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## Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone

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### Abstract

Cahokia Mound 72 contains 272 human burials dating to the Lohmann and early Stirling phases (ca. 1050–1150 AD) of the Mississippian period. Substantial status- and gender-related differences in burial style are apparent. Some burials are associated with large quantities of prestigious grave goods, suggesting high status. Mass graves of young adult females with skeletal indicators of poor health suggest low status and nutritional stress. Nitrogen isotope ratios of bone collagen show that high status individuals ate much more animal protein, but carbon isotope ratios of collagen suggest these individuals ate only ca. 10% less maize than lower status individuals. Apatite carbon isotopes show low status females ate ca. 60% more maize than high status individuals, which confirms the large nitrogen isotope difference of females in mass graves. These results indicate high and low status individuals had significantly different diet compositions and nutritional qualities. The stable isotope evidence supports paleopathological data for status-related differences in health, and dental morphological data for presumed genetic differences in origin. These data also provide insights into the nutrition- and health-related dimension of regional hierarchical organization of settlements and social inequality of this complex chiefdom in the greater Cahokia region.

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### Introduction

The Cahokia site is centrally located in the Mississippi River valley in west-central Illinois. The most intensive period of occupation and greatest social complexity dates to the Lohmann and early Stirling phases of the Mississippian culture, ca. AD 1050–1150 (Pauketat, 1998). During this era the site is estimated to have covered 13 km<sup>2</sup> (five square miles), with over 120 mounds identified, including Monk's Mound, the largest pre-Columbian structure in North America. Mound 72, a small

ridge-top mound located near the southern periphery of the site, contains a remarkable series of burial features that mirror the diversity and hierarchical complexity of Cahokia society and its powerful position in the region (Emerson and Hargrave, 2000; Emerson et al., 2003; Fowler et al., 1999; Milner, 1984; Pauketat, 2002). Mound 72 contains 272 individuals in 25 burial features. Their burial treatments and pathologies suggest significant status- and gender-related differences in health and diet. High status individuals with special burial treatments have low frequencies of skeletal indicators of poor health and nutrition. Low status, mainly young adult females, who were apparently sacrificed at the site and interred in mass graves, have higher frequencies of pathologies indicative of poor health and nutritional stress. Non-metric dental traits suggest these individuals were not from the

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same population as those of high status (Fowler et al., 1999).

Systematic differences in the stable carbon and nitrogen isotope ratios of major classes of dietary resources in the Cahokia region are preserved in the isotopic composition of skeletal tissues (Ambrose, 1993; Hedman et al., 2002). Isotopic analysis of Mound 72 skeletons may thus provide insight into the dietary dimensions of status- and gender-related differences in burial treatment at Mound 72. Almost all wild and domestic dietary resources of Mississippian populations in eastern North America (Johannessen, 1993a,b; Kelly and Cross, 1984) are based on plants that use the C<sub>3</sub> photosynthetic pathway,<sup>2</sup> and therefore have  $\delta^{13}\text{C}$  values<sup>3</sup> averaging  $-26.5\%$ . Plants such as maize use the C<sub>4</sub> photosynthetic pathway, and have significantly less negative  $\delta^{13}\text{C}$  values, averaging  $-12.5\%$  (O'Leary, 1981; Smith, 1972; Deines, 1980). This difference in plant  $\delta^{13}\text{C}$  values is preserved in the tissues of consumers. Analysis of the carbon isotope ratios of consumer bone thus provides a long-term record of the proportions of C<sub>3</sub> and C<sub>4</sub> resources consumed in prehistoric diets (van der Merwe and Vogel, 1978). Maize is the only significant C<sub>4</sub> plant in Mississippian diet, so the  $\delta^{13}\text{C}$  values of bone should provide an unambiguous quantitative index of the amounts of maize consumed. Maize can be considered a low quality dietary staple in comparison to all animal foods, and to most C<sub>3</sub> plant foods, because of its low protein content and low levels of some essential amino acids. If low status individuals had limited access to high quality foods, and relied to a greater extent on maize, then they should have higher frequencies of diet-related pathologies, and less negative  $\delta^{13}\text{C}$  values than high status individuals.

Previous stable isotope research on Mound 72 skeletons (Bender et al., 1981; Buikstra and Milner, 1991; Buikstra et al., 1994) analyzed only carbon isotope ratios of bone collagen. The wide range of  $\delta^{13}\text{C}$  values observed within and between burial groups suggested substantial inter-individual differences in maize consumption. Results on many of the individuals previously analyzed, especially those with low  $\delta^{13}\text{C}$  values, are of questionable validity due to poor bone preservation (Buikstra et al., 1994). Quantitative data on criteria for collagen preservation (DeNiro, 1985; Ambrose, 1990)

<sup>2</sup> C<sub>3</sub> and C<sub>4</sub> plants produce 3- and 4-carbon molecules, respectively, in the first steps of photosynthesis.

