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Determining Olmec maize use through bulk stable carbon isotope analysis

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Bulk stable carbon isotope analysis on absorbed organic residues in ceramics can be an effective method for discerning patterns of maize use when the ceramics come from relatively uniform archaeological contexts. The bulk stable carbon isotope method is faster and less costly than the more commonly used compound-specific stable carbon isotope analysis. Moreover, the bulk stable carbon isotope method can determine the presence of C4 plant carbon in samples in which organic compounds have degraded. Bulk stable carbon isotope analysis was used to discern patterns of maize (*Zea mays mays*) use among a sample of 24 ceramic sherds from an Early Franco Period feasting deposit (ca. cal 650 B.C.) at the Olmec site of San Andrés, La Venta, Tabasco, Mexico. A comparison of the δ 13C results of different categories of ceramics showed that proportionally more maize was used in luxury beverage service wares than in utilitarian vessels, suggesting that maize-based beverages were prominent in this probable elite feasting episode.

1. Introduction

Maize (*Zea mays mays*) use patterns were inferred by comparing the results of bulk stable carbon isotope analysis in absorbed organic residues in ceramics from a deposit made over a relatively short period of time, apparently in the context of a feasting event. Higher proportions of maize-signature (C4 plant signature) carbon occurred in luxury beverage serving wares than in utilitarian ceramics. This study demonstrates the usefulness of bulk stable carbon isotope analysis of absorbed organic residues in ceramics for exploring patterns of maize use among categories of ceramics from relatively homogeneous archaeological contexts, such as ceramics from the same stratum. This method differs from compound-specific stable carbon isotope analysis (Reber and Evershed, 2004a,b) in that it measures the δ ^{13}C signature of all of the carbon in a sample rather than only measuring the carbon in specific compounds. Bulk stable carbon isotope analysis therefore enables researchers to detect C4 plant use even in samples in which organic compounds have degraded because of taphonomic processes. The bulk stable carbon isotope method is faster and more cost effective, with a far simpler sample preparation protocol, than the compound-specific technique.

Bulk stable carbon isotope analysis was conducted on absorbed organic residues in 24 ceramics from a Middle Formative period midden dating to ca. cal 650 B.C. (Pohl et al., 2002) at the site of San Andrés, located 5 km northeast from the major Olmec center of La Venta, Tabasco, Mexico. Mary Pohl and Kevin Pope excavated San Andrés in 1997, 1998, and 2000 (Pohl et al., 2004). Christopher von Nagy (2003) conducted ceramic analysis, and Daniel Seinfeld (2007) performed the bulk stable carbon isotope study. The excavations revealed an Olmec midden located within a single stratum of black–grey–silty clay (BGS clay) that was hypothesized to have been feasting refuse. The δ ^{13}C signatures of the ceramic samples demonstrated that luxury wares had a higher proportion of C4 plant carbon, most likely from maize, than the utilitarian ones. The prominence of maize-based beverages, including maize beer and gruels, in Olmec feasting explain this pattern found in the isotopic analysis.

1.1. *Principles of isotopic analysis*

Stable carbon isotope analysis measures the ratio of ^{13}C, a stable isotope of carbon, to ^{12}C. This difference is expressed as the δ ^{13}C value. C3 and C4 plants have different photosynthetic pathways that produce distinct isotopic ratios of ^{13}C and ^{12}C (Deines, 1980; Farquhar et al., 1989:503; Smith, 1982; Tykot, 2004). C4 plants have an approximate average δ ^{13}C value of −12.5‰, and C3 of −26.5‰ (Tykot, 2004). Experimental work conducted in the present study and by others (Hart et al., 2007; Morton and Schwarcz, 2004)

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demonstrates that these distinct isotope signatures are reflected in archaeological residues in ceramics.

