A GIBBS SAMPLER APPROACH TO THE DATING OF PHASES IN THE MOUNDVILLE SEQUENCE

Vernon James Knight, Jr., Lyle W. Konigsberg, and Susan R. Frankenberg

Vernon James Knight, Jr, Department of Anthropology, University of Alabama, Box 870210, Tuscaloosa, AL 35487-0210

Lyle W. Konigsberg and Susan R. Frankenberg, Department of Anthropology, University of Tennessee, 252 South Stadium Hall, Knoxville, TN 37996-0720

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ABSTRACT

The Gibbs sampler is a method for analyzing groups of ^{14}C dates where there is archaeological information about the relationship between the dated contexts. Applying the Gibbs sampler to 107 dates from five phases of the Moundville sequence in the Black Warrior Valley, Alabama results in newly simulated and refined phase boundaries and phase durations expressed on the calendar scale. In addition, we use the Gibbs sampler to investigate the controversial claim of a chronological overlap between the Terminal Woodland West Jefferson phase and the Early Moundville I phase.

Current attempts to model the rise, internal development, and decline of Mississippian societies are tied, more often than not, to ceramic phase chronologies (see, e.g., the papers in Scarry 1996). As these chronologies inevitably undergo refinement, there is a greater need for precision in assigning calendar dates to these units. Obviously, in all such diachronic reconstructions, whether or not they are based on phase constructs, the caliber of the regional chronometric database is a critical component. In light of that there are at present 138 "absolute" dates for Moundville and related sites in the Black Warrior Valley of Alabama. Most of these were obtained in the last 15 years and many are presented here for the first time.

For the Moundville sequence, not only has the quantity of available dates burgeoned in recent years, but the quality and complexity of the regional chronometric database also have steadily improved. To give a few examples: (a) There has been a more concerted effort to appropriately sample contexts of interest. (b) The database has been enriched by the addition of thermoluminescence and paleomagnetic dates. (c) The AMS technique has been increasingly applied to the problem of small samples. (d) There has been a growing awareness and use of $^{13}C/^{14}C$ isotope ratios in correcting dates. (e) Interpretation of radiocarbon dates has been enhanced and simplified by the availability of high precision ^{14}C calibration curves and widely distributed computer software such as Washington University's CALIB program (Stuiver and Reimer 1993).

Despite this improvement, no effort has been made to reassess the calendar dating of the regional phase sequence currently in use (Figure 1). At the time this sequence of ceramic phases was first worked out by Steponaitis (1980, 1983), absolute dates were few. For example, in the absence of any radiocarbon dates, the Moundville II phase had to be guess-dated, while the calendar placement of Moundville III had to rely on a single assay on related materials from outside the Black Warrior Valley. None of the available dates, moreover, were calibrated.

Clearly, enough data are now available to put the dating of this phase sequence on a much firmer footing. Why should we be concerned with such a refinement? Not merely for the sake of calibration, or for the satisfaction of being more precise. Rather, with better controls available, there has been increasing interest in documenting certain processes and rates of occurrence associated with social and political changes. Such measurements often require estimates of the length of ceramic phases on the calendar scale. For example, Steponaitis (1998) attempts to track the frequency of burials through time at Moundville, and compares this with the deposition rate of sherds through time at the site. Both measurements require estimates of phase duration.

THE DATES AND ACCOMPANYING ISSUES

Tables 1-6 present those dates, 107 in number, that are judged to be conservatively associated with the material culture of a specific ceramic phase of the late prehistoric/ protohistoric sequence in the Black Warrior Valley. They come from the Black Warrior Valley exclusively; it is no longer necessary to rely upon "cognate" dates on comparable material culture from adjacent regions, such as those from the Lubbub Creek locality in the Tombigbee Valley. The first five tables list the radiocarbon dates by ceramic phase, ordered by uncalibrated date. Where available, $^{13}C/^{14}C$ ratios are given in per mil units with the corresponding adjusted age. Table 6 adds three paleomagnetic dates for the Moundville I phase and two thermoluminescence dates for the Moundville III phase.

The dates are associated with the following five ceramic phases: West Jefferson, Moundville I, Moundville II, Moundville III, and Moundville IV (the latter called Alabama River phase in much of the literature). It will be important for the following discussion to tell exactly what these entities are and to make explicit their relationship to each other. How these matters are conceptualized has a bearing on how the analysis is handled. Figure 2 is a chart showing the main pottery diagnostics for each phase. It is straightforwardly adapted from Steponaitis's original seriation and stratigraphic studies, with minor modifications based on the best current information. Artifact assemblages meeting a certain size threshold (which need not be discussed here) and which derive from relatively undisturbed midden and feature contexts are assigned to a phase based on what are essentially type fossils. The type fossils consist of a combination of defined ceramic type-varieties, decorative modes, and modes of vessel shape. One will note that it is the introduction, rather than the relative frequency, of each diagnostic that is important. As modeled from seriation and stratigraphic evidence, new stylistic features are introduced gradually throughout the sequence. For each phase several such features are modeled as concurrent introductions, for all practical purposes. It is these introductions that define the phase boundaries, in effect defining a terminus post quem for each segment of the sequence. For example, a large assemblage that contains any quantity of beaded rims, slab bases on bottles, or sherds classifiable as Moundville Engraved, *var. Wiggins*, individually or severally, and that also lacks Carthage Incised *var. Carthage* or any of its companion ceramic forms, is by definition a Late Moundville II phase assemblage.

Thus construed, there are no gaps between phases and there is no overlap between phases. A primary assumption is that new ceramic styles in the sequence were introduced rapidly and uniformly throughout the Black Warrior Valley, such that any time lag would be negligible and that contemporaneous site components within the valley would share the same repertoire of basic ceramic styles. Many of the ceramic markers in the Moundville sequence are, in fact, recognizable at a broader scale as horizon styles that appear concurrently in similar form across large areas of the Southeast.

A brief scan of the uncalibrated radiocarbon assays for each phase reveals that each batch has an easily identified "core" of dates. Gratifyingly, these core dates follow from phase to phase in the expected order, and they correspond within reason to Steponaitis's original estimates. Each batch also contains outliers, however, that naggingly overlap with the dates from adjacent phases, both on the early and late ends. Some of these outliers are fairly egregious, centuries removed from any reasonable estimate of the age of the phase. No effort has been made to purge the tables of these obvious "bad apples." Other dates are impressionistically closer to the core, but still overlap with dates from other phases in a manner seemingly in violation of the dictum just presented. All large series of radiocarbon dates possess such outliers, and to that extent, dealing with them has to be a priority. Methodologically, the policy adopted here will be to grant primacy to the model, and thus to disregard those dates that violate the dictum of no overlap between adjacent phases. An explicit and justifiable procedure for identifying such dates is required.

Some of the apparent overlap, of course, is merely due to the nature of the dates as probability distributions, and in fact some sets of outliers do resemble the tails of a sampling distribution. Other "bad" dates, in the sense of statistically irreconcilable ones, signal problems mostly having to do with the fact that what is actually being dated, in all these cases, is carbon, not the artifacts or features recorded in hopeful association with it. Errors can occur in the selection of appropriate samples, and contamination can occur during field recovery, in subsequent handling, or during the pretreatment process in the radiocarbon laboratory. Seemingly too recent outliers may result from contamination by modern carbon, although obvious cases of such contamination in the present batch appear to be few. Based on the facts at hand one can deduce that a much more acute problem, at least at the Moundville site, is that of "old" carbon, an issue to which we will return at the end. As will be seen, patterning among the early outliers has something to tell us about the phenomenon of redeposition at the site.

