12 Assessing dietary and subsistence transitions on prehistoric Aruba

Preliminary bioarchaeological evidence

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Introduction

Traditional models of Caribbean culture history generally postulate that the earliest prehistoric occupations of the region (Paleo-Indian or Archaic Age), beginning as early as ca. 7000 BP, were dominated solely by hunter-gatherer-fishers, and that farming was a later (Ceramic Age) introduction to the region by Saladoid migrants arriving from the Orinoco River Delta area of north-eastern South America beginning around 2500 BP (Rouse 1992). Much archaeological research over the last several decades has called into question the simplistic dichotomy between so-called Archaic (hunter-gatherer-fisher) and Ceramic Age (horticultural/agricultural) modes of subsistence (Keegan 2006; Pagán Jiménez 2011; Rodríguez Ramos 2010). Although there is as yet no consensus on these topics, multiple lines of evidence indicate that: 1) certain practices (often inappropriately) exclusively associated with farming communities (e.g., production and use of ceramics, translocation of plants and animals, widespread landscape alterations) occurred during the Archaic Age; 2) subsistence and dietary patterns and subsequent diachronic changes were highly variable in different parts of the insular Caribbean; and 3) hunting-gathering-fishing likely made important contributions to prehistoric Caribbean food-ways well into the Ceramic Age and beyond. Many questions concerning synchronic and diachronic variation in ancient Antillean food-ways in general and regarding dietary and subsistence transitions between Archaic Age and Ceramic Age populations in particular, remain unresolved (see also Pestle and Rodríguez Ramos, this volume). These lacunae are in part a reflection of the relative dearth of information about Archaic Age occupations of the Caribbean, with factors such as low population densities, high mobility patterns, poor preservation conditions, and highly variable research histories greatly reducing the quality and quantity of archaeological evidence required to address these questions.

For this study, we applied a combined bioarchaeological approach, utilizing dental anthropological and stable isotopic analyses to assess long-term changes in subsistence patterns on prehistoric Aruba. We argue that human dentitions are ideal foci for intensified research owing to their vast potential as archives for a wide variety of human behavioral processes and to their generally good states of preservation relative to many other types of archaeological materials from the prehistoric Caribbean. Comparisons of patterns of dental pathologies and isotope results between individuals from the Archaic Age sites of Canashito and Malmok and the Ceramic Age (Dabajuroid) sites of Santa Cruz, Savaneta, and Tanki Flip do not reveal distinct differences between the two groups.[1]

Background

The Archaic or Pre-Ceramic occupation of Aruba persisted well into the first millennium AD, which is relatively late in comparison to other parts of the insular Caribbean. Archaic lifestyle on the island is traditionally characterized as based on a hunter-gatherer-fisher food economy, with a major focus on marine resource acquisition, a lack of ceramics and horticulture/agriculture, and social organization in small bands (National Archaeological Museum Aruba 2010). Archaic sites tend to be identified based mainly on the lack of ceramics, with archaeological remains recovered at Archaic sites on Aruba predominantly comprising shell food remains. Two Archaic sites with human burials are incorporated into this study.

Canashito is a limestone rock-shelter in central Aruba, close to the large Ceramic Age/contact period settlement of Santa Cruz. Shell food remains were recovered from the slope leading to the entrance of the rock-shelter, and five human burials were uncovered under the abri. Radiocarbon dating of one of the skeletons revealed a date of 1960 ±65 BP, or cal. AD 83–394 (Versteeg et al. 1990; Wagenaar Hummelinck 1959). Malmok is a burial site on the north-western tip of Aruba, in an area that is ideally positioned to exploit a variety of ecological zones. Investigations at the site show that the cemetery was used between the 6th and 9th centuries AD. An oval-shaped shell midden, consisting of a very shallow deposit of food remains, was found just north of the burial area, and was considered not to have been the result of long-term exploitation of the area or permanent habitation. Radiocarbon dating of shell material from the midden indicated that it pre-dates the burials by at least two centuries. Over 60 burials have been identified at the site, although not all individuals have been excavated (Versteeg 1991, 1993; Versteeg et al. 1990).

The Ceramic Age occupation of Aruba is traditionally contrasted with the Archaic occupation, and is thought to represent a new wave of migration from the mainland to the island, bringing with it ceramics, large settlements, and an agricultural food economy (National Archaeological Museum Aruba 2010). The three Ceramic Age sites incorporated in this study, Santa Cruz, Savaneta, and Tanki Flip, comprised large habitation sites with a main period of use during AD 950–1250, although they are thought to have been inhabited up to the arrival of the Spaniards in the early 16th century (Bartone and

Versteeg 1995; National Archaeological Museum Aruba 2010). Santa Cruz is located approximately halfway between the windward and leeward coasts of Aruba, and is situated near the confluence of two guts (rooien) on arable land, making this area particularly attractive for agriculture (Versteeg 2001). Human skeletal remains were recovered in the area during excavations by Boerstra in 1971 and by Versteeg in 1991–1992. Excavations by Leiden University and the Archaeological Museum Aruba in 1991–1992, under the direction of Aad Versteeg, uncovered 31 burials, many containing the remains of multiple individuals (Boerstra 1974, 1982; Versteeg 1997, 2001). Savaneta is situated on a limestone substrate on the south-western coast of Aruba, in the middle of an area with some of the best land for agriculture in the south of Aruba (Versteeg 2001; Versteeg and Rostain 1997; Versteeg and Ruiz 1995). Tanki Flip, located at 3 km from the coast in north-western Aruba, is situated on moisture-retaining diorite subsoil, close to a number of guts, making it well suited to agriculture in the predominantly dry Aruban environment (Versteeg 2001; Versteeg and Rostain 1997). Excavations in 1994–1995 revealed 13 oval and circular house structures. Seven burials containing the remains of 15 individuals were uncovered in 1994–1995. Previously, a large number of human skeletons had been uncovered at the three sites by Egbert Boerstra (Boerstra 1976; Versteeg and Rostain 1997). Based on the traditional understanding of food-ways during the Archaic and Ceramic Age occupations of Aruba, it is expected that the dental and isotopic analyses in this study will reflect differences in dietary practices between the Archaic and the Ceramic Age groups.

