THE MALEVOLENT DEMONS[1] OF CERAMIC PRODUCTION: WHERE HAVE ALL THE FAILURES GONE?

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Resumen: La producción y distribución son consideradas como dimensiones importantes de intercambio, especialmente en el caso de la cerámica. Poco se conoce sobre la evidencia directa de la producción de cerámica en las tierras bajas mayas. Mientras los métodos indirectos de producción han sido evaluados, pocos estudios han examinado específicamente la evidencia directa, y las discusiones acerca de las fallas de producción son escasas. En este escrito examinamos el problema de la producción de carámica a través de un experimento conducido a reproducir los indicadorers de las fallas. Los resultados, utilizando alfarería maya antigua y pequeños conglomerados preparados, demuestran reacciones determinadas y predecibles de los desgrasantes básicos a las variaciones de temperatura. Las implicaciones de estos datos ilustran el porqué la producción cerámica continúa siendo objeto de evasión para los arqueólogos mayistas y la necesidad de desarrollar nuevas estrategias para identificar la producción cerámica arqueológicamente.

Abstract: Production and distribution are widely seen as important dimensions of exchange, especially in the case of ceramics. Little is known about direct evidence for ceramic production in the Maya lowlands. While indirect methods of production have been evaluated, few studies have specifically examined direct evidence, and discussions of production failures are rare. In this paper we examine the problem of ceramic production through an experiment conducted to replicate signatures of failure. Results of our experiment using ancient Maya pottery and prepared briquettes demonstrate distinct and predictable reactions of basic tempers to temperature variation. The implications of these data illustrate why ceramic production remains elusive to archaeologists in the Maya area and the need to develop new strategies to identify ceramic production archaeologically.

In the Maya lowlands, as with many contexts where pottery was employed, archaeologists have recovered literally millions of ceramic artifacts. Yet, few obvious production by-products have been clearly identified, and few ceramic production tool kits have been recognized (e.g., Ashmore, 1988; Beaudry, 1984; Becker 1973; Lucero, 1994; Sheets, 1979). This problem has resulted in the successful use of indirect methods to evaluate production in the Maya area, as well as in other regions of the world.

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[1] These malevolent demons are Syntrips (Smasher), Smaragos (Crasher), Asbetos (Unquenchable), Sabaktes (Shake-to-Pieces), and Omodamos (Conqueror of the Unbaked). So common were firing failures, that these demons made their way into Homer's corpus of songs recorded by Herodotus in around the second to third centuries A.D. (translated in Noble, 1965: 190 and 191).

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Indirect methods for identifying production focus on procurement, technology, and distribution. Geological sources of clays and tempers, evaluation of paste compositions, measurement of vessel dimensions, and stylistic distributions are all ways to address production patterns. Studies using indirect evidence focus on the technology of the vessels themselves such as standardized orifice size and wall thickness (e.g., Rice, 1981, 1991; but see Arnold and Nieves, 1992), assessing the availability of clay and temper, and evaluating the composition of vessel paste through petrographic analysis or chemical characterization (e.g., Arnold et al., 1991; Barba and Ramírez, 1987; Fry, 1980; 1981; Gilman, 1989; Neff and Bishop, 1988; Rands and Bishop, 1980).

The goal of this paper is not to question these indirect methods; their usefulness in illuminating social and economic spheres is undeniable. Rather, we want to ascertain the reasons archaeologists find it difficult to recover direct evidence of ceramic production in the Maya lowlands. Specifically, why are ceramic production failures largely absent from collections? Where have all the production failures gone? Are failures elusive due to the nature of investigation or preservation? In this study, we present a firing experiment conducted to address these questions on ceramic production through the evaluation of different types of paste. The results of our experiment have implications for research on ceramic production not just in the Maya area, but wherever production areas have escaped detection.

Direct physical remains of ceramic production primarily consist of kilns and firing areas (Evans, 1978; Nicklin, 1979; Stark, 1985; Tosi, 1984). True kilns, however, were not used during the earliest periods of pottery production, nor were they generally used in the New World before Columbus, with a few exceptions (e.g., Ciudad Ruiz, 1995; Connell, 1994; Pool and Santley, 1992; Russell, 1993; Shimada et al., 1994; Stark, 1984, 1985; Stone and Turnbull, 1941; Sullivan, 1988), even by modern potters (e.g., McBryde, 1945; Reina and Hill, 1978; Thompson, 1958). Most significantly for our purposes, kilns were not used prehistorically in the Maya lowlands (Rice, 1987a).