APPLICATION OF THE GIBBS SAMPLER METHOD

Ideally, in choosing an approach to analyzing the dates, the fact that we possess a fair amount of archaeological information derived from stratigraphy and seriation about ceramic phases and their relative order should carry some weight. Such tools as the CALIB program allow one to calibrate the dates individually, or to combine the distributions in those few cases where multiple dates are available from precisely the same context. What is needed, however, is a method capable of incorporating the archaeological information directly in the analysis, rather than merely calibrating the dates and afterward judging to what degree they agree or fail to agree with the archaeology. What is called for is, in short, an archaeologically informed method of working with batches of dates.

Just such a methodology has been worked out in recent years, principally in England. The procedure begins with calibrated radiocarbon date distributions, as in the example shown in Figure 3. This graphic, generated using the OxCal program (Bronk Ramsey 1995), depicts a Moundville II phase date from Mound G at Moundville. On the left-hand side is the curve representing the ^{13}C adjusted date with its error term expressed in radiocarbon years BP, in this case 660 ± 60. Winding across the chart from the upper left side is the appropriate segment of the high precision calibration curve of Stuiver and Pearson (1986), its width representing one standard deviation. At the bottom is the resulting calibrated date distribution. Note that this particular calibrated distribution is distinctly bimodal, with separate peaks at about AD 1300 and AD 1370 caused by a pronounced "knot" in the calibration curve. Because of it, all dates in this neighborhood will have bimodal calibrated distributions, making it difficult to discriminate between early versus late dates in the fourteenth century AD. This problem aside, the issue before us is to consider these calibrated distributions not in isolation but jointly, and to also incorporate any prior knowledge concerning relative ages, relevant terminus post quem (TPQ) or terminus ante quem (TAQ) ages, and non-radiocarbon assays.

This feat of incorporation can be handled by the Gibbs sampler method. The Gibbs sampler (Gelfand and Smith 1990; Smith and Roberts 1993), as applied to the archaeological case, is an iterative simulation technique that essentially re-estimates the calibrated date distributions according to archaeologically defined constraints. Initial distributions are re-sampled using a Markov Chain Monte Carlo procedure, resulting in "posterior" distributions that consist of samples from the original distributions that are consistent with the imposed constraints. From this sampling procedure, it is possible to model such things as phase durations, calendar-age boundaries between adjacent phases, probabilities associated with a specified ordering of events, the interval between two events, and so forth. If no constraints are imposed, the posterior distribution will closely approximate the initial calibrated distribution, as we simply have a simulation from the prior (calibration) distribution

Buck et al. (1992) introduced the Gibbs sampler as a method for analyzing groups of ^{14}C dates where there is archaeological information about the relationships between the dated contexts, and the method has been extensively described in Buck, Cavanagh and Litton (1996) and Litton and Buck (1996). Among their examples was the simulation of beginning and ending dates of four successive phases at Danebury, an Iron Age hillfort, using a series of phase dates basically comparable to the Moundville data used here. Phase boundaries were modeled not as specific calendar dates but rather as probability distributions. Similarly, Christen (1994) and Buck et al. (1994) applied the Gibbs sampler to the problem of estimating the calendar-age boundaries and the duration of Chancay culture on the Peruvian coast, based on a series of ^{14}C dates. They incorporated in their analysis the archaeological knowledge that Chancay is entirely pre-Columbian by specifying a terminus ante quem of 1550 AD as a constraint, being the date of Pizzaro's incursion. Importantly, Christen (1994:495-498) devotes explicit attention to the problem of outliers, devising a method to find the posterior probability that each date in a phase requires a temporal shift. During the Gibbs sampling procedure, those dates that have a high probability of requiring a temporal shift are detected, and subsequently can be deleted from the analysis. Closer to our own subject matter, Konigsberg and Frankenberg (1995) applied the Gibbs sampler to estimating the calendar age boundaries of the Mississippian Thruston phase in central Tennessee. They showed that merely by imposing the constraint that all of the dates refer to the same archaeological phase, the procedure results in shorter and more satisfactory phase boundaries than otherwise. In a second example, anticipating the present one, Konigsberg and Frankenberg used published Moundville-area ^{14}C dates to estimate the boundary between the West Jefferson and Moundville I phases, finding boundary dates about 60 to 85 years more recent than Steponaitis's original estimates. This difference, they suggest, is merely due to calibrating the dates.

The OxCal calibration program, authored by Christopher Bronk Ramsey of the Oxford Radiocarbon Accelerator Unit, is capable of all of the operations required for a Gibbs sampler analysis of the Moundville dates. This Microsoft Windows-based program is available by FTP over the World Wide Web (http://info.ox.ac.uk/departments/rlaha/oxcal/oxcal.htm). The reader is referred to the OxCal program's documentation (Bronk Ramsey 1995) for information on the mathematical methods it employs.

Before proceeding further, however, it is necessary to discuss several procedural assumptions about the archaeological record. The first two have already been mentioned, but are worth reiterating.

1. All assays assigned to a phase share a relationship to a defined segment of the material culture sequence, as independently constructed by means of stratigraphy and seriation.

2. The samples refer to abutting phases, between which there are no gaps, and between which there is no possibility of overlap. The absence of gaps or overlaps is not a necessary assumption (indeed, we will remove this assumption later in the paper), but is made here simply for convenience.

3. Information about the relative ages of the samples taken from a particular phase is unknown. (To be frank, this is not strictly true. For example, using pottery diagnostics, one can narrow down many of the dates to the subphase level, e.g., early versus late Moundville I phase. We could incorporate such information in the analysis, but it simplifies matters greatly not to do so.)

4. The samples are representative of the entire phase. Naturally, it would be difficult to simulate a phase boundary if we happened to lack dates near that boundary. Here it is enough to say that there are no known biases in the samples. Stated more positively, the data are known to include assays from both early and late subphases of each defined phase except Moundville IV.

Another issue in need of resolution is that some of the radiocarbon dates, particularly those for the West Jefferson and Moundville IV phases, do not possess $^{13}C/^{14}C$ isotope ratio corrections. Such an inconsistency is a serious matter, since these ratios, which are on the order of −26 per mil, result in uncalibrated dates several decades more recent than uncorrected dates. Bearing in mind that the goal is to approximate actual calendar dates to the extent possible, it would be best to standardize the series by estimating a correction for those dates lacking them. Fortunately such an estimate is straightforward, since the reported $^{13}C/^{14}C$ ratios are highly uniform throughout the series (mean = −27.4, stand. dev. = 1.26, range = −24.6 to −30.6). The average correction factor is −40 radiocarbon years, and the solution adopted here is to apply this average correction to all uncorrected dates.

The next step is to identify those outliers for each phase that are statistically incompatible with the remaining dates. The OxCal program employs an "agreement index," expressed as a percentage, that indicates for each date the degree to which the posterior distribution overlaps with the original calibrated distribution (its mathematical definition is given in Bronk Ramsey 1995:appendix). The smaller the overlap, the greater the lack of fit between initial and posterior distributions. In applying the agreement index during the Gibbs sampler procedure, OxCal uses a cutoff point of 60%, below which an error message is generated flagging the nonconforming outliers. Bronk Ramsey suggests that this cutoff point is similar to a 5% level disagreement in a chi squared test. As applied to the Moundville date series, separate runs of the Gibbs sampler to each pair of abutting phases detected 38 outliers not meeting this criterion, which were then deleted from the analysis. The rate of rejection is 35 percent, or about one-third of the dates.

With the dates standardized and the incompatible outliers eliminated, the Gibbs sampler can be applied to the full series of remaining dates. The OxCal run file appears as in Figure 4. Note that the dates are grouped into defined phases and the request is made to simulate the boundaries and spans of each (these are requested using the "Difference" command). Note as well that the three paleomagnetic dates for the Moundville I phase and the two thermoluminescence dates for the Moundville III phase are inserted in the appropriate places as calendar dates with associated error terms. The Gibbs sampler merely samples from these bell-shaped distributions in the same manner as from the calibrated ^{14}C distributions. Finally, a terminus ante quem (TAQ) is specified as an additional constraint. On archaeological grounds the Moundville IV phase is known to predate the establishment of French colonies on the northern Gulf Coast, as no Colonial-era artifacts have been excavated at Moundville IV phase sites. The calendar date 1699 (initial French contact) thus provides an acceptable limitation on the recent end of the series.