However, in a recent study of starch grains trapped in human dental calculus from three Aruban Archaic individuals and one Ceramic Age individual,[2] tuberous root plants were identified, including marunguey (*Zamia* sp.), sweet potato (*Ipomoea batatas*), cocoyam (*Xanthosoma* sp., *Xanthosoma* cf. *sagittifolium*), and manioc (*Manihot esculenta*), indicating that starchy plant crops comprised a part of the diet in both periods. Furthermore, in three of the four sampled individuals, maize starch (*Zea mays*, cf. *Zea mays*) was identified. Some of the uncovered starch grains displayed alterations in morphometric characteristics and patterns of damage consistent with pressure and heat treatment, i.e., from food preparation (Mickleburgh and Pagán Jiménez 2012). Although starch grain evidence from dental calculus does not provide insight into the size of the plant food contribution to the diet, these results do indicate that next to the collection of wild plant foods, starchy food crops typically considered to have formed the basis of the agricultural food economy in Ceramic Age settlements were also contributing to Archaic diets. Last, the presence of large shell middens and the numerous remains of marine fauna at all three of the Ceramic Age sites included in the samples is testimony to the fact that marine food continued to comprise an important part of the diet at these habitation sites (Grouard 1995, 1997; Versteeg and Rostain 1997). In order to investigate potential dietary differences and assess long-term dietary transitions between the two

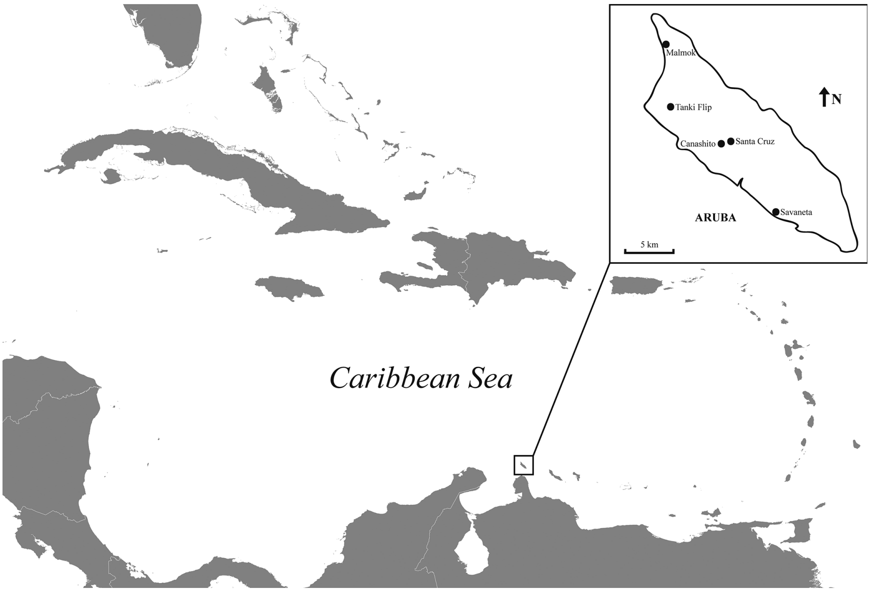

Figure 12.1 Map of the Caribbean, with inset of Aruba showing sites. (Produced by H. Mickleburgh).

groups, we compared rates of dental pathology and dental wear, enamel carbon isotopes, and dentine collagen carbon and nitrogen isotopes between Archaic and Ceramic Age individuals from five sites on Aruba (Figure 12.1).

Methods and material

The sample available for dental analysis comprises 23 individuals, from 2 Archaic sites (Canashito and Malmok) and 3 Ceramic sites (Santa Cruz, Savaneta, and Tanki Flip). Dentitions were examined macroscopically and microscopically for the presence of dental wear and pathology. Caries, AMTL, abscesses, and dental calculus were recorded per individual and per tooth/socket. Dental calculus was recorded following Brothwell (1981: 155). Dental wear was scored according to Smith's ordinal scale (Smith 1984). As a relatively large number of teeth were missing due to taphonomic and collection issues, to maximize sample size all observed teeth for each individual were scored. Intra-individual rates of molar wear, calculated with principal axis analysis, which avoids the effects of different age profiles between populations as it relies on the interval in which the adjacent molars erupt (approximately six years), can offer insights into abrasiveness of foods and food preparation techniques (Scott 1972, 1979; Sokal and Rohlf 1981; Watson et al. 2013). However, due to the small sample size in this study, comparisons with principal axis analysis were not undertaken. To nonetheless gain insight into possible distinct differences between the groups, the difference in mean degree of wear of adjacent first and second molars was compared between the two groups.

