THE STANDARDIZATION HYPOTHESIS AND CERAMIC MASS PRODUCTION: TECHNOLOGICAL, COMPOSITIONAL, AND METRIC INDEXES OF CRAFT SPECIALIZATION AT TELL LEILAN, SYRIA

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Archaeologists often use measurements of standardization in ceramics as evidence for specialized craft production. Analysis of fine-ware bowl kiln wasters from the urban center of Leilan, Syria (ca. 2300 B.C.) provides a rare opportunity to test the standardization hypothesis against the archaeological record of a single production event. Scanning-electron microscopy, xeroradiography, neutron activation, and metric analyses of the wasters show extreme uniformity in manufacturing technology, chemical composition, and vessel dimensions. However, when contrasted with sherds of the same bowl type from other contexts at Leilan, a higher degree of compositional and metric variability is observed. This "cumulative blurring" effect stems from the use of long-lived types from multiple workshops. Although "cumulative blurring" increases sample variability, it does not obscure the overall homogeneity of these ceramics. Our results suggest that standardization can be a reliable index of craft specialization only under conditions of close spatial and chronological control over the archaeological record.

Los arqueólogos usan a menudo medidas de estandarización cerámica como evidencia de producción artesanal especializada. El análisis de desechos de horno correspondientes a cuencos de pasta fina provenientes del centro urbano de Leilan, Siria (ca. 2300 A.C.) ofrece la rara oportunidad de poner a prueba la hipótesis de estandarización utilizando el registro arqueológico de un evento de producción. La microscopía electrónica de barrido, la xerorradiografía, la activación de neutrones, y los análisis métricos de los desechos muestran una extrema uniformidad en las técnicas de manufactura, la composición química y las dimensiones de las vasijas. Sin embargo, cuando se los contrasta con tiestos del mismo tipo de cuenco procedentes de otros contextos en Leilan, se observa un mayor grado de variabilidad composicional. Este efecto de "obscurecimiento acumulativo" es consecuencia del uso de tipos de larga duración procedentes de diferentes talleres. Aun cuando el "obscurecimiento acumulativo" aumenta la variabilidad de las muestras, no obscurece la homogeneidad general de esta cerámica. Nuestros resultados sugieren que la estandarización puede ser un índice confiable de especialización artesanal solamente bajo condiciones de estrecha proximidad espacial y control cronológico sobre el registro arqueológico.

In this paper, we examine some of the indexes most frequently used to infer specialized craft production in complex societies. The presentation has three parts. We start by defining craft specialization and the standardization hypothesis, which serves to identify this form of production organization in the archaeological record. The second part examines technological, compositional, and metric indexes of standardization, using as a test case ceramic production at Tell Leilan, Syria. Finally, we discuss some of the main ways by which ancient cultural and natural processes can combine with modern sampling problems to blur the evidence for standardization in specialized mass production.

Craft specialization is a characteristic of all known states, and is considered by most archaeologists to be a key factor in the political economy of complex societies (e.g., Clark and Parry 1990:290; Flannery 1972). However, the definition of the term "specialization," its origins, and the archaeological identification of this form of production organization all remain the focus of vigorous debates (e.g., Brumfiel and Earle 1987; Feinman et al. 1984; Rice 1981).

Economic specialization can be defined as the investment of labor and capital toward the production of a particular good or service, in that a person produces *more* of that commodity, and *less* of others, than he or she consumes (Alchian and Allen 1969:204). Specialized production is thus

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the production of surpluses for exchange (Bates and Lees 1977; Costin 1991:4), regardless of whether those exchanges are symmetric or asymmetric. The increased scale of specialized production can be detected in the archaeological record by examining (a) manufacturing facilities, e.g., workshops; (b) exchange patterns; and (c) most commonly, by increasing standardization in the physical and stylistic characteristics of the goods produced by specialists.

A number of researchers have hypothesized that the goods produced in mass quantities by specialists can be recognized in the archaeological record by their high degree of standardization (Balfet 1965:163; Feinman et al. 1984:299; Rice 1981:220–221; Sinopoli 1988:586). Following Rice (1991:268), the term "standardization" is defined here as the relative degree of homogeneity or reduction in variability in the characteristics of an artifact, or the process of achieving that relative homogeneity. Standardization is a relative concept that can only be defined through comparison of two or more artifact assemblages with differing degrees of homogeneity (Costin 1991:35; Rice 1991:268). The underlying assumption is that a high degree of standardization or homogeneity in vessel dimensions reflects specialized mass production, while variation or relative heterogeneity is taken to indicate household production. Ideally, one should establish the degree of standardization by comparing the products of the same population and cultural tradition (Arnold and Nieves 1992). Not all specialist-produced goods are standardized; luxury and high-status goods produced by elite-dependent ("attached") specialists may be unique (Costin 1991:34). However, virtually all standardized goods are made by specialists.

Several factors have been proposed to account for the trend toward standardization in specialized craft production, especially ceramic manufacture. Feinman et al. (1984:299) note the roles of cost effectiveness and improved efficiency, suggesting that "the increase(s) in task mechanization and routinization, made possible by economies of scale" are important causes of standardization. Similarly Balfet (1965:170) attributes the emergence of standardization to the high degree of repetition involved in large, frequent production runs. Standardization can emerge through the "risk-averse" or "conservative" tactics of craft specialists such as potters who often adhere to proven raw material sources and manufacturing procedures (Rice 1991:268). The greater standardization of specialist-produced goods may also function to communicate information about social status and group affiliation within large, heterogeneous complex societies (Wattenmaker 1990:12–16).

The standardization hypothesis suggests that specialized production of ceramics should be detected in archaeological assemblages through standardization in raw-material composition and manufacturing techniques (Rice 1981:223), form and dimensions (Balfet 1965:163; Sinopoli 1988), and surface decoration (Hagstrum 1985). Standardization of raw materials for ceramics is generally examined by studying the chemical or mineralogical composition of clays through techniques such as instrumental neutron-activation analysis (INAA) or petrography (Bishop et al. 1982, 1988). However, detailed metrical analysis of vessel form and dimensions (e.g., Benco 1987; Longacre et al. 1988; Rice 1981; Sinopoli 1988; Wattenmaker 1990) is probably the approach most commonly used to identify standardization (and thus imply craft specialization) in the archaeological record.

Although ethnoarchaeological studies generally support the standardization hypothesis for ceramics, they have also isolated several problems in the most commonly used metric indexes of standardization. Longacre et al.'s (1988) ethnographic study of standardization in the dimensions of Philippine traditional pottery showed that metric investigations of ceramic standardization in the archaeological record are potentially misleading because the archaeologists may unwittingly lump vessels into a single typological class, despite the possibility that the potters who made the vessels might have viewed them as belonging to several different emic categories. Identification of specialization in the archaeological record will be most reliable when several variables provide parallel lines of evidence for standardization (Bishop et al. 1988; Costin 1991:35).

In the following evaluation of the standardization hypothesis, we examine not only vessel dimensions, but also manufacturing technology and chemical composition as two variables that remain largely unaffected by emic classificatory differences expressed in nuances of vessel form or dimensions. Here, we compare technological, compositional, and metric data as complementary indexes of standardization for an assemblage of unequivocally mass-produced ceramics from an ancient Near Eastern complex society.