RESULTS

OxCal calibrates each date, and then runs the Gibbs sampler on the resulting probability distributions. After 29,456 iterations, the present run terminated reporting a final convergence of C > 97.5%. Figure 5 graphically depicts the outcomes of the simulation of each phase boundary, given as probability distributions. At one standard deviation, the corresponding calendar date ranges are as follows.

Beginning, West Jefferson	990 - 1055 AD
Boundary, West Jefferson - Moundville I	1098 - 1140 AD
Boundary, Moundville I - Moundville II	1242 - 1267 AD
Boundary, Moundville II - Moundville III	1381 - 1409 AD
Boundary, Moundville III - Moundville IV	1480 - 1550 AD
End, Moundville IV	1686 - 1699 AD

Simulated spans of each phase are shown graphically in Figure 6. At one standard deviation, the corresponding calendar-year spans are as follows.

West Jefferson	45 - 120 years
Moundville I	110 - 165 years
Moundville II	121 - 161 years
Moundville III	80 - 165 years
Moundville IV	140 - 215 years

Using the modes of each boundary distribution to draw the breakpoints, a new chronological chart can be constructed which lines up with Steponaitis's original estimates as shown in Figure 7. Some implications of these new estimates are as follows.

West Jefferson Phase

There is no getting around the fact that the actual calendar age of this Terminal

Woodland phase is quite a bit more recent than previously believed. This difference is due to two things: the effect of a 40-year shift required by $^{13}C/^{14}C$ correction, plus the effect of calibration, both of which reduce the age as expressed in uncorrected radiocarbon years. According to the analysis, the West Jefferson phase begins basically after AD 1000 and lasts until the early twelfth century AD. It is the shortest of the phases, lasting perhaps less than a century.

Moundville I Phase

Moundville I consequently starts about 70 years later than previous estimates, as Konigsberg and Frankenberg found in their study. It has a longer duration than the West Jefferson phase, lasting perhaps 140 years.

Moundville II Phase

New estimates for Moundville II are remarkably close to those originally intuited by Steponaitis, which is amazing in view of the fact that he had no Moundville II dates whatsoever to work with at the time. Moundville II begins in the middle of the thirteenth century, perhaps a decade or so after originally estimated, and lasts somewhat longer than 100 years, until about the end of the fourteenth century. Despite the difficulties associated with the grand wobble of the calibration curve in this time range, mentioned earlier, this outcome seems perfectly acceptable.

Moundville III Phase

At this point in the sequence the revised datings are again quite close to the original estimates. Moundville III spans the fifteenth century and encroaches into the sixteenth, lasting perhaps a bit more than a century.

Moundville IV Phase

An unexpected outcome of the analysis is that the Moundville III - IV phase transition is placed in the early, as opposed to the middle sixteenth century. Although it is still in the ballpark of the original estimate of AD 1550, the bulk of the probability distribution is distinctly earlier than the critical year 1540, the date of DeSoto's passage and therefore the date of important eyewitness accounts of Black Warrior Valley towns. Our radiocarbon evidence thus favors, after all, the notion that DeSoto's army encountered Moundville IV phase villages rather than late Moundville III settlements, as was earlier suspected by Peebles (1986:33) and others.

ALTERNATIVE SCENARIOS

Up to now the phases that make up the Moundville sequence have been assumed to be abutting, without any overlap. However, this assumption renders moot an archaeological issue that is actually of considerable interest and which, it may be safely said, remains incompletely resolved. Namely, it has been suggested by some that Moundville I, which is to say Mississippian, material culture *does not* uniformly and rapidly replace West Jefferson phase material culture in the Black Warrior Valley (see Steponaitis 1983:80-81). Two alternative scenarios have been suggested. In the first (Jenkins 1978; Seckinger and Jenkins 1980), West Jefferson and Moundville I material culture complexes are interpreted as the product of different, contemporaneous peoples, one indigenous Woodland and the other intrusive Mississippian. In this view, as the carriers of Mississippian material culture migrated into the Black Warrior Valley, a plural society existed for a time as the two peoples coexisted. In the second scenario (Mistovich 1988), two different peoples are not involved, but the tempo of transition from Woodland to Mississippian material culture differed measurably between the center (i.e., Moundville) and the rural periphery, whose inhabitants clung to Woodland material culture for a much longer time. Either scenario, if true, violates our assumption with regard to abutting phases.

It is worthwhile, in light of this, to reexamine the chronometric evidence. The Gibbs sampler method is easily adapted to the problem. We merely remove the constraint that these two phases do not overlap, and replace this constraint with a weaker one. Specifically, if β_2 represents the year (BP) at which the West Jefferson phase began, and α_2 represents the termination of this phase, while β_1 and α_1 represent the comparable boundaries for Moundville I, then we require that $\beta_2 > \beta_1$ and $\alpha_2 > \alpha_1$. This constraint means that the West Jefferson phase must have started before the Moundville I phase began, and that the West Jefferson phase must have ended before the Moundville I phase terminated. These constraints allow for overlapping or abutment and even gaps between phases What is not allowed is for the Moundville I phase to be earlier than the West Jefferson phase, or for the Moundville I phase to be contained entirely within the temporal boundaries for the West Jefferson phase.

The model we have described is not easily incorporated in the OxCal program, so we have resorted to writing our own program for the analysis. We give a brief synopsis of the algorithm here, but save a detailed description for elsewhere. While OxCal uses rejection sampling to sample dates and boundaries, we instead use inverse sampling (see Buck, Cavanagh, and Litton 1996:195-198 for a description of these two methods). Inverse sampling has the advantage that only one random number need be drawn to simulate any date or boundary. To simulate dates we form the cumulative distribution across yearly calendrical dates for each assay, and then constrain the simulated date to lie between phase boundaries by restricting a random uniform deviate to the two points on the cumulative distribution. To sample boundary dates we use a method given in Christen (1994), with the additional constraints that $\beta_2 > \beta_1$ and $\alpha_2 > \alpha_1$. We use a "burn-in" or "dememorization" period of 5000 iterations, and then store every 12th iteration of the Gibbs Sampler until we have sampled 10,000 times (see Christen (1994) for a discussion of "burn-in" and spacing of retained iterates). For the 10,000 Gibbs Sampler iterates we retain the beginning and ending dates for each phase. We consider the ending and starting boundaries for West Jefferson and Moundville I, respectively, as well as the difference in years between these two events. Here we take the difference as the years BP for the beginning of Moundville I minus the years BP for the end of West Jefferson. Consequently, a positive number of years represents overlapping phases, a value of zero represents abutting phases, and a negative value represents a gap.

Having made this alteration, Figures 8 and 9 show the resulting boundary distributions for the end of West Jefferson and the beginning of Moundville I, and for the overlap/gap of these two phases. At one standard deviation, the phase boundaries are as follows.

Ending date, West Jefferson	AD 1095 - 1203
Beginning date, Moundville I	AD 1049 – 1121

At one standard deviation the overlap/gap distribution runs from 2 to 125 years, while the median is 61 years (of overlap). Although part of the distribution is negative (indicating a temporal gap), this makes up a relatively small part of the distribution.

Interestingly, much remains unchanged from the analysis where we assumed that West Jefferson and Moundville I abutted. A definite shift does appear, however, between the boundary distributions for end of West Jefferson and the beginning of Moundville I, suggesting a phase overlap on the order of 60 years. It is therefore possible to conclude that a calendar-date overlap between the two sets of dated contexts is real but relatively small. Considering the fact that most of the West Jefferson dates presently available were obtained from sites on an upper fork of the Black Warrior River 54 km distant from Moundville, these are the kind of results that might be expected if Mistovich's periphery-lag model were correct, in the sense that some of the dated late West Jefferson contexts in the upper Warrior Valley could be fully contemporaneous with some of the dated early Moundville I phase contexts in the Moundville vicinity (i.e., the "Picnic Area" locality reported by Scarry [1998]).

