Journal of Archaeological Method and Theory, Vol. 13, No. 2, June 2006 (© 2006)
DOI: 10.1007/s10816-006-9003-3

Explaining Shell-Tempered Pottery in Prehistoric Eastern North America

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Published online: 17 June 2006

Explanations for the rise in frequency of shell-tempered pottery in the Eastern United States have vacillated between historical and functional accounts. Using evolutionary theory, the historical records of first appearance and diffusion are woven with physical properties of shell-tempered pottery that may have led to its selection. An appreciation of the scale at which change occurs and the units of analysis most appropriate for understanding that change is necessary for an explanation that can account for the widespread use of shell-tempering and the more-or-less coincident rise in its frequency. A hypothesis with empirical consequences is offered as a starting point for understanding this phenomenon.

KEY WORDS: shell-tempered pottery; evolutionary explanations; units of analysis; firing strategies; Eastern United States.

INTRODUCTION

Throughout much of Eastern North America during the Late Woodland/Early Mississippian period (ca. AD 700–1100), the frequency in use of shell-tempered pottery increased dramatically. In this essay I review some problems in understanding this phenomenon and lay the groundwork for an evolutionary explanation. Previously, I offered such an explanation for one locality, the Malden Plain in southeastern Missouri (Feathers and Scott, 1989; Feathers, 1990; Feathers *et al.*, 1998), but this explanation cannot be extrapolated to the rest of the East. The larger question involves the widespread distribution of shell-tempered pottery and its more or less coincident (within a few hundred years) rise in frequency in different places.

Interest in the problem extends at least to the 1930's when stratigraphy and seriation placed shell-tempered pottery late in chronological sequences throughout

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the East. Ford's (1936) elegant chronological work in the Lower Mississippi Valley associated shell tempering with the most recent prehistoric period. Other work in the Midwest showed shell tempering to be late there as well (Cole and Deuel, 1937; Griffin, 1938, 1939; Lewis and Kneberg, 1946). By the mid 1930s shell tempering was considered diagnostic of the Late Prehistoric period (Deuel, 1937; McKern, 1939) and served as a chronological marker for otherwise undated material. Shell-tempered pottery is found throughout the river valleys of the Midwest, along the Gulf and Mid-Atlantic seaboards and even onto the Great Plains. Only in the extreme Southeast and in the far north is shell-tempered pottery absent.

Explanations for the occurrence of shell-tempered pottery have appeared in the published record as early as Holmes (1903). These explanations tend to vacillate between historical accounts employing diffusion or migration and functional accounts stressing adaptive significance. Combinations of historical and functional accounts have also been offered. As an example of the latter, Price and Lynott (Lynott, 1986; Lynott and Price, 1989; Price, 1986) argue that shell-tempered pottery originated as an innovation in some heartland (they suggest the eastern Ozarks) and then diffused from there replacing indigenous pottery because of superior functional properties. The issue is considered here from three perspectives: (1) how the change occurred, locally and regionally; (2) why it occurred, in terms of sorting mechanisms; and (3) the scale at which the change can best be understood.

THEORETICAL BACKGROUND

An evolutionary explanation is appropriate for any system containing variation that is transmitted differentially. It involves two steps: (1) describing the system in such a way that the changes in variation can be monitored, and (2) ascribing mechanisms to account for the change (Jones *et al.*, 1995). Adjustments back and forth between the two steps are necessary to achieve a sufficient explanation.

Describing variation is not an obvious task because variation is continuous and in constant flux. Therefore classification is needed to define units that can be compared across time. Change is detected by monitoring changes in the frequency of these units (e.g., pottery types), which must hold some attributes in common (e.g., all made of fired clay) but have other attributes (e.g., temper) that vary. The classification is theoretical but must interface with empirical units (e.g., vessels) so that hypotheses about the relation among the theoretical units can be evaluated (Dunnell, 1986). Scale, as I shall stress later, is an important consideration.

In evolutionary parlance, the unit that evolves is some aggregate of lower level units called "interactors" on which sorting occurs (the term "interactor" was introduced and has been extensively discussed by philosopher of science David Hull (1980, 1989)). It is the differential persistence of interactors that describe the evolution of the higher level unit. A distinction has been made between replicators, entities of transmission, and interactors, entities that interact with the environment to cause differential replication (Hull, 1989, cf Dawkins, 1982). Selection is the intersection of the replication and interaction processes, both of which can operate at different levels. The distinction is illustrated in biology by the distinction between genes and organisms, but is less well defined in cultural evolution, although Dawkins (1982) introduced the term "meme" as a replicating unit of information analogous to the gene.

To serve as an interactor, a unit must, among other things, be able to reproduce and be functionally independent (in the sense of being able to exist on it own, as, for example, a whole body can, but an arm cannot) (Dunnell, 1995). Can pottery serve as an interactor? It appears to fail on both accounts, although the issue is complex. Pottery does not reproduce in a biological sense, yet nothing in the above definition of an interactor specifies how reproduction takes place. That reproduction, or replication (Leonard and Jones, 1987), takes place through the medium of a potter may not be critical to its ability to serve as an interactor. On the other hand, pottery, as a subject of archaeological study, is not independent of its manufacturer or user. It has no use beyond that of its users, serving in a sense as just an extension of the digestive system or some other part of human physiology. Yet it is not tied to a single individual (such as bones in the paleontological record), because more than one person can use or be involved in the manufacture of the same pot. This reflects the more fluid transmission of cultural traits as opposed to biological ones. With culture, descent with modification is not restricted to generational change. This means that pottery is not simply a surrogate for a biological interactor. What exactly the interactor is behind pottery for the case under consideration here, I defer for the moment.

In this paper I first take up shell temper itself. I then consider the distribution of shell-tempered pottery from several localities in the East, as described in the literature, to detect how the change to high frequencies of shell-tempered pottery occurred. Next I review and evaluate various mechanisms to account for the change in one locality. Finally, I consider the issue of units in somewhat more detail and suggest that the change to shell temper from a regional perspective requires examination of the phenomenon at different scales.

THE NATURE OF SHELL TEMPER

No explanation for the timing and distribution of shell-tempered pottery can proceed without first defining shell temper. Temper is a peculiar archaeological term applied to non-plastic materials in pottery that serve to reduce drying shrinkage among other functions. Early use of the term (e.g., Holmes, 1903; Squier and Davis, 1848) was as a verb. "Tempering" referred to mixing various materials in water to achieve a certain consistency. Sometime during the early part of this century, when interest shifted to the enumeration of traits, the term became a noun used to describe the non-plastic additive, as well as any naturally incurring inclusions (March, 1934). With this grammatical shift the significance of the term changed from manufacturing technique to ceramic properties. While the effect of temper, particularly shell, on ceramic properties is important, the shift separated shell temper from its manufacturing context, allowing an unwarranted assumption that it could be added or subtracted to pottery without altering other aspects of the manufacturing process.

The "shell" represents the hard exoskeleton of various invertebrates exploited prehistorically in the East (most commonly freshwater mussels). Shell is constructed of calcium carbonate bound by organic polymers. The carbonate takes either of two forms: aragonite or calcite. Often the inner layers are aragonite while outer layers are calcite (Mann, 1990). While the shells of molluscan species used for temper no doubt varied with availability from place to place, broad compositional similarity of shell suggests variation in species had little effect on ceramic properties. More important is variation in amount, size and shape of shell particles. The distinction often made, for example, between fine and coarse textured shell-tempered pottery (e.g., Teltser, 1993) probably refers to two quite different kinds of pottery that have in common only the biological origin of the temper material. How shell reacts with other constituents of the pottery also varies, so the effect on properties is a function not only of the shell itself but of the entire composition.

Perhaps the best studied property of shell is its behavior when heated. If the original structure is aragonite, this will transform to calcite when heated to about 300–400°C, insuring that almost all shell encountered in pottery is calcite. The change involves a transformation from a block-like to a plate-like lattice structure and a slight increase in volume. To preclude this expansion from occurring during firing of the pottery, to ease crushing by destroying the organic component, and to aid workability by taking advantage of the plate-like structure of calcite, the transformation was likely effected by preheat (Feathers, 1990; Million, 1975; Rice, 1987), although preheating shell was not practiced everywhere (Stephensen, 1963).

Another change occurs at about 600–800°C, depending on time and duration of firing, when calcite decomposes into calcium oxide (lime) and carbon dioxide. This has a dramatic influence on the subsequent mechanical strength of pottery. Strength increases if the decomposition is followed by subsequent recombination of lime with other materials into high temperature calcium aluminosilicates. Finer-grained shell particles facilitate this process. Strength decreases if the lime does not recombine, but rather absorbs moisture upon cooling and expands, leading to spalling or even disintegration. If pottery is not sufficiently fired to decompose the calcite, shell affects strength in other ways. The plate-like structure of calcite increases ceramic toughness, particularly if the particles are coarse and abundant (Feathers and Scott, 1989).

Since the variation in the shell temper, firing and other constituents of Eastern pottery presumably produced equally variable effects, explaining shell temper's rise in frequency during the Late Prehistoric period requires an appreciation of some universal or near-universal quality of shell. While various shell-tempered potteries represent at one scale an assortment of different kinds of containers with varied performance qualities, at another scale they must have in common some aspect that makes their widespread, temporally-constrained distribution in the East historically understandable.

THE TIMING OF DIFFUSION

Because of the spatial and temporal distribution of shell-tempering in the East, a common assumption is that it is all derived from a single source. While independent invention cannot be ruled out completely, it probably cannot account for the appearance of shell-tempering in so many places at roughly the same time during the Late Woodland. The most apparent exception is an Early to Middle Woodland appearance of shell-tempered pottery along the mid-Atlantic coast (Gleach, 1988; Phelps, 1983). This ware was cordmarked or net-impressed and gave way in the Late Woodland to shell-tempered ware that was stamped or fabric impressed, following the same trend in surface treatment as found on rock-tempered counterparts immediately inland (Phelps, 1983). Stephensen (1963) notes that shell in Middle Woodland pottery in eastern Maryland was apparently not burned prior to being mixed with the pottery and did not exhibit the plate-like characteristics of shell-tempering in the Midwest or mid-South. Rather it resembled the crushed rock of contemporary grit-tempered pottery and may have just been a substitute temper in rock-poor coastal regions. The historic relationship, if any, of these ceramics to shell-tempered ceramics west of the Appalachians has not been studied, but they likely represented separate technological traditions.

If independent invention is unlikely to account for the frequency of shell tempering throughout the rest of the eastern Woodlands, the source of the shell-tempering variant throughout this area must be from either migration or diffusion. Migration, while undoubtedly accounting for origins in some places (e.g., Blitz and Lorenz, 2002), is largely discounted by the continuities in other cultural aspects that are evident in most places. Diffusion is the most likely alternative, but the key question is timing: when did diffusion of shell tempering occur? Price and Lynott's hypothesis places the diffusion sometime after AD 600, coincident with the rise in frequency. I argue the initial diffusion and the rise in frequency were separated in time. The difference is important for understanding why the change in frequency occurred.

The following survey of occurrence of shell tempering as reported from the literature is far from exhaustive but is adequate to illustrate the difficulties in

Price and Lynott's hypothesis. First, evidence points to a much earlier appearance of shell-tempering in different areas than Late Woodland diffusion from a Central Mississippi valley heartland would suggest. Second, the nature of the shell-tempered pottery that increased in frequency at a later time reflects in many places local development, not diffusion. These points are illustrated from four regions: the Central Mississippi valley, the Mid-South, the middle Ohio and the American Bottom.

Documenting the rise of shell tempering in the East from the literature is not an easy task. Rarely is the dating of sufficient precision. Typically the pottery itself is not dated. (This can be done by luminescence and some initial work in this regard by my laboratory suggests a more complicated chronology than suspected, as I will discuss.) Rather the pottery is dated by association to general time frames established by stratigraphy or seriation and tied to a calendrical scale by dating of non-ceramic events, most commonly using radiocarbon (e.g., Steponaitis, 1983). Associations are extended typologically by cross-dating so that similar ceramics are lumped into the same time frame. Changes in the frequency of a particular class of pottery cannot be monitored with precision by this procedure, particularly if the pottery lacks distinctive features that change rapidly, as is the case during the time of interest here (AD 600–900). Beginnings are almost impossible to detect in this frame as well because occurrences outside the usual associations are labeled "intrusive" (e.g., Allsbrook, 1995).

Central Mississippi Valley

Price and Lynott identify the Central Mississippi Valley, including southeastern Missouri and northeastern Arkansas, as the heartland of shell-tempered pottery. The earliest shell-tempered pottery in this region is called the Varney tradition (Morse and Morse, 1990; Price, 1986). The pottery is coarse-textured with large shell particles and often has red slips on either or both surfaces. The tradition exhibits considerable variation in tempering and other properties, particularly to the east in the Cairo Lowland, where much of the pottery also contains grog temper (Morse and Morse, 1990) and to the west in the Ozark foothills where some ceramics have distinctive shapes (Lynott, 1986). Red slips are rare on earlier sand-tempered pottery of Southeast Missouri, but is common on earlier grog-tempered pottery in western Tennessee (Mainfort, 1996), pottery that in all respects except temper resemble the Varney pottery in southeast Missouri. (This latter pottery also differs from red-slipped grog-tempered pottery, called Larto Red, found further south.)

Rise in the frequency of shell-tempered pottery dates to the ninth century, but thermoluminescence dates for Ozark pottery suggest shell-tempered pottery appeared as early as the seventh century (Price, 1986). Morse and Morse (1990) argue shell-tempered pottery originated in the Cairo Lowland in the eighth century or earlier, particularly evident in the lowest midden deposits at Towosahgy and early deposits at Hoecake (Lafferty and Price, 1996). They document earlier pottery tempered with grog, "transitional" pottery tempered with grog and shell, and later pottery tempered with shell. Because such "transitional" pottery is lacking in other areas, they argue shell tempering must have first developed here. However, such "transitional" pottery may reflect functional differences and have nothing to do with origins. Co-occurrence of early shell-tempered and grog-tempered pottery has also been reported for eastern Arkansas, where dates of AD 500–700 have been suggested (Mulvihill, 1996), but luminescence dating (unpublished dates from my laboratory) suggests this association is not temporal. Early shell-tempering has also been reported for early deposits at Toltec, in central Arkansas (Rolingson, 1987, Nassaney, 1991).

Despite disagreement as to the specific place of origin, both Price (1986) and Morse and Morse (1990) believe the central valley to be the source of shell-tempered pottery for other regions of the East. If this were true, one might expect increasingly later dates for the introduction of shell temper as distance increases from the heartland. Some formal continuity in properties between the pottery from donor and receptor regions should also be demonstrable.

There is some support for this further south in the Mississippi Valley, where a temporal gradient appears to characterize the rise in frequency of shell-tempered pottery (Fig. 1). Shell-tempered pottery does not appear in high frequencies in sites such as Winterville and Lake George in the southern Yazoo Basin until AD 1200–1400 and in the Tensas basin of northeastern Louisiana until AD 1500 or later (Kidder, 1998). However, more than one observer sees strong ceramic continuity between earlier grog-tempered pottery of these southern regions and the later shell-tempered pottery. Kidder (1998) notes that designs carry over from grog to shell-tempered pottery in northeastern Louisiana. Ford argued early on that many shell-tempered ceramic types from the Lower Mississippi Valley are derived from grog-tempered predecessors (Phillips *et al.*, 1951: 446). Thus Mazique Incised became Barton Incised and Larto Red became Old Town Red.