<sup>3</sup> Stable isotope ratios are expressed using the  $\delta$  (delta) notation, as parts per thousand (‰, permil) *difference* from a standard reference material:

$$\delta (\text{‰}) = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000,$$

where  $R$  is the ratio of the heavier to the lighter isotope. The standard for carbon is a marine limestone fossil (PDB) (Craig, 1957), and that for nitrogen is atmospheric N<sub>2</sub> (AIR) (Mariotti, 1983).

are unavailable for some samples, so the extent to which this isotopic diversity may be due to variation in preservation, diagenesis and/or contamination remains undetermined. However, in this predominantly C<sub>3</sub> environment, soil contaminants would derive from C<sub>3</sub> plants with low  $\delta^{13}\text{C}$  values. The highest bone  $\delta^{13}\text{C}$  values (Tieszen, 1991) are likely to reflect maize consumption. High  $\delta^{13}\text{C}$  values were found among some, but not all, low-status female sacrifices, indicating they had maize-dominated diets (Buikstra et al., 1994).

Stable isotope analyses of bone collagen nitrogen and bone apatite carbonate carbon, hereafter 'apatite,' provide insight into additional dimensions of diet. When combined with collagen carbon isotopes, they can be used to reconstruct trophic level and more accurately estimate dependence on maize and other C<sub>4</sub> plants (Ambrose et al., 1997; Ambrose and Norr, 1993; Hedman et al., 2002). Controlled diet experiments show that collagen preferentially records the carbon isotopic composition of dietary protein (Ambrose and Norr, 1993; Tieszen and Fagre, 1993a). These experiments also show that bone apatite carbonate accurately reflects the carbon isotopic composition of the whole diet. Maize is a low-protein (ca. 10%) dietary resource, so the  $\delta^{13}\text{C}$  value of bone collagen is likely to underestimate maize consumption, but apatite should provide an accurate estimate. Nitrogen isotope ratios increase by approximately 3.3‰ between trophic levels (Ambrose, 1991, 2000; Schoeninger and DeNiro, 1984), and freshwater aquatic animal resources often have higher  $\delta^{15}\text{N}$  values than terrestrial ones (Katzenberg, 1989), so bone collagen  $\delta^{15}\text{N}$  values can be used to evaluate sources of dietary protein. Analysis of bone collagen nitrogen and apatite carbonate can thus provide greater insights into the dietary dimensions of status- and gender-related differences of prehistoric human populations at Mound 72. Results presented in this study demonstrate that high and low status groups had diets with very different amounts of maize and animal protein.

### Diet reconstruction with bone collagen and apatite stable isotopes

Krueger and Sullivan (1984) developed the first sophisticated models of the relationship between the carbon isotope composition of dietary macronutrients and those of collagen and apatite carbonate. Their models inspired controlled diet experiments by Ambrose and Norr (1993) and Tieszen and Fagre (1993a) that permit refined reconstructions of diets in Mound 72. We will describe the original models, the results of controlled diet experiments, refined models, the data from Mound 72, and the implications for dietary dimensions of social complexity and inequality during the apogee of cultural developments at Cahokia.

Diet reconstruction with stable isotopes is predicated on the assumption that you are what you eat. In other words, there is a direct relationship between the isotopic composition of the diet and consumer tissues. Two contrasting models of the diet-to-tissue carbon isotope relationship have been proposed (Schwarcz, 1991, 2000). In the *Linear Mixing* (Scrambled Egg) model, all carbon atoms in the diet, whether from proteins, fats or carbohydrates, are incorporated equally into all animal tissues. Conversely, the *Macronutrient Routing* model proposes dietary proteins are preferentially incorporated into tissue proteins, and dietary energy (carbohydrates and fats) into bone apatite carbonate.

The protein to collagen routing model is correct in part because 19% of the carbon atoms in bone collagen come from essential amino acids, which must be obtained from dietary protein (Klepinger and Mintel, 1986; Ambrose, 1993). However, some non-essential amino acids behave like essential ones. This class of semi-essential amino acids is termed *Conditionally Indispensable* because growth rate, and recovery from illness and injury are retarded when they are absent from the diet (Young and El-Khoury, 1995; Reeds, 2000). Conditionally indispensable amino acids account for ca. 46% of the carbon atoms in collagen. A more realistic estimate of the amount of routing of protein carbon to collagen is thus closer to 65% (Ambrose et al., 1997; Schwarcz, 2000). Almost all nitrogen in collagen is derived from dietary protein, so routing of nitrogen is uncontested (Ambrose, 2000).

Krueger and Sullivan (1984) proposed that bone apatite carbonate is derived from blood CO<sub>2</sub>, which ultimately comes from cellular energy metabolism. Therefore apatite carbonate δ<sup>13</sup>C should reflect that of the energy source. Their routing model is often incorrectly portrayed as stating that non-protein carbon is exclusively incorporated into bone apatite carbonate, and that protein carbon is not (e.g., Ambrose and Norr, 1993). However, amino acids that are not used for protein synthesis are used for energy. If virtually all dietary macronutrients, including proteins, are used for energy metabolism, then apatite carbonate should fit the linear mixing model.

