A GRAPH-THEORETIC APPROACH TO THE EVOLUTION OF CAHOKIA

Peter Peregrine

Many researchers have linked the evolution of the prehistoric center Cahokia to its location near the confluence of the Mississippi, Missouri, and Illinois rivers. It is possible to evaluate this idea mathematically through the graph-theoretic concept of centrality. The analysis suggests that Cahokia was located at the point of highest centrality in the Mississippi River drainage.

Según algunos investigadores, la evolución del centro prehistórico de Cahokia fue el resultado de su localización cerca de la confluencia de los ríos Misisipi, Misuri, e Ilinois. Es posible evaluar esta teoría matemáticamente, por medio del concepto de centralidad, derivado de la "teoria gráfica." El análisis indica que Cahokia está situada en la posición de más centralidad dentro del drenaje del Río Misisipi.

The prehistoric site of Cahokia was located near the confluence of the Missouri and Mississippi rivers in what is today East St. Louis, Illinois (Figure 1). During the Stirling (A.D. 1050–1150) and Moorehead (A.D. 1150–1250) phases of occupation, Cahokia became a major center for Mississippian populations in the American midcontinent region (Fowler 1974, 1978; Fowler and Hall 1978). The question of why Cahokia evolved into a major center has long been of interest to American archaeologists (Ford 1974:405–407; Fowler 1974:8–14, 1977). Certainly the availability of rich alluvial soils, able to support intensive maize horticulture, had great influence on the population's ability to support political centralization (Fowler 1974:3, 33–34; also see Peebles 1978; Ward 1965). Riverine and forest resources in the area surrounding the site also must have been vital to the Cahokian's ability to intensify (Bareis and Porter 1984; Fowler 1974:3, 1978:457–460). But the presence of an ample environmental setting does not alone explain Cahokia's emergence (Smith 1978:478–488, 496).

INTERREGIONAL EXCHANGE AND THE EVOLUTION OF CAHOKIA

The position taken by some to explain the evolution of Cahokia is to hypothesize that the site served as a center for interregional exchange (the term exchange is used throughout the paper to refer to the movement of goods between individuals or groups of individuals, and is not meant to preclude the presence of trade, marketing, tribute, or the like). The specific hypothesis to be evaluated in this paper is that Cahokia's evolution was fostered by its advantageous location at the confluence of several major rivers. This location would have allowed Cahokia's inhabitants to manipulate the exchange of goods along the Missouri River to the west, the Illinois River to the north and (through the Great Lakes) to the east, and the Mississippi River to the north and south (Fowler 1974; Hasenstab 1987; Kelly 1980:231).

Interregional exchange flourished during the Mississippian period. Mississippian sites commonly contain a diversity of exchanged materials from widely disparate sources, such as obsidian from the Rocky Mountains, copper from Lake Superior, and shell from the Gulf of Mexico (Griffin 1967: 189–190; Muller 1978:307–322; Steponaitis 1986:391–393; also see Brose et al. 1985). Artistic styles and decorative motifs also were exchanged among Mississippian communities, culminating in a group of pan-Mississippian designs that have come to be known as the "Southern Cult" (Waring and Holder 1945; cf. Brown 1976). It seems likely that much of this exchange was conducted along

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American Antiquity, 56(1), 1991, pp. 66–75.

