Journal of Anthropological Archaeology 31 (2012) 334–352

Contents lists available at SciVerse ScienceDirect

Journal of Anthropological Archaeology

journal homepage: www.elsevier.com/locate/jaa

Immigration to Tikal, Guatemala: Evidence from stable strontium and oxygen isotopes

Lori E. Wright *

Department of Anthropology, Texas A&M University, College Station, TX 77843-4352, United States

ARTICLE INFO

Article history:
Received 6 June 2011
Revision received 3 February 2012
Available online 3 March 2012

Keywords:
Maya
Tikal
Stable strontium isotope ratio
Stable oxygen isotope ratio
Tooth enamel
Immigration
Urbanism

ABSTRACT

This paper presents strontium and oxygen isotopic measurements on archaeological human teeth from the ancient Maya city of Tikal, Guatemala, that illuminate the role that migration played in the history of the state. Stable strontium isotope ratios of human teeth parallel the bedrock geology of the location where foods were grown, while stable oxygen isotope ratios reflect the sources of water imbibed, and track geographic variation in the isotopic composition of rain water. Because tooth enamel forms during childhood and is not remodeled during life, we can identify foreign-born individuals at Tikal by their outlying strontium and oxygen isotope ratios. These data indicate that approximately 11–16% of the sampled Tikal skeletons spent their childhood at distant sites. Most of the migrant burials date from the Early Classic period and are high status contexts. Several royal burials demonstrate long distance movement of both males and females, and shed light on the identification of epigraphically-known individuals. Yet, both Early and Late Classic migrants are found in lower status domestic burials. Interaction with distant peers was important in the rise of the Tikal polity, however, immigration from all social tiers contributed to the city's rapid population growth.

Introduction

For nearly a century, material culture evidence of interaction between ancient Mesoamerican states has spawned competing theories of conquest and exchange, as well as models that see Mesoamerican cities as multiethnic products of both rural–urban and long-distance migration (Braswell, 2003; Miller, 1983). For the ancient Maya, the city of Tikal has been a focus of ongoing debate regarding the role of central Mexican powers in its Early Classic rise to political prominence. Moreover, settlement studies at Tikal in the 1960s revealed a large and fairly dense population, which spurred debate about the nature of Maya urbanism (Chase and Chase, 1996; Culbert et al., 1990; Fox et al., 1996; Haviland, 1969, 1970, 1997a; Sanders and Webster, 1988). This paper reports on strontium and oxygen isotope studies of Tikal human skeletons that provide primary evidence of migration and are part of a larger bioarchaeological investigation of this important Maya city.

Tikal lies near the center of the ancient Maya world, in the northern part of the Guatemalan Department of Petén, Fig. 1. Excavated by the University of Pennsylvania's Tikal Project (hereafter, PTP) from 1958 to 1964 (Coe, 1967; Sabloff, 2003) and by the Proyecto Nacional Tikal (PNT) in the 1980s (Laporte and Fialko, 1995), Tikal has been the subject of detailed settlement survey (Puleston, 1983), domestic excavation (Becker, 1999; Haviland, 1985), investigation of public architecture (Coe, 1990a; Laporte and Fialko, 1995), and epigraphic study (Jones and Satterthwaite, 1982; Martin, 2003). The city has featured prominently in debates about the nature of Maya urbanism and population density (Chase et al., 1990; Haviland, 1970, 1997a; Sanders and Webster, 1988). Although most scholars would agree that the site should be considered "urban" and a "city", there remain many questions about the nature of population growth at Tikal and elsewhere. Population estimates for Tikal suggest a considerable Early Classic occupation, both near the site core, as well as in peripheral areas. The city center saw exponential population growth during the 6th and 7th centuries AD, reaching 45,000 (Haviland, 2003) to 62,000 persons (Culbert et al., 1990) at AD 700. Around AD 800, however, the population began to decline rapidly. The rapid rise of the Early and Late Classic population raises several questions that are germane to the character of the city itself. Was this rapid growth endogenous? Did migration contribute to the city's growth? Did migrants come to Tikal from nearby rural areas? Or might they have also come from distant regions, both rural and urban? Moreover, what happened when the city fell into decline? Did foreign visitors continue to pass through?

The Early Classic period (AD 250–550) at Tikal is of special interest to archaeologists because of material evidence for contact between Tikal and central Mexico (Braswell, 2003). A handful of

* Fax: +1 979 845 4070.
E-mail address: lwright@tamu.edu

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doi:10.1016/j.jaa.2012.02.001

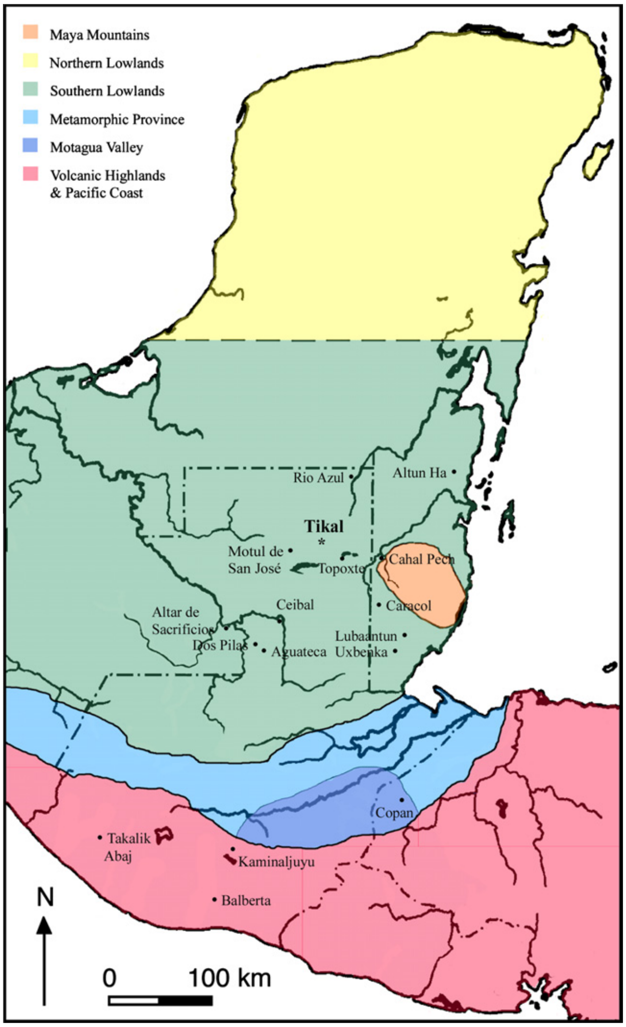

Fig. 1. Location of Tikal in the Maya area, indicating sites mentioned in the text and strontium isotope regions defined by Hodell et al. (2004).

structures at Tikal show *talud-tablero* architecture, an architectural style that first emerged in highland Tlaxcala and Puebla (García Cook, 1981) but has oft been considered characteristic of Teotihuacan. Although the proportions of the *talud-tablero* form shown at Tikal differ significantly from that found in central Mexico (Laporte, 1989, 2003), the presence of highland Mexican obsidian in diverse domestic contexts across Tikal (Moholy-Nagy, 1999), together with Teotihuacan iconography on some vessels and sculpture (Coggins, 1975) indicated some form of contact between the two states. Epigraphic work now suggests that a ruler of Teotihuacan sent an emissary to Tikal in AD 378, named Sihyaj K'ahk', who then installed the son of Teotihuacan's ruler on the throne of Tikal (Martin, 2003; Martin and Grube, 2008; Stuart, 2000). The tomb thought to hold the remains of this king, Yax Nuun Ahiin I (Burial PTP-010), the tomb of his son, Sihyaj Chan K'awiil II (PTP-048), and the hieroglyphic monuments that describe their reigns are the contexts most imbued with foreign imagery at the site (Coggins, 1975, 1979; Martin, 2003). Together with the question of population growth in the Early Classic period, such evidence for foreign interaction make the study of mobility crucial to an understanding the city's political history and development.