In order to reconstruct prehistoric diets, an accurate estimate of the isotopic shift—the fractionation factor—must be assessed between the isotopic composition of diet and bone. Observations on humans and large herbivores (Vogel and van der Merwe, 1977; Vogel, 1978; Lee-Thorp et al., 1989; Krueger and Sullivan, 1984) show that collagen δ<sup>13</sup>C is enriched by 5‰ relative to the diet. Krueger and Sullivan (1984) also observed that herbivore apatite δ<sup>13</sup>C is enriched by +12‰ over the assumed diet. The herbivore apatite–collagen difference (Δ<sup>13</sup>C<sub>ap–coll</sub>) is thus ca. 7‰. Carnivore carbonate is enriched by only 8–9‰ relative to the diet (Krueger and Sullivan, 1984; Lee-Thorp et al., 1989). If carnivore collagen is also enriched

by 5‰, its Δ<sup>13</sup>C<sub>ap–coll</sub> should be 3–4‰. Krueger and Sullivan (1984) explained this low Δ<sup>13</sup>C<sub>ap–coll</sub> value as follows: carnivores derive more energy from fats, and fats have 5‰ less <sup>13</sup>C than other dietary macronutrients. If metabolized fats preferentially label apatite, then carnivores should have lower carbonate δ<sup>13</sup>C values, and thus smaller Δ<sup>13</sup>C<sub>ap–coll</sub> values.

This collagen–apatite spacing model does not explain deviations from the diet–collagen spacing of 5‰ that may be due to macronutrient routing of protein. Human diets often include foods that differ greatly in their macronutrient and isotopic compositions, so an accurate estimate of protein routing is needed for diet reconstruction. For example, in eastern North America, maize was the only major prehistoric C<sub>4</sub> staple. It has a high <sup>13</sup>C content, but has only about 10% protein. Most dietary protein came from <sup>13</sup>C-depleted C<sub>3</sub>-feeding animals such as fish and deer (which are 85–90% protein), and from nuts, leaves and seeds of C<sub>3</sub> plants, which usually have more than 20% protein. If dietary protein carbon is routed to collagen, then maize should be under-represented in bone collagen.

#### Experimental determination of diet–bone isotopic relationships

Observations and experiments on large mammals consistently produced estimates of diet–collagen spacings of +5‰, as noted above, while controlled diet experiments with small animals frequently obtained collagen–diet spacing values significantly less than 5‰ (reviewed in Ambrose and Norr, 1993). Two controlled diet experiment programs were performed to investigate this discrepancy from estimates that were based on large versus small mammals, and to evaluate the macronutrient routing and linear mixing models (Ambrose and Norr, 1993; Tieszen and Fagre, 1993a). Both programs obtained similar results. In the most rigorously designed diet experiments (Ambrose and Norr, 1993), rats were raised from conception to maturity on eight different diets with purified protein (casein, from milk) and non-protein ingredients. Each diet had different carbon isotope ratios, with 5, 20, and 70% protein. Some diets were pure C<sub>3</sub> or C<sub>4</sub>; other diets included C<sub>3</sub> protein with C<sub>4</sub> non-protein, or C<sub>4</sub> protein with C<sub>3</sub> non-protein. Another five diet configurations, at three protein levels (15 diets), were synthesized using marine fish protein (tuna), combined with C<sub>3</sub> and/or C<sub>4</sub> non-protein ingredients.

Results demonstrate that apatite δ<sup>13</sup>C values were enriched by approximately 9.4‰ over the diet, even when diets had different amounts of protein, and protein and non-protein components had different δ<sup>13</sup>C values. Apatite–diet spacing (Δ<sup>13</sup>C<sub>ap–diet</sub>) was effectively constant, confirming the linear mixing model for apatite. In contrast, the δ<sup>13</sup>C value of collagen relative to diet was

experimentally manipulated from  $-2.3\text{‰}$  when the diet comprised  $C_3$  protein and  $C_4$  non-protein, to  $+11\text{‰}$  when protein was  $C_4$  and non-protein was  $C_3$ . This deviation from the expected  $+5\text{‰}$  diet–collagen enrichment corresponds to under- or overestimation of the amount of  $C_4$  by as much as 45% (Ambrose and Norr, 1993). Collagen–diet spacings were thus systematically dependent upon the difference between protein and non-protein  $\delta^{13}\text{C}$  values. You are *not* what you eat plus 5‰ when protein and non-protein macronutrients have different isotope ratios. Collagen  $\delta^{13}\text{C}$  closely tracked protein  $\delta^{13}\text{C}$ , confirming the routing model for collagen. A  $\Delta^{13}\text{C}_{\text{coll-diet}}$  of  $5.1\text{‰}$  was obtained for experimental rats when dietary protein and non-protein components had the same  $\delta^{13}\text{C}$  value, which validated previous estimates based on large mammals. This ca. 5‰ spacing for monoisotopic diets was obtained for all protein levels. Monoisotopic experimental diets produced a  $\Delta^{13}\text{C}_{\text{ap-coll}}$  value of  $4.4\text{‰}$  ( $\Delta^{13}\text{C}_{\text{ap-diet}}$  of  $9.4\text{‰}$  minus  $\Delta^{13}\text{C}_{\text{coll-diet}}$  of  $5\text{‰}$  =  $4.4\text{‰}$ ). Because  $\Delta^{13}\text{C}_{\text{ap-diet}}$  was constant, and  $\Delta^{13}\text{C}_{\text{coll-diet}}$  varied in response to protein  $\delta^{13}\text{C}$ ,  $\Delta^{13}\text{C}_{\text{ap-coll}}$  values were varied systematically in controlled diet experiments, from  $>11\text{‰}$  when the diet comprised  $C_3$  protein and  $C_4$  non-protein, to ca.  $0\text{‰}$  when protein was  $C_4$  and non-protein was  $C_3$ . These experiments clearly support Krueger and Sullivan's (1984) models of protein-to-protein routing for collagen and linear mixing for apatite.

