RECONSTRUCTING THE PALEODIET OF THE CADDO THROUGH STABLE ISOTOPES

Diane Wilson and Timothy K. Perttula

Maize agriculture is often regarded as a key component in understanding and evaluating the Mississippian culture and related cultures. It is becoming clear that the spread and intensification of maize agriculture relates to the dissemination of Mississippian cultural traits in a variety of ways, rather than through a set trajectory. In this article, we focus on the Caddo, who have been postulated to have subsisted on smaller amounts of maize than other Mississippian-like groups to their east and northeast. The use of stable isotope analysis provides a direct means of comparing the amounts of maize consumed among various Mississippian-related cultures. We synthesize the results of Caddo stable isotope studies to compare the process of maize agricultural intensification among the Caddo to other archaeological cultures that shared Mississippian traits. We find that the Caddo consumed less maize throughout the prehistoric sequence than their neighbors.

La agricultura de maíz es a menudo considerada como un componente clave en el entendimiento y la evaluación del Mississippiano y sus culturas relacioadas. Es evidente que la extensión y la intensificación de la agricultura de maíz estan relacionadas con la diseminación de los rasgos culturales del Mississippiano en una variedad de sentidos y costumbras, en lugar de ser a traves de una trayectoria establecida. En este document nos concentramos en Caddo, quienes se han postulados por haber subsistido en cantidades más pequeñas de maíz que otros grupos parecidos a Mississipiano encontrados a su este y nordeste. El uso del análisis de isótopo estable proporciona un medio directo para comparar las cantidades del maíz consumido entre varios Mississipianos y sus culturas relacionadas. En este document nos interesa sintetizar utilizando los resultados de los studios de los isotopes estables de Caddo para comparar el proceso de la intensificacion del maíz Agricola entre Caddo y otras culturas arqueológicas que compartieron rasgos de Mississippiano. Encontramos que Caddo consumió menos maíz en todas partes de la secuencia prehistoric en comparacion con sus vecinos.

Across much of Eastern North America, archaeological evidence indicates maize was grown at low levels for hundreds of years (Fritz 2011:506). After that, the increased reliance on maize was a complex process (Ambrose et al. 2003; Greenlee 2006; Hutchinson et al. 1998; Rose 2008; Schoeninger 2009; Schurr 1992; Schurr and Schoeninger 1995; Schwarcz et al. 1985). Fritz (2011:506) indicated that it was not until ca. 800–1200 years ago that maize became a major crop in a number of places in the region as a whole. Stable isotope data have shown that maize agriculture became an important component of the diet for Mississippian and related cultures in Eastern North America ca. A.D. 1000 and later (Ambrose et al. 2003; Bender et al. 1981; Buikstra and Milner 1991; Buikstra et al. 1994; Fritz 2011; Greenlee 2006; Gremillion 2011; Lynott et al. 1986; Rose 2008; Rose et al. 1991; Schurr and Schoeninger 1995; Schwarcz et al. 1985).

This article has two primary goals. The first is to summarize the available stable isotope data on human remains from archaeological sites of the Caddo tradition in southwest Arkansas, northwest Louisiana, eastern Oklahoma, and East Texas. The second goal is to test the hypothesis that maize was never consumed by the Caddo in the same amounts seen in other Mississippian-related cultures. In this comparison, an emphasis is placed on three Mississippian-related cultures, the Caddo, Middle Mississippian, and Fort Ancient populations. In so doing, it is apparent that a potentially significant difference exists in the

Diane Wilson ■ Wilson Associates, Inc., 20 Rascally Rabbit Rd., Marstons Mills, MA 02648 (dewilson@capecod.net)
Timothy K. Perttula ■ Archeological & Environmental Consultants, LLC, 10101 Woodhaven Dr., Austin, TX 78753

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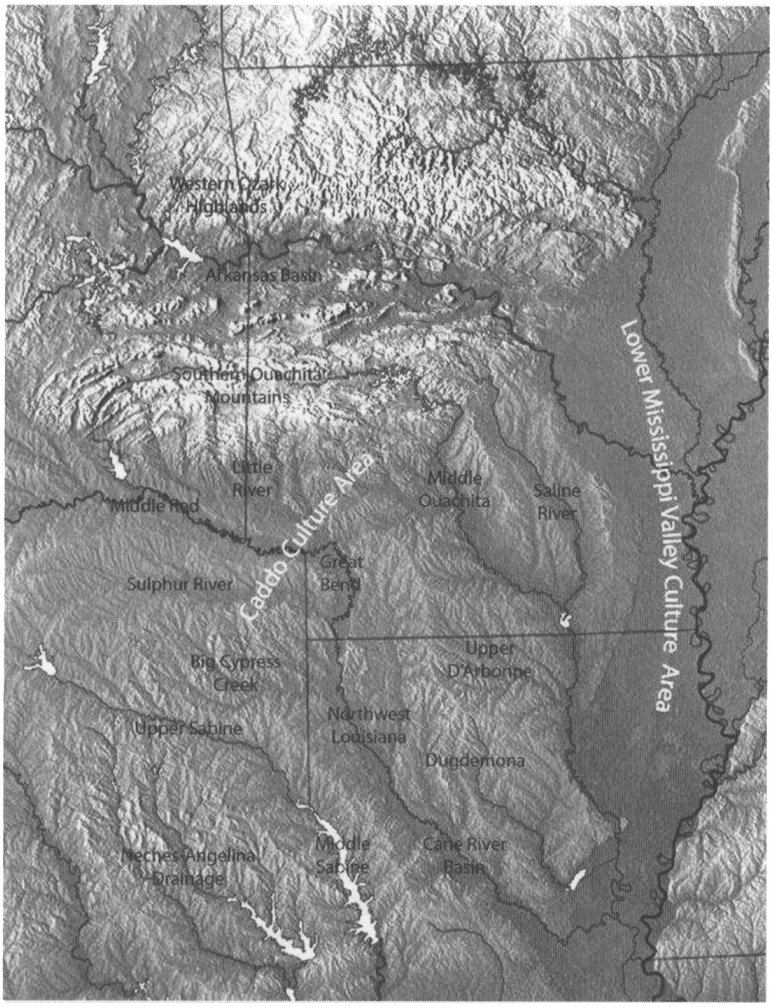


Figure 1. The Caddo archaeological region.

carbon isotope ratio ($\delta^{13}C$ ‰ value) of maize in some portions of Eastern North America that should be taken into account prior to any interpretation of the relative amount of maize consumed by a specific culture. We demonstrate that the Caddo practiced limited maize agriculture until ca. A.D. 1200–1400, that they intensified maize agriculture at approximately the same time as their Mississippian neighbors but consumed maize in approximately half the quantities of the Middle Mississippians, and that the consumption of bison by some Caddo may have complicated stable isotopic dietary interpretations.

Herein, the term Caddo is archaeological and applied to the ca. A.D. 800–1860 archaeological record associated with the Caddo peoples, who historically had several known confederacies and kin-related alliances. Considerable diversity existed among these peoples, and in fact there is some debate as to whether there were other cultures in the region (e.g., Schambach 1995, 2000). The archaeological term Caddo is used in distinction to the linguistic category, "Caddoan."

The beginnings of archaeological cultures that are identified as Caddo date to ca. A.D. 800–900 with the development of regional chiefdoms in East Texas, along the Red River, and in other geographic locales, including the Ozarks of southwestern Missouri, Louisiana, the Ouachita Mountains, and the West Gulf Coastal Plain in southwestern Arkansas (Figure 1). The different regions inhabited by the Caddo have resulted in a

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varied archaeological record with a broad division of Northern and Southern traditions.

Many of the developments that characterize the cultural practices of Caddo peoples paralleled developments in other Mississippian cultures, including an adaptation to river valley ecosystems, long distance trade, ascribed status, the construction of civic-ceremonial centers with platform and burial mounds, spectacular mortuary treatments of high status individuals, and participation in the Southeastern Ceremonial Complex. Maize figures prominently in the Caddo origin (Bolton 1987). Both the Caddo and Mississippians consumed a vast array of plants and animals, but shared the four primary components of deer, fish, maize, and nuts. Both cultures provisioned elites with choice cuts of meat (Jackson and Scott 1995; Jackson et al. 2012; Yerkes 2005). While the Caddo lived near the Southern Plains, there is little faunal evidence to suggest that bison was an important component of the diet, particularly for prehistoric Southern Caddo populations. Bison hunting would have required large travel costs and the burden of processed carcass transport. Compared to their Mississippian neighbors to the north, the Caddo experienced a longer growing season that allowed for two annual crops of maize (Bolton 1987), compared to one in the American Bottom.