In addition to this AD 378 *entrada*, epigraphic data suggest considerable interaction between and movement amongst Maya cities throughout the Classic period (Culbert, 1991). Royal marriages occurred between members of distant cities (Molloy and Rathje, 1974), presumably involving movement of the female spouse. However, dynastic lines are also known to have passed through women on occasion (Hewitt, 1999), so elite males may also have migrated from site to site. At Tikal, the inscriptions appear to record the line of succession passing through a "Lady of Tikal" in the 6th century AD (Martin, 1999, 2003). Moreover, captives of war might be enslaved by their victors, and thus join the burial assemblage at a place far from their natal site. Was long distance migration gender-biased among the Maya, due to the exchange of elite brides? Or did young males or indeed, entire families move in search of economic opportunity? Was migration primarily an elite behavior, tied to political interaction at the elite level alone, or did commoners also move to new communities with regularity? Did commoners move only within a smaller local region? While mobility served as a strategy of resistance for the colonial Maya (Farriss, 1984; Restall, 1997), the question of non-elite movements in the Classic period has been difficult to address archaeologically. Inomata (2004) suggests that non-elites were not tightly bound to their natal states, and that attracting and retaining subjects was one of the challenges of emerging polities. Is Tikal's rapid growth inherent evidence of it success in recruiting immigrants from other competing states?

Isotopic measures of mobility

One way to approach these questions is through the chemical signals of provenance that are recorded in skeletal tissues, especially the stable isotopes of strontium (Sr) and oxygen (O). Strontium isotopes provide a measure of the geological provenance of skeletons by way of food consumption. Oxygen instead reflects the sources of water imbibed, thus the two measures provide independent and complementary data. Bone remodels during life (Hedges et al., 2007), incorporating new atoms from food and water, and it is porous, incorporating exogenous materials during burial (Price et al., 1992; Wright and Schwarcz, 1996), so it does not provide the best sample material for migration studies. By contrast, dense tooth enamel is not porous and is not remodeled during life; it preserves the signal from childhood years when it mineralized. Enamel is also much more resistant to diagenetic exchange with the burial environment (Budd et al., 2000).

Strontium has two stable isotopes, the ratio between which varies systematically in different geological contexts. ^{86}Sr is not radiogenic, while ^{87}Sr is formed from the decay of rubidium, which is found only in the earth's crust, not in the mantle. Therefore, young volcanic rocks have low $^{87}Sr/^{86}Sr$ ratios, near .704, while old metamorphic rocks have higher ratios, reaching beyond .715. Sedimentary rocks have values that depend on the ratio of seawater, which has changed over time, and range from .707 to .710 (Dasch, 1969; DePaolo and Ingram, 1985; Faure, 1986; Faure and Powell, 1972; Palmer and Elderfield, 1985). Strontium enters the skeleton via foods consumed and substitutes for calcium in bone mineral. Although the total intake of strontium varies among different diets (Brown, 1973; Burton and Wright, 1995), the stable isotopic ratio averages the composition of all foods taken in, and reflects the geological origin of the soils on which they were grown, rather than food choices (Bentley, 2006). Strontium isotopes are well suited to the study of prehistoric mobility in Mesoamerica due to the marked divergence in the underlying geology of the region (Price et al., 2008).

Measurements on archaeological skeletons from Mesoamerica (Freiwald, 2011; Price et al., 2007, 2008, 2010; Wright et al., 2010) and environmental samples (Hodell et al., 2004; Thornton, 2011) provide a useful baseline for interpreting strontium isotope ratios at Tikal (Fig. 1). Together, these data show that the volcanic Guatemalan highlands have very low $^{87}Sr/^{86}Sr$ ratios near .704 and the Paleozoic province of the southeastern Maya area has slightly higher ratios, near .706. The southern lowlands vary between .707 and .708, the northern lowlands are close to .709, and the Maya Mountains show the highest values, near .718.

Stable oxygen isotopes may help to discriminate between geologically similar areas that cannot be separated using strontium isotopes alone. Oxygen has two stable isotopes, ^{18}O and ^{16}O, the ratio between which is represented as $\delta^{18}O$, and is calculated relative to a standard, either Vienna Standard Mean Ocean Water (vSMOW) or PeeDee Belemnite (vPDB), respectively used for $\delta^{18}O$ ratios measured on bioapatite phosphate (PO_4) or carbonate (CO_3) (Schwarcz and Schoeninger, 1991). Oxygen in the body tissues is derived from water imbibed, and to a much lesser extent, food (Bryant and Froelich, 1995; Kohn, 1996; Longinelli, 1984). The $\delta^{18}O$ of rainfall varies systematically around the world, with higher values in equatorial regions and coastal areas, where the first rains fall from rain clouds that have formed over the ocean, and lower values at higher elevations and in rainshadows (Rozanski et al., 1993).

Rainfall in the Maya area is dominated by moisture carried on northeasterly trade winds from the Caribbean, with progressive rainout across the isthmus, and a smaller contribution of Pacific moisture to the west of the continental divide. Recent study of the $\delta^{18}O$ of surface waters in Guatemala has shown that $\delta^{18}O$ patterning is determined primarily by the rainout of ^{18}O as clouds move over the lowlands, together with temperature-dependent equilibrium fractionation at altitude (Lachniet and Patterson, 2009). Thus, $\delta^{18}O$ of river water is highest along the coast of Belize, and gradually declines as weather systems move inland across the Petén. A more precipitous drop in $\delta^{18}O$ occurs as one moves up into the highlands, however, $\delta^{18}O$ rises more steeply on the Pacific piedmont and coast. The Maya area experiences marked seasonality in rainfall, which is sparse from December through April. Although the effects of seasonality on $\delta^{18}O$ have not yet been directly studied in the Maya area, river water $\delta^{18}O$ may not vary dramatically throughout the year, because it should be biased by the larger amount of wet season precipitation. The Petén lakes show marked evaporative enrichment compared to source water, giving them higher $\delta^{18}O$ than elsewhere (Lachniet and Patterson, 2009). At Tikal, the $\delta^{18}O$ ratios of ancient drinking water may also have been affected by evaporative enrichment in artificial water reservoirs, especially during the dry season.

This paper reports $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ data for tooth enamel from 97 Tikal burials that span the chronological occupation of the city, as well as a broad range of architectural, and thus social, contexts. Since tooth enamel is not remodeled after it is formed, teeth hold a record of childhood provenance that can be studied in the remains of adults who ultimately came to be buried at Tikal and sheds light on where these individuals spent their childhood before coming to Tikal. After first defining local Tikal signatures for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$, this paper explores the identities of Tikal burials that are shown to be immigrants, as well as key burials that were not, and considers the role of immigration in the growth and history of the city.