Understanding the relationship between the protein-whole diet difference and  $\Delta^{13}\text{C}_{\text{ap-coll}}$  permits reconstruction of the  $\delta^{13}\text{C}$  values of protein and non-protein components of diets by analyses of prehistoric bone apatite and collagen  $\delta^{13}\text{C}$  values. For prehistoric human bone, if  $\Delta^{13}\text{C}_{\text{ap-coll}}$  is greater than  $4.4\text{‰}$ , then dietary protein was more negative than the whole diet. In eastern North America this would represent a diet of  $C_3$ -feeding animals plus maize.

Krueger and Sullivan's (1984) apatite–collagen spacing model has been considered an indicator of trophic level that can be applied to humans (Lee-Thorp et al., 1989). However, the amount of fats in animals is unlikely to be high enough to explain the carnivore diet–apatite difference. Rather, the difference in apatite–collagen and apatite–diet  $^{13}\text{C}$  spacing values between herbivores and carnivores may be partly a function of protein routing effects as noted above (Ambrose and Norr, 1993), and partly a function of isotope effects in ruminant digestion (Metges et al., 1990).

Ruminant herbivore guts support a large community of methane-producing symbiotic digestive microbes. The relationship between  $\delta^{13}\text{C}$  values of whole diet, metabolic  $\text{CO}_2$ , biogenic methane, apatite and  $\Delta^{13}\text{C}_{\text{ap-coll}}$  has been determined by controlled diet experiments on rodents and cows (Ambrose and Norr, 1993; Balasse et al., 2002; DeNiro and Epstein, 1978; Tieszen and Fagre, 1993a; Metges et al., 1990). Rodent breath and blood

$\text{CO}_2$  have slightly less  $^{13}\text{C}$  than the diet (ca.  $-0.5\text{‰}$ , Tieszen and Fagre, 1993a), so apatite is enriched by about 10‰ relative to respired metabolic  $\text{CO}_2$ . Symbiotic microorganisms in ruminant digestive systems produce very large amounts of methane (Crutzen et al., 1986) that has a very low  $\delta^{13}\text{C}$  value of approximately  $-44\text{‰}$  relative to the diet (Metges et al., 1990). Production of  $^{13}\text{C}$ -depleted methane is balanced isotopically by simultaneous generation of microbial metabolic  $\text{CO}_2$  with a  $\delta^{13}\text{C}$  value of ca.  $+15\text{‰}$  relative to the diet. Ruminant blood and respired  $\text{CO}_2$  are thus enriched in  $^{13}\text{C}$  due to methanogenesis (Metges et al., 1990). Therefore  $\Delta^{13}\text{C}_{\text{ap-diet}}$  should also be higher, and should be proportional to the amount of methane generated. Cow breath  $\text{CO}_2$  is  $+3.5\text{‰}$  relative to the diet, and apatite is  $13.5\text{‰}$  (Balasse et al., 2002), so the difference between metabolic  $\text{CO}_2$  and apatite  $\delta^{13}\text{C}$  remains ca. 10‰, as for non-ruminants.

The methanogenesis- $\text{CO}_2$  mass balance model predicts that  $\Delta^{13}\text{C}_{\text{ap-diet}}$  of herbivores is controlled mainly by the amount and  $\delta^{13}\text{C}$  value of  $\text{CO}_2$  cogenerated during methanogenesis. Bovids generate the largest amounts of methane (Crutzen et al., 1986), and their  $\Delta^{13}\text{C}_{\text{ap-diet}}$  is estimated to be 13.5–14‰ (Balasse et al., 2002; Cerling and Harris, 1999). Equids generate ca. 80% less methane (scaled to body mass), and have lower apatite  $\delta^{13}\text{C}$  values than sympatric bovids on the same diets (Cerling and Harris, 1999). Rats and carnivores generate insignificant amounts of methane (Crutzen et al., 1986), and have the lowest  $\Delta^{13}\text{C}_{\text{ap-diet}}$  values (Ambrose and Norr, 1993). Metabolic  $\text{CO}_2$  is not incorporated into animal proteins, and thus does not cause herbivore  $\Delta^{13}\text{C}_{\text{coll-diet}}$  to deviate from 5‰.

Relative rates of methanogenesis provide the most parsimonious explanation for the systematic difference in  $\Delta^{13}\text{C}_{\text{ap-diet}}$  values between methanogenic ruminant bovids and equids, and non-methanogenic rodents and carnivores. Humans also generate insignificant amounts of methane (Crutzen et al., 1986), and are likely to have  $\Delta^{13}\text{C}_{\text{ap-diet}}$  values like those of rodents and carnivores. Krueger and Sullivan's (1984) trophic level model does not account for the effects of methanogenesis on respired  $\text{CO}_2$   $\delta^{13}\text{C}$ , and also does not consider the effects of varying protein versus whole diet  $\delta^{13}\text{C}$  values on  $\Delta^{13}\text{C}_{\text{coll-diet}}$  values. Therefore  $\Delta^{13}\text{C}_{\text{ap-coll}}$  values cannot be considered a simple measure of human trophic levels. Moreover,  $\Delta^{13}\text{C}_{\text{ap-diet}}$  values of ruminant herbivores are not an appropriate model for human vegetarian diets because of the unusual isotopic effects accompanying herbivore methane production.