Stable isotope methods comprised analyses of carbon isotope composition of dental enamel ($\delta^{13}C_{en}$), and carbon ($\delta^{13}C_{co}$) and nitrogen ($\delta^{15}N$) isotopes of dentine collagen. Sample processing and measurements were conducted at the VU University Amsterdam, and the details of analytical procedures and protocols are reported elsewhere (Laffoon 2012; Laffoon et al. 2013, 2016). Briefly, for enamel extraction the external crown surface was first cleaned, and 4–5 mg of core enamel was removed. Powdered enamel was pre-treated by sequential soaking in 2.5% bleach (NaOCl) and Ca-acetate buffered acetic acid (CH_3COOH), with thorough rinsing in ultrapure water (MilliQ-H_2O) following the protocol of Bocherens et al. (2011). Enamel $\delta^{13}C$ was measured on a DeltaPlus IRMS integrated with a GasBench auto-sampler, after dissolution of samples in 100% H_3PO_4 at 45°C for 24 hours. Measurements were normalized to the VPDB scale using an in-house carbonate standard (VICS) calibrated to a certified reference material (NBS-19). Instrument performance was monitored by an international standard (IAEA-CO1) with a reproducibility of ±0.2‰ (1σ).

For collagen sampling, the outer surface was first rinsed and mechanically cleaned, and a ~200–500mg fragment was removed. Collagen extraction followed a modified version of the protocol reported by Brown et al. (1988). Dentine fragments were demineralized in 0.6 M hydrochloric acid (HCl) at 4°C for 5–10 days (acid refreshed after 48 hours) and rinsed to neutral; soaked in a 0.125 M sodium hydroxide (NaOH) solution for 20 hours and rinsed again; gelatinized in 0.001 M HCl at 80°C for 24 hours; and then condensed and freeze-dried. Collagen $\delta^{13}C$ and $\delta^{15}N$ were measured on a ThermoQuest IRMS Delta XPplus with a Flash EA. Sample calibration was done with international standards (USGS-40 and USGS-41), and (IAEA-310A and IAEA-NO3) for $\delta^{13}C$ and $\delta^{15}N$ isotope analyses respectively. All isotope results are reported as delta (δ) values in per mille (‰) relative to VPDB for carbon and AIR for nitrogen.

Results of dental analysis

Comparison of the caries frequency of the two groups reveals a considerably higher rate in the Ceramic Age group (9.64%) than the Archaic Age group (0.00%). A chi-square test indicates the difference is statistically significant ($\chi^2(1, N=291) = 12.749, p=0.00$). The higher caries rate in the Ceramic Age group suggests that this group was consuming more cariogenic foods than the Archaic Age group. These may have included simple sugars, such as glucose, sucrose, and fructose, as well as other carbohydrates, including starches. Comparison of the overall caries frequency of 9.64% with a large number of populations with varying subsistence patterns worldwide, places the Ceramic Age group most closely within the range of mixed diets (e.g., fisher-gardeners), or agricultural diets with relatively low caries frequencies (Pezo Lanfranco and Eggers 2012; Turner 1979). However, caries rates are affected by a large number of factors, including overall population health and susceptibility, specific food crops, and food preparation techniques, meaning that such global comparisons are of limited interpretative value. When compared to caries frequencies observed in other Ceramic Age Caribbean assemblages, the Aruban Ceramic Age group falls in the lower range (Mickleburgh 2013, 2014).

Comparisons of dental pathology rates between samples are known to be influenced by differing age profiles and differentially preserved/affected teeth. Furthermore, the different teeth and tooth surfaces in the dentition are differentially susceptible to carious lesions (Hillson 2001; Pezo Lanfranco and Eggers 2010, 2012; Wasterlain et al. 2009). To investigate such potential sources of variation, patterns of caries are usually assessed by sex, age group, tooth, and tooth surface; however, due to the small sample used in this study, this was not attempted. Nevertheless, based on known differential susceptibility of the different tooth elements and surfaces, some inferences can be made. The caries in the Ceramic Age group for the greater part only affected premolars and molars, with occlusal surfaces and cement-enamel junction affected to an equal degree. It is known that the molars and premolars are most susceptible to carious attack, even in diets with relatively low amounts of cariogenic foods. In populations with low carbohydrate intake, caries tend to predominantly affect the first molars, with second and third molars, premolars, and subsequently incisors and canines affected more frequently with greater carbohydrate consumption (Hillson 2001). The occlusal surfaces and cement-enamel junctions are likewise most susceptible to carious lesions, whereas the smooth surfaces of the crowns tend to be affected in highly cariogenic diets (Hillson 2001; Pezo Lanfranco and Eggers 2010, 2012; Wasterlain et al. 2009). As such, the pattern of caries location observed in the Ceramic Age group may indicate that the proportion of cariogenics in the diet was not extremely high. Combined with a relatively low overall caries frequency in comparison to other Ceramic Age communities in the region, this suggests a diet including, but not focused on, cariogenic plant foods, or alternatively a diet with highly cariogenic foods, but also containing a large amount of caries inhibiting foods (e.g., meat or fish).

On closer examination of the caries frequencies in both groups, it is apparent that the higher rate observed in the Ceramic Age group is mostly the result of high rates observed in individuals from the site of Santa Cruz, possibly indicating a distinct difference in dietary practices between Santa Cruz and the other two Ceramic Age sites (Table 12.1). Excluding Santa Cruz, the caries frequency of the Ceramic Age group is distinctly lower (1.85%), and falls well within the range most typically observed in subsistence types with low intake of cariogenics, i.e., a small proportion of sugars

Table 12.1 Caries rate per site

Site	*N*	*Frequency*
Canashito	47	0.00
Malmok	78	0.00
Santa Cruz	58	24.14
Savaneta	75	1.33
Tanki Flip	33	3.03

and starches, often combined with caries inhibiting foods and food preparation techniques (Pezo Lanfranco and Eggers 2010, 2012; Turner 1979).