Many prehistoric potters used open-air fires (e.g., Costin, 1986; Pool, 1992; Rice, 1987a; Santley *et al.*, 1989; Sinopoli, 1991: 103; Stark, 1992), as likely did the ancient Maya. Open-air firing sites are often ephemeral, and unless reused consistently over time, may leave little trace. Depending on size, firing areas may be indistinguishable from hearths and are typically located outside habitation areas for reasons of safety (e.g., Arnold, 1991: 104; Deal, 1983; Gilman, 1989; Hack, 1942; Reina and Hill, 1978; Sullivan, 1988). As archaeological research usually concentrates on visible architectural remains, rather than beyond and between structures where the areas where prehistoric pottery firing likely occurred (see Deal, 1983, 1988; Hagstrum, 1989; Stark, 1992; Sullivan, 1988), this compounds the problem.

Prehistoric production ideally should leave telling evidence of ceramic manufacture. However, the techniques involved are often simple with perishable tools and few facilities. Straight-sided objects such as raspers and sticks are used today by traditional potters for scraping and graving tools; pebbles are used to smooth and burnish vessels (e.g., Arnold, 1988; Kosakowsky and Hammond, 1991: 173; McBryde, 1945; Reina and Hill, 1978; Thompson, 1958). All these would be difficult to identify archaeologically (Rice, 1987b; Rye, 1981).

Since unfired vessels would not survive the test of time, the only direct evidence of ceramic manufacturing by-products would be production failures resulting from firing errors. Temperatures of any firing, and particularly open-air fires, fluctuate and require skill to control. Too much draft during firing will result in vessels breaking, while high temperatures may cause vessels to loose their form through cracking, shattering, or melting. Traditional potters today in all parts of the world can lose an average of 35 up to 100 percent of their vessels during firing (see Rice, 1987b: Table 6.1). Shattered vessels might be indistinguishable from vessels broken during normal use and discard, and overfired vessels, commonly referred to as "wasters" are infrequently reported (Beaudry, 1984; Lucero, 1992; Rice, 1987a). But just how difficult would their identification be? Are there specific conditions under which one might find evidence of such failures? Our firing experiment provides significant answers to the quest for direct evidence of ceramic production areas in the Maya lowlands.

A series of experiments was designed to ascertain the effects of firing temperatures on ceramic products. Using prepared briquettes and prehistoric Maya sherds, we fired samples at temperatures within and above the range of open-air fires in an effort to bracket the nature of changes that occur during firing. Traditional open-air temperatures can range from 625°C to over 900°C (Rice, 1987b: 156 and 157; Rye, 1981: 102 and 103; Shepard, 1976: 87; e.g., Arnold, 1988: 34; Pfeiffer, 1983: 166). Controlling temperature in open-air fires is a challenge, but knowledge and experience in the manipulation of fuel, insulation, and vessel composition have resulted in a degree of predictability in firings (Rye, 1981: 98).

Ceramic technology in the Maya lowlands

As is the case around the world, the Maya lowlands provide the raw materials for ceramic manufacture: clay and temper (Jones, 1986: 9-56; Shepard, 1962: 252-254; West, 1964). The predominant clay type in the limestone shelf of the Maya lowlands is calcareous in nature and is considered to be part of the smectite family of clay minerals, also known as montmorillonite (Darch and Furley, 1983). A valuable property of these clays is the fact that they typically fuse at relatively low temperatures. Montmorillonite clay is also quite sticky, a characteristic that can result in high shrinkage rates during drying and firing, and thus, may result in cracking (Rice, 1987b: 49). Tempering agents offset this problem.

Ancient Maya potters used pastes consisting of three major temper types, either naturally inclusive or added by the potter: limestone, volcanic ash, and grog (e.g., Barba and Ramírez, 1987). Limestone is the most accessible temper type since the bedrock of the Maya lowlands consists of limestone (West, 1964). The stable form of calcium carbonate, calcite, is the major constituent of limestone (Jones, 1986: 12). Consequently, limestone temper features most conspicuously in ceramics of all shapes and sizes throughout prehistory (Jones, 1986: 12-19). Coarse and fine inclusions of limestone temper would depend on function and style and are found both for utilitarian and special-use vessels.

Volcanic ash, characteristically used during the Late Classic period (A.D. 600-900), is largely restricted to fine pastes designated for serving rather than cooking functions (e.g., decorated plates and drinking vessels). No local source of volcanic ash has been recorded within the lowlands proper, and the closest known source is 150 km distant from the lowland Maya area. While it is possible that ash lenses may have existed in the lowlands sometime in prehistory (Ford and Glicken, 1987; Ford and Rose, 1995), their presence is not detectable today and evidence suggests that volcanic ashes are unlikely to form beds in tropical lowland conditions.

