Journal of Archaeological Science (1997) **24,** 497–504

Technological Changes in Prehistoric Ceramics from Eastern Puerto Rico: An Exploratory Study

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(*Received 1 September 1995, revised manuscript accepted 15 April 1996*)

Studies of Caribbean pottery have focused on shifts in style and decoration while changes in ceramic technology have received little attention. This work presents the results of an exploratory project on the study of changes in pottery technology to overcome some aspects of this deficiency. Collections from the Proyecto Arqueológico del Valle de Maunabo, Puerto Rico, representing all periods of the Ceramic Age, were used and several physical properties including original firing temperature, porosity, and density were studied. The results show that some of the periods were characterized by technological changes. Preliminary interpretations of these changes are discussed.

Keywords: POTTERY, CERAMIC AGE, CARIBBEAN PREHISTORY, CEDROSAN SALADOID, ELENAN OSTIONOID, CHICAN OSTIONOID, TECHNOLOGICAL ANALYSIS, POROSITY, DENSITY, PETROGRAPHY, EQUIVALENT TEMPERATURES.

Introduction

Traditionally, studies of Caribbean ceramics have been performed from a cultural and chronological perspective concentrating mainly on the analysis of decorative designs and techniques and elements of shapes. Changes in diagnostic ceramics are normally seen as reflecting simple cultural shifts which are assumed to be innate in any culture or society. Most attempts to explain them are typically superficial (Curet, 1992, 1996). This approach has proved successful in defining ceramic periods, cultures, and population movements (Rouse, 1986, 1992); however, it is limited to the study of pottery decoration and form, thereby ignoring the great bulk of ceramics, which are utilitarian.

Little attention has been paid to other ceramic dimensions, which address function and technology traits (see Goodwin, 1979; Mann, 1986; Donahue, Watters & Millspaugh, 1990; Lambert *et al*., 1990; Carini, 1991; Winter & Gilstrap, 1991; Feuss & Donahue, 1992; van As & Jacobs, 1992; Feuss *et al*., 1993 for few exceptions). If these traits can be measured accurately, functional and technological variables can be useful in spatial, chronological, and comparative studies of ceramics, and can help explain changes in material culture. Furthermore, this type of study can determine if ceramics are manufactured properly to perform specific functions independently of their decorative or aesthetic features. For example, it has been assumed that due to its highly complex and elaborate decoration, early Caribbean pottery tends to be of higher quality than ceramics from later periods. However, some of the results presented below indicate that later ceramics were better manufactured to perform certain utilitarian functions (e.g. cooking, storing liquids) than early pottery. Thus, studies that combine changes in decorative and utilitarian modes of the ceramics can be used to understand better and explain shifts in ceramic assemblages.

This paper is a report of an exploratory project on technological variables of sherds from surface collections obtained in the Valley of Maunabo in eastern Puerto Rico (Figure 1). At this initial stage the purposes of the study are to: (1) make crude and rough measurements of several technological variables on ceramics from different chronological periods to determine if significant differences exist between ceramic styles or series that will merit more detailed studies in the future; and (2) encourage Caribbean archaeologists to consider this line of research in the future. The ceramic samples for the study were selected from surface material from single-component sites collected by the Archaeological Project of the Valley of Maunabo. The variables measured by the project consist of both macro- and microscopic traits. The discussion presented here, however, concentrates only on few of the microscopic traits under study, specifically apparent porosity, apparent water absorption, apparent density, and original firing temperatures. Other characteristics such as temper uniformity, paste texture, and vessel thickness will be presented in a future paper.

Although the collections and sample sizes used in the study are limited, the results presented here show interesting patterns, some of which contradict previous