Nitrogen isotope ratios increase between trophic level, and thus provide a measure of consumption of animal protein. A step-wise increase in  $\delta^{15}\text{N}$  of 3.0–3.4‰ occurs between trophic levels (Schoeninger and DeNiro, 1984; Ambrose, 1991). However, because plants have very little protein (10–25%), and meat is mainly protein

(85–90%), a small amount of meat (including mammals, fish and birds) dominates the diet nitrogen isotope ratio, and can greatly increase the  $\delta^{15}\text{N}$  value of the consumer. In a diet with 15% meat, approximately half the nitrogen comes from meat. On a 50% meat diet, meat accounts for 85% of the nitrogen. Assuming a difference of 3‰ between plants and meat, a 15% meat diet will cause a 1.5‰ increase in  $\delta^{15}\text{N}$ , but a 50% meat diet increases diet  $\delta^{15}\text{N}$  by 2.5‰ compared to a plant-based diet. Moving from 50% to 100% meat changes diet  $\delta^{15}\text{N}$  by only 0.5‰. Because the relationship of amount of meat *versus* plant to consumer  $\delta^{15}\text{N}$  is nonlinear, one cannot accurately estimate the percentage of meat versus plant protein from  $\delta^{15}\text{N}$  values. However, all else being equal, a higher  $\delta^{15}\text{N}$  value does indicate more meat consumption.

### Materials and methods

Sample preparation followed methods described in detail by Krueger and Sullivan (1984; Ericson et al., 1989). Bones were manually cleaned, and then crushed to a coarse powder. Bone was treated with 1 N acetic acid to remove exogenous carbonates, then reacted under vacuum with 1 M HCl to release apatite carbonate  $\text{CO}_2$ , which was purified by cryogenic distillation for mass spectrometry. The demineralized residue was heated in slightly acid distilled water (pH 3) to dissolve (gelatinize) collagen. Acid-insoluble contaminants (rootlets, minerals, humic acids, etc.) were removed by filtration. The filtrate was dried, combusted, and  $\text{CO}_2$  and  $\text{N}_2$  were purified by cryogenic distillation for mass spectrometry. Bone preservation was remarkably poor (Buikstra et al., 1994). Well-preserved gelatin was identified as a transparent, glossy, yellow dried residue. Powdery white to brown dried residues were considered non-collagenous. C:N ratios (DeNiro, 1985; Ambrose, 1990) were not determined. Gelatinized collagen yields were very low, and only nine out of 25 samples produced enough collagen for reliable analysis and interpretation. One individual (Burial 44, Feature 105) had anomalously good preservation, and may be intrusive.

Percentages of  $\text{C}_4$  foods in the diet were calculated<sup>4</sup> following Schwarzc (1991), and Ambrose et al. (1997, p. 357). End-member  $\delta^{13}\text{C}$  values for  $\text{C}_3$  and  $\text{C}_4$  foods were assumed to be  $-25\text{‰}$  and  $-10\text{‰}$ , respectively. The  $\text{C}_3$  end-member reflects a correction of  $+1.5\text{‰}$  (Balasse

et al., 2002) for the fossil fuel burning effect, which has lowered modern atmospheric  $\text{CO}_2$   $\delta^{13}\text{C}$  values (Stuiver et al., 1984), and the  $\text{C}_4$  end-member reflects the high  $\delta^{13}\text{C}$  value, averaging  $-10\text{‰}$ , for prehistoric maize kernels (Tieszen and Fagre, 1993b). Because of analytical uncertainty, interindividual variation in diet-tissue spacings on controlled diets, variability in past foodweb isotopic composition, and uncertainty regarding the mean  $\text{C}_3$  and  $\text{C}_4$  end-member values of foods actually consumed at Cahokia, the accuracy of our estimates of dietary  $\% \text{C}_4$  should be considered  $\pm 10\%$ .

The construction of Mound 72, its burial features, artifact associations, and important attributes of the skeletons (age, gender, pathologies, etc.) were described by Jerome Rose in the comprehensive monograph by Fowler et al. (1999), and are briefly summarized here. Of the nine individuals that provided reliable isotopic data from Mound 72 (Table 1), four have been assigned to a high status group. The southeast corner of the mound contains two primary extended burials associated with a platform of over 10,000 shell beads laid out in a falcon or eagle design. This remarkable feature is surrounded by four retainer burials (Feature 101). One retainer (Burial 12) has been analyzed. Seven extended burials are associated with large quantities of exotic artifacts, including copper, mica and projectile points made from exotic and local cherts (Feature 102). Feature 106 contains four headless, handleless males. No individuals from these dramatic features yielded suitable collagen for analysis. The northwest end of the mound contains a charnel house (Feature 219). Bundle Burial 162 and primary extended Burial 120 in this feature have been analyzed. Feature 229 contains a mass grave of mixed age and sex individuals, and several had been decapitated or pierced by projectile points. These sacrifices were overlain by a group of primary extended burials on cedar litters, which suggests high status. Burial 201 (possibly female) was analyzed from the upper group. Gender of the other high status individuals could not be determined.