Mid-South

The rise of shell-tempered pottery in the Mid-South is commonly attributed to outside influence (e.g., Jenkins and Krause, 1986: 120, Jenkins, 2003) but an alternative reading of the evidence supports a distinctive shell-tempered pottery tradition of local origins. Rise to high frequency of shell-tempered ceramics occurs in the 11th century more or less coincident with the appearance of large mound centers. Shell tempering, however, first appears at least a century earlier as a minor component of primarily grog-tempered (to the west) or limestone-tempered (to the east) Late Woodland assemblages (Faulkner, 1972; Jenkins, 1981; Schroedl

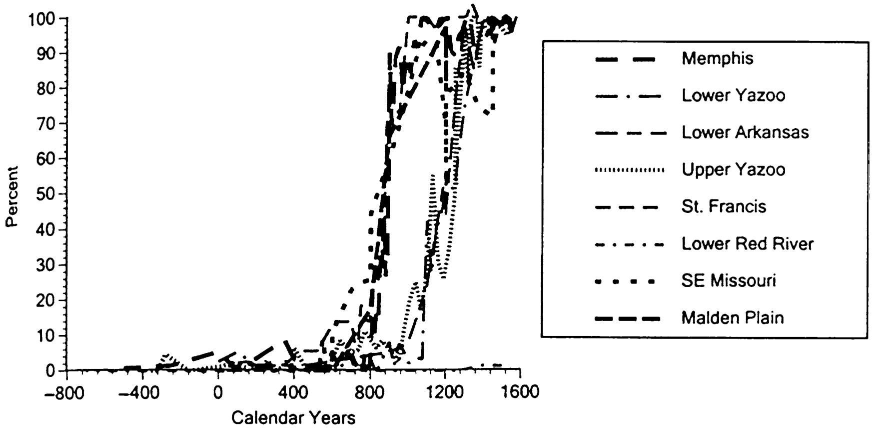


Fig. 1. Frequency of shell-tempered pottery as a function of time for various parts of the Lower Mississippi Valley, based on survey data from Phillips *et al.* (1951), Ford (1952), Feathers (1990), and various references in O'Brien and Wood (1998). The surveys cover a large portion of the valley and the assemblages are reasonably placed in time by seriation and radiocarbon dating, although the data are of variable quality and extreme outliers had to be removed. Rise in frequency occurred earliest in the northern part of the region (SE Missouir, Malden Plain, Memphis, St. Francis), somewhat later in the central region of the Yazoo and Lower Arkansas basins, and hardly at all in portions of Louisiana (Lower Red River). (This figure first appeared in Feathers *et al.*, 2003).

et al., 1990; Steponaitis, 1983). Some of these "transitional" sites date as early as AD 700 in Tennessee and one site yielded radiocarbon dates of AD 324–410. This potentially early occurrence of shell-tempered pottery has been discounted solely by the circular argument that shell-tempered pottery is supposed to date later (Faulkner, 1972).

How much temporal overlap exists between the shell-tempered and earlier pottery is subject to debate, primarily because of poor dating (Futato, 1987; Jenkins, 1982; Jenkins and Krause, 1986; Mistovich, 1988; Rafferty, 1986; Welch, 1990, 1994), but also debated is the degree of similarity between the two sets. Mistovich (1988), working in the Black Warrior drainage of west-central Alabama, argues for a gradual replacement of grog-tempered by shell-tempered ceramics and sees the main distinguishing feature between the two groups as temper. Basic shapes, surface treatments, rim modes and handle forms are common to both; and changes in handles from loop to strap design are repeated in both (Mistovich, 1988). Welch (1994) argues the similarities are overdrawn but allows for overlap and does not dispute continuity. In other areas, such as western Tennessee, Welch (1998) acknowledges the two sets of pottery are very similar in shape and decorative motif (Garland, 1992). Jenkins (2003), Seckinger and Jenkins (2000) argues that statistical analysis of radiocarbon dates shows substantial overlap (see also Jackson, 2004) but, despite standard jar forms being formed with either grog or shell temper, the restriction of some decorative features and some forms to only shell-tempered fabrics suggests to him co-habitation by two ethnic groups, an aboriginal group making grog-tempered pottery and an intrusive group making shell-tempered pottery. Aside from the difficulties of equating pottery with ethnic groups, this view treats temper as a strictly stylistic attribute with no selective value, a position that considering the properties of shell temper may be hard to defend.

Very recent luminescence dating by my laboratory suggests the relationship between limestone, grog and shell-tempered pottery in northern Alabama and central Tennessee to be quite complex, with significant temporal overlaps. Shell-tempered specimens found at West Jefferson sites in central Alabama may date as early as A.D. 200 and an A.D. 600 date has been obtained for a shell-tempered specimen from the mound at Shiloh National Historic Park.

In other parts of the Mid-South, evidence for an intrusion of migrants who brought shell-tempered pottery with them is stronger. Blitz and Lorenz (2002) give as an example the Lower Chattahoochee River valley, where shell-tempered pottery associated with the Rood phase has no continuity with earlier pottery in the region but is similar to pottery made to the northwest. Also early Rood settlements were heavily fortified and located in areas not inhabited by earlier groups, in contrast to central Alabama where grog-tempered and shell-tempered pottery are often found in the same places (e.g., Hammerstedt, 2001).

Blitz (1993) makes a similar case for the Tombigbee drainage in Alabama, where the rise in the frequency of shell-tempered pottery is considered more abrupt because of discontinuities in shape and decoration. While acknowledging Late Woodland precedents for some attributes of shell-tempered pottery, Blitz (1993) argues further that the widespread and rapid rise in frequency of shell-tempered pottery across a large portion of the Mid-South must mean something other than simple indigenous development.

Some of these differences may reflect variable rates of change, but even if shell tempering is attributed to external influence, a source outside the Mid-South is not easily identified. While there are many similarities, early shell-tempered pottery of west-central Alabama does differ from early shell-tempered pottery of the central Mississippi valley. Where the latter is coarse textured and slipped, the early Alabama examples are of two forms (Steponaitis, 1983). One contains abundant coarse shell but is usually unslipped and represented primarily by jar forms. The other contains sparse fine shell, has a burnished "black filmed" surface, and is found in bowl and bottle shapes. While fine shell-tempered pottery appears later in the Mississippi Valley, it rarely occurs in early shell-tempered assemblages (Teltser, 1993). At an early "farmstead" in the Mid-South studied by Mistovich (1988), where grog-tempered ceramics are also abundant, the fine shell-tempered pottery represents more than half the total shell-tempered sherds.

Middle Ohio River Valley

Scattered radiocarbon dates place the first appearance of shell-tempered pottery in the middle Ohio River valley as early as AD 575 (Rafferty, 1974: 211). High frequencies of shell-tempered pottery, however, do not occur until the 10th and 11th centuries (Turnbow and Henderson, 1992).

The early shell-tempered ceramics are identified with the Baum ceramic series, a grouping that includes not only shell but also grit and mixed shell/grit tempering. Disparate tempering materials are lumped into this classification because of broad similarities in other attributes of the ceramics, including exterior surface treatment, lip treatment and vessel form. They also show continuity with Late Woodland predecessors (Turnbow and Henderson, 1992; Ullman, 1985). (As another example, distinctive angular shoulders characteristic of the Late Woodland grit-tempered Newtown ceramics continue on early shell-tempered pottery (Seeman and Dancey, 2000; Pollack and Henderson, 2000).) Prufer and Shane (1970) made a separate class for the shell-tempered sherds only because they thought these represented a later, Mississippian horizon. Unlike shell-tempered pottery from the Mississippi Valley, the Baum shell-tempered ceramics are predominately cordmarked and slips are absent. The particle size and abundance of the temper is quite varied.

The rate at which shell-tempered pottery rises in frequency is also variable. It forms 3.3 percent of all sherds at the Blain site (Prufer and Shane, 1970) in Ohio, but more than 50 percent at the contemporary Cleek-McCabe site in Kentucky (Rafferty, 1974). The continuities with Late Woodland pottery and the wide variation in the expression of early shell tempering both argue for local development.

American Bottom and Illinois

Even within a single region local differences in the expression of shell tempering is incompatible with a late prehistoric diffusion model. Cahokia in the American Bottom and its hinterlands provide an example. Cahokia has long been credited with having significant influence on its neighbors during the 11th and 12th centuries (Emerson and Lewis, 1991). Evidence for this influence includes shell-tempered pottery.

Shell tempering first appears in the American Bottom during the so-called Patrick phase, dated by radiocarbon as early as 6th and 7th century and extending at least to AD 900 (Fortier and Jackson, 2000). While the bulk of the pottery assigned to this phase is tempered with grog or grit, a few vessels have a surface application of clay tempered with numerous small shell fragments, interpreted as repair patches (Fortier *et al.*, 1983; Kelly *et al.*, 1983). Some ceramic pipes are also shell-tempered (Kelly, 1990a). Shell as the primary non-plastic in vessels has scattered early appearances (Milner, 1983a) but does not begin to dominate assemblages until after AD 1000. The shell is abundant and coarse, and the pottery often slipped (Kelly, 1990b: 127), attributes some have attributed to southern influence from the central valley (Hall, 1991; Milner, 1983b).

In the southern part of the American Bottom, there is a brief switch to limestone temper prior to the adoption of shell, imparting perhaps some of the same chemical properties as shell (Hoard *et al.*, 1995). Finely crushed limestone temper also characterizes pottery at this time just to the southwest in the northeast Ozarks during the Maramec Spring phase, which is dated to as early as the 6th century. Shell-tempered pottery constitutes less than 2 percent of pottery at many Maramec Spring sites (Reeder, 2000). Rare early 6th century shell tempered pottery is also reported along the Missouri River in central Missouri, although the accuracy of the dates is uncertain (Hoard, 2000).

Whatever the reason for the increase in shell-tempering in the American Bottom and whatever the influence Cahokia had on neighboring regions, in some of these areas early shell-tempered pottery is of quite a different sort. In the upper Kaskaskia Valley in central Illinois, for example, the use of shell temper began to increase in frequency after AD 1000 but, in contrast to Cahokian vessels, it was not typically used as the only major tempering agent (Moffat, 1991). Shell was mixed with grog and sand and only slowly increased in abundance through time. Further, slipping rarely appears until later times. Early shell-tempered pottery in southwestern Michigan, also attributed to contact with the American Bottom, is typically cordmarked, unlike Cahokian ceramics but like Woodland predecessors, (Brashler *et al.*, 2000).

Even in areas were there is evidence for actual migration of Cahokian people, such as the Apple River region of northwestern Illinois, the "introduced" shell-tempered pottery is distinct from that of the American Bottom. In the Apple River region, the shell temper is finer and slipping is rare (Emerson, 1991). At Aztalan, where a Cahokian-style community was superimposesd over an earlier Woodland ceremonial center, the pottery continued in a Woodland tradition with a few Cahokian style shell-tempered pots and hybrids thrown in (Salkin, 2000). Ceramics in Late Woodland sites in southern Wisconsin, some dating as early as the 8th century, are dominated by grit-tempered pottery, but all sites dating to this period contain a small amount of shell-tempered pottery (Salkin, 2000). A separate manifestation with shell-tempered pottery, Oneota, arose in eastern Wisconsin by AD900, before Aztalan.

In the Lower Illinois Valley, almost in Cahokia's backyard, grit-tempered vessels persisted as the predominate ceramic for more than 200 years after shell tempering was introduced (Farnsworth *et al.*, 1991). Even with evidence of Cahokian colonies (which contained a full suite of Cahokian pottery) and acculturation in the form of hybrid vessels (Delaney-Rivera, 2004), Woodland pottery tradition persisted.

Summary

Two observations can be made about these data. First, while the *rise in frequency* of shell tempering may have occurred earlier in the central Mississippi valley than in other regions, the same cannot be said for the *appearance* of shell tempering (Fig. 2). Scattered reports of early shell-tempered pottery throughout the East indicate first appearance predated rise in frequency by several centuries. Even rise of frequency does not follow a simple temporal gradient consistent with diffusion from a heartland, since high frequencies are noted as early, if not earlier, in distant regions such as the middle Ohio and west-central Alabama as in areas closer to the supposed Missouri heartland such as Cahokia.

Second, in nearly every region arguments for local development of shell-tempered pottery are made. The shell-tempered pottery that rose in frequency in the Late Woodland resembles its predecessors–whether tempered with grog, limestone, or grit–in several dimensions such as vessel shape and surface finish. If anything diffused it was shell temper alone, not a larger suite of ceramic technological traits and practices, most of which show local continuity. But given the unusual firing properties of shell, it is unlikely shell could diffuse without its technological context. The varied expressions of shell-tempered pottery from region to region and even within regions suggest very localized adaptations. Assuming diffusion did occur at some point, it happened at a much earlier date. In most areas, the late prehistoric dominance of shell-tempered pottery represents a rise in frequency of a minor variant long part of the ceramic tradition.

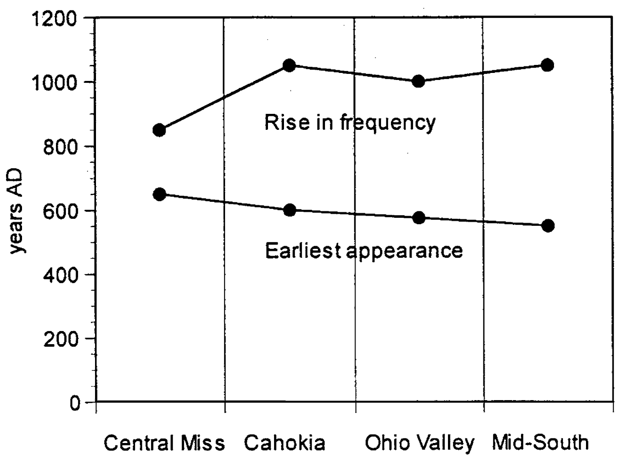


Fig. 2. Approximate mean dates (in years AD) of the first appearance and the rise of frequency in shell-tempered pottery. Values are estimated from the literature and degree of accuracy is variable.

Another possible explanation for the distribution of shell-tempering deserves mention. Some correlation between the spread of shell-temper with the spread of maize agriculture has been noted (Osborn, 1988). A traditional argument for the appearance of shell-tempering is the migration of maize farmers from the central Mississippi valley, who carried shell-tempered ceramics with them. This correlation is particularly noticeable in the southern part of the Mississippi basin. Yet in the Northern Mississippi region, including Iowa and western Illinois, the rise in frequency of maize cultivation seems to correlate with a particular globular-shaped, grit-tempered cord-marked pottery (Benn and Green, 2000) and in other places maize seems to either follow or to precede the increase in shell-tempered pottery (Simon, 2000). The role of maize in Late Woodland economies is also highly variable (Nassaney and Cobb, 1991).

Osborn (1988) has argued that shell-tempering increased the nutritional value of maize, citing the ethnographic observation that lime slaking removes some nutritional deficiencies and adds required elements. But he provides no evidence that shell-tempering actually accomplished this purpose, particularly whether the pottery was fired high enough to break down the carbonate to provide sufficient lime. And even if true, the functional link between shell-tempered pottery and maize may well be an acquired relationship, as Osborn acknowledges, which arose after each was independently developed for other reasons. Even in the Lower Mississippi valley, most see the late period complexity associated with maize agriculture as a local outgrowth from earlier Coles Creek and Plaquemine cultures. Smith (1996) notes that many hallmarks of "Mississippian" culture, such as plaza and platform mound architecture and shell-tempered ceramics, arrived at different places at different times.