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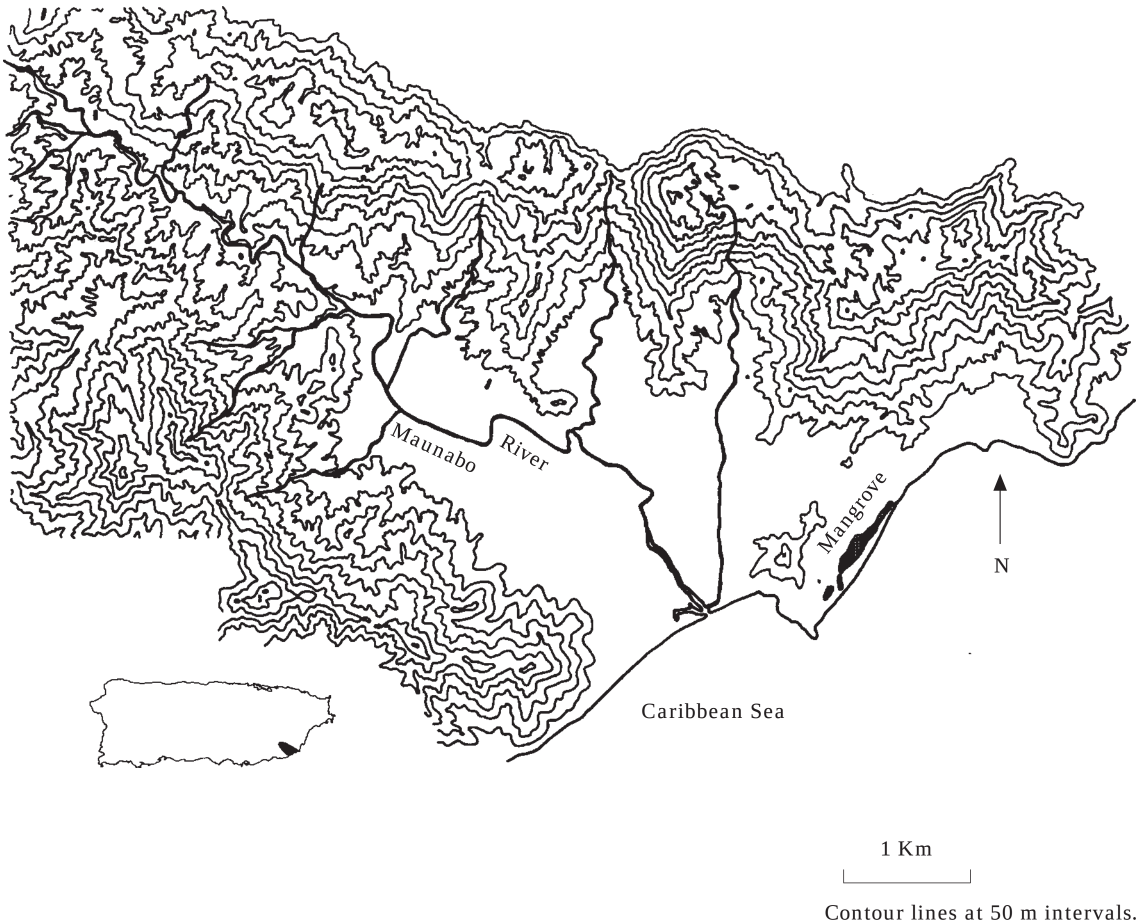

Figure 1. Topographical map of the valley of Maunabo.

misconceptions about the technological levels of prehistoric Puerto Rican ceramics. However, it is recognized that these results should be verified by further experimentation. Due to limitations of the samples, little effort is made here to explain the differences in technological characteristics of the ceramics across time. Future studies are being planned to deal with such explanations.

The Prehistory of Eastern Puerto Rico

The prehistoric sequence of eastern Puerto Rico has been presented elsewhere in detail by other Caribbeanists (Rouse, 1982, 1986, 1992; Rodríguez, 1992*a*,*b*) and a review here would be redundant. Instead, a short summary of the sequence of the Ceramic Age (Table 1) is presented which will follow Rouse's scheme published in 1992.

Cedrosan Saladoid series

The Cedrosan Saladoid (300 BC–AD 600) refers to the first agricultural and ceramic groups that migrated to Puerto Rico from north-eastern South America, particularly from the mouth of the Orinoco river. The Saladoid series is characterized by the high quality of its ceramics, the use of paint as the main technique of decoration, and by particular vessel shapes such as bell-shaped bowls. In general, ceramics are hard, relatively thin, and of finer paste than later series. Decoration normally consists of painting the vessels with one or more colours; white on red, white on orange, and red on buff being the most common combinations.