Caddo Agriculture: Archaeological, Bioarchaeological, and Paleobotanical Data

Paleobotanical and archaeological evidence shows that corn came to the Caddo region no earlier than ca. A.D. 400, several hundred years after squash began to be cultivated and used. The classic triumvirate of the maize, beans, and squash subsistence base did not occur in Caddo lands until late in the prehistoric record, as beans were not common until ca. A.D. 1400. The three were introduced separately and took hold gradually. The paleobotanical record indicates that maize did not replace domesticated indigenous weedy annuals, nuts, and animal foods in dietary importance for several hundred to nearly one thousand years, until ca. A.D. 1300 when maize was intensively grown (Perttula 2008). Instead, maize was likely grown alongside weedy annuals and first consumed in small quantities. By the end of the Middle Caddo period (ca. A.D. 1400–1450), there is archaeological evidence of the abandonment of less favorable lands for agriculture and the development of more complex Caddo communities in locales where maize production was intensified. However, both paleobotanical data and stable isotopes show that in some locations maize was an important component of the diet earlier than the Middle Caddo period.

The archaeological and paleobotanical record suggests that we should expect variability in the use of maize. There is evidence for regionally varied use in domesticates that precede maize, namely the starchy (chenopod, knotweed, little barley, and maygrass) and oily (sumpweed and sunflower) seed complex (Perttula 2008). In Historic times, the Caddo had two means of growing food. They grew crops both in small family plots and in large communal fields. The utilization of small family plots in prehistoric Caddo communities would likely have resulted in different diets within a number of communities or dispersed villages. In addition to possible differences in gardening practices, the Caddo environment is extremely varied, ranging from the Ouachita Mountains and Arkansas River Valley to the Western Gulf Coastal Plain, and this environmental diversity, especially in agricultural potential and distribution of arable lands, would have affected maize agricultural adoption and the amounts of maize eaten by various Caddo groups. The maximum development of maize agricultural economies occurred in the riparian and broad alluvial valleys in the Western Gulf Coastal Plain of Arkansas, Louisiana, Oklahoma, and Texas. Within the Gulf Coastal Plain, the Red and Ouachita River valleys were apparently the most agriculturally productive (Perttula 2008).

Bioarchaeological data relevant to the study of Caddo subsistence has been somewhat limited due to the poor preservation of human remains and non-systematic study of the remains to answer subsistence-related questions. Nevertheless, it is important to examine the preserved human remains from Caddo sites for evidence of diet because it is the most direct means of determining what a person ate, and also because Rose et al. (1998:116) have shown that the paleobotanical record does not always match the bioarchaeological record for Caddo populations. Bioarchaeo-

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logical studies have also indicated regional differences in diet among the Caddo, with Harmon and Rose (1989:47) describing the development of agriculture among the Caddo as "the product of local circumstance."

The largest regional summary of the development of agriculture based on bioarchaeological analysis largely agreed with this characterization (Burnett 1990, 1999). In Burnett's summary (1990, 1999), she subdivided the Southern Caddo region into river basins and vegetative regions. Further, Burnett hypothesized that the relationship between maize and the natural environment was stronger than a simple increase in maize consumption through time. Burnett (1990, 1999) and Rose et al. (1998) described a higher dietary contribution of maize among the aboriginal inhabitants of the Post Oak Savannah and Blackland Prairie than in the Pineywoods. However, in an examination of the East Texas Caddo dental data, Wilson (2012) found vegetative region was an important variable only for Blackland Prairie populations, who had the lowest caries rates and highest attrition rates. With the intensification of maize agriculture, this region was abandoned in favor of more agriculturally suitable lands. Both Rose et al. (1998) and Wilson (2012), in their examination of different Caddo populations, concluded that caries rates may not be accurate measures of the amount of maize eaten and may have been influenced by other carbohydrate sources, and therefore it is important to perform stable isotope testing of human remains as a direct measure of the amount of maize consumed.

Maize Signatures

In inland Eastern United States archaeological populations, stable carbon isotope studies have been successful because the introduction of a C_4 plant can be easily detected in the predominately C_3 environment. For some of the Caddo populations, however, detection of maize may be muddied by consumption of bison, a C_4 grazer. In order to get an accurate picture of the Caddo diet, it is important to compare apatite and collagen carbon and nitrogen values in regards to the archaeological record.

In order to compare the introduction of maize and the actual amount consumed across vast areas, archaeologists have assumed that maize signatures do not vary. Values can be influenced by laboratory and processing differences. C_4 plants are often thought to be less affected by local environmental conditions such as precipitation, temperature, shade, and so forth in their carbon isotope discrimination (Codron et al. 2005; O'Leary 1988; Tieszan and Boutton 1989), although this idea has been challenged (Bowman et al. 1989; Buchmann et al. 1996; Van der Water et al. 2002; Weiguo et al. 2005; Yoneyama et al. 2010). Buchmann et al. (1996) found that grasses with the same photosynthetic subtype as maize (NADP-ME species) had lower carbon isotope discrimination in shade than in sun. Henderson et al. (1992) found increased short-term carbon isotope discrimination for maize in response to very low light that they attributed to reduced Rubisco activity.

Along with light, genetic variability and natural variations in atmospheric CO_2 can affect carbon isotope discrimination. In her study of archaeological maize samples, Wagner (1988), working in the Upper Midwest, found samples to vary by 2.5‰, from -11.2‰ to -8.7‰. Tieszen and Fagre (1993) argued that differences were likely genetic and regional, although different recognized types of maize, such as White Flint and Yellow Flour, did not have different isotopic signatures. More recently, carbon isotope discrimination has been shown to vary genetically in maize with heterosis, resulting in higher delta $(\Delta)^{13}C$ (Araus et al. 2010). Previous experiments have shown that selective breeding of maize can vary protein content from 9–36 percent and oil from 2–14 percent (Doehlert and Lambert 1991); such factors would influence not only the isotopic signature of maize, but also the way it is represented in the collagen of its consumer. This needs to be considered when archaeologists assume that maize has a protein content of 10 percent and is therefore underestimated in bone collagen (Hedman 2006).

In order to accurately compare stable isotope signatures on human remains from different regions, it is important to consider maize values from the specific regions examined. We have compiled 404 isotopic signatures on maize from Eastern North America. From these samples, there are a wide range of values, with a mean of -10.18‰ and a standard deviation of 1.20. The

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Table 1. Mean Carbon Isotope Ratios for Maize.

Region	$\delta^{13}C$ + s.d.	N	Reference
Northeast	-9.6 + 1.0	11	Hart et al. 2003; Little 2002
Ontario Iroquois	-9.1 + 0.3	9	Schwarcz et al. 1985
Oneota	-11.2 ± 0.1	2	Bender et al. 1981; Bender 1968
Southern Plains	-10.0 ± 0.9	37	Brooks, personal communication 2011; Drass, personal communication 2011; Bender 1968
Central Plains	-9.4 ± 0.9	53	Adair and Drass 2011; Jack Ray, personal communication 2011; Roper and Adair 2011
Jornada Mogollon	-10.6 ± 1.2	57	Myles Miller, personal communication 2011
Great Basin	-10.3 ± 0.7	11	Coltrain and Leavitt 2002; Creel and Long 1986
Southwest	-11.1 ± 1.3	15	Janetski et al. 2012; Spielmann et al. 1990; Creel and Long 1986; Bender 1968
Fort Ancient	-8.5	unknown	Schurr and Schoeninger 1995
Middle Mississippian	-10.0 ± 1.1	14	Arkansas Archeological Survey 2011; Butler et al. 2011; Simon, personal communication 2011; Schurr and Schoeninger 1995
Plaquemine	-9.8 ± 0.7	6	Marvin Jeter, personal communication 2012; Arkansas Archeological Survey 2011; Jeff Girard, personal communication 2011
South Appalachian	-9.7 ± 1.8 (site mean)	7	Keene 2004; Schoeninger et al. 2000

Isotope ratios are expressed in parts per thousand (‰) in reference to the Pee Dee Belemite standard. N = the sample number except for the Ontario Iroquois, Fort Ancient, and South Appalachian Mississippian samples, for which sample means follow references cited. s.d. = standard deviation.

maize isotope signatures can be grouped into regional categories (Table 1). A one-way ANOVA test indicates that there are differences between these groupings in isotopic signatures, suggesting that environmental influence, genetic factors, and/or natural variations in atmospheric CO_2 have affected maize isotopic signatures in the archaeological record. The most divergent of these groups is in the Fort Ancient sites from the Ohio Valley, with the highest mean maize isotopic signature (-8.52‰), but sample size is very small.

