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Cover Page Footnote

The author wishes to thank the Colonial Williamsburg Foundation for making pottery from the Martin's Hundred excavations available for study, the National Park Service Colonial National Historic Park for graciously permitting sherds from Jamestown and Green Spring to be sampled, and the Virginia Department of Historic Resources for allowing pottery from the Morgan Jones and Lawnes Creek sites to be included in the analytical program. In addition, personal thanks go to Bill Pittman, David Riggs, Beth Acuff, and Keith Egloff, my colleagues at these institutions who made this work possible.

The Virginia Earthenwares Project: Characterizing 17th-Century Earthenwares by Electronic Image Analysis

Thomas E. Davidson

This study employs electronic image analysis to characterize and identify 17th-century, Virginia-made earthenware ceramics. Digitized microscopic images of pottery from five different archaeologically discovered 17th-century production sites are examined, and the grain-size characteristics of the wares are reported. The potential of electronic image analysis as a tool for the study of archaeological ceramics is discussed.

L'étude utilise l'analyse d'images électroniques pour caractériser et identifier de la céramique en terre cuite du XVII^e siècle fabriquée en Virginie. Elle examine des images microscopiques digitalisées de poterie de cinq différents sites de fabrication du XVII^e siècle, découverts par l'archéologie, et en présente les caractéristiques. Elle commente les possibilités qu'offre l'analyse d'image électroniques pour ce qui est de la céramique archéologique.

Introduction

Archaeologists excavating 17th-century sites in Virginia face a ceramic identification and classification problem that is encountered commonly by historical archaeologists working on colonial sites in the United States. Virtually every 17th-century site in Virginia has yielded a ceramic assemblage that includes a substantial percentage of undecorated glazed and unglazed earthenware sherds, but very little is known about the specific origins or dates of manufacture for these simple utilitarian wares. In Virginia the undecorated earthenwares usually exhibit the same range of forms as common 17th-century English or Dutch earthenwares, but not all of the European-style pots found in Virginia are imports. Some of the vessels were made by Virginia potters who learned their craft in England or elsewhere in Europe, and who reproduced both the forms and the technology of Old World earthenware pottery-making in Virginia. The Virginia products tend to be of poorer quality than contemporary English or Dutch earthenwares, but it is not always possible to establish which vessels in an assemblage are imports and which are local Virginia products, or to distinguish among the different locally made wares.

At the present time archaeologists can use visual criteria including form, color, texture,

and glaze quality to identify some of the locally produced pottery of 17th-century Virginia. A handful of 17th-century pottery manufacturing sites have been found in the state, and ceramic wasters from these sites serve as the key to the identification of the Virginia earthenwares when they are encountered at other excavated sites (Noël Hume 1969: 208–220; Hudson 1975). Even though archaeologists know, or believe they know, how to recognize some of the Virginia earthenwares, the characteristics of the wares have not been rigorously defined. There is no objective, quantifiable way to identify the products of the known Virginia ceramic production sites. In addition, documentary evidence indicates that there were other pottery kilns operating in 17th-century Virginia that have not been located archaeologically (Virginia State Archives 1652). The products of these other production sites undoubtedly are present in ceramic assemblages from Virginia archaeological sites, but they have not been recognized as locally-made wares because no body of comparative source material exists for them.

The Virginia Earthenwares Project

An obvious first step toward sorting out the coarse earthenwares of 17th-century Virginia is to systematically examine sherds from the known pottery production sites and then

to determine what characteristics best serve to identify these ceramic wares and distinguish them from each other. The aim of the Virginia Earthenwares Project is to analyze 17th-century Virginia-made earthenwares that come from known production sites and to develop a set of defining criteria for the wares that could be turned into a practical ceramic identification procedure for archaeologists. Once base-line data have been generated for the known Virginia pottery production sites, then the project can be expanded to take in other earthenwares present at Virginia sites whose sources are unknown.