Ante mortem tooth loss (AMTL) is slightly higher in the Ceramic Age group (6.02%) than the Archaic Age group (4.00%). The difference is not statistically significant (χ^2(1, N=291) = 3.39, p=0.07), but may be related to the higher caries rates in the Ceramic Age group. Although dental wear can contribute to AMTL, it is more likely that caries was a major contributor, since while the rate of dental wear is lower in the Ceramic Age (see later), the frequency of both AMTL and caries increases. Periodontal disease, which was not scored here, may have contributed substantially to AMTL.

Additional comparative data from a dental study carried out by Jouke Tacoma on 24 other adult dentitions from the site of Malmok, was combined with the data from the current study to increase the sample size of the Archaic Age group (Versteeg et al. 1990). Tacoma scored AMTL, caries, alveolar abscesses, and congenital absence of the second premolars and third molars. In the 690 observed teeth, he found 3 carious teeth (2 premolars, 1 molar), belonging to 3 individuals. He observed 6 individuals with AMTL (n=22). The combined results of both studies reveal a similar picture to the results of the current study alone. Caries rates differ significantly between the Archaic (0.36%) and the Ceramic (9.64%) groups (χ^2(1, N=981) = 62.40, p=0.00). AMTL rates are lower in the Archaic (3.31%) than in the Ceramic (6.02%) group; however, the difference is still not statistically significant (χ^2(1, N=981) = 2.79, p=0.10).

An independent-samples t-test showed a significant difference in the mean dental wear scores for Archaic (mean=1.56, SD=0.81) and Ceramic samples (mean=0.50, SD=0.71); t(32)=4.07, p=0.00. This suggests that the rate of wear was considerably lower in the Ceramic Age group than in the Archaic Age group, indicating a reduction in the abrasivity of the overall diet, which could be related to the consumption of less abrasive foods, different food preparation techniques, or a combination of both factors. Based on the distinctly higher caries frequency found at Santa Cruz, the same comparison of the difference in mean degree of wear of adjacent first and second molars was made, excluding this site from the calculation. An independent-samples t-test again showed a significant difference in the scores for Archaic (mean=1.56, SD=0.81) and Ceramic means (mean=0.69, SD=0,75); t(27)=2.96, p=0.00, although the rate of wear appears to be higher in the Ceramic Age group when Santa Cruz is excluded. The latter is consistent with the other Ceramic Age sites consuming a more marine or terrestrial animal oriented diet with only a very small horticultural/agricultural/ contribution.

Results of isotope analyses

The samples available for isotope analysis comprised nine individuals in total (Table 12.2). Although the sample size is limited, this preliminary data is used to explore possible differences in dietary patterning between Archaic and Ceramic Age groups and forms a basis for future sample selection and research. Dentine sampling focused on root tips, and not coronal dentine, where the tissue represents collagen formation in later childhood years. As such, they should contain little to no input from breastfeeding. Nonetheless, caution is warranted when comparing dentine versus bone collagen isotope results. In terms of collagen preservation, several samples produced insufficient collagen for isotopic analyses. Collagen yields for the remaining nine samples were variable, but the collagen quality control indicators (wt% C, wt% N, and atomic C:N ratios) fell within the acceptable ranges for archaeological skeletal materials (Ambrose 1990).

The isotope results display several notable patterns (Figures 12.2 and 12.3). The sole individual from the Archaic site of Canashito has significantly lower $\delta^{13}C_{en}$ (–11.0‰), $\delta^{13}C_{co}$ (–17.1‰) and $\delta^{15}N$ (11.1‰) values compared to all the other individuals indicating a much more terrestrial oriented diet. Previous strontium isotope ($^{87}Sr/^{86}Sr$) analysis of these same samples (Laffoon 2012) revealed that the individual from Canashito also possesses a high $^{87}Sr/^{86}Sr$ value that is inconsistent with childhood origins on Aruba based on comparisons with the estimated range of bioavailable $^{87}Sr/^{86}Sr$ variation on this island (Laffoon et al. 2012) and is thus a nonlocal. Based on comparison with macro-regional models of $^{87}Sr/^{86}Sr$ variation (Bataille et al. 2012), the nearest location consistent with such a $^{87}Sr/^{86}Sr$ value is the north-central coast of Venezuela. This different natal origin may

Table 12.2 Sampling information and stable isotope results

ID	*Site*	*Context*	*element*	$\delta^{13}C_{en}$	$\delta^{13}C_{co}$	$\delta^{15}N_{co}$
3	Canashito	Archaic	1.7	–11.05	–17.13	11.10
6	Malmok	Archaic	3.8	–4.63	—	—
10	Malmok	Archaic	2.5	–4.84	–10.30	14.58
13	Malmok	Archaic	4.4	–3.94	–9.57	14.79
490	Malmok	Archaic	2.4	–5.32	–11.14	15.46
200	Tanki Flip	Ceramic	1.5	–3.08	—	—
488	Tanki Flip	Ceramic	1.3	–5.97	–7.01	15.99
237A	Savaneta	Ceramic	3.3	–2.59	—	—
1	Santa Cruz	Ceramic	1.7	–8.72	—	—