There are 121 Caddo maize signatures included in this study (Table 2). Most are from Texas, ranging from the Formative (ca. A.D. 800–1000) through Historic Caddo (ca. A.D. 1680–1800+) periods in age. The mean is -10.25‰, with a standard deviation of 1.28.

Caddo Agriculture: Stable Isotope Analysis

Burnett (1999) has hypothesized that the local environment in the southern Caddo area was more influential in the consumption of maize than time. In another regional bioarchaeological synthesis, Rose et al. (1998) found that maize consumption among Caddo groups was less than 15 percent of the diet and variable prior to A.D. 1100, after which it became uniformly high. The same study compared stable carbon isotope data on human bone collagen from Caddo populations to Late Baytown populations from Louisiana and found that maize can be detected up to 200 years earlier among the Caddos than among people of the Lower Mississippi Valley. Lower Mississippi Valley populations have not been tested for stable isotopes in sufficient numbers to test the latter of Rose et al.'s (1998) hypotheses.

A total of 199 stable isotope results have been compiled from 179 Caddo individuals from 58 sites (Table 3). Rogers' (2011) study in Eastern Oklahoma made it possible to compare Southern Caddo populations with Northern Caddo populations. Most of the results are from East Texas (46 percent of the samples), followed by eastern Oklahoma (28 percent), Arkansas (17 percent), and Louisiana (8 percent). The individuals are burials recovered from single and multiple mound centers, cemeteries, villages, farmsteads, and hamlets. Samples from the Crenshaw site in southwestern Arkansas are partially represented in this study. Individuals represented in skull pit features from the site were not included here as they are not considered to be Caddo in cultural affiliation (Schambach et al. 2011).

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Table 2. Delta ^{13}C Values from Caddo Maize.

Time Period	Site	$\delta^{13}C‰$ (PDB)	Reference
Formative	41CE19	-10.3	Perttula 1997
		-10.1	
Early Caddo	23MD128	-9.7	Jack Ray, personal communication 2011,
	41CE19	-12.0	Perttula 1997
		-11.8	
		-10.4	
	41CP304	-12.8	Perttula 2008
	41LR135	-12.1	Perttula 2008
		-11.8	
		-11.6	
	41RK214	-12.8	Perttula 2008
		-10.1	
	41RK4	-10.1	Perttula 2008
		-9.4	
	41UR30	-9.7	Perttula 2011, assembler
Middle Caddo	Taylor Mound	-9.0	Marvin Jeter, personal communication 2012,
	34MC1030	-10.4	Elsbeth Dowd, personal communication 2012,
	41AN38	-10.4	Perttula et al. 2011
		-10.2	
		-9.7	
		-9.5	
		-9.2	
		-9.2	
	41AN51	-10.2	Perttula et al. 2012
	41CE19	-11.8	Perttula 1997
		-10.1	
	41CP408	-8.5	Perttula and Ellis 2012
	41FT425	-8.6	Perttula 2008
	41HP106	-10.7	Perttula 2008
	41NA242	-10.0	Perttula 2008
	41RK170	-9.6	Perttula 2008
	41RK214	-13.2	Perttula 2008
Middle Caddo	41RK214	-12.3	Perttula 2008
		-11.9	
		-11.2	
		-10.3	
		-10.0	
		-9.9	
		-9.7	
		-9.5	
	41RK243	-9.3	Perttula 2008
	41SM273	-9.6	Perttula and Nelson 2004
	41SM404	-9.9	Perttula 2008
		-9.5	
	41TT851	-13.7	Ross Fields, personal communication 2011
		-11.1	
		-10.2	
		-9.5	
		-9.0	
		-9.0	
		-8.7	
	41TT852	-9.9	Ross Fields, personal communication 2011
		-9.4	
		-9.1	
		-8.6	
Late Caddo	3HS60	-8.6	Trubitt 2012
	34HS9	-10.4	Rogers 2006
	34MC8	-12.4	Bender 1968
	41CP88	-9.9	Sherman et al. 2011
	41AN38	-10.4	Perttula et al. 2011
		-9.7	

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Table 2 (continued). Delta ^{13}C Values from Caddo Maize.

Time Period	Site	$\delta^{13}C‰$ (PDB)	Reference
		-9.5	
	41CE299	-14.5	Perttula 2008
	41CP220	-11.2	Perttula 2008
		-9.4	
		-9.5	
	41CP304	-10.9	Perttula 2008
		-10.5	
		-10.1	
		-9.5	
Late Caddo	41CP304	-9.3	Perttula 2008
		-9.2	
	41CP408	-10.7	Perttula and Ellis 2012
		-10.4	
		-10.0	
		-10.0	
		-9.5	
	41HE139	-11.6	Perttula 2008
	41HE343	-11.9	Perttula 2008
	41HS15	-15.3	Fields and Gadus 2012
		-10.5	
		-10.4	
		-10.3	
		-10.3	
		-10.3	
		-9.8	
		-9.8	
		-9.7	
		-9.6	
		-9.5	
		-9.2	
		-7.3	
	41PN149	-12.9	Perttula 2008
	41SM325	-10.1	Walters 2008
	41TT653	-11.4	Perttula 2008
	41TT851	-10.3	Ross Fields, personal comunication 2011
		-9.7	
		-8.9	
	41TT852	-11.3	Ross Fields, personal communication 2011
		-10.6	
		-10.3	
		-9.5	
		-9.5	
		-9.4	
		-9.4	
		-9.4	
		-9.3	
		-9.2	
Late Caddo	41TT852	-9.2	Ross Fields, personal communication 2011
		-9.1	
		-8.5	
	41TT853	-10.4	Ross Fields, personal communication 2011
		-8.9	
Historic Caddo	41HS15	-11.2	Fields and Gadus 2012
	41TT653	-10.3	Perttula and Sherman 2009
	41TT852	-13.6	Ross Fields, personal communication 2011
		-11.1	
		-10.4	
		-10.0	
		-10.0	
		-9.3	

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Temporal Variation

Individuals were sorted by time following the Caddo chronology presented by Story (1990) and Perttula (2012), which facilitates comparisons within the Caddo archaeological region. The majority of the stable isotope results are for carbon on collagen (188 results from 183 individuals). A Kruskal-Wallis one-way ANOVA test shows that $\delta^{13}C$ collagen values differ significantly through time ($p = .00$). Collagen values increased through time except between the Middle and Late Caddo (ca. A.D. 1400–1680) periods. The decrease in collagen values is seen in the Southern Caddo populations, but not among the Northern Caddos, who have higher variability. Table 4 shows that Northern Caddo populations had a higher contribution of C_4 to the protein portion of the diet, particularly in the Early (ca. A.D. 1000–1200) and Late Caddo periods.

Delta ^{13}C collagen results suggest that C_4 contributed a minor portion to the protein intake for some individuals of the Caddo in the Late Fourche Maline and Formative Caddo periods. Three individuals do, however, have a high C_4 contribution to protein: two from the Hurricane Hill site (41HP106) along the South Sulphur River in the modern Blackland Prairie at the western edge of the Texas Caddo region, and one from the Hooks site (34LF19) in the Northern Caddo region. Populations living on the prairies would have had greater access to bison, as did those in the northern region. No pattern of status or sex difference is apparent.