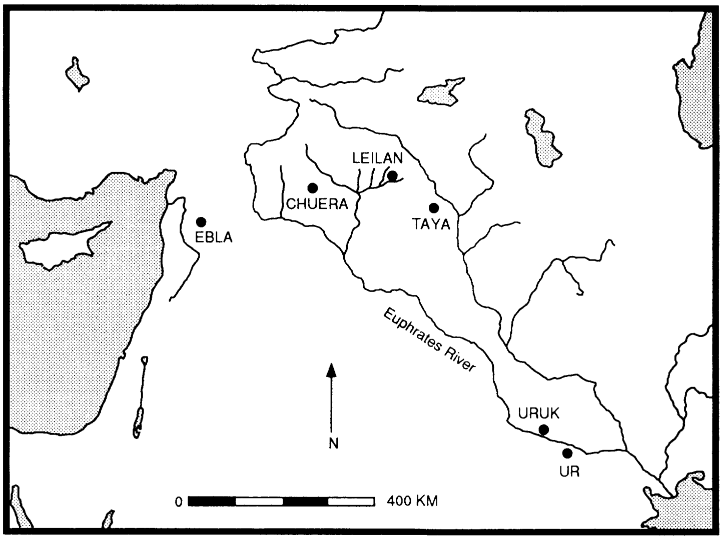

Figure 1. Map of Near East showing the location of Tell Leilan and selected other third millennium B.C. urban centers.

SOCIAL COMPLEXITY AND CERAMIC PRODUCTION AT LEILAN

State societies developed and spread throughout Greater Mesopotamia during the fourth and third millennia B.C. In the dry farming zone of northern Syria and northern Mesopotamia, settlements such as Chuera (Orthmann 1986), Leilan (Weiss 1983, 1986, 1990, 1991a; Weiss et al. 1990), Mozan (Buccellati and Kelly-Buccellati 1988), Taya (Reade 1968, 1973), and Tell al-Hawa (Wilkinson 1990), reached urban proportions (40 ha or larger) by 2600 B.C., with Ebla (Matthiae 1980) and the plains of Alepo following about 150 years later (Weiss 1991b).

Tell Leilan is located in the Habur River headwaters region along the Wadi Jarrah, a perennial stream in the fertile northern part of the Habur plains in northeast Syria (Figure 1). Excavations by Harvey Weiss of Yale University have shown that by the mid-third millennium B.C., Leilan had grown to a size of more than 90 ha, becoming one of the largest urban centers in this part of northern Mesopotamia (Weiss 1983, 1986, 1990, 1991a; Weiss et al. 1990:47). About two hundred years later, a massive fortification wall was constructed to protect the city (Weiss 1991a). In the surrounding hinterlands, the regional settlement system shows signs of reorganization into a four-level site-size hierarchy from which the urban center of Leilan apparently systematically extracted large-scale agricultural surpluses (Stein and Wattenmaker 1990, 1993). Overall, the changes in site size, architecture, and regional organization argue for a related complex of demographic, economic, and political developments that apparently reflect the emergence of state level societies in this area.

Subsequent to the urban expansion at Leilan, a major change in ceramic production took place (Weiss 1990:205–208, 217). In the earlier Leilan period III (ca. 3200–2500 B.C.), fine wares accounted for 57 percent of the ceramic assemblage. The most common rim was "closed slightly inverted beaded" and the most common base was pointed. About 30 percent of the fine wares were painstakingly decorated with elaborate incised, excised, or punctate designs (Schwartz 1985, 1988: 42–51). In period II (ca. 2500–2200 B.C.), after the initial urban expansion, decorated ceramics all but disappeared, to be replaced by "open-simple-rim," flat base, undecorated fine wares (Schwartz 1988:40–42; for further comments on the development of fabrication technology at Leilan see Vandiver [1993]). By the later part of this period (Leilan IIb) these greenish "open-simple-rim" fine-ware bowls had become one of the most characteristic ceramic forms at Leilan and numerous other sites in northern Mesopotamia (e.g., Oates 1982:Figure 1; Schwartz 1988:Figure 28, nos. 4–7; Weiss 1983:Figure 10, nos. 1–2).

The Leilan Fine-Ware Stacked Wasters

Fused, nested stacks of the fine-ware bowls are nearly ubiquitous on the surface at Leilan (see e.g., Meijer 1986:Figure 18r), leaving little doubt as to the large quantities of this ware being produced. A group of four large waster stacks, each consisting of at least 50–65 fused period IIb fine-ware bowls, was recovered in the 1985 excavations in Operation 3 in the eastern part of the Leilan lower town (Akkermans 1990:581). Although vitrified and fused, the individual bowls in the waster stack were remarkably intact, showing almost no signs of warping, bloating, or sagging. A portion of one of the stacks, containing 27 whole bowls and bowl fragments, was brought to the United States for examination at the Conservation Analytical Laboratory (CAL) of the Smithsonian Institution (Figure 2). Analysis of these wasters provides a rare opportunity to test the standardization hypothesis against the archaeological record of a single production event where we know that the bowls were all made within a short period of time and fired together as the product of a single workshop. The degree of standardization in this production event serves as a baseline for comparison with the more usual archaeological sample of typologically identical fine-ware bowl sherds from domestic refuse contexts elsewhere at Leilan. This allows us to investigate several key questions related to the standardization hypothesis: (1) how much variability actually exists within a given category of specialist-produced ceramics? (2) What are the sources of variability within assemblages of specialist-produced ceramics? (3) How does the variation in a single production event compare to the overall range of variation in this bowl type at a single site? Scanning-electron and optical microscopy, xeroradiography, INAA, and metric analyses of the Leilan stacked waster bowls and fine-ware bowls from domestic refuse at Leilan show that these two samples provide markedly differing evidence for standardization in manufacturing technology, chemical composition, and vessel dimensions.

INDEXES OF STANDARDIZATION

Manufacturing Technology: The Ceramic Production Process

Physical analysis of modern clay samples, examination of the waster bowls, and reconstructions of the steps involved in ceramic manufacture all indicate that the Leilan open-simple-rim fine-ware bowls were produced by standardized procedures. Scanning-electron microscopy and optical microscopy of fractured and polished sections of individual bowls in the waster stack show each to possess a uniformly fine-grained, calcareous matrix with very few individual grains exceeding 75 microns (μm). This particle size range corresponds to the silt and clay size fraction. The near absence of particles greater than 75 μm makes the intentional introduction of aplastic material (temper) unlikely. The raw material used to make these bowls was, therefore, either a naturally fine-grained calcareous clay or was levigated by the potters prior to its use.

A survey of modern clay beds that sampled 30 locations along annual or perennial water courses in the Leilan area found no natural deposits of well-sorted (i.e., naturally fine-grained) clays (Blackman 1992). Laboratory wet sieving of 10 of the 30 samples (Blackman 1993) shows that the local alluvial deposits contain on average (by weight) 1–2 percent coarse sand and pebbles ($>$ 425 μm); 10–15 percent fine to coarse sand (75–425 μm); and 85–89 percent silt and clay sizes ($<$ 75 μm). Given the results of the survey and the low energy depositional environment of the region, it is unlikely that extensive beds of naturally well-sorted deposits exist in the area around Leilan (Blackman 1992). The raw material thus appears to have been systematically levigated by the potters to remove most of the size fraction greater than about 75 μm, as preparation for the manufacture of fine-ware bowls.