Given the nature of the available ceramic evidence from 17th-century Virginia archaeological sites, it would be difficult if not impossible to develop a completely reliable identification procedure for local earthenwares that is based on stylistic criteria alone. Because an archaeologist generally has only a small sample of locally-produced sherds from each site context with which to work, complete vessel profiles usually cannot be reconstructed. Vessel color, surface finish, and glaze quality do vary among production sites, but the variation is not systematic enough to provide a reliable set of defining criteria for all local wares. Complicating the issue further, local potters sometimes practiced their trade at more than one pottery production site in the region, so the same styles and techniques of manufacture may be observable in the products of different kilns. One late 17th-century potter named Morgan Jones, for example, operated kilns at different locations both in Virginia and Maryland (Kelso and Chappell 1974).

A more promising line to pursue in the identification of Virginia-made earthenwares is to examine the physical attributes of the clays from which the vessels are made. It is unlikely that earthenware kilns operating in different geographic locations would exploit precisely the same clay sources, since clay is a raw material that 17th-century potters typically obtained locally. The idea of analyzing the clay fabric of 17th-century Virginia earthenwares in order to identify their place of manufacture is not new.

In the late 1970s spectrographic analyses were performed on sherds from the 17th-century site of Martin's Hundred near Williams-

burg, Virginia, and on sherds from various other 17th-century sites in England in order to determine whether the clay of the local Martin's Hundred pots could be distinguished from the clays used for the imported ceramics (Noël Hume 1982: 105–106). Recently 17th-century architectural tiles from sites in the vicinity of Williamsburg have been analyzed by the techniques of xeroradiography and acid extraction in order to determine the source of the clays used in their manufacture (Metz 1995). These studies demonstrate that there is considerable potential for the characterization of the 17th-century earthenwares through the technical analysis of pottery fabrics.

The traditional way of describing and characterizing pottery fabrics is by ceramic petrology (Orton, Tyers, and Vince 1993: 140). Through the use of an optical microscope, thin sections of sherds are examined to identify the nature of the ceramic body. Once a number of sherds of a particular ceramic ware are viewed and their shared characteristics noted, those shared characteristics become the set of criteria that define the ware. Ideally those characteristics are unique enough to distinguish that specific ware from any other wares that may occur in the same region during the same time span.

The microscopic examination of thin sections can be an extremely valuable tool for ceramic analysis, but as an approach to the problem of identifying 17th-century Virginia earthenwares it has some serious practical drawbacks. The preparation and analysis of thin sections is a time-consuming process that requires the services of a person trained in optical mineralogy. Also, the effectiveness of this technique in distinguishing among ceramics made in a single geographical region is heavily influenced by the amount of natural geological variation there is within the clays of that region. The smaller the range of variation in the clays, the harder it is to identify the different ceramics made from them. Seventeenth-century Virginia ceramic production was concentrated in the coastal plain region where unconsolidated, water-deposited materials are the rule. Silty alluvial clays are typical there, and clays of this type offer the mineralogist relatively little with which to work. Since the ultimate aim of the Virginia Earthenwares Project was to develop an identification procedure

that could be used directly by archaeologists, the analytical technique selected needed to be one that focused on traits that could be observed and measured by non-specialists. This is not the case with optical mineralogy.

For similar reasons radio-chemical compositional analysis techniques like Neutron Activation Analysis were not employed in the project. Neutron Activation Analysis (NAA) can be extremely effective at distinguishing among ceramics from different production sites, but the technique requires specialized equipment and skills that are not generally accessible to archaeologists. Also, the discriminating criteria used in the NAA technique are the amounts of chemical trace elements present in clays (Mommsen et al. 1991). With a few exceptions the elements measured by NAA are present in such small amounts that they have no effect on the physical appearance of the clay, or on the pots made from the clay. Consequently NAA data alone do not provide a basis for the visual characterization of the ceramic vessels that have been analyzed, even though this technique certainly could establish the chemical "fingerprints" of the different clay compositional groups.

What was needed for the Virginia Earthenwares Project was an analytical procedure that produced fully-quantifiable results that could be tied directly to observable physical characteristics of the ceramic vessels. In addition, the procedure had to be able to discriminate among pottery fabrics made from geologically similar clays. Finally, the results of the procedure had to have the potential for development into a practical ceramic classification system that could be used by archaeologists.