ANOTHER LOOK AT OUTLIERS

It is certainly possible, if not highly probable, that some proportion of the outliers detected and eliminated from the analysis are not the result of contamination. One must begrudgingly consider the possibility that these dates are accurate assays of the age of the sample carbon, and that the problem lies in the association of that carbon with the artifacts. Our supposition of an "old carbon" problem at the Moundville site has been mentioned as a source of this kind of error, related to the massive scale of landscape modification and soil redeposition involved in the construction of the mound center. The history of the site is such that the great bulk of the residential occupation occurred during the Moundville I phase, with resident population much reduced thereafter (Knight and Steponaitis 1998; Steponaitis 1998). As a result, virtually all Moundville II and Moundville III phase contexts at Moundville contain anachronistically early pottery, particularly Moundville I phase diagnostics, as early residential deposits were reworked and often redeposited in the mound-building enterprise. If the pottery points to this conclusion, what of the carbon samples identified as early outliers for the later phases?

Examination of the rejected outliers associated with the early end of the Moundville II, III, and IV sets of dates shows that 8 out of 11 (73%) fall into a quite narrow time range, with uncalibrated midpoints between AD 1010 to 1190. Calibrated, these eight dates would all fall comfortably in the Moundville I phase. Thus the early-end outliers convincingly show the same pattern as the sherds. It is possible to conclude that Moundville I-era deposits containing abundant sherds and charcoal were indeed thoroughly re-worked as soils in the later history of the Moundville center and also at other mound sites, such that the sherds and the (more difficult to detect) anomalously early charcoal pervade the later contexts and contribute significantly to errors in ^{14}C dating of those contexts.

CONCLUSIONS

Availability of the high precision ^{14}C calibration curves adds much confidence to the expression of dates for archeological phases on the calendar scale, as opposed to the radiocarbon scale. The Gibbs sampler method has much to offer as a means of jointly analyzing sets of dates where prior knowledge of archaeological relationships, particularly phase and sequence relationships, can be brought to bear. Chronometric dates associated with ceramic phases in the Moundville sequence, analyzed using the Gibbs sampler, result in simulated phase boundaries and phase durations that can now be employed for a variety of purposes with a certain degree of empirical confidence.

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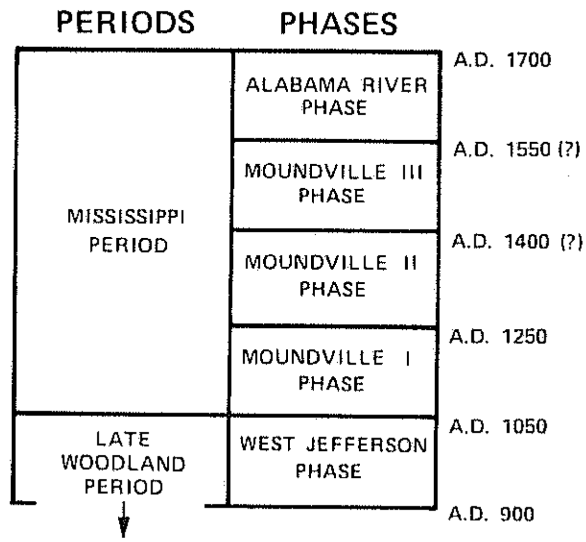

Figure 1. Moundville phase chronology currently in use. From Steponaitis (1983).

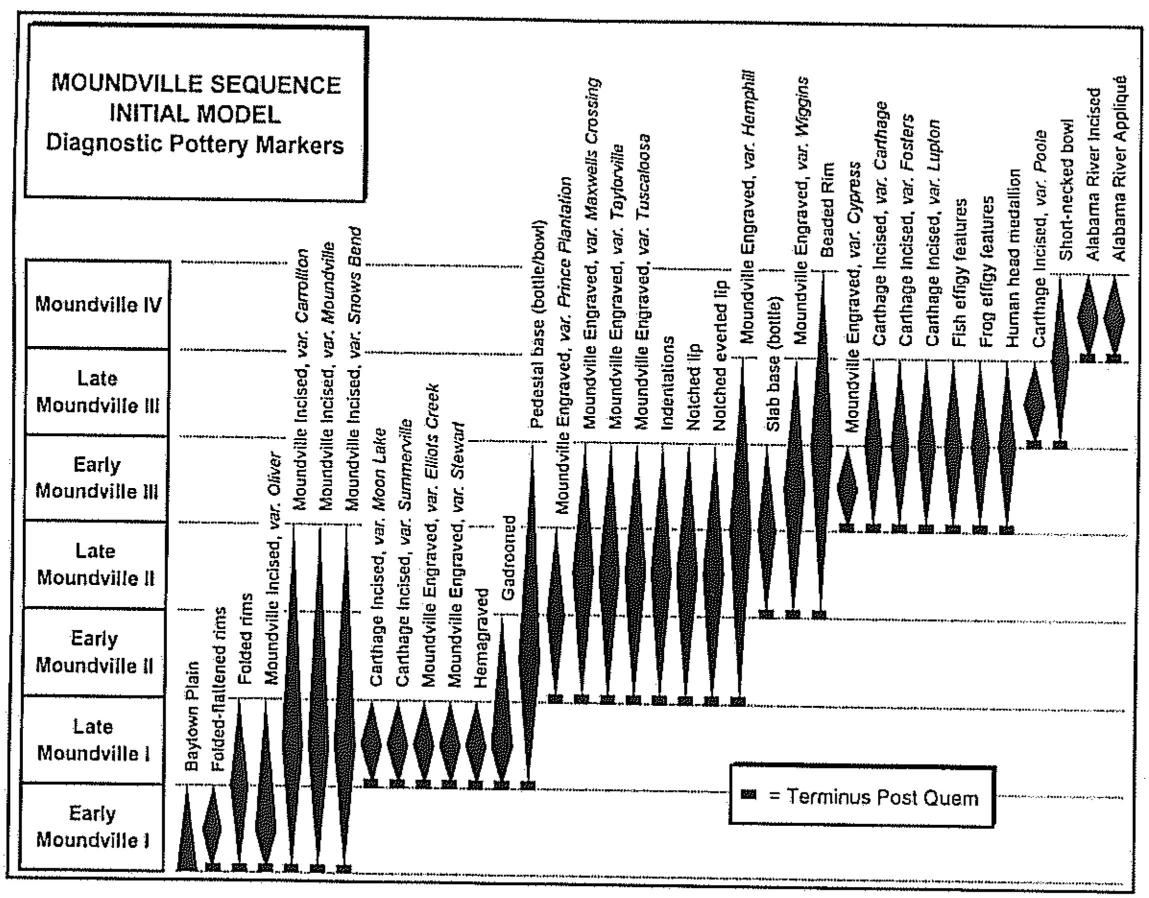

Figure 2. Pottery diagnostics for Moundville phases.

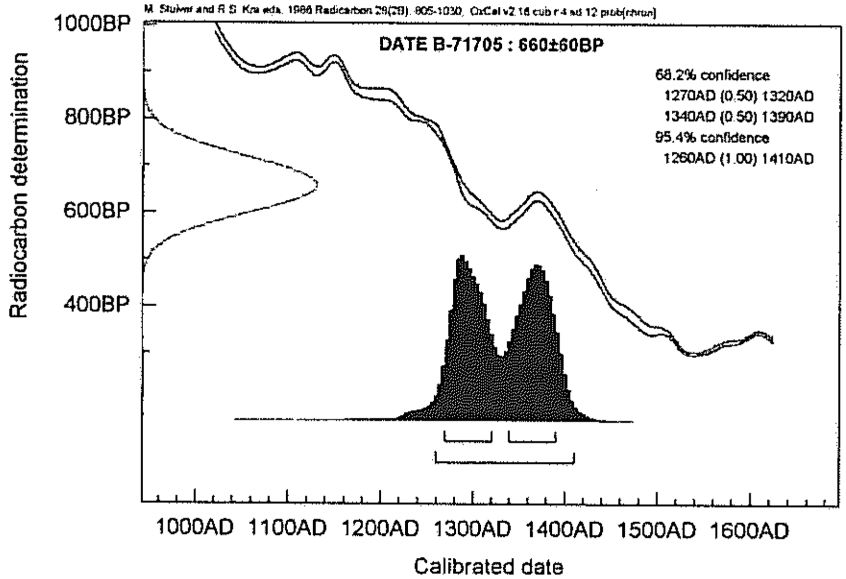

Figure 3. Example Moundville ^{14}C date calibrated using OxCal.