Materials and methods

Study of carbon and oxygen stable isotopes in Tikal teeth was initially designed with the goal of studying age related changes in diet and nursing behavior. Accordingly, I selected mandibular canines and third molars since these teeth span important developmental ages. Mandibular canine enamel forms from approximately birth to 4.5 years (Anderson et al., 1976; Massler et al., 1941; Skinner and Goodman, 1992), while third molar enamel forms from 9.3 to 13 years (Skinner and Goodman, 1992). Additionally, third molars and mandibular canines from the University of Pennsylvania Tikal Project (PTP) burials had been sampled for study of enamel defects (Danforth, 1989), so targeting the same teeth made use of remaining portions of the sectioned teeth, without additional destruction. A small number of deciduous canines sampled by Danforth were also analyzed. For burials not sampled by Danforth, teeth were embedded in epoxy and 1 mm thick sections were cut in the longitudinal plane using a Buehler Isomet slow speed saw with a diamond wheel blade. Sections were cleaned with distilled water and 100% ETOH, and affixed to glass microscope slides with a sheet of Parafilm melted between the section and slide at 65 °C. After removing the dentine and cleaning the dentoenamel junction with a round tungsten carbide drill tip mounted in a Foredom flex shaft rotary tool, 2 mg samples were drilled from the enamel adjacent to the dentoenamel junction using a Brasseler 0.5 mm diameter tungsten carbide drill bit in the same tool. For molars, three samples were collected at equidistant points from the inner enamel adjacent to the dentoenamel junction on the buccal aspect: A, close to the cusp, B, midcrown, and C, close to the cervical margin. For canines, four equidistant samples were collected in the same manner, with A the most cuspal, and D the most cervical, all from the buccal aspect. Samples were taken from buried enamel adjacent to the dentoenamel junction, and from the full 1 mm thickness of the section. Thus, surface enamel and later-forming imbricational layers contributed little enamel to the samples, which aim to focus on narrow windows of enamel development. For the present contribution, $\delta^{18}O$ data collected for the samples are averaged to give a single value for each skeleton. For some teeth, cervical or cuspal samples were not available or the small sample size caused sample/standard mismatch in gas volume, so a reliable $\delta^{18}O$ could not be obtained. Thus, some burials are represented by only one or two averaged measurements. Age-related changes in $\delta^{18}O$ and $\delta^{13}C$ within the crown are the focus of a future paper. At Tikal, these enamel samples show quite variable isotopic change from cuspal to cervical enamel, patterns also seen at Kaminaljuyu (Wright, in press a). While some attenuation of age related isotopic change within the tooth is a product of the continued increase in mineral density during the maturation phase of amelogenesis (Passey and Cerling, 2002; Suga, 1982), averaging the available data approximates the composition of large enamel samples reported in many other studies.

Powdered enamel samples were analyzed for $\delta^{18}O$ in the Department of Geology and Geophysics at Texas A&M University. Enamel samples were reacted with 100% orthophosphoric acid at 80 °C for 12 min in the individual reaction chambers of a Kiel II carbonate machine. $\delta^{18}O$ ratios on sample gasses were measured directly in a Finnegan MAT 251 isotope ratio mass spectrometer. The measurements were corrected to the PDB standard by comparison with aliquots of NBS19 and an internal laboratory carbonate standard, analyzed with each sample run.

Nine third molar samples from PNT burials reported in Table 1 were prepared as part of a pilot study at McMaster University prior to the design of the sampling protocol described above. These samples were taken as enamel sections spanning from cusp to cervix on the distal aspect of the tooth, powdered and homogenized. The enamel was treated with 1.5% sodium hypochlorite, followed by 1 M acetic acid buffered to pH 4.5, and rinsed to neutrality. Isotope ratios were measured on gas produced in an Isocarb attached to a VG Optima mass spectrometer. Experiments showed little systematic change in $\delta^{18}O$ with treatment, thus no acetic treatment was used for the later samples because of the desire for small incremental samples, and the potential loss of sample material during centrifuging. These M3 data are included in Table 1 and discussed in the text, but are not used in statistical assessment of the local Tikal value due to the different preparation protocol.

Table 1
Isotopic composition of Tikal tooth enamel.