Table 1. Chronology of the prehistoric occupations in eastern Puerto Rico

Series	Style	Dates
Chican Ostionoid	Esperanza	AD 1200–1500
Elenan Ostionoid	Santa Elena Monserrate	AD 900–1200 AD 600–900
Saladoid	Cuevas Hacienda Grande/La Hueca	AD 400–600 300 BC–AD 400

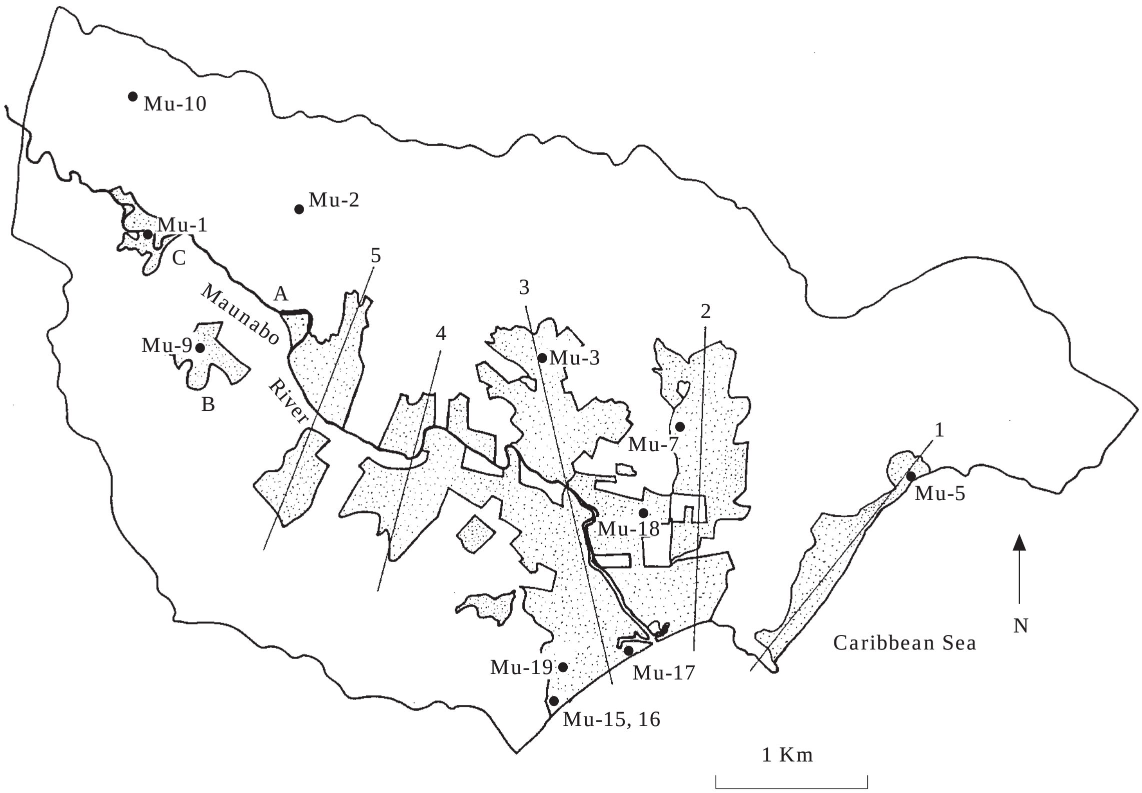

Figure 2. Map of the valley of Maunabo showing the survey units as shaded areas and sites included in the study.

Other decorative techniques include false negative, cross-hatched incisions and engraving, excisions, and modelled zoomorphic and anthropomorphic *adornos*, among others. To date, this series has been subdivided into three styles: (1) Hacienda Grande (300 BC–AD 400); (2) La Hueca (300 BC–AD 400); and (3) Cuevas styles (AD 400–600).

Elenan Ostionoid series

The Elenan Ostionoid series (AD 600–1200), according to Rouse (1982), represents the first series produced by local development in eastern Puerto Rico and is composed of two styles; the Monserrate (AD 600–900), and Santa Elena (AD 900–1200) styles. During the early phase of the first half of this period (i.e. the Monserrate style), the technology and shapes of the final Saladoid pottery were retained, including the tabular lugs, strap handles, and red-painted and slipped ceramics, while no major addition of other kinds of decoration was made. The persistence of Saladoid traits in the early part of the Elenan Ostionoid period makes the assignment of this ceramic material to either one of the series very difficult, since there is no clear break in the ceramic trend. Nonetheless, the distinction between the series becomes more apparent when, later, the Monserrate style is characterized by large amounts of plain and red-slipped pottery contrasting with the great variety and larger quantity of decoration in the previous Saladoid series. In general, the Monserrate ceramics are thicker, coarser and rougher, while vessel shapes are simplified.