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SEQ "West Jeff to Mdv IV"
{
 BOUND "Start West Jeff";
 PHASE "West Jefferson"
 {
  DATE "UGa-652" 1035 70;
  DATE "UGa-633" 1010 60;
  DATE "UGa-609" 965 60;
  DATE "UGa-610" 955 65;
  DATE "UGa-624" 945 65;
  DATE "UGa-612" 905 70;
  DATE "UGa-611" 905 70;
  DATE "B-101509" 880 90;
  DATE "UGa-649" 850 75;
  DATE "UGa-625" 850 60;
  DIFF "Span West Jeff";
 };
 BOUND "West Jeff to Mdv I";
 PHASE "Moundville I"
 {
  DATE "B-71708" 1010 80;
  DATE "B-1106" 1010 80;
  DATE "B-1485" 950 65;
  DATE "B-53770" 940 90;
  DATE "B-53398" 940 70;
  DATE "B-53389" 880 70;
  DATE "B-71694" 860 60;
  DATE "B-53400" 840 70;
  DATE "UGa-1663" 840 55;
  DATE "B-1107" 835 80;
  DATE "B-68121" 830 60;
  CAL "Okla-1777" 1120 46;
  DATE "B-53771" 820 80;
  CAL "Okla-1778" 1140 15;
  DATE "B-71700" 800 70;
  DATE "B-53768" 780 90;
  DATE "B-71699" 780 60;
  DATE "B-71698" 750 70;
  DATE "B-53382" 720 120;
  CAL "Okla-1775" 1230 23;
  DIFF "Span Mdv I";
 };
 BOUND "Mdv I to Mdv II";
 PHASE "Moundville II"
 {
  DATE "B-71710" 780 50;
  DATE "B-44473" 750 60;
  DATE "B-44468" 720 80;
  DATE "B-71709" 740 50;
  DATE "B-44469" 680 50;
  DATE "B-71697" 660 70;
  DATE "B-71705" 660 60;
  DATE "B-71704" 640 70;
  DATE "B-82816" 640 70;
  DATE "B-71703" 640 50;
  DATE "B-44471" 610 60;
  DATE "B-71711" 580 50;
  DATE "B-79968" 570 70;
  DATE "B-79973" 570 50;
  DATE "B-79972" 550 60;
  DATE "B-86993" 480 80;
  DIFF "Span Mdv II";
 };
 BOUND "MDV II to Mdv III";
 PHASE "Moundville III"
 {
  DATE "B-36154" 550 50;
  DATE "B-1110" 530 80;
  DATE "B-82815" 520 60;
  DATE "B-71706" 510 60;
  DATE "B-71692" 500 60;
  DATE "B-44472" 490 60;
  DATE "B-115824" 470 70;
  DATE "B-44466" 470 60;
  DATE "B-9951" 360 50;
  DATE "B-1483" 340 65;
  CAL "Alpha-1231" 1520 50;
  CAL "Alpha-1232" 1530 40;
  DIFF "Span Mdv III";
 };
 BOUND "Mdv III to Mdv IV";
 PHASE "Moundville IV"
 {
  DATE "UGa-2036" 440 145;
  DATE "UGa-2038" 365 60;
  DATE "B-79966" 360 50;
  DATE "B-115826" 320 60;
  DATE "DIC-1249" 300 55;
  DATE "UGa-4009" 260 65;
  DATE "UGa-4005" 260 60;
  DATE "UGa-4013" 165 70;
  DATE "UGa-4008" 160 65;
  DATE "UGa-3034" 140 50;
  DATE "UGa-4006" 125 60;
  DIFF "Span Mdv IV";
 };
 BOUND "End Mdv IV";
 TAQ "French Contact"
 {
  CAL "TAQ" 1699;
 };
};
```

Figure 4. OxCal run file for Gibbs Sampler.

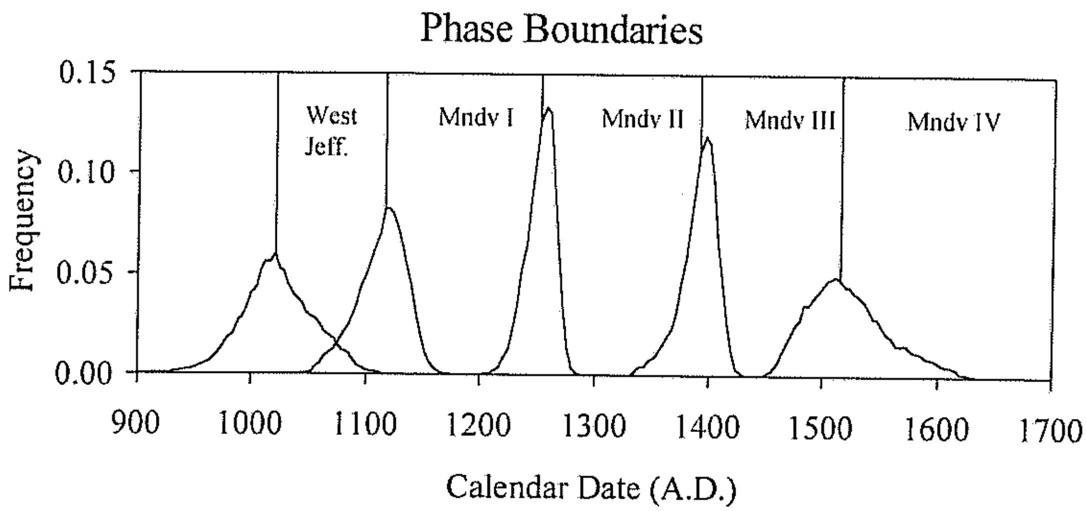

Figure 5. Distribution of Gibbs Sampled phase boundaries and for the start of the West Jefferson phase.

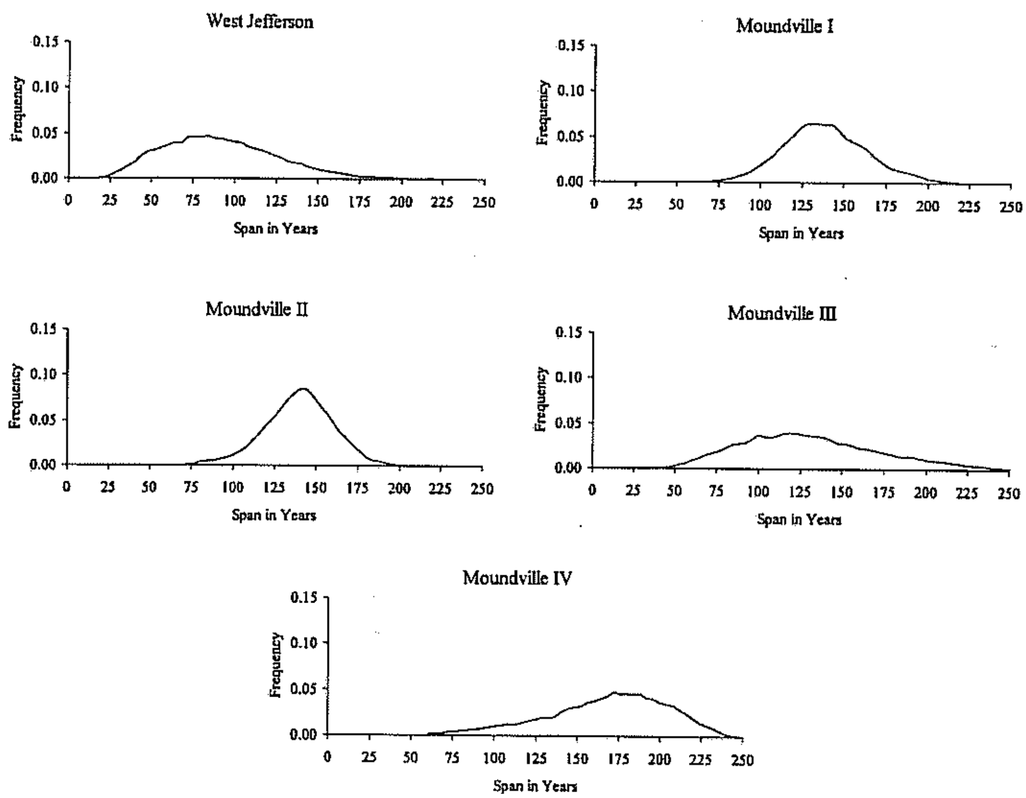

Figure 6. Distributions of span (in years) for each phase.

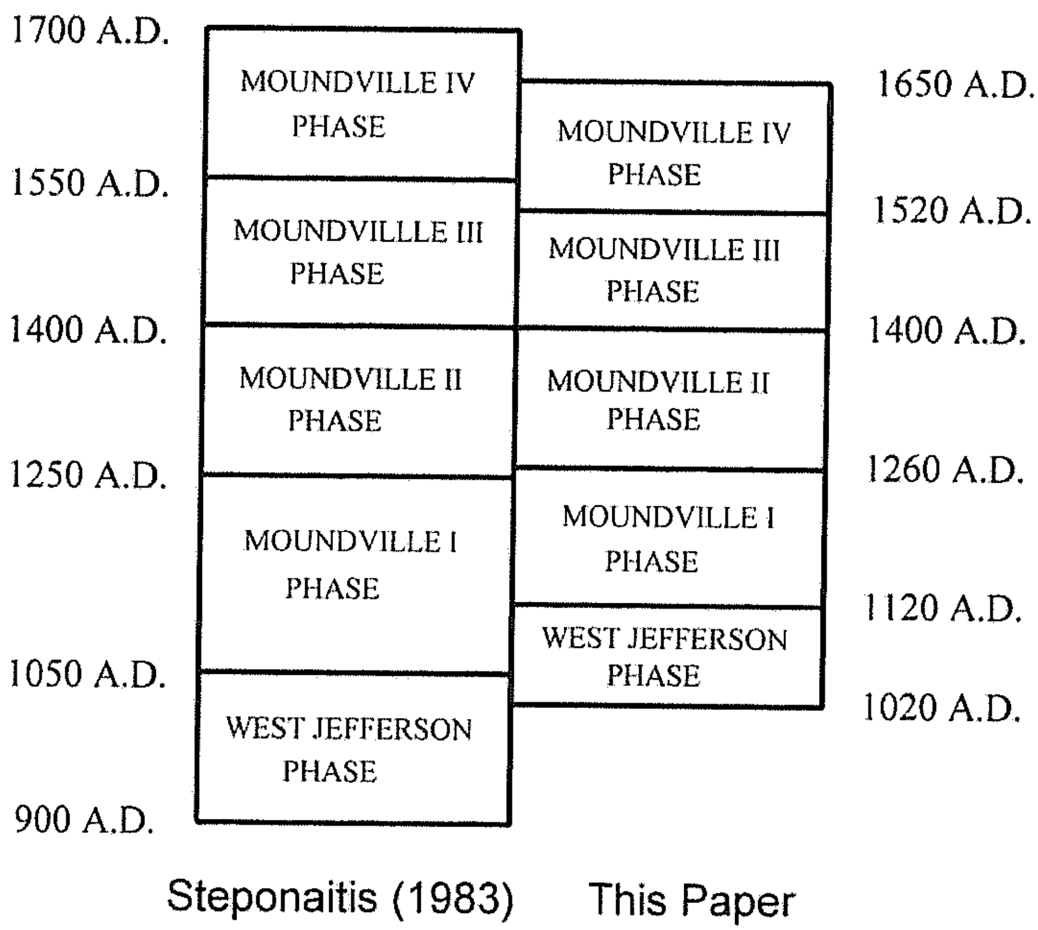

Figure 7. Revised chronological chart of Moundville phases.

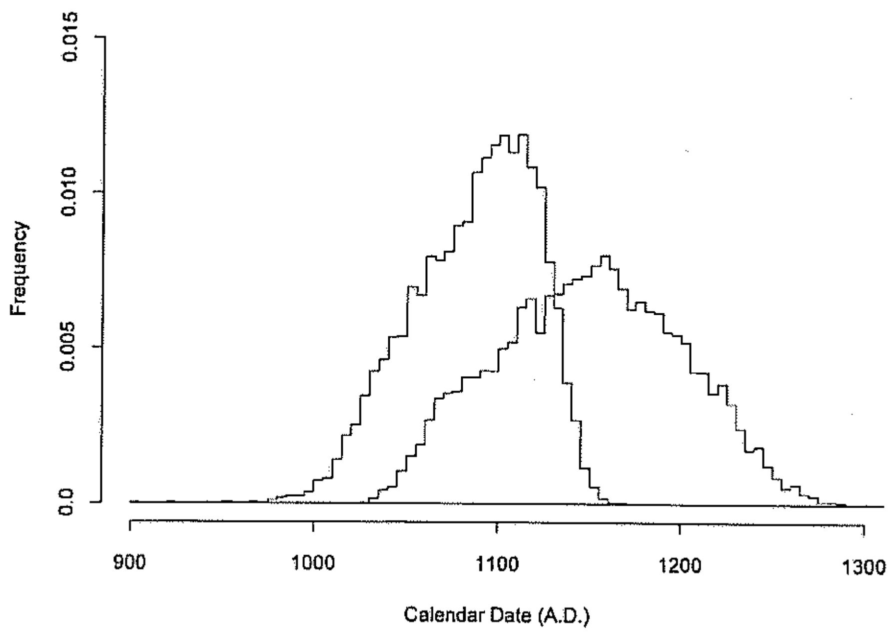

Figure 8. Distributions for the end of the West Jefferson Phase (earlier distribution) and the Beginning of the Moundville I phase (later distribution) based on 10,000 iterations of the Gibbs Sampler, with restrictions as listed in the text.

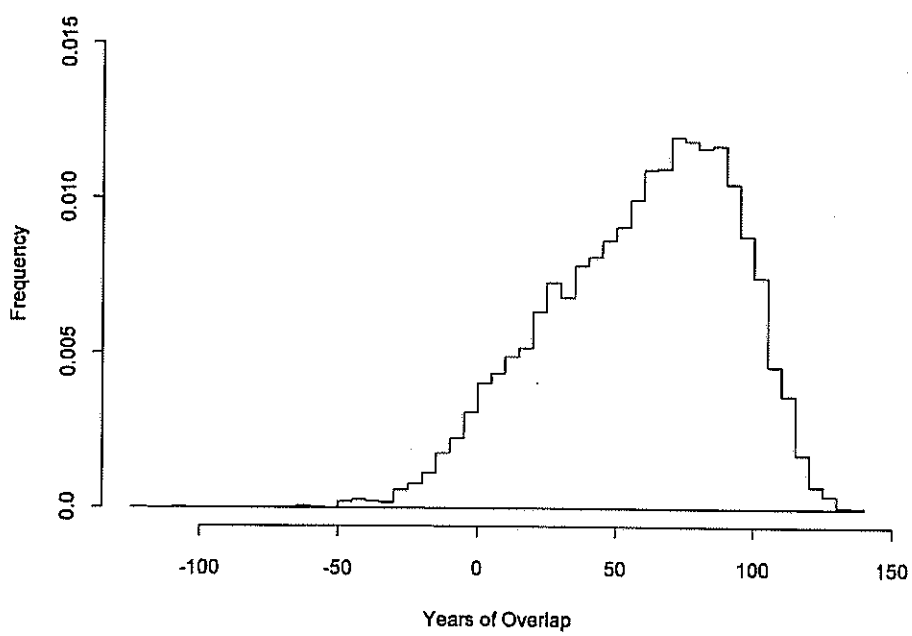

Figure 9. Distribution for temporal overlap/gap for the West Jefferson and Moundville I phases from the Gibbs Sampler results as shown in Figure 8. Negative values represent a gap between the end of the West Jefferson phase and the beginning of the Moundville I phase, a zero value indicates abutment, and positive values represent overlap.

6-15-98

Table 1

WEST JEFFERSON PHASE RADIOCARBON DATES

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
UGa-651	3850 ± 70	--------	--------	1900 BC ± 70	Site 1Je31	Jenkins and Neilsen 1974:156