Burial	Structure	Date	Age	Sex[a]	LAC#[b]	Sr Tooth[c]	$^{87}Sr/^{86}Sr$	Average $\delta^{18}O$ (‰PDB)	
								Canine	Molar 3
Proyecto Nacional Tikal excavations									
PNT-001	5C-54	Preclassic	20–35 years	F	0.70814	M3	0.70814	−1.1	−.1[d]
PNT-003•	5C-54	Preclassic	20–50 years	M?	0.70792	M3	0.70792	−2.4	−1.0[d]
PNT-004	5C-54-sub1	Preclassic	20–35 years	F	0.70794	Canine	0.70794	−2.3	
PNT-006	5C-49	Late Classic	20–35 years	I		M3			−2.8
PNT-009	5C-49	Late Classic	15 ± 3 years	I	0.70827	M3	0.70827	−2.1	−1.0[d]
PNT-010	5D-87	Late Classic	20–35 years	F?	0.70789	Canine	0.70789	−3.5	
PNT-014	6D-6	Late Classic	5.5 ± 1.5 years	I	0.70811	Canine	0.70811	−2.3	
PNT-019	5D-86	Early Classic	35–50 years	I	0.70814	M3	0.70814		−3.0
PNT-021	5D-86	Preclassic	Adult	I	0.70848	M3	0.70848		−2.1[d]
PNT-022#12	5D-86 Plaza	Early Classic	8 ± 2 years	I	0.70789	Canine	0.70789		
PNT-022B	5D-86 Plaza	Early Classic	15 ± 3 years	I	0.70789	Canine	0.70789	−3.2	−3.9
PNT-022D	5D-86 Plaza	Early Classic	35–50 years	M?	0.70775	Canine	0.70775	−3.8	
PNT-023	5D-82	Early Classic	9 ± 3 months	I	0.70815	M3	0.70815		
PNT-025	5D-84	Early Classic	20–35 years	M?					−3.0[d]
PNT-028	5C-47	Late Classic	20–50 years	M?	0.70819	M3	0.70819	−1.8	−1.2[d]
PNT-038A	5C-45	Late Classic	Adult	F	0.70841	Canine	0.70841	−2.0	
PNT-039	5C-45	Late Classic	Adult	I	0.70825	M3	0.70825		−2.0
PNT-041A	5C-46	Terminal Classic	30–40 years	M	0.70766	Canine	0.70766	−1.3	
PNT-041B	5C-46	Terminal Classic	20–50 years	I	0.70808	M3	0.70808		−2.8
PNT-046	6C-50	Late Classic	20–35 years	F?	0.70818	M3	0.70818		−1.6[d]
PNT-048	6C-50	Late Classic	20–50 years	M					−3.3
PNT-049	6C-50	Late Classic	20–35 years	M?	0.70806	M3	0.70806		−2.1
PNT-055	6C-53	Late Classic	35–50 years	M	0.70830	M3	0.70830		−3.2[d]
PNT-058A	Gr. 6C-XVI-sub-73–75	Late Classic	15 ± 3 years	F	0.70802	Canine	0.70802	−2.8	
PNT-068A	5C-42	Terminal Classic	20–35 years	F	0.70797	M3	0.70797		−2.4
PNT-071	7C-26	Late Classic	>50 years	M?	0.70829	Canine	0.70829	−2.7	
PNT-073	6D-7	Late Classic	20–35 years	F	0.70786	M3	0.70786	−3.5	−2.2[d]
PNT-081	6D-14	Late Classic	20–35 years	M?	0.70798	M3	0.70798		−2.4
PNT-082	6D-14 patio	Late Classic	20–50 years	M?				−4.4	
PNT-083	6D-14	Late Classic	35–50 years	F	0.70798	Canine	0.70798	−1.8	−3.3
PNT-088	8B-4	Late Classic	20–50 years	M?	0.70822	Canine	0.70822	−3.3	−3.5
PNT-089	7B-11	Late Classic	20–35 years	M?	0.70828	M3	0.70828		−2.0
PNT-090	7B-11	Late Classic	20–35 years	I	0.70415	M3	0.70415	−4.7	
PNT-095	7B-15	Late Classic	20–35 years	F?				−4.1	−4.7
PNT-096A	Gr. 6D-XX	Late Classic	20–35 years	M				−3.3	
PNT-097	Gr. 6D-XX	Late Classic	35–50 years	M					−2.0
PNT-104A	6C-35	Early Classic	20–35 years	F?					−4.7
PNT-104B	6C-35	Early Classic	35–50 years	F?	0.70801	Canine	0.70801	−2.8	
PNT-108A	6C-32	Late Classic	20–35 years	M				−3.9	
PNT-109A	6C-35	Late Classic	35–50 years	M					−2.0
PNT-117	7B-18	Late Classic	>50 years	I	0.70779	Canine	0.70779	−1.8	
PNT-118	7B-18	Late Classic	Adult	F					−3.5
PNT-124B	7B-18	Late Classic	>35 years	M?				−1.6	
PNT-126	7B-18	Late Classic	20–35 years	I	0.70813	Canine	0.70813	−2.1	−2.4
PNT-132	7B-18	Early Classic	Adult	I	0.70753	Canine	0.70753	−3.1	−4.1
PNT-138B	6C-25	Late Classic	35–50 years	I				−2.6	
PNT-141A	Gr. 6C-XVI-sub-50	Early Classic	12–15 years	F	0.70682	Canine	0.70682	−4.0	
PNT-142	6C-32/35	Late Classic	35–50 years	M?				−2.9	−2.6
PNT-144	7B-18	Late Classic	35–50 years	M?	0.70835	Canine	0.70835	−2.0	
PNT-145	Gr. 6D-XX	Late Classic	6 ± 2 years	I				−2.5	
PNT-146	Gr. 6D-XX	Late Classic	20–35 years	F				−1.9	−2.6
PNT-147	Gr. 6D-XX	Late Classic	>50 years	I				−1.9	−1.0
PNT-149	Quarried structure	Late Classic	20–35 years	M?				−3.1	−2.5
PNT-154	Gr. 6C-XVI-sub-88	Late Classic	35–50 years	M	0.70752	Canine	0.70752	−1.0	
PNT-162	6D-20	Late Classic	>50 years	F?	0.70830	Canine	0.70830	−3.5	
PNT-165	6D-5 plaza	Early Classic	20–35 years	M?	0.70790	Canine	0.70790	−2.9	−2.7
PNT-167	6D-19	Early Classic	15–18 years	F?	0.70830	M3	0.70830		−3.9
PNT-172D	6D-22	Early Classic	Adult	I	0.70831	Canine	0.70831	−2.4	
PNT-174	Gr. 6C-XVI, Sub-86/87	Early Classic	Adult	I					−2.3
PNT-180	3D-53	Late Classic	5 ± 0.5 years	I				−2.2	
PNT-182	3E-43	Late Classic	20–35 years	M	0.70799	M3	0.70799	−2.4	−2.3
PNT-183	3D-53	Late Classic	20–35 years	M				−2.5	−3.0
PNT-184	3D-54	Late Classic	18–20 years	F				−3.1	−3.3
PNT-185	3D-37	Late Classic	35–50 years	M?	0.70836	Canine	0.70836	−3.0	
PNT-186	3E-44	Terminal Classic	20–35 years	I	0.70813	M3	0.70813		−2.4
PNT-189	3D-37	Late Classic	35–50 years	F					−2.4
PNT-212A	3D-43	Early Classic	35–50 years	M	0.71626	M3	0.71626		−2.1
PNT-212B	3D-43	Early Classic	15–18 years	F?	0.70821	Canine	0.70821	−3.0	
PNT-213	Zona N, Plaza E	Late Classic	15 ± 3 years	F?					−2.5
PNT-223	3E-XII Plaza E	Late Classic	>50 years	M				−2.4	

(*continued on next page*)

Table 1 (*continued*)