The vast majority of terrestrial plants are C3 plants (Smith, 1982). The C4 photosynthetic pathway is a relatively recent adaptation by plants in warm, arid, semitropical and tropical environments to fix atmospheric CO_2 more efficiently. C4 plants are present in 16 of 300 families of flowering plants, and they constitute a minority in all families in which they exist (Smith, 1982:100). This rarity of C4 plants means that the distinctive $\delta\ ^{13}C$ signature of C4 plants ($-12.5‰$) can only come from a limited number of plant species (Tykot, 2004).

Maize was the most prominent C4 crop in New World contexts before European contact (Reber and Evershed, 2004a; Smith, 1982:102). Maize and a species of *Chenopodium* were the only C4 plants recovered in paleobotanical work at San Andrés (Lentz et al., 2006; Pope et al., 2001; Smith, 1982). Paleobotanical analysis (Lentz et al., 2006; Pope et al., 2001) indicates that maize was the only major C4 food plant found at San Andrés, and therefore any C4 isotopic signature probably originated from maize.

2. Research design

The results of isotope analysis for the various ceramics in the San Andrés midden can be compared because they all came from a single, densely packed stratum and were subject to nearly identical taphonomic processes. Therefore, any post-depositional alteration of the ceramics' isotopic signatures should be uniform across the various vessel classes. This narrow archaeological context differs from the broad regional comparisons conducted by Reber and Evershed (2004a) and by Morton and Schwarcz (2004), where ceramics from many time periods and locations would be subject to differential postdepositional processes. The tempering of the San Andrés ceramics had no effect on their isotopic signature because they were all tempered with inorganic materials such as sand and volcanic ash. The carbon isotopic signature of the ceramics therefore reflects the types of foods used in the vessels over the period of their use.

Bulk stable carbon isotope analysis can be especially useful in determining maize-use patterns in some archaeological contexts because of problems with compound-specific stable carbon isotope analysis. The rapid decomposition of maize lipids during taphonomic processes can impede the compound-specific technique because the lipids examined in this form of analysis are often no longer intact (Reber and Evershed, 2004b). The bulk stable carbon isotope technique offers an advantage over the compound-specific technique in some cases because the bulk stable carbon isotope technique measures the isotopic signature of all the carbon in the sample, thereby avoiding difficulties associated with the degradation of lipids sought in the compound-specific technique.

3. Materials and methods

3.1. Samples

Twenty-four ancient ceramics from the San Andrés midden were analyzed and divided into four analytical categories based on the temper and the ware of the vessels as described in von Nagy's (2003) ceramic typology of the region. The categories are as follows: luxury volcanic ash tempered ($n = 14$), luxury sand tempered ($n = 4$), utilitarian sand tempered ($n = 4$), and an "other" category ($n = 2$) (Fig. 1). These categories also reflected differences in function based on their archaeological contexts across the region and on different amounts of labor that went into their construction (von Nagy, 2003). Luxury wares are those ceramics that were primarily used for ceremonial functions and serving foods and beverages in special events rather than for everyday use preparing foods (von Nagy, 2003:185). Ceramics at San Andrés classified as luxury wares come from a tradition of differentially fired wares that was the primary serving and ceremonial pottery for a millennium in the north Tabasco plain (von Nagy, 2003:269,833). Luxury wares tend to be found in more limited contexts and are rarely found in smaller, low-ranking hamlet sites (von Nagy, 2003:186). Utilitarian wares are more widespread and common. The production of luxury wares required more labor than that of utilitarian wares. Luxury wares tended to be finely made and decorated. More labor was also expended on procuring the tempering agents, such as volcanic ash, used in luxury wares (von Nagy, 2003:185, 199).

Fig. 1. Examples of complete vessels that are representative of the types of vessels within analytical categories including luxury volcanic ash tempered wares, luxury sand tempered wares, and utilitarian sand tempered wares (Photographs by Richard Brunck; pictures not to the same scale).