UGa-650	1360 ± 70	--------	--------	AD 590 ± 70	Site 1Je31	Jenkins and Neilsen 1974:155
UGa-652	1075 ± 70	--------	--------	AD 875 ± 70	Site 1Je31	Jenkins and Neilsen 1974:156
UGa-633	1050 ± 60	--------	--------	AD 900 ± 60	Site 1Je32	Jenkins and Neilsen 1974:157
UGa-609	1005 ± 60	--------	--------	AD 945 ± 60	Site 1Je33	Jenkins and Neilsen 1974:157
UGa-610	995 ± 65	--------	--------	AD 955 ± 65	Site 1Je33	Jenkins and Neilsen 1974:157
UGa-624	985 ± 65	--------	--------	AD 965 ± 65	Site 1Je32	Jenkins and Neilsen 1974:156
UGa-612	945 ± 70	--------	--------	AD 1005 ± 70	Site 1Je33	Jenkins and Neilsen 1974:158
UGa-611	945 ± 70	--------	--------	AD 1005 ± 70	Site 1Je33	Jenkins and Neilsen 1974:158
UGa-649	890 ± 75	--------	--------	AD 1060 ± 75	Site 1Je31	Jenkins and Neilsen 1974:155
UGa-625	890 ± 60	--------	--------	AD 1060 ± 60	Site 1Je32	Jenkins and Neilsen 1974:156

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-101589	920 ± 90	−27.5	880 ± 90	AD 1070 ± 90	Site 1Tu570	not previously published
Beta-1109	810 ± 70	--------	--------	AD 1140 ± 70	Jones Ferry	Welch 1998:Table 7.1

6-15-78

Table 2.

MOUNDVILLE I PHASE RADIOCARBON DATES

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-53390	3400 ± 70	–25.2	3400 ± 70	1450 BC ± 70	Moundville, NW Riverbank	Scarry 1995:92
Beta-53392	1300 ± 90	–26.6	1270 ± 90	AD 680 ± 90	Moundville, NW Riverbank	Scarry 1995:92
Beta-1105	1135 + 105	–25.5	1130 ± 105	AD 820 ± 105	Moundville, North of Mound R	Scarry 1986:150
Beta-53393	1130 ± 90	–27.4	1100 ± 110	AD 850 ± 110	Moundville NW Riverbank	Scarry 1995:92
Beta-53401	1130 ± 70	–26.7	1100 ± 70	AD 850 ± 70	Moundville, NW Riverbank	Scarry 1995:93
Beta-71708	1080 ± 90	–29.2	1010 ± 80	AD 940 ± 80	Moundville, Mound G	not previously published
Beta-1106	1035 ± 80	–26.7	1010 ± 80	AD 940 ± 80	Moundville, North of Mound R	Scarry 1986:150
Beta-1485	990 ± 65	--------	--------	AD 960 ± 65	Moundville, North of Mound R	Scarry 1986:150
Beta-53770	1000 ± 90	–28.6	940 ± 90	AD 1010 ± 90	Moundville, NW Riverbank	Scarry 1995:93
Beta-53398	980 ± 70	–27.3	940 ± 70	AD 1010 ± 70	Moundville, NW Riverbank	Scarry 1995:93
UGa-1663	880 ± 55	--------	--------	AD 1070 ± 55	Bessemer, Structure 13	Walthall and Wimberly 1978:118

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Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-53389	910 ± 70	–26.8	880 ± 70	AD 1070 ± 70	Moundville, NW Riverbank	Scarry 1995:92
Beta-1107	875 ± 80	--------	--------	AD 1075 + 80	Moundville, South of Conference Building	Scarry 1986:164
Beta-71694	950 ± 60	–30.2	860 ± 60	AD 1090 ± 60	Moundville, Mound E	not previously published
Beta-53400	880 ± 70	–27.0	840 ± 70	AD 1110 ± 70	Moundville, NW Riverbank	Scarry 1995:93
Beta-68121	870 ± 60	–27.5	830 ± 60	AD 1120 ± 60	Hog Pen	Welch 1998:Table 7.1
Beta-53771	850 ± 80	–26.9	820 ± 80	AD 1130 ± 80	Moundville, NW Riverbank	Scarry 1995:93
Beta-71700	850 ± 70	–28.2	800 ± 70	AD 1150 ± 70	Moundville, Mound F	not previously published
Beta-71699	840 ± 60	–28.5	780 ± 60	AD 1170 ± 60	Moundville, Mound F	not previously published
Beta-53768	820 ± 90	–27.2	780 ± 90	AD 1170 ± 90	Moundville, NW Riverbank	Scarry 1995:92
Beta-71698	780 ± 70	–26.9	750 ± 70	AD 1200 ± 70	Moundville, Mound F	not previously published
Beta-53382	810 ± 120	–30.6	720 ± 120	AD 1230 ± 120	Moundville, NW Riverbank	Scarry 1995:92
Beta-71701	740 ± 80	–27.7	700 ± 80	AD 1250 ± 80	Moundville, Mound F	not previously published

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Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