Mass graves with primary extended burials contain a predominance of young adult females, aged 20–25 years. These features are interpreted as mass burials of low status sacrificial female retainers. Analyses of dental morphology suggest that they did not belong to the breeding population of the high status individuals, and may have been sacrificial tribute from surrounding outlying areas under their domination (Fowler et al., 1999, p. 82). Feature 214 is a rectangular pit with 24 individuals systematically arranged in two layers in one row. Two individuals from this feature (burials 142 and 146) produced reliable isotopic data. Feature 105 is a square pit with 53 individuals arranged in two rows of two layers of bodies aligned head-to-head. Two individuals (burials 44 and 53) from this mass grave had well-preserved collagen. Feature 237, which is a small

<sup>4</sup> Percent  $\text{C}_4$  is calculated as follows:

$$\% \text{C}_4 = (-25 - (\delta_b - \Delta)) / 15 \times 100,$$

where  $-25\text{‰}$  is the  $\text{C}_3$  end-member  $\delta^{13}\text{C}$  value,  $\delta_b$  is the  $\delta^{13}\text{C}$  value of collagen or apatite,  $\Delta$  is the diet–collagen (5.1‰) or diet–apatite (9.4‰) spacing, and 15 is the difference between the  $\text{C}_3$  and  $\text{C}_4$  end-members ( $-10\text{‰}$ ).

rectangular pit with 19 bodies in two layers, provided one individual (Burial 186) with reliable isotopic analyses.

## Results

Three of the high status burials (12, 162, 201) have relatively high  $\delta^{15}\text{N}$  values, ranging from 9.7‰ to 11.9‰, and one outlier (Burial 120) has an anomalously low value of 7.9‰ (Fig. 1, Table 1). Four low-status individuals from the mass graves have significantly lower  $\delta^{15}\text{N}$  values, ranging from 7.9‰ to 8.7‰, which indicates substantially less animal protein. Collagen  $\delta^{13}\text{C}$  values of three high status burials range from  $-18.8$ ‰ to  $-17.8$ ‰. The high status outlier (Burial 120)

has a relatively high  $\delta^{13}\text{C}$  value of  $-14.3$ ‰. Low status collagen  $\delta^{13}\text{C}$  values range from  $-18.4$ ‰ to  $-16.0$ ‰. Their average  $\delta^{13}\text{C}$  ( $-17.1$ ‰) is only 1.2‰ less negative than that of the three high status, high  $\delta^{15}\text{N}$  individuals. Assuming all  $^{13}\text{C}$ -enrichment of collagen is due to maize consumption, then high and low-status groups had diets with 10% and 19% maize, respectively, and the high status outlier consumed ca. 37% maize. The low status individual with anomalously well-preserved collagen (Burial 44) has a  $\delta^{15}\text{N}$  value close to the low status average (Table 1), but has the highest collagen  $\delta^{13}\text{C}$  value in this sample set, reflecting a diet with 45% maize.

Apatite  $\delta^{13}\text{C}$  values of high status individuals range from  $-10.0$ ‰ to  $-6.7$ ‰, and those of low status individuals range from  $-4.6$ ‰ to  $-1.6$ ‰ (Fig. 2). High and

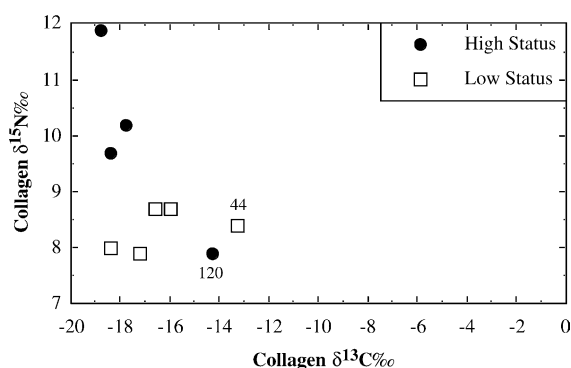


Fig. 1. Carbon and nitrogen isotopes of collagen of high and low status individuals from Mound 72, Cahokia. Outliers for each status group are indicated by their burial numbers.

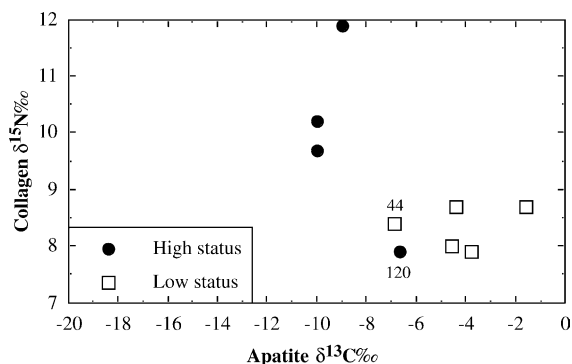


Fig. 2. Carbon isotopes of apatite and nitrogen isotopes of collagen of high and low status individuals from Mound 72, Cahokia. Outliers for each status group are indicated by their burial numbers.