By the Early Caddo period, a small amount of C_4 is evident in the carbon collagen signatures for most of the individuals sampled. Four of the 21 individuals show no evidence of C_4 contribution to protein, while two show intensive contribution of C_4 resources. The two individuals with high $\delta^{13}C$ values were from the Northern Caddo region and both were from mound sites (Harlan (34CK6) and Spiro (34LF40). Two of the individuals without C_4 were from Northern Caddo sites. As in the prior period, sex did not seem to affect diet. The effect of social status is more ambiguous at this time. Rogers (2011) hypothesized that high status individuals consumed more maize. This does not appear to be the case for the Southern Caddos, as the two individuals from the George C. Davis (41CE19) mound center had similar lower $\delta^{13}C$ signatures and were of different social statuses. Sample size is small and needs to be enlarged to further investigate Rogers' (2011) hypothesis. Despite this, differences in mean $\delta^{13}C$ values between the Northern and Southern Caddo regions were only .6‰.

Between the Early and Middle Caddo periods, $\delta^{13}C$ collagen values indicate a significant increase in the C_4 contribution to protein (Table 4). The increase in carbon collagen corresponds to a period of bison abundance on the Southern Plains (Huebner 1991), which could have resulted in increased access for some of the westernmost Caddo groups. The highest values are from the Arkansas River Valley and the Sanders site (41LR2) on the Red River. Both carbon collagen and individual variation remained higher in the Northern region and may reflect bison consumption. Sanders is one of the few southern Caddo sites where bison remains have been found, although this is in the form of tools (Jackson et al. 2000). Schambach (1995, 2000) has argued that Sanders was a trading outpost for the Arkansas River Caddo and served as a trading center from which bison products entered the Red River Valley. Of those individuals with higher C_4 signatures, five males and two females had a higher C_4 contribution to protein, while three females, three individuals of indeterminate sex, and no males had little C_4 in their protein. While this suggests more C_4 in the male diet during the Middle Caddo period, the sample size is small. Unlike the Early Caddo period, social status was not related to C_4 dietary protein.

There is a further increase in $\delta^{13}C$ collagen values from the Middle to Late Caddo periods for Northern Caddo populations, but there is a small decrease in the Southern Caddo mean. Nine individuals had $\delta^{13}C$ collagen values indicative of little to no contribution of C_4 to dietary protein. Only one was from a Northern Caddo site. Seven had enriched C_4 protein; all but one were from northern sites. No relationship to sex or status was apparent. There is a large difference between Northern and Southern Caddo $\delta^{13}C$ collagen values in the Late Caddo period. Delta ^{13}C collagen values are higher in the Northern Caddo population, indicating more C_4 input to protein at a time when there is more bison and more maize in the archaeological record.

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Table 3. Mean Stable Isotope Values for Humans from Caddo Sites.

Site	$\delta^{13}C \pm$ s.d. collagen ‰ (PDB)	N	$\delta^{13}C \pm$ s.d. apatite ‰ (PDB)	N	$\delta^{15}N \pm$ s.d. collagen ‰ (AIR)	N	Reference
Late Fourche Maline							
3LR49	-21.7 ± .3	4					Rose et al. 1998
3MI6	-17.8 ± .3	3			9.3 ± .6	3	Akridge 2013
34LF15	-17.8	1			10.4	1	Rogers 2011
34LF17	-19.0	1			11.4	1	
34LF19	-17.9 ± 1.7	3			10.0 ± .3	3	
34LF21	-19.7	1			10.8	1	
34LF28	-20.1	1			10.2	1	
34LF29	-21.8	1			10.6	1	
34LF33	-19.6 ± .3	2			9.2 ± .3	2	
34LF40	-16.4	1					
34LF43	-19.1 ± 0	2			9.5 ± .7	2	
34LT11	-19.2 ± .4	3			10.0 ± .9	3	
A.D. 800–1000							
3MI6	-19.5 ± 1.2	10			9.3 ± .8	10	Akridge 2013; Rose et al. 1998
3SV10	-20.1 ± 1.1	5					
41HP106	-15.1 ± .2	3	-8.0 ± .9	2	9.0 ± .1	2	Gill-King 1999
16RR4	-20.2 ± 1.9	3					
34CK6	-18.6 ± .9	2			9.3	1	Rogers 2011
41CE19	-20.3 ± 2.0	2	-11.4 ± .4	2	8.7	1	Perttula 1997; Wilson 2011
A.D. 1000–1200							
3MI6	-19.8 ± 1.6	3					Rose et al. 1998
34CK6	-16.1 ± 1.1	6			10.0 ± .8	5	Rogers 2011
34HS25	-19.6 ± .9	4			10.6 ± .7	2	
34LF40	-14.1 ± 3.2	2			10.0 ± .7	2	
34MI63	-21.9	1					
41CE3	-19.3	1	-14.6	1	4.8	1	Wilson 2012
41CE19	-18.4	1	-8.7	1	9.7	1	Wilson 2011
41CP245	-21.2	1					Perttula 2008
41HP106	-16.5 ± 1.1	3	-9.5 ± .7	3	8.8 ± .3	3	Gill-King 1999
41RR11	-20.2	1					Perttula 1997
A.D. 1200–1400							
3HE63	-13.6 ± 1.0	2					Rose et al. 1998
34CK39	-16.6 ± 3.4	5			11.2 ± .4	5	Rogers 2011
34LF31	-11.0 ± 1.4	2			10.7 ± .6	2	
34LF40	-16.0 ± 3.4	4			9.6 ± 1.1	3	
34SQ11	-13.3 ± 1.0	6			10.5 ± .5	6	
41AN38	-17.5 ± 1.8		-10.0 ± .7		7.0 ± 0.3	2	Wilson 2011
41AN56			-7.6	1	12.4	1	Wilson 2011
41CE290	-15.9	1	-10.9	1	11.5	1	
41CS1	-14.6	1					Derrick 1997
41HP106	-15.2	1	-7.3	1	9.2	1	Gill-King 1999
41LR2	-11.6 ± 1.5	3					Wilson and Cargill 1993
41NA231	-18.1	1	-10.8 ± 2.3	3	10.8	1	Wilson 2008
41NA242	-16.3	1	-7.9	1	8.7	1	
41NA285	-15.1 ± 1.7	2	-11.6	1	6.3	1	
41RK170	-15.3	1					Perttula and Nelson 2003a
41RR11	-15.5	1					Perttula 1997
41RR16			-8.1 ± 0.1	2			Derrick et al. 2008
41RR77	-13.0 ± 2.1	2					Perttula 1997
41TT13	-13.4	1					Rogers et al. 2003

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Table 3 (continued). Mean Stable Isotope Values for Humans from Caddo Sites.

Site	$\delta^{13}C \pm$ s.d. collagen ‰ (PDB)	N	$\delta^{13}C \pm$ s.d. apatite ‰ (PDB)	N	$\delta^{15}N \pm$ s.d. collagen ‰ (AIR)	N	Reference
A.D. 1400–1680							
16CD13	-15.9 ± 1.1	5					Rose et al. 1998
34LF31	-13.4 ± 4.6	5			9.8 ± 0.8	4	Rogers 2011
34LF80	-11.4 ± 0.2	3			9.5 ± 0.9	3	
41AN21	-13.9	1	-6.8	1	6.3	1	Wilson 2011
41AN32	-12.2	1	-4.8	1	10.4	1	
41AN34	-14.8	1	-9.1	1	13.2	1	
41AN38	-18.8 ± 2.3	4	-8.6 ± 1.6	4	9.7	1	Wilson 2011
41AN54			-7.8 ± 0.5	2	13.0 ± 0.9	2	
41AN67	-13.2	1	-6.3	1	7.0	1	Wilson et al. 2012
41CE4	-9.7	1	-7.7 ± 0.1	2			Wilson 2011
41CE6	-12.8	1	-7.0 ± 0.5	2	5.9 ± 4.3	2	
41CE15	-14.1 ± 1.1	2	-6.7	1	10.8	1	
41CE17	-13.3	1	-12.1	1			
41CP10	-14.0	1					Turner and Smith 2002
41RK170	-15.1	1					Perttula and Nelson 2003a
41RR11	-15.7 ± 1.7	2					Perttula 1997
41RR16			-8.1 ± 0.1	2			Derrick et al. 2008
41RR77	-15.5 ± 2.1	2					Perttula 1997
41SM300	-21.8	1					Perttula and Nelson 2003b
41TT13	-18.7 ± 3.7	9					Rogers et al. 2003
Post-A.D. 1680							
3LA97	-14.1 ± 1.0	8					Rose et al. 1998; Wolfman 1984
16BO236	-14.0 ± 2.1	7	-9.1 ± 0.8	7	10.5 ± 2.9	7	Tiné and Tieszen 1997
41CE12	-13.7 ± 0.7	7	-7.4 ± 1.4	7	6.6 ± 4.3	7	Wilson 2011

Table 4. Summary of Caddo Stable Isotope Means and Adjusted Standard Deviations.