THE NATURE AND DETECTION OF SELECTION

Frequency changes, as a record of the differential transmission of variables, are caused by sorting mechanisms. Sorting operates on interactors and at any particular scale of interactor there can be two causes of sorting: those which are a consequence of differential environmental interaction and those which are not (Dunnell, 1978, 2006). The first, called selection, is directional, while the second is random. Sorting by selection is called functional and results in adaptations. Sorting of attributes with equivalent selective value producing distributions governed by random processes is called stylistic. It is important to emphasize that function and style, as used in the evolutionary literature, are not properties of particular attributes but rather causes of sorting.

Sorting occurs at different scales, and sorting that occurs at one scale can affect the distributions at another scale in a way that is neither selective nor random (Vrba and Gould, 1986), but simply incidental. For example, a population which increases in frequency in some region, say by a migration that replaces an indigenous group who cannot compete, may cause a change in frequencies of kinds of pottery in that region that has nothing to do with the adaptational qualities of the pottery. The pottery of the new group may even be less well adapted than the pottery of the indigenous group, if the selection of one group over the other is occurring because of other attributes such as those dealing with food procurement. The pottery is carried along for the ride. The same process could happen at a less inclusive scale. Ceramic color, for example, is a consequence of raw materials and firing. If the latter changes because of selection for cheaper sources or fuels, color may also display a directional change even though there is no direct color selection. The change in color in this case is not functional, but rather is merely incidental to changes occurring at a higher scale.

Because a technological variant was not selected initially does not mean that it may not become so at a later time. Traits that occur because of random or incidental processes form a pool of variability on which selection can operate under new conditions (Gould and Vrba, 1982). Or, traits that are selected for one reason may later become selected for an entirely different reason.

Distinguishing functional, stylistic and incidental causes is an empirical question. I argue in this section that rise in the frequency of shell-tempered pottery at the expense of sand-tempered pottery in southeastern Missouri was a functional change (Dunnell and Feathers, 1991; Feathers, 1990; Feathers and Scott, 1989). Shell-tempered pottery became an adaptation. This should not be confused with biological adaptation in the sense that people who made shell-tempered pottery produced more off-spring than those people who made sand-tempered pottery. Cultural transmission allows inheritance across genetic lines, so people can learn from others besides parents and can change the kind of pottery they make. It simply means that shell-tempered pottery performed better within the adaptive environment of the manufacturers than sand-tempered pottery, so more shell-tempered pottery was made, giving it "replicative success" (Leonard and Jones, 1987). Not all attributes of the shell-tempered pottery can be attributed to functional (or even random) sorting, some were incidental by-products, increasing in frequency only because shell-tempered pottery did.

The pottery is described in detail elsewhere (Feathers, 1990), but some relevant features will be summarized here. Pottery was analyzed from 10 assemblages from various parts of the Malden Plain (Table I). The Malden Plain is a relict Pleistocene land form with little evidence of Holocene deposition. Except for subterranean anthropogenic pits, almost the entire archaeological record lies within the plowzone. Most assemblages were derived from systematic surface collections, conducting by the University of Washington under the direction of Robert Dunnell (Dunnell and Feathers, 1991). Three assemblages, Woodall Farm, Cude, and Davids Creek Farm, were collected by amateurs (Feathers, 1990). At Woodall Farm, the collectors worked closely with the University of Washington, resulting

Table I. Pottery Assemblages

Assemblage	# of analyzed sherds
Early (ca. AD 500–700)	
Coldwater Farm (CF)	546
South Pelts (SP)	233
Robards West (RW)	74
Middle (ca. AD 700–1000)	
Woodall Farm (WF)	1790
Robards Farm (RB)	877
Cude (CD)	230
South Langdon (SL)	260
Late (ca. AD 1000–1400)	
County Line (CL)	1185
Davids Creek Farm (DC)	103
Langdon (LN)	5

Note. Sampling design differed from assemblage to assemblage. Resulting biases are reviewed in Feathers (1990). The five sherds from Langdon were used in firing analysis only and cannot be considered representative of the whole assemblage. Abbreviations are used for assemblages in other tables.

in a comparable collection to the others. At Cude and Davids Creek Farm some collection bias is apparent but neither assemblage is so large as to significantly affect conclusions (Feathers, 1990).

Three assemblages contain only sand-tempered sherds, four contain both sand- and shell-tempered sherds, and three contain primarily shell-tempered sherds. Only limited chronological information is available: from the occasional presence of time-constrained decorative features dated elsewhere in the Mississippi Valley (e.g., occasional nodes and punctations on early sand-tempered sherds, folded rims on late sand-tempered and early-shell tempered pottery, slips and occasional cordmarking on early shell-tempered pottery, and various incisions, punctations, and painted designs on some late shell-tempered pottery) and from a suite of 38 thermoluminescence dates (Dunnell and Feathers, 1991, 1994). The three with only sand-tempered sherds are the oldest (ca. AD 500–700) and occur as simple spatial clusters displaying a single density node. All are located on well-drained embankments overlooking a body of water (slough, river or lowland swamp). Other kinds of assemblages (excepting those with single or a very small number of artifacts) in different microenvironments are unknown for this time period, so that the three assemblages chosen here can be considered representative. The four mixed assemblages are intermediate in age (ca. AD 700–1100) and occur as clusters arranged linearly along well-drained embankments in similar environments as the earlier ones. The clusters are larger, however, and some may have associated mounds, but no other kinds of assemblages are known for this time period. The predominately shell-tempered assemblages represent Middle Mississippian expressions (ca. AD 1100–1400), but, unlike the earlier groups, do not constitute a representative sample of settlement types. All three come from large, probably stockaded villages, but smaller sites are also known. They are included for comparison purposes only.

In the following discussion, early sand-tempered pottery refers to sherds from the early assemblages, late sand-tempered and early shell-tempered pottery refers to sherds from the middle-aged assemblages and late shell-tempered pottery refers to sherds from the latest group.

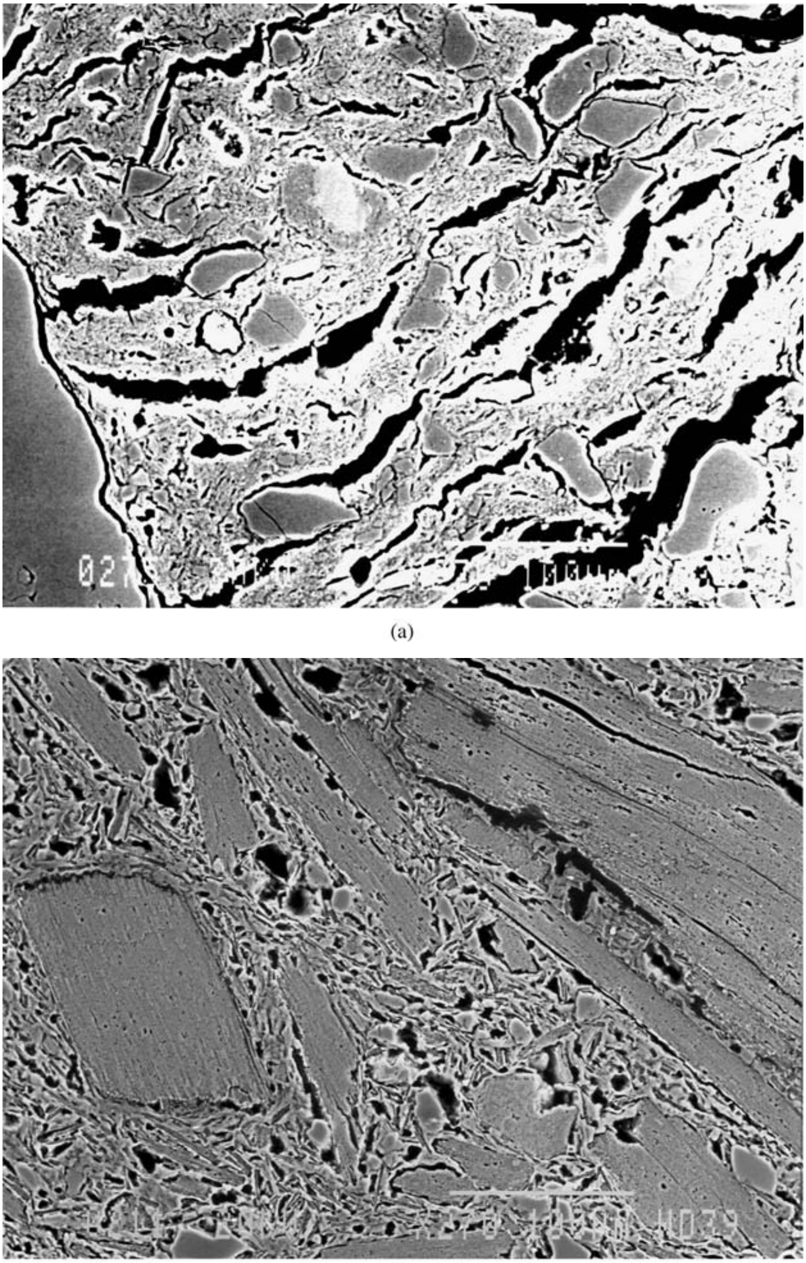
Aside from temper, the composition of the pottery throughout the sequence is quite similar, as determined by elemental X-ray spectral analysis combined with mineralogical analysis by X-ray diffraction. Figure 3 shows major components in backscatter imaging on a scanning electron microscope (SEM). The large inclusions in the sand-tempered example are rounded sand particles of quartz or feldspar. Elongated fibrous inclusions in the shell-tempered example are calcitic shell particles. Notice the abundance of temper of various sizes in both samples and differences in temper shape and orientation. The matrices of both sherds consist of a non-stratified mixture of illite and smectite with small inclusions of quartz, feldspar, iron oxide and titanium dioxide.

The vessels were probably formed by coiling. Horizontally-aligned pores, which may be attributed to coiling (Rye, 1981), are revealed by xeroradiographic images of several sherds, both sand- and shell-tempered (Fig. 4). Other evidence of primary forming technique has probably been erased by secondary scraping of both surfaces. Surface finish is more distinct (Table II). Many sand-tempered sherds are roughened on the exterior by cord or fabric impressions, shown in the xeroradiographic image (Fig. 4). Although some early shell-tempered pottery is also cord-marked, most is smoothed. Slips are rare on sand-tempered sherds but predominate on early shell-tempered sherds, only to become rare again on late shell-tempered sherds.

Morphological differences are measured by thickness, proportion of body parts (Table III) and sherd curvature (Fig. 5). Although shell-tempered sherds are somewhat thinner and more variable in thickness, the difference between them and the sand-tempered sherds is small. Neither is there much difference in proportion of body parts. Differences in horizontal curvature are also few, but some variation is noted in vertical curvature, the shell-tempered pottery being somewhat more globular and more varied in shape.

Firing is discussed in more detail below, but by way of introduction, data on color and firing cores are presented in Table IV. Brighter colors and fewer cores indicate a higher degree of oxidation for early sand-tempered pottery compared to later pottery. The difference is insignificant between late sand- and early shell-tempered pottery.

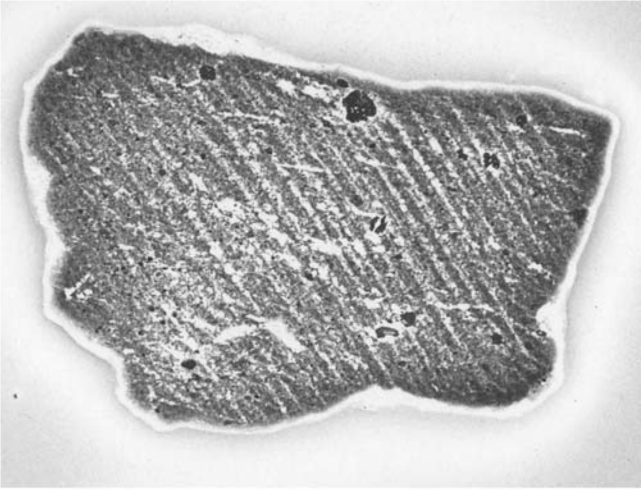
While differences between sand- and shell-tempered pottery from the Malden Plain are quite apparent, equally striking are the similarities between the two, particularly in matrix composition, morphology and color/firing core. Surface



(a)

(b)

Fig. 3. Scanning electron microphotographs in backscatter imaging of a sand-tempered pottery sample from South Pelts site (top) and a shell-tempered pottery sample from Langdon site (bottom). Note the abundant temper of different sizes, shapes and orientations in both samples.



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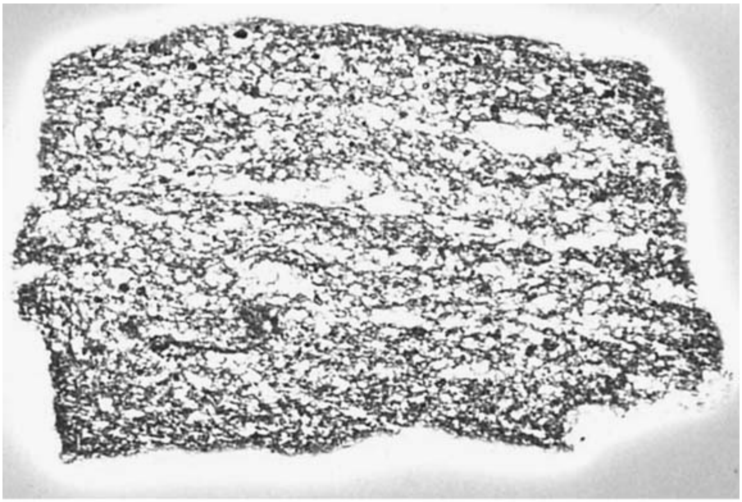

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Fig. 4. Xeroradiographic renditions of sand-tempered (top) and shell-tempered (bottom) pottery, both from Woodall Farm. Note the textured surface which crosscuts the pore alignments in the sand-tempered specimen. Many pores in the shell-tempered specimen represent leached shell, but the orientation of the elongated shell pieces also suggest coils.

Table II. Surface Treatments

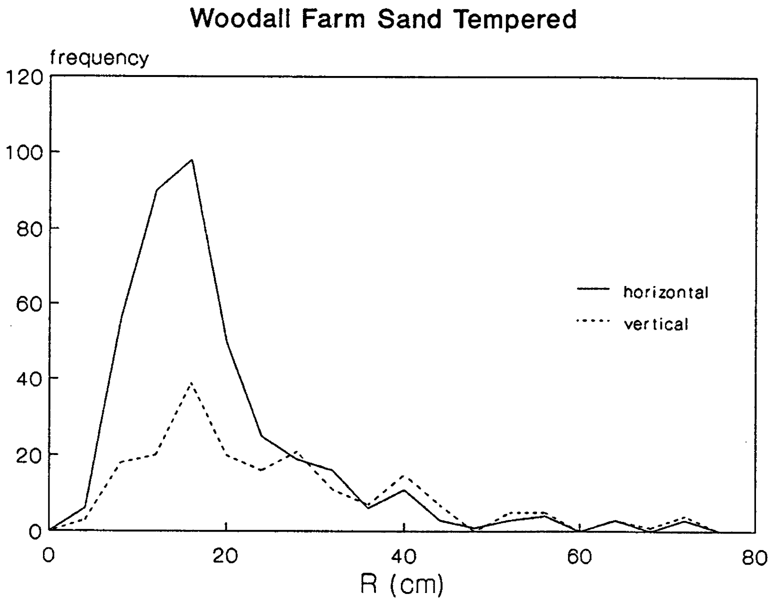
	Interior Surface		Exterior Surface	
Assemblage	Smoothed	Textured	Smoothed	Textured
Sand-Tempered				
CF	401	0	314	85
SP	218	1	132	84
RW	67	0	22	40
SL	202	0	82	104
WF	969	0	160	825
RB	149	0	70	75
CD	153	0	22	130
Shell-Tempered				
WF	710	0	671	26
RB	467	1	475	3
CD	72	0	69	1
DC	103	0	96	3
CL	919	0	920	0
	None	Slips Interior	Exterior	Both
Sand-Tempered				
All	2195	5	1	0
Shell-Tempered				
WF	280	90	148	244
RB	244	120	95	160
CD	39	11	14	11
DC	75	21	4	3
CL	892	13	13	3

Note. Only sherds with non-eroded surfaces are counted. Assemblage abbreviations after Table I.