Table 1

Isotopic composition of bone collagen and bone apatite carbonate of low and high status individuals from Mound 72, Cahokia

Feature no.	Burial no.	Burial type (gender, age)	$\delta^{15}\text{N}$	Collagen $\delta^{13}\text{C}$	Apatite $\delta^{13}\text{C}$	$\Delta^{13}\text{C}_{\text{ap-coll}}$	Collagen %C <sub>4</sub>	Apatite %C <sub>4</sub>
<i>High status</i>								
101	12	PE (? adult)	11.9	-18.8	-9.0	9.8	7.3	44.0
219*	120	PE (? adult)	7.9	-14.3	-6.7	7.6	37.3	59.3
219	162	BD (? 25–30)	10.2	-17.8	-10.0	7.8	14.0	37.3
229	201	PE (F? adult)	9.7	-18.4	-10.0	8.4	10.0	37.3
Mean (all high status)			9.9	-17.3	-8.9	8.4	17.2	44.5
Mean (excluding Burial 120)			10.6	-18.3	-9.7	8.7	10.4	39.6
<i>Low status</i>								
105	53	PES (? ?)	8.7	-16.0	-1.6	14.4	26.0	93.3
214	142	PES (F? 20–25)	8.7	-16.6	-4.4	12.2	22.0	74.7
214	146	PES (F 20–25)	8.0	-18.4	-4.6	13.8	10.0	73.3
237	186	PES (F 20–25)	7.9	-17.2	-3.8	13.4	18.0	78.7
Mean			8.3	-17.1	-3.6	13.5	19.0	80.0
105**	44	PES (? ?)	8.4	-13.3	-6.9	6.4	44.0	58.0

PES, primary extended sacrifice; PE, primary extended; BD, bundle burial; \*, isotopic composition outlier; \*\*, anomalously well-preserved outlier.

Calculation of %C<sub>4</sub> is described in Footnote 4.

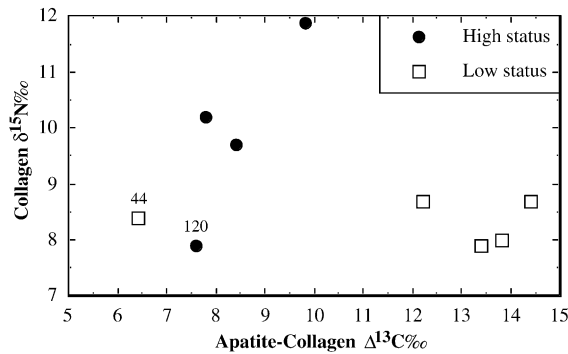


Fig. 3. Apatite-collagen carbon isotope difference values ( $\Delta^{13}C_{ap-coll}$ ) and nitrogen isotopes of collagen of high and low status individuals from Mound 72, Cahokia. Outliers for each status group are indicated by their burial numbers.

low status groups thus differed by 6‰ in apatite, compared to only 1‰ in collagen. Estimates of % $C_4$  in their diets based on apatite  $\delta^{13}C$  are substantially higher: high and low status groups consumed averages of 45% and 80% maize, respectively. The well-preserved low status (Burial 44), and the high status outlier (Burial 120) both consumed ca. 60% maize.

Average  $\Delta^{13}C_{ap-coll}$  values of low status individuals (13.5‰) are much higher than those of high status individuals (ca. 8.5‰), with the exception of the well-preserved low status individual (Burial 44), which had the lowest  $\Delta^{13}C_{ap-coll}$  value (6.4‰) in this sample set (Fig. 3). Because apatite  $\delta^{13}C$  values are high relative to those of collagen, they indicate dietary protein sources of high status individuals were mainly  $C_3$ , while the bulk diet included ca. 45%  $C_4$ . Low status individuals also obtained most of their protein from  $C_3$  sources, but their bulk diet included substantially more low-protein  $C_4$  foods.

## Discussion and conclusions

Low status individuals from Cahokia Mound 72 have some of the highest  $\Delta^{13}C_{ap-coll}$  values ever reported for human bones, which indicate substantial status-related differences in diet. However, these high values also raise questions regarding diagenetic alteration of the bone apatite carbonate. Diagenesis could cause an increase in apatite  $\delta^{13}C$  values by exchange with atmospheric  $CO_2$ , which has a  $\delta^{13}C$  value of ca. 7‰, so a small diagenetic increase in all apatite  $\delta^{13}C$  values cannot be discounted. This would result in a small overestimation of bulk diet % $C_4$ . However, the soil  $CO_2$ , likely derived from  $C_3$  plant decomposition and respiration, would have had a  $\delta^{13}C$  value of ca. -23‰ (Cerling, 1984). This would cause a decrease in apatite  $\delta^{13}C$  values, and underestimation of bulk diet % $C_4$ . Given the spatial proximity of the burials considered here, it can be assumed that diagenesis would

have affected all bones equally. If present, diagenesis should result in convergence of apatite carbonate  $\delta^{13}C$  values for high and low status individuals. Therefore diagenesis is unlikely to account for the status-related dietary differences observed in Mound 72.