Grog is simply crushed or ground pieces of pottery prepared for use as temper. This would seem to be readily available once pottery technologies were in place. Nevertheless, the use of grog as a tempering agent was restricted to the

Preclassic Period before A.D. 250 in the Maya area (Jones, 1986: 20 and 21).

These tempering agents each have distinct properties that affect their reaction under specific firing conditions. Limestone, a calcium carbonate ($CaCO_3$), is unstable at about 850°C and begins to dissociate to calcium oxide or lime —CaO— and carbon dioxide gas —CO_2— (Freeth, 1967: 110; Rice, 1987b: 98; Rye, 1976: 120; Shepard, 1976: 30). This reaction ultimately reduces temper volume through expansion and escape of gas that weakens and damages vessel walls. Calcium oxide, in turn, absorbs water to form calcium hydroxide ($Ca[OH_2]$) which is soluble in water. Hydration of lime increases volume, which can cause pressure that also can weaken, crack, break, or crumble vessels. Evidence for initial stages of carbonate dissociation, or calcination, is identified by white and friable limestone inclusions. On the whole, however, limestone is a good additive to clay. Under heat, limestone expands at a similar or slower rate than clay itself up to 600°C (Sinopoli, 1991: 14; Rye, 1981: 127), and can be a dependable and durable tempering agent for most purposes.

There are various mechanisms potters can use to offset carbonate dissociation. One way is to fire vessels at low enough temperatures to avoid dissociation. Potters can also process limestone before it is added to clay for greater stability. Stability can be attained through burning limestone prior to making paste, or by using fine-grained particles which results in less damage during rehydration and expansion (Rice, 1987b: 98; e.g., Rye, 1976: 130). Another way involves the addition of salts to the paste (Rye, 1981: 33; e.g., Rye, 1976; cf. Arnold, 1971). In the Maya lowlands, salt would have been available from coastal areas and through extraction processes from palms as practiced by present-day Maya (McKillop, 1995).

Volcanic ash is primarily composed of glass (silica) and associated volcanic materials, such as biotite, hornblende, and feldspar. Silica, the main component of ash, does not alter or melt (vitrify) until temperatures in excess of 1100°C are attained (Rice, 1987b: 103; Shepard, 1976: 83). Moreover, volcanic ash, as a fine to very-fine angular additive, together with clay, increases the melting point of paste. Consequently, this combination of features makes volcanic ash tempered vessels stable and predictable within the temperature range of open-air fires. While a highly predictable tempering agent, its fine quality is best suited for particular vessel types that do not involve continual reheating, such as cooking vessels.

Grog, or crushed pottery, functions as a good additive for clay and was used as are all tempers to strengthen clay for vessel forming and firing. Clay bonds well to the irregular and angular shape of sherd temper which improves vessel strength (Jones, 1986: 20). Furthermore, grog has already been through the firing process and is chemically inert. Thus, it is stable and predictable when re-fired in the range of open-air fire temperatures. Grog offers versatility in that it can be easily ground finely or coarsely. Despite these advantages, grog was predominantly used during the Preclassic Period, before A.D. 250, and most often is found mixed with calcite temper.

The properties of temper, the relationship between clays and tempers, the problems of matching pastes and slips, and the reactions of pastes under varying firing conditions, were well understood by prehistoric potters. The widespread, even preferred use of limestone, suggests that potters recognized the constraints of the various tempers and worked within their bounds. Still, the vagaries of pottery production would plague the potter's craft, and our experiment was designed not only to evaluate this knowledge but to explore the conditions that could result in failures.

Ceramic firing experiment

Four experimental firings were conducted to directly assess results of firing production failures within the range of earthenware firings (cf. Barba and Ramírez, 1987; Costin, 1986: 185-188).[2] In an effort to control the firing environment and simulate prehistoric open-air conditions, a gas heated, flue controlled kiln was used at the UCLA Art Ceramics Laboratory of the Department of Art. Samples were fired in an oxidizing atmosphere only once to prevent thermal fatigue and to permit comparison of samples among firing stages.

We began the experiment with an average low earthenware firing of 720°C, well above the temperature where organic matter in clay typically burns out (300-400°C). Firing temperatures were increased incrementally, culminating at 1205°C, where iron rich clays begin to melt. The first two firing stages of 720°C and 905°C fall within standard temperatures of traditional open-air firings (Rice, 1987b; Shepard, 1976). The third stage was at 1015°C, the extreme upper margin of open-air fires (see Rye, 1981: 127). The fourth and final firing stage was at 1205°C, well beyond the upper limit of an open-air fire (Table 1). These four stages bracket traditional open-air firing conditions and provide a wide range of results for comparison.