Burial	Structure	Date	Age	Sex[a]	LAC#[b]	Sr Tooth[c]	$^{87}Sr/^{86}Sr$	Average $\delta^{18}O$ (‰$_{PDB}$)	
								Canine	Molar 3
University of Pennsylvania Tikal Project excavations									
PTP-002	7F-30	Late Classic	>50 years	I	0.70847	Canine	0.70847	−1.9	
PTP-010X (A)[e]	5D-34	Early Classic	Adult	M?	0.70832	Canine	0.70832		
PTP-010E or F	5D-34	Early Classic	11–12 years	I	0.70831	Dec. Canine	0.70831	−2.2	
PTP-010J	5D-34	Early Classic	6 ± 2 years	I	0.70805	Dec. Canine	0.70805		
PTP-010W7 (G)[e]	5D-34	Early Classic	>19 years	I	0.70819	M1	0.70819		
PTP-010A (G)[e]	5D-34	Early Classic	>19 years	I	0.70828	M1	0.70828		−3.2
PTP-022B	5D-26	Early Classic	20–35 years	I		Canine		−2.8	
PTP-023	5D-33	Late Classic	20–35 years	I	0.70751	M3	0.70751		−6.2
PTP-035	4F-8	Early Classic	Adult	I	0.70824	Canine	0.70824	−4.8	
PTP-045	4F-26	Late Classic	Adult	I	0.70804	Canine	0.70804	−2.3	−4.4
PTP-048B	5D-33	Early Classic	15 ± 3 years	I	0.70811	M3	0.70811		−6.2
PTP-048C	5D-33	Early Classic	11 ± 3 years	I	0.70822	Canine	0.70822	−3.3	
PTP-049	2G-59	Late Classic	20–35 years	I	0.70795	Canine	0.70795	−3.2	
PTP-050	2G-59	Late Classic	20–35 years	I	0.70804	Canine	0.70804	−2.8	
PTP-052	2G-59	Late Classic	Adult	I				−1.9	
PTP-055	2G-59	Late Classic	15 ± 3 years	I	0.70819	Canine	0.70819	−1.8	
PTP-057	2G-59	Late Classic	Adult	I	0.70800	Canine	0.70800	−2.1	
PTP-062	Chultun 2G-2	Preclassic	20–35 years	I					−4.4
PTP-069	3F-26	Late Classic	>35 years	F	0.70850	Canine	0.70850	−4.3	
PTP-077	5D-11	Late Classic	20–35 years	I	0.70825	Canine	0.70825	−2.9	
PTP-091	4H-4	Late Classic	Adult	I	0.70822	Canine	0.70822	−1.3	
PTP-096	4H-4	Late Classic	35–50 years	I	0.70809	Canine	0.70809	−3.7	
PTP-097A	4H-4	Late Classic	35–50 years	M?	0.70797	Canine	0.70797	−1.4	
PTP-101	4H-4	Early Classic	Adult	I	0.70800	Canine	0.70800	−2.5	−2.7
PTP-103	4H-4	Late Classic	Adult	I				−1.6	
PTP-105	4H-4	Late Classic	20–35 years	I	0.70770	M3	0.70770		−2.3
PTP-107A	4H-4 chultun	Early Classic	20–35 years	M?	0.70832	Canine	0.70832	−2.5	−4.6
PTP-107E	4H-4 chultun	Early Classic	>35 years	F?	0.70823	Canine	0.70823	−4.1	
PTP-107G1	4H-4 chultun	Early Classic	20–35 years	M?	0.70890	Canine	0.70890	−4.9	−4.9
PTP-107G2	4H-4 chultun	Early Classic	20–35 years	M?	0.70810	Canine	0.70810	−4.7	−4.2
PTP-109	4H-4	Late Classic	Adult	I				−2.7	
PTP-125A	5D-22	Preclassic	20–35 years	M	0.70835	Canine	0.70835	−2.2	
PTP-128	Plat.6E-sub1	Preclassic	35–50 years	I				−3.9	
PTP-135	6C-41-1st	Late Classic	2–3 years	I		Dec. Canine		−2.5	
PTP-151A	Plat.6E-1	Late Classic	20–35 years	M?	0.70779	Canine	0.70779	−5.0	−5.6
PTP-152	6E-26	Early Classic	Adult	I	0.70810	Canine	0.70810	−3.4	
PTP-158	5F-1	Preclassic	20–35 years	M?	0.70809	Canine	0.70809	−3.6	−4.9
PTP-160A	7F-30	Early Classic	>35 years	M	0.70901	Canine	0.70901	−2.8	
PTP-160B	7F-30	Early Classic	7 ± 2 years	I	0.70772	Dec. Canine	0.70772	−2.5	
PTP-161	Plat.6E-1	Late Classic	4 ± 1 years	I	0.70826	Canine	0.70826	−2.8	
PTP-162	7F-30	Early Classic	>35 years	F	0.70850	M3	0.70850		−2.8
PTP-164	5D-4	Preclassic	15–20 years	M?	0.70822	Canine	0.70822	−1.8	−2.0
PTP-168	6E-1	Terminal Classic	20–35 years	M?	0.70802	Canine	0.70802	−2.8	
PTP-174	5D-79	Late Classic	9–10 years	I	0.70820	Canine	0.70820	−4.2	
PTP-177	5D-71	Early Classic	20–35 years	M	0.70836	M3	0.70836	−3.3	−3.3
PTP-180	5D-50	Late Classic	Adult	F?				−4.1	
PTP-182	5D-46	Early Classic	Adult	F?	0.70651	P3	0.70651	−4.0	−5.5
PTP-186	3H-9	Late Classic	Adult	M?					−3.4
PTP-190	7F-30	Late Classic	15 ± 3 years	I				−2.3	
PTP-196	5D-73	Late Classic	>35 years	M	0.70803	Canine	0.70803	−5.0	
PTP-201	5D-22	Terminal Classic	15 ± 3 years	I	0.70812	Canine	0.70812	−1.1	
PTP-209	Uolantun SE482	Early Classic	Adult	I	0.70837	Canine	0.70837	−3.5	
PTP-214	Uolantun SE482	Early Classic	20–35 years	M?				−4.2	−4.5
PTP-215	5D-48	Postclassic	9–10 years	I				−1.2	
PTP-PD111-22	Chultun 5C-1	Early Classic	20–35 years	M?	0.70774	M1	0.70774		
PTP-PD111-26	Chultun 5C-1	Early Classic	20–35 years	M?	0.70796	I2	0.70796		
PTP-PD170-36	Temple 6	Early Classic	20–35 years	I	0.70802	M1	0.70802		
PTP-PD170-55	Temple 6	Early Classic	20–35 years	I	0.70803	I1	0.70803		
PTP-PD170-63	Temple 6	Early Classic	20–35 years	F?	0.70810	M2	0.70810		
PTP-PD231	Chultun 6C-11	Early Classic	35–50 years	M?	0.70417	Canine	0.70417	−5.9	
PTP-PD274	No assoc. str.	Early Classic	Adult	M?	0.70796	M3	0.70796		
Cooperación Española excavations									
PTI-001	5D-1	Terminal Classic	14–18 years	M	0.70406	M3	0.70406		−6.7
PTV-001	5D-5	Late Classic	15 ± 3 years	F	0.70822	M3	0.70822		−2.3
PTV-002	5D-5	Late Classic	18–22 years	M	0.70822	M3	0.70822		−2.5

[a] M, Male; M?, probable male; F, Female; F?, probable female; I, indeterminate.
[b] University of Wisconsin-Madison Laboratory for Archaeological Chemistry sample number.
[c] Tooth sampled for stable strontium isotope ratio measurement.
[d] Data measured at McMaster University, using homogenized large enamel samples.
[e] Individual designation used by Coe (1990b). See Wright (2005b) for correlation of skeleton identities in PTP-010.

Fourier-transform infrared spectroscopy (FTIR) of enamel from these nine PNT burials following the methods of Wright and Schwarcz (1996) showed no evidence of calcite peaks, carbonate uptake or diagenetic exchange, with consistent crystallinity indices (4.2–4.8) and CO_3/PO_4 ratios (.088–.096). Moreover, CO_2 yields on these samples were 2.0–2.5% by weight, and do not indicate significant carbonate contamination. Since the samples are taken from buried enamel, the likelihood of diagenetic change is slight.

Strontium isotope samples were taken from many of the same teeth as the light stable isotope samples, although only one tooth was sampled per burial. Most of the Sr samples are from mandibular canines, but a few other teeth were sampled due to the vagaries of tooth availability, especially for key burials with non-local material culture. In most cases, 30–50 mg of enamel was liberated from the margins of the crown, mesial or distal to the longitudinal sections. However, separate samples were cut from the crown spanning from cusp to cervix for some teeth. Details of the sample treatment have been published elsewhere (Wright, 2005a). In brief, the samples were soaked in 5% ultrapure acetic acid to remove any diagenetic carbonates. Samples were then ashed at 825 °C in sterile silica glass tubes for 8 h. The ash was dissolved in concentrated HNO_3, dried in a sterile laminar flow drying box, and re-dissolved in ultrapure 2.5 N HCl. Using 2.5 N HCl as the mobile phase, Sr was isolated using cation exchange chromatography. The strontium isotope ratios were measured at the University of North Carolina in Paul Fullagar's lab on a Micromass Sector 54 multicollector thermal ionization mass spectrometer (TIMS).

This research was carried out as one component of a broad bioarchaeological study of Tikal remains, for which data analysis is ongoing. All age and sex estimates, and skeletal inventory data reported here were collected in the course of this work, following standard methods (Buikstra and Ubelaker, 1994; Steele and Bramblett, 1988), and are my own, unless otherwise cited. For the PTP remains, sex determination is now impossible for many due to the fact that only teeth were retained from many skeletons. Table 1 reports sex estimates for all individuals for whom several pelvic or cranial indicators of sex are curated. Those identified by few criteria, or by metric discriminant functions are given as "probable." Similarly, a rough estimate of age at death is possible only by reference to dental wear for many adult skeletons, though I used the best available age indicators for each skeleton, including transition analysis (Boldsen, 1997).