Table III. Morphology Data

	thickness (mm)			% Body Parts			
Assemblage	*N*	mean	s.d	*N*	Body	Neck	Rim
Sand-Tempered							
CF	359	5.74	1.05	96	87.5	10.4	2.1
SP	959	6.38	1.14	217	88.9	4.6	6.5
RW	74	6.25	1.36	24	100	0	0
SL	182	6.23	1.15	89	88.8	6.7	4.5
RB	136	6.53	1.38	63	92.1	4.8	3.2
CD	150	6.22	1.19	101	87.1	7.9	5.0
WF	1017	6.82	1.30	217	98.2	0	1.8
Shell-Tempered							
WF	761	6.09	1.57	314	87.3	8.3	4.5
CD	68	6.22	1.19	51	88.2	5.9	5.9
RB	409	5.70	1.42	198	89.4	10.1	0.5
CL	884	6.26	1.48	434	82.0	12.7	5.3
DC	98	6.03	1.38	62	90.3	8.1	1.6

Note. Distribution of body parts is among sherds 2–4 cm in maximum dimension to normalize comparisons.



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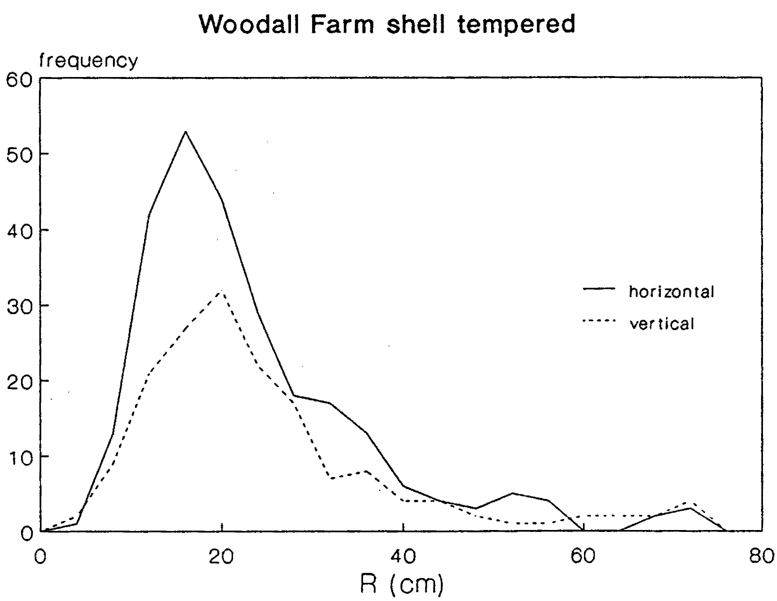

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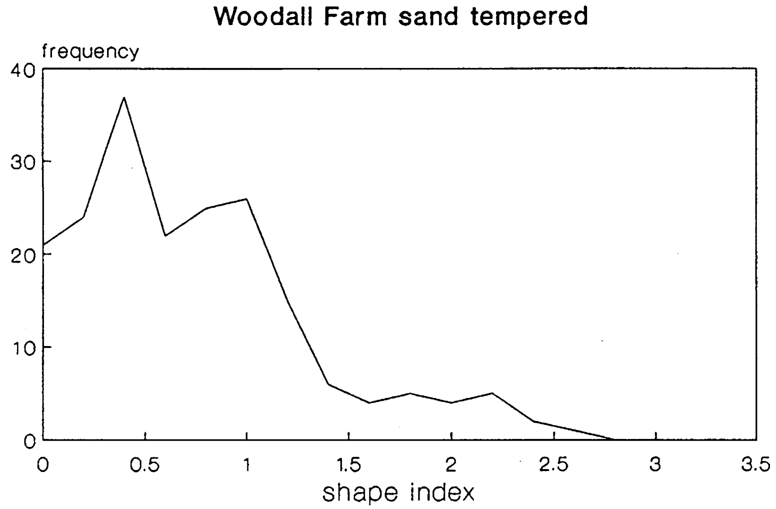
Fig. 5. (a and b) Distribution of horizontal and vertical curvature (R, approximating radii of curvature) for sand- and shell-tempered sherds from Woodall Farm. R (in cm) is the perpendicular radius derived from the largest arcs measurable in the horizontal and vertical dimensions, as well as these could be determined by sherd shape. (c and d) Distributions of shape indices, defined as the ratio of horizontal to vertical curvature, for sand- and shell-tempered sherds. Values of 1.0 represent spherical shapes. See Feathers (1990) for measurement details.



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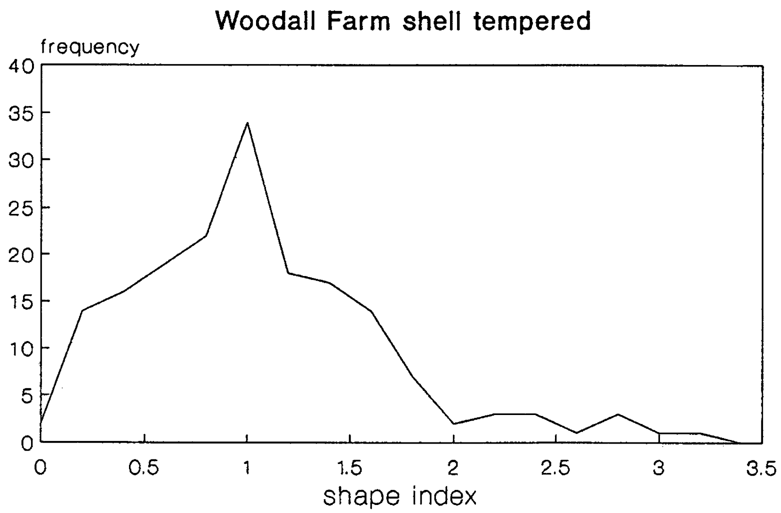


(d)

Fig. 5. Continued

treatment appears to correlate with temper, but examples of cordmarking on shell-tempered sherds and slips on sand-tempered sherds are present. The change in temper is dramatic, but most other data point to technological similarity and historical continuity. The congruent distribution across space of the late sand- and early-shell tempered sherds also testifies to continuity (Dunnell and Feathers, 1991).

Table IV. Color and Firing Core Data

	N	DG	LG	BR	LB	YO
Interior Color						
Early Sand (3)	756	10.1	2.1	13.9	28.3	45.6
Late Sand (4)	1466	25.3	3.8	22.6	31.4	17.0
Early Shell (3)	1241	18.3	1.8	14.7	40.4	24.8
Late Shell (2)	986	28.5	4.1	17.1	36.5	13.8
Exterior Color						
Early Sand (3)	805	1.5	1.2	8.1	24.1	65.1
Late Sand (4)	1485	3.5	0.5	19.3	40.9	35.9
Early Shell (3)	1315	3.0	1.7	7.4	49.7	38.1
Late Shell (2)	967	7.3	3.0	13.0	42.0	34.6
	N	No core	Some core			
Firing Core						
Early Sand (3)	818	44.7	55.3			
Late Sand (4)	1485	20.9	79.1			
Early Shell (3)	1315	25.1	74.9			
Late Shell (2)	1024	12.6	87.4			

Note. Color was measured by reference to Munsell charts and collapsed into five categories: DG: dark gray, LG: light gray, BR: brown, LB: light brown, YO: yellow orange (see Feathers, 1990). Values are in percent. Number in parenthesis refers to the number of assemblages included in each temper category. The sizes of the assemblages are not equal.

To identify selection as the cause for the rise in frequency of shell-tempered pottery requires a two-part argument. First, shell must be shown to change the physical properties of the pottery. Second, these changed properties must relate to how the pottery was made or used: shell must improve fitness, or the probability of selection. The question is empirical and cannot be resolved simply by documenting a frequency increase, which may be the result of other sorting mechanisms.

Some have argued that shell temper has an intrinsic advantage over other tempering material commonly used in prehistoric Eastern North America (e.g., Bronitksy and Hamer, 1986; cf. Feathers, 1989), but this is not supported empirically. In some regions, shell tempering increased initially and then decreased in frequency (Gleach, 1988; Knight, 1979); in others it is introduced but never reaches majority status (Hoffman, 1984; Wedel, 1986). Thus it does not have selective advantage under *all* sets of conditions present in the prehistoric East. This underscores the weakness of functional approaches which rely on substantitive generalizations about the nature of ceramic properties (e.g., Arnold, 1985). Evolutionary explanations are historically contingent and require the demonstration of selection in every case (Gould and Lewontin, 1979).

To attribute rise in the frequency of shell-tempered pottery to selection, one or more physical properties influenced by shell temper must be shown to affect fitness. This is done first by showing that shell temper alters either production costs (ease of replication) or performance values (effectiveness in use) and second by relating these changes to environmental pressures (as an alternative approach see Schiffer and Skibo, 1987; Skibo and Schiffer, 2001). The ability to demonstrate the latter varies. The most convincing evidence may come from the ceramics themselves. For example, if several changes occur at different times but all affect a given property in the same direction, the probability these changes are coincidental is small. The probability that selection is involved is also high if a change improving one physical property is accompanied by other changes counteracting deleterious side effects. If fitness were not favorably affected, the costs of counteracting changes could not be explained. Another possibility is to look at use wear (Skibo, 1992). Identifying particular uses may be difficult because of equifinality problems but correlating use wear patterns – if they can be distinguished from post-depositional alterations – with particular physical properties could be a fruitful if largely unexplored avenue of research. Use-wear analysis was not attempted on the ceramics studied here.

Before reviewing the functional evidence, the possibility that the increase in frequency of shell-tempering was simply a stylistic change needs to be ruled out (Feathers *et al.*, 2003). While some have questioned whether any change is fully stylistic (e.g., Shennan and Wilkinson, 2001), studies of the distribution of some decorative traits have shown resemblance to the stochastic, "battleship-shaped" distributions that neutral traits should follow (Neiman, 1995, Lipo, 2001). The change in frequency of shell-tempered pottery, in contrast, follows a quite different path. A long period of low frequencies is followed by an abrupt increase in frequency to a point of fixation where all other tempering materials are nearly eliminated, a condition that was maintained until European contact. Figure 1 shows the change in frequency as tabulated for different parts of the Lower Mississippi Valley. Such a distribution certainly would not be expected for a stylistic change.

I briefly review two properties affected by shell tempering in southeastern Missouri ceramics to explain why one was likely driving selection and why the other was probably an incidental by-product. The first is mechanical strength, or resistance to breakage, a property that influences a wide variety of ceramic uses. A series of experiments comparing the strength of replicate sand- and shell-tempered ware has been reported elsewhere (Feathers, 1990; Feathers and Scott, 1989). Table V compares fracture toughness and work-of-fracture, compiled from fracture tests on chevron-notched specimens. Fracture toughness measures energy required to extend a crack at its forward tip. It represents the stresses involved in breaking the bonds that hold a material together. It does not include energy used in microprocesses occurring in the vicinity of the crack tip, such as branch microcracking, plastic deformation and pull-out of second phase materials such as temper. The total energy consumed in propagating a crack is represented by work-of-fracture. Shell-tempered samples have a 60 percent greater fracture toughness than sand-tempered samples, but, more significantly, a 135 percent greater work-of-fracture. This is illustrated by plotting R, the resistance to crack growth, against crack length (Fig. 6). For shell-tempered samples, R increases as the crack grows, impeding its propagation and increasing overall durability. Materials with rising

Table V. Fracture Parameters from Notched Specimens

	Sand-Tempered		Shell-Tempered	
	K_{Ic}	WOF	K_{Ic}	WOF
	0.0517	2.1819	0.0847	4.9746
	0.0560	2.3622	0.0816	6.3236
	0.0349	1.9413	0.0663	3.3432
	0.0535	2.3548	0.0806	6.5500
	0.0564	2.2871	0.0829	4.9760
	0.0667	3.1885	0.1162	7.5193
Mean	*0.0532*	*2.3860*	*0.0854*	*5.6144*

Note. K_{Ic} is plain fracture toughness (MPa $\times$ m$^{1/2}$). WOF is work of fracture (J/m^2).

R curves also tend to have high resistance to thermal shock damage (Hasselman, 1969; Sakai *et al.*, 1983). Improved toughness and thermal shock resistance for shell-tempered pottery have also been reported by others (Steponaitis, 1983, 1984; West, 1992).

Documenting improved strength properties does not in itself prove that the change to shell temper was governed by selection. Increased strength could be incidental. Were changes in other variables also leading toward greater strength? Data in this regard are weak. A tendency toward finer grain sizes from early sand- to late sand-tempered pottery appears to increase strength slightly, and a small tendency through time towards larger diameters and more globular vessels indicates improved resistance to fracture because of smaller radii of curvature (Feathers, 1990). Better evidence comes from negative side effects. Porosity measures on several sherds (Table VI) indicate increased permeability for early shell-tempered ceramics. If reduced permeability were the principle adaptive value of the pottery, shell temper could not have been advantageous, but counteractive measures appear to have been taken. Application of slips correlates strongly with porous early shell-tempered ceramics. While quantitative evidence for the effectiveness of slips at reducing permeability is not available, its effectiveness in slowing leaching of shell by water has been noticed on some sherds where the only shell remaining is immediately under the slip. Experimental work on other ceramics, although in different historical circumstances, has also suggested slips can reduce permeability (Schiffer, 1988, 1990). The added costs of applying slips is difficult to explain unless the fitness of these shell-tempered ceramics was substantially increased in some other way.

But perhaps such correlations are coincidental and slips had no adaptive significance in terms of pottery itself. Slips did increase production costs, so could not be neutral in terms of pottery production on a broader scale. One would have to argue that increased production costs themselves were selective, or that production costs were minor compared to other selective pressures, regulating visual appearance for example, unrelated to pottery use. Under what conditions

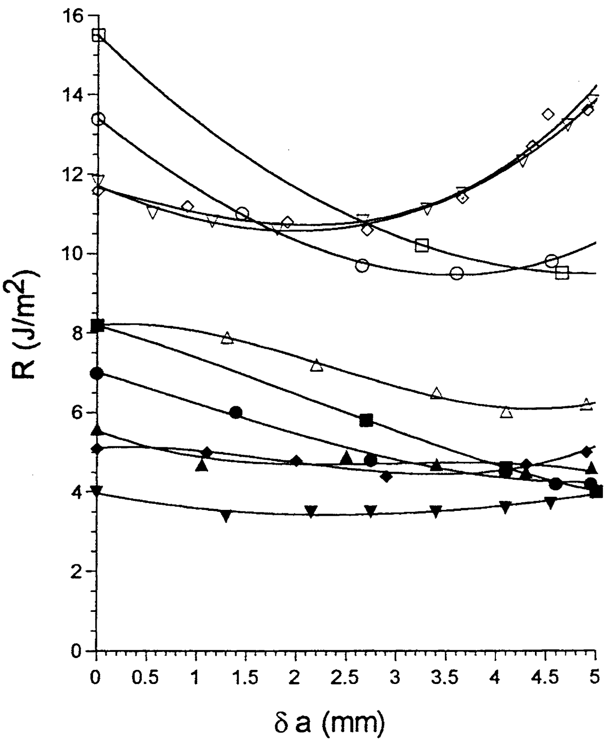


Fig. 6. Relationship between crack growth, R, and crack length, a, for chevron-notched test specimens tempered with sand (solid symbols) and shell (open symbols). The same shaped symbol represents specimens whose notches were cut at the same time and thus represent nearly identical notch geometry. The original decrease in the curves represents machine compliance. The shape of the curves on the right side is more meaningful, a rising curve representing increased resistance to crack growth as the crack gets larger.