After clay preparation, the fine-ware bowls were formed by a standardized set of production steps that included: (a) initial forming on the wheel; (b) removal for partial drying; (c) trimming/thinning of the outer surface; and (d) final finishing by smoothing on the wheel prior to firing. The 27 bowls in the waster stack were all made using the same methods and sequence of manufacture. Xeroradiography and optical microscopy (see e.g., Vandiver 1988) show evidence for the use of the potter's wheel as opposed to a turntable (tournette) in the forming process. The pores (the white regions in Figure 3) are elongated and aligned diagonally at a steeper angle to the base than are the throwing

Figure 2. Photograph of the kiln waster stack, sectioned to show the stacking of the bowls.

ridges, or grooves made by the potter's hands as the clay was squeezed between them (Vandiver 1987:31). The steepness of the angle of porosity to throwing ridges, about 30°, and the diagonal stretch marks (Figure 4) on the vessel interiors imply the use of a considerable amount of force in the shaping of the bowls. The combined evidence of diagonal elongation and alignment of porosity, throwing and trimming ridges of approximately similar size and number, and diagonal stretch marks indicate rapid rotation of a potter's wheel, probably with some type of flywheel attached.

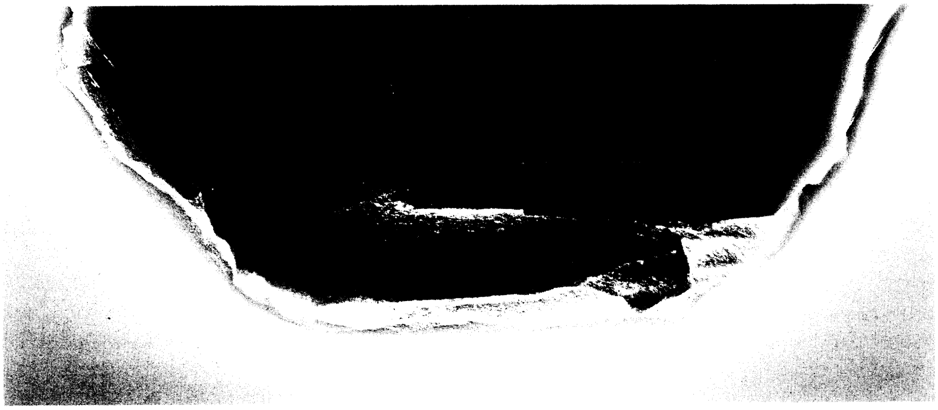

Figure 3. Xeroradiograph of the stacked waster bowls, showing horizontal throwing ridges at a 30° angle to the elongation of porosity (raised arrow). The air-filled pores appear as white spots in the ceramic paste.

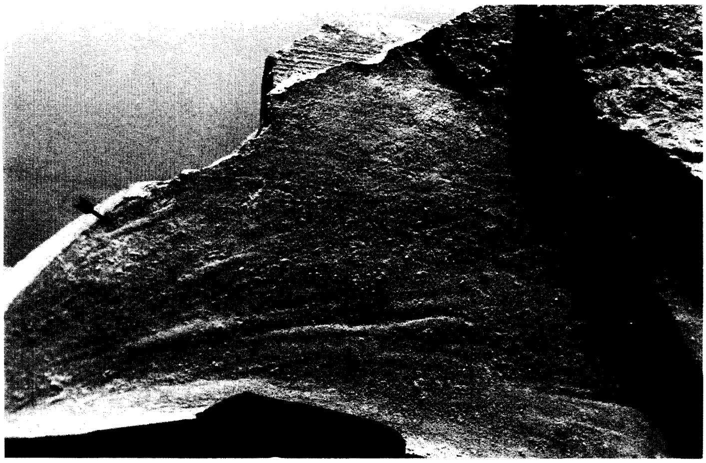

Figure 4. Interior stretch marks (arrow) on the stacked waster bowls, indicating rapid turning, high force, and slight rotation of the top of the bowl compared to the bottom.

After this initial forming stage, the bowls were removed from the wheel for drying. In the next stage of manufacture, the bowls were again placed on the wheel for trimming. Excess clay was removed when the bowls were partially dry, probably just prior to the stage of leather hardness. At this stage the clay is no longer plastic and is strong enough to maintain its shape. Grooves or trimming marks on the exterior of the base (Figure 5) show six to eight turns of the potter's wheel during which the bowl was scraped to remove excess clay. The trimming marks continue up the outer side walls (Figure 6) to within about 1 cm of the rim. The outer wall thus appears to have been thinned by trimming, rather than by throwing alone. The bowls would have been thrown in an upright position, partially dried, and inverted for trimming. The rim would have flattened and deformed slightly during this trimming operation requiring some repair. Therefore, as the final forming step, the bowls were set upright, in the original throwing position, to smooth the rim by wiping and to reform the shape. The wiping marks (Figure 7) cross over the trimming marks on

Figure 5. Wheel-thrown base exterior of a bowl in the waster stack, showing trimming marks formed by sliding of grit along in grooves.

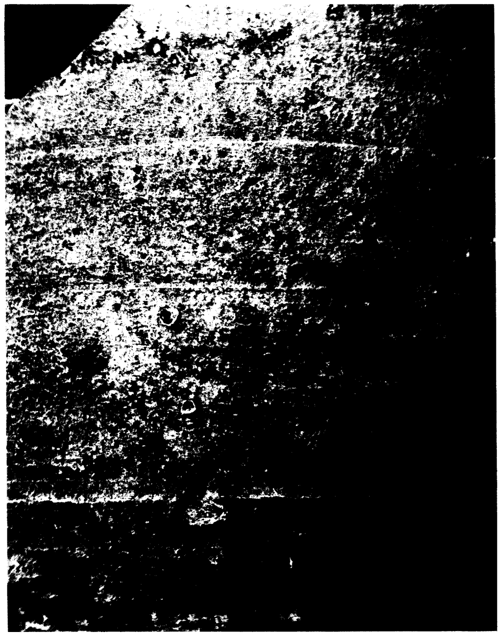

Figure 6. Macrograph at 12× magnification showing incised grooves (striations) formed by trimming the exterior walls of the waster bowls almost to the rim.

the exterior and the throwing marks on the interior, confirming that wiping was the final step in the forming sequence.

The multiple stages of fine-ware bowl manufacture provided several opportunities to make adjustments in vessel shapes and dimensions. Once a group of bowls had been thrown and dried, the potters were able to correct for variation in wall thickness, distortion due to handling, shrinkage during drying, and rim deformation during the trimming process. These final modifications assured maximal standardization for the entire production run and were necessary for the kiln-setting strategy employed by the Leilan potters.

The fine-ware bowls were fired in nested stacks as shown by the waster examined in this study. No spurs, points, or other spacers were used to separate the individual bowls; on the contrary, the bowls were tightly nested with large areas of surface contact between individual bowls (Figure 2). Individual stacks (over 15 were examined in the field by M. J. B.) showed no evidence of the use of external support structures in the kiln. The fine-ware bowls thus appear to have been fired as free-standing stacks with the only support possibly being provided by neighboring stacks in the kiln. Some fused stacks of bowls recovered in excavations at Leilan reached heights of 2 m. In order to maintain stability in stacks of 60–100 unfired bowls up to 2 m in height, a high degree of uniformity in shape and dimension was essential.