DIC-1243	690 ± 60	--------	--------	AD 1260 ± 60	Moundville, North of Mound R	Steponaitis 1983:104
Beta-53388	710 ± 80	–27.6	670 ± 80	AD 1280 ± 80	Moundville, NW Riverbank	Scarry 1995:92
Beta-1289	690 ± 65	–26.6	665 ± 65	AD 1285 ± 65	Moundville, North of Mound R	Scarry 1986:150
Beta-53767	690 ± 60	–27.4	650 ± 60	AD 1300 ± 60	Moundville, NW Riverbank	Scarry 1995:92
DIC-1245	610 ± 95	--------	--------	AD 1340 ± 95	Hog Pen	Bozeman 1982:62
Beta-68122	650 ± 50	–29.3	580 ± 50	AD 1370 ± 50	Hog Pen	Welch 1998:Table 7.1
UGa-1664	330 ± 65	--------	--------	AD 1620 + 65	Bessemer, Ceremonial Mound	Walthall and Wimberly 1978:120
DIC-1241	120 ± 60	--------	--------	AD 1830 ± 60	Moundville, North of Mound R	Steponaitis 1983:104

Table 3.

MOUNDVILLE II PHASE RADIOCARBON DATES

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-71696	980 ± 90	–27.0	940 ± 90	AD 1010 ± 90	Moundville, Mound E	not previously published
Beta-71702	900 ± 60	–26.2	880 ± 60	AD 1070 ± 60	Moundville, Mound F	not previously published
Beta-86994	840 ± 130	–24.6	850 ± 130	AD 1100 ± 130	Moundville, Mound Q	not previously published
Beta-44470	850 ± 70	--------	--------	AD 1100 ± 70	Moundville, Mound Q	not previously published
Beta-44473	790 ± 60	--------	--------	AD 1160 ± 60	Moundville, Mound Q	not previously published
Beta-79967	800 ± 50	–25.8	790 ± 50	AD 1160 ± 50	Moundville, Mound E	not previously published
Beta-71710	820 ± 50	–27.5	780 ± 50	AD 1170 ± 50	Moundville, Mound G	not previously published
Beta-44468	760 ± 80	--------	--------	AD 1190 ± 70	Moundville, Mound Q	not previously published
Beta-71709	810 ± 50	–29.5	740 ± 50	AD 1210 ± 50	Moundville, Mound G	not previously published
Beta-44469	720 ± 70	--------	--------	AD 1230 ± 70	Moundville, Mound Q	not previously published
Beta-71697	720 ± 70	–28.9	660 ± 70	AD 1290 ± 70	Moundville, Mound E	not previously published

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-71705	700 ± 60	–27.2	660 ± 60	AD 1290 ± 60	Moundville, Mound G	not previously published
Beta-44471	650 ± 60	--------	--------	AD 1300 ± 60	Moundville, Mound Q	not previously published
Beta-82816	660 ± 70	–26.2	640 ± 70	AD 1310 ± 70	Moundville, Mound Q	not previously published
Beta-71704	690 ± 70	–28.1	640 ± 70	AD 1310 ± 70	Moundville, Mound G	not previously published
Beta-71703	690 ± 50	–27.7	640 ± 50	AD 1310 ± 50	Moundville, Mound G	not previously published
Beta-71711	640 ± 50	–28.6	580 ± 50	AD 1370 ± 50	Moundville, Mound G	not previously published
Beta-79973	610 ± 50	–27.5	570 ± 50	AD 1380 ± 50	Moundville, Mound Q	not previously published
Beta-79968	580 ± 70	–25.3	570 + 70	AD 1380 ± 50	Moundville, Mound E	not previously published
Beta-79972	580 ± 60	–26.9	550 ± 60	AD 1400 ± 60	Moundville, Mound Q	not previously published
Beta-86993	540 ± 90	–28.3	480 ± 80	AD 1470 ± 80	Moundville, Mound Q	not previously published
Beta-79971	490 ± 60	–27.7	450 ± 60	AD 1500 ± 60	Moundville, Mound Q	not previously published

0-13-10

Table 4.

MOUNDVILLE III PHASE RADIOCARBON DATES

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-1290	3020 ± 70	--------	--------	1070 BC ± 70	Hills Gin Landing	Welch 1998:Table 7.1
Beta-71690	1220 ± 130	–28.3	1160 ± 120	AD 790 ± 120	Moundville, Mound R	not previously published
Beta-1111	945 ± 85	–25.4	940 ± 85	AD 1010 ± 85	Snows Bend	Welch 1998:Table 7.1
Beta-115825	920 ± 60	–26.7	900 ± 60	AD 1050 ± 60	Moundville, Mound E	not previously published
Beta-44467	770 ± 70	--------	--------	AD 1180 ± 70	Moundville, Mound Q	not previously published