Luxury volcanic ash tempered ceramics included wares designated by von Nagy (2003) as Desengaño black-and-white, Encrucijada black-and-white, and Tanochapa black. Ceramics included in the luxury sand tempered ceramics included Naranjeño black-and-white and unspecified fine sand tempered wares. The high proportion of luxury serving ceramics in the feasting deposit at San Andrés is consistent with the serving of foods and beverages during feasts.

Utilitarian ceramics were sand tempered and represented by the Gogal plain and Bronce unslipped types during the Early Franco period in the Grijalva delta (von Nagy, 2003:832). These ceramics were crude, unembellished, and used primarily for day-to-day domestic activities.

The "other" category of ceramics included 2 samples that did not fit within any of the previous two categories. One of these samples was a censor base, not used in food preparation or service, and the second was a Flores Waxy vessel. Flores Waxy ware is distinct from all other ceramics from San Andrés in the Early Franco period and may be related to similar ceramics from the Maya area (von Nagy, 2003:294–295).

Sampling procedure maximized the possibility of detecting absorbed organic residues. Samples were taken from base and body sherds mostly from larger, thicker-walled vessels that were probably in contact with foods and beverages for extended periods of time.

The study involved a relatively small number of samples ($n = 24$) because the restricted nature of the feasting deposit at San Andrés limited the number of vessels available to test. The project's research design focused on understanding food and beverage use within this feasting deposit, and samples from other parts of the site were omitted. Available sherds were further limited by the sampling procedure, which emphasized body sherds from vessels that would have had more prolonged contact with the foods and beverages that they contained.

3.2. *Modern experimental samples*

Six modern ceramics were analyzed to set a baseline for interpreting the results of the analysis of the ancient samples. They also helped gauge the extent to which the δ ^{13}C signatures of the beers soaked into the ceramics. These modern samples consisted of 3 blank, unmodified ceramics, a ceramic soaked in maize beer (C4 carbon signature), a ceramic soaked in manioc beer (C3 carbon signature), and a ceramic soaked in honey wine (C3 carbon signature). Beverages used in the experiments included traditional beers recorded in Bruman's (2000) ethnographic survey of Mesoamerican beverages. Manioc beer was also tested because of the presence of manioc in the paleobotanical analysis of the site (Pope et al., 2001) and because of the prevalence of manioc beer in tropical New World cultures (Uzendoski, 2004). A sample of ground maize kernels from the same batch that produced the maize beer was also tested.

3.3. *Sample preparation*

Ceramic samples were prepared by using a chisel to remove a 1–2 g chip from larger pieces of each ceramic sample. The ceramic chips were gently washed with distilled water and dried at a low temperature in a drying oven. The chips were then ground to the consistency of a silt-like powder in a mortar and pestle. Gloves were worn during sample preparation, and the mortar and pestle and all other equipment were washed with solvents to prevent contamination. These powdered samples were stored in plastic storage bags; 1.5 mg of each of the samples was placed in tin sample cups that were folded into small cubes. Storage of the powdered samples in plastic bags could have masked some of the C4 plant carbon signature, and we recommend avoiding this procedure in future studies (Barnard et al., 2007). Since samples were prepared and stored in the same manner, storage in the plastic bags would have had little effect on the overall results or conclusions. Powdering the inner wall of the ceramics, the portion that would have been in contact with the vessel's contents, would likely have been an equally effective method for obtaining analytical samples because this portion of the ceramic would have been the primary locus of organic residue absorption (Stern et al., 2000).

3.4. *Bulk stable carbon isotope analysis*

Samples were analyzed using a CarloErba elemental analyzer (EA) that was connected to a Finnigan MAT DELTA Plus XP stable isotope ratio mass spectrometer (IRMS) via a ConFlo-III interface. Samples enclosed in tin cups folded into small cubes were placed in the sample feeder for the EA. The EA burned the samples at 1020 °C, instantly converting them to gasses (e.g., CO_2, N_2, N_xO_x, H_2O). The gasses were passed through a reduction column that converted N_xO_x to ON_2. A water trap separated CO_2 from N_2 gas, and the CO_2 went to the mass spectrometer via the ConFlo-III interface. The mass spectrometer detected the relative abundance of the stable carbon isotopes ^{12}C and ^{13}C in the CO_2.