After a careful consideration of available ceramic analysis methods, the analytical procedure that seemed to have the most potential for meeting the needs of the Virginia Earthenwares Project was a form of petrological analysis called textural analysis (Orton, Tyers, and Vince 1993: 141). This technique, sometimes referred to as grain-size analysis, characterizes ceramic wares on the basis of the number and size of the inclusions that occur in the fabric of the vessels. Textural analysis was pioneered by Peacock (1971) in the 1970s precisely to deal with the problem of identifying ceramic fabrics that contain a relatively narrow

range of inclusions, as do the Virginia coarse earthenwares.

On a practical level the chief drawback of textural analysis is that collecting the basic grain-size data is very time consuming if it is done by looking through a microscope and counting and individually measuring the inclusions in a sample. This practical difficulty has limited the use of textural analysis in the study of archaeologically recovered ceramics. It is now possible, however, to automate data collection for textural analysis with electronic imaging. Electronic image analysis has the potential to transform textural analysis into a very time- and cost-efficient method of characterizing ceramic wares.

Electronic image analysis is an increasingly popular research tool that is routinely employed to identify, examine, and characterize materials in scientific fields as diverse as metallurgy and medicine, although as yet there are only a few published examples of its use in the field of archaeology (e.g., Middleton, Freestone, and Leese 1985). Electronic image analysis transforms visual data into numbers that can be analyzed, manipulated, and compared objectively. With the proper equipment the image produced by an optical microscope can be captured and stored in digital form within a computer. The digitized image is then available for analysis by mathematical procedures that can produce fully quantifiable results.

Electronic image analysis does not identify what kind of inclusions are present in a sample, but simply determines the number, size, and location of the inclusions. Inclusions are any large particle or feature present in a clay body (Orton, Tyers, and Vince 1993: 70). Inclusions may be present naturally in the source clay or may be added by human action during the manufacturing process. As far as the Virginia earthenware vessels are concerned, quartz particles are the most common kind of inclusions found, followed by iron ore grains, quartzite, and, occasionally, feldspar. All of these inclusions can occur naturally in the clays of the region, although it is also possible that some were added to the clay as temper during the manufacture of the vessels.

Sherds from five different 17th-century pottery production sites were included in the

Figure 1. Map of 17th-century James River pottery production sites. North is to the top and the Morgan Jones site, not shown, is c. 100 km north of Jamestown.

Virginia Earthenwares Project. Four of the sites—Jamestown, Martin's Hundred, Green Spring, and Lawnes Creek—are located along the James River in southern Virginia (FIG. 1). The fifth, the Morgan Jones Site, is located along the Potomac River in the northern part of the state. These five pottery production sites range in date from ca. 1620 to the turn of the 18th century. All of the sites produced glazed and unglazed earthenware pottery in forms that were used mainly for food preparation or storage (FIG. 2). The sherds from the Jamestown, Green Spring, and Morgan Jones sites were found in direct association with excavated kiln structures, while the sherds from Martin's Hundred and Lawnes Creek came from waster dumps on sites where earthenware kilns must have existed, but where the kilns themselves have not yet been identified.

The earliest ceramic production site of the five is Martin's Hundred. The analyzed Martin's Hundred sherds are wasters from a single large trash-filled feature at Site C and probably date to the period 1619–1622 (Noël Hume 1982: 193–195). No kiln structure was discovered at Site C but the wasters were found in a context

that unquestionably identifies them as locally-produced ceramics. All of the analyzed sherds came from excavated units within the Site C feature.

Several years before the Martin's Hundred excavations took place another pottery production site was discovered farther up the James River at Jamestown, Virginia's 17th-century capital city. A group of three kilns called Feature 111 was excavated in the 1950s by National Park Service archaeologists. The ceramic samples that were included in this analysis were all recovered from Unit A, a context in the near vicinity of the kilns (Cotter 1958: 110–112). The date of the Jamestown kilns is uncertain. The stratigraphic level containing the kilns overlay a feature dating to the second quarter of the 17th century, but it is not clear how much time elapsed between the abandonment of the feature in the lower stratum and the construction of the kilns.

The Jamestown site is located only 3 mi from a 17th-century pottery production site at Green Spring. The Green Spring site probably was in use some time between 1665 and 1680 and cannot predate 1660. All of the analyzed

Figure 2. A 17th-century storage jar found at the Causey's Care Site (440CC0178), but probably made at Jamestown, Virginia.

samples from Green Spring were wasters recovered from the immediate vicinity of an excavated kiln structure (Caywood 1955: 12).