Two methods were used to measure temperature: an Olympic optical pyrometer and Orton pyrometric cones (see Table 1; see Appendix). Pyrometers are put directly into the kiln and measure temperatures above the range of mercurial thermometers. Pyrometric cones are "small pyramids compounded of materials...similar to glazes, whose precise composition varies so that the cones will melt and bend at specific temperatures given a standard rate of temperature increase" (Rice, 1987b: 82). The combination of these two measuring devices allowed for accurate temperature control.

Each firing stage was set up in the same manner. Samples were placed on a stone slab in a standard order.[3] Samples were labeled by the stage number at which they were fired (1-4). Prior to each firing, all samples were dried overnight in the kiln at *ca.* 250°C. The drying rids samples of excess water and maintains comparability among them.

Before and after each firing, a number of features were described for each sample item. We recorded vessel time period, form, presence or absence of slip, temper type, and percent of temper (Appendix). In addition, Munsell colors were recorded for the paste cross section before and after firing. Finally, each sample was tested for reaction to HCl in order to assess the presence of carbonates and as a measure of calcium carbonate dissociation.

After each firing, the amount of total firing time was documented and then the overall condition of each sample was described. The following standard terms were used:

1) hard — retained their form (usable)
2) friable — easily crumbled (unusable)
3) crumbled — reduced to sand particles (unusable)
4) sintering — began to fuse (usable)
5) vitrification — melted (unusable)

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[2] Cathy Costin (UCLA Institute of Archaeology) suggested the basic format for this experiment.

[3] The sherds were placed on a stone slab in a specific order in anticipation of numbers burning off during firing.