The results are reported in the standard notation as δ ^{13}C in reference to the PDB standard. The percentages of C4 plant carbon were represented for each sample. The formula $x = (\delta \text{ sample} + 27) \div 14$ was used to calculate the approximate percentage of C4 plant carbon present in each sample (Yang Wang, personal communication to Seinfeld, 2006). This percentage was used mainly as a relative measurement between the different categories of ceramics and not as a direct reflection of the amount of maize used in each vessel. The amplitude (APT), which provides an approximation of the amount of CO_2 analyzed by the IRMS, was also reported. The APT therefore reflects the relative amount of absorbed organic residue in each sample.

4. Results

Bulk stable carbon isotopic analysis of absorbed ceramic residues revealed differences in the relative amount of C4 signature plant carbon indicating differences in maize use between luxury and utilitarian wares (Table 1 and Figs. 2 and 3). The %C4 plant carbon is not a direct reflection of the proportion of C4 plant use in each vessel. It is rather a relative indicator used to compare the various analytical categories of ceramics broadly.

A comparison of the amplitude (APT) of the signal analyzed by the IRMS among the blank, beer-soaked, and ancient samples demonstrates that the ancient samples contained absorbed organic residues. The blank samples had an average APT of 1005, the beer-soaked samples had an average APT of 7920.3, and the ancient samples had an average APT of 6301.4. The average APT of the ancient samples was far closer to that of the beer-soaked samples than to that of the blanks. Comparison of the median APT readings of these three classes of samples prevents high APT readings in some ancient samples from skewing the mean. The ancient samples had a median APT of 2507, which was between the median APT of the blank ceramics (1147) and the beer-soaked ceramics (5528). This pattern suggests that the organic residues in the ancient samples were somewhat degraded by post-depositional processes and that some of the samples with a low APT may not have contained sufficient organic residues. Overall, patterns in the APT values of the ancient and modern samples demonstrate that the majority of ancient samples contain absorbed organic residues and that results reflect the types of foods used in the ceramics.

The majority of the ancient ceramic samples had δ ^{13}C values somewhere between the average values for C3 and C4 plants. These results indicate that the ceramics contained a mix of different types of plants or that a variety of types of organic materials were used in the vessels at different times. The mixed signal could also have resulted from environmental interference from the largely C3 environment in which the ceramics were buried for nearly 3000 years (Reber and Evershed, 2004a:23–24). The δ ^{13}C results may therefore represent a low estimate for the original C4 signature carbon residues.

Analysis of the modern experimental ceramic samples helped in interpreting the results from the ancient ceramics. The modern ceramics proved that carbon from beers soaks into the ceramic matrixes and that the isotopic signatures of the beers' plant materials are reflected in that of the ceramic samples. The blank, untreated ceramic samples had strong C3 plant carbon signatures. These results are consistent with what would be expected for ceramics because the C3 plant signature is the standard in most terrestrial environments.

The δ ^{13}C ratios of the beer-soaked ceramics followed hypothesized patterns. As expected, the ceramics soaked in manioc beer (δ ^{13}C: −26.7) and honey wine (δ ^{13}C: −27.1) exhibited a purely C3 plant carbon signature, and the ceramic soaked in maize beer had a nearly pure C4 plant carbon signature (δ ^{13}C: −14.9, 91% C4). The maize beer soaked sample lacked a 100% C4 plant carbon signature because the formula to calculate % C4 plant carbon uses an average δ ^{13}C of −14, and there is some variation in the exact δ ^{13}C of C4 plants.