The complex firing technology of the Leilan fine wares also shows a level of skill and standardization consistent with manufacture by specialists. The dense, impermeable quality of the Leilan fine wares was achieved by firing the bowls to the point of partial vitrification in a reducing atmosphere, requiring some sort of roofed kiln. To date, the kilns themselves have not been excavated at Leilan and no exact dimensions can be given. However, the 2-m-high stacks of wasters indicate large kilns, with minimum roof heights of over 2 m, were used in firing the fine-ware bowls.

Ceramics fired to the point of partial vitrification have the advantages of greater durability and lower porosity. For calcareous clays, such as those used to make fine-ware bowls, the relative fuel inefficiency of reduction firing (only partial fuel combustion) vs. oxidation firing is more than offset

Figure 7. Wipe marks (arrow) associated with reshaping the rims of the waster bowls and subsequent wiping to smooth the surface.

by the lower temperature at which initial vitrification occurs. Further, in the reduction firing of calcareous clays, vitrification structures remain stable over a wider range of temperatures, 850–1,050°C, than oxidation firing (Maniatis and Tite 1981:65). As a result, the temperature control needed to assure a standardized product becomes much less critical (Maniatis and Tite 1981:75). The wider range of thermal tolerance is important, as it is extremely difficult to regulate the temperature of traditional kilns. Thus, by using a reduction technology to fire the local calcareous clays, the Leilan potters were able to consistently achieve a high level of standardization in the texture and hardness of their ceramics. The greenish fine-ware bowls at Leilan and other northern Mesopotamian sites were generally fired at 950–1,050°C (Schneider 1989:42), i.e., at the upper limits of temperature tolerances for stable partial vitrification. When firing temperatures exceed this range (at about 1,100°C) further vitrifaction occurs very rapidly, resulting in kiln wasters such as the one analyzed here. To avoid mishaps of this sort, the production of greenish fine-ware bowls would have required potters with high levels of skill, judgment, and pyrotechnic experience to monitor the firing process.

The available evidence indicates that all open-simple-rim greenish fine-ware bowls at Leilan were manufactured using the same technology determined from examination of the wasters. Although variations can be seen in paste color and degree of vitrification, these stem from differences in kiln fuel, firing duration, temperature, and oxygen supply—factors that one would expect to vary slightly with each kiln firing.

Standardized procedures were followed at every step of the bowl-production process. The clays were carefully levigated to achieve a uniform, fine paste, and each bowl was formed and trimmed with an economy of motion. The considerable amount of force used in initially forming the clay, as evidenced by the stretch marks, indicates a rapid process of manufacture. The thinness and standardization of shape and dimensions both indicate a high level of skill, with the same hand movements and often the same number of rotations per processing step evident from one bowl to the next. The kiln setting scheme, i.e., multiple, tightly fitted stacks of bowls with no spacers to reduce the risk of sticking, seems indicative of a strategy that emphasizes quantity over risk aversion. The reduction-firing technology emphasizes production of fine wares with nearly identical texture and hardness, while providing a broad range of thermal tolerance that minimizes firing risks. These standardized, efficient techniques of clay preparation, bowl formation, kiln setting, and firing are all consistent with mass production by highly skilled specialists.

Compositional Analysis

Compositional analysis of the wasters and other fine-ware bowls provide a second, independent index of standardization in ceramic manufacture at Leilan. Chemical analysis of the bowls in the waster stack using INAA shows a remarkably high degree of homogeneity in the chemical composition of the constituent clays.

The analysis was conducted at the Conservation Analytical Laboratory/Smithsonian Institution's Neutron Activation Analysis Facility using the NBS Research Reactor at the National Institute of Standards and Technology. The irradiation and gamma-ray spectroscopy were carried out following analytical procedures described elsewhere in detail by Blackman (Blackman 1984:23–25, 1986).

Due to the extreme hardness of these partially vitrified ceramics, sample preparation and sampling procedures were modified to ensure maximum comparability and to minimize possible sample contamination. All ceramics were soaked and ultrasonically cleaned using deionized water to remove surface contamination and postdepositional precipitated salts. From a portion of each sherd, about 1 mm of the surface was abraded away with a tungsten-carbide burring tool and the resultant powder discarded. This step was taken to further assure that any surfacial contamination remaining after washing was not incorporated in the sample. To eliminate drill-bit contamination, unavoidable in drilling vitrified ceramics, samples were prepared using a brittle-fracture technique developed by Venkatesh Iyengar for use on biological samples. The ceramics were immersed in liquid nitrogen for 10 minutes, and the resultant hypercooled, brittle sherds were then easily milled into powder using an agate mortar and pestle. Eighteen individual bowls were sampled and analyzed from the fine-ware waster stack along with 22 sherds of the same fine-ware bowl type from excavated domestic contexts in Operation 4 at Leilan (Stein 1990a).

The compositional data for the 18 waster-stack samples and for 20 of the Operation 4 samples are presented in Table 1. Two of the 22 Operation 4 fine-ware sherds, morphologically and stylistically identical to the other sherds, had chemical compositions that were similar to one another, but quite different from the other 20 fine-ware sherds. These two samples most likely represent imported ceramics and were therefore excluded from the group in Table 1. While the presence of exogenous fine-ware bowls at Leilan has important implications for the regional organization of ceramic production and distribution, this topic is beyond the scope of this paper and is addressed in a separate publication (Stein and Blackman 1991).

The within-group variance, expressed as the coefficient of variation (C.V.) for each element (C.V. = 1 sigma/mean x 100), can be used as an index of compositional homogeneity in the group. Low C.V.s, therefore, reflect an extremely uniform chemical composition. When applied to chemical-compositional data, however, C.V. measurements are influenced by analytical errors inherent to the analytical techniques used in addition to the natural and cultural variation in the chemical composition of the sample. A truer measure of homogeneity must factor out, as far as possible, variation due to this analytical error. In neutron-activation and gamma-ray spectroscopic analysis, for carefully prepared and weighed samples, the largest sources of analytical error are the Poisson counting statistics for the gamma energy used to quantify each element. Subtracting this quantifiable counting error from the C.V. results in a more reproducible normalized estimate of internal homogeneity and allows direct comparison of homogeneity for chemical composition groups with quite different individual elemental concentrations. Table 2 compares the normalized C.V.s for the waster stack, Operation 4 fine wares, and NIST standard reference material SRM 679 (a brick clay).

Twenty-five elements in the fine-ware waster group have normalized C.V.s that average just under one percent, indicating an extremely homogeneous composition. Four elements (Rb, Ca, Sr, and Sb) have negative normalized C.V.s, caused by the C.V.s actually being *less than* the counting error. Only arsenic (As) displays a normalized C.V. of greater than four percent. This is probably due to the loss of variable amounts of arsenic through volatilization upon firing.