Later in time, the Santa Elena style shows a gradual increase in the number of thicker, coarser and rougher ceramics, less use of red paint and slip, and simplified shapes. Strap handles common in the Cuevas and Monserrate styles decrease in number until they disappear, leaving only vestigial ridges on the vessel wall. Most of the decoration is restricted to crude, vertical, rectilinear incisions close to the rims of bowls, frequently accompanied by appliqué strips.

Chican Ostionoid series

The Chican Ostionoid series (AD 1200–1500) is the last prehistoric ceramic group present in Puerto Rico before the arrival of the Europeans. The Esperanza style is the dominant one in eastern Puerto Rico and tends to be characterized by the use of a large number of incisions and combinations of incised lines and punctuations. Most of the designs are placed on the shoulders of cazuela-type bowls (i.e. incurving bowls). The use of paint is almost absent, although vessels slipped with red paint are still present. Strap handles are completely absent while modelled–incised head lugs are still common.

Table 2. Description of sites from the valley of Maunabo used in the study

Site	Site type	Series	Style	Dates
Mu–5	Coastal habitational	Cedrosan Saladoid	Indeterminate	300 BC–AD 600
Mu–16	Coastal habitational	Elenan Ostionoid	Monserrate	AD 600–900
Mu–18	Inland habitational	Elenan Ostionoid	Sante Elena	AD 900–1200
Mu–7	Inland habitational	Chican Ostionoid	Esperanza	AD 1200–1500

The Archaeological Project of the Valley of Maunabo

The Valley of Maunabo is a small coastal valley located in the south-eastern coast of Puerto Rico (Figure 1). In general, the valley has a triangular shape and is well delimited by the ocean on the southern and eastern sides, as well as two mountain ranges on the north and the west. The valley has a wide variety of ecological habitats concentrated in a small space, including coastal areas, mangroves, lagoons, valley bottom, piedmonts, and mountains with sub-tropical forests.

The archaeological project of the Valley of Maunabo consisted of an intensive sampling survey that covered the different environmental zones present in the region. About 9 km^2 were surveyed and 12 sites ranging from the Saladoid to the Chican Ostionoid series were investigated (Figure 2). Four of the sites are located right on the coast, three on the valley bottom, one close to the piedmont, one on a flat area in the highland, two are rock shelters in the mountains, and one is a cluster of two petroglyphs along the river.

Surface material was collected from most of the sites. A seriation analysis (Curet, 1992) which employed cross-dating of ceramic styles and a combination of multidimensional scaling and cluster analysis determined that of these sites, eight seemed to be single-component, two are multicomponent, while the last two could not be cross-dated due to the lack or low number of diagnostic ceramics. Ceramic samples from four single-component, habitational sites (Mu–5, Mu–7, Mu–16, and Mu-18 in Figure 1), representative of all the series defined for eastern Puerto Rico (see Table 2), were selected for the study presented in this paper. The selection of these sites was based on several criteria; chronology, collection sizes, size of sherds, and site type. Site Mu–5 is considered here as representing the Saladoid series and not a specific style since the seriation analysis was not able to assign it to a specific ceramic style (i.e. either to the La Hueca, Hacienda Grande, or Cuevas style). Site Mu–16 represents the Monserrate style, Mu–18 the Santa Elena style, and Mu–7 the Esperanza style (Table 2).

Fifteen sherds from each of the four single-component sites were selected for this study (i.e. 60 sherds altogether). To ensure a representative sample, an effort was made to select only sherds that appeared to have been part of undecorated (utilitarian) vessels and exhibited a range of paste, sherd size, and thickness. An initial petrographical study suggests that prehistoric potters used local materials for temper. Judging from the subangular and angular shape of the inclusions, it seems that they did not use natural, beach or river sands but crushed larger pieces of rock and grog to obtain the desired size. In general, the Saladoid pottery tended to be harder, thinner and contained finer and better-sorted temper than ceramics from the other series.

Porosity

All ceramic material has some degree of porosity which is produced by pores or voids (e.g. spaces) existing between or within the solid particles. Porosity affects a wide range of ceramic properties, including strength, resistance to spalling, permeability of liquids, and heat conductivity (Rice, 1987: 231, 351). Aspects related to pottery use-life such as durability and serviceability of vessels are related to porosity. In cooking vessels, for example, porosity increases the resistance of fired pottery to thermal shock since the pores and air pockets tend to buffer the stresses produced by sudden changes in temperature (Shepard, 1980: 126; Rice, 1987: 351). However, porosity also increases permeability and seepage, making it undesirable for boiling and storing liquids. In many ethnographical cases this weakness is overcome by applying post-firing treatment to the vessel surfaces, typically sealing the interior surface with some mineral or vegetal substances.

Porosity can also affect thermal conductivity. Pottery with high numbers of closed pores will tend to have lower thermal conductivity than that with open pores (Rice, 1987: 368). In the former case, the air trapped in the closed pores will serve as an insulator, while in the latter, large, open, and connected pores will increase thermal conductivity because they permit hot phases to pass throughout the body.

In summary, high porosity is desirable mainly for ceramics exposed to high degrees of thermal stress. In cases where liquids are being processed or stored, seepage and permeability can be reduced by coating the interior surface of the vessel. From this perspective, high porosity will be favourable in cooking pottery. Additionally, to achieve effective thermal conductivity, porosity should be based on open pores. A high degree of closed pores will be desirable in serving vessels since they tend to be good insulators. Thus, physical properties related to porosity such as apparent porosity, density, specific gravity, and water absorption are relevant for identifying the ceramic classes that would have been suited to tasks such as water storage, dry storage, or cooking. These physical properties are discussed below for the case of the sherds from the Valley of Maunabo.

Porosity measurements were obtained following the procedure described by Simon & Burton (1989). Sherds were cleaned, air dried, and then dried in an oven at 110°C for 2 h prior to processing. A dry weight ($W1$) was taken using an electronic scale, then the sherds were saturated by soaking in distilled water for 24 h. The second weight ($W2$) was taken of each water-saturated sherd. The third weight ($W3$) was taken next by weighing the saturated sherd, suspended from a stationary dowel by a piece of nylon thread in a beaker of distilled water. The beaker of water was placed on the electronic balance and the scale turned to zero prior to placing the suspended sherd in the water. This procedure measures the weight of the sherd not displaced by the water without extra calculations.

The procedure described above measured only the open pore space that can be penetrated by water. Thus, the variables that can be calculated from this data are apparent, rather than true, measurements. True measurements would be measured accurately only if all the pore space, both closed and open, was measured. Nevertheless, since open pores are the ones that determine the performance characteristics of the sherds (i.e. the way the pottery would have responded when heated or filled with liquids), the apparent measurements are an appropriate approximation.

Six physical properties were calculated from the procedure described above: total volume of the sherd (VT); volume of open pores (VO); apparent porosity (AP); apparent density (AD); apparent specific density (AS); and apparent water absorption (AW). These properties were calculated using the following formulae:

$$VT = W2 - W3$$

$$VO = W2 - W1$$

$$AP = \frac{VO}{VT} \times 100$$

$$AD = \frac{W1}{VT}$$

$$AS = \frac{W1}{(VT\text{-}VO)}$$

$$AW = \frac{VO}{WI} \times 100$$

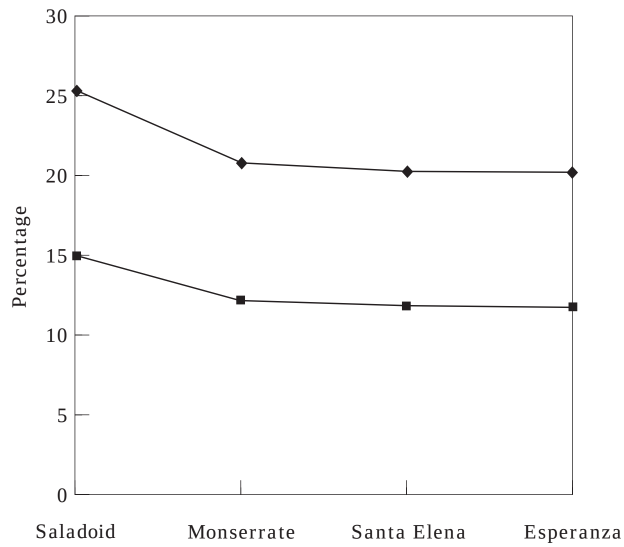

Figure 3. Graph illustrating means for apparent porosity and apparent water absorption (%) for utilitarian pottery from the different ceramic styles. (–◆–, Apparent porosity; –■–, apparent water absorption).

Apparent porosity is the volume of the saturated open pores compared to the total volume of the sherd and it may be expressed as a percentage by volume. Apparent density is the total weight compared to the total external volume. Apparent specific gravity is the whole mass weight compared to a volume of the water equal to the total mass volume minus the volume of the open pores. Apparent water absorption is the percentage increase in weight upon saturation with water. These physical characteristics are determined by a wide variety of factors including intrinsic properties of the raw materials (i.e. type of clay and temper, size, shape, grading and packing of particles, the specific constituents of the paste), firing temperatures, and other treatments to which the material was subjected during manufacture (Rice, 1987: 351). These concepts have been explained thoroughly elsewhere (Grimshaw, 1971; Shepard, 1980; Rice, 1987).

Figures 3–5 present the mean values for the four apparent measurements performed on the sample. As can be appreciated from the graphs, the Monserrate, Santa Elena, and Esperanza sherds tend to present similar values for apparent porosity, apparent specific gravity, and apparent water absorption, while the Saladoid sherds had higher values in these three measurements. Apparent density is the only property that strays from this pattern. The Saladoid series shows the lowest value for the mean apparent density and the Esperanza style has the highest one. The two styles of the Elenan Ostionoid series, the Monserrate and Santa Elena style, present similar values for the mean apparent density. Results of ANOVA tests indicate that there are significant differences ($P < 0{\cdot}05$) between sherds from the Saladoid series and those from the other two series (i.e. Elenan and Chican Ostionoid)

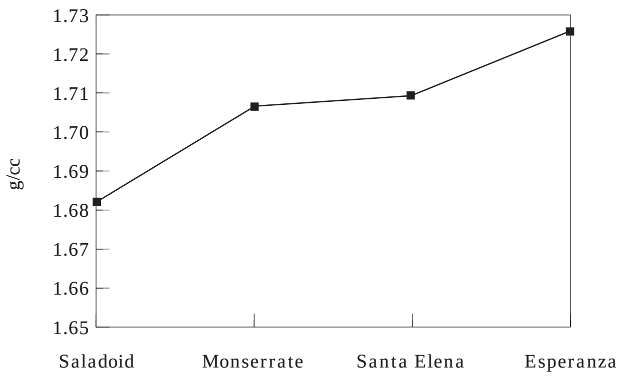

Figure 4. Graph illustrating means for apparent density for utilitarian pottery from the different ceramic styles.

for all these four variables. Differences between the Monserrate, Santa Elena, and Esperanza styles were not significant for any of these variables. This suggests that ceramics belonging to the Saladoid series are technologically different from those of the later series, while utilitarian pottery belonging to the Elenan and Chican Ostionoid series tends to be similar in this respect.

Although it is difficult to explain these results due to the small size of the sample, it is obvious that porosity differs significantly among the sherds from the Saladoid, Elenan, and Chican Ostionoid series. In general, the values measured indicate that Saladoid pottery presents higher porosity than later styles. This explains the fact that they also are the ones with the highest value for water absorption. The high degree of porosity could have been produced by the well-sorted and low number of inclusions present in Saladoid pottery (i.e. fine and well-sorted temper). Matrices containing particles of different sizes will have lower porosity and permeability than matrices that contain particles of relatively the same size (Grimshaw, 1971: 411–412; Simon & Burton, 1989: 115). These conclusions are opposite to the general belief that Saladoid ceramics are denser than other series. Saladoid ceramics, also, had the lowest value for mean apparent density which is concomitant with high porosity. Sherds from the Esperanza style produced the highest values for this last physical property.

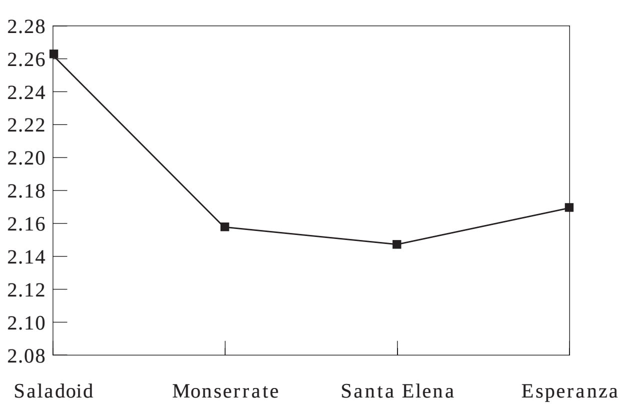

Figure 5. Graph illustrating means for apparent specific gravity for utilitarian pottery from the different ceramic styles.

Original or Equivalent Firing Temperatures

Being able to estimate the firing temperatures of pottery helps archaeologists assess the general technological level of the potters from different periods, sites, or regions. Furthermore, since many relevant physical properties of ceramics are influenced by firing temperatures, estimating the original firing temperature assists in making inferences regarding vessel function.

There are several ways of estimating the original firing temperature of ceramics. However, the measure of thermal expansion during or after refiring is one of the methods widely used in archaeometry today and it was the one employed in this study to estimate the equivalent firing temperature. The principles, advantages, and disadvantages of this method have been discussed elsewhere in the literature (Roberts, 1963; Tite, 1969; Kaiser & Lucius, 1989) and a brief summary is presented here.

When a body of clay is heated, a series of complex and irreversible structural changes takes place. One of these changes is shrinking of the clay material produced by a wide variety of processes that occur at different temperatures during firing (e.g. water loss, collapse of the crystal lattices, sintering, bonding of particles, and vitrification). When the firing of the clay stops, these processes are halted and the clay is now a piece of ceramic. As with any solid, a piece of ceramic will expand when it is reheated. However, when the temperature of reheating reaches the original firing temperature, the processes of sintering and vitrification resume and the ceramic begins to shrink. Thus, with some exceptions, the temperature at which the shrinkage process begins during refiring is an approximation of the original firing temperature. This approximation is called equivalent firing temperature and is defined as ‘‘that constant temperature which would have brought about the same amount of sintering as was achieved during the original firing’’ (Tite, 1969: 132).

The same 60 sherds as used in the determination of porosity were used in the estimation of the original firing temperature. Before starting the refiring procedure, the sherds were dried in an oven at 110°C for 1 h. The initial temperature of the refiring experiment was 100°C, which is an extremely low temperature, to set ‘‘a baseline’’. The length of time is important to give enough time for the physico-chemical processes to happen, and 1 h was selected following the recommendations made by Tite (1969). The length, width, and interior and exterior surface colours were registered for each of the sherds after each one of the intervals. Observations were registered every 100°C interval, keeping the sherd for 1 h at each temperature. The final temperature was 1000°C. It was expected that this procedure would produce estimates of the equivalent

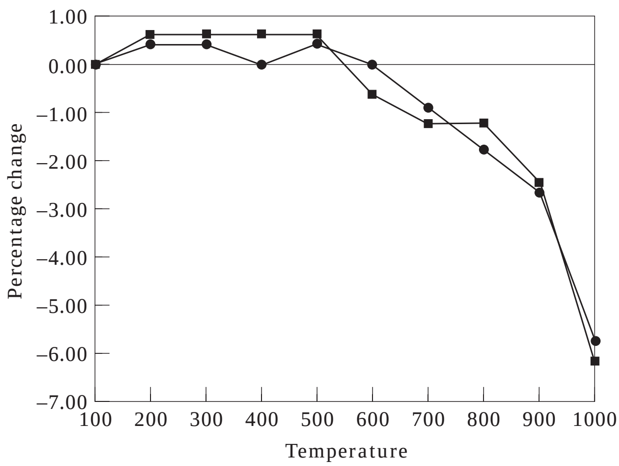

Figure 6. Graph illustrating an example of a sherd's percentage change in length and width after refiring. (–●–, Length; –■–, width).

firing temperatures within a 100°C margin of error. The results of one sherd from Mu–5 (Saladoid series), one from Mu–7 (Esperanza style) and of two from Mu–18 (Santa Elena style) had to be discarded due to inconsistencies of the changes in the dimensions of the sherds. Altogether, the results of 56 of the original 60 sherds are used in the following discussion.

The equivalent firing temperatures were estimated using the percentage of changes in length, width, and colour with temperature (see Figure 6 for an example). Figure 7 presents the percentage of sherds from the different ceramic categories originally fired at different ranges of temperature according to the results of the experiments presented here. Two major points can be appreciated from this figure. The first one is that while most of the ceramics from the Saladoid series and Monserrate and Santa Elena styles were fired in temperatures between 500 and 600°C, those belonging to the Esperanza style are equally distributed in temperatures between 400 and 800°C. Second, the distribution of equivalent temperatures among the Saladoid series and Santa Elena style are very similar; both of them have sherds fired from 400 to 700°C. The Monserrate and Esperanza styles tend to include sherds with higher equivalent temperatures (i.e. between 400 and 800°C).

It is interesting to point out that these results, if supported by further studies, indicate that most of the utilitarian pottery from the Saladoid series was fired at similar temperatures as that from later ceramic categories. This contradicts most of the assumptions made by many Caribbean archaeologists (including myself) in that Saladoid pottery, due to its hardness, was fired at higher temperatures than later ceramics. These results seem to indicate that the characteristics of the Saladoid ceramics were produced mainly by the treatment of the paste and not by the firing procedure.

Conclusions

The limited results presented here indicate that significant differences exist in technological characteristics between the utilitarian ceramics of the Saladoid, Elenan Ostionoid, and Chican Ostionoid series of eastern Puerto Rico. In summary, it has been observed that:

(1) even though Saladoid ceramics tend to be harder and contain finer paste they are less dense and more porous than later ceramics;
(2) Saladoid, Elenan, and Chican Ostionoid ceramics seem to have been fired at similar temperatures; and
(3) based on these two statements it can be suggested that technological and physical differences between the Saladoid pottery and those

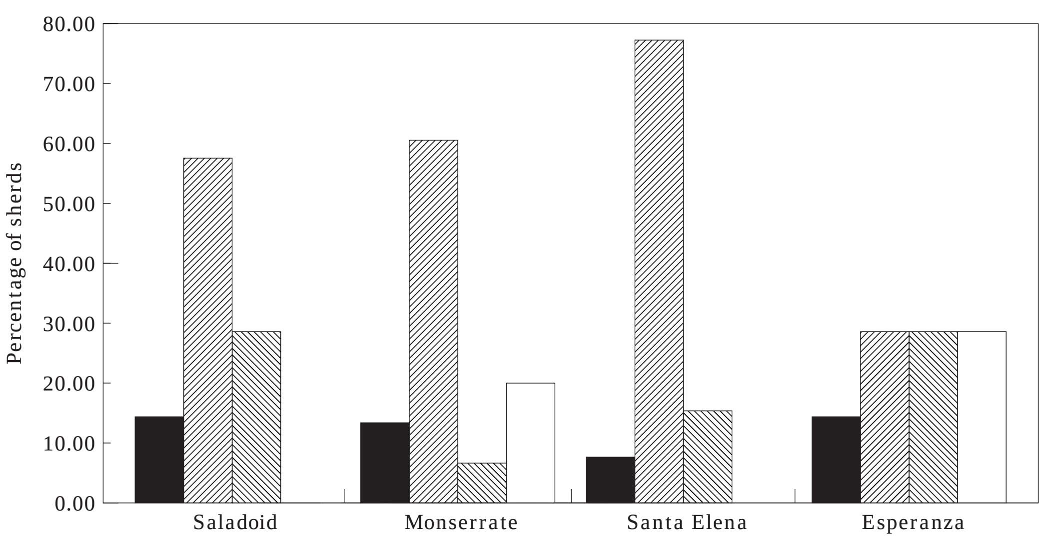

Figure 7. Graph summarizing the refiring results by equivalent temperatures (°C) and ceramic styles. (■, 400–500; ▨, 500–600; ▧, 600–700; □, 700–800).

from other series are the results of the treatment of the paste and not of the firing procedure nor the raw material used in their manufacture.

These results raise some questions on previous assumptions about the ceramics of the different series. This study is the first step of a wider research program which will concentrate on: (i) gathering a larger and better sample of both decorated and utilitarian pottery; (ii) classifying the pottery according to vessel shapes and rim forms; and (iii) refining the measurements and procedures used here.

Acknowledgements

I am thankful to Heather Manley, Bryant Pappas, and Daniel Welch, students from Gettysburg College, for their invaluable help in measuring most of the physical variables included in this work. I appreciate the help of Allan Paulson (Arts Department, Gettysburg College) and Cheryl Vogel (Biology Department, Gettysburg College) in allowing me to use their equipment to run the analysis presented in this paper. I also thank Mary Jane Berman, Irving Rouse, Dave Watters, and Samuel Wilson for comments on earlier versions of this paper. A grant provided by the Consejo para la Protección del Patrimonio Arqueológico Terrestre de Puerto Rico enabled me to gather and analyse the field and part of the laboratory data. Most of the laboratory analysis, however, was done with a grant from the Grant Advisory Commission of Gettysburg College.

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