Table VI. Apparent Porosity Measurements

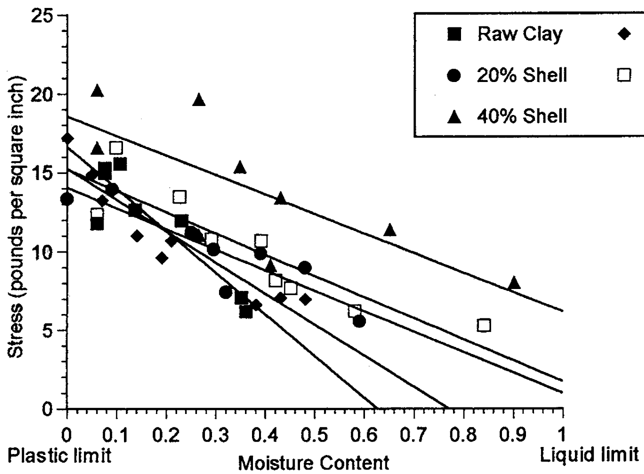
	N	mean (%)	s.d
Early Sand-Tempered	10	24.4	3.1
Late Sand-Tempered	12	26.3	2.0
Early Shell-Tempered	6	43.6	6.1
Late Shell-Tempered	3	27.6	7.3

Note. Apparent porosity was measured using the formula $P = (W - D)/(W - S)100$, where W equals saturated weight, D equals dried weight, and S equals suspended weight in water. Of the assemblages studied here, only a few shell-tempered sherds that did not have the shell leached were available for measurement.

energy expenditure for elaborations with no apparent increase in fitness (termed "waste") can be selected has been considered by Dunnell (1989) and others (Cannon *et al*., 1998; Neiman, 1997). Recent work has suggested that such "waste" can become selective for individuals or groups, of which pottery is an attribute, either as bet-hedging during periods of environmental fluctuations by preventing overproduction (Cannon *et al*., 1998) or during times of competition over scarce resources by identifying individuals with high competitive ability (Neiman, 1997). The Hopewell phenomenon, which found its greatest expression in the more environmentally uncertain north, and the Mississippian elaboration, which occurred during increased competition for agricultural land, may be explained this way (Dunnell, 1989, 1999). When shell-tempered ceramics increased in frequency during the Late Woodland in southeastern Missouri, little other evidence for artistic elaboration is present compared to earlier and later times (Dunnell and Feathers, 1991). Across the East, the Late Woodland, known for its rather drab ceramics, has been described as a period of economic and population growth due to the enhanced productivity of agriculture (Steponaitis, 1986; Bense, 1994). Selective pressures for economically efficient tools, not ones with additional expenses, were strong in other cultural domains. It is not likely that simple artistic elaboration can explain slips. But what about other selective pressures, such as for visual effects, which are not directly related to pottery use, that might override production costs. Again such pressures are not evident in patterns of other cultural domains. More likely visual effects, if any, were a consequence of slip selection, not a cause of it. But was increased mechanical strength the trade-off that inspired increased production costs?

A second property affected by shell tempering in southeastern Missouri ceramics is workability during the forming process (Million, 1975). Workability is a property commonly used to describe the ease with which a plastic mass can assume a shape imposed on it by an applied stress (Baudran and Deplus, 1959). Its value depends on forming method, but for techniques such as coiling where the vessel is formed by hand and must support its own weight during construction, the two most important variables are yield value and amount of deformation without rupture. Workable clays maximize both quantities. Unconfined compression tests (Fig. 7) using samples of sand and shell mixed with local Malden Plain clay show that samples with the highest concentration of shell (40 percent) have both the highest yield value and comparable deformation properties (Feathers, 1990). Increased strength did not compromise deformation as might happen with a stiffer clay.

The advantage of more workable clay is greater flexibility in the size and shape of vessels. Later Mississippian ceramics have often been described as representing an increase in number and variety of vessel forms (Morse and Morse, 1983: 241, 266), but the shape data on the early shell-tempered pottery (Table III, Fig. 5) indicate little difference from the sand-tempered predecessors. If increased workability were driving the change in temper, a corresponding increase



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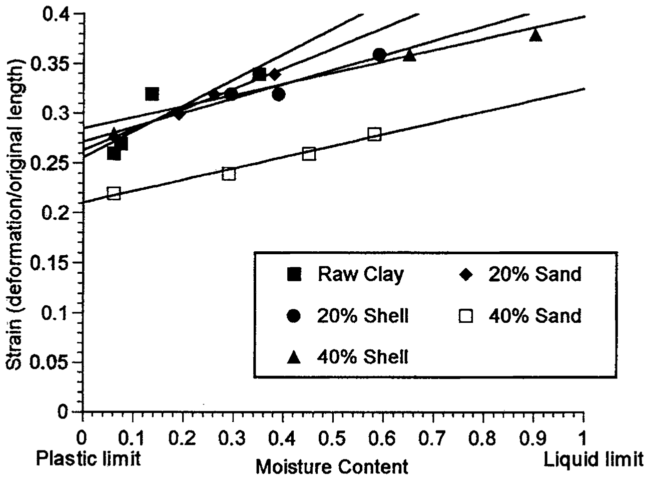


(b)

Fig. 7. (top) Change in unconfined compression strength as a function of moisture content for raw clay and four replicate plastic bodies. Moisture content is standardized along the X-axis to represent the plastic range for each sample as determined by the Atterberg limits (Worrall, 1986). Regression lines are fit to the data points for each composition. (bottom) Change in strain at maximum deformation as a function of moisture content, standardized as in the top graph, for the same samples. Strain is ratio of change in length to original length. See Feathers (1990) for details.

in morphological variability should be evident. It is not. Rather increased variation seems to happen later. Increased workability seems therefore an incidental effect that later acquired selective value when demand for a wider variety of shapes arose.

In summary, non-stylistic distributions and consideration of porosity and slips suggests the increased frequency of shell-tempered pottery was a functional change. Morphological data suggest increased workability was not the driving force. Increased strength remains the best alternative, supported by weak evidence of other steps to increase strength and by the absence of other data to suggest strength was not the dominant selective force. None of this explains where shell temper came from nor why shell temper and not some other route to increased strength was taken. Nor does it explain its timing. The larger issue of pan-Eastern spatial and temporal distribution requires consideration of these matters.

A QUESTION OF UNITS AND A POSSIBLE RESOLUTION

A recurring problem in evolutionary theory is the scale of the interactor – which players in the arena are being sorted (Dunnell, 1995; Eldridge, 1985). A unit on which sorting can operate requires (1) the ability to reproduce, (2) functional independence from other entities, and (3) fast turnover in relation to the conditions of sorting (Dunnell, 1995). As mentioned earlier, pottery is reproducible through the medium of the manufacturer, although it is not fully independent of the manufacturer. However, cultural transmission frees pottery from genetic restrictions, so that reproduction is not tied to biological generations. This gives it the potential of fast turnover. But what are the proper units in the case of shell-tempering?

A first consideration is the empirical units on which measurements are to be made and compared. Sherds, easily perceived and measured because boundaries are unambiguous, are not appropriate units for tracing evolution because they are a depositional product. Individual vessels, which do have systemic meaning, may not be appropriate either. Manufacturers usually make more than one vessel and it is likely that manufacturing constraints will not favor tailoring each vessel to its intended use. Rather efficiency dictates manufacturing compromises. The proper unit must then be some collection of sherds or vessels, an assemblage. (Sherds can define an assemblage as well as vessels despite apparent bias or incompleteness in the information they convey. For example, differential breakage patterns or differential vessel size may seem to bias sherd counts but only insofar as sherds are representing vessels. If the assemblage is the unit, sherd counts are not biased, but rather a source of information on breakage patterns and vessel size, which are then characteristics by which assemblages can be compared. That vessels are not likely appropriate units is archaeologically advantageous because whole vessels are rarely preserved and their reconstruction often problematic.)

With assemblages as measuring units boundaries become problematic. This leads back to the original question, since the boundaries must be defined so that the assemblage is congruent with the theoretical sorting unit, the interactor. The interactor, some manufacturing and use unit, could correspond to individuals, families, households, communities, or nations, and could vary for different places, for different times and even for different attributes. The boundaries depend on manufacturing and use practices. At the individual scale, the assemblage includes all vessels made and used by any one person, who makes and uses the vessels independently of all others. At larger scales, manufacture and use are regulated by processes, such as division of labor and allocation of resources, which affect more than single individuals. The criterion for assemblage boundaries is functional integration. Boundaries are widened until all parts of the manufacturing and use system that can stand independently are included.

Defining boundaries for assemblages can be accomplished as follows. Ceramics in the archaeological record are not distributed evenly across the planet but appear as clusters. Provisionally, one could draw boundaries around single clusters defined by some density criterion (traditional notion of site), but actual units could be larger, encompassing several clusters, or smaller, including only a portion of a cluster. Clusters could be considered single units only if over some range of time they are functionally redundant: they occupy similar environmental contexts and contain a similar range of artifacts. A cluster representing a domestic midden may not be comparable with another cluster representing a cemetery, but they may both be part of the same assemblage. Two clusters, redundant with each other, may still not be separate units if, for example, a third cluster, representing a large center, is not redundant with the others. Where clusters are not redundant, parts must be combined until functional redundancy is achieved. Functional redundancy does seem to hold for the assemblages compared in the analysis of Malden Plain ceramics presented above (Feathers, 1990), with the exception of the late shell-tempered assemblages, which seem to be parts of larger units.

Defining temporal boundaries is less problematic. Since cultural transmission is more or less continuous, any arbitrary division of time of equal duration gives units suitable for measuring change. Inadequate dating prevents precise adherence to this condition for the Malden Plain study, but the assemblages contain stylistic markers known to cover a limited time range and form a spatial structure suggesting single nodes or simple patterning. Differences in duration are probably not significant.

I propose that replacement of sand-tempered pottery by shell-tempered pottery in southeastern Missouri was due to selection at a comparatively small scale. Shell-tempered pottery rose in frequency because individual vessels made with shell were better adapted to the local environment than were those made with sand. Sorting could have been at a scale as small as the manufactures of individual households. Those households with shell-tempered pottery were at a competitive advantage. I suspect selection at such a scale was also responsible for the success of shell-tempered pottery in other parts of the East, where it replaced earlier kinds of pottery, although perhaps for different reasons.

The assemblages I described for southeastern Missouri probably encompass something more than what is intuitively considered a household, which also implies some genetic relationship, but they are probably nevertheless adequate for comparison. Cultural transmission is not restricted to genetic lines. People in close spatial proximity inherit from one another (Lipo *et al.*, 1997).

The timing of the change and the relatively concurrent widespread distribution in the East, however, cannot be explained by small-scale selection. I propose that this can be explained by selection at a higher scale not of shell-tempered pottery itself but for conditions that increased the fitness of shell-tempered pottery. This idea is based on an analysis of firing of southeastern Missouri ceramics.

The question of availability of variants is seldom addressed in functional arguments based on adaptive significance (e.g., Schiffer and Skibo, 1987). Yet selection of a particular variant cannot occur if the variant does not occur. I suggested earlier that shell-tempering appeared long before it rose in frequency, being present as a minor variant for some time. This implies that it did not undergo strong selection because of other conditions. These conditions must not only have prevented the success of shell tempering but changed prior to its rise in frequency by independent processes.

This alternative is considered for the southeastern Missouri case by evaluating the hypothesis that (1) firing strategies prevented the early success of shell tempering because of risk from spalling and (2) a change in these strategies during the Late Woodland period when sand tempering still predominated allowed the eventual selection of shell. This evaluation requires estimating the firing conditions of various pottery, examining the effect of firing on the decomposition of shell, and placing changes in firing in a temporal context relating to the rise in frequency of shell tempering. Results are summarized here.

Thirty-two sherds were analyzed, including four from the early sand-tempered assemblage of South Pelts, ten late sand-tempered and 13 early shell-tempered sherds from Woodall Farm, two early shell-tempered sherds from Cude, and five late shell-tempered sherds from Langdon. Criteria for sampling included surface color and presence/absence of a dark inner core. Replicate standards were constructed from clay collected at Langdon and sand or shell also collected locally. Estimations of degree of firing (some combination of temperature, rate and duration) and firing atmosphere were compared with threshold values for shell decomposition beyond which shell-tempered pottery could not be fired. Experimental details are given elsewhere (Feathers *et al.*, 1998).

An ordinal arrangement of sherds by degree of firing was possible by combined results from X-ray diffraction (XRD), differential thermal analysis (DTA) and Fourier transform infrared spectrometry (FTIR) (Table VII). Sherds fired to a higher degree show no clay mineral peaks or only illite in the XRD patterns, no dehydroxylation peaks in DTA, and no smectite dual peak in FTIR. Lower-fired sherds have strong smectite expressions in XRD and FTIR and prominent DTA dehydroxylation peaks. Medium-fired sherds lie between these extremes. Postdepositional effects on this ordinal arrangement, either from contaminants or from rehydration of clay minerals, were determined to be present but not to affect the overall order. That the order reflects degree of firing was corroborated by scanning electron microscopy (SEM). Figure 8 shows 5000x micrographs of sand-tempered sherds from the low-, medium- and high-fired groups. The smoothing and rounding of particles in the high-fired example are reflective of early sintering.

High-fired sherds were determined to have surpassed the carbonate decomposition threshold, assuming an oxidizing atmosphere, by successive refirings of selected sherds using both a conventional SEM and an environmental scanning electron microscope (ESEM). The latter allows the sample to be heated while under view. The threshold was estimated by firing replicates to be about 800°C using an 8°C/min rate and no soak time at maximum temperature. Figure 9 shows ESEM photos of one high-fired sand-tempered sherd, displaying no structural changes by 800°C, indicating an original firing temperature of at least that high. Only subtle structural changes are noticed by 975°C.

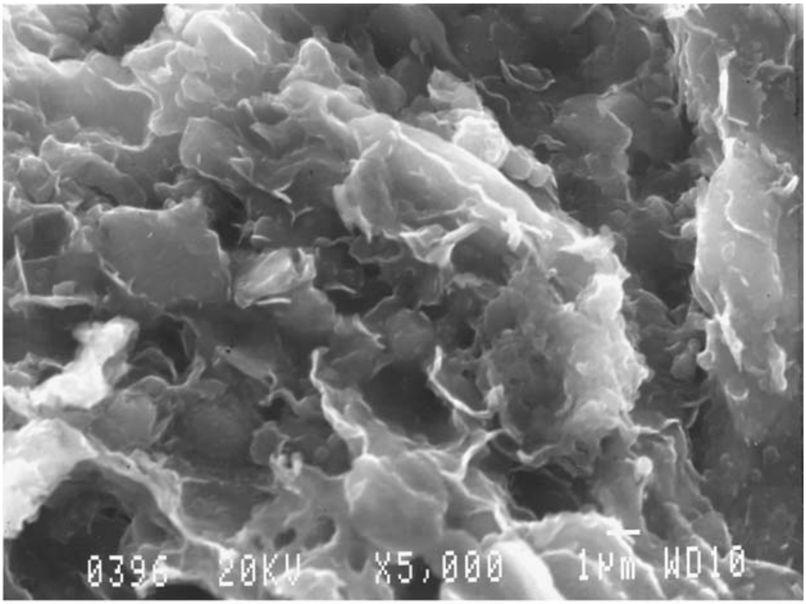
Reducing atmospheres, especially those created by impedance of air flow, retard the decomposition of the carbonate by buildup of the decomposition product CO_2. Temperatures somewhat above 800°C are then possible without decomposition. Reduction/oxidation was measured on 22 sherds by Mössbauer spectroscopy which measures the oxidation state of iron (Feathers *et al.*, 1998). Table VIII shows that only one sherd, an early sand-tempered sample, was fired under conditions not viable for shell temper. This sherd was high fired and highly oxidized, as evident from the presence of hematite. No other high-fired sherd contained hematite, even though experimental firing of clay to 800°C produced abundant hematite. Some degree of reduction for these sherds is inferred. This is obvious for those containing ferrous iron, but not so clear for two shell-tempered sherds that were high fired but contained no ferrous iron and no firing cores. This anomaly is explained by a two-stage firing process: reduction past 800°C followed by oxidation during cooling once below the decomposition threshold. Most early shell-tempered sherds, even those containing abundant ferrous iron, are fully oxidized on the surface, suggesting that a later oxidation stage in the firing protocol was a common practice.