The Morgan Jones site, located in Westmoreland County, Virginia, is the most thoroughly investigated and most tightly dated of the known 17th-century kiln sites in Virginia (Kelso and Chappell 1974). Documentary evidence indicates that the Morgan Jones site operated only for a single year, 1677, before economic difficulties forced its owner to cease production. The analyzed samples from this

site were recovered during the excavation of the kiln structure.

The final site included in the analysis program is Lawnes Creek. The Lawnes Creek pottery production site has never been excavated and no historical documentation has been located that refers to it. The site consists of a dense scatter of ceramic wasters that was encountered during a surface survey by the staff of the Virginia Department of Historic Resources (Virginia Department of Historic Resources 1978). The forms exhibited by

Lawnes Creek pottery, and the presence of Lawnes Creek vessels at other excavated 17th-century sites in Virginia, indicate a last quarter of the 17th-century date for pottery manufacturing at the site.

Image Analysis Procedure

Each of the Virginia earthenware sherd samples was mounted on edge in a block of resin and then ground and polished to produce a flat undamaged surface over the whole sherd section. This is a standard preparation technique for rigid specimens such as metals or geological samples that are to be examined by optical microscopy. The samples were viewed under a binocular microscope at 40x, which gave a total image area of approximately 4.5 sq mm. A video camera attached to the microscope fed the images of the samples to a videographics adapter installed in a microcomputer. The images were digitized using the videographics adapter and an image acquisition and analysis software package called Java (developed by Jandel Scientific of Corte Madera, California). Java produces a usable image that consists of 196,000 individual picture elements, or "pixels," each of which has a light intensity value of between 0 and 255, with 0 being the lowest possible light level and 255 being the highest possible light level. These intensities are called gray-scale values. The gray-scale values have no absolute significance. It is the relationships among the gray scale values within a single sample and among the gray scale values of samples that have been recorded under the same lighting conditions that measure real differences in the samples.

Java has a number of routines that permit the digitized image to be sampled, measured, and processed in various ways. Simple measurement of intensity levels across a whole image can sometimes yield useful results, but the full potential of video image analysis cannot be achieved without image processing. Image processing is the application of mathematical transforms to the intensity values of the pixels. Processing basically consists of two procedures: enhancing contrast between pixels, and subtracting irrelevant background pixels from the scene. With the Virginia ceramics it is clear that the important visual

distinctions among the different images result from the presence or absence of certain classes of inclusions in the sample. Since the inclusions are so important, it is useful to look at the pixels representing them separately from the rest of the pixels in the scene.

The Virginia earthenware images were processed in two ways. First the gray-scale values were standardized for each of the images by setting the median pixel value of each image at 128 (the mid-point on the 0 to 255 scale) and correcting all other gray-scale values in the scene proportionately. This standardization effectively set the background pixel values of all of the images to the same value range, since the median value of an image always proved to be the same as the predominant background pixel intensity. Standardization compensates for differences in the lightness or darkness of the clay matrix, which may interfere with the recognition of inclusions.

Second, within the standardized images, a gray-scale range that was associated with the most common classes of inclusions in the Virginia pottery samples was identified. For all of the wares except those from Green Spring the most common inclusions were clear quartz sand grains, which showed up best in a standardized gray-scale range of 32–103. This same intensity range served well to distinguish iron ore grains, which were the main inclusions in Green Spring pottery. Using Java all pixels with gray scale values outside of the 32–103 intensity range were excluded from the images. Then counts were made of the total number of pixels within that value range for each image, the total number of separate inclusions in that range for each image, and the size of each of these inclusions. The Java program calculates all of these figures automatically.

The Data

The image analysis results for the Virginia earthenware samples are given in Tables 1 and 2. The first figure for each sample is the percentage of the total image scene that the measured class of inclusions takes up. That figure was obtained by dividing the total image size, 196,000 pixels, into the total number of pixels falling in the 32–103 intensity range. The

Table 1. Inclusions in Martin's Hundred sherds.

