utilitarian pottery, but also aesthetically extraordinary works of art using open and pit firing techniques. A case in point is the Sierra de los Tuxtlas, where today potters in different communities use kilns or open fires to make the same range of forms (P. Arnold 1991). Furthermore, the commonly cited advantages of kilns are most evident in kilns that are more complex than the simple circular updraft kilns used by prehispanic and contemporary potters in the Tuxtlas. Given the additional labor required, it is reasonable to ask why potters developed kilns in the first place, particularly in the New World, where until recently prehispanic kilns were thought not to exist (e.g., D. Arnold 185:218).

The preceding discussion of pressures on fuel sources suggests the possibility that a need for increased fuel efficiency may have provided the impetus for kiln

technology at Matacapan. This argument fails for two reasons. First, the earliest well-documented kiln at Matacapan dates to the Early Classic, when Matacapan was small, with an estimated population of fewer than 1250 people in about 43 ha, and regional population densities were on the order of 7 people per sq km (Pool 1991; Santley 1991:7). Population densities were higher in the Late Formative period, which yielded possible kiln wall fragments at the village site of Bezuapan, but the maximum estimated regional density of 13.9 per sq km (Santley 1991:5) seems insufficient to stress fuel supplies.

Second, many authors have noted that kilns in general and simple updraft kilns in particular may be less fuel efficient than open firing because heat is expended in heating the kiln structure and much heat is lost through the top of the kiln (Rice 1987:160; Rye 1981:25). In the Tuxtlas, P. Arnold (1991b:17) found that open firings produced an average of about 51 usable vessels per *carga* of fuel (about 35 kg), while kiln firings produced only about 32 usable vessels per *carga*, making the open firings about 88% more fuel efficient in terms of their vessel-to-fuel ratio. It therefore appears that if fuel efficiency were the overriding concern at Matacapan, bonfires would have been favored over kilns.

Neither do the higher temperatures achievable in kilns appear to have provided the impetus for their use at Matacapan. Clay sources utilized by the Matacapan potters have been identified by X-ray fluorescence spectrometry (Pool and Santley 1992). Experiments on samples of these clays indicate that firing in an oxidizing atmosphere produces colors similar to those of archaeological Fine Orange ceramics from Matacapan at between 750°C and 800°C. Higher temperatures were achieved at points in the prehispanic kilns, but they often produced warped and vitrified sherds. Simple updraft kilns do not appear to provide a clear advantage over open firings in achieving this temperature range. Using flame color as an indicator, P. Arnold (1991a:55) estimated maximum temperatures in the modern Tuxtlas updraft kilns to be a little above 800°C and those in open firings to be between 700°C and 850°C. According to Gosselain (1992:244), reported temperature ranges for open, pit, and updraft kiln firings overlap considerably, with all types achieving temperatures of 600°C to 900°C. Furthermore, temperatures in updraft kilns commonly vary by as much as 100°C to 300°C even within the same firing (Nicholson and Patterson 1989:79-83, Rye 1981:Table 3; Sheehy 1988:Table 2).

D. Arnold (1985:215-218) argues that the cross-cultural distribution of kilns reflects their effectiveness in mitigating the effects of weather and climate. Certainly the Sierra de los Tuxtlas, where potting communities experience annual rainfall totals of 2000-2500 mm, would appear to conform to this pattern. Although the open tops of the Tuxtlas kilns provide little protection from rain without a protective structure, the downslope orientation of firebox doors at Matacapan would have provided some protection from runoff on the ground. A climatic explanation, however, is weakened by the observation that modern Tuxtlas potters typically use open firings in areas that have only marginally less rainfall than San Isidro Texcaltitan, where kilns are used (P. Arnold 1991:58-59). Furthermore, the only evidence for a structure directly associated with a kiln at Matacapan is the wall footing in the Southeastern Locality, which appears to provide more protection for the potter than the kiln.

P. Arnold (1991:107-109) advances the argument that kilns, by mitigating microenvironmental variations, such as shifts in the wind, allow potters on small houselots to conserve space, and this does appear to be one advantage for the potters of San Isidro Texcaltitan, whose houselots are smaller, on the average, than those in other pottery-making communities. No such constraints on houselot size appear to have existed in Early Classic Matacapan or Late Formative Bezuapan, however (Pool 1991, 1996; Santley 1991:7).

Finally, kilns are often associated with more intensive production, particularly in the minds of archaeologists (e.g., Peacock 1982:8-10, Sinopoli 1991:101, Santley et al. 1989, van der Leeuw 1984). Cross-culturally, this association has considerable validity, but it does not hold for prehispanic Matacapan, where kilns are found in both low intensity and high intensity production contexts, nor for the modern Tuxtlas, where potters using kilns and open fires produce pottery at similar rates (P. Arnold 1991:27-28)..

The question then remains, why did the ancient potters of Matacapan adopt kiln technology? The principal advantage of the kind of simple updraft kilns used at Matacapan appears to be control over firing conditions, specifically control over the firing atmosphere and the *rate* of heating. In comparing thermometric data from 27 ethnographic firings reported from various parts of the world, Gosselain (1992:246) found that, on the average, open and pit firings required only 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 the vessels from the fuel. In marked contrast, updraft kilns required an average of 259 min to achieve maximum temperature. Gosselain (1992:244-246) concludes that "the heating rate is by far the most specific parameter for each of the firing techniques" that he considered, and that this observation "might explain, more than temperatures reached or thermic homogeneity, the choices and innovation in the field of firing techniques."