Time Period (A.D.)	$\delta^{13}C_{col} \pm$ s.d. collagen	N	$\delta^{13}C \pm$ s.d. apatite	N	$\delta^{15}N \pm$ s.d. collagen	N
400-1000	-19.4 ± 1.8	44	-9.7 ± 2.0	4	9.6 ± .8	29
N. Caddo	-19.2 ± 1.3	20			10.0 ± .7	16
S. Caddo	-19.5 ± 2.1	24			9.2 ± .7	13
1000-1200	-18.1 ± 2.6	23	-10.4 ± 2.4	5	9.8 ± .9	14
N. Caddo	-17.3 ± 2.7	13			10.1 ± .7	9
S. Caddo	-19.2 ± 2.2	10			9.2 ± 1.0	5
1200-1400	-14.8 ± 2.7	38	-9.3 ± 1.9	14	10.0 ± 1.6	25
N. Caddo	-14.6 ± 3.1	17			10.5 ± .8	17
S. Caddo	-14.9 ± 2.5	21			9.1 ± 2.3	8
1400-1680	-15.6 ± 3.6	42	-7.9 ± 1.7	18	9.6 ± 2.7	17
N. Caddo	-12.7 ± 3.6	8			9.7 ± .8	7
S. Caddo	-15.9 ± 3.3	36			9.5 ± 3.4	10
Historic Caddo	-14.0 ± 1.4	22	-8.3 ± 1.6	14	8.6 ± 4.4	14

Isotope ratios are expressed in parts per thousand (‰).

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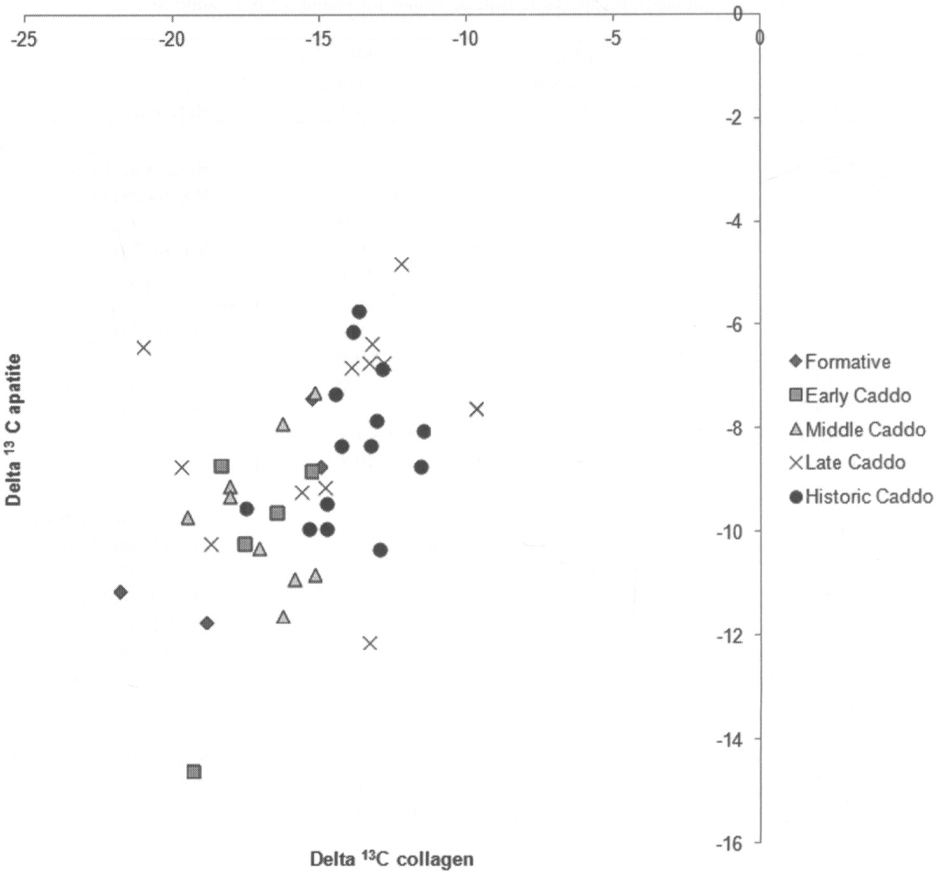


Figure 2. Delta ^{13}C collagen and apatite values for Southern Caddo individuals show an overall increase with considerable individual variation.

The C_4 contribution to protein intake reached its peak during the Historic period (after A.D. 1680). During the Historic period, the C_4 contribution to the diet was most similar within and among sites. All individuals are from the Southern Caddo region. No pattern of sexual or status-based diet difference was detected.

Apatite is a better indicator of small changes in maize consumption because it represents the whole diet. Delta ^{13}C signatures on bioapatite were available for 55 individuals. All were from the Southern Caddo archaeological region. Like collagen, $\delta^{13}C$ apatite values also significantly increase through time ($p = .01$), but there is considerable individual variation (Figure 2). The temporal trend is more evident if we presume that individuals from the Hurricane Hill site were consuming bison in sufficient quantities to result in abnormally high carbon signatures. Not until the Late Caddo period is a significant increase seen in maize contribution to the overall diet, which remains in place into the Historic period. The peak increase in apatite mean occurs later than in carbon collagen. For Southern Caddos, a corresponding decrease in nitrogen indicates that a high protein C_4 dietary source is unlikely for the majority. As has been demonstrated in the Midwest (Hedman et al. 2002; Rose 2008), there are individuals in the Early and Middle Caddo periods with more maize in their diet, and individuals during the Late and Historic Caddo periods with limited amounts of maize in their diet. No pattern of sex or status-based dietary difference is evident. During the Early Caddo period four individuals have diets consistent with little to no C_4 input. By the Late Caddo period only three (of 19) individuals have apatite signatures indicative of little to no C_4 in their diet. This pattern persists

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into the Historic Caddo period with three individuals (of 13) having little to no C_4.

Percentages of C_4-based foods in the diet were estimated using:

$$\%C_4 = \left|(-26 - [\delta_{apatite} - \Delta])\right| / 16 \times 100.$$

This equation follows Ambrose et al. (1997, 2003), but with some modification. The first change follows the intent of Akridge (2013) in the addition of an absolute value to the equation to avoid a resulting negative percent. End member $\delta^{13}C$ values for C_3 and C_4 foods are assumed to be -26‰ and -10‰. Recent results from controlled feeding experiments on a variety of mammals indicate that 12‰ is a reasonable estimate of Δ, or the diet-apatite spacing in omnivores (Lee-Thorp 2008; Passey et al. 2005). However, Kellner and Schoeninger (2007) use an offset of 9.7‰ for bone, arguing that Passey et al.'s (2005) numbers are on enamel and that the impact of bone versus enamel is not yet known. For this study we use Kellner and Schoeninger's (2007) offset value, as it produces middle range values. The percentages reported here should be regarded as rough estimates due to variation in diet-tissue spacing, differential laboratory procedures and equipment, and uncertainty about past food web isotopic composition. The estimates based on apatite indicate that maize was an important part of the early Caddo diet. During the Formative period values were -8.7‰, -11.1‰, and -11.7‰. The lowest value indicates that 29 percent of the diet in the Formative period samples came from C_4 resources. While this is a surprisingly high percentage given the available information in the paleobotanical record, it is possible that the consumption of amaranth could have influenced the findings. The same individual's collagen value indicates that C_4 is not present in the protein portion of the diet, and therefore bison can be excluded as a major contributor to the diet. However, the individual from the Hurricane Hill site had an elevated collagen value, suggesting that bison was an important component of this person's diet. Estimates from apatite values from the Early Caddo period range from 11 to 56 percent of the diet being C_4-based. Only at the Hurricane Hill site are collagen values elevated. During the Middle Caddo period estimates range from 15 to 62 percent of the diet being C_4-based. The highest apatite value in the sequence is in a female from a Late Caddo village site, with 72 percent of the diet being C_4-based. At this time, by individual, maize ranged as low as 26 percent of the diet. During the Late Caddo period one individual had elevated collagen and average apatite signatures suggestive of some bison consumption. At the Lang Pasture site (41AN38), three individuals had very low collagen and low apatite signifying little C_4 consumption, and another individual had a high overall C_4 consumption with none in the protein portion of the diet, indicating maize was the C_4 source. The mean apatite value from the Historic period was nearly the same as from the Late Caddo period, but the range was smaller with estimates of C_4 from 38 to 66 percent of the diet.