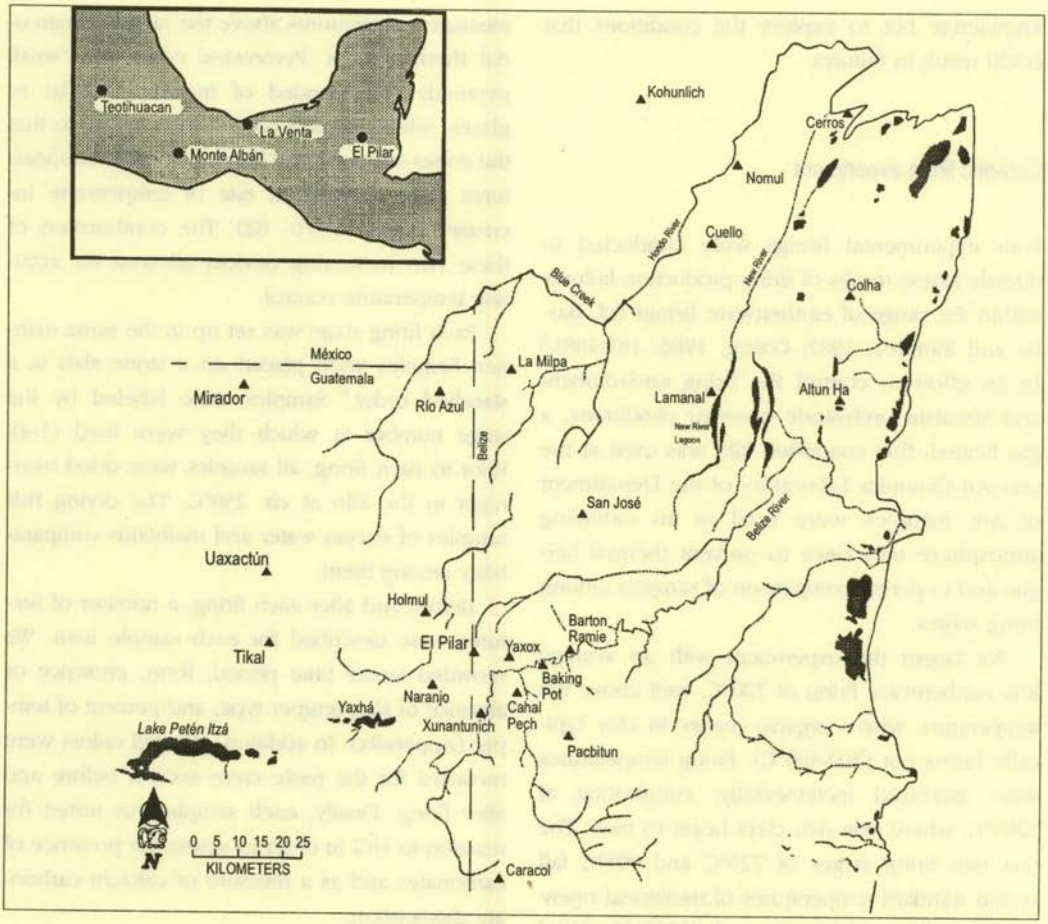

Figure 1. Map

During each firing stage, the kiln flue was kept open to maintain an oxidizing atmosphere. Temperatures were brought up slowly to prevent shock and to ensure consistency among the firings. Because of these procedures, the amount of time allowed to reach the desired temperatures was from three to seven hours. This amount of time is longer than average for traditional firings (12-18 minutes; Shepard, 1976: Table 3), exposing samples to a higher degree of oxidation than generally found in open-air firings, thus affecting color but not firing results (cf. Rye, 1981: 123-134). The kiln was turned off once the pyrometric cones and pyrometer indicated the desired temperature. At this point for each firing, the flue was closed to slow cooling and to prevent shattering. After cooling for 12 hours, the samples were removed from the kiln, described, and photographed.

Experiment samples

The experiment included a total of 114 samples consisting of prepared briquettes and ancient ceramic sherds. Briquette samples were prepared using montmorillonite clay from the Belize River area (determined through XRF analysis,

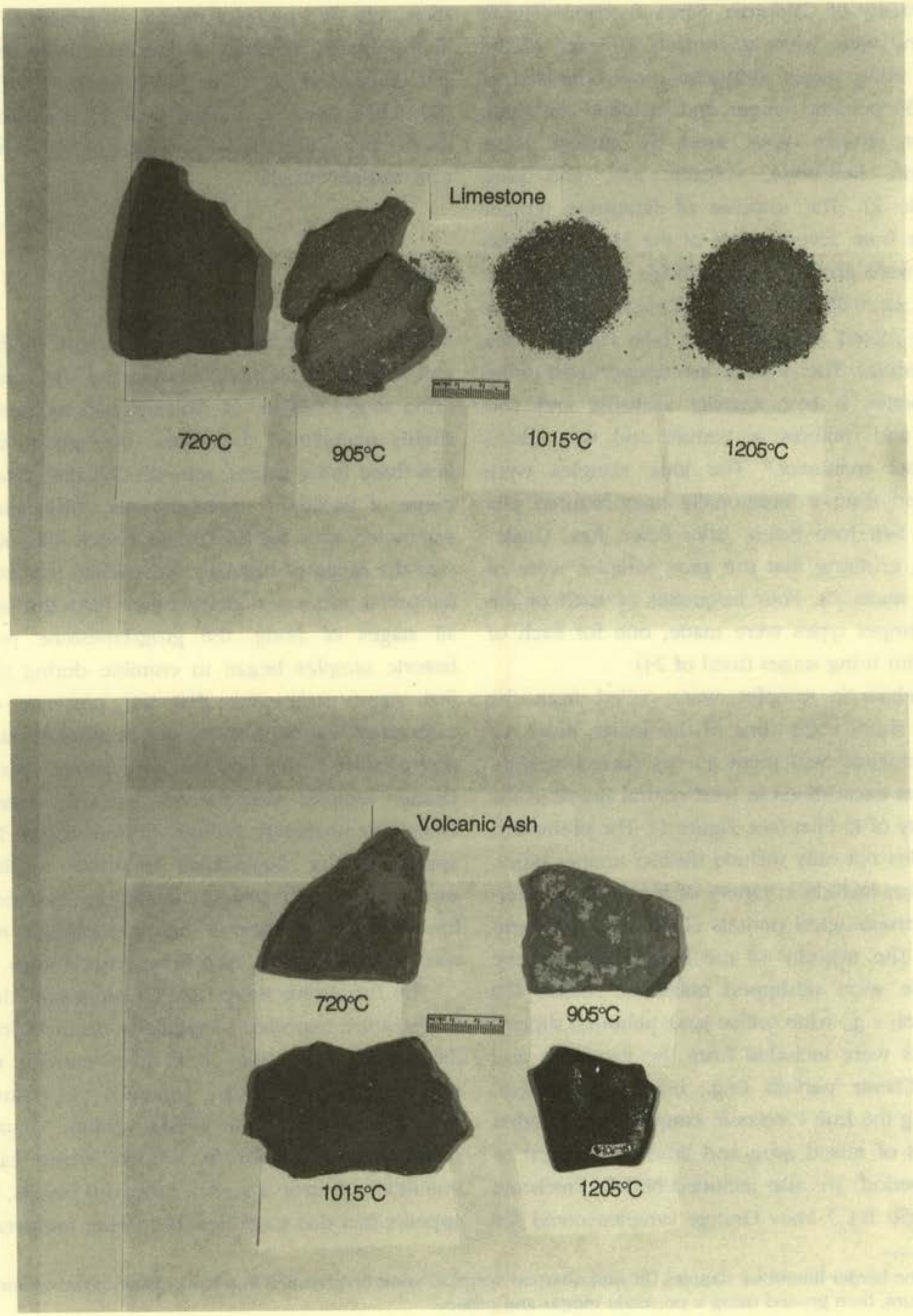
Limestone
720°C
905°C
1015°C
1205°C
Volcanic Ash
720°C
905°C
1015°C
1205°C