Table 1

List of samples with the δ ^{13}C, percent C4 plant carbon, and amplitude (APT) for each sample. The APT represents the amplitude of the signal analyzed by the IRMS and roughly reflects the amount of CO_2 analyzed. Form codes: n/a = not applicable; I = restricted bowl (tecomate); II = flat based dish; III = jar; VII = chimneyed bowl (urn) (form codes from von Nagy, 2003).

Sample	Ware	Form	δ 13C (‰)	Estimated C4%	APT
Modern Samples					
Blank Ceramic #1	Modern	n/a	−27.1	0	642
Blank Ceramic #2	Modern	n/a	−26.2	6	1226
Blank Ceramic #3	Modern	n/a	−28.4	−11	1147
Maize beer	Modern	n/a	−13.9	91	5528
Honey wine	Modern	n/a	−27.1	0	4899
Manioc beer	Modern	n/a	−26.7	3	13,334
Luxury Volcanic Ash Tempered					
Plate #9	Encrucijada black-and-white	Plate	−24.3	19	1697
Vessel 3	Tancochapa black	I	−25.3	12	598
Vessel 8	Tancochapa black	I	−22.7	30	983
Vessel 21	Tancochapa black	I	−21.0	42	1533
Sample #25	Tancochapa black	I	−25.7	10	1641
Vessel 12	Desengaño black-and-white	II	−20.6	45	2842
Vessel 15	Desengaño black-and-white	VII	−20.0	49	14,434
Vessel 22	Desengaño black-and-white	VII	−19.0	56	27,279
Vessel 31	Desengaño black-and-white	I	−22.9	29	2979
Sample #40	Desengaño black-and-white	n/a	−27.3	24	7774
Sample #50	Desengaño black-and-white	VII	−21.0	42	1452
Sample #53	Desengaño black-and-white	n/a	−20.3	47	11,947
Sample #57	Desengaño black-and-white	VII	−18.6	59	2172
Sample #61	Desengaño black-and-white	VII	−21.8	37	999
Under Vessel 2 next to Vessel 24	Desengaño black-and-white	n/a	−25.4	12	13,786
Vessel [C]	Desengaño black-and-white	n/a	−21.7	37	17,514
Luxury Sand Tempered					
Vessel [B]	Unspecified	n/a	−25.5	11	1077
Vessel [E]	Naranjeño black-and-white	n/a	−21.2	41	10,541
Sample #56	Naranjeño black-and-white	n/a	−22.1	35	1688
Sample #29	Unspecified	n/a	−23.1	28	14,113
Utilitarian Sand Tempered					
Vessel 5	Gogal plain	I	−25.9	8	1684
Vessel 10	Gogal plain	III	−24.1	19	7976
Vessel 16	Gogal plain	I	−26.0	6	8112
Vessel 28	Gogal plain	III	−25.5	10	6858
Other					
Sample #41	Flores Waxy	Dish	−23.2	27	1377
Sample#49	Censor base	Censor	−23.8	23	780

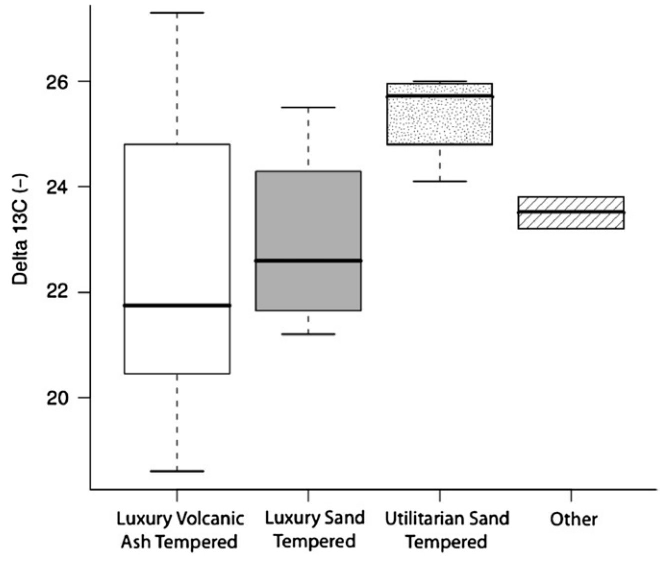

Fig. 2. Boxplot showing the average and distribution of δ ^{13}C values of absorbed organic residues in the analyzed ceramic samples. The results are organized by ceramic category. The luxury volcanic-ash-tempered and luxury sand-tempered ceramics have a δ ^{13}C closer to the −13‰ that is the average value for C4 plants such as maize. These results show that maize was used in higher proportions in the luxury wares than in the utilitarian ones.