The extent of this compositional homogeneity can be seen by comparing normalized C.V.s between the wasters and the standard reference material (SRM 679) used as a check standard in INAA analysis. Standard reference materials are highly homogeneous substances of known chemical composition that, when analyzed along with the archaeological samples, can be used as a check on

Table 1. Elemental Composition of Leilan Fine-Ware Stacked Wasters. Mean Elemental Concentrations and Coefficients of Variation Compared with NIST SRM 679 (Brick Clay) and Open Simple-Rim Greenish Fine-Ware Bowls from Leilan Operation 4.

	Waster Stack (n = 18)		SRM 679: Brick Clay (n = 140)		Fine ware: Op. 4 (n = 20)	
Element	Mean	C.V.	Mean	C.V.	Mean	C.V.
Na (%)	.585	2.2	.136	2.4	.676	8.5
K (%)	1.57	5.3	2.31	5.8	1.62	8.7
Rb (ppm)	89.0	4.3	220.0	7.3	79.5	13.3
Cs (ppm)	4.47	3.0	9.68	2.6	4.08	15.1
Ca (%)	12.5	4.3	—	—	13.3	12.5
Sr (ppm)	424.0	10.9	—	—	660.0	20.0
Ba (ppm)	424.0	17.1	474.0	13.3	380.0	17.0
Sc (ppm)	17.3	1.3	23.0	1.8	16.7	6.1
Cr (ppm)	335.0	2.3	109.0	3.0	349.0	5.5
Fe (%)	5.19	1.2	9.03	3.1	5.06	4.9
Co (ppm)	31.2	1.3	26.8	2.1	30.9	6.4
Zn (ppm)	114.0	2.3	132.0	3.6	101.0	9.0
As (ppm)	10.1	10.6	10.0	5.9	7.2	33.0
Sb (ppm)	.936	7.6	.978	16.7	.869	12.0
La (ppm)	36.8	1.2	56.6	1.6	36.0	5.3
Ce (ppm)	68.9	1.4	103.0	2.0	67.9	6.8
Sm (ppm)	6.19	1.9	9.17	2.3	6.07	4.3
Eu (ppm)	1.35	1.3	1.70	2.4	1.32	5.9
Tb (ppm)	.942	7.9	1.23	12.1	.843	11.7
Yb (ppm)	3.14	4.9	4.12	5.2	3.01	6.7
Lu (ppm)	.473	6.1	.614	6.7	.452	9.6
Hf (ppm)	5.64	1.9	4.62	3.1	5.93	4.5
Ta (ppm)	1.18	4.6	1.24	6.8	1.09	16.5
Th (ppm)	9.5	1.3	14.4	2.3	9.3	6.5
U (ppm)	1.92	16.5	2.38	15.1	1.90	21.3

analytical precision and accuracy (Blackman 1986; Harbottle 1982:68). Samples of SRM 679 have been included in 140 separate irradiations, over a seven-year period, to serve as a check on inter-irradiation data comparability. As such, the C.V.s for this data set represent the cumulative effect of *all* analytical errors including counting statistical error. The Leilan stacked wasters, analyzed in two separate irradiations, display normalized C.V.s comparable to or less than those for SRM 679 (Table 2), indicating that the wasters have a chemical composition even *more* homogeneous than that of the NIST standard reference material. The high level of compositional uniformity shown by the analysis of the stacked wasters suggests that the clays used to make these bowls were carefully prepared as a single batch and strongly supports the standardization hypothesis.

However, this compositional homogeneity becomes somewhat blurred when we extend the analysis to include other open-simple-rim fine-ware bowls from Leilan. Chemical analysis of the sherds from the domestic refuse contexts at Operation 4 display normalized C.V.s from *three to five times greater* than those of the stacked wasters (Table 2), documenting a considerably greater degree of heterogeneity in this chemical composition group.

Although the waster-stack bowls show much less internal variation than the finished fine-ware bowls from Operation 4, there can be little doubt that both sets of bowls belong to the same chemical compositional group. In other words, the wasters are simply a subset within the broader category of fine-ware bowls made by specialized potters at Leilan. This can be shown by demonstrating that: (a) the chemical composition of the wasters falls statistically within the range of compositions for the other Leilan fine wares; and (b) the Leilan fine wares and wasters, considered as a group, are compositionally distinct from ceramics known to have been manufactured at other sites in the area.

Table 2. Comparison of the Normalized Coefficients of Variation for the Leilan Stacked Wasters, Operation 4 Fine Wares, and SRM 679: Brick Clay.

Element	Waster Stack (n = 18) C.V.	Fine Ware: Op. 4 (n = 20) C.V.	SRM 679: Brick Clay (n = 140) C.V.
Na (%)	1.8	8.1	1.8
K (%)	.7	4.1	2.8
Rb (ppm)	−1.0	8.0	3.6
Cs (ppm)	.6	12.7	.9
Ca (%)	−4.3	3.6	—
Sr (ppm)	−.3	8.8	—
Ba (ppm)	2.7	2.6	3.1
Sc (ppm)	1.2	6.0	1.7
Cr (ppm)	1.7	4.9	2.0
Fe (%)	1.0	4.7	2.9
Co (ppm)	.9	6.0	1.6
Zn (ppm)	.3	7.0	1.6
As (ppm)	7.1	29.5	2.4
Sb (ppm)	−.1	4.3	8.3
La (ppm)	.8	4.9	1.3
Ce (ppm)	.8	6.2	1.5
Sm (ppm)	1.4	3.8	2.0
Eu (ppm)	.1	4.7	1.3
Tb (ppm)	.4	4.1	5.3
Yb (ppm)	1.3	3.1	2.0
Lu (ppm)	.8	4.3	2.2
Hf (ppm)	.5	3.1	1.3
Ta (ppm)	.3	4.6	2.1
Th (ppm)	.4	5.6	1.6
U (ppm)	4.0	9.8	3.6

Note: Normalized C.V. is defined as sample C.V. minus error due to counting statistics.

To examine the relation between the wasters and Operation 4 fine wares, the compositional data were analyzed using the statistical program ADCORR, developed by E. V. Sayre and others at Brookhaven National Laboratory. For a preselected core group of samples, the program used Mahalanobis distance to calculate a multidimensional space defined on the basis of elemental concentrations. The position of each sample in the core group and in any reference group is then calculated relative to the centroid of this space. Hotelling's T^2 statistic is then used to calculate the multivariate probability of the sample belonging to the core group (for a more detailed description of the statistics see Bieber et al. 1976; Bishop et al. 1988:321).

First, the 18 stacked wasters were defined as the core group and the multivariate probabilities of the Operation 4 fine wares belonging to the waster group were calculated. The extreme homogeneity of the wasters defined a multivariate compositional space so compact that all but three of the 22 Operation 4 fine wares were excluded from the waster core group at the 99 percent confidence level, and all but a single bowl were excluded at the 95 percent confidence level (Table 3). In a second run, the core group consisted of the wasters combined with the fine-ware bowls from Operation 4. The stacked wasters showed high probabilities of membership within this more variable core group (Table 4). Taken together, the statistical analysis suggests that the wasters form a tightly cohesive subset of the larger compositional group representing fine-ware bowls made at Leilan.

The complexities of multivariate analysis aside, a simple binary plot of iron vs. scandium shows that the Leilan compositional group (the pooled data set of wasters and finished bowls) is readily distinguishable at the 95 percent confidence level from fine wares and fine-ware kiln wasters found

Table 3. Mahalanobis Distance Calculations, Hotelling's T^2 Multivariate Probabilities of Group Inclusion: Core Group = Leilan Wasters; Comparison Group = Leilan Operation 4 Fine Wares.