Collagen carbon isotopes are biased toward the isotopic composition of dietary protein, and substantially underestimate the contribution of maize to the diets of low status individuals. On experimental diets, the highest  $\Delta^{13}C_{ap-coll}$  values were obtained for very low protein diets that had  $C_3$  protein and  $C_4$  carbohydrates (Ambrose and Norr, 1993). Therefore low  $\delta^{15}N$  and  $\delta^{13}C$  values of collagen for low status individuals demonstrate that the high apatite  $\delta^{13}C$  (and thus high  $\Delta^{13}C_{ap-coll}$ ) values reflect a diet dominated by low-protein maize, with  $C_3$  protein derived mainly from plants, plus small amounts of meat of  $C_3$ -feeding animals. The low status outlier (Burial 44) and high status outlier (Burial 120) consumed less  $C_3$  protein than other individuals. Specialized low quality diets may account for high incidence of dental caries and other diet-related pathologies of sacrificed females (Fowler et al., 1999).

The diets of individuals from Mound 72 can be compared with those from other sites in eastern North America, the Midwest and the Mississippi and Illinois River valley region. Isotopic evidence demonstrates that maize was the main staple  $C_4$  plant during the Late Woodland and Mississippian periods in the lower Illinois Valley and American Bottom area (Ambrose, 1987; Bender et al., 1981; Buikstra and Milner, 1991; Buikstra et al., 1994; Hedman et al., 2002; Schober, 1998; van der Merwe and Vogel, 1978), and throughout Eastern North America (Greenlee, 1998; Lynott et al., 1986; Schoeninger and Schurr, 1994; Schurr, 1992; Schurr and Redmond, 1991; Vogel and van der Merwe, 1977). Intensive maize agriculture was adopted in eastern North America around 900 AD (Ambrose, 1987; Schwarcz et al., 1985; van der Merwe, 1982), but maize consumption was variable regionally and temporally (Buikstra et al., 1994; Hedman et al., 2002; Schober, 1998). Complex social formations arose by AD 1050 during the Mississippian period (Pauketat, 1998; 2002), after a reliance on maize had been established in this region. However variability in the isotopic composition of Cahokia Mound 72 burials suggests far less reliance on maize by healthy, high-status individuals. Differences in status and health may be related to diet quality, gender and geographic origin.

Analyses of collagen carbon and nitrogen and apatite carbon isotopes of skeletal populations from late Woodland and Mississippian sites in the lower Illinois River Valley and American Bottom (Schober, 1998; Hedman et al., 2002; Williams et al., 1997) provide a local baseline for the interpretation of the amounts of maize in diets of individuals buried at Cahokia Mound 72. High status individuals generally have an isotopic

composition that most closely resembles that of Hill Prairie (Mound 251) males (Hedman et al., 2002). The extremely high  $\Delta^{13}\text{C}_{\text{ap-coll}}$  value of low status individuals at Mound 72 is unusual: only one female from Schild Knoll A (Schober, 1998) and one from Corbin (Hedman et al., 2002) have  $\Delta^{13}\text{C}_{\text{ap-coll}}$  values greater than 10‰. The Mound 72 low status outlier (Burial 44) and high status outlier (Burial 120) have isotopic compositions that resemble those of individuals from pencontemporary sites in the uplands of the greater Cahokia region and lower Illinois River Valley, including Schild Knoll A and B females (Schober, 1998) and Corbin Mounds (Hedman et al., 2002).

These results suggest future directions for research on diet reconstruction with stable isotopes in eastern North America. First, because apatite carbonate carbon isotopes are not biased toward the protein component of the diet, it should provide insights into the early stages of maize agriculture in eastern North America (Ambrose and Norr, 1993). Small amounts of maize have been recovered from several Middle Woodland sites that date to ca. 0–250 AD (Conard et al., 1984; Johannessen, 1993a; Riley et al., 1994). Human bone collagen stable carbon isotope evidence suggests maize consumption did not become significant until after AD 900. However several sample sets dating to the first appearance of maize show a slight shift away from pure  $\text{C}_3$  collagen values (Ambrose, 1987). If very small amounts of maize were consumed during the initial stages of maize agriculture, it should be more clearly evident in apatite carbon isotopes.

Research on the nutritional dimension of social complexity during the Mississippian period at Cahokia Mound 72 should be expanded. The carbon and nitrogen isotopic composition of more individuals from each burial context should be determined. Strontium isotope analysis can provide important information on geographic origin (Price et al., 1994; Sillen et al., 1998). For example, it could be used to determine whether the paramount bead platform burials, primary extended sacrifices, headless, handless males, sacrificed individuals in mass graves, and other types of burials were long term residents of Cahokia, or immigrants, captives or sacrificial tribute from the hinterlands or other regions.

Mound 72 was an important ritual focal point for Cahokia during its period of greatest size and social complexity around AD 1050–1150 (Fowler et al., 1999; Pauketat, 2002). The diversity and complexity of burial features, artifact caches, differential distribution of nutrition and health-related pathologies, and dental micromorphological evidence for breeding population subdivisions, indicate a complex, hierarchically stratified society that exerted dominance over, and received tribute from, surrounding regions (Fowler et al., 1999; Pauketat, 1998). The stable isotopic compositions of individuals from different types of features within

Mound 72 reflects this diversity and complexity, and provides an independent line of evidence for the dietary dimensions of social inequality. The pattern of dietary diversity recorded at Cahokia may be paralleled at pencontemporary Mississippian mound sites during this period of significant social stratification, and complex interactions and integration within the greater Cahokia region (Pauketat, 2002).

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