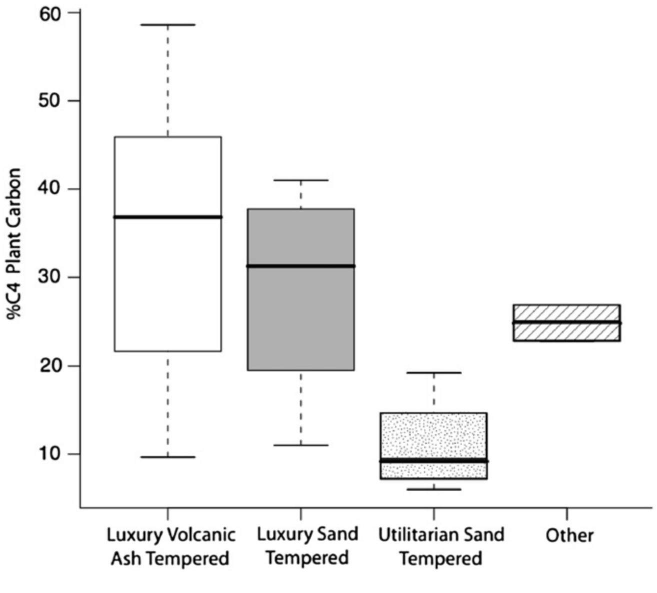

Fig. 3. Boxplot showing the average and distribution of the estimated %C4 plant carbon of absorbed organic residues in the analyzed ceramic samples. The results are organized by ceramic category. Higher percentages of C4 plant carbon suggest high levels of maize use. These results indicate that maize was used in a higher proportion in luxury wares than in utilitarian ones.

Statistical analysis using a *t*-test demonstrates the significance of the results despite the relatively small sample size. Samples from the luxury ceramic categories, both volcanic ash and sand tempered, contained significantly more C4 plant carbon than those from the utilitarian ware category ($t = 2.323$, $p = 0.030$, $\mathrm{df} = 22$, $n_1 = 20$, $n_2 = 4$, equal variances assumed) Fig. 2. This pattern holds true even when discounting samples with relatively low APT values, those with an APT of less than 1865. This threshold was determined by the APT values of the blank modern samples. The number 1865 represents two standard deviations (based on all blank ceramics) greater than the highest APT reading of a blank sample to ensure that only samples with APT values sufficiently higher than the blank ceramics were considered. Luxury wares contained significantly more C4 plant carbon than the utilitarian wares ($t = 1.76$, $p = 0.015$, $\mathrm{df} = 14$, $n_1 = 13$, $n_2 = 3$, equal variances assumed), even discounting the results from the samples with relatively low APT values. These results demonstrate the validity of the conclusions based on these overall results.

The use of dry ingredients in some vessels is an unlikely explanation for their relatively low APT values. Two of the samples with the lowest APT values were Vessel 3 and Vessel 8, both of which were restricted bowls (*tecomates*), which would most likely have been used to hold liquids. Other similar vessels have high APT values. The exact cause of the low APT values in some vessels therefore remains unclear.