Leilan Op. 4 Fine-Ware Sample Number	Percent Probability of Inclusion in Waster Core Group
LSP178	.072
LSP179	.000
LSP180	.000
LSP181	.001
LSP182	.031
LSP183	.348
LSP184	.012
LSP185	.000
LSP186	.000
LSP187	9.579
LSP188	.025
LSP189	.058
LSP190	.000
LSP370	.011
LSP371	.007
LSP372	.040
LSP373	.045
LSP374	.014
LSP375	1.524
LSP376	.152
LSP377	1.494
LSP378	.402

Note: Elements used to form characteristic vectors for Mahalanobis distances: K, Sc, Cr, Fe, Rb, Cs, La, Eu, Hf, and Th.

(and therefore almost certainly manufactured) at other sites in the Leilan region (Figure 8) (Stein 1990b). These results strongly suggest that the wasters form a relatively homogeneous component within the more variable, but still distinctive, compositional group of fine-ware ceramics manufactured by specialists at Leilan.

Measurements of Vessel Dimensions

Metric analysis forms the third main index of standardization. Several different methods are commonly used to monitor variability of forms and dimensions in ceramic assemblages. In some cases, diversity measures provide a useful standardization measurement (e.g., Benco 1987; Rice 1991). However, diversity indexes were not applicable to the analysis of the Leilan fine-ware bowls/wasters, which focused on a single ceramic type, rather than the entire range of Leilan period IIb ceramic forms. Instead, we used C.V.s and F ratios to describe and evaluate the degree of standardization in vessel dimensions. Coefficients of variation permit comparison between different ceramic assemblages, since variability is expressed in the form of a percentage. Unfortunately, as Arnold and Nieves (1992) have noted, it is not possible to test the statistical significance of differing C.V. values. However, F ratios can compare the amount of variation within and between two ceramic assemblages in terms amenable to formal significance tests.

Five measurements were made on the largely intact bowls of the stacked waster: rim diameter, wall thickness 1 cm down from the rim, vessel height, base diameter, and maximum basal thickness (Figure 9). However, rim diameter was the only measurement that could be consistently made on both the wasters and the finished fine wares from Operation 4. Rim-diameter measurements were made using a standard rim-diameter chart; digital calipers were used for all other measurements. Rim diameters were measured for 23 fine-ware bowls in the stacked waster and 66 fragmentary

Table 4. Mahalonobis Distance Calculations, Hotelling's T^2 Multivariate Probabilities of Group Inclusion: Core Group = Combined Wasters and Operation 4 Fine Wares.

Waster Sample Number	Percent Probability of Inclusion in Combined Operation 4 and Waster Fine-Ware Core Group
LSW131	98.936
LSW132	98.561
LSW133	97.429
LSW134	98.312
LSW135	76.392
LSW136	99.335
LSW137	92.943
LSW138	99.510
LSW139	73.821
LSW140	97.467
LSW141	99.480
LSW142	98.612
LSW143	97.812
LSW144	58.221
LSW145	77.762
LSW146	78.378
LSW147	95.240

Note: Elements used to form characteristic vectors for Mahalanobis distances: K, Ca, Cr, Fe, Rb, Sr, Sb, La, Eu, and Lu.

fine-ware bowls from Operation 4. The bowls in the waster stack show a high degree of metric standardization (Table 5). C.V.s on the five recorded measurements are all less than 10 percent. Although intercultural comparisons must be viewed with caution, it is still worth noting that the C.V.s for the Leilan wasters are comparable to the low C.V. percentages observed by Longacre and his colleagues for ethnoarchaeological collections of specialist-produced Paradijon cooking pots in

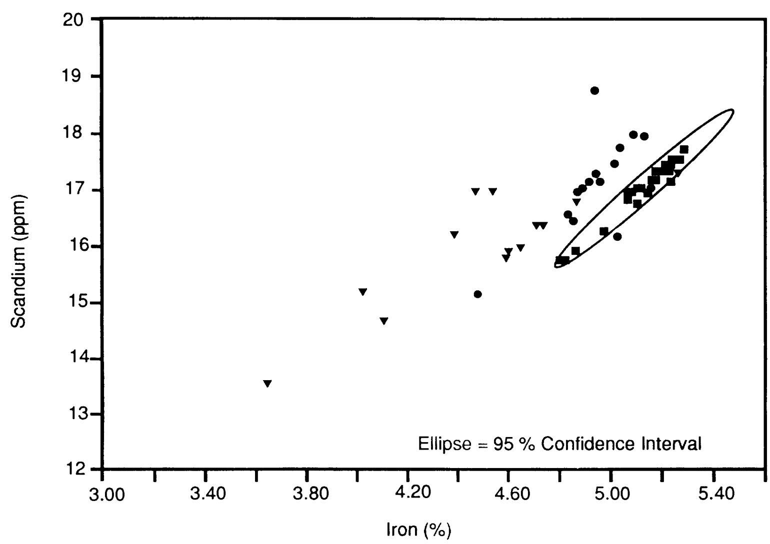

Figure 8. Iron vs. scandium concentration plot for combined Leilan wasters/Operation 4 ceramics compared with wasters from two village production sites (Farsouk Kebir and Gir Souar) within a 10-km radius of Leilan. Key: Squares = Leilan fine-wares and wasters; dots = Farsouk Kebir fine-wares and wasters; and upside-down triangles = Gir Souar fine-wares and wasters.

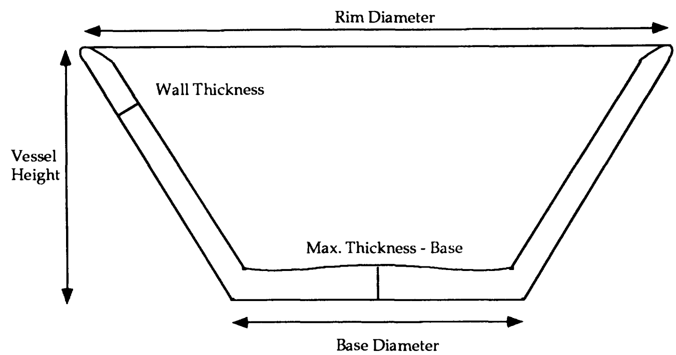

Figure 9. Schematic section (not to scale) of an open-simple-rim fine-ware bowl, showing the location of the measurements made on the waster-stack bowls.

the Philippines (Longacre et al 1988:Table 1). In short, metric data from the Leilan wasters show a level of homogeneity consistent with expectations for specialized mass production of standardized utilitarian goods.

As was the case with the compositional data, the metric evidence for a high degree of standardization displayed by the stacked wasters becomes more confused when the analysis is extended to include the finished fine-ware bowls from Operation 4. The C.V.s for the Operation 4 fine-ware rim diameters are more than twice the C.V. values for the stacked waster rims (Table 6). This holds even when the two extreme outliers (the largest and smallest rim diameters—each more than two standard deviations from the mean--see Figure 10) are excluded from consideration (Table 6). *F*-ratios confirm that the fine wares in the stacked wasters are significantly less variable than the Operation 4 fine wares (Table 7). However, although the waster rim diameters show less *variation* than the finished fine-ware bowls, the actual diameter *measurements* show a close relation between the two groups. Both have modal rim diameters of 17 cm. The main difference between the measurements of the two groups stems from the presence of two extreme outliers at the upper and lower tails of the distribution of Operation 4 rim diameters. The waster rim diameters form a tight, homogeneous cluster falling completely within the more variable range of rim diameters from Operation 4 (Figure 10). In other words, the metrics provide no real grounds to define the wasters and Operation 4 fine wares as different groups; rather, they must be considered as subpopulations of a single ceramic type.