Sherd ID	Total Area (%)	Total Number	Mean Diameter (mm)	Number by size category				
				7&8	5&6	3&4	2	1
3113F(1)	4.42	80	0.0563	0	3	11	18	48
3113F(2)	3.70	93	0.0477	0	1	16	23	53
3113F(3)	4.92	99	0.0534	0	3	12	28	56
3113F(4)	6.55	91	0.0642	0	4	19	26	42
3113F(5)	5.96	96	0.0597	0	4	9	31	52
3110C(1)	5.99	125	0.0525	0	3	16	53	53
3110C(2)	3.37	89	0.0465	0	0	14	26	49
3110C(3)	4.68	87	0.0555	0	2	16	24	45
3110C(4)	4.82	106	0.0509	0	4	14	38	50
3110C(5)	5.93	93	0.0600	0	6	13	27	47
3112A(1)	5.82	78	0.0654	0	4	15	23	36
3112A(2)	4.67	80	0.0578	0	2	16	28	34
3112A(3)	5.60	91	0.0594	0	4	16	30	41
3112A(4)	5.22	75	0.0631	0	4	14	21	36
3112A(5)	3.73	70	0.0553	0	1	13	23	33
3113C(1)	5.62	103	0.0559	0	3	17	33	50
3113C(2)	5.63	116	0.0527	0	7	16	40	53
3113C(3)	6.64	88	0.0657	1	0	10	27	50
3113C(4)	7.09	115	0.0594	0	2	25	34	54
3113C(5)	6.75	131	0.0544	0	4	18	37	72
3110D(1)	3.84	77	0.0535	0	1	14	28	34
3110D(2)	4.81	84	0.0575	0	7	5	35	37
3110D(3)	5.40	100	0.0556	0	3	14	30	53
3110D(4)	6.19	91	0.0627	0	4	19	26	42
3110D(5)	7.51	98	0.0663	0	3	23	26	46
3111G(1)	5.85	106	0.0562	0	4	15	33	54
3111G(2)	5.66	109	0.0546	0	4	18	37	50
3111G(3)	7.21	121	0.0584	0	6	16	38	61
3111G(4)	8.47	129	0.0613	0	6	21	46	56
3111G(5)	6.78	116	0.0579	0	6	13	30	67
3110E(1)	5.70	156	0.0457	0	2	20	47	87
3110E(2)	4.59	121	0.0467	0	0	14	55	52
3110E(3)	8.46	127	0.0618	1	1	14	45	66
3110E(4)	6.61	126	0.0548	1	2	15	40	68
3110E(5)	6.56	115	0.0571	1	1	17	35	61
3111A(1)	5.95	147	0.0482	0	5	11	45	86
3111A(2)	6.38	122	0.0547	0	3	14	43	62
3111A(3)	4.42	114	0.0472	0	3	13	33	65
3111A(4)	4.59	110	0.0489	0	0	17	37	56
3111A(5)	5.95	102	0.0578	0	2	15	41	44
3111C(1)	6.74	128	0.0549	0	2	20	41	65
3111C(2)	5.95	111	0.0554	0	4	17	36	54
3111C(3)	4.31	117	0.0460	0	1	16	41	59
3111C(4)	5.24	112	0.0517	0	1	18	38	55
3111C(5)	6.72	133	0.0538	0	4	15	37	77
3113B(1)	3.56	86	0.0487	0	1	9	29	47
3113B(2)	3.86	116	0.0437	0	2	10	26	78
3113B(3)	4.94	122	0.0481	0	2	18	35	67
3113B(4)	5.42	119	0.0515	0	5	15	41	58
3113B(5)	4.43	111	0.0478	0	1	18	34	58

Table 2. Inclusion in other 17th-century sherds.

