LARGE-SCALE PATTERNS IN THE CHEMICAL COMPOSITION OF MISSISSIPPIAN POTTERY

Vincas P. Steponaitis, M. James Blackman, and Hector Neff

Neutron activation analysis of Mississippian sherds from 21 regions across the Southeast has revealed the existence of distinctive chemical groups that are associated with four large geographical areas. One such group is associated with sites along the Mississippi River and its western tributaries, a second is associated with sites on the Appalachian Rim in Tennessee, a third is associated with sites on the Piedmont and associated drainages, and a fourth is associated with sites in Alabama. This pattern reflects the existence of several large, clay-mineral provinces in the Southeast that now can be recognized as sources in future studies of long-distance exchange.

El análisis de activación de neutrones de tiestos Misisipí procedentes de 21 regiones a lo largo del sureste de Estados Unidos ha revelado la existencia de grupos químicos distintos asociados con cuatro áreas geográficas. Uno grupo se asocia con sitios a lo largo del Río Misisipí y sus tributarios occidentales; un segundo grupo se asocia con sitios en el Borde de Appalachia en Tennessee; un tercero se asocia con sitios en el piedemonte y drenajes asociados; y un cuarto se asocia con sitios en Alabama. Este patrón refleja la existencia de varias provincias grandes de arcillas-minerales en el Sureste que hoy pueden reconocerse como fuentes en futuros análisis de intercambio a larga distancia.

Archaeological studies of long-distance trade in the southeastern United States have traditionally focused on stone and prestige goods such as copper, galena, and marine shell (Bishop and Canouts 1993; Johnson 1994; Lafferty 1994). Considerably less attention has been devoted to studying the movement of pottery. Archaeological and ethnohistorical evidence both suggest that trading pots was a widespread practice among the Indians of the Southeast (e.g., Steponaitis 1983; Swanton 1946). But, apart from the frequent recognition of ceramic exchange in the archaeological record (based on the occasional discovery of sherds that appear to be nonlocal), few systematic studies have been done to delineate the exchange networks that once existed or to describe how these networks changed through time.

One reason these studies have been slow to come about has been the lack of reliable criteria by which vessels made in different regions can be identified. Although nonlocal pottery has sometimes been recognized by means of stylistic comparisons, this method alone is inadequate for two reasons. First of all, most prehistoric pottery one finds in Mississippian sites is undecorated and, therefore, provides little basis for stylistic comparison. Second, even when an apparently nonlocal pot is identified, it is difficult to be sure whether the vessel is truly an import or is simply a local copy of a foreign style. Thus, in any comprehensive study of ceramic exchange, stylistic comparisons should always be supplemented by chemical or mineralogical studies that are capable of linking the raw material in the artifact to a geological source.

Yet anyone who contemplates using chemical or mineralogical methods to "source" the pottery found at a particular site immediately confronts a problem: There is no way to know a priori the compositional differences among the sources one hopes to discriminate. Or, to put the matter another way, say one were to characterize chemically a large sample of sherds from a single site;

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one could statistically identify similarities and differences among groups of sherds within the sample, but exactly how different would a group have to be before it could be confidently classified as nonlocal?

Obviously, the only way to answer this question is to approach the matter empirically. Before one can confidently start "sourcing" sherds, one must first do a baseline study that defines the compositional characteristics of the sources themselves. It was with this consideration in mind that we initiated such a baseline study for the southeastern United States. Our strategy has been to obtain samples of sherds from many different regions and to characterize these samples by neutron activation analysis. Our goal has been to determine empirically the chemical "fingerprints" of the Mississippian ceramics made in various parts of the Southeast and thereby to set the stage for future studies of trade in pots.

Of course, the number of clay deposits in the southeastern United States that could have been used for pottery production is virtually infinite, and it is clearly impractical to try to discriminate them all. Yet it is reasonable to expect, on both empirical and theoretical grounds, that the clays found within broad geological or geomorphological units will have certain compositional characteristics in common. Previous studies have shown, for example, that alluvial clays found within a single drainage basin tend to be similar to each other and different from the clays found in other drainages, especially if these drainages cut through distinctive geological formations (e.g., Maggetti 1982; Tobia and Sayre 1974). Because our eventual goal is to delineate exchange between regions, it is this large-scale variation in clay sources that we hope to recognize and to define.

The rest of this paper is divided into four parts. First, we briefly describe our methods; second, we present our results; third, we show how the chemical patterns relate to regional geology; and last, we discuss the implications of our findings for future research.

Methods

Instrumental neutron activation analysis (INAA) is a method that has been used quite commonly in archaeological provenance studies (Bishop et al. 1982; Harbottle 1982; Rapp 1985). It provides data on the elemental composition of a specimen and does so with remarkable precision. Although detection limits vary from one element to another, most of the elements used in our study could be detected in concentrations of the order of 1 ppm.

Our procedure was to obtain approximately 1 g of powder from the interior of each sherd with a tungsten carbide drill. Each sample was thoroughly mixed, dried, and then subsampled to remove 100 mg for further analysis. These subsamples were irradiated together with standards in a nuclear reactor for 4 hours at a flux of 7.7×10^{13} n/cm^2/sec. After 6 days they were counted for 1 hour with an intrinsic germanium detector; after 30 days they were counted again for 2 hours. All the activation was carried out by Blackman at the Conservation Analytical Laboratory INAA Facility, Smithsonian Institution, using the National Bureau of Standards Research Reactor at the National Institute of Standards and Technology. Additional details on the analytical protocols and instrumentation have been published elsewhere (Blackman 1984:23–25, 1986; Blackman et al. 1989:64–65, Table 1).

Twenty-five elements were measured with sufficient reliability for analysis: sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), calcium (Ca), strontium (Sr), barium (Ba), scandium (Sc), hafnium (Hf), tantalum (Ta), chromium (Cr), iron (Fe), cobalt (Co), zinc (Zn), arsenic (As), antimony (Sb), lanthanum (La), cerium (Ce), samarium (Sm), europium (Eu), terbium (Tb), ytterbium (Yb), lutetium (Lu), thorium (Th), and uranium (U).

Results

We determined the elemental composition of sherds from 21 different regions across the Southeast, from eastern Oklahoma to the Appalachian Mountains (Figure 1, Table 1).[1] These are the Spiro and Little Rock regions in the central and lower Arkansas River valley, respectively; the Great Bend region of the central Red River valley; the Natchitoches region farther down the Red River basin in western Louisiana; the Big Lake region of the central Mississippi River valley, just south of the Missouri "bootheel"; the Pecan Point region of the