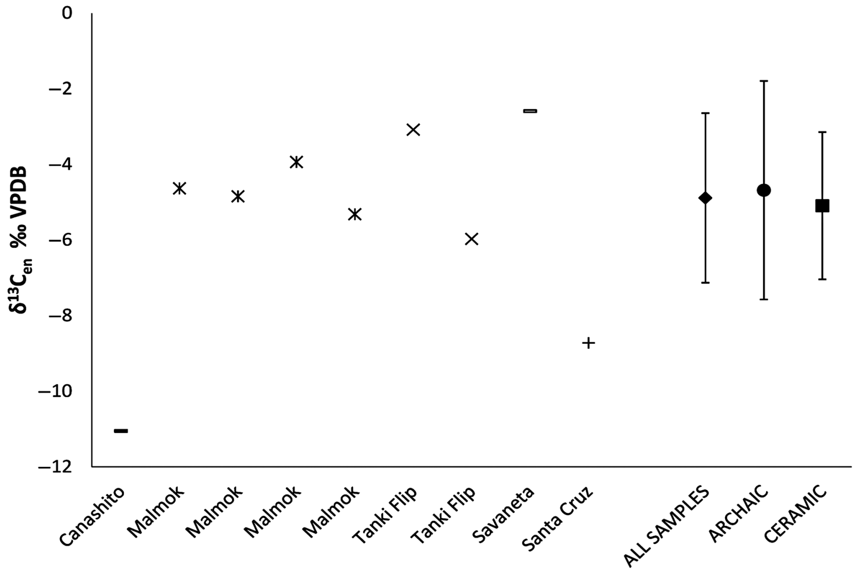

Figure 12.2 Chart of $\delta^{13}C_{en}$ results showing individual isotope values; and the mean (±1σ) for All, Archaic, and Ceramic samples separately. (Produced by H. Mickleburgh).

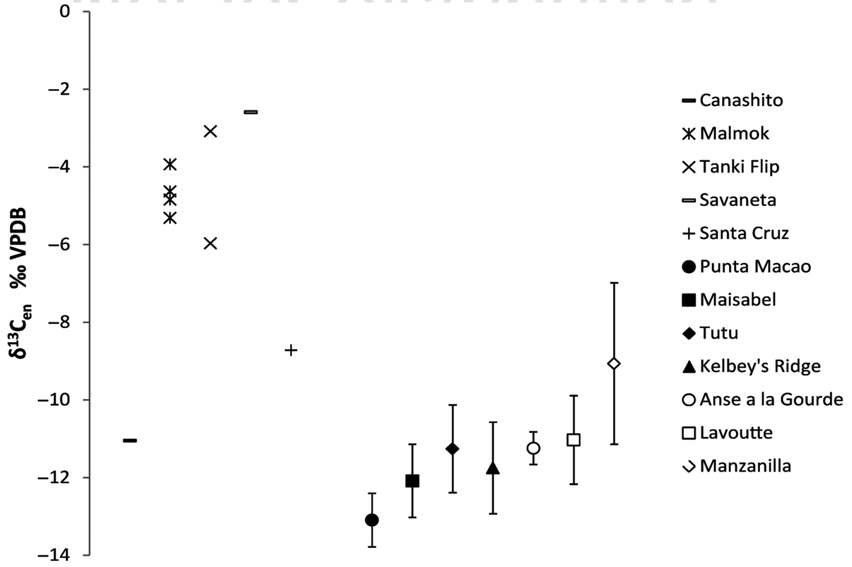

Figure 12.3 Chart of $\delta^{13}C_{co}$ and $\delta^{15}N$ results showing individual isotope values; and the mean (±1σ) for All, Archaic, and Ceramic samples separately. (Produced by H. Mickleburgh).

also account for the observed difference in diet between this sample and the other Aruban samples in this study. As such, this individual sample will not be included in the statistical or comparative analyses.

All individuals from the Archaic Age site of Malmok have extremely elevated $\delta^{13}C_{en}$ (range: –5.3 to –3.9‰), and $\delta^{13}C_{co}$ (range: –11.1 to –9.6‰) and $\delta^{15}N$ (range: 14.6 to 15.5‰). The highly enriched collagen values indicate that marine resources were the dominant source of dietary protein for these individuals. The enriched $\delta^{13}C_{en}$ values could result either from large contributions of C_4/CAM plant[3] resources to whole diet and/or that marine protein sources contributed substantially to dietary energy (i.e., high protein, low carbohydrate diets). For the Ceramic Age individuals, it is interesting to observe that their $\delta^{13}C_{en}$ values are also relatively elevated (ranging from –8.7 to –2.6‰) and overlap extensively with the Archaic Age individuals from Malmok. The Ceramic Age samples from Savaneta and Tanki Flip also have highly elevated $\delta^{13}C_{en}$ values that are very similar to Malmok. The single collagen sample from Tanki Flip has the highest $\delta^{13}C_{co}$ (–7.0‰) and $\delta^{15}N$ (16.0‰) values in the entire dataset indicating heavy reliance on marine resources for dietary protein. The single specimen from Santa Cruz possesses a $\delta^{13}C_{en}$ value (–8.7‰) that is intermediate between the two other extremes in the Aruban data set (i.e., between the much lower value for the Canashito nonlocal and the relatively higher values at the other three sites).

Overall, there are no statistically significant differences between the Archaic and Ceramic Age samples in mean $\delta^{13}C_{en}$ (Archaic = –4.7‰; Ceramic = –5.1‰). Although based on limited data, there is a substantial difference between the three Archaic Age individuals from Malmok (mean = –10.3‰) and the single Ceramic Age individual from Santa Cruz (–7.0‰) in collagen $\delta^{13}C_{co}$, but a much smaller difference in $\delta^{15}N$ (14.9‰ and 16.0‰, respectively) (Table 12.3). Similar to some of the patterns in the dental data noted earlier, when comparing the isotope data by site, the Santa Cruz individual has a markedly lower $\delta^{13}C_{en}$ value compared to both the Archaic and the other two Ceramic Age sites. Excluding the Santa Cruz individuals from the comparison, there is little observable difference in $\delta^{13}C_{en}$ values between the Archaic Age (mean = –4.7‰) and Ceramic Age (mean = –3.9‰) samples. Thus based on the isotopic evidence there was no major diachronic shift in diet between the Archaic and Ceramic Age on Aruba per se, although there are apparent differences in diet between the (likely more recent) Santa Cruz individual and all of the other Aruban Archaic and Ceramic Age individuals combined (see discussion later).