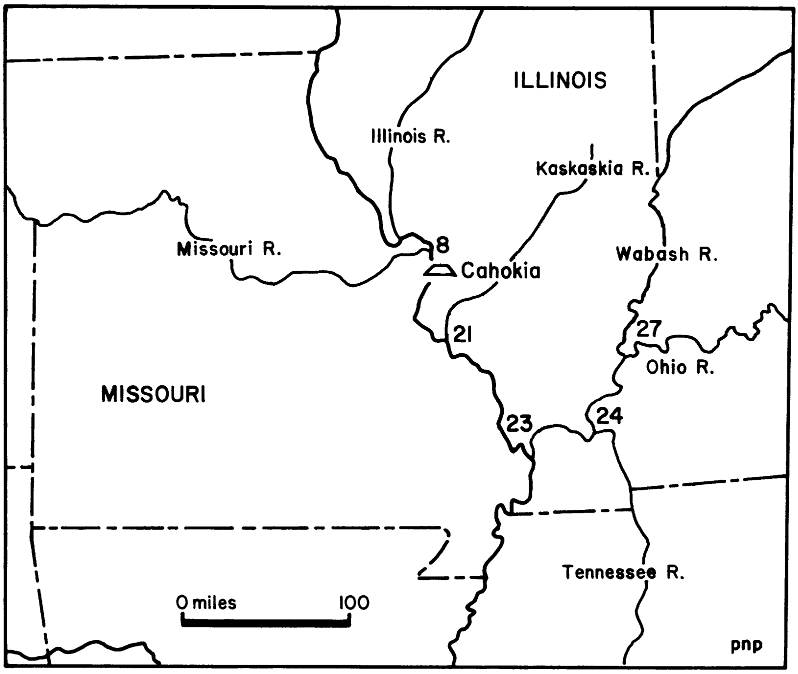

Figure 1. The Central Mississippi Valley showing the location of Cahokia and neighboring points used in the graph analyses.

the major rivers of the Mississippi drainage, particularly in the northern range of Mississippian societies (Lafferty 1977:53, 171–183; Little 1987; Wright 1967).

A variety of economic systems have been hypothesized to explain why Cahokia as an exchange center would have become a major population and political center for Mississippian societies in the midcontinent. Among these are chiefly redistribution and tribute systems (Chmurny 1973; Fowler 1974, 1977; Lafferty 1977), market (or market-like) systems (Hasenstab 1987; Kelly 1980; Porter 1974, 1977), and prestige-good systems (Peregrine 1990; Welch 1986). Regardless of which economic system is hypothesized to have been operating (and regardless of the nature of the goods being exchanged), if controlling the movement of goods through the Mississippi River drainage was an important element in Cahokia's evolution, then the site should have evolved where such control was facilitated. In short, Cahokia should be located where riverine exchange could be controlled most readily.

A GRAPH-THEORETIC APPROACH TO CAHOKIA'S EVOLUTION

An effective way to define this type of control point in an exchange network is through the graph-theoretic concept of centrality. A graph is simply a two-dimensional structure consisting of spatially distinct points joined by lines (Hage and Harary 1983:3). The Mississippi River drainage can be portrayed readily as a graph, using points to represent river heads and junctions and lines to represent the rivers themselves (Haggett and Chorley 1969). Point centrality has been defined in three ways: (1) as that point in the graph with the highest *degree* (i.e., the highest number of lines adjacent to it); (2) as that point that falls on the most paths *between* other points; and (3) as that point that is maximally *close* to all other points (Freeman 1979:219; Hage and Harary 1983:30–39). Whichever definition is chosen, centrality has been linked to the ability to control the flow of goods and information in exchange networks (Cook et al. 1983:281; Markovsky et al. 1988:220–221), and it is precisely this type of control that needs to be demonstrated for Cahokia's location in order to evaluate this paper's hypothesis.

Table 1. Rivers Graphed in Figures 2 and 3.

Points	River
1–45	Mississippi
2–3	Minnesota
4–5	Wisconsin
6–7	Des Moines
8–9	Illinois
8–20	Missouri
10–11	Kansas
11–12	Republican
11–13	Smoky Hill
14–15	Platte
15–16	South Fork (Platte)
15–17	North Fork (Platte)
18–19	Yellowstone
21–22	Kaskaskia
23–33	Ohio
24–25	Tennessee
24–26	Cumberland
27–28	Wabash
29–30	Kentucky
31–32	Scioto
33–34	Allegheny
33–35	Monongahela
36–41	Arkansas
37–38	Canadian
39–40	Cimarron
42–43	Ouachita
42–44	Red

As Freeman (1979:221, 224, 226) explains, each definition of centrality can be thought of as focusing on a different control property for a given point. The degree of a point can be used as an index of its potential communication activity. Betweenness can be used as an index of the potential of a point to control communication. Closeness can be used as an index of a point's independence or efficiency. Each of these factors would be related to the ability to control goods flowing through a particular location. Therefore, each measure should have some meaning for Cahokia's evolution if its evolution was fostered by the ability to control riverine exchange.

Previous Graph-Theoretic Settlement Studies

Another reason for employing centrality measures to test this paper's hypothesis is that they have been used successfully in similar applications. Irwin-Williams (1977:148–149) offered a brief discussion of various graph-theoretic measures that could be used to analyze prehistoric exchange, and explained that "It may readily be seen that elements of the network [graph-theoretic] approach . . . will provide information on a variety of specific [archaeological] questions." In particular, she described how measures like centrality could be used to explore the effect exchange may have had on prehistoric settlement in the Puerco River region of northwestern New Mexico (Irwin-Williams 1977:149–150; also see Irwin [1978] for a similar application to prehistoric settlement in coastal Papua New Guinea).