"CUMULATIVE BLURRING" OF STANDARDIZATION EVIDENCE

The Leilan fine-ware stacked waster represents a single production event in which a large number of nearly identical bowls were formed and fired by highly skilled craft specialists. Technological, compositional, and metric examinations of the bowls in the waster stack all show a high degree of homogeneity consistent with the expectations of the standardization hypothesis. However, when

Table 5. Metric Evidence for Standardization Using Leilan Fine-Ware Stacked Waster Measurements.

Measurement	n	Mean	S.D.	C.V.
Rim diameter (cm)	23	18.52	1.70	9.19
Maximum thickness (mm)	14	6.54	.61	9.40
Thickness 1 cm below rim (mm)	28	4.32	.35	8.14
Vessel height (cm)	13	6.85	.30	4.40
Base diameter (cm)	13	8.15	.16	1.98

Table 6. Metric Evidence for Standardization Using Rim-Diameter Measurements for Fine-Ware Wasters and Operation 4 Fine-Ware Bowls.

Material	n	Mean	S.D.	C.V.
Stacked wasters	23	18.52	1.70	9.19
Op. 4 fine wares	66	16.55	3.12	18.85
Op. 4 fine wares	64[a]	16.47	2.58	15.68

[a] Two outliers omitted.

finished fine wares from Operation 4 are added to the analysis, the uniformity displayed by the wasters becomes much more diverse. The Operation 4 fine wares show a much greater degree of compositional and metric variability than the stacked wasters. The differences in relative homogeneity between the two groups might be explained in two different ways: either (1) the wasters were manufactured by specialists, while the Operation 4 fine wares were not; or (2) the increased variability stems from the fact that the fused wasters represent a single production event, while the finished fine-ware bowls from Operation 4 reflect both random and nonrandom noise resulting from multiple production events in multiple workshops through time. Technological and compositional analysis have shown that both sets of bowls were made at Leilan, from the same raw materials using identical forming and firing technologies. On this basis, we can safely reject the first possibility. The second interpretation, therefore, appears to be the most likely. Multiple production events in several different workshops, even when carried out by specialists, can be expected to increase the amount of variability in chemical composition and vessel dimensions, an effect that we can characterize as "cumulative blurring."

Several factors can cause the cumulative blurring of the standardization indexes examined in this paper. The archaeological sample of fine-ware bowls at Leilan represents the cumulative results of multiple production events in time and space. The first factor, time, is a function of the longevity of ceramic types. Open-simple-rim greenish fine-ware bowls were manufactured throughout Leilan period IIb, a time span of 200–300 years. Thus, several generations of potters would have manufactured this bowl type, with concomitant variation as an inevitable result. Once introduced, this variation is extremely difficult to factor out. Even when we defined the analytical groups conser-

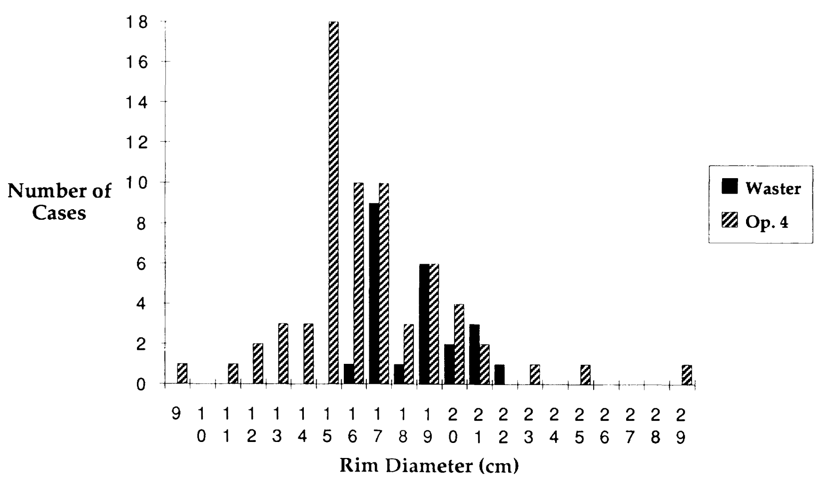

Figure 10. Histogram of waster rim diameters and Operation 4 fine-ware rim diameters.

Table 7. Metric Evidence for Standardization Using Rim Diameters: F Ratios for Fine-Ware Stacked Waster and Operation 4 Fine-Ware Bowls.

F-Ratio	Degrees of Freedom (Numerator)	Degrees of Freedom (Denominator)	F-Calc.	Upper Tail F-Crit. (.025%)	Lower Tail F Crit. (.025%)
Finished/ waster	65	22	3.3583*	2.14	.51546

* $p < .05$.

vatively by excluding samples the chemical composition or metric characteristics of which marked them as clear outliers, the cumulative blurring effect was still evident.

A second probable source of cumulative blurring lies in the organization of specialized ceramic production. Leilan was a large urban center, with consistent, high levels of demand for utilitarian ceramic vessels. In this situation, one would expect there to have been multiple potters and/or multiple workshops working concurrently to produce the same ceramic forms within this urban center. In a study of pottery production at the medieval south Indian city of Vijayanagara, Sinopoli (1988:582, 1989) suggests that "noncentralized production" by numerous independent craft specialists would produce a relatively diverse ceramic assemblage due to variation between individual workshops in methods and materials. This variation develops not only from innate differences in the abilities of individual potters, but also as a direct result of competition among noncentralized workshops. In an ethnoarchaeological study of noncentralized Ticul potters in Mexico, Arnold and Nieves (1992) noted that each workshop has its own measurement standards and procedures. These are carefully guarded as trade secrets, despite the fact that all the workshops are producing the same ceramic types for the same market. The differing measurement standards used by competing independent workshops in a noncentralized system can thus be expected to generate higher levels of metric variability among the products of these workshops than would be seen in the products of a single workshop, even though every pot is made by a craft specialist.

Noncentralized specialist production is almost certainly a factor in ceramic variability at Leilan as well. Ceramic fine-ware production in the region dominated by Leilan in period IIb seems to be organized on a noncentralized model (Stein and Blackman 1991). Chemical characterization documents production at several sites (Figure 8) and distribution to non-producing sites shows no evidence for centralized control (Stein and Blackman 1991).

Table 8. Leilan Operation 4 Fine-Ware Rim Diameters: Breakdown by Context, Compared with Wasters and Pooled Figures for all Operation 4 Fine Wares.

Context	n	Mean	S.D.	C.V.
Lot 1	8	16.63	1.92	11.57
Lot 23	5	18.60	3.21	17.26
Lot 24	5	16.80	2.49	14.82
Lot 27	7	17.00	4.00	23.53
Lot 28	11	14.64	2.91	19.87
Lot 29	12	16.92	4.56	26.97
Pooled Op. 4	66	16.66	3.12	18.85
Wasters	23	18.52	1.70	9.19

Note: Contexts with fewer than five measured rim diameters omitted from table.