These results, when combined with the color and core data from the much larger sample (Table IV), show that firing strategies changed during the Woodland period. Early sand-tempered pottery is highly oxidized, and at least one example out of four was fired under conditions ill-suited for shell. While the sample is small, the important observation is the variability in firing: some, maybe only a small percentage of firings exceeded the decomposition threshold. Late sand-tempered pottery, by contrast, all seems to have been fired under conditions that would have allowed production without spalling of shell-tempered pottery. The sample size was much larger but the variation was less, at least by removing the upper range

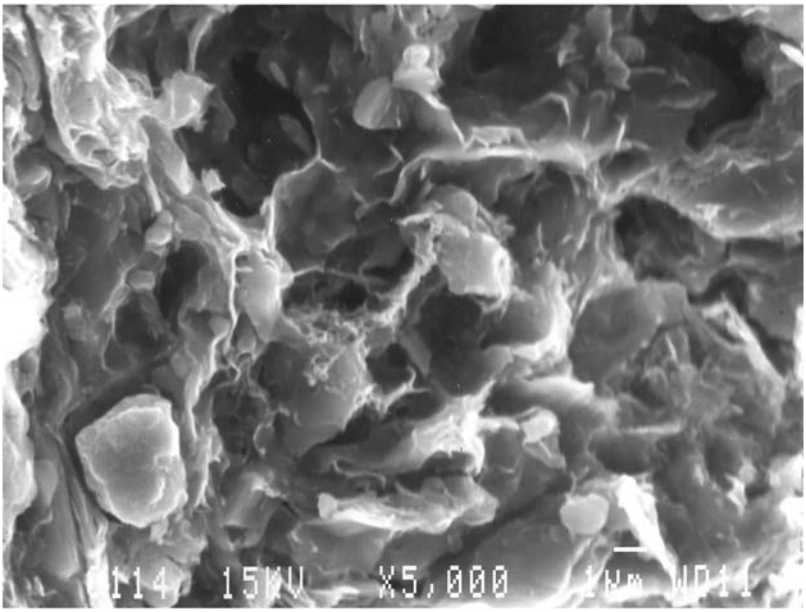
Table VII. Estimation of Degree of Firing

Sherd	XRD			DTA		
	Clay peaks			Hydroxyl peak		FTR
	Illite	Smectite	Kaolinite	°C	Height	smectite peak
			Sand-Tempered			
High Fired						
SP13	absent	absent	absent	absent		absent
WF18	weak	absent	absent	absent		absent
WF46	weak	absent	absent	absent		absent
SP11	weak	absent	strong	absent		weak
Medium Fired						
WF70	weak	absent	absent	498	0.08	weak
WF47	weak	weak	absent	490	0.04	weak
WF67	weak	weak	absent	494	0.03	weak
WF71	weak	weak	absent	497	0.06	weak
Low Fired						
WF45	weak	weak	absent	504	0.12	strong
WF86	strong	weak	absent	510	0.09	strong
WF64	strong	strong	absent	501	0.33	strong
WF38	strong	strong	absent	504	0.07	strong
SP10	strong	strong	absent	523	0.15	strong
SP8	strong	strong	absent	508	0.17	strong
			Early Shell-Tempered			
High Fired						
WF1140	weak	absent	absent	absent		absent
CD30-2	absent	absent	absent	absent		weak
WF1009	weak	absent	absent	absent		absent
WF1053	weak	absent	absent	absent		absent
WF1120	weak	absent	absent	absent		absent
Medium Fired						
WF1094	weak	absent	absent	504	0.04	absent
CD29-4	weak	absent	absent	504	0.08	absent
WF1041	strong	absent	absent	502	0.08	weak
WF1007	strong	absent	absent	504	0.1	weak
Low Fired						
WF1001	strong	weak	absent	505	0.22	weak
WF1071	strong	strong	absent	513	0.08	strong
WF1013	strong	strong	absent	499	0.08	strong
WF1005	strong	strong	absent	500	0.08	strong
			Late Shell-Tempered			
Medium Fired						
LN181-5	weak	absent	absent	507	0.07	weak
Low Fired						
LN181-3	weak	weak	absent	492	0.06	strong
LN181-1	strong	weak	absent	485	0.04	strong
LN181-4	strong	weak	absent	514	0.08	strong
LN181-2	strong	strong	absent	490	0.04	strong

Note. XRD: X-ray diffraction, DTA: differential thermal analysis, FTIR: Fourier transform infrared spectrometry, SP: South Pelts, WF: Woodall Farm, CD: Cude, LN: Langdon. South Pelts are early sand-tempered; Woodall Farm are late sand-tempered. The height of the DTA peaks are fraction of full deflection. The presence of kaolinite in SP11 was determined to be post-depositional in origin.

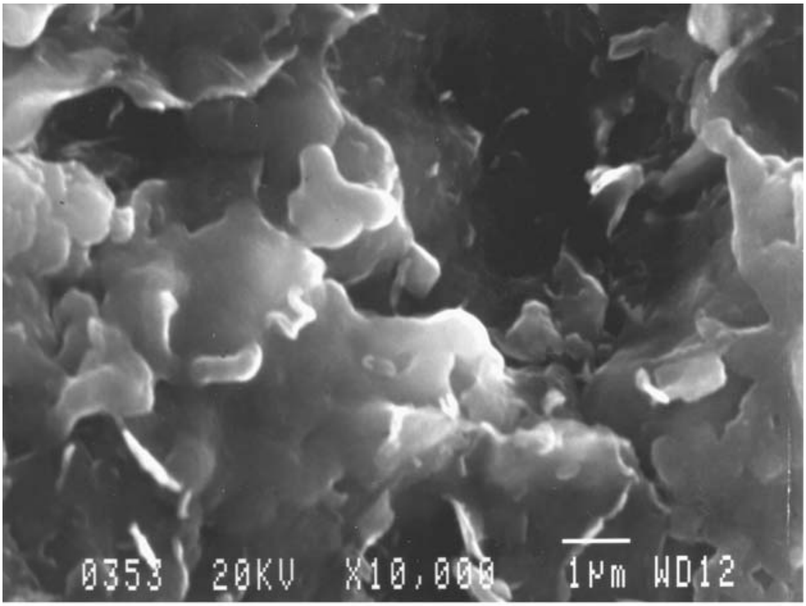


(a)



(b)

Fig. 8. (a) SEM micrograph for low-fired sand-tempered pottery. (b) SEM micrograph for medium-fired sand-tempered pottery. (c) SEM micrograph for high-fired sand-tempered pottery. Note the more rounded edges and smoother surfaces in this sherd, evidence of early sintering. All specimens are from Woodall Farm.

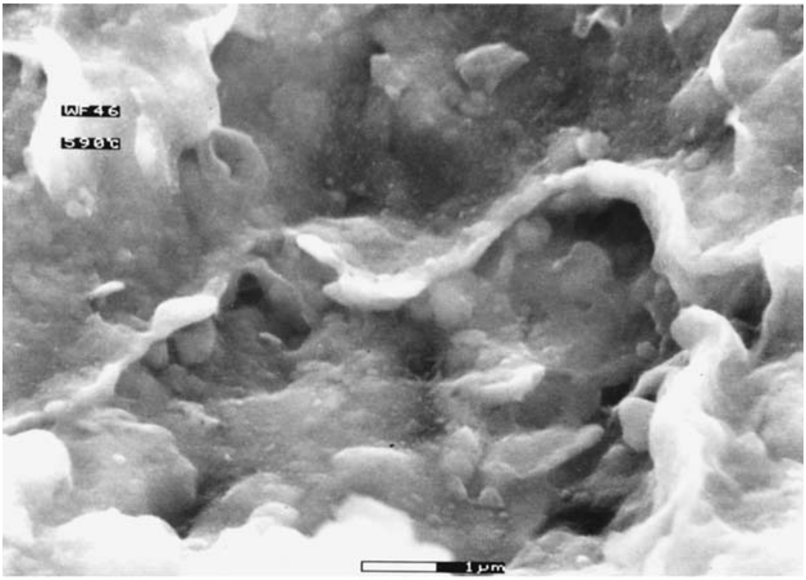


(c)

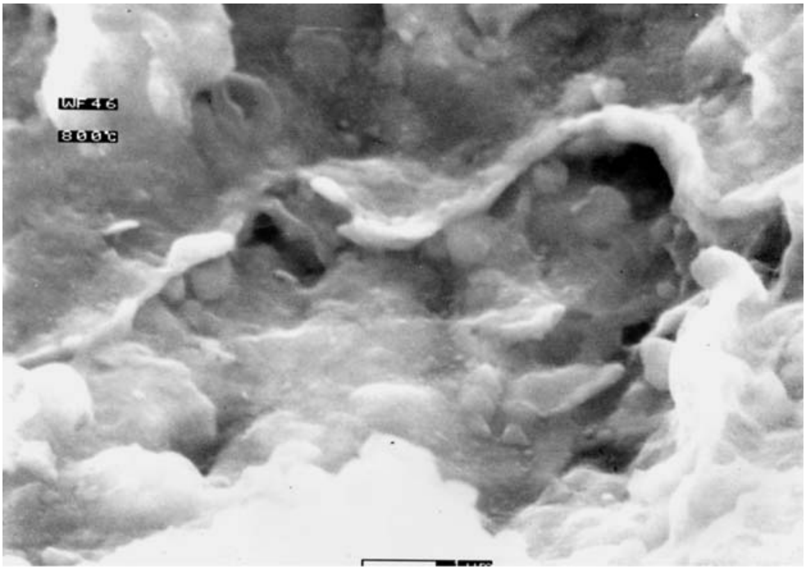
Fig. 8. Continued.

of firing beyond the threshold. It is no surprise that shell-tempered pottery did in fact rise in frequency at this time.

Why the firing strategy changed in southeastern Missouri is unknown. It apparently changed prior to and independent of any changes in composition, shape, forming technique or surface treatment. This suggests a cause extrinsic to pottery, most likely a change in fuel availability. No data on fuel use are available from southeastern Missouri, but data from other regions show that fuels did change with time. Wood charcoal from several floodplain sites in the American Bottom shows during the Woodland period a dramatic shift from floodplain to upland species, attributed to extensive clearing for plant cultivation (Johannessen, 1984; Rindos and Johannessen, 1991). Similar clearing in southeastern Missouri might explain changes in availability of fuel and in firing strategies. The nature of the firing change would depend on how fuel availability changed, but one possible result may have been increased use of cane, used ethnographically in firing pottery (Swanton, 1946: 553). Grasses such as cane have a higher ash content that might allow localized reduction (Tillman, 1991). Prior to the change in fuel availability, selection may have favored fuel that promoted higher temperatures, which would increase the strength of sand-tempered pottery.

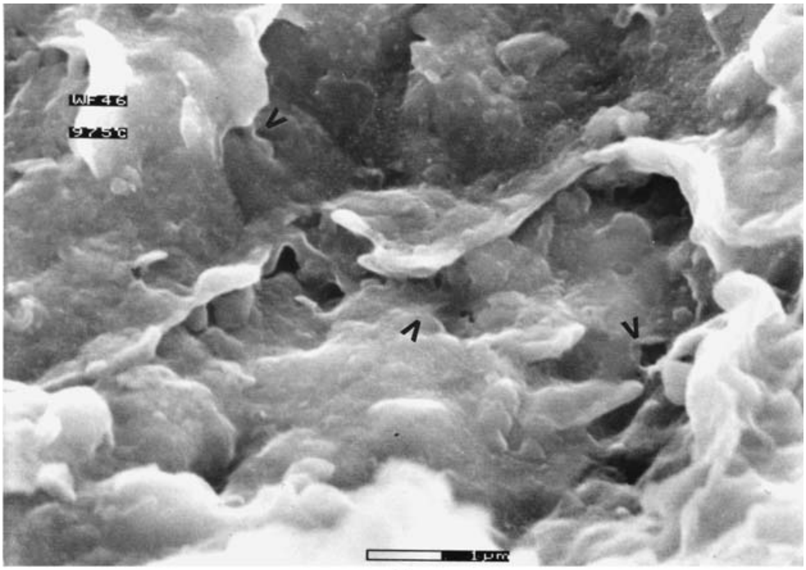


(a)



(b)

Fig. 9. ESEM micrographs for high-fired sand-tempered pottery refired, showing structural changes at three temperatures: (a) 590°C, (b) 800°C, and (c) 975°C. The specimen from Woodall Farm is the same shown in Figure 8c. No change is readily apparent between 590° and 800°C, but subtle changes in morphology can be seen by 975°C, as shown by the arrows.



(c)

Fig. 9. Continued.

Table VIII. Mössbauer Results

Sherd	Iron oxide	Fe^{+3}/Fe^{+2} Ratio	Firing	Core size
Sand-Tempered				
SP13	present	6.9	high	none
WF45	absent	no ferrous	low	none
WF47	absent	no ferrous	medium	<50%
SP10	absent	no ferrous	low	<50%
SP11	absent	1.5	high	50-70%
WF67	absent	no ferrous	medium	50-70%
WF18	absent	0.85	high	>70%
WF46	absent	1.4	high	>70%
WF38	absent	no ferrous	low	>70%
Shell-Tempered				
WF1009	absent	no ferrous	high	none
WF1120	absent	no ferrous	high	none
WF1071	absent	no ferrous	low	<50%
WF1005	absent	3.8	low	50-70%
WF1013	absent	11.0	low	50-70%
CD30-2	absent	0.21	high	>70%
WF1140	absent	0.8	high	>70%
WF1094	absent	4.1	medium	>70%
WF1007	absent	0.2	medium	>70%
LN181-1	absent	14.0	low	>70%
LN181-2	absent	no ferrous	low	>70%

Note. Firing categories are based on data from Table VII. Core sizes are percentages of full sherd thickness. The iron oxide present in SP13 was identified as maghemite. (Feathers *et al*., 1998).

Selection of firing strategy, if influenced strongly by available fuels, should occur at a higher scale than selection for temper, if the latter is governed largely by mechanical strength. Temper can vary from vessel to vessel, but availability of fuel affects all vessels uniformly from a given region. The scale would increase to the assemblage produced by a single subsistence system.