In two influential articles, Pitts (1965, 1979) considered the location of Moscow in terms of its ability to control riverine trade. In the first article, Pitts (1965) used a rather complex measure of betweenness and a simple measure of closeness to see how Moscow's "connectivity" (an unfortunate term, as connectivity relates to a measure of graph structure, not point location—what Pitts meant was centrality) related to its importance in the twelfth- and thirteenth-century Russian exchange network. He found a reasonably high correlation (Pitts 1965:19). In the second article, prompted by some valid criticism of the first, Pitts (1979) used two different betweenness measures and a

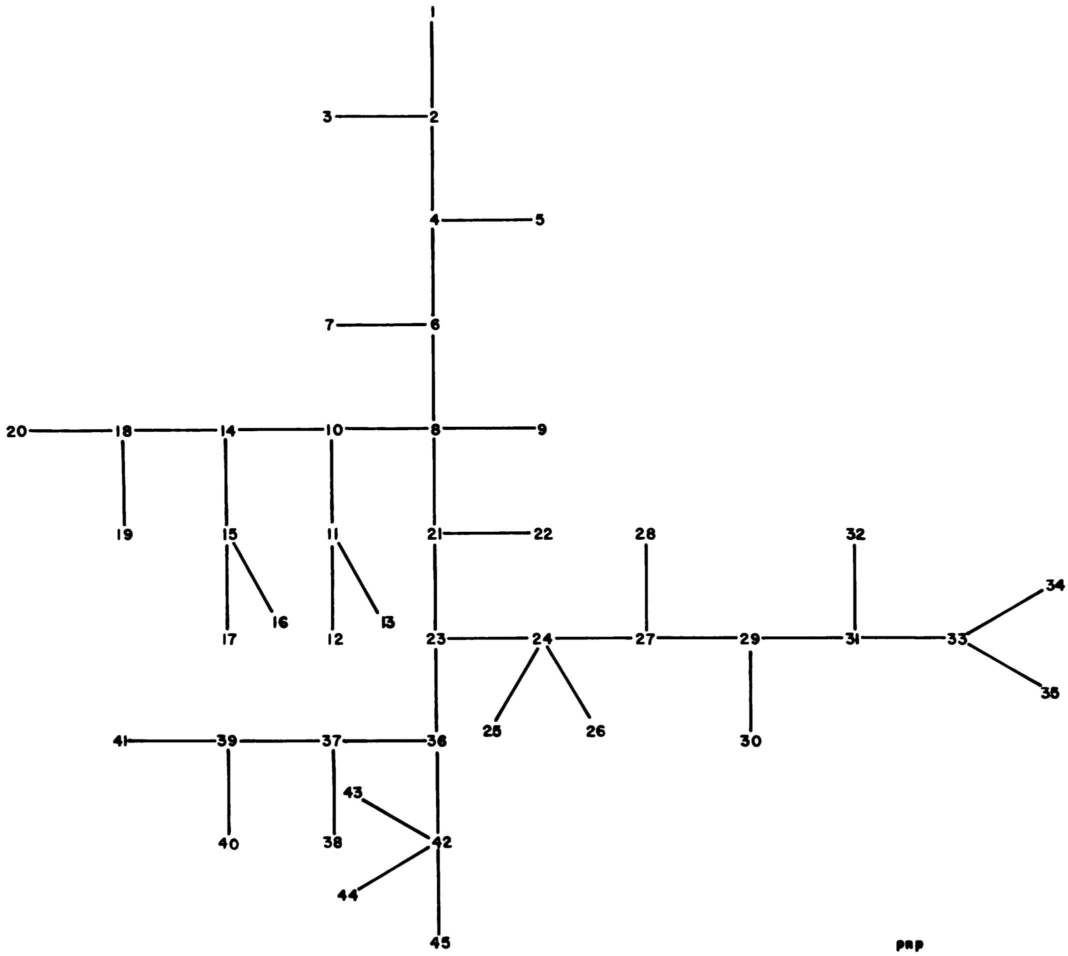

Figure 2. Graph of the Mississippi River system.

measure of closeness to look again at Moscow's centrality in the medieval river-trade network. By plotting the percentage of aggregate short-path distances (closeness) against the percentage of intermediate node occurrence (betweenness), Pitts (1979:291) effectively showed Moscow's strong centrality in the system.