5. Discussion

Bulk stable carbon isotope analysis demonstrated that differences in the δ ^{13}C signatures between the luxury and utilitarian ware categories resulted from variation in the types of foods used in the vessels. A comparison of the average results of each category helps clarify the patterns of maize use in the different categories (Figs. 2 and 3). The archaeological context of the analyzed ceramics and ethnographic and ethnohistoric evidence about Mesoamerican feasting foods and beverages suggest that the patterns observed in the carbon isotope analysis likely reflect the use of maize as a feasting food among the Early Franco period San Andrés Olmec. Macrobotanical maize specimens (Pope et al., 2001) and maize phytoliths on grinding implements generally used for processing maize (Dolores Piperno and Irene Holtz, personal communication to Pohl, 2002) provide evidence for maize use at San Andrés during the Middle Formative period. The types of artifacts and their spatial patterning in the BGS clay midden at San Andrés support the assertion that it was created by elite feasting activities. Feasts are public ritualized food sharing events that stand in contrast to day-to-day food consumption and that contain symbolic representations of social relations (Dietler, 1996:89). The BGS clay midden contained a number of nearly complete ceramic serving vessels including large platters, jars, urns, and drinking cups (von Nagy et al., 2000), and greenstone prestige items (Perrett, 2003; Pohl et al., 2002), as well as abundant faunal and floral material (Lentz et al., 2006; Pohl et al., 2004). The tight clustering of the artifacts and faunal remains and their containment within a complex but relatively coherent stratigraphic layer indicate that they were deposited in several dumping episodes over a relatively short span of time, as one would expect with feasting activity (Pohl et al., 2004).

Ethnographic (Bruman, 2000) and ethnohistoric (Coe, 1994) data demonstrate the traditional use of maize as a feasting cuisine throughout Mesoamerican history, especially as gruels (Coe, 1994) and various types of beers (Bruman, 2000; Coe, 1994; Smalley and Blake, 2003). Thus, maize was likely consumed either as a gruel or a beer in this Middle Formative period feasting context at San Andrés. This hypothesis is supported by the patterns of isotopic results across categories of feasting ceramics.

Luxury serving wares had the highest proportion of C4 signature plant carbon because they were used to serve maize-based feasting foods and beverages. Ceramics in this class included serving wares used in feasting contexts for holding liquids for distribution to smaller bowls (von Nagy et al., 2000:13–14). Ethnographic and ethnohistoric evidence on feasting beverages in Mesoamerica suggests that maize beers and maize gruels may have been served in open-mouthed vessels (Bruman, 2000; Coe, 1994; Smalley and Blake, 2003). The open-mouthed form of the luxury wares was conducive to serving and storing beverages (von Nagy et al., 2000:13–14). Open-mouthed vessels are common in feasting deposits cross-culturally (Dabney et al., 2004). This isotope analysis demonstrates that these urns held foods or beverages with a relatively high proportion of maize (average C4% of 48.6). These San Andrés wares were probably used for serving beverages because they were part of a larger suite of beverage service wares that included individual drinking cups (von Nagy et al., 2000:13–14). The cups were omitted in the present study because only rim sherds were available, and rim sherds were less likely to have had sufficient contact with beverages to absorb their isotopic signature.

The wide variety of foods used in utilitarian wares is one explanation for their relatively low proportion of C4 signature plant carbon. This pattern can be explained by the "food web effect," which describes how a ceramic vessel's carbon isotope signature reflects the δ ^{13}C signature of all foods that have been used in the vessel over its use-life and deposition (Hart et al., 2007; Morton and Schwarcz, 2004; Reber and Evershed, 2004a:23–24). The food web effect can mask or add C4 plant carbon to a sample. The luxury wares analyzed from this context were beverage service wares (von Nagy et al., 2000:13–14). Ethnographic and ethnohistoric information (Bruman, 2000; Coe, 1994) suggests that such wares would have derived their carbon from plant-based beverages, such as alcoholic beverages or gruels, rather than from animal fat. Therefore the C4 signature plant carbon in the luxury wares likely came from maize rather than animals that ate maize. Utilitarian vessels such as those in the utilitarian sand tempered category were used widely in everyday domestic activities such as food preparation and storage (von Nagy, 2003:832) and would therefore have been exposed to a wider variety of carbon sources.