Beta-36154	590 ± 50	--------	--------	AD 1360 ± 50	Powers	Welch 1998:Table 7.1
Beta-1110	570 ± 80	--------	--------	AD 1380 ± 80	White	Welch 1998:Table 7.1
Beta-44472	530 ± 60	--------	--------	AD 1420 ± 60	Moundville, Mound Q	not previously published
Beta-82815	580 ± 60	–29.0	520 ± 60	AD 1430 ± 60	Moundville, Mound R	not previously published
Beta-44466	510 ± 60	--------	--------	AD 1440 ± 60	Moundville, Mound Q	not previously published
Beta-71706	530 ± 60	–26.5	510 ± 60	AD 1440 ± 60	Moundville, Mound G	not previously published

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
Beta-71692	570 ± 60	–29.2	500 ± 60	AD 1450 ± 60	Moundville, Mound R	not previously published
Beta-115824	490 ± 40	–26.0	470 ± 70	AD 1480 ± 40	Moundville, Mound E	not previously published
Beta-9951	400 ± 50	--------	--------	AD 1550 ± 50	White	Welch 1986:53
Beta-1483	380 ± 65	--------	--------	AD 1570 ± 65	Hills Gin Landing	Welch 1998:Table 7.1
DIC-1247	260 ± 50	--------	--------	AD 1690 ± 50	Hills Gin Landing	Welch 1998:Table 7.1
Beta-1484	245 ± 65	--------	--------	AD 1705 ± 65	Hills Gin Landing	Welch 1998:Table 7.1
DIC-1242	110 ± 50	--------	--------	AD 1840 ± 50	Moundville, North of Mound R	Steponaitis 1983:126

Table 5.

MOUNDVILLE IV PHASE RADIOCARBON DATES

Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
UGa-4007	760 ± 75	--------	--------	AD 1190 ± 75	Baker	Curren 1984:241
Beta-79965	630 ± 80	–27.7	590 ± 80	AD 1360 ± 80	Moundville, Mound E	not previously published
UGa-2036	480 ± 145	--------	--------	AD 1470 ± 145	Moody Slough	Curren 1984:241
UGa-2038	405 ± 60	--------	--------	AD 1545 ± 60	Moody Slough	Curren 1984:241
Beta-79966	380 ± 50	–26.7	360 ± 50	AD 1590 ± 50	Moundville, Mound E	not previously published
DIC-1249	340 ± 55	--------	--------	AD 1610 ± 55	Baker	Curren 1984:241
Beta-115826	360 ± 60	–27.6	320 ± 60	AD 1630 ± 60	Moundville, Mound E	not previously published
UGa-4009	300 ± 65	--------	--------	AD 1650 ± 65	Moody Slough	Curren 1984:241
UGa-4005	300 ± 60	--------	--------	AD 1650 ± 60	Moody Slough	Curren 1984:241
UGa-4013	205 ± 70	--------	--------	AD 1745 ± 70	Big Prairie Creek	Curren 1984:241
UGa-4008	200 ± 65	--------	--------	AD 1750 ± 65	Moody Slough	Curren 1984:241

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Lab Number	^{14}C Age BP	$^{13}C/^{14}C$ Ratio	^{13}C-adjusted Age BP	Uncalibrated Date	Site/Area	Source
UGa-3034	180 ± 50	--------	--------	AD 1770 ± 50	Moody Slough	Curren 1984:241
UGa-4006	165 ± 60	--------	--------	AD 1785 ± 60	Moody Slough	Curren 1984:241
UGa-4017	130 ± 65	--------	--------	AD 1820 ± 65	Moody Slough	Curren 1984:241
UGa-4015	130 ± 55	--------	--------	AD 1820 ± 55	Big Prairie Creek	Curren 1984:241
UGa-4014	modern	--------	--------	modern	Big Prairie Creek	Curren 1984: 241
UGa-4016	modern	--------	--------	modern	Big Prairie Creek	Curren 1984:241
UGa-3033	modern	--------	--------	modern	Moody Slough	Curren 1984:241

Table 6.

6-13-10

ADDITIONAL CHRONOMETRIC DATES

Lab Number	Age BP	Calendar Date	Phase	Type of Date	Site/Area	Source
Okla-1777	830 ± 46	AD 1120 ± 46	Moundville I	Paleomagnetic	Moundville, South of Conference Building	Scarry 1986:150
Okla-1778	810 ± 15	AD 1140 ± 15	Moundville I	Paleomagnetic	Moundville, South of Conference Building	Scarry 1986:150
Okla-1775	720 ± 23	AD 1230 ± 23	Moundville I	Paleomagnetic	Moundville, South of Conference Building	Scarry 1986:150
Alpha-1231	--------	AD 1520 ± 50	Moundville III	TL	White	Welch 1998:Table 7.1
Alpha-1232	--------	AD 1530 ± 40	Moundville III	TL	White	Welch 1998:Table 7.1