Finally, Rothman (1987) employed graph-theoretic concepts in a discussion of the interpretation of data from regional archaeological surveys. Rothman (1987) argued that graph theory is particularly useful for archaeological analyses because (1) concepts have precise definitions, (2) quantitative features of empirical structures can be calculated readily, and (3) the structure of an observed system can be verified or disconfirmed through logically derived axioms and theorems (also see Hage and Harary 1983:9). In addition, Rothman (1987:75) explained that graph theory is broadly applicable in terms of its potential subjects and is therefore a powerful tool for analyzing a wide range of archaeological questions. Rothman went on to illustrate the utility of graph-theoretic analyses in regional archaeology with survey data from the Susiana Plain.

ANALYSES AND RESULTS

The graph used in the analyses that follow is shown in Figure 2, and a list of the rivers is given in Table 1 (defined by their source and termination points on the graph). Of course, the choice of

Table 2. Point Scores on Five Measures of Centrality.

Point	Scores				
	RB[a]	RC[b]	RD[c]	GC[d]	GD[e]
01	0	137	23	51	6
02	90	158	68	65	74
03	0	137	23	54	8
04	172	184	68	75	74
05	0	156	23	57	6
06	246	216	68	87	70
07	0	178	23	61	4
08	603	254	91	101	197
09	0	204	23	78	8
10	382	224	68	78	91
11	90	187	68	75	62
12	0	158	23	59	6
13	0	158	23	53	4
14	251	194	68	80	64
15	90	165	68	65	51
16	0	142	23	50	6
17	0	142	23	46	4
18	90	165	68	47	23
19	0	142	23	36	3
20	0	142	23	31	2
21	532	262	68	100	170
22	0	209	23	83	11
23	638	263	68	101	153
24	404	234	91	100	208
25	0	190	23	60	3
26	0	190	23	60	3
27	312	205	68	89	104
28	0	171	23	67	4
29	246	179	68	76	80
30	0	152	23	62	8
31	172	157	68	68	91
32	0	136	23	60	11
33	90	138	68	58	114
34	0	121	23	49	8
35	0	121	23	54	23
36	354	229	68	81	57
37	172	194	68	68	98
38	0	163	23	43	2
39	90	165	68	70	92
40	0	142	23	53	6
41	0	142	23	21	2
42	133	192	91	64	75
43	0	162	23	70	4
44	0	162	23	35	2
45	0	162	23	54	8

Note: Scores have been standardized to integer values by multiplying them by 1,000 and rounding off remaining decimals.
[a] Relative betweenness.
[b] Relative closeness.
[c] Relative degree.
[d] Geographic closeness.
[e] Geographic degree.

rivers that make up this graph could be influential to the outcome of the analyses. All rivers that are part of the Mississippi drainage could not be included, or the analyses would become enormously complex. A simple cutoff by stream order, size, or the like would not be very effective either, as some second-order and small streams are important as transportation routes. I decided to simply