At Leilan, the 66 measured fine-ware rim sherds from Operation 4 were derived from 16 different microstratigraphic contexts, all dating to Period IIb. Even when we attempt to control for the longevity of this ceramic type by looking at each microstratigraphic unit individually, rim-diameter C.V.s differ markedly for each context and in all cases are larger than the C.V. of the waster rims (Table 8). Clearly, these numbers must be viewed with great caution due to the small sample sizes involved. However, the higher levels of variability in the microstratigraphic contexts of Operation 4 are consistent with what we would expect for noncentralized specialist production—i.e., multiple workshops at any given time at Leilan during period IIb.

Two to three centuries of noncentralized ceramic production would create variability not only in vessel dimensions, but in chemical composition as well. It is common for potters from a single settlement to draw on multiple clay sources (see e.g., Arnold et al. 1991:72–74; De Atley and Melson 1986). Clay is widely accessible in deposits exposed by numerous incised channels of the north–south-oriented seasonal watercourses in the Leilan area. In any given year, heterogeneity in the chemical composition of the fine-ware bowl assemblage would arise through the actions of a number of independent workshops exploiting multiple local clay sources, each differing only slightly from its neighbors. Even within a single clay source, repeated extraction over a long period of time can increase compositional heterogeneity of a ceramic assemblage due to clinal variation in the chemical makeup of individual deposits (Attas et al. 1982:181–190; Myers and Blackman 1986:64). Further, actions by the potters themselves, in refining the raw materials and preparing the ceramic clay for use may lead to inter- (Jornet et al. 1985) and intraworkshop (Blackman 1992) variability in paste composition.

Cumulative blurring of standardization indexes thus develops through a combination of ancient natural and cultural processes such as: (a) natural variation in local clay deposits; (b) differences between potters in skills or raw-material sources; and (c) the degree of centralization, administration, or competition in ceramic manufacture. These difficulties can be compounded by modern sampling procedures, especially those which stem from using inclusive stratigraphic, chronological, and typological units to organize and interpret archaeological data. In many cases the ancient and modern causes of cumulative blurring are simply unavoidable. In recognizing these sources of bias, however, one can compensate for their effects and more accurately evaluate the evidence for standardization in craft production.

CONCLUSIONS

In this paper, we have examined the standardization hypothesis through the complementary lines of technological, compositional, and metric indexes applied to both kiln wasters and finished ceramics from Tell Leilan. These two data sets are particularly useful because they have allowed us to compare variability between the rare evidence from a single production event and the more common archaeological assemblage of finished ceramics recovered in fragmentary form from domestic contexts of consumption and discard. This comparison, therefore, provides baseline data on the amount of variability, induced through time, in the output of specialized production in complex societies.

At one level, the standardization hypothesis is clearly correct. We have seen that utilitarian goods, mass produced by a given specialist workshop at a given time, are extremely homogeneous or standardized. However, the archaeological record of specialized ceramic manufacture at Leilan does not represent just one workshop; instead the data reflect the cumulative output of multiple-production events, at multiple different workshops. The bowls made in each event may be highly standardized, but variation in vessel dimensions and clay composition can occur between production events at the same workshop and certainly between workshops. At any given time, there may have been several noncentralized, independent workshops mass producing fine-ware bowls at Leilan. Over the course of the two- or three- century span of Leilan period IIb, the number of production events would have been extremely large, resulting in the increased variability observed in the Operation 4 fine-ware. Thus, in long-lived ceramic types from multiple workshops, the evidence for metric and compositional standardization can be blurred.

We have documented here the amount of metric and compositional variability introduced into the Leilan period II ceramic production through the above outlined causes. Some perspective on the magnitude of this induced variability is provided by comparison with the observed compositional variability in specialist-produced ceramics of comparable age from Godin Tepe in Iran (Henrickson and Blackman 1992). The Godin III-5 ceramics, although representing a much shorter time period (ca. 40–50 years), show slightly greater C.V.s than the Leilan Operation 4 ceramics. In both cases, even with the blurring, C.V.s for most elements are well under 10 percent; as noted earlier, this is consistent with the limited range of variation found by ethnoarchaeological studies of specialist-produced ceramics (Longacre et al. 1988). These results suggest that multiple production events can blur, but do not completely obscure the standardization signature of craft specialists engaged in mass production of utilitarian ceramics.

Our examination of Leilan ceramic production suggests that standardization can be an effective index of craft specialization under conditions of close spatial and chronological control over the samples in question. The generally accepted standardization indexes become increasingly reliable, the closer one can get to isolated individual workshops and production events. By recognizing and controlling for these aspects one can use the standardization hypothesis as an effective methodology in reconstructing the productive organization of complex societies.

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BIG POTS FOR BIG SHOTS: FEASTING AND STORAGE IN A MISSISSIPPIAN COMMUNITY

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In small-scale societies, ritual feasts are often an important setting for social integration and status competition. Material evidence of feasting and food storage may be preserved in community ceremonial precincts, such as platform mounds. To identify food-consumption activities, ceramic samples from mound and village contexts at the prehistoric Lubbub Creek site in Alabama are compared. There are no significant differences in the distribution of decorated types, ware categories, or vessel shapes. However, the mound has a more restricted range of vessel sizes and disproportionately larger vessels than the village sample. These results, together with supporting feature and faunal data, suggest that mound activities included large-group feasts and food storage.

En las sociedades de menor escala, los festejos rituales son frecuentemente un escenario importante para la integración social y competición de status. Restos arqueológicos de festejos y almacenaje de alimentos pueden ser preservados en zonas ceremoniales de la comunidad, por ejemplo en los montículos. Para identificar las actividades de alimentación, se comparan muestras de cerámica procedente del montículo y del pueblo con la del sitio prehistórico de Lubbub Creek en el estado de Alabama. No hay una diferencia significante en la distribución de tipos de decoración, la categoriá de fabricación, ni de las formas de las vasijas. Sin embargo, el montículo tiene una escalá mas restringida en lo que se refiere a los tamaños de las vasijas y tiene un número desproporcionado de vasijas más grandes que las muestras encontradas en el pueblo. Estas vasijas grandes son evidencia de grandes festejos y el almacenaje de comida. Los restos óseos también apoyan esta misma interpretación.

Archaeologists have long been concerned with understanding the nature and development of social ranking in nonstate societies. Theories of chiefdom development often promote the idea that formal offices of leadership appeared in response to demographic or environmental stresses that demanded "managers" to oversee intensified food production and external relationships (Johnson and Earle 1987; Peebles and Kus 1977; Service 1975). Others emphasize how internal social demands may stimulate resource intensification and status differences. In one such "social" model (Bender 1979, 1985), generation of food surpluses need not be a demographic or environmental imperative, but rather a social strategy to extend alliances, reinforce obligations, and promote prestige. Kin groups that amassed more food held the advantage in the competitive arena of feasts and gift giving that serves to bind together households in small-scale societies (Hayden 1990; Steponaitis 1986).

In both perspectives on the rise of social ranking, control of access to resources emerges as a

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