Selection for increased importance of agricultural practices in subsistence was widespread throughout the East during the Late Woodland, partly because of long-term historical plant/human interactions, but also because of the nature of agriculture, whose increasing yields support increasing populations and whose large variations in yield put expansive pressure on the land (O'Brien, 1987; Rindos and Johannessen, 1991; Smith, 1986). Clearing because of agriculture may have established the conditions – either more reduced or lower temperature firing – that made shell tempering, a very minor component of local ceramic traditions, advantageous. This may also account for the apparent, although not absolute, correlation of shell-tempering with maize agriculture. Increase in shell-tempered pottery was then a consequence of localized selective conditions that governed the manufacture and use of pottery, something that probably varied from place to place as the local pottery varied.

Documenting and explaining increasing frequencies of shell tempering across the East then requires larger units than the small clusters used here to explain one local development, units that encompass regional subsistence. While it may be difficult to identify these larger units with any degree of specificity, the hypothesis has empirical consequences.

(1) The rise in frequency of shell-tempered pottery in localities other than southeastern Missouri must follow a change in firing strategy from one that entailed some risk in using shell temper to one that lowered the risk. The hypothesis is falsified if earlier firing regimes entailed little risk in using shell temper.
(2) The reason for selection of shell temper, in terms of vessel properties, should differ from place to place as the use, raw materials, and manufacturing processes differ.
(3) Change in firing strategies should correspond to changes in fuel availability as evident from wood use.

The first consequence is borne out to some degree in the southern portion of the American Bottom. Not only does wood use change, but firing also appears to have changed prior to any frequent use of shell-tempering, if ceramic color is any clue. Middle Woodland ceramics are predominantly reddish orange but darker colors become more prominent during the later Woodland/Early Mississippian period (Kelly *et al*., 1983; Fortier *et al*., 1983). Shell tempering rose in frequency after the color change.

CONCLUSIONS

The explanation for the rise in frequency of shell-tempered pottery that I have offered here can in no way be considered conclusive. The data are sketchy and the evidence sparse. Detailed technical analysis is not available for most localities. When more is known, the proposed scenario will no doubt seem simplistic, if not wrong. The purpose of this paper has been not to arrive at an explanation but rather to illustrate what an explanation might look like. I hope to have identified critical points that need exploring and have offered a beginning hypothesis that can be tested empirically. These points can be summarized as follows:

(1) Detailed information on the temporal and spatial distribution of shell-tempered pottery is lacking. We need to be able to trace changing frequencies of shell-tempered pottery from place to place. This is not a simple task and will probably involve dating individual sherds by, for example, luminescence.

(2) Much more information is need on the physical properties of prehistoric ceramics, both their performance values (how ceramics compare in mechanical strength, thermal shock resistance, portability, permeability, containment properties, etc.) and production costs. The latter includes detailed information on firing strategies, which is particularly important given the thermal behavior of calcium carbonate. Information is also needed on the selective context of the ceramics, to the extent that it can be known. How do different ceramic properties correlate with each other (perhaps the most tractable clues, as, for example, the correlation of slips with early shell-tempering) and how do ceramics correlate with other aspects of subsistence (for shell-tempering, the correlation with maize agriculture needs particular attention.)

(3) Finally, explaining technological change requires consideration of the scale at which evolution occurs. I have illustrated how selection at two scales, minimally, is required to explain rise in frequency of shell-tempered pottery during the Late Prehistoric period of eastern North America.

It is essential that hypotheses about the rise in frequency of shell-tempered pottery are empirically testable. Osborn's speculation (1988) about the relationship between maize and shell-tempering remains just that – speculation – unless empirical tests are devised that can allow falsification. I have tried to offer a hypothesis based on firing strategies that can be tested by, among other things, documenting changes in firing patterns in different parts of the eastern Woodlands. Too often speculations about technological change are so far removed from the archaeological record as to be not only useless, but, by asking the wrong kinds of questions, to underestimate the value of the long term record of change archaeology provides.

From a larger perspective, the method proposed here of integrating both functional information and unique historical trajectories can hopefully find use in the understanding of prehistoric technological change in general, and get beyond the processural/post-processural debate that seems to dwell in either the functional or historical camp but not both. (For another example of the fruitful approach of combining the functional and historical, see Pierce, 2005.) A strictly functional approach cannot account for the source of change (why shell temper and not some other way to increase strength), only its direction. A strictly historical approach cannot account for direction (why did shell-tempering become fixed at the near exclusion of all other temper kinds), just source. In either case, mere description appears to substitute for explanation, cause being assumed by simply specifying the conditions of change rather than positing a mechanism. For a functionalist specifying certain external pressures seems sufficient to explain changes; for a historicalist specifying the ceramic tradition seems sufficient. In this paper I have tried instead to look at the intersection of both, proposing various mechanisms, primarily selection, to account for changing frequencies of variants.

ACKNOWLEDGMENTS

Some of the research reported in this paper was funded through a fellowship to the former Conservation Analytical Laboratory, Smithsonian Institution. Several individuals there assisted in the project, including my supervisor, Pamela Vandiver. Luminescence dating results were made possible by the National Science Foundation. Leopold May and the Catholic University of America donated time in the Mössbauer study. Other work was performed at the University of Washington through the Departments of Materials Science, Civil Engineering and Anthropology. William D. Scott, professor of Materials Science, assisted with the mechanical tests. Archaeological materials were provided by Robert C. Dunnell, who also leant intellectual guidance and labored through several earlier versions. Robert Leonard and Lee Lyman provided valuable comments.

REFERENCES CITED

Allsbrook, R. C. (1995). Limestone, grog and shell: an intemperate view of pottery temper in the Tennessee Valley. Paper presented at the 60th annual meeting of the Society for American Archaeology, Minneapolis.

Arnold, D. E. (1985). *Ceramic Theory and Cultural Process*, Cambridge University Press, Cambridge.

Baudran, A., and Deplus, C. (1959). The rheological behavior of clay bodies. *Transactions of the British Ceramic Society* **58**: 454–469.

Benn, D. W., and Green, W. (2000). Late Woodland cultures in Iowa. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 429–496.

Bense, J. (1994). *Archaeology of the Southeastern United States: Paleoindian to World War I*, Academic Press, San Diego.

Blitz, J. H. (1993). *Ancient Chiefdoms of the Tombigbee*, University of Alabama Press, Tuscaloosa.

Blitz, J. H., and Lorenz, K. G. (2002). The Early Misssissippian frontier in the Lower Chattahoochee-Apalachicola River valley. *Southeastern Archaeology* **21**: 117–135.

Brashler, J. G., Garland, E. B., Holman, M. B., Lovis, W. L., and Martin, S. R. (2000). Adaptive strategies and socioeconomic systems in northern Great Lakes riverine environments: the Late Woodland of Michigan. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 543–579.

Bronitksy, G., and Hamer, R. (1986). Experiments in ceramic technology: the effects of various tempering materials on impact and thermal shock resistance. *American Antiquity* **51**: 89–101.

Cannon, M. D., Madsen, M. E., and Lipo, C. P. (1998). "Wasteful" behavior in evolutionary and ecological perspective. Paper presented at the 63rd annual meeting of the Society for American Archaeology, Seattle, WA.

Cole, F.-C., and Deuel, T. (1937). *Rediscovering Illinois: Archaeological Explorations in and around Fulton County*, University of Chicago Press, Chicago.

Dawkins, R. (1982). *The Extended Phenotype: the Gene as the Unit of Selection*, W. H. Freeman, Oxford.

Delaney-Rivera, C. (2004). From edge to frontier: Early Mississippian occupation of the Lower Illinois River valley. *Southeastern Archaeology* **23**: 41–56.

Deuel, T. (1937). The application of a classificatory method to Mississippi Valley archaeology. In Cole, F.-C., and Deuel, T. (eds.) *Rediscovering Illinois: Archaeological Explorations in and around Fulton County*, Appendix I, University of Chicago Press, Chicago, pp. 207–219.

Dunnell, R. C. (1978). Style and function: a fundamental dichotomy. *American Antiquity* **43**: 192–202.

Dunnell, R. C. (1986). Methodological issues in Americanist artifact classification. In Schiffer, M. B. (ed.) *Advances in Archaeological Method and Theory*, Vol. 9, Academic Press, New York, pp. 149–207.

Dunnell, R. C. (1989). Aspects of the application of evolutionary theory in archaeology. In Lamberg-Karlovsky, C. C. (ed.), *Archaeological Thought in America*, Cambridge University Press, New York, pp. 35–49.

Dunnell, R. C. (1995). What is it that actually evolves? In Teltser, P. (ed.), *Evolutionary Archaeology: Methodological Issues*, University of Arizona Press, Tucson, pp. 33–50.

Dunnell, R. C. (1999). The concept of waste in an evolutionary archaeology. *Journal of Anthropological Archaeology* **18**: 243–250.

Dunnell, R. C. (2006). Measuring relatedness. In Lipo, C. P., O'Brien, M. J., Collard, M., and Shennan, S. J. (eds), *Mapping our Ancestors: Phylogenetic Approaches in Anthropology and Prehistory*, Aldine Transaction, New Brunswick, N. J., pp. 109–116.

Dunnell, R. C., and Feathers, J. K. (1991). Late Woodland manifestations of the Malden Plain, Southeast Missouri. In Nassaney, M. S., and Cobb, C. R. (eds.), *Stability, Transformation, and Variation: the Late Woodland Southeast*, Plenum Press, New York, pp. 21–45.

Dunnell, R. C., and Feathers, J. K. (1994). Thermoluminescence dating of surficial archaeological material. In Beck, C. (ed.), *Dating in Exposed and Surface Context*, University of New Mexico Press, Albuquerque, pp. 115–137.

Eldridge, N. (1985). *Unfinished Synthesis*, Oxford University Press, Oxford.

Emerson, T. E. (1991). *Cahokia and the Hinterlands*, The Apple River Mississippian culture of northwestern Illinois. 164–182.

Emerson, T. E., and Lewis, R. B. (eds.) (1991). *Cahokia and the Hinterlands*, University of Illinois Press, Urbana.

Farnsworth, K. B., Emerson, T. E., and Glenn, R. M. (1991). Patterns of Late Woodland/Mississippian interaction in the Lower Illinois Valley drainage: a view from Starr Village. In Emerson, T. E., and Lewis, R. B. (eds.), *Cahokia and the Hinterlands*, University of Illinois Press, Urbana, pp. 83–118.

Faulkner, C. H. (1972). The Mississippian-Woodland transition in the middle South. *Bulletin of the Southeastern Archaeological Conference* **15**: 38–45.

Feathers, J. K. (1989). Effects of temper on strength of ceramics: response to Bronitsky and Hamer. *American Antiquity* **54**: 579–588.

Feathers, J. K. (1990). Explaining the evolution of prehistoric ceramics in southeastern Missouri. Ph.D. dissertation, University of Washington, Seattle.

Feathers, J. K. (1993). Thermoluminescence dating of Southeast Missouri pottery and the problem of disequilibrium. *Archeomaterials* **7**: 3–20.

Feathers, J. K., Berhane, M., and May, L. (1998). Firing analysis of south-eastern Missouri Indian pottery using iron Mössbauer spectroscopy. *Archaeometry* **40**: 59–70.

Feathers, J. K., Schiffer, M. B., Sillar, B., Tite, M. S., Kilikoglov, V., and Vekinis, G. (2003). Comments on M. S. Tite, V. Kilikoglou and G. Verkinis, 'Review article: strength, toughness and thermal shock resistance of ancient ceramics, and their influence on technological choice," *Archaeometry*, 43(3) (2001), 301–324, and reply. *Archaeometry* **45:** 163–183.

Feathers, J. K., and Scott, W. D. (1989). A prehistoric ceramic composite from the Mississippi Valley. *American Ceramic Society Bulletin* **68**: 554–557.

Ford, J. A. (1936). *Analysis of Indian village site collections from Louisiana and Mississippi*, Louisiana State Geological Survey, Department of Conservation, Anthropological Study No. 2.

Ford, J. A. (1952). Measurements of some prehistoric design developments in the southeastern states. *Anthropological Papers of the American Museum of Natural History* **44**(3), New York.

Fortier, A. C., and Jackson, D. K. (2000). The formation of a Late Woodland heartland in the American Bottom, Illinois cal A.D. 650–900. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 123–147.

Fortier, A. C., Lacampagne, R. B., and Finney, F. A. (1983). *The Fish Lake Site*. American Bottom Archaeology, FAI-270 Site Reports, Vol. 8. University of Illinois Press, Urbana.

Futato, E. M. (1987). *Archaeological Investigations at Shell Bluff and White Springs, Two Late Woodland Sites in the Tombigbee River Multi-Resource District*. Report of Investigations No. 20. Office of Archaeological Research, Alabama State Museum of Natural History, University of Alabama, University, Alabama.

Garland, E. B. (1992). *The Obion Site: An Early Mississippian Center in Western Tennessee*. Report of Investigations No. 7, Cobb Institute of Archaeology, Mississippi State University, Mississippi State.

Gleach, F. W. (1988). A rose by any other name: questions on Mockley chronology. *Journal of Middle Atlantic Archaeology* **4**: 85–98.

Gould, S. J., and Lewontin, R. C. (1979). The Spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme. *Proceedings of the Royal Society of London* series B, **205**: 581–598.

Gould, S. J., and Vrba, E. S. (1982). Exaptation – a missing term in the science of form. *Paleobiology* **8**: 4–15.

Griffin, J. B. (1938). The ceramic remains from Norris Basin, Tennessee. In Webb, W. S. (ed.), *An Archaeological Survey of the Norris Basin in Eastern Tennessee*, Bureau of American Ethnology Bulletin 118, pp. 253–358.

Griffin, J. B. (1939). Report on the ceramics of Wheeler Basin. In Webb, W. S. (ed.), *An Archaeological Survey of Wheeler Basin on the Tennessee River in Northern Alabama*, Bureau of American Ethnology Bulletin 122, pp. 127–165.

Hall, R. L. (1991). Cahokia identity and interaction models of Cahokia Mississippian. In Emerson, T. E., and Lewis, R. B. (eds.), *Cahokia and the Hinterlands*, University of Illinois Press, Urbana, pp. 3–34.

Hammerstedt, S. W. (2001). Late Woodland and Mississippian settlement of the Black Warrier valley: a preliminary assessment. *Journal of Alabama Archaeology* **47**: 1–45.

Hasselman, D. P. H. (1969). Unified theory of thermal shock fracture initiation and crack propagation in brittle ceramics. *Journal of the American Ceramic Society* **52**: 600–604.

Hoard, R. J. (2000). Late Woodland in central Missouri, the Boone phase. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 211–239.

Hoard, R. J., O'Brien, M. J., Khorasgany, M. G., and Gopalaratmam, V. S. (1995). A materials-science approach to understanding limestone-tempered pottery from the Midwest. *Journal of Archaeological Science* **22**: 823–832.

Hoffman, J. L. (1984). The Plains village: the Custer Phase. In Bell, R. E. (ed.), *Prehistory of Oklahoma*, Academic Press, New York, pp. 287–305.

Holmes, W. H. (1903). Aboriginal pottery of the Eastern United States. *Twentieth Annual Report of the Bureau of American Ethnology*, 1898–1899, pp. 1–201. Washington, D.C.

Hull, D. L. (1980). The units of evolution. In Jensen, U. J., and Harre, R. (eds.), *Studies in the Philosophy of Evolution*, The Harvester Press, London, pp. 23–44.

Hull, D. L. (1989). *The Metaphysics of Evolution*, State University of New York Press, Albany.

Jackson, P. D. (2004). Co-existence of the West Jefferson and Moundville I phases. *Journal of Alabama Archaeology* **50**: 1–17.

Jenkins, N. J. (1981). *Gainesville Lake Area Ceramic Descriptions and Chronology*. Report of Investigations 12, Office of Archaeological Research, University of Alabama, Tuscaloosa.