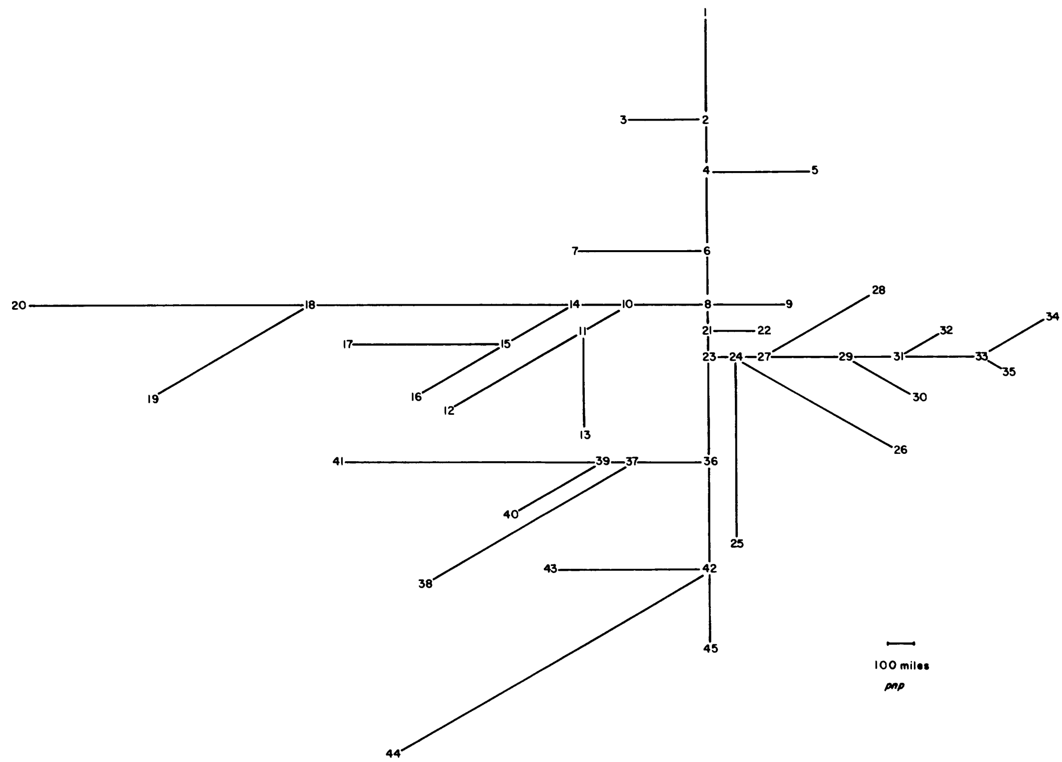

Figure 3. Geographic graph of the Mississippi River system.

use the rivers shown on the inset maps of Part I of the *National Water Summary 1985* (United States Geological Survey 1985). These are the rivers that the United States Geological Survey has identified as the major elements of the Mississippi drainage.

Table 2 shows the rating of each point in Figure 2 on five measures of centrality (standardized to an integer value). The first three measures are relative betweenness (betweenness/n − 1 where n is the number of points in the graph), relative closeness (closeness/n − 1, with closeness being an inverse value), and relative degree (degree/n − 1) all generated by the CENTRALITY procedure in the UCINET GRAPH 3.0 software package (MacEvoy and Freeman 1987).

The last two measures of centrality in Table 2 were created by the author in order to bring some "real-world" conditions into the graph analysis. The first of these is called *geographic closeness.* It is simply the inverse row sum of a distance (geodesic) matrix derived from the graph, but with the distances (geodesics) being measured by the geographic distance between points rather than the number of lines linking them (steps). A graph based upon geographic distances between points is given as Figure 3. The values of geographic closeness presented in Table 2 are relative measures (geographic closeness/n − 1). The final measure of centrality is called *geographic degree.* This measure is created by weighting each line incident upon a point by the inverse of its length, summing these weights, and multiplying by the degree of the point:

$$(\text{geographic degree})_P = \left(\sum (1/L)\right) \times D \qquad (1)$$

where L equals the length of a path incident on point P and D equals the degree of point P. The multiplier D is used simply to make the range of possible values greater. Lines incident on point P that are long under equation (1) are given less weight than lines that are short. Since degree is a measure of communication activity, it makes sense that if a point is far away the potential to communicate with it is lower than if the point were closer. Geographic degree is simply an expression

Table 3. Ranking of Points by Centrality.

Point	Total
8	1,246
23	1,196
21	1,132
24	1,037
10	848
36	789
27	778
6	687
29	649
14	657
37	600
4	573
31	556
42	555
39	485
11	482
33	468
2	455
15	439
18	393
22	326
9	313
25	276
26	276
7	266
28	265
43	259
45	247
12	246
30	245
5	242
13	238
32	230
40	224
3	222
44	222
16	221
35	221
1	217
17	215
41	208
19	204
38	204
34	201
20	198

of this idea, giving greater weight to communication potential with points that are closer than those that are more distant. For example, the degree of points 18 and 21 are both 3, but the geographic degree of point 18 is 1 because it is relatively distant from its adjacent points, while the geographic degree of point 21 is 7.5 because it is relatively close to its adjacent points. Again, this measure is presented in Table 2 as a relative one (geographic degree/n − 1).

It is interesting to note that the correlation between closeness and geographic closeness for this graph is .856, and the correlation for degree and geographic degree is .868 (computed from a regression analysis using the PLOT procedure in SPSSX [SPSS, Inc. 1988]). These strong correlations suggest that it is not necessary to take "real-world" conditions into account when measuring centrality in this graph. Weighting these measures by distance created very little variation in the outcome of the analyses. Whether this is true with other graphs is beyond the scope of this paper, but similar correlations should not be surprising if one remembers that these are measures of basic graph structure, and although geographic weighting may change various elements of the graph, the graph as a whole and as a structure will not change dramatically (compare Figures 2 and 3).