The food web effect also applies to the postdepositional environment of an archaeological sample (Hart et al., 2007; Morton and Schwarcz, 2004; Reber and Evershed, 2004a). There is a possibility that the burial matrix can change a sample's δ ^{13}C signature by adding C3 or C4 signature plant carbon. Paleobotanical analysis (Lentz et al., 2006) demonstrated that the burial environment of San Andrés consisted largely of C3 plants, and it is unlikely that C4 plant carbon would have been added to samples via the food web effect. The uniform depositional context of the samples used in the current study ensures that the samples were likely equally affected by the post-depositional food web effect, and therefore the comparative results remain valid.

5.1. The usefulness of bulk stable carbon isotope analysis

Researchers such as Reber and Evershed (2004a) and Hart et al. (2007) have questioned the usefulness of bulk stable carbon isotopic analysis of ceramics in tracking patterns of prehistoric maize use. Reber and Evershed (2004a) successfully used compound-specific stable carbon isotopic analysis using gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) to detect absorbed organic residues in ceramics from 17 different sites in the Mississippi valley. This biomarker approach avoided potential problems with the food web effect.

Hart et al. (2007) also discussed problems inherent in using bulk stable carbon isotope analysis to track maize use patterns in ceramics. Their work was a response to an article by Morton and Schwarcz (2004), who tracked maize use in encrusted residues on ceramics from Ontario over the past 2000 years. According to Hart et al.'s (2007) analysis of experimental samples, the percentage of C4 plant carbon observed in charred residues is affected by the carbon content of the various burned foods that contributed to the residues. This differential contribution of carbon can skew the observed C4 plant carbon percentage toward over-representing foods with higher carbon contents rather than showing an accurate direct proportion of the amount of C4 plants used in foods (Hart et al., 2007:810).

Despite these valid critiques of the method, the present study demonstrates that bulk stable carbon isotope analysis of absorbed ceramic residues is a useful approach for comparing patterns of maize use broadly in different categories of ceramics within a single archaeological context. The analysis of the San Andrés feasting ceramics avoids problems with masking the exact proportion of C4 plant carbon as discussed by Reber and Evershed (2004a) and Hart et al. (2007) because this analysis compares the analytical results of different ceramic categories rather than trying to measure the direct proportion of C4 plant carbon use within a single vessel. The proportion of C4 plant carbon may be masked in some San Andrés vessels that were used for different foodstuffs because of the food web effect. Nevertheless, the conclusion that proportionally more C4 plant material, likely maize, was used in luxury serving vessels than in everyday utilitarian wares remains valid.

6. Conclusions

Bulk stable carbon isotopic analysis conducted on a Middle Formative period sample of ceramics from a feasting deposit (ca. cal 650 B.C.) from the Olmec site of San Andrés revealed different patterns of maize use in luxury and utilitarian wares. Luxury ceramics on average contained significantly higher proportions of C4 plant carbon than utilitarian ones. These results suggest that maize was used in relatively high proportions in elite feasting contexts, where luxury serving ceramics were more widely used. The categories of vessels with the highest maize content are consistent with those that could be used to serve maize-based alcoholic beverages or gruels, which are historically popular feasting cuisines throughout Mesoamerica (Bruman, 2000; Coe, 1994; Smalley and Blake, 2003). The present study demonstrates the usefulness of bulk stable carbon isotope analysis for comparing maize use patterns between categories of ceramics from directly comparable archaeological contexts, such as ceramics from the same archaeological stratum. The bulk stable carbon isotope method offers advantages over other techniques, such as compound-specific stable carbon isotope analysis (see Reber and Evershed, 2004a,b), because it is less expensive and can analyze more degraded organic residues. This method is less useful in analyzing samples from less homogenous contexts, however, because such diverse contexts could cause overly differential interference from carbon in the burial matrices.

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