Sherd ID	Total Area (%)	Total Number	Mean	Number by size category				
			Diameter (mm)	7&8	5&6	3&4	2	1
Jamestown								
J1	2.81	128	0.0355	0	0	3	46	79
J2	2.23	76	0.0410	0	1	7	16	52
J3	3.57	128	0.0400	0	0	12	42	74
J4	4.91	154	0.0427	0	1	12	55	86
J5	3.52	161	0.0353	0	1	4	44	112
J6	1.65	81	0.0340	0	0	5	16	60
Green Spring								
GS1	7.08	121	0.0578	1	3	6	32	79
GS2	7.81	91	0.0700	1	0	12	24	54
GS3	5.56	73	0.0660	1	0	5	19	48
GS4	5.71	100	0.0572	2	1	7	31	59
GS5	3.58	137	0.0386	0	1	9	37	90
GS6	5.58	126	0.0516	0	5	9	31	81
Morgan Jones								
MJ2	2.91	63	0.0515	0	0	10	19	34
MJ3	2.25	37	0.0591	0	1	5	12	19
MJ4	1.26	25	0.0538	0	0	5	11	9
MJ5	1.37	28	0.0531	0	0	6	6	16
MJ7	3.08	45	0.0627	0	2	9	13	21
MJ8	2.22	40	0.0564	0	1	5	20	14
MJ10	2.62	33	0.0674	0	1	9	13	10
Lawnes Creek								
LW1	12.60	100	0.0849	2	5	23	34	36
LW2	5.52	50	0.0796	1	2	15	13	19
LW3	5.50	50	0.0794	1	3	10	16	20
LW4	5.94	46	0.0861	1	1	5	17	22
LW5	4.15	47	0.0712	0	4	10	17	16
LW6	5.30	72	0.0649	0	3	11	26	32
LW8	5.28	65	0.0683	0	3	13	27	22

remaining columns show the total number of inclusions represented in each image, the mean inclusion diameter in millimeters, and the distribution of the inclusions by size category. The inclusion size categories used are based on the mesh sizes of standard geological sieves (Fieller and Nicholson 1991: 79):

- A) size 7 & 8 Medium Sand (0.250–0.500 mm)
- B) size 5 & 6 Fine Sand (0.125–0.250 mm)
- C) size 3 & 4 Very Fine Sand (0.063–0.125 mm)
- D) size 1 & 2 Silt (<0.063 mm)

Silt is normally considered to range down to zero in particle size, but for this project an arbitrary cutoff point of 0.016 mm was adopted instead. This makes calculations easier and

inclusion counting more accurate. The silt above 0.016 mm in size is further divided into two categories: size 2 Silt (0.032–0.063 mm) and size 1 Silt (0.016–0.032 mm).

Inclusions larger than medium sand size (≥ 0.500 mm) were not included in the size tables because inclusions this large are normally not present in the analyzed Virginia samples. A visual examination of other examples of Martin's Hundred, Lawnes Creek, and Green Spring pottery indicates, however, that these larger inclusions may occasionally turn up. Inclusions larger than 0.500 mm are rare, though, and as far as the five Virginia earthenwares are concerned they can safely be disregarded for characterization purposes.

Table 3. Means and pooled standard deviations for all Martin's Hundred sherds.

Percent Total Area	5.58 + 0.952
Total Number of Inclusion	107.0 + 11.5
Mean Inclusion Size	0.0549 + 0.00433 mm
Category 5-6 Inclusions	2.94 + 1.55
Category 4-6 Inclusions	15.3 + 3.30
Category 2 Inclusions	34.0 + 5.51
Category 1 Inclusion	54.33 + 8.29

The Results

One initial assessment that needed to be made about Virginia earthenwares was the degree of homogeneity in fabric that pots from a single Virginia production site were likely to exhibit. Ceramic vessels will always show some range of variation in inclusion occurrence even if the vessels were made from the same clay and were manufactured by the same set of techniques. It is important to determine the range of within-source variation if textural analysis is to be used to discriminate among different earthenware fabrics.

In order to address the question of homogeneity each of the 10 Martin's Hundred sherds was analyzed at five different locations that were at least 5 mm apart on the polished surface. The results of these analyses are given in Table 1. The greatest amount of variation, both within and among samples, was in the percentage of the total image scene covered by the measured inclusions. Some individual sherds showed a standard deviation of over 20% in this category. By contrast total numbers of inclusions for the same sherds showed a standard deviation of less than 15%. Least variable were the mean inclusion diameter figures, which in all but one case had standard deviations of 10% or less. The range of mean inclusion sizes for the samples taken from the most heterogeneous Martin's Hundred sherd is not much smaller than the total range for all samples taken from the 10 Martin's Hundred sherds (TABLE 3). These results suggest that the clay for the 10 Martin's Hundred vessels came from a single relatively homogeneous source, and that the pottery manufacturing process used at this site did not introduce any significant additional variation into the clay body of the vessels.