Identifying local signals of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ at Tikal

Table 1 contains demographic and contextual information regarding the burials and teeth sampled, together with the $^{87}Sr/^{86}Sr$ and average $\delta^{18}O$ ratios obtained. A central issue in isotopic studies of ancient migration is the need to define local isotopic signatures for the site in question. Because the issues governing local variability differ for strontium and oxygen, I discuss each in turn.

Strontium

Two approaches have been used to define local signatures for strontium isotopes: a statistical approach using archaeological human data, and a non-human comparative approach (Bentley, 2006; Bentley et al., 2004; Price et al., 2002). The success of a human statistical approach depends on the variability of ratios in the local environment, and the proportion of the skeletal sample that might indeed have been migrants. While both of these parameters may vary widely in different archaeological contexts, we can expect the majority of the population to have been born locally at most sites, and if they consumed locally grown foods and the local environment is geologically monotonous, we should expect a normal distribution of Sr isotope ratios. Alternately, "biologically available" strontium can be measured by sampling modern flora or fauna that share the same habitat as the ancient inhabitants. For a number of reasons, the former approach is more successful for Tikal (Wright, 2005a).

Tikal lies on Paleocene limestone, like much of central Petén. The soil, rock, water, and plant samples collected within 50 km of Tikal by Hodell and colleagues (2004) range between .7074 and .7081. Modern rodents cannot be sampled at Tikal, which is located in a national park. However, two agoutis and two rats collected north of San Jose, Petén (about 30 km southwest of Tikal, with the same Paleocene limestone found at Tikal), each show $^{87}Sr/^{86}Sr$ of .7079. Thus, we might expect agricultural products consumed by Tikal humans to have comparable $^{87}Sr/^{86}Sr$.

In Mesoamerica, maize is traditionally processed in an alkaline solution to dissolve the pericarp from the kernels (Katz et al., 1974). This treatment dramatically raises the Ca content of the maize, and determines the Sr/Ca ratio of the whole diet (Burton and Wright, 1995). Stable carbon isotopic ratios of Tikal collagen demonstrate that maize provided more than half of the diet (Wright, 2003). Thus we should consider alkaline processing to be the primary source of strontium in ancient Maya diets, and the primary determinant of the strontium isotope ratios of Maya skeletons. In addition to limestone, the Tikal Maya could also have used the *Pomacea* snail to make lime for processing maize, by analogy with the Lacandon Maya, who burn and slake freshwater *Pachychilus* snail shells to produce lime (Moholy-Nagy, 1978; Nations, 1979). Three *Pomacea* shells from an aguada 10 km north of Tikal, on the margin of the Bajo Santa Fe average 0.7078. Together, these data suggest a local Tikal signature of 0.7078–.7081.

$^{87}Sr/^{86}Sr$ was measured for only one tooth per individual, primarily mandibular canines and third molars. There is no difference in the mean $^{87}Sr/^{86}Sr$ of 56 canines and 30 third molars ($t = .322$, $df = 84$, $p = .748$), so the data are considered together for statistical analysis. Fig. 2 illustrates the $^{87}Sr/^{86}Sr$ data by time period and relative to the regional clusters defined by Hodell et al.'s (2004) survey of environmental $^{87}Sr/^{86}Sr$ data in the Maya area. The Tikal $^{87}Sr/^{86}Sr$ data cluster together at .7080, the interface between reported values for the northern and southern Maya lowlands (Hodell et al., 2004; Price et al., 2008). $^{87}Sr/^{86}Sr$ data for eight skeletons that correspond to very different geological environments (the volcanic highlands, the Paleozoic Motagua valley, Quaternary coastal deposits in the lowlands, and the Maya Mountains) can be readily identified by their divergent values, and represent 8% of the sample, occurring in Early, Late and Terminal Classic periods.

Comparison of the distribution of Tikal human $^{87}Sr/^{86}Sr$ to the Normal distribution provides a way to identify further non-local individuals, as previously reported (Wright, 2005a). The present study uses a slightly larger sample than published originally, although the interpretation of the sample distribution does not differ. Table 2 contains descriptive statistics for the now larger "complete" dataset, for the data "trimmed" of geologically distant samples, and for the final "local" sample, excluding outliers. Although not a statistical outlier, I also exclude one $^{87}Sr/^{86}Sr$ measurement for a burial from Uolantun (PTP-209) some 10 km southeast of Tikal from the trimmed and local samples. These statistics differ minimally from those of the original sample (Wright, 2005a). Both the complete dataset and the trimmed dataset differ significantly from Normal using the Shapiro Wilk statistic. Chauvenet's (Taylor, 1982) and Peirce's (Ross, 2003; Saunder, 1903) criteria for the exclusion of outliers would eliminate data below .70749. Because three burials have $^{87}Sr/^{86}Sr$ of .7075, and are quite distant from the remaining data, I exclude these burials to obtain a "local" range: .70766 to .70850. The Shapiro Wilk statistic indicates that the "local" sample approximates a Normal distribution.

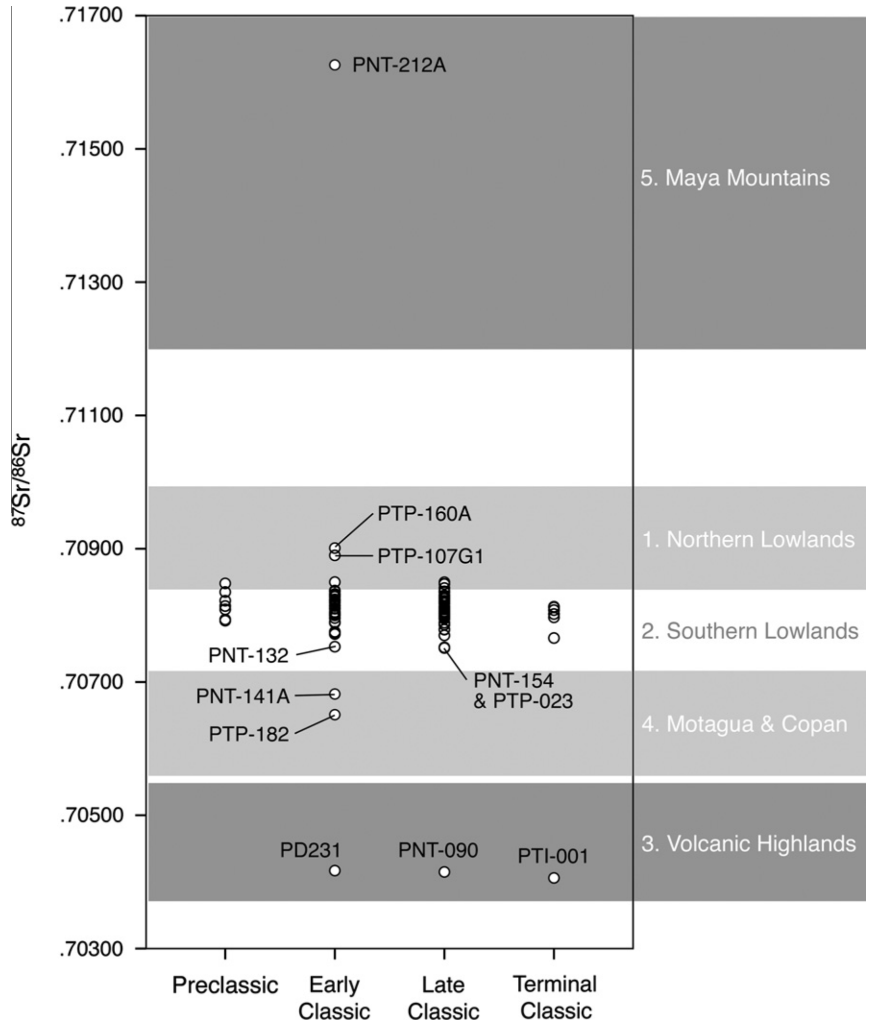

Fig. 2. Distribution of strontium isotope ratios in Tikal teeth, with bars showing regional clusters defined by Hodell et al. (2004). Non-local skeletons are identified to burial.