The Aruban isotope results can also be compared to published tooth enamel (Laffoon et al. 2013), and bone apatite and collagen isotope data (Healy et al. 2013; Krigbaum et al. 2013; Laffoon and de Vos 2011; Norr 2002; Pestle 2010; Stokes 1998) from other precolonial populations of the Caribbean (Table 12.4). Carbon isotopes in enamel and bone bioapatite are not necessarily equivalent as they reflect different periods of mineralization; with enamel forming primarily in childhood, while bone not only continually

Table 12.3 Summary statistics of Aruban isotope results (excluding Canashito)

		$\delta^{13}C_{en}$	$\delta^{13}C_{co}$	$\delta^{15}N_{co}$
ALL*	MEAN	−4.9	−9.5	15.2
	MIN	−8.7	−11.1	14.6
	MAX	−2.6	−7.0	16.0
	SD	1.9	1.8	0.6
	N	8	4	4
ARCHAIC*	MEAN	−4.7	−10.3	14.9
	MIN	−5.3	−11.1	14.6
	MAX	−3.9	−9.6	15.5
	SD	0.6	0.8	0.5
	N	4	3	3
CERAMIC	MEAN	−5.1	−7.0	16.0
	MIN	−8.7	−7.0	16.0
	MAX	−2.6	−7.0	16.0
	SD	2.8	−7.0	16.0
	N	4	1	1

Table 12.4 Stable isotope data from several precolonial populations in the Antilles. Enamel $\delta^{13}C$ data are from Laffoon et al. 2013, 2016; Bone $\delta^{13}C$ and $\delta^{15}N$ data are from 1: Healy et al. 2013); 2: Krigbaum et al. 2013; 3: Laffoon et al. 2016; 4: Laffoon and de Vos 2011; 5: Stokes 1998; 6: Norr 2002

Island	*Site*	$\delta^{13}C_{en}$	$\delta^{13}C_{ap}$	$\delta^{13}C_{co}$	$\delta^{15}N$	
		mean ±1σ	*mean ±1σ*	*mean ±1σ*	*mean ±1σ*	*source*
Aruba	Multiple	−4.9 ± 1.9	n/a	−9.5 ± 1.8	15.2 ± 0.6	*
Trinidad	Manzanilla	−9.1 ± 2.1	−7.9 ± 0.4	−12.6 ± 0.9	10.0 ± 0.2	1
Carriacou	Grand Bay	n/a	−8.6 ± 0.6	−12.8 ± 0.9	11.1 ± 0.5	2
St. Lucia	Lavoutte	−11.0 ± 1.1	−9.1 ± 1.4	−16.0 ± 0.7	11.6 ± 0.5	3
Guadeloupe	Anse à la Gourde	−11.2 ± 0.4	−8.4 ± 1.3	−14.8 ± 0.8	10.9 ± 0.7	4,5
Saba	Kelbey's Ridge	−11.7 ± 1.2	−11.0 ± 1.3	−15.7 ± 0.6	10.8 ± 0.5	5
St. Thomas	Tutu	−11.3 ± 1.1	−10.5 ± 0.9	−15.5 ± 0.9	12.2 ± 0.9	6
Puerto Rico	Maisabel	−12.1 ± 0.9	−9.9 ± 0.9	−18.1 ± 1.0	9.7 ± 0.7	5
Domin. Rep.	Multiple	−13.1 ± 0.7	−12.1 ± 2.1	−17.7 ± 0.7	11.9 ± 0.4	5
Bahamas	Multiple	n/a	−10.8 ± 2.1	−13.4 ± 1.4	9.8 ± 1.0	5

remodels throughout life but is also more susceptible to post-mortem alteration. Therefore, caution is advised when comparing enamel and bone carbon isotope data. Precolonial individuals from the Antilles possess $\delta^{13}C_{ap}$ values ranging from approximately −7 to −14‰. In general, these results have been interpreted as reflecting mixed diets including minor to moderate

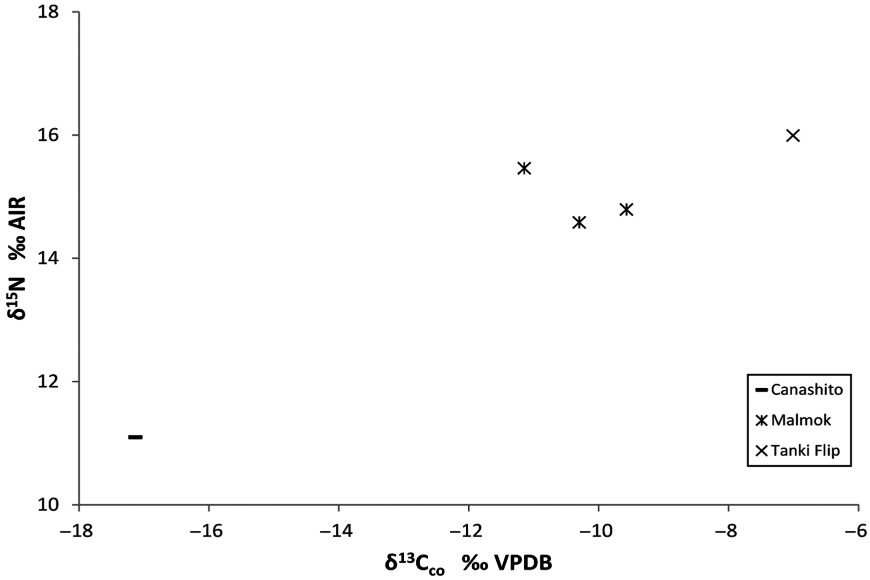

Figure 12.4 Chart of δ13C_{en} results showing individual isotope values from this study compared to the mean $\delta^{13}C_{en}$ (±1σ) for other precolonial sites in the Antilles. (Produced by H. Mickleburgh).