The next step in the analysis was to determine whether vessels made at other Virginia production sites were sufficiently different from the Martin's Hundred sherds, and from each other, to form discrete groups on the basis of one or more of the measured characteristics. Table 2 presents the results for the four other groups of Virginia earthenware sherds. As Leese observed for his British ceramic grain size data, mean inclusion size measured in millimeters proved to be a particularly effective discriminator among the different sherd groups (Leese 1983). The procedure chosen for the comparison of the sherd groups was a form of the "t" test, a statistical test that is useful for evaluating hypotheses about the equivalency of two samples. This test is employed in geology for comparing samples derived from two naturally occurring populations that may or may not be different (Davis 1973: 96-97). The "t" test is only suitable in cases where the sample data meet the conditions of normal distribution and equal variance, but through the use of a Kolmogorov-Smirnov test for normality and a Levene Median test for equal variance it was possible to determine that the Virginia ceramic data met these conditions.

"t" test comparisons of inclusion size between each possible pair of sherd groups demonstrates that the Jamestown and Lawnes Creek groups clearly separate out from the Martin's Hundred group and all other sherd groups, as well as each other, at a better than 0.1% level of significance. Mean inclusion sizes were fairly close for the Martin's Hundred, Morgan Jones, and Green Spring sample groups.

When numbers of inclusions per sample are compared, however, Martin's Hundred

differentiates quite readily from Morgan Jones, but not from Green Spring. The total range for the Morgan Jones sherd group is 25–63 inclusions per sample, while the Green Spring group ranges from 73–137 and the Martin's Hundred group from 75–156. Only the Green Spring and Martin's Hundred sample groups require examination of the grain size category data to establish a clear difference between them. While the samples in these two sherd groups exhibit a similar mean inclusion size and total number of inclusions, the distribution of inclusions by size category is not similar for the two wares. A smaller percentage of the inclusions in the Green Spring sherds fall into the sand size range (>0.063 mm) than is the case for the Martin's Hundred sherds. The mean total numbers of inclusions in the two sets of samples are practically identical, $107 + 12$ for Martin's Hundred and $108 + 22$ for Green Spring, but the mean numbers of sand-size inclusions are $18.3 + 3.8$ and $10.5 + 2.6$, respectively.

The Green Spring group has a mean inclusion size similar to that of the Martin's Hundred group because Green Spring sherds are more likely to contain medium sand size inclusions (0.250–0.500 mm), a fact that tends to pull up the mean size for all inclusions. Green Spring pottery showed the most variability in inclusion size of the five Virginia earthenwares, and it is the only one of the five in which iron ore grains form the principal inclusion class. Iron inclusions are also present in significant quantities in the clay used for pottery making at Jamestown. Quartz inclusions always outnumber iron inclusions in the Jamestown pottery samples, however. Unlike quartz sand inclusions, iron ore inclusions are vulnerable to thermal transformation when the clay containing them is fired at standard earthenware kiln temperatures. The variability in the Green Spring inclusion pattern therefore may be a product of the pottery manufacturing process used at the site. Alternatively it may just be that the iron ore inclusions naturally present in the Green Spring clay are less well size sorted than sand-silt inclusions of the other Virginia earthenware clays.

As far as the quartz sand-silt wares from Martin's Hundred, Jamestown, and Lawnes Creek are concerned, inclusion-based distinc-

tions among the products of the different manufacturing sites are easily recognizable. Jamestown sherds have a smaller average inclusion diameter than any of the other sand-silt wares, while Lawnes Creek sherds have a larger average inclusion diameter than the other wares (FIGS. 3–5). Morgan Jones and Martin's Hundred sherds show much the same average inclusion diameters, but the total number of inclusions in the Martin's Hundred sherds is always significantly higher than for the Morgan Jones sherds (TABLE 2).

The inclusion size distributions for the quartz sand-silt wares typically are continuous; that is to say, all grain size categories are present between the smallest and largest inclusions that are to be found in a given sample. This is not true of Green Spring sherds, two of which contained medium sand sized inclusions and silt sized inclusions but lacked fine sand sized inclusions. It would seem highly unlikely that these larger iron inclusions were added as temper to the Green Spring clay, especially since naturally occurring clays in the Green Spring area normally contain iron inclusions. The discontinuous distribution of the Green Spring iron inclusions probably results either from the use of a more heterogeneous clay source or from thermal transformation during the firing process, as discussed above.