Table 2
Descriptive statistics for $^{87}Sr/^{86}Sr$ composition of Tikal mandibular canines and third molars.

Statistic	Complete	Trimmed	Local
Mean	0.70805	0.70810	0.70812
Standard deviation	0.00113	0.00022	0.00019
Count	97	88	86
Minimum	0.71626	0.70751	0.70766
Maximum	0.71626	0.70850	0.70850
Variance	1.3E−06	4.7E−08	3.6E−08
Coefficient of variation	0.00160	0.00031	0.00027
Skewness (standard error)	2.689 (.245)	−.604 (.257)	−.241 (.261)
Kurtosis (standard error)	32.2 (.485)	.342 (.508)	−.295 (.517)
Median	0.70811	0.70811	0.70812
Mode	0.70822	0.70822	0.70822
Shapiro Wilk statistic	0.447	0.968	0.985
Degrees of freedom	97	88	85
Significance	0.000	0.029	0.410

Provisionally, these "local" individuals can be considered to have spent their childhoods at Tikal, though admittedly other nearby sites, such as Uolantun, El Zotz and Uaxactun might have equivalent local values. For instance, Burial PTP-209 from Uolantun measures .70837. It is difficult to define the geographic extent of this local "Tikal" signature, given the absence of comparative data from all sites in the region.

The mean (.70812) and mode (.70822) of the "local" $^{87}Sr/^{86}Sr$ sample are essentially coincident, but are somewhat higher than the range given by the fauna, *Pomacea*, and rock samples from Tikal (.7078–.7081). While it is possible that local variability in both food and lime sources is not adequately characterized, other data reported from the central Petén is very homogeneous (Hodell et al., 2004), and argues against a distinctive, higher value for Tikal. One possibility is that sea salt imported from the Yucatan or Belize coasts may have raised Tikal human $^{87}Sr/^{86}Sr$ ratios. Sea salt has a ratio of 0.7092, and contains abundant Sr. A dose of only six grams of sea salt per day could raise strontium isotope ratios from the faunal range to the human mean observed at Tikal (Wright, 2005a). This is less than the average salt intake of Yucatec Maya in the 1920s (Andrews, 1983; Redfield and Villa Rojas, 1934) and many cultures today.

Oxygen

Defining a local signature for $\delta^{18}O$ ratios in human remains is somewhat more complicated than for strontium, because $\delta^{18}O$ is shaped by more variables. Faunal bone data are not applicable because fractionation in $\delta^{18}O$ during bone mineral precipitation is determined in part by species-specific body temperatures. Moreover, water sources for fauna may differ in $\delta^{18}O$ from human water catchments, due to distinct evaporation and recharge rates. To date, all $\delta^{18}O$ studies of migration have used human data to define

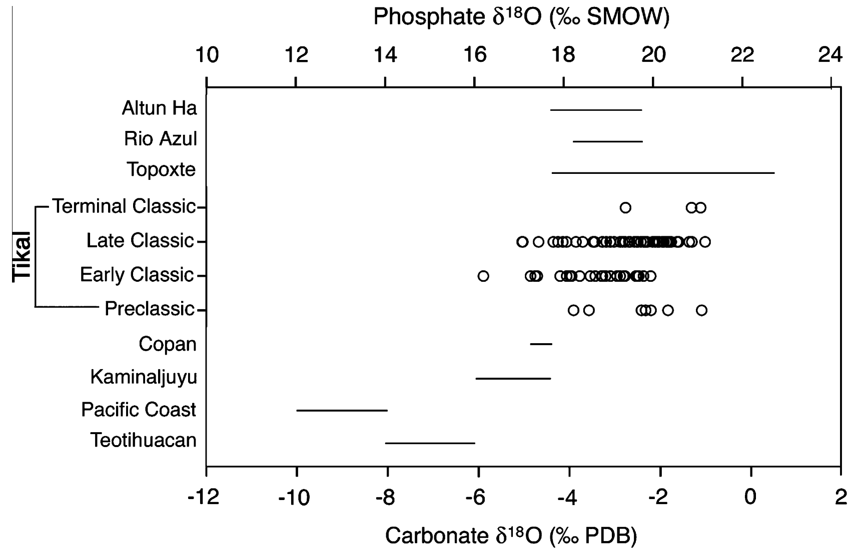

Fig. 3. Average oxygen isotope ratios measured in Tikal canines, by time period. Comparative data are from Metcalf et al. (2009), Price et al. (2008, 2010), White et al. (1998, 2001a,b), and Wright et al. (2000, 2010).

local values, however, this has not been done in a statistical manner due to the fairly small sample sizes used in most studies.

Fig. 3 illustrates the average $\delta^{18}O$ measured Tikal canines ($n = 90$) by time period, as well as comparative data ranges for key Mesoamerican sites where $\delta^{18}O$ has been reported. These $\delta^{18}O$ data are for bone phosphate from Rio Azul (White et al., 2001a), Teotihuacan (White et al., 1998), and the Pacific coast of Guatemala (Balberta, Los Chatos/Mananatial) (Metcalf et al., 2009), and bone carbonate for Altun Ha (White et al., 2001b). Data for Kaminaljuyu (Wright et al., 2010), Topoxte (Wright et al., 2000) and Copan (Price et al., 2010) are enamel carbonate. Sites in the Maya lowlands, such as Altun Ha and Rio Azul show higher $\delta^{18}O$ ratios, while sites in the Guatemalan highlands and on the Pacific coast and piedmont show lower $\delta^{18}O$. Domestic burials at Copan show slightly higher ratios than highland Kaminaljuyu, however, they are at the low extreme of lowland sites further north. At Tikal, canine $\delta^{18}O$ shows a fairly broad range, overlapping those of the lowland sites, as well as Copan and Kaminaljuyu, suggesting that the tails of the distribution are those of non-local children. At nearby Topoxte, a broad range is also seen, with a number of individuals having positive $\delta^{18}O$, perhaps indicating intake of water from Lake Yaxha, which is evaporatively enriched (Lachniet and Patterson, 2009). Higher values still (25.4–28.1‰$_{SMOW}$) have been reported from Ambergris Caye (Williams et al., 2005), that could only be explained by extreme evaporative enrichment of collected rainwater, assuming that diagenetic change is not responsible. There may also be considerable local variability within each region that is not represented by the spotty sampling carried out to date. For example, a premolar found on a 900 BC house floor at Tak'alik Ab'aj, on the Pacific coastal piedmont, at −5.6‰$_{PDB}$ (Wright, unpublished data), is more than two permil higher than phosphate data reported from the Pacific coastal sites of Balberta and Los Chatos/Mananatial.