Nitrogen isotope results were available for 104 individuals. Increases in $\delta^{13}C$ collagen are associated with decreases in $\delta^{15}N$ values for the Southern but not the Northern Caddo populations (Figure 3). This shows that changes in C_4 intake are from maize rather than bison for most of the Southern Caddos. If bison were responsible for increases in $\delta^{13}C$ collagen, the trophic level should remain consistent if one terrestrial meat source is substituted for another. With the exception of the Late Caddo period, this is the case for the Northern Caddo. Evidence of maize and bison increase in later contexts in Northern Caddo sites while mean nitrogen values peak from A.D. 1200–1400, when there is a considerable increase in $\delta^{13}C$ collagen. This may be a time of increased bison consumption. After that, Northern Caddo mean nitrogen isotope values are at their lowest, as are mean carbon collagen isotope values, signifying an increase in dietary maize.

Variation in N^{15} increases through time. This is most evident in the Late and Historic Caddo periods when intensified maize agriculture is apparent. This suggests that increased maize consumption occurred in a time of increased dietary diversity rather than being a unifying cultural feature. No pattern of sexual or status-based difference in diet is apparent. During the Historic Caddo period, two infant signatures are high (both at 13.9‰), the likely result of breast feeding. In contrast, a child of approximately five years of age had a signature of 1.6‰, which would be consistent with the use of a weaning plant, likely maize gruel. Adult signatures were also varied, with a middle-aged adult

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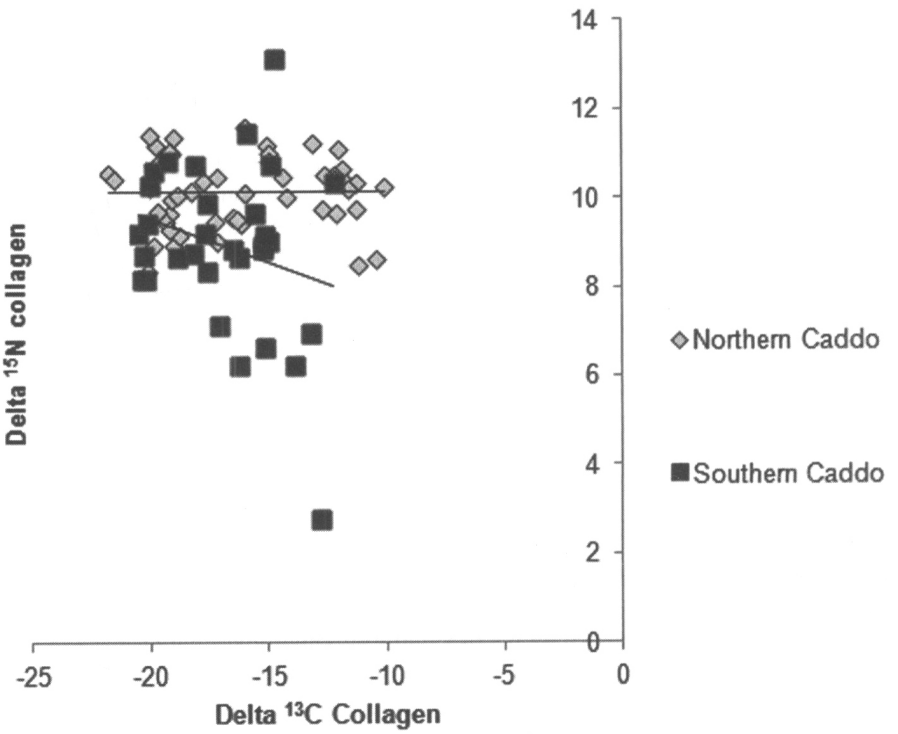


Figure 3. Delta ^{13}C and delta ^{15}N collagen adult values exclusive of Historic Period.

male having a signature of 12.7‰, indicative of a substantial freshwater fish and/or terrestrial omnivore/carnivore-based component of the diet. This contrasts with another male from the same site with a signature of 2.9‰, which is suggestive of a plant-based diet. The Historic Caddo variation is seen in village sites, one (41CE12, Jim Allen) with half of the adult population exhibiting N^{15} values suggesting that maize consumption replaced meat protein. Yet there are others at the site with normal and elevated nitrogen values in combination with high C_4 in the protein portion of the diet: a pattern that may be the result of bison, which were known to have been hunted by Caddo groups in Historic times.

Comparisons with Mississippi-Related Cultures

Previous isotopic and bioarchaeological studies suggest that the Caddo did not practice maize agriculture to the extent seen in other Mississippian-related cultures, but this has never been quantified (e.g., Powell 1985; Rogers 2011; Rose et al. 1991). The use of stable isotopes provides a direct way to measure the amount of C_4 consumption in the diet and can be used to accurately compare populations. In comparing the evolution of maize agriculture among the Caddo to its evolution in related agricultural populations, it is important to keep in mind the maize values discussed earlier. Based on these values, we should cautiously assume that the Caddo isotopic values should be approximately 2‰ lower than Ohio Valley populations given the same amount of maize ingested. Other Mississippian populations are within 1‰ of the Caddo mean and are therefore considered comparable.

For more than two decades, heterogeneity in the amount of maize in the diet has been repeatedly documented in Mississippians and their related cultures (e.g., Hedman et al. 2002; Rose 2003, 2008; Schurr 1992; Wilson 1997). In accordance with Schurr's (1992) study of isotopic variability in Middle Mississippian populations, the adjusted, or sample, standard deviation was used to examine dietary variation. Schurr regarded an adjusted standard deviation of greater than 2‰ as indicative of considerable dietary variability.

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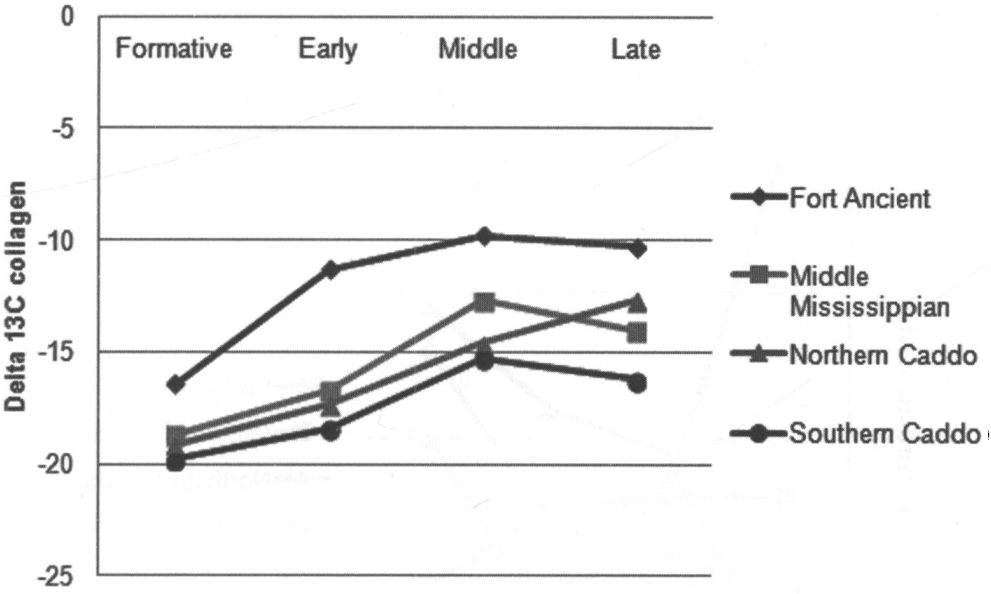


Figure 4. Delta ^{13}C collagen mean values. Time periods are arranged according to the Caddo chronological framework.