contributions of C_4 plants and/or aquatic protein sources to the whole diet of precolonial Antilleans. Notably, the Aruban data from this study are higher in $\delta^{13}C$ than almost all precolonial $\delta^{13}C_{ap}$ reported to date (n>350).

The enamel $\delta^{13}C_{en}$ results from this study can be most directly compared to published $\delta^{13}C_{en}$ data (Laffoon et al. 2013) from various precolonial sites in the Antilles (Figure 12.4). Despite differences in $\delta^{13}C_{en}$ values between bone and enamel samples at certain sites (Table 12.4), the overall range and geographic patterning of the $\delta^{13}C_{en}$ data in the Caribbean are highly comparable. For example, except for a few outliers, the vast majority of precolonial Antilleans possess $\delta^{13}C_{en}$ values ranging from about –13.5 to –8‰. As is the case relative to the bone apatite dataset, the Aruban $\delta^{13}C_{en}$ results are extremely elevated relative to $\delta^{13}C_{en}$ from all other Antillean populations analyzed to date. This pattern holds true independently of chronology, as both the Archaic and Ceramic Age samples from Aruba are substantially enriched relative to all other precolonial populations. Unfortunately, to our knowledge, there are as yet no other Archaic Age enamel or bone apatite $\delta^{13}C$ data sets from the Antilles available for comparison. Similarly, within a broader regional perspective the Aruban collagen isotopes results are also much higher in both $\delta^{13}C_{co}$ and $\delta^{15}N$ than all other precolonial populations (Figure 12.5). In fact, the geographic patterning of the Aruban collagen isotope data mirror those of the enamel and bone carbon isotope data in this

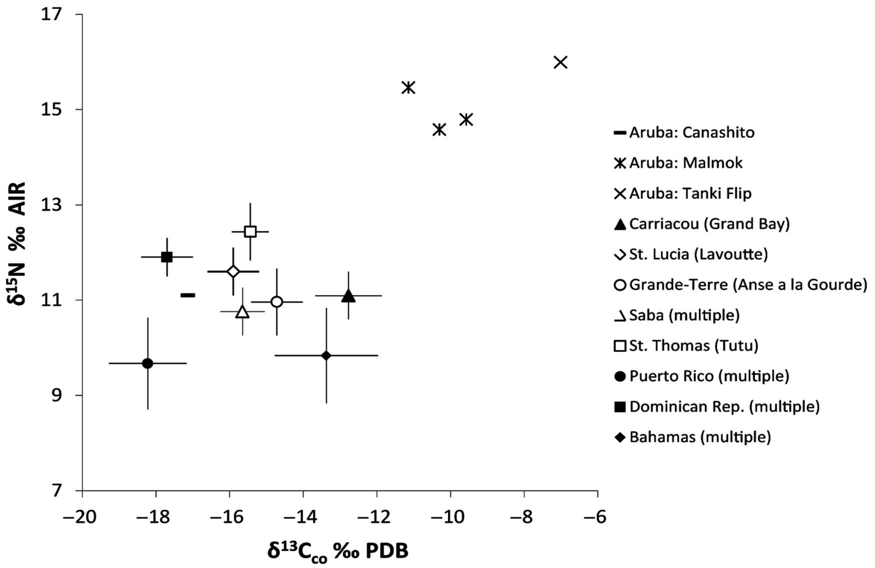

Figure 12.5 Chart of $\delta^{13}C_{co}$ and $\delta^{15}N$ results showing individual isotope values; and the mean (±1σ) for All, Archaic, and Ceramic samples separately. (Produced by H. Mickleburgh).

regard. Therefore, based on these preliminary results, precolonial dietary patterns on Aruba in both the Archaic and Ceramic Ages may have been substantially different than elsewhere in the insular Caribbean.

These dietary differences could possibly derive from higher rates of marine protein consumption on Aruba owing to a general scarcity of terrestrial animal protein sources. However, the same can also be said for various Lesser Antillean populations which, based on multiple lines of evidence, were clearly heavily reliant on marine resources and yet possess much lower collagen (and enamel) isotope values than the Aruban data reported here. Another possibility is that these precolonial Arubans were consuming greater quantities of C_4 resources than other Antillean populations, as has been observed for multiple Mesoamerican populations (e.g., Metcalfe et al. 2009; Rand et al. 2013; Somerville et al. 2013) which possess comparably elevated $\delta^{13}C_{en}$ owing to heavy reliance on maize. Additionally, other food sources with high $\delta^{13}C$ values, including C_4 plants (e.g., amaranths) or CAM plants (e.g., pineapple and agave), were available in the precolonial Antilles (Pestle 2010) and may have been consumed by precolonial Arubans. Based on the isotopic ecology of the region, it seems likely that the consumption of large quantities of (higher trophic level) marine protein in addition to some non-trivial contributions from C_4/CAM plants would be required to produce the extremely elevated values recorded for all three isotopic proxies in this study.