In the summer of 1996, a potter of San Isidro Texcaltitan echoed Gosselain's hypothesis when I asked her why she and others in San Isidro used kilns instead of firing pottery in the open as people do in Sehualaca. First she expressed surprise that other people did not use kilns. After a few moments' thought (and with no further prompting from me) she explained that in San Isidro they used firewood (*leña*) *and heated the kilns slowly ("con calma")* for about 1 1/2 hours, after which they add firewood until the upper portion glows red. She added that she did not believe she could heat the pottery as slowly in an open fire, and that the vessels would be likely

to break. I then asked why she did not use palm fronds instead of firewood. She responded that she did, occasionally, but that the palms were on private land. Although this potter included the type of fuel in her response, she emphasized the slow rate of heating and she appears to consider firewood as a preferable fuel for controlling the heating schedule, while indicating that palm fronds could be used and occasionally were.

Citing Gibson and Woods (1989), Gosselain (1992:257) also notes that only coarse pottery can be fired under the rapid heating conditions of open firing, because the open texture of coarse pottery allows the steam to escape, whereas steam may build up in fine-paste pottery and cause it to shatter. At Matacapan, most of the Classic period pottery belongs to four wares: Fine Orange, Fine Gray, Coarse Orange, and Coarse Brown. Fire clouds appear on the surfaces of 22.9% of a random sample of 367 Coarse Brown sherds from excavated production contexts, but are much less common on the other three wares (7.6% of 877 Fine Gray sherds, 5.2% of 991 Fine Orange sherds, and 1.2% of 598 Coarse Orange sherds) (Pool 1990:Table 14). These data indicate that less control was exercised over the atmosphere in which Coarse Brown pottery was fired, suggesting that it was more often fired in the open, and the other wares were usually kiln-fired. Moreover, surface collections in production areas that emphasized Coarse Brown manufacture are notable for their lack of kiln debris. Coarse Brown is by far the coarsest of the Classic and Late Formative period wares, containing more temper (28.1%-32.7% by volume) and coarser temper (modal maximum aplastic size = coarse sand) than the other wares (Pool 1990: Tables 11 and 13). In contrast, the maximum aplastic size in most Coarse Orange sherds is medium sand, and the average aplastic density ranges from 11.3% to 26.1% by volume. The fine paste ceramics are untempered, but have minor amounts of natural calcareous and other aplastics.

Untempered fine paste pottery first appears in the central Tuxtlas in the Late Formative period and becomes common in the Early Classic. Similarly, the first direct evidence for kiln firing occurs in the form of kiln wall fragments from a Late Formative context at the site of Bezuapan, which was sealed by the ash from a volcanic eruption. The earliest *in situ* kiln dates from the Early Classic at Matacapan, after which kilns become common. The development of kiln technology in the central Sierra de los Tuxtlas therefore appears to coincide with the appearance and increasing popularity of ceramics whose fine paste and uniform surface hues required the greater control over heating rate and firing atmosphere afforded by kilns. That control of the firing atmosphere was a concern for the ancient kiln-using potters is further suggested by the stone that was found blocking the entrance to the firebox in Kiln 3 at Comoapan.

CONCLUSION

In this paper I have described the construction of the prehispanic kilns at Matacapan, as well as the variation in the products of those kilns and the organization of ceramic production. The Matacapan kilns were simple, rather small, circular updraft kilns made primarily of fiber tempered mud, or adobe, and built either entirely above ground, or partially excavated into the usually sloping ground surface. Kilns were used principally for firing fine paste wares in both oxidizing and reducing atmospheres, as well as oxidized jars with volcanic ash temper. In contrast, coarser brown jars tempered with sand, which often included quartz and feldspar clasts in addition to volcanic ash, appear to have usually been fired in the open, resulting in a higher incidence of fire clouds due to less control over firing atmosphere. Kilns of the same design were used in the entire range of production contexts at Matacapan, from small-scale domestic production loci to large-scale nucleated industries. They were definitely in use by the Early Classic period (A.D. 300-450), and perhaps as early as the Late Formative period (400 B.C.-A.D. 100), coinciding with the appearance and expansion of the fine paste ceramic tradition at the site. Kiln technology continued in conjunction with open firing through the Classic period, and both techniques continue to be used by modern potters in the region. Given these data, and considering both the advantages and disadvantages of simple updraft kilns, it appears that at Matacapan the innovation of kiln firing was a response to the need for greater control over firing atmosphere, and particularly the rate of heat increase, required in the production of fine paste ceramics.

The evolution of ceramic pyrotechnology reflects solutions to specific problems that vary from culture to culture depending on the raw materials available, the uses to which the products are put, and the organization of pottery production. The Matacapan case may or may not provide a model for the invention and adoption of kilns in other cultural contexts. The important point is that now that the idea that kilns were introduced to the New World by Europeans has been put to rest, Mesoamerica provides fertile ground for research into the independent invention of kiln technology.

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NOTES

[1]The surface collection program implemented at Matacapan was multi-staged. The first stage employed a systematic interval transect strategy in which 3 m x 3 m collection squares were placed at 13 m intervals along transects spaced 50 to 100 m apart (Santley et al. 1984:10-14). Four ceramic production areas were later resampled using a more intensive stratified random strategy (Pool 1990:196-204). In addition, each kiln and waster dump in the large Comoapan workshop complex was sampled with a provenienced collection square (Arnold et al. 1993:177). The surface data discussed in this article derive from the systematic transect sample, unless otherwise stated.

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