Figure 2

University of California, Santa Barbara) (Figure 1) and were used as controls for each of the four firing stages. Briquette paste consisted of *ca.* 35 percent temper and included the three major temper types used by ancient Maya potters: limestone, volcanic ash, and grog (Table 2). The samples of limestone temper come from several areas of the Maya lowlands and were ground[4] into particles ranging in size from *ca.* 0.05 to 3 mm in diameter before they were mixed with the clays (see Figure 1; see Appendix). The volcanic ash temper used in the briquettes is commercially available and was fine and uniform in texture and was added without treatment.[5] The grog samples were ground from a traditionally manufactured olla from San Jose Peten, Lake Peten Itza, Guatemala, ensuring that our grog samples were of local materials. Four briquettes of each of the six temper types were made, one for each of the four firing stages (total of 24).

Prehistoric samples were culled from the body sherd collections of the Belize River Archaeological Settlement Survey (BRASS) residential test excavations in west-central Belize in the vicinity of El Pilar (see Figure 1). The prehistoric samples not only include distinct temper types, but also include a variety of forms from different chronological periods (Table 3; see Appendix). The majority of the body sherds in the sample were unslipped utilitarian vessels (79 percent; e.g., wide orifice jars), although slipped vessels were included from the Preclassic and Late Classic periods (e.g., bowls and plates). Among the Late Preclassic samples, we included sherds of mixed grog and limestone typical of that period. We also included Middle Preclassic (550-250 B.C.) Mars Orange samples noted for their very fine paste of either self-tempered or well-prepared volcanic ash and/or calcite temper (Gifford *et al.,* 1976: 73-74, Shepard, 1955: 32). There were a minimum of 23 prehistoric sherds per firing stage for a total of 90 prehistoric samples in all.

Results

Limestone tempered samples became friable and eventually crumbled during the successive firing stages (Figure 2). Volcanic ash tempered sherds maintained their form throughout the first three firing stages, representing the widest range of traditional open-air fires. Vitrification was noted after the final stage, which falls outside the range of open-air fires. While the grog tempered briquettes retained their form through all stages of firing, the grog/limestone prehistoric samples began to crumble during the first stage, suggesting that the presence of carbonates will be unstable unless measures are taken to offset this problem (see above). Mars Orange samples were the only ones to remain essentially unaltered through all four stages. To appreciate the significance of these results, especially with regard to identifying evidence for ceramic production in the archaeological record, we will discuss each firing stage in turn.

The first firing stage (720°C) represents the temperature expected to regularly occur in traditional open-air fires. It is high enough to fully harden earthenware ceramics, yet is low enough to control the disassociation of unstable calcium carbonate tempers which can potentially destroy a vessel. From our results, it appears that this stage is at the upper tempera-

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[4] The harder limestone samples (hi' and quarried samples) were first crushed in a jaw crusher in the ceramic kiln room, then ground using a porcelain mortar and pestle.

[5] Commercial volcanic ash consists of silica (73 percent), alumina (12 percent), potassium (8 percent), sodium (2 percent), iron (1 percent), calcium (1 percent), and titanium (0.5 percent).

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ture margin for untreated limestone tempered vessels. The briquettes remained hard and maintained their essential form, while a third of the prehistoric samples became friable, representing incipient dissociation and vessel instability (Table 4; see Appendix). Those that were friable were not suitable for use as containers. As expected, all volcanic ash and grog samples retained their form and were consistently hard. The results of the briquette samples indicate that low fires were adequate enough to produce functional vessels.