Since the sample size for Tikal is fairly large, we can examine $\delta^{18}O$ statistically to further define the local range. As expected, nursing elevated the $\delta^{18}O$ of enamel in Tikal canines, which form during the first 4.5 years of life (Wright and Schwarcz, 1998). A paired t test shows that canines average 0.45‰ more enriched in ^{18}O than third molars from the same individual ($t = 2.92$, $df = 24$, $N = 25$, $p = 0.007$). Thus, I examine the data separately for canines and third molars. Variability in the duration of nursing is expected in any population, so adjusting values to compensate for this effect is not practical. Deciduous canines are not considered in these statistical analyses, nor are the samples prepared at McMaster. Deciduous teeth represent maternal body water because they form *in utero*, and should have values comparable to post-weaning third molars.

Intratooth variability in $\delta^{18}O$ and patterns of child feeding with age at Tikal will be addressed in a separate paper. As at Kaminaljuyu (Wright, in press a) there is considerable variability in

Table 3
Descriptive statistics for $\delta^{18}O$ composition of enamel from Tikal mandibular canines and third molars.

Statistic	Canine $\delta^{18}O$ (‰ PDB)		Molar $\delta^{18}O$ (‰ PDB)	
	Complete	Local	Complete	Local
Mean	−2.89	−2.69	−3.31	−3.05
Standard deviation	1.04	0.83	1.26	0.89
Count	87	77	54	47
Minimum	−5.9	−4.36	−6.66	−4.93
Maximum	−1.02	−1.1	−1.04	−1.95
Variance	1.09	0.693	1.59	0.79
Coefficient of variation	−0.36	−0.31	−0.38	−0.29
Skewness (standard error)	−.448 (.258)	−0.103 (.274)	−.89 (.33)	−.74 (.35)
Kurtosis (standard error)	−.175 (.511)	−0.747 (.541)	−.17 (.64)	−.65 (.68)
Median	−2.79	−2.69	−2.88	−2.78
Mode	Multiple	Multiple	Multiple	Multiple
Shapiro Wilk statistic	0.98	0.98	0.92	0.90
Degrees of freedom	87	77	54	47
Significance	0.165	0.230	0.001	0.001

$\delta^{18}O$ within individual teeth from Tikal. This is obscured by the averaged microsample data used here, as indeed by the more common process of sampling a homogenized large span of enamel (Wright and Schwarcz, 1998). Thus, it should be underscored that these point estimates underrepresent the variable composition of each tooth, but provide the best approximation for comparison with the larger homogenized samples reported from other sites.

Table 3 contains descriptive statistics for $\delta^{18}O$ in averaged canine and third molar samples. Histograms of the data are in Fig. 4. The mandibular canine distribution is not markedly different from a normal distribution, and has a non-significant Shapiro Wilk statistic, although it is skewed toward isotopically heavier values and shows two modes. The third molar distribution is skewed in the same direction, but has three modes, and the significant Shapiro Wilk statistic indicates that the distribution of molar $\delta^{18}O$ is not Normal.

Fig. 5 shows the Normal Q–Q probability plots for third molar and canine average $\delta^{18}O$. Filled circles indicate skeletons for which non-local $^{87}Sr/^{86}Sr$ were obtained, and are identified to burial. Open circles represent individuals for which $^{87}Sr/^{86}Sr$ data were not obtained, or that had local Tikal $^{87}Sr/^{86}Sr$. Skeletons with local $^{87}Sr/^{86}Sr$ are identified by burial numbers only in the tails of the distribution. Chauvenet's criterion would not exclude any of these $\delta^{18}O$ data as being "ridiculously improbable" members of the sample (Taylor, 1982), and Pierce's criterion (Ross, 2003; Saunder, 1903) would exclude only the canine $\delta^{18}O$ from PTP-PD231, which also has non-local $^{87}Sr/^{86}Sr$. Samples with nonlocal $^{87}Sr/^{86}Sr$ lie in the tails of the distributions for the most part, however, two individuals with nonlocal $^{87}Sr/^{86}Sr$ show canine $\delta^{18}O$ close to the mean. Of them, PNT-132 is among the .7075 outliers excluded from the local $^{87}Sr/^{86}Sr$ sample; its molar $\delta^{18}O$ value is also in the midst of the distribution. PTP-160A shows a $^{87}Sr/^{86}Sr$ value of .7090, consistent with Quaternary coastal deposits in the lowlands, whether in the Gulf coastal margin, the Belize River valley or the Caribbean coast. To the left of these individuals on the graph are two samples with $^{87}Sr/^{86}Sr$ values comparable to the city of Copan, PTP-182 and PNT-141A. Samples with non-local $^{87}Sr/^{86}Sr$ from volcanic highland environments are located in the tails of the distribution

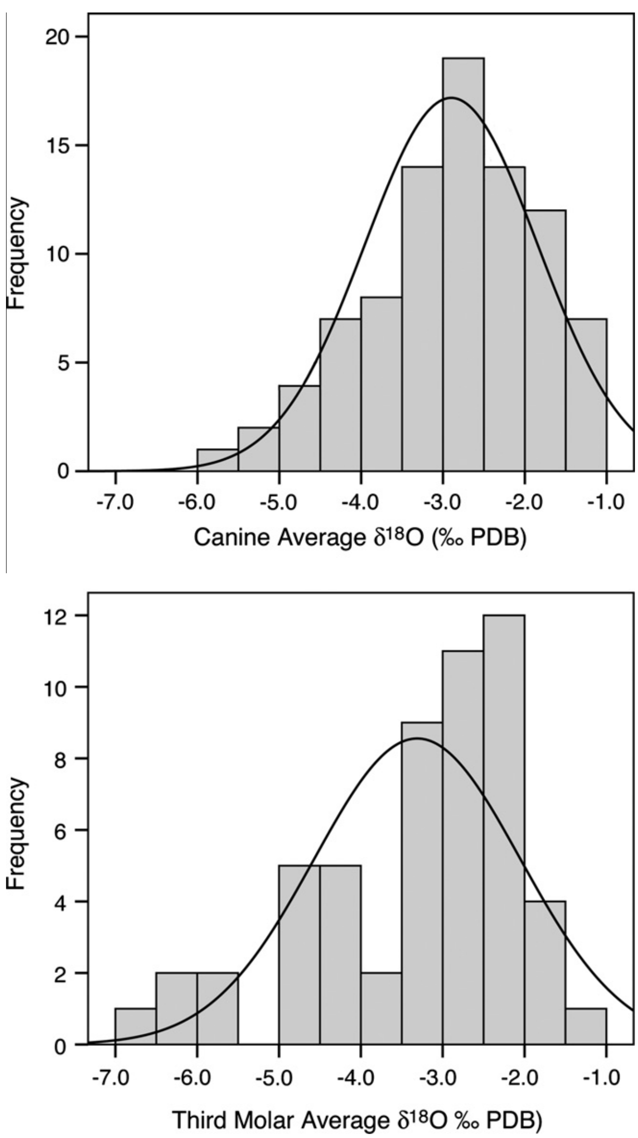

Fig. 4. Distribution of average $\delta^{18}O$ values in Tikal canine and third molar enamel. Curved line represents a normal distribution for comparison.