Selection of stable isotope data from other populations depended on the population being inland, lacking European influence, accurate dating, and population demographics (Table 5). Although we wished to readdress Rose et al.'s (1998) hypothesis that maize is detected earlier in stable carbon isotopes from the Caddo region than in the Lower Mississippi Valley, samples from that region were limited.

In examining better-sampled contemporary archaeological cultures, dietary differences in the adoption of maize are apparent. When compared to Middle Mississippian and Ohio Valley populations, a statistically significant difference in $\delta^{13}C$ collagen values is seen (p = .03) for sites contemporaneous with the Formative Caddo period (ca. A.D. 800–1000), but the differences are small and could be the result of differences in maize isotopic values. The Ohio Valley populations have the highest $\delta^{13}C$ signatures, which could be the result of rapid maize agricultural intensification or a difference in maize stable isotopic signatures (Figure 4). While adjusted standard deviations from the Ohio River Valley and Middle Mississippian values were greater than 2.0, the Ohio Valley adjusted standard deviation was very high, suggesting the highest degree of dietary variation (Figure 5). Apatite values corresponding to the Formative Caddo period were not available from outside the Caddo region. Some nitrogen values from this period were available for comparison, namely Rose's (2003) study in west-central Illinois. The nitrogen means were similar in both Caddo populations and in the contemporaneous Middle Mississippian populations. Collagen values suggest that protein sources were mostly C_3 animals and fish. C_4 consuming animals would have been largely absent from the diets of comparative populations and serve to evaluate the method of differentiation used to discriminate between bison and maize in the diet. For these populations, as $\delta^{13}C$ collagen values increase, $\delta^{15}N$ values decrease, indicating that maize replaces a portion of meat protein in the overall diet.

During the period from ca. A.D. 1000–1200, the Fort Ancient populations again stand in contrast to Caddo and Mississippian populations in terms of C_4 contribution to dietary protein (p = .00). Caddo populations are almost 1‰ depleted in $\delta^{13}C$ collagen compared to their Mississippian neighbors. However, the Fort Ancient mean is just over 6‰ more enriched in C_4 than Caddo populations, indicating a significantly greater contribution of C_4 resources to the protein component of the diet in the Ohio Valley populations, even if

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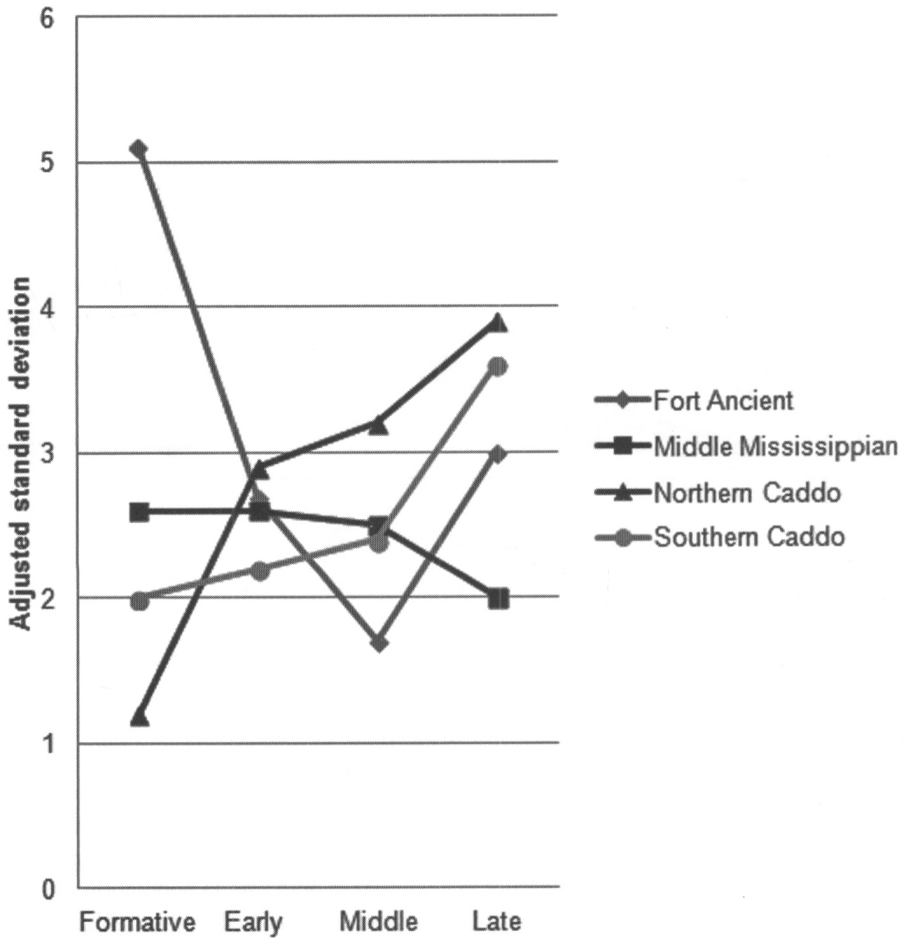


Figure 5. Adjusted standard deviation shows possible differences in the scale at which maize agriculture was practiced. Time periods follow the Caddo chronological framework.

the differences in maize signatures are taken into account, as well as the bison contributions to the diet of Northern Caddos. All well-sampled populations from this time had similarly high adjusted standard deviations for $\delta^{13}C$ collagen, suggesting similar dietary variability. The same variability is seen in $\delta^{13}C$ apatite, but few apatite results were available from this time period, consisting of only five results from the Caddo region and 12 results from Mississippian populations. These suggest a difference in the overall contribution of maize to the diet between the Caddo and Mississippian populations, but the sample size is small and problematic ($p = .05$). The Caddo sample is from only two sites, Hurricane Hill and Solon Stanley (41CE3), while the Mississippian sample is from Cahokia's Mound 72 and Schild Knoll A. More isotopic study of individuals that date to this time period is needed to confirm the apparent results. In the Fort Ancient populations, nitrogen isotope values support a higher overall dietary contribution of maize to the diet, at the expense of protein sources and trophic level, than in the Caddo and Mississippian populations. Nitrogen values are highest for the Caddo populations, suggesting the highest trophic level among the Northern and Southern Caddo, but the sample size is small.

A similar difference in $\delta^{13}C$ collagen values between the Fort Ancient and Caddo populations is seen between A.D. 1200–1400, when the Caddo mean is lower than any of the comparative populations. The two Caddo populations do not differ at this time, with a combined mean of -14.8‰.

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Table 5. Stable Isotope Mean Values and Adjusted Standard Deviations.

Region	$\delta^{13}C \pm$ s.d. collagen ‰ (PDB)	N	$\delta^{13}C \pm$ s.d. apatite ‰ (PDB)	N	$\delta^{15}N \pm$ s.d. collagen ‰ (AIR)	N	Reference
A.D. 500–1000							
Ohio River Valley	-16.4 ± 5.1	56					Greenlee 2002
Middle Mississippian	-18.7 ± 2.6	97			9.9 ± .7	82	Rose 2003; Lynott et al. 1986
Lower Mississippi Valley	-20.4 ± 3.0	5					Rose et al. 1985
A.D. 1000–1200							
Fort Ancient	-11.3 ± 2.7	93			8.1 ± .5	39	Greenlee 2002; Schurr and Schoeninger 1995
Middle Mississippian	-16.7 ± 2.6	60	-7.0 ± 3.0	12	9.2 ± .9	28	Ambrose et al. 2003; Rose 2003; Schober 1998; Lynott et al. 1986; Bender et al. 1981
Oneota	-16.1 ± 2.5	8					Bender et al. 1981
South Appalachian Mississippian	-15.0 ± 4.6	4					Schoeninger et al. 2000
A.D. 1200–1400							
Fort Ancient	-9.8 ± 1.7	140			8.2 ± .7	78	Greenlee 2002; Schurr and Schoeninger 1995
Middle Mississippian	-12.7 ± 2.5	157	-5.7 ± 2.1	108	9.3 ± 1.2	105	Hedman 2006; Schurr and Powell 2005; Rose 2003; Hedman et al. 2002; Schober 1998; Wilson 1997; Lynott et al. 1986
Oneota[1]	-12.0 ± 1.1	35	-5.2 ± 1.0	35	9.5 ± .4	35	Emerson et al. 2005
Plaquemine	-12.0	1			8.4	1	Hogue and Melsheimer 2008
South Appalachian Mississippian	-11.6 ± 3.0	4					Schoeninger et al. 2000
A.D. 1400–1680							
Fort Ancient	-10.3 ± 3.0	31					Greenlee 2002
Middle Mississippian	-14.0 ± 2.0	30			10.4 ± .9	27	Rose 2003; Lynott et al. 1986
Plaquemine[2]	-12.9	1			9.2	1	Hogue and Melsheimer 2008
South Appalachian Mississippian	-10.8 ± 1.0	37					Schoeninger et al. 2000

[1]As reported, individual samples not reported and final sample is implied.
[2]Site mean rather than individual mean as reported.