The second stage (905°C) represents the upper range of temperature traditionally attained in open-air fires. This temperature falls above the temperature for limestone dissociation (850-900°C) and, not surprisingly, the majority of limestone tempered samples (including the one prehistoric sample with grog) exhibit friability. Even when many samples initially retained their basic form, they would be useless as containers since they easily crumbled into sand-sized particles when handled (Table 5; see Appendix). In terms of the limestone tempered samples, the results of the second firing are dramatic: 12 percent (prehistoric) to 25 percent (briquettes) survived in usable condition. Recalling that the second stage firing was at 905°C, within the range of traditional open-air fires, the implications are that more than 75 percent of carbonate tempered vessels in such a firing would produce failures.

Both the prehistoric and prepared briquettes of volcanic ash, as anticipated, were uniformly hard and continued to retain their form. This also was the case for the grog tempered briquette. Such results would provide perfectly usable vessels.

The third firing stage (1015°C) represents a temperature at which traditional open-air fires would not ordinarily achieve, but at which they may peak. All limestone tempered samples, inclusive of the briquettes, became completely friable or crumbled (Table 6; see Appendix). Such radical changes would be classed as seriously over-fired; none of the products would have been usable.

All volcanic ash samples and grog tempered briquettes retained their form at this firing stage. Although the slips did not survive this temperature (flaked off), these results indicate that volcanic ash and grog temper additives are stable even when unusually high temperatures are reached.

The fourth stage (1205°C) represents a temperature that falls well outside the range of traditional open-air fires and was conducted to bracket the results. This final stage permitted the identification of the temperature at which volcanic ash and grog tempered ceramics might exhibit changes. Results observed at this stage would not be expected for archaeological cases where open-air fires were used.

In the case of the limestone tempered samples, the reaction was consistent with the third firing stage: the samples were unstable, friable, and crumbled (Table 7; see Appendix). Volcanic ash samples exhibited, for the first time, significant alterations in form as a result of the high temperature. Sintering, where the paste fuses, and vitrification, or melting, were present. While these alterations are diagnostic of an over-firing environment, such high temperatures would not be expected for open-air fires. Curiously, the Mars Orange prehistoric samples and grog briquette samples essentially maintained their form through this firing stage. Clearly, the combined clay and temper characteristics of these samples can withstand very high temperatures, and failures are not necessarily likely to be obvious in ceramic collections.

With these results, we can begin to understand the nature of earthenware ceramic production failures fired in open-air fires. Limestone tempered ceramics are extremely sensitive to temperature, but despite this evident problem, potters over time in the Maya area used various forms of calcium carbonate as a tempering agent. It is available and abundant, and obviously could be controlled as a temper agent based on their obvious presence in most Maya ceramic collections. Yet, when failures did occur, as amply illustrated experimentally, their signature would be lost to archaeologists. All that remained from misfired limestone tempered vessels were crumbs.

On the other side of the continuum of firing are the volcanic ash tempered ceramics. These are well designed for any high temperature, even peak temperatures that might be attained in an open-air fire environment. Since the problems of open-air firings are constant, there would be errors in the firings of volcanic ash tempered vessels. Mistakes in these firings, however, would not expect to be affected by temperatures typically attained in open-air fires, but would be left to he other factors such as bursting, breaking, crashing, and crushing during firing. The results of these mishaps would not necessarily be distinguishable in the archaeological record from pottery associated with normal use and discard, especially since broken ceramics are among the greatest proportions of collections where pottery was used (see Grove and Buge, 1978).

There is little doubt that direct evidence of ceramic firing failures is an elusive aspect of the archaeological record, especially in the Maya lowlands. Any limestone tempered vessel would not withstand overfiring and from there would vanish from the material record. Volcanic ash would regularly withstand overfiring and thus would reveal little, if any, material evidence of failure. This makes any effort to identify ceramic production based on production failures difficult at best.

Implications for Archaeology

The results of the firing experiment have significant implications for the investigation of prehistoric ceramic production activities. Firing reactions of carbonates and silica tempers represent the two extremes of the continuum of ceramic production. Production failures of these temper types would be difficult to identify in the Maya lowlands. Our firing experiment has provided empirical evidence that production failures will be difficult to recognize archaeologically. The lack of obvious production failures, however, does not necessarily limit our ability to identify ceramic production loci. Archaeologists interested in ceramic production activities can consider alternative methods of detection (e.g., Wright, 1989).