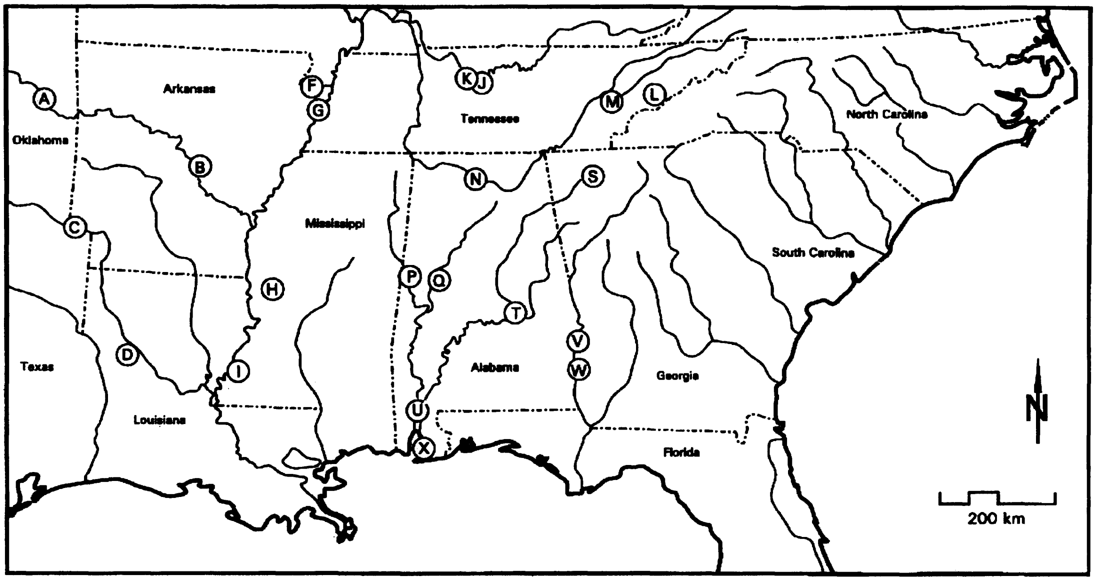

Figure 1. Map of the southeastern United States showing the regions used in the present study. A, Spiro region; B, Little Rock region; C, Great Bend region; D, Natchitoches region; F, Big Lake region; G, Pecan Point region; H, Lower Yazoo region; I, Natchez region; J, Nashville region; K, Lower Harpeth region; L, Sevierville region; M, Tellico region; N, Wheeler Lake region; P, Gainesville Lake region; Q, Black Warrior region; S, Carters Lake region; T, Wetumpka region; U, Mobile Delta region; V, Eufaula region; W, Fort Gaines region; X, Mobile Bay region.

Mississippi Valley in northeastern Arkansas; the Lower Yazoo basin of west-central Mississippi; the Natchez region of southwestern Mississippi (comprising the loess bluffs just east of the Mississippi's alluvial valley); the Lower Harpeth and Nashville regions in the Cumberland River drainage of central Tennessee; the Sevierville and Tellico regions of the upper Tennessee River drainage in eastern Tennessee; the Wheeler Lake portion of the central Tennessee valley in northern Alabama; the lower Black Warrior drainage in west-central Alabama; the Gainesville Lake region along the Tombigbee River in western Alabama; the Carters Lake region on the Coosawatee River in northwestern Georgia; the Wetumpka region at the junction of the Coosa and Tallapoosa rivers in central Alabama; the Mobile Delta and Mobile Bay regions of southern Alabama; and the Eufaula and Fort Gaines regions of the lower Chattahoochee River valley.

In general, we activated 10 sherds from each region, taking care to select specimens that appeared to be stylistically local. In a few cases—notably Natchitoches, Gainesville Lake, and Mobile Bay—our sample was smaller. We analyzed 186 sherds in all; 75.8 percent were shell tempered, 15.6 percent were tempered principally with grog, and 8.6 percent were tempered exclusively with grit or sand (see Table 1).

Before we could use the elemental data for regional comparisons, it was important to take account of the variability due to differences in the abundance of shell temper. As the amount of temper increases, the concentrations of elements associated with shell are enhanced, and, by the same token, the concentrations of elements associated principally with the clay are diluted. Because differences in the amounts of shell temper often reflect function rather than geographical origin (Steponaitis 1983:33–45), this source of variation had to be controlled. For our purposes, such control was accomplished by transforming the data mathematically to simulate the removal of the shell. First, the elements believed to be most associated with shell temper (calcium and strontium) were dropped from the data set. Second, concentrations of the remaining 23 elements were recalculated to remove the effects of shell dilution. This correction was achieved for each sherd by means of the formula

Table 1. Provenience and General Description of Characterized Sherds.

Region (Symbol):[a] Site (Reference)	Characterized Sherds[b]
Spiro (A):	
Cat Smith (Wyckoff and Barr 1967)	4 Leflore Plain (grog), 5 Woodward Plain
Little Rock (B):	
Goldsmith Oliver (Jeter et al. 1990)	5 Mississippi Plain
Toltec (Rolingson 1982)	5 Baytown Plain (grog)
Great Bend (C):	
Bowman (Hoffman 1970:167–169)	5 Crockett Curvilinear Incised (grog), 5 Haley Complicated Incised
Natchitoches (D):	
Los Adaes (Neuman 1984:291–294)	3 Emory Punctuated and Incised
Big Lake (F):	
Zebree (Morse and Morse 1976)	9 Varney Red Filmed, 1 Mississippi Plain
Pecan Point (G):	
Upper Nodena (Morse 1973)	4 Bell Plain, 5 Mississippi Plain
Lower Yazoo (H):	
Lake George (Williams and Brain 1983)	5 Bell Plain, 5 Mississippi Plain
Natchez (I):	
Emerald (Cotter 1951)	2 Fatherland Incised (grog), 2 Plaquemine Brushed (grog)
Foster (Steponaitis 1974)	3 Leland Incised (grog), 2 Mazique Incised (grog)
North (Brain et al. n.d.)	1 Mazique Incised (grog)
Nashville (J):	
Gordontown (Myer 1927)	2 Bell Plain, 8 Mississippi Plain
Unnamed site[c]	1 Bell Plain
Lower Harpeth (K):	
Mound Bottom (Kutruff and Kutruff 1992)	2 Bell Plain, 2 Mississippi Plain, 1 Kimmswick Fabric Impressed
Sevierville (L):	
McMahan (Holmes 1883:292–303)	1 Bell Plain, 9 Mississippi Plain
Tellico (M):	
Bussell Island (Harrington 1922:63–82)	2 Bell Plain, 5 Mississippi Plain, 3 McKee Island Brushed
Wheeler Lake (N):	
Benton 71[d]	6 Mississippi Plain
Benton 210[d]	3 Mississippi Plain
Gainesville Lake (P):	
Lubbub (Peebles 1983)	4 Mississippi Plain
Black Warrior (Q):	
Moundville (Steponaitis 1983)	3 Bell Plain, 5 Mississippi Plain, 2 Moundville Engraved
Carters Lake (S):	
Little Egypt (Hally 1980)	1 Lamar Plain (grit), 8 Dallas Plain, 1 Dallas Filleted
Wetumpka (T):	
1Ee136[e]	6 shell-tempered plain, 3 grit-tempered plain, 3 shell/grit-tempered plain
Mobile Delta (U):	
Bottle Creek (Brown and Fuller 1993)	3 Bell Plain, 3 Mississippi Plain
Pine Log Creek (Curren 1992:170–172)	1 D'Olive Incised, 1 Moundville Incised
Unnamed site[f]	1 Pensacola Incised
Eufaula (V):	
Roods Landing (Caldwell 1955)	2 Cool Branch Incised (grit), 3 grit-tempered plain, 2 shell-tempered plain, 3 shell/grit-tempered plain
Fort Gaines (W):	
Cemochechobee (Schnell et al. 1981)	3 shell/grit-tempered plain, 7 grit-tempered plain
Mobile Bay (X):	
Mary Ann Beach (Brown and Fuller 1993:99–103)	1 Mound Place Incised, 1 Moundville Incised

[a] Letters refer to those used in Figures 1, 4, 9, and 12.

[b] Named types are shell tempered unless otherwise noted parenthetically.

[c] Sherd collected by J.W. Powell in 1877 from site "near Nashville" (National Museum of Natural History catalog number 32051).

[d] Sherds collected by Jesse Benton from sites in the Tennessee River flood plain (Wheeler Lake) about 6 miles east of Decatur, Alabama (site files, Division of Archaeology, Alabama State Museum of Natural History, Tuscaloosa).