Table 3 presents the points of the graph in Figure 2 ranked in order of their summed scores on the five measures of centrality. Point 8, the site where Cahokia is located, ranks first by a good margin. Cahokia apparently is located at the point of highest centrality in the Mississippi River drainage. This, of course, supports the hypothesis that Cahokia evolved in a location where riverine exchange could be controlled readily.

CONCLUSIONS

Cahokia was located at the point of highest centrality in the Mississippi River drainage. Although others have suggested this based upon their intuitive understanding of the site's location (Fowler 1974; Kelly 1980), by using the analytical tools of graph theory this study has been able to demonstrate Cahokia's centrality objectively and empirically. This is a significant accomplishment because it may lead to a better understanding of why this major Mississippian center evolved. Certainly the plentiful natural resources of the American Bottom region allowed Cahokia's inhabitants to both live in a large sedentary community and to support craft specialists and political personnel. But perhaps more importantly, Cahokia's centrality in the Mississippi River system meant that goods moving across the midcontinent by riverine transport had to pass through Cahokia in most cases. This would have allowed Cahokia's inhabitants the potential to exercise some control over riverine exchange in the Mississippi Basin. Regardless of the theoretical perspective used to understand Cahokia's function within Mississippian societies, the potential to control riverine exchange from its advantageous location may have been a vital element in the evolution of this major prehistoric center.

Acknowledgments. Research presented here was partially supported by a David Ross Grant from the Purdue Research Foundation. Computer facilities were provided by the Purdue University Computing Center and the Social Research Institute. Computer time was supported by the President's Fund for Computing. The author wishes to thank Richard Blanton, Robert Fry, Criss Helmkamp, Leonard Lipshitz, George Milner, and Bruce Smith for their comments, suggestions, and criticisms. Any omissions or errors remain my own.

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Received September 11, 1989; accepted July 10, 1990

A MULTIDIMENSIONAL INVESTIGATION OF BIOCULTURAL RELATIONSHIPS AMONG THREE LATE PREHISTORIC SOCIETIES IN TENNESSEE

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Interrelations among three roughly contemporaneous late prehistoric Mississippian societies in Middle and East Tennessee are reexamined in terms of currently available biological, archaeological, and ethnohistoric data. Previous researchers have suggested a close relation between two of those cultures—Mouse Creek and Middle Cumberland—to the exclusion of the third, Dallas. However, multivariate analyses of craniofacial and mandibular dimensions of individuals from the three groups suggest a greater biological relation between Dallas and Mouse Creek than between Mouse Creek and Middle Cumberland. In addition, a comparison of intrasite settlement patterning, ceramic and mortuary variability, and ethnohistoric data across the three groups support the skeletal analysis. Relations between Dallas and Mouse Creek may mirror similar processes of sociopolitical reorganization occurring throughout the Southeast in the late prehistoric period.

Las interrelaciones que existieron entre tres sociedades Mississippian *aproximadamente contemporáneas del periodo prehistórico tardío en el centro y el este de Tennessee se reexaminarán aquí a partir de datos biológicos, arqueológicos, y etnohistóricos disponibles actualmente. Investigadores previos han sugerido que existía una relación muy cercana entre dos de estas culturas—las de Mouse Creek y Middle Cumberland—sin contar la tercera cultura, llamada Dallas. Sin embargo, un análisis multivariable de las dimensiones del cráneo, la cara, y la mandíbula de los restos de esqueletos de individuos de estos tres grupos indica una relación biológica significativa entre Dallas y Mouse Creek y ninguna relación entre Mouse Creek y Middle Cumberland. Además, una comparación del patrón de asentamiento, los artefactos cerámicos, la variedad en forma de los entierros humanos, y los datos etnohistóricos de los tres grupos apoyan los resultados del análisis del esqueleto. Puede ser que las relaciones entre las culturas Dallas y Mouse Creek reflejen procesos semejantes de reorganización sociopolítica que ocurrieron a través del sudeste de los Estados Unidos durante el periodo prehistórico tardío.*

The study of late prehistoric Native American societies has been a central focus of archaeological research in the southeastern United States for over a century (e.g., Lewis and Kneberg 1946; Moore 1915; Thomas 1894). As a result of several decades of research (particularly since the 1930s), much has been learned about the late prehistoric Mississippian cultures in the Southeast (e.g., Dickens 1976; Hatch 1976; Klippel and Bass 1984; Lewis and Kneberg 1946; Moore 1986; Peebles 1974;

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American Antiquity, 56(1), 1991, pp. 75–88.