Only one well-dated result from the Lower Mississippi Valley was available, and it has a value of 12.0‰. The Middle Mississippian mean $\delta^{13}C$ collagen value is intermediate between the Caddo and Fort Ancient values. Again, if a difference in maize $\delta^{13}C$ isotopic value is factored in, the Fort Ancient mean value is more similar to the other means, with the exception of the Caddo. While the Middle Mississippian and Caddo contribution of C_4 resources to dietary protein remains similarly heterogeneous, a homogenous diet is indicated by adjusted standard deviations for the Fort Ancient population. The variation in C_4 contribution to protein is greater than seen in the overall diet, as indicated by apatite adjusted standard deviations. The same difference between Middle Mississippian and Southern Caddo mean apatite values is seen in this temporal interval. The two regions had significantly different apatite values (p = .00), indicating that Mississippian populations consumed significantly greater amounts of maize than Caddo populations at this time. The Caddo consumed one-third the C_4 resources of the Middle Mississippians. Nitrogen values, like carbon isotope values, were most different between the Fort Ancient and Caddo populations. Caddo populations had the highest nitrogen values, suggesting the highest contribution

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of aquatic resources to their diet or the highest trophic level among the populations that have been examined.

During the period between ca. A.D. 1400–1680, collagen values suggest a difference in the C_4 contribution to the protein portion of the diet between the Northern Caddos and those to the south (p = .03). The collagen values from the Southern Caddo populations are lower than in any other region examined and suggest a lower C_4 contribution to the protein portion of the diet. As in the earlier time periods, the Fort Ancient population has the most enriched collagen mean, but the difference in maize signatures could account for this. Dietary heterogeneity in terms of $\delta^{13}C$ collagen was highest for the Caddo and lowest for the Middle Mississippian population. No significant difference in nitrogen isotope values was seen among the Caddo and Middle Mississippian populations. Adjusted standard deviations for nitrogen were high only for the Caddo.

Few post-A.D. 1680 results suggest no significant difference between the Southern Caddo and the Lower Mississippi Valley archaeological cultures in $\delta^{13}C$ collagen and $\delta^{15}N$ values, although more samples are needed from this time period.

Conclusions

This study shows that for Caddo populations, maize consumption peaked later and never reached the same levels as seen in other related cultural groups. Review of maize isotope values suggests a regional difference in the $\delta^{13}C$ values. The mean maize value for the Fort Ancient culture is 2.0‰ higher than the overall mean from the Caddo samples included here. While it is beyond the scope of this article to try to determine the specific factors that may account for differences in isotopic signatures, more study of this issue is needed. Excluding the two Oneota samples (due to sample size), the lowest mean $\delta^{13}C$ maize means are from the Southwest, Great Basin, and Jornada regions. The Caddo mean had a high standard deviation, suggesting a large degree of variability that may be the result of either a subsistence economy in which two annual crops of maize were grown; differences in breeding, cooking, or growing practices; or significant environmental variability within the Caddo homeland.

Previous isotopic and bioarchaeological studies have suggested that the Caddo did not practice maize agriculture to the extent seen in other Mississippian-related cultures. Stable isotope analysis provides a means of analytic comparison. While a diet based on maize agriculture and meat protein sources of deer and fish is a commonality for Caddo and other Mississippian-related cultures, stable isotopes have shown that Mississippian-related cultures did not have a homogenous pattern of maize adoption and consumption. This is notable when we consider that people likely consumed maize for a variety of reasons. Food not only sustains life, but is imbued with cultural meaning. Food items are powerful cultural symbols that are consumed for economic, environmental, and historical reasons, and they are laden with identity (Sahlins 1972). The heterogeneity of the archaeological record demonstrates that these various factors all likely influenced individuals in the past when making dietary choices. Clearly history and identity played a role as maize consumption increased through time.

Delta ^{13}C collagen values suggest that the Caddo and other Mississippian-related populations followed somewhat different paths in the adoption and intensification of maize agriculture. When separated into Northern and Southern Caddo populations, the Southern Caddos parallel the maize contribution to protein seen in the Middle Mississippian population, although the maize contribution is consistently lower for the Southern Caddos. For these two populations, the maize contribution to protein peaks during the period from A.D. 1200–1400 and then decreases. Apatite values from post-A.D. 1400 Middle Mississippian contexts are needed to determine if maize consumption follows protein contribution or is different, as in the case of the Caddo. The Ohio River Valley populations, overall, intensified maize consumption rapidly and consumed more maize throughout the time sequence examined. After A.D. 1400, the C_4 contribution to protein leveled off for the Fort Ancient and Caddo populations.

It is intriguing that collagen $\delta^{13}C$ values show that the largest change in a C_4 contribution to the protein portion of the diet occurred in the Middle Caddo period. The difference in timing between the C_4 contribution to the whole diet and the protein portion of the diet warrants further examina-

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tion. Increased bison consumption at certain times and places could cause such a pattern, but archaeological evidence for this is mostly lacking, particularly in faunal assemblages in the Southern Caddo region. Of course, while bison's rare occurrence in most faunal assemblages from Caddo sites does not mean that it was not exploited for food, it does suggest that its consumption would have been limited in some way. A change in terrestrial meat protein from deer to bison would be virtually undetectable using $\delta^{15}N$ signatures. In the related cultures reviewed here, there was a decrease in $\delta^{15}N$ signatures as $\delta^{13}C$ collagen signatures increased, showing the trophic level drop with intensification of maize consumption. For the Southern Caddo populations, the same pattern is evident in all time periods, suggesting little influence of bison on isotopic composition. Northern Caddo populations did consume more bison, and their collagen values are higher from ca. A.D. 1000. It is during the period of A.D. 1200–1400 that values are similar between the Northern and Southern Caddos. The Sanders site is exceptional for many reasons, including the presence of bison scapula hoes in large numbers, some occurring as grave goods (Jackson et al. 2000). Carbon collagen values from this site are high, and when removed from the Southern Caddo sample, the sample mean decreases to -15.6‰, making the difference between the Middle and Late Caddo periods insignificant.

For more than a decade, heterogeneity in the amount of maize in the diet has been repeatedly documented in Mississippian cultures and their related cultures. During a period of introduction of a new food source, we might expect dietary variability to be high, as some individuals, families, and villages adopt new food items more rapidly, while others cling to old ways and traditions. Such dietary variation might be expected to decrease once the new food item becomes more productive and is further incorporated into the traditions of a given culture. Dietary variation among these groups did not decrease over time. Differences in the amount of maize consumed among individuals within and between sites likely reflect planting practices, with an increased variety reflecting an increased reliance on family plots, as opposed to communal fields (Rose 2008). For consumers of bison who experienced high transport costs, we might also expect a great deal of variability within communities in which some members had access to bison and others had little to none.

An examination of the three best sampled populations shows three different patterns of dietary variability through time. The Caddo show an increase in C_4 heterogeneity until the Historic period. The Middle Mississippian pattern is relatively consistent through time, but decreases in the period from A.D. 1400–1680. The Fort Ancient population starts with a high degree of C_4 variability and decreases until ca. A.D. 1400, when variation again increases. For the Southern Caddo, at least, this variation likely represents a high degree of family plot use as part of daily maize consumption practices.

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