[e] Sherds collected from an alluvial terrace at the junction of the Coosa and Tallapoosa Rivers in Elmore County, Alabama (site files, Division of Archaeology, Alabama State Museum of Natural History, Tuscaloosa).

[f] Sherd collected by A. S. Gaines in 1877 from "shell bank between Mobile and Tenesaw Rivers," a few miles from the city of Mobile (National Museum of Natural History catalog number 30898).

Table 2. Results of Principal Components Analysis.

	Principal Component							
	1	2	3	4	5	6	7	8
Coefficients:								
Na	.1088	.6084	.4583	.4659	-.2945	.0056	.2365	-.0697
K	.3363	.1361	-.1778	.0690	-.0789	.6007	-.1533	-.0691
Rb	.3003	.1161	-.0592	.0768	.1325	.3782	-.1487	.1462
Cs	.2624	.0725	-.1217	-.1110	-.0852	.0814	-.1753	.2548
Ba	.1633	.2233	.4372	-.3812	.6606	.0021	.2032	-.1090
Sc	.1253	-.0464	.0394	-.0291	.0991	.0467	-.1921	-.1054
Hf	-.0448	-.0945	.2201	-.0952	-.2293	.0647	-.0775	-.0941
Ta	-.0068	-.0377	.1898	-.1530	-.0320	.0666	-.1250	.2022
Cr	.1195	.0114	.1061	-.0737	.0829	-.1855	-.2150	-.0091
Fe	.2397	.0781	-.0995	-.0653	.1713	.0762	-.0489	-.1111
Co	.1516	-.0429	-.1656	.5114	.2712	-.3025	-.2513	-.3870
Zn	.1841	.0729	-.0180	.2294	.2255	-.3090	-.3250	.4284
As	.3173	.2790	-.4856	-.3029	-.1348	-.2585	.3058	-.3397
Sb	.1707	.3160	-.0313	-.2586	-.2605	-.3859	-.1383	.3612
La	.2000	-.1684	.1583	-.0159	-.0050	-.0486	.0684	.0557
Ce	.1975	-.1803	.1667	.0528	-.0676	-.0759	.0244	-.0146
Sm	.2716	-.2368	.0979	.0585	-.0323	-.0756	.1363	-.0256
Eu	.2865	-.2288	.0717	.1106	-.0160	-.0904	.1789	.0063
Tb	.2650	-.2801	.0735	.0975	-.0859	-.0397	.1991	.0421
Yb	.2189	-.2174	.0794	-.0159	-.1337	-.0372	.1261	.0541
Lu	.2152	-.2053	.0892	-.0658	-.1433	.0216	.1343	.0476
Th	.0931	-.0376	.0643	-.0845	-.0527	.0570	-.1345	-.0008
U	.0718	-.0241	.2971	-.2428	-.2850	-.0840	-.5388	-.4784
Eigenvalue	.3087	.1430	.0729	.0466	.0437	.0375	.0228	.0168
Variance (%)	40.44	18.74	9.543	6.105	5.724	4.917	2.990	2.202

Notes: Analysis based on variance-covariance matrix of $\log_{10}$-transformed element concentrations in ppm. Coefficients are scaled so that the sum of squared values for each component equals 1.

$$e' = (10^6 e)/(10^6 - 2.5c)$$

where e' is the corrected concentration of any element in ppm, e is the measured concentration of that element in ppm, and c is the amount of calcium in ppm (Steponaitis and Blackman 1981). This formula assumes that all the calcium in a sherd is bound up in calcium carbonate and that all the calcium carbonate is associated with shell temper.[2] Although this method is not perfect, in our experience it works well and certainly produces far more useful results than we would get if we ignored the problems of shell dilution entirely. Indeed, a recent experimental study by Cogswell et al. (1993) has empirically confirmed the utility of this method in approximating the composition of the original clay prior to tempering.[3]

No mathematical correction was applied to the minority of sherds that were tempered with materials other than shell. For grog-tempered sherds, such correction is unnecessary because the grog itself is made of clay, presumably the same clay that comprises the rest of the paste. Grit- and sand-tempered sherds, on the other hand, are subject to dilution effects analogous to those that occur with shell. Unfortunately, the elements that comprise quartz are not detected by neutron activation, leaving us with no data on which to base a correction. Yet despite the potential problems, the uncorrected sherds behaved no differently in our analyses than the corrected, shell-tempered specimens (i.e., the shell- and quartz-tempered sherds generally clustered together by region). This result suggests that the distortions caused by quartz temper were not great enough to obscure the broad geographical patterns in composition, at least for the present sample.

Once the effects of shell temper were removed, it then became possible to explore the general patterns of similarity and dissimilarity among the regions we sampled. This was accomplished by

Table 3. Distribution of Chemical Groups by Geographical Area.

Area:	Chemical Group					
Region	Western	Northern	Eastern	Southern	Ungrouped	Total
Western:						
Spiro	3	0	0	0	6	9
Little Rock	10	0	0	0	0	10
Great Bend	10	0	0	0	0	10
Natchitoches	3	0	0	0	0	3
Big Lake	9	0	0	0	1	10
Pecan Point	9	0	0	0	0	9
Lower Yazoo	10	0	0	0	0	10
Natchez	2	0	0	0	8	10
Northern:						
Nashville	0	11	0	0	0	11
Lower Harpeth	0	7	0	0	3	10
Sevierville	0	8	0	0	2	10
Tellico	0	10	0	0	0	10
Eastern:						
Carters Lake	0	0	6	0	4	10
Eufaula	0	0	9	0	1	10
Fort Gaines	0	0	8	0	2	10
Southern:						
Wheeler Lake	0	0	0	4	5	9
Gainesville Lake	0	0	0	2	2	4
Black Warrior	0	0	0	0	10	10
Wetumpka	0	0	0	1	9	10
Mobile Delta	0	0	0	7	2	9
Mobile Bay	0	0	0	1	1	2
Totals	56	36	23	15	56	186

what has become a standard procedure for analyzing data of this kind (Bieber et al. 1976; Glascock 1992:15–25; Harbottle 1976:42–60; Sayre 1975): (1) the data were log$_{10}$-transformed; (2) missing values in the data were replaced by using a "best-fit" criterion based on Mahalanobis distance, a multivariate analog of a *z*-score; (3) the principal components were extracted from a variance-covariance matrix and the first eight components (encompassing more than 90 percent of the total variance) were retained for further analysis (Table 2); (4) a clustering algorithm (average linkage based on mean euclidean distance) was used to generate preliminary groups; (5) these preliminary groups were refined by calculating for each sherd the probabilities of membership in each group (based on Mahalanobis distance) and reassigning the sherds accordingly. The last step was repeated iteratively until a stable classification was achieved. Sherds that could not be comfortably placed in any of the compositional groups were left ungrouped.

This procedure yielded four major compositional groups, which (for reasons that will soon become apparent) we call "Western," "Northern," "Eastern," and "Southern." These four groups subsumed 70 percent (n = 130) of the analyzed sherds; the remaining 30 percent (n = 56) were ungrouped (Table 3).

The relationships among these groups are nicely illustrated with bivariate scatter diagrams involving the major principal components. When the second principal component is plotted against the first (Figure 2), the Eastern and Western groups separate cleanly, whereas the Northern and Southern groups overlap somewhat. This overlap is virtually eliminated by taking account of the third principal component, as in a graph showing the third principal component plotted against the first (Figure 3). If one were to look at a three-dimensional plot showing all three components simultaneously, each group would appear as a discrete cloud of points not overlapping with any of the others.