More attention to production sites themselves is vital to the quest for direct evidence of ceramic manufacture. Ethnographic case studies demonstrate that potters frequently focus major production activities on specific vessel forms (e.g., Chávez, 1992; Deal, 1983: 65-66; Hagstrum, 1989; Hunt, 1989; Kramer, 1985; McBryde, 1945; Thompson, 1958). This may have been the case in the prehistoric Maya area (Potter and King, 1995; e.g., Lucero, 1992, 1994; Stark, 1985). Other evidence of ceramic production includes hardened oxidized surfaces, storage areas of clay and temper, stockpiled vessels, and artifacts associated with vessel manufacture such as molds and mortars and pestles used to grind minerals for paints (Deal, 1983; Hayden, 1987; Kramer, 1985; Sullivan, 1988).

The results of our ceramic experiment underscore the need for more innovative ways to evaluate ceramic production, particularly in the Maya area. Evaluations of ceramic density distributions could help to isolate potential production sites where specific vessel forms appear in unusually high proportions may represent stockpiling or errors in firings. Examinations beyond structures in search of other activities may reveal firing areas. Efforts should also consider means for the isolation of potential tool kits. These are challenges we need to face if we are to fully appreciate the integral role of ceramic production and distribution in ancient societies.

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APPENDIX

Table 1. Temperatures

Firing Stage	*Temperature (°C)*	*Pyrometric Cone Number*[a]	*Temperature Traits*
1	720	018	average open air-fire
2	905	010	upper range of open air-fire
3	1015	06	peak of open air-fire
4	1205	5	above open air-fire

[a] Based on UCLA Ceramic Art Laboratory Listing.

Table 2. Briquette Samples

Briquette	*Temper Type and Location*	*n*
A	reworked limestone (sand), Tikal area, Peten, Guatemala	4
B	quarried limestone, Tikal area commercial volcanic ash	4 4
D	hi' or crystalline limestone, north of Lake Peten Itza	4
E	grog; from a traditionally manufactured olla, San Jose, Peten	4
F	surface limestone, El Pilar area, Belize	4
Total		24

Note: Each briquette was approximately 4 x 3 x 1 cm in size (Before drying and firing).

Table 3. Prehistoric Samples

Period/Temper	*limestone*	*Volcanic Ash*	*Grog*	*Total*
Preclassic (before A.D. 250)	—	—	4	4
Middle Preclassic Mars Orange (550-250 B.C.)	—	5	—	5
Late Preclassic (300 B.C.-A.D. 250)	41	—	—	41
Late Classic (A.D. 600-900)	20	20	—	45
Total	61	25	4	90

Table 4. Firing Stage Two (905°C) Results

Temper Type	*Paste Condition*	*Slip Condition*
Prepared Briquettes		
Limestone n=4	100% hard	—
Volcanic Ash n=1	hard	—
Grog n=1	hard	—
Prehistoric Samples		
Limestone n=15	67% hard 33% friable	beginning to crack
Volcanic Ash n=5	100% hard	from lustrous to matte
Mars Orange n=1	hard	—
Grog/ Limestone n=1	crumbled	—

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Table 5. Firing Stage Two (905°C) Results

Temper Type	*Paste Condition*	*Slip Condition*
Prepared Briquettes		
Limestone n=4	25% hard 25% friable 50% crumbled	—
Volcanic Ash n=1	hard	—
Grog n=1	hard	—
Prehistoric Samples		
Limestone n=16	12% hard 69% friable 19% crumbled	flaking
Volcanic Ash n=5	100% hard	some beginning to flake
Mars Orange n=1	hard	—
Grog/ Limestone n=1	crumbled	—

Table 6. Firing Stage Three (1015°C) Results

Temper Type	*Paste Condition*	*Slip Condition*
Prepared Briquettes		
Limestone n=4	100% crumbled	—
Volcanic Ash n=1	hard	—
Grog n=1	hard	—
Prehistoric Samples		
Limestone n=15	33% friable 67% crumbled	flaking
Volcanic Ash n=5	100% hard	flaking
Mars Orange n=1	hard	—
Grog/ Limestone n=1	crumbled	—

Table 7. Firing Stage Four (1205°C) Results

Temper Type	*Paste Condition*	*Slip Condition*
Prepared Briquettes		
Limestone n=4	25% hard 25% friable 50% crumbled	—
Volcanic Ash n=1	hard	—
Grog n=1	hard	—
Prehistoric Samples		
Limestone n=16	100% crumbled[a]	crumbled
Volcanic Ash n=5	100% vitrified	vitrified
Mars Orange n=2	50% hard 50% friable[b]	—
Grog/ Limestone n=1	crumbled	—

[a] 61% initially retained form, but crumbled when exposed to air after *ca*. 12 hours.

[b] One sample contained some limestone temper.

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