Jenkins, N. J. (1982). *Archaeology of the Gainesville Lake Area: Synthesis*. Report of Investigations 23, Office of Archaeological Research, University of Alabama, Tuscaloosa.

Jenkins, N. J. (2003). The terminal Woodland/Mississippian transition in west and central Alabama. *Journal of Alabama Archaeology* **49**: 1–62.

Jenkins, N. J., and Krause, R. A. (1986). *The Tombigbee Watershed in Southeastern Prehistory*, University of Alabama Press, Tuscaloosa.

Johannessen, S. (1984). Paleoethnobotony. In Bereis, C. J., and Potter, J. W. (eds.), *American Bottom Archaeology*, University of Illinois Press, Urbana, pp. 197–214.

Jones, G. T., Leonard, R. D., and Abbott, A. L. (1995). The structure of selectionist explanations in archaeology. In Teltser, P. A. (ed.), *Evolutionary Archaeology: Methodological Issues*, University of Arizona Press, Tucson, pp. 3–32.

Kelly, J. E. (1990a). Range site community patterns and the Mississippian Emergence. In Smith, B. D. (ed.), *The Mississippian Emergence*, Smithsonian Institution Press, Washington, D. C., pp. 67–122.

Kelly, J. E. (1990b). The emergence of Mississippian culture in the American Bottom region. In Smith, B. D. (ed.), *The Mississippian Emergence*, Smithsonian Institution Press, Washington, D. C., pp. 123–152.

Kelly, J. E., Fortier, A. C., Ozuk, S. J., and Williams, J. A. (1983). *The Range Site: Archaic through Late Woodland Occupations*, American Bottom Archaeology, FAI-270 Site Reports, Vol.16, University of Illinois Press, Urbana.

Kidder, T. R. (1998). Mississippi mound groups and communities in the Lower Mississippi Valley. In Lewis, R. B., and Stout, C. (eds.), *Mississippian Towns and Sacred Spaces*, The University of Alabama Press, Tuscaloosa, pp. 123–150.

Knight, V. J., Jr. (1979). Ceramic stratigraphy at the Singer-Moye site. *Journal of Alabama Archaeology* **25**: 138–151.

Lafferty, R. H., III, and Price, J. E. (1996). Southeast Missouri. In McNutt, C. H. (ed.), *Prehistory of the Central Mississippi Valley*, The University of Alabama Press, Tuscaloosa, pp. 1–46.

Leonard, R. D., and Jones, G. T. (1987). Elements of an inclusive evolutionary model for archaeology. *Journal of Anthropological Archaeology* **6**: 199–219.

Lewis, T. M. N., and Kneberg, M. (1946). *Hiwassee Island: An Archaeological Account of Four Tennessee Indian Peoples*, University of Tennessee Press, Knoxville.

Lipo, C. P. (2001). *Science, style and the study of community structure: an example from the central Mississippi River valley*, British Archaeological Reports S918, Archaeopress, Oxford.

Lipo, C. P., Madsen, M. E., Dunnell, R. C., and Hunt, T. (1997). Population structure, cultural transmission, and frequency seriation. *Journal of Anthropological Anthropology* **16**: 301–333.

Lynott, M. J. (1986). Two emergent Mississippian sites in the eastern Ozarks, Southeast Missouri. Paper presented at the 51st annual meeting of the Society for American Archaeology, New Orleans.

Lynott, M. J., and Price, J. E. (1989). The Late Woodland to emergent Mississippian transition in the eastern Ozark region, Southeast Missouri. Paper presented at the 54th annual meeting of the Society for American Archaeology, Atlanta.

Mainfort, R. C., Jr. (1996). The Reelfoot Lake Basin, Kentucky and Tennessee. In McNutt, C. H. (ed.), *Prehistory of the Central Mississippi Valley*, The University of Alabama Press, Tuscaloosa, pp. 77–96.

Mann, S. (1990). Crystal engineering: the natural way. *New Scientist* **125**(March 10): 42–47.

March, B. (1934). *Standards of pottery description*. Occassional Contributions from the Museum of Anthropology of the University of Michigan No. 3, Ann Arbor.

McKern, W. C. (1939). The Midwestern Taxonomic Method as an aid to archaeological study. *American Antiquity* **4**: 301–313.
Million, M. G. (1975). Ceramic technology of the Nodena phase people (ca. AD1400-1700). *Southeast Archaeological Conference Bulletin* **18**: 201–208.
Milner, G. R. (1983a). *The Robinson's Lake Site*. American Bottom Archaeology, FAI-270 Site Reports, Vol. 10, University of Illinois Press, Urbana.
Milner, G. R. (1983b). *The Turner and DeMange Sites*. American Bottom Archaeology, FAI-270 Site Reports, Vol. 10, University of Illinois Press, Urbana.
Mistovich, T. S. (1988). Early Mississippian in the Black Warrior Valley: the pace of transition. *Southeastern Archaeology* **7**: 21–38.
Moffat, C. R. (1991). Mississippian in the Upper Kaskaskia Valley: new data from Lake Shelbyville and new interpretations. In Emerson, T. E., and Lewis, R. B. (eds.) *Cahokia and the Hinterlands*, University of Illinois Press, Urbana, pp. 239–256.
Morse, D. F., and Morse, P. (1983). *Archaeology of the Central Mississippi Valley*, Academic Press, New York.
Morse, D. F., and Morse, P. (1990). Emergent Mississippian in the Central Mississippian valley. In Smith, B. D. (ed.), *The Mississippian Emergence*, Smithsonian Institution Press, Washington, D.C., pp. 153–173.
Mulvihill, T. S. (1996). Investigations of a Late Woodland site in Northeast Arkansas. Paper presented at the 53rd annual meeting of the Southeastern Archaeological Conference, Birmingham.
Nassaney, M. S. (1991). Spatial-temporal dimensions of social integration during the Coles Creek period in central Arkansas. In Nassaney, M. S., and Cobb, C. R. (eds.), *Stability, Transformation, and Variation: the Late Woodland Southeast*, Plenum Press, New York, pp. 177–220.
Nassaney, M. S., and Cobb, C. R. (1991). Patterns and processes of Late Woodland development in the greater southeastern United States. In Nassaney, M. S., and Cobb, C. R. (eds.), *Stability, Transformation, and Variation: the Late Woodland Southeast*, Plenum Press, New York, pp. 285–322.
Neiman, F. D. (1995). Stylistic variation in evolutionary perspective: inferences from decorative diversity and interassemblage distance in Illinois Woodland ceramic assemblages. *American Antiquity* **60**: 7–36.
Neiman, F. D. (1997). Conspicuous consumption as wasteful advertising: a Darwinian perspective on spatial patterns in classic Maya terminal monument dates. In Barton, C. M., and Clark, G. A. (eds.), *Rediscovering Darwin: Evolutionary Theory and Archeological Explanation*, Archaeological Papers of the American Anthropological Association, No. 7, pp. 267–290.
O'Brien, M. J. (1987). Sedentism, population growth, and resource selection developments. *Current Anthropology* **28**: 177–197.
O'Brien, M. J., and Wood, W. R. (1998). *The Prehistory of Missouri*, University of Missouri Press, Columbia.
Osborn, A. (1988). Limitations of the diffusionist approach: evolutionary ecology and shell-tempered ceramics. In Hugill, P. J., and Dickson, D. B., *The Transfer and Transformation of Ideas and Material Culture*, Texas A&M University Press, College Station, pp. 23–44.
Phelps, D. S. (1983). Archaeology of the North Carolina coast and coastal plain: problems and hypotheses. In Mathis, M. A., and Crow, J. J. (eds.), *The Prehistory of North Carolina*, North Carolina Division of Archives and History, Raleigh pp. 1–51.
Phillips, P., Ford, J. A., and Griffin, J. B. (1951). *Archaeological Survey in the Lower Mississippi Alluvial Valley, 1940–1947*, Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 25.
Pierce, C. (2005). Reverse engineering the ceramic cooking pot: cost and performance properties of plain and textured vessels. *Journal of Archaeological Method and Theory* **12**: 117–157.
Pollack, D., and Henderson, A. G. (2000). The Late Woodland cultures in Kentucky. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 613–641.
Price, J. E. (1986). Emergent Mississippian occupation in the southeastern Ozarks of Missouri. Paper presented at the 51st annual meeting of the Society for American Archaeology, New Orleans.
Prufer, O. H., and Shane, O. C., III (1970). *Blain Village and the Fort Ancient Tradition in Ohio*, Kent State University Press, Kent, Ohio.

Rafferty, J. E. (1974). *The Development of the Fort Ancient Tradition in northern Kentucky*. PhD dissertation, University of Washington, Seattle.

Rafferty, J. E. (1986). Summary and conclusions. In Rafferty, J. E. and Starr, M. E. (eds.), *Test Excavations at Two Woodland Sites, Lowndes County, Mississippi*, Report of Investigations No. 3, Cobb Institute of Archaeology, Mississippi State University, Mississippi State, Mississippi, pp. 13–39.

Reeder, R. L. (2000). The Maramec Spring phase. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 187–209.

Rice, P. M. (1987). *Pottery Analysis: A Sourcebook*, University of Chicago Press, Chicago.

Rindos, D. and Johannessen, S. (1991). Human-plant interactions and cultural change in the American Bottom. In Emerson, T. E., and Lewis, R. B. (eds.) *Cahokia and the Hinterlands*, University of Illinois Press, Urbana, pp. 35–45.

Rolingson, M. A. (1987). An assessment of the significance of clay-tempered ceramics and platform mounds at the Toltec Mounds site. In Marshall, R. A. (ed.), *The Emergent Mississippian: Proceedings of the Sixth Mid-South Archaeological Conference*, Cobb Institute of Archaeology, Mississippi State University, Occasional Papers 87-01, pp. 107–116.

Rye, O. S. (1981). *Pottery Technology*, Manuals on Archaeology 4, Tarazacum, Washington, D. C.

Sakai, M., Urashima, K., and Inagaki, M. (1983). Energy principles of elastic-plastic fracture and its application to the fracture mechanics of a polycrystalline graphite. *Journal of the American Ceramic Society* **66**: 868–874.

Salkin, P. H. (2000). The Horicon and Kekoskee phases: cultural complexity in the Late Woodland stage in southeastern Wisconsin. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 525–542.

Schiffer, M. B. (1988). The effects of surface treatment on permeability and evaporative cooling effectiveness of pottery. In Farquhar, R. M., Hancock, R. G., and Pavlish, L. A. (eds.), *Proceedings of the 26th International Archaeometry Symposium*, Archaeometry Laboratory, University of Toronto, Toronto, Canada, pp. 23–29.

Schiffer, M. B. (1990). The influence of surface treatment on heating effectiveness of ceramic vessels. *Journal of Archaeological Science* **17**: 373–381.

Schiffer, M. B., and Skibo, J. M. (1987). Theory and experiment in the study of technological change. *Current Anthropology* **28**: 595–622.

Schroedl, G. F., Boyd, C. C., Jr., and Davis, R. P. S., Jr. (1990). Explaining Mississippian origins in east Tennessee. In Smith, B. D. (ed.), *The Mississippian Emergence*, Smithsonian Institution Press, Washington, D. C., pp. 175–196.

Seckinger, E. W., Jr., and Jenkins, N. (2000). A plural society in prehistoric Alabama. *Journal of Alabama Archaeology* **46**: 43–57.

Seeman, M. F., and Dancey, W. S. (2000). The Late Woodland period in southern Ohio: basic issues and prospects. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 583–611.

Shennan, S. J., and Wilkinson, J. R. (2001). Ceramic style change and neutral evolution: a case study from Neolithic Europe. *American Antiquity* **66**: 577–593.

Skibo, J. M. (1992). *Pottery Function: a Use-alteration Perspective*, Plenum Press, New York.

Skibo, J. M., and Schiffer, M. B. (2001). Understanding artifact variability and change: a behavioral framework. In Schiffer, M. B. (ed.), *Anthropological Perspectives on Technology*, University of New Mexico Press, Albuquerque, pp. 139–149.

Simon, M. L. (2000). Regional variations in plant use strategies in the Midwest during the Late Woodland. In Emerson, T. E., McElrath, D. L., and Fortier, A. D. (eds.), *Late Woodland Societies: Tradition and Tranformation across the Midcontinent*, University of Nebraska Press, Lincoln, pp. 37–75.

Smith, B. D. (1986). The archaeology of the Southeastern United State: from Dalton to deSoto, 10,500-500 B.P. *Advances in World Archaeology* **5**: 1–92.

Smith, G. P. (1996). The Mississippi River drainage of western Tennessee. In McNutt, C. H. (ed.), *Prehistory of the Central Mississippi Valley*, The University of Alabama Press, Tuscaloosa, pp. 97–118.

Squier, E. G., and Davis, E. H. (1848). *Ancient Monuments of the Mississippi Valley*, Vol. 1, Smithsonian Contributions to Knowledge, Washington, D. C.

Stephensen, R. L. (1963). The artifacts. In Stephensen, R. L., and Ferguson, A. L. L. (eds.) *The Accokeek Creek Site: a Middle Atlantic Seaboard Culture Sequence,* Anthropological Papers, Museum of Anthropology, University of Michigan No. 20, pp. 82–168.

Steponaitis, V. P. (1983). *Ceramics, Chronology, and Community Patterns: an Archaeological Study of Moundville*, Academic Press, New York.

Steponaitis, V. P. (1984). Technological studies of prehistoric pottery from Alabama: physical properties and vessel function. In van der Leeuw, S. E., and Pritchard, A. C. (eds.), *The Many Dimensions of Pottery*, University of Amsterdam, Amsterdam, pp. 79–127.

Steponaitis, V. P. (1986). Prehistoric archaeology in the Southeastern United States, 1970–1985. *Annual Review of Anthropology* **15**: 363–404.

Swanton, J. R. (1946). *The Indians of the Southeastern United States*, Bureau of American Ethnology Bulletin 137.

Teltser, P. A. (1993). An analytical strategy for studying assemblage scale ceramic variation: a case study from southeast Missouri. *American Antiquity* **58**: 530–543.

Tillman, D. A. (1991). *The Combustion of Solid Fuels and Wastes*, Academic Press, San Diego.

Turnbow, C. A., and Henderson, A. G. (1992). Ceramic analysis. In Henderson, A. G. (ed.), *Fort Ancient Cultural Dynamics in the Middle Ohio Valley*, appendix, Prehistory Press, Madison, pp. 295–382.

Ullman, K. L. (1985). *The ceramics from the Kramer village site (33Ro33), Ross County, Ohio*. Kent State Research Papers in Archaeology No. 5. Kent State University Press, Kent, Ohio.

Vrba, E. S., and Gould, S. J. (1986). The hierarchical expansion of sorting and selection: sorting and selection cannot be equated. *Paleobiology* **12**: 217–228.

Worrall, W. E. (1986). Clays and Ceramic Raw Materials. *Elsevier Applied Science Publishers*, London.

Wedel, W. R. (1986). *Central Plains Prehistory*, University of Nebraska Press, Lincoln.

Welch, P. D. (1990). Mississippian emergence in west central Alabama. In Smith, B. D. (ed.), *The Mississippian Emergence*, Washington, D. C, pp. 197–225.

Welch, P. D. (1994). The occupational history of the Bessemer site. *Southeastern Archaeology* **13**: 1–26.

Welch, P. D. (1998). Middle Woodland and Mississippian occupations of the Savannah site in Tennessee. *Southeast Archaeology* **17**: 79–92.

West, S. M. (1992). *Temper, thermal shock and cooking pots: a study of tempering materials and their physical significance in prehistoric and traditional cooking pottery.* Unpublished M.Sc. thesis, University of Arizona, Tucson.