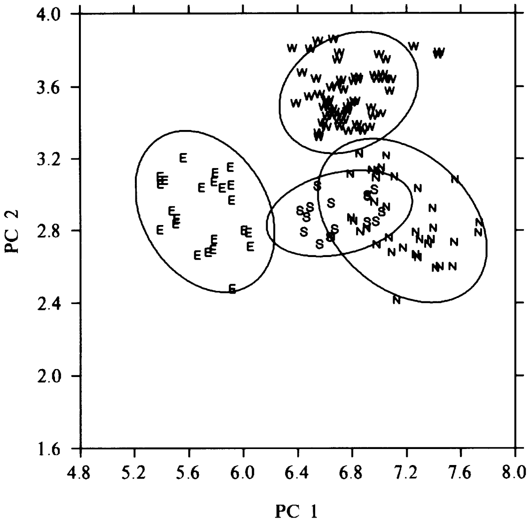

Figure 2. The second principal component plotted against the first, showing the four chemical groups. Boundary ellipses are drawn at the 90 percent level. N, Northern group; E, Eastern group; S, Southern group; W, Western group.

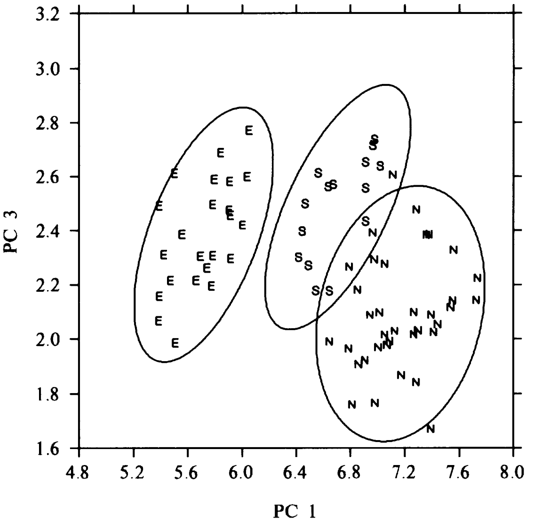

Figure 3. The third principal component plotted against the first, showing the separation among the Eastern, Southern, and Northern groups. Boundary ellipses are drawn at the 90 percent level. Western group not shown for the sake of clarity. N, Northern group; E, Eastern group; S, Southern group.

When we examine a map of the Southeast showing where the sherds comprising these compositional groups are from, the geographical correlates of the chemical patterning become clear (Figure 4). All the sherds comprising each chemical group come from within one of the four discrete areas marked on this map: the Western group includes the Mississippi Valley and parts west; the Northern group includes the four regions we sampled in Tennessee; the Eastern group subsumes all our regions in Georgia within the upper Coosa and Chattahoochee drainages; and the Southern group (perhaps the least cohesive of our constructs) includes most, but not all, of the regions we sampled in Alabama. As we explain presently, the existence of these large-scale geographical groupings is not accidental but reflects broad patterns in the composition of Southeastern clays.

Clay-Mineral Provinces in the Southeastern United States

A great variety of clays were available to Mississippian potters in the Southeast. These included (1) residual clays from saprolites (i.e., deposits of weathered rock), (2) sedimentary clays from ancient Coastal Plain beds, and (3) alluvial clays from flood plains and terraces. Such deposits generally contain a limited number of clay minerals, which can occur in an almost unlimited number of combinations. The principal clay minerals found in the Southeast are smectite (also called montmorillonite), kaolinite, illite, and chlorite.[4] Mixed-layer clays occur as well; as their name implies, these minerals have a composite structure in which layers of two or more clay varieties—usually smectite, illite, and/or chlorite—are chemically interleaved (Grim 1968; Millot 1970; Rice 1987:31–53; Weaver 1989).

Despite this variability, some combinations of clay minerals occur more commonly than others, and their geographical distribution is often conditioned by large-scale patterns of geology and drainage. In the continental United States, for example, smectite tends to dominate in the west, while kaolinite is far more common in the east; similarly, illite and chlorite are far more prevalent in the north than in the south (Griffin 1962:Figure 2; Hathaway 1972; Kennedy 1965; Neiheisel 1966:Figure 2; Neiheisel and Weaver 1967:Figure 1; Olive et al. 1989; Potter et al. 1975). For the present purposes, we find it useful to discuss the compositional variation across the Southeast in terms of six clay-mineral provinces (Figure 5),

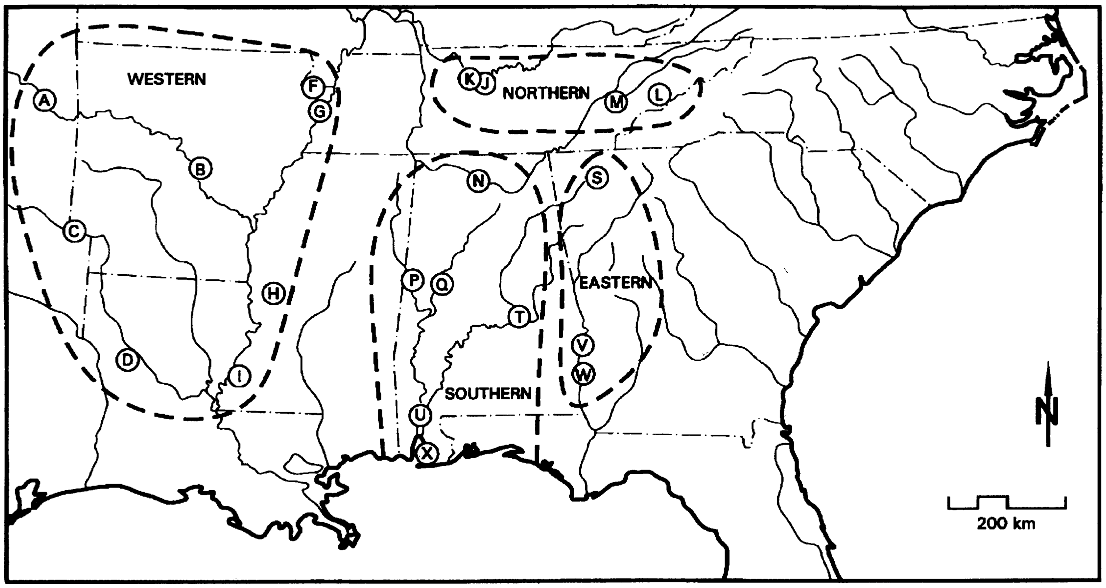

Figure 4. Geographical areas encompassing the four chemical groups. A, Spiro region; B, Little Rock region; C, Great Bend region; D, Natchitoches region; F, Big Lake region; G, Pecan Point region; H, Lower Yazoo region; I, Natchez region; J, Nashville region; K, Lower Harpeth region; L, Sevierville region; M, Tellico region; N, Wheeler Lake region; P, Gainesville Lake region; Q, Black Warrior region; S, Carters Lake region; T, Wetumpka region; U, Mobile Delta region; V, Eufaula region; W, Fort Gaines region; X, Mobile Bay region.

loosely based on the physical divisions defined by Fenneman (1938; Fenneman and Johnson 1946; see also Kinney 1966). Although the clays within each province are not perfectly uniform, their variability is restricted enough to facilitate description and to explain the geographical patterns evident in the composition of our sherds.

Ouachita-Ozark Province

This province rests on the Paleozoic rocks that comprise the Ouachita Mountains and the southern half of the Ozark Plateaus. Stretching across eastern Oklahoma and northwestern Arkansas, it is one of the few places west of the Mississippi River in which smectite is not dominant. Rather, its residual clays are generally kaolinite-illite mixtures, accompanied by chlorite and (sometimes) mixed-layer varieties (Griffin 1962:Figure 2; Hunt 1979; Potter et al. 1975:Figures 6–12). Alluvial clays associated with the minor streams that drain this area are mineralogically much like the residual clays just described. Clays in the Arkansas River valley, however, are quite different; because of the size of the Arkansas Basin, these sediments contain a typical western assemblage dominated by smectite and illite, with lesser amounts of kaolinite (Table 4).

Western Gulf Province

This province includes the Mississippi River's alluvial valley and Coastal Plain areas to the west. It covers southeastern Arkansas, western Tennessee, the western edge of Mississippi, most of Louisiana, and adjoining portions of Texas and Oklahoma. Geologically, the sediments here date from the Upper Cretaceous through the Holocene.

Most of the alluvium in the Lower Mississippi Valley comes from western sources. Hence, the clay-mineral assemblage is dominated by smectite and illite and also typically includes kaolinite along with traces of chlorite and mixed-layer clays (Table 4) (Griffin 1962:Figure 2; Maher 1983:24–25, 171–174; Neiheisel and Weaver 1967:Figure 1; Potter et al. 1975:Figures 11 and 12).

Coastal Plain clays west of the Mississippi Valley exhibit a more variable composition. Smectite is usually dominant, with lesser amounts of illite, kaolinite, and chlorite (Hunt 1979; Maher 1983:25–26; Olive et al. 1989; Potter et al. 1975). Deposits rich in kaolinite also sometimes

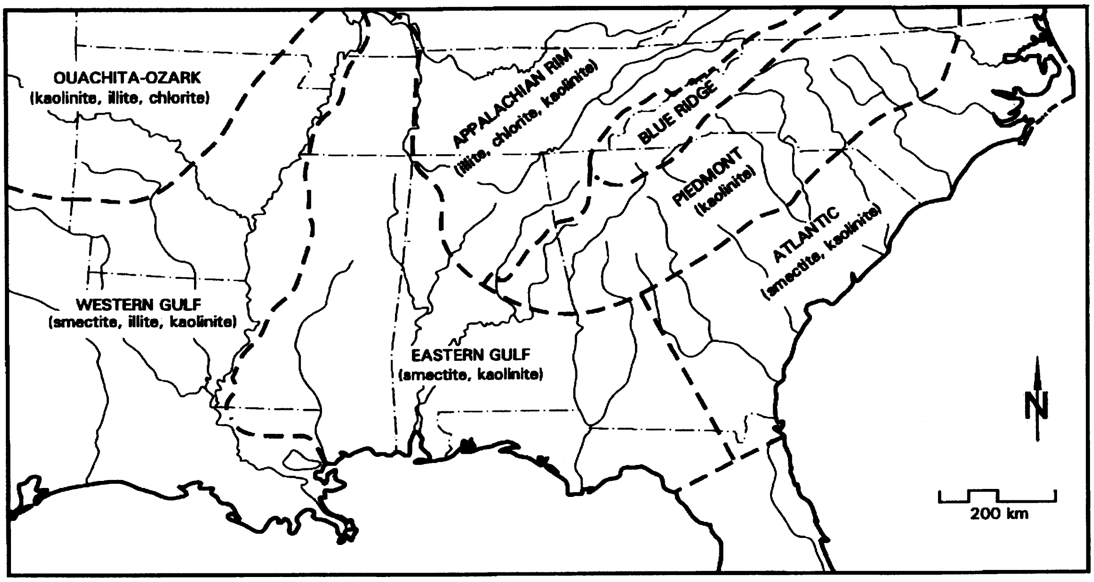

Figure 5. Clay-mineral provinces in the southeastern United States. Dominant clay minerals within each province are listed parenthetically.

occur (e.g., Griffin 1962:763–765).

Appalachian Rim Province

This is an area of Paleozoic sedimentary rocks covering northern Alabama and the eastern two-thirds of Tennessee. It subsumes Fenneman's (1938) Ridge and Valley Province, Cumberland Plateau, Nashville Basin, and Highland Rim.

Clays here are usually illite-kaolinite mixtures with little or no smectite, but the relative importance of these minerals varies depending on location. The northern (Tennessee) half of this province is geologically older and tends to produce assemblages dominated by illite, with lesser amounts of kaolinite, chlorite, and mixed-layer varieties—a composition typical of alluvial clays in the Tennessee-Cumberland Basin (Table 4). Farther south, in Alabama, the assemblages are more commonly dominated by kaolinite, with lesser amounts of illite and sometimes smectite (Clarke 1966, 1968a; cf. Hunt 1979; Olive et al. 1989).[5]

Piedmont Province

The Piedmont is a large tract of metamorphic and igneous rocks that forms the eastern fringe of the Appalachian Mountains. It includes central North Carolina, western South Carolina, northern Georgia, and parts of eastern Alabama.

Piedmont clays contain large amounts of kaolinite (ca. 70–90 percent), lesser quantities of illite, occasional traces of chlorite, and virtually no smectite. One finds little variance from this norm (Clarke 1963; Griffin 1962:Figure 2; Hunt 1979; Kennedy 1965; Neiheisel and Weaver 1967:Figure 1; Olive et al. 1989; Pevear 1972; Windom et al. 1971).

Eastern Gulf Province

This unit encompasses the large tracts of Upper Cretaceous, Tertiary, and Quaternary Coastal Plain sediments east of the Mississippi Valley and south of the Appalachians. It includes most of Mississippi, southern Alabama, southern Georgia, and the Florida panhandle.

Mineralogically, it is perhaps the most diverse of our provinces (Clarke 1966, 1968b, 1970; Griffin 1962; Grim 1936; Hunt 1979; Maher 1983:27–30; Neiheisel and Weaver 1967; Priddy 1961; Snowden and Priddy 1968:82–84). The extensive clay beds that comprise the ancient coastal sediments typically consist of smectite and kaolinite, with minor amounts of illite. Overall, smectite tends to predominate. But the relative proportions of smectite and kaolinite vary greatly, from almost pure smectite on one extreme, to almost pure kaolinite on the other.

Table 4. Clay-Mineral Assemblages of Major Rivers and Basins Draining into the Gulf of Mexico.

Basin Category:[a] River or Basin	Size Fraction (μ)	Clay Minerals: Smectite (%)	Kaolinite (%)	Illite (%)	Chlorite (%)	Mixed-Layer (%)
Great Plains basins:						
Arkansas River basin (n = 16)[b]	<10	28.0	23.2	28.0	8.5	12.2
Red River basin (n = 16)[b]	<10	37.7	20.8	27.3	6.5	7.8
Midcontinental basin:						
Lower Mississippi basin (n = 20)[b]	<10	44.7	20.0	23.5	5.9	5.9
Lower Mississippi River (n = 68)[c]	<2	60–80	10–20	20–30	trace	trace
Appalachian Rim basins:						
Tennessee-Cumberland basin (n = 12)[b]	<10	1.3	22.8	36.7	19.0	20.3
Coastal Plain basins:						
Lower Tombigbee River (Jackson, Ala.)[d]	<2	ca. 70	ca. 30	?		
Piedmont basins:						
Lower Flint River (Bainbridge, Ga.)[e]	<2	ca. 10	ca. 90	?		
Lower Chattahoochee River (Steam Mill, Ga.)[e]	<2	ca. 25	ca. 75	?		
Apalachicola River (n = 77)[c]	<2	0–20	60–80	<5	trace	
Lower Alabama River (Claiborne, Ala.)[d]	<2	ca. 40	ca. 60	?		
Appalachian Rim-Piedmont-Coastal Plain basin:						
Mobile River (n = 5)[c]	<2	40–50	40–50	<5	trace	

[a] Based on the predominant source of riverine sediment.

[b] Percentages are basinwide averages. Data are from Potter et al. (1975:Table 2), recomputed to equal 100 percent. The Lower Mississippi basin includes samples only from the main Mississippi channel and minor tributaries south of Cairo, Illinois; samples from major tributary basins (such as Arkansas and Red Rivers) are averaged separately.

[c] Approximate composition of clays carried in the main channel (from Griffin 1962:Table1).

[d] Approximate composition of clays carried in the main channel (estimated from Griffin 1962:Figure 7).

[e] Approximate composition of clays carried in the main channel (estimated from Griffin 1962:Figure 8).

The highly kaolinitic clays tend to occur in both the stratigraphically earliest (Upper Cretaceous) and the stratigraphically latest (Oligocene through Pleistocene) sediments. Smectitic clays tend to dominate in the middle portions of the sequence (later Upper Cretaceous through Eocene). Geographically, this means that the kaolinitic clays are concentrated along the Fall Line and the Gulf Coast, with an area of mostly smectitic clays in between (see Bicker 1969; Olive et al. 1989; Szabo et al. 1988).[6]

As one might expect, alluvial clays in this province also vary greatly in composition, depending on the nature of the upstream basin (Table 4). Sediments of rivers that rise in the Piedmont (such as the Chattahoochee and the Flint) are highly kaolinitic. Sediments of rivers confined to the Coastal Plain (such as the Tombigbee) are usually dominated by smectite. And rivers (such as the Mobile) that are fed by both Piedmont and Coastal Plain tributaries tend to carry kaolinite and smectite in roughly equal proportions.[7]

Atlantic Province

This unit represents the Upper Cretaceous and later Coastal Plain sediments between the Piedmont and the Atlantic shore (Kinney 1966). Geologically, it is the northeastward extension of the Eastern Gulf province just described, and mineralogically they have much in common. Clays in the ancient coastal deposits are mostly smectite, although some are rich in kaolinite and most contain minor quantities of illite; chlorite is virtually absent. As in the Eastern Gulf province, kaolinitic clays are most common in the oldest and youngest sediments of this unit, along the Fall Line and Atlantic Coast, respectively (Olive et al. 1989). Alluvial clays of rivers that rise in the Piedmont are mostly kaolinite, while those of Coastal Plain rivers are richer in smectite (Hathaway 1972; Neiheisel and Weaver 1967; Pevear 1972; Windom et al. 1971).

Table 5. Distribution of Chemical Groups by Clay-Mineral Province.

Province:	Chemical Group					
Region	Western	Northern	Eastern	Southern	Ungrouped	Total
Ouachita-Ozark:						
Spiro	3	0	0	0	6	9
Western Gulf:						
Little Rock	10	0	0	0	0	10
Great Bend	10	0	0	0	0	10
Natchitoches	3	0	0	0	0	3
Big Lake	9	0	0	0	1	10
Pecan Point	9	0	0	0	0	9
Lower Yazoo	10	0	0	0	0	10
Appalachian Rim:						
Nashville	0	11	0	0	0	11
Lower Harpeth	0	7	0	0	3	10
Sevierville	0	8	0	0	2	10
Tellico	0	10	0	0	0	10
Wheeler Lake	0	0	0	4	5	9
Piedmont:						
Carters Lake	0	0	6	0	4	10
Eastern Gulf:						
Natchez	2	0	0	0	8	10
Eufaula	0	0	9	0	1	10
Fort Gaines	0	0	8	0	2	10
Gainesville Lake	0	0	0	2	2	4
Black Warrior	0	0	0	0	10	10
Wetumpka	0	0	0	1	9	10
Mobile Delta	0	0	0	7	2	9
Mobile Bay	0	0	0	1	1	2
Totals	56	36	23	15	56	186

Discussion

When the geographical distribution of our chemical groups (Figure 4, Table 5) is compared to the clay-mineral provinces just described (Figure 5), some very straightforward correlations are apparent.

The Western group contains virtually all the sherds from the Western Gulf province, an area that is dominated by smectite and illite. Only five sherds are from elsewhere. The three Spiro-region specimens come from the Ouachita-Ozark province. Although this province as a whole generally lacks smectite, the alluvial clays of the central Arkansas Valley—where the sherds were found—are smectite-rich, much like the Western Gulf clays (Table 4). Two other specimens come from the Natchez Bluffs, at the extreme western edge of the Eastern Gulf province. The site where both sherds were excavated (Emerald Mound) is only 12 km from the Mississippi flood plain, and so we may reasonably assume that these sherds were made of Mississippi Valley (i.e., Western Gulf) clays. In short, our Western group seems to reflect the smectite-illite association that is so characteristic of the Mississippi River and its western tributaries.

This interpretation is strengthened when we look at the relative abundances of elements that are closely associated with these minerals. Smectite is distinctive among the clay minerals in containing substantial quantities of sodium; illite, on the other hand, is the only clay mineral that contains large amounts of potassium (Grim 1968; Millot 1970; Rice 1987; Weaver 1989). As one would expect with smectite-illite clays, Western sherds have the highest concentrations of sodium (Figure 6) and the second-highest concentrations of potassium (Figure 7) among the four groups.

The Northern group includes only sherds from the northern half of the Appalachian Rim, an area

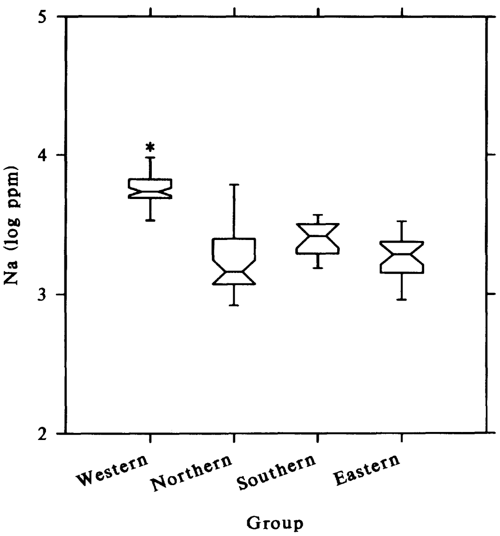

Figure 6. Box plot showing concentrations of sodium (Na) in sherds of the four chemical groups. Notches represent 90 percent confidence intervals around the medians.

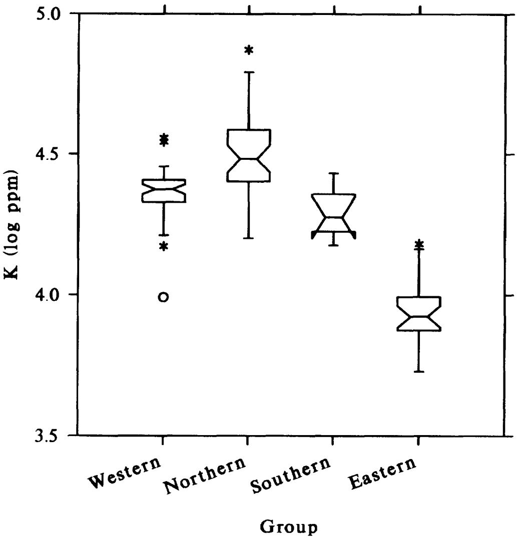

Figure 7. Box plot showing concentrations of potassium (K) in sherds of the four chemical groups. Notches represent 90 percent confidence intervals around the medians.

dominated by illite and with virtually no smectite. Not surprisingly, these sherds exhibit the highest concentrations of potassium and low concentrations of sodium (Figures 6 and 7).

The Eastern group contains sherds from sites either on the Piedmont or along rivers in the Eastern Gulf province that carry mostly Piedmont-derived sediments. The clays in these regions should consist largely of kaolinite, with little or no smectite and illite. Again, this conclusion is borne out by the elements: Eastern sherds exhibit very low values of both sodium and potassium (Figures 6 and 7).

Finally, the Southern group includes four sherds from the southern half of the Appalachian Rim province and 11 sherds from the Eastern Gulf province, which all come from either the geologically oldest (Upper Cretaceous) or the youngest (Miocene-Pleistocene) sections of the Coastal Plain. These are the areas of their respective provinces that have the greatest abundance of kaolinitic clays. Thus, the Southern group probably represents a particular mixture of kaolinite, illite, and smectite (in that order), a combination known to occur in both provinces. The elemental concentrations are consistent with this notion in that the Southern sherds exhibit moderate concentrations of potassium and low (but not the lowest) concentrations of sodium, suggesting a moderate and low abundance of illite and smectite, respectively (Figures 6 and 7).

In light of these patterns, it is instructive to look again at the results of the principal component's analysis presented earlier (Table 2, Figures 2 and 3). Note that potassium (associated with illite) has the highest coefficient on the first principal component and that sodium (associated with smectite) has the highest coefficient on the second component (Table 2). Thus, the scatter plot of the first two principal components (which together account for nearly 60 percent of the total variance) essentially summarizes the compositional relationships just discussed (Figure 2). The Western group, rich in both smectite and illite, scores high on both components. The Northern group, rich in illite but lacking smectite, scores high on the first component but low on the second. The Eastern group, highly kaolinitic but deficient in illite and smectite, scores low on both components. And the Southern group, principally a kaolinite-illite mixture with some smectite, has middling scores on the first component and low scores on the second component.

It is also worth noting that a bivariate plot of the elements sodium and potassium, corrected for shell dilution and log-transformed, separates the

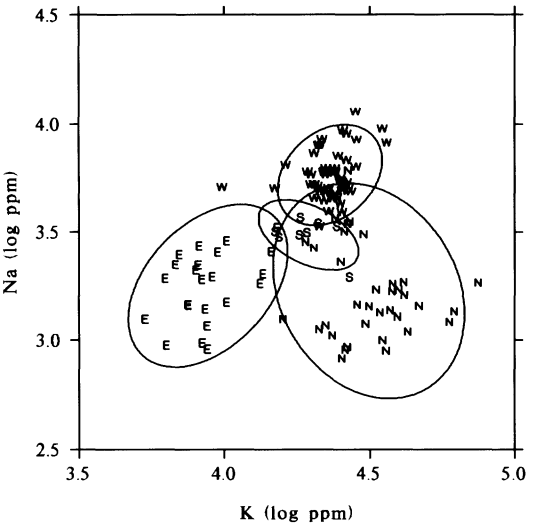

Figure 8. Scatter plot of sodium (Na) versus potassium (K) in sherds of the four chemical groups. Concentrations are corrected for shell dilution and $\log_{10}$-transformed. Boundary ellipses are drawn at the 90 percent level. N, Northern group; E, Eastern group; S, Southern group; W, Western group.

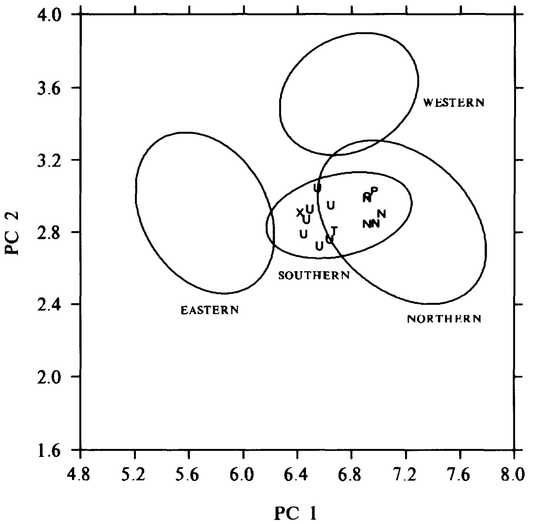

Figure 9. Second principal component plotted against the first, showing sherds of the Southern group superimposed on the boundary ellipses of the four chemical groups. Ellipses are drawn at the 90 percent level. N, Wheeler Lake region; P, Gainesville Lake region; T, Wetumpka region; U, Mobile Delta region; X, Mobile Bay region.

four compositional groups almost as well as do the first two principal components (Figure 8).

Problems and Prospects

Now that we have explained the basic pattern, let us consider in more detail some of the problems and anomalies that remain to be solved by future research.

First, it is important to realize that, with additional work, all of our geographical groups may well be subdivided into finer units. Each of our current groups shows internal patterning that suggests the existence of chemical subgroups. Such patterning is particularly evident in the Southern group (Figure 9). Note that the sherds from the Mobile Delta and Mobile Bay all cluster on the left side of the ellipse, while the sherds from Wheeler Lake all cluster on the right. With larger samples (as discussed below), we will almost certainly be able to differentiate these clusters statistically. Interestingly, the Wheeler Lake cluster falls at the end of the ellipse that is closest to the Northern group—certainly no coincidence given that Wheeler Lake lies within the Appalachian Rim province.

We must also consider the sherds that have remained ungrouped in our current analysis. Most of these sherds come from sites in the Eastern Gulf province (Table 5)—a clear reflection of the mineralogical variability that exists in this area. Our statistical procedures require that the number of members in a group be somewhat greater than the number of variables used in calculating similarity (in this case, the eight principal components). The fact that we typically sampled only 10 sherds per region made it practically impossible to find groups confined to a single region, which might well be necessary in areas that are mineralogically diverse. Thus, defining additional groups will involve not only investigating more regions but also activating a larger sample of sherds from each. With such additional sampling, we are confident that the many ungrouped sherds from the Natchez, Black Warrior, and Wetumpka regions will eventually fall into new groups that better reflect the characteristics of local clays.[8]

A similar sampling problem almost certainly accounts for the prevalence of ungrouped sherds in the Spiro region, located in the Ouachita-Ozark province (Table 5). Of the nine sherds we activated, three fell into the Western group and six were left ungrouped. As we suggested earlier, the Western-group sherds were probably made from Arkansas River clays (which are rich in smectite), while the

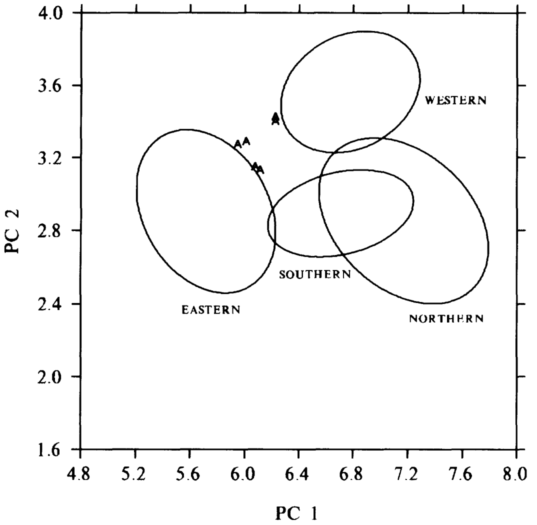

Figure 10. Second principal component plotted against the first, showing ungrouped sherds from the Spiro region superimposed on the boundary ellipses of the four chemical groups. Ellipses are drawn at the 90 percent level.

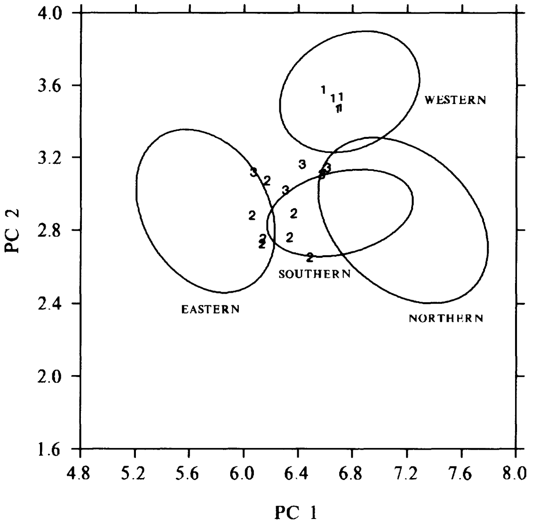

Figure 11. Second principal component plotted against the first, showing Plaquemine-style sherds found at Moundville superimposed on the boundary ellipses of the four chemical groups. Ellipses are drawn at the 90 percent level. 1, first Plaquemine group; 2, second Plaquemine group; 3, third Plaquemine group.

ungrouped sherds were probably made from residual or tributary-stream clays (which are likely to be the kaolinite-illite mixtures more typical of this province). Most of the ungrouped sherds from Spiro are chemically similar to the Eastern group (Figure 10), which suggests a kaolinitic composition. Yet, with only six sherds, our method precludes isolating this source statistically.

Finally, in order to show how these baseline data can be useful in delineating ancient trade, let us consider an example from ongoing research on the composition of sherds from the Moundville site in the Black Warrior region.[9] Among the Moundville sherds analyzed in this study were a number that stylistically appeared to be imports from the Plaquemine culture, sites of which occur in the Lower Mississippi Valley and the adjacent hills of southwestern Mississippi (including the Natchez Bluffs). Compositionally, these sherds fell into three clusters, all of which were different from the local Moundville clays. When these clusters are plotted in the space containing our previously defined groups (Figure 11), an interesting pattern emerges. One cluster (denoted by the number 1) falls squarely within the Western group and is chemically indistinguishable from it. The two other clusters (marked by the numbers 2 and 3) fall in the general vicinity of the three easterly groups but cannot be assigned comfortably to any of them. Clearly, the first cluster originated in the Mississippi alluvial valley, whereas the other two clusters probably come from the hills east of the valley. The latter interpretation is strengthened when we project the eight ungrouped sherds from the Natchez region on the same set of axes (Figure 12). These Natchez sherds—which we believe come from the same hills—fall in the same general area of the graph as the non-Western clusters from Moundville. In other words, we have taken a group of stylistically similar trade sherds and have shown chemically that (1) they are not local to Moundville, and (2) they come from at least two different sources. Most importantly, by using the compositional reference groups defined in this paper, we have been able to make some general inferences as to where these sources were located.

In sum, much more work can and must be done to refine our understanding of the large-scale patterns of chemical variation in the clays used by Mississippian potters. But the validity of the approach is now beyond question, and, as this sort

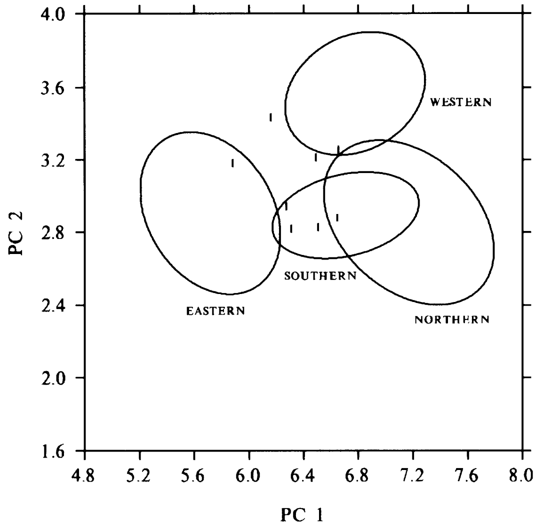

Figure 12. Second principal component plotted against the first, showing ungrouped sherds from the Natchez region superimposed on the boundary ellipses of the four chemical groups. Ellipses are drawn at the 90 percent level.

of work proceeds, it promises to shed considerable light on the patterns of ancient trade and interaction in the Southeast.

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Notes

1. The elemental data on our sample of 186 sherds may be obtained from the authors and currently resides on the World Wide Web at:

http://www.missouri.edu/~murrwww/archdata.html.

2. Although we believe that this assumption provides a reasonable approximation for our shell-tempered sherds, it should be noted that calcium carbonate sometimes occurs as a natural inclusion in clays. To the extent that such "natural" calcium carbonate is present in a specimen, our formula will tend to overcorrect for the dilution caused by the temper, making the estimated concentrations of the other elements somewhat higher than they should be.

3. Cogswell et al. (1993) show that, in addition to calcium and strontium, shell temper also contains minor amounts of sodium, which could conceivably act as a "contaminant" when one is trying to determine the chemical composition of the original clay. In this case, there are compelling reasons to believe that such contamination, even if present, was so small as to have no effect on our interpretations. Note that,

whereas calcium and strontium are positively correlated ($r = .74$) in our sherds, calcium and sodium are negatively correlated ($r = -.28$). Moreover, about one-half of the sherds in our Western group, which has the highest sodium values, contain no shell temper at all. Thus, there can be little doubt that most of the variance in sodium is due to differences in clay rather than temper.

4. Other, less important clay minerals that occur in the Southeast are halloysite, gibbsite, and dioctahedral vermiculite. The last is usually produced as a weathering product in soils; unlike the other two, it can also be a constituent of mixed-layer clays (Millot 1970).

5. The relationship between geological age and clay-mineral composition in the Appalachian Rim province is probably not coincidence. Weaver (1967) has noted a global pattern of change in the composition of shales, which occurs stratigraphically at the Lower Mississippian—Upper Mississippian boundary. Shales that predate this boundary contain mostly illite and very little smectite; in contrast, shales that postdate this boundary contain substantially less illite and correspondingly more smectite. Most of the rocks in the Tennessee portion of this province predate Weaver's boundary; most of the rocks in the Alabama portion postdate it (Szabo et al. 1988; Hardeman et al. 1966). Weaver attributes this change to the extensive development of terrestrial plant life during the Late Paleozoic.

6. It is worth noting that not all of the authors we cite have mapped clays in the Eastern Gulf consistently. For example, Neiheisel and Weaver (1967:Figure 1) show this area as being dominated by smectite, whereas Griffin (1962:Figure 2) shows it as being dominated by kaolinite. This apparent contradiction perhaps can be explained in part by differences in what was being mapped and where samples were obtained. Neiheisel and Weaver depicted the distribution of all clays "available for erosion and transport," a category that included both soils and subsoil sediments "from the surface to the base level of the streams" (1967:1085). From either a lack of information or a desire to generalize, they did not depict the presence of substantial kaolinite deposits along the Gulf Coast. Griffin, on the other hand, was concerned only with soil clays. Because weathering alters smectite to kaolinite, soils tend to be enriched in the latter. Also, many of Griffin's samples seem to fall along the Alabama River, which (because of its sources) is highly kaolinitic (Table 4).

7. Some rivers with Coastal Plain basins, such as the Pearl, do carry considerable amounts of kaolinite (Griffin 1962:Table 4). This occurs in cases in which the river drains considerable areas of kaolinite-rich sediment (e.g., the Oligocene and later formations of southern Mississippi and Alabama).

8. A recent study (Neff et al. 1991) has shown that the Black Warrior clays are indeed chemically distinctive. By activating additional samples, we have been able statistically to isolate a coherent "Moundville group," which is chemically similar, but not identical, to the Southern group discussed here.

9. This research, a continuation of that reported by Neff et al. (1991), is currently being carried on by V. Steponaitis, H. Neff, P. D. Welch, and M. D. Glascock.

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