As is apparent, there are clear limitations to dietary reconstructions based on isotope data alone. While various lines of evidence can be marshalled in the interpretation of stable isotope data, other relevant information obtained directly from individual skeletal remains are the most comparable and potentially most informative. Comparisons between individual enamel stable isotope results from this study and the results of previous micro-botanical research on starch grains in dental calculus (Mickleburgh and Pagán Jiménez 2012) from some of the same individuals can provide additional insights in terms of dietary assessments.

Amongst the Aruban samples included in the starch grain analyses, the Archaic Age samples (Malmok and Canashito) contained maize, cocoyam, manioc, marunguey, and sweet potato. The Ceramic Age samples (Tanki Flip and Savaneta) contained maize, marunguey, and pepper (*Capsicum* sp.). Except for maize which is a C_4 plant, all of these plants utilize the C_3 pathway and thus have very low $\delta^{13}C$. Corresponding isotope and starch grain results are available for four individuals: Canashito B3; Malmok B6; Malmok B10; and Tanki Flip B200. Of these, three out of four (except Malmok B6) possessed one or more maize starch grains in their dental calculus providing direct evidence for maize consumption. Investigating their $\delta^{13}C_{en}$ values more closely, however, reveals some disparity between the presence/absence of maize starch grains and $\delta^{13}C_{en}$ values for these three individuals. For example, of the three individuals with maize starch grains in their calculus, Canashito 3 (the nonlocal individual with possible mainland origins) has the lowest $\delta^{13}C_{en}$ value in the Aruban sample set, while Malmok B10 and Tanki Flip B200 have two of the highest values. In addition, Malmok B6 has a nearly identical $\delta^{13}C_{en}$ value to Malmok B10, but did not have any maize starch grains.

The lack of clear correlations between the two data sets may derive from the very small sample sizes and/or issues of differential preservation and identification of starch grains. Additionally, this may also simply result from the fact that the two methods vary in the types of information they provide, with starch grains indicating the presence of certain plants in the diet and carbon isotopes reflecting long-term averages of various dietary components. Nevertheless, the highly elevated $\delta^{13}C_{en}$ values of several Archaic Arubans lends further support to one of the main conclusions of the starch grain study, e.g., that people were consuming maize on Aruba much earlier than previously recognized (as early as 350 BC to AD 150). A similar conclusion was proposed in a recent study combining isotope and starch grain analyses on Archaic Age populations from north-western Cuba, based on the presence of starch grains from cultigens (beans, maize, and/or sweet potatoes) and elevated bone collagen $\delta^{13}C$ values (Chinique de Armas et al. 2015). The correspondence between multiple lines of evidence from different regions and islands indicates that the consumption of maize was quite widespread, initiated fairly early on, and may have varied in intensity and/or importance both temporally and spatially in the precolonial Caribbean.

Conclusions

The dental pathology and wear differences between the Aruban Archaic and Ceramic Age groups appear to mirror a similar shift observed in a larger regional study of Early Ceramic Age and Late Ceramic Age (Mickleburgh 2013, 2014) dental patterns. Comparisons between the two groups revealed an increase in pathology rates paired with a decrease in rate of wear over time, indicating a growing focus on refined, cariogenic foods, such as horticultural/agricultural produce. However, as noted, the difference in pathology rates is mostly due to the high rates observed at one Ceramic Age site: Santa Cruz. If we exclude Santa Cruz, the data are more suggestive of continuity in dietary practices rather than change.

Similarly, the isotope results indicate a general lack of difference in isotope values between the two groups (excluding the single nonlocal individual from Canashito), and that much of the observed chronological variation can be attributed to the specimen from Santa Cruz. This may indicate either that no dietary change occurred, or that if it did occur it is not observable from stable isotope results. However, based on the observed dental pathology rates, this is unlikely, and, as such, the combined results of our study are suggestive of continuity in diet. The reduction in food abrasiveness, observable both with and without the Santa Cruz individuals, most likely reflects changing food preparation techniques between the two periods, corresponding with the adoption of a broad set of ceramic food preparation utensils.

In summary, the preliminary bioarchaeological evidence presented here suggests that, with the exception of Santa Cruz, the Ceramic Age individuals in this study did not consume a substantially different diet from the Archaic individuals, although food processing techniques likely changed with the introduction of ceramic utensils. This adds to the growing body of evidence indicating that Archaic Age food-ways were more similar to later periods than traditionally recognized (Chinique de Armas et al. 2015; Mickleburgh and Pagán Jiménez 2012; Pagán Jiménez 2011; Pagán Jiménez et al. 2015). In addition, based on the preliminary results of the isotope data precolonial dietary patterns on Aruba in both the Archaic and Ceramic Ages may have been substantially different than elsewhere in the insular Caribbean. However, caution must be applied, as these preliminary results are based on a small number of individuals.

In order to investigate Aruban food-ways more thoroughly further research is needed, particularly more comparative analyses of larger datasets of apatite (enamel and bone) versus collagen (dentine and bone) stable isotope results, which reflect different aspects of diet (whole diet versus protein, respectively), which, combined with analysis of dental pathology and wear, paleobotanical research, and contextual site information, will provide a better understanding of dietary and subsistence transitions over time.

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Notes

1 While we make use of two groups traditionally considered to be temporally and socioeconomically distinct (Archaic and Ceramic Age), our analyses are intended to investigate temporal developments in dietary practices (reflected in our samples which span a long occupation history of Aruba).

2 Malmok (burials 6 and 10), Canashito (burial 3), and Tanki Flip (burial 200) (Mickleburgh and Pagán Jiménez 2012).

3 C_3, C_4 and CAM (crassulacean acid metabolism) refer to the different forms of carbon fixation used during photosynthesis.

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