The image analysis results do not provide a definite answer to the question of whether any of the Virginia earthenwares have had quartz sand deliberately added to the clay matrix as temper. Sand frequently was used as temper by post-medieval potters working in England, but many clays of the Virginia Tidewater already contain quartz sand and silt. The continuous grain size distribution and general homogeneity of the analyzed Virginia samples suggest a natural origin for the quartz sand and silt inclusions in these ceramic wares. The possibility of the deliberate addition of temper in the form of locally procured sand cannot be ruled out, however.

Conclusion

Textural analysis by electronic imaging has proved to be an effective way of characterizing 17th-century Virginia earthenwares. For the earthenwares that contain quartz sand-silt as

Figure 3. Micro-photograph of a typical Jamestown sherd (average inclusion dia. 0.0381 mm).

Figure 4. Micro-photograph of a typical Martin's Hundred sherd (ave. inclusion dia. 0.0549 mm).

Figure 5. Micro-photograph of typical Lawnes Creek sherd (ave. inclusion dia. 0.0763 mm.)

their major inclusion class, the determination of mean inclusion size and frequency of inclusion occurrence provides sufficient data to distinguish the wares from each other. Green Spring pottery, which contains iron ore fragments as its major inclusion class, cannot be differentiated from Martin's Hundred pottery by the simple measurement of mean inclusion size and number. On a practical level, however, the fabric of Green Spring pottery is visually so different from the other Virginia earthenwares that there is no possibility of confusing the Green Spring samples with any of the other locally produced wares.

The series of ceramic analyses reported on here measured only a single class of inclusions that are present in Virginia earthenwares. The Virginia ceramic samples also contain other, less numerous inclusions with different gray-scale value ranges as well. This is true in particular of the Martin's Hundred sherds. The potential exists, therefore, to analyze other inclusion classes in the same ceramic samples and to produce additional, independent source signatures for some or all of the Virginia earth-

enwares. As more 17th-century wares are added to the Virginia earthenwares database, it may become necessary to look at other inclusion classes in order to discriminate among all of the different pottery production sites. One great advantage of the electronic image analysis approach to ceramic identification is that once the sherd images have been made, they are available on the computer for re-analysis should this become necessary.

The image analysis results from the Virginia earthenwares samples readily translate into a practical ceramic identification procedure that is usable by any archaeologist who has access to a good quality binocular microscope. While it is much easier to count inclusions and determine inclusion diameter by electronic means, counting can be done by eye using an appropriately scaled eyepiece graticule. Since the characteristics of the main inclusion class present in the Virginia earthenwares have already been defined by image analysis, it is relatively simple to determine whether a suspected Virginia-made sherd falls within the pre-defined inclusion size and fre-

quency range of a known Virginia earthenware. This determination by itself cannot provide absolute identification, since the possibility always exists that the sherd comes from a ceramic vessel made at a different, unknown production site with the same inclusion signature. Given that only a small number of Virginia earthenware production sites are likely to have been in operation at any one time during the 17th century, however, the probability of misidentification is low.

Ceramic characterization by electronic image analysis does not replace other forms of ceramic analysis, since the technique cannot independently answer questions about either the mineralogy or the chemical composition of clays or the inclusions in clays. Ideally electronic image analysis should be used in conjunction with other techniques, especially NAA, when this is possible. Even by itself, however, image analysis shows considerable potential for answering a range of questions about local ceramic manufacture and trade. This is true not just for 17th-century Virginia, but for any region and time period where stylistically similar earthenwares were produced by small-scale local manufacturers who left relatively little record of their activities. In many cases the humble undecorated utilitarian earthenwares that historical archaeologists often neglect in favor of imported tablewares will hold the key to the accurate cross-dating of sites and assemblages and to the understanding of local marketing patterns. By using electronic image analysis, archaeologists who are not also specialists in the technical analysis of ceramics, can gain access at relatively low cost to some of the important information that is locked up in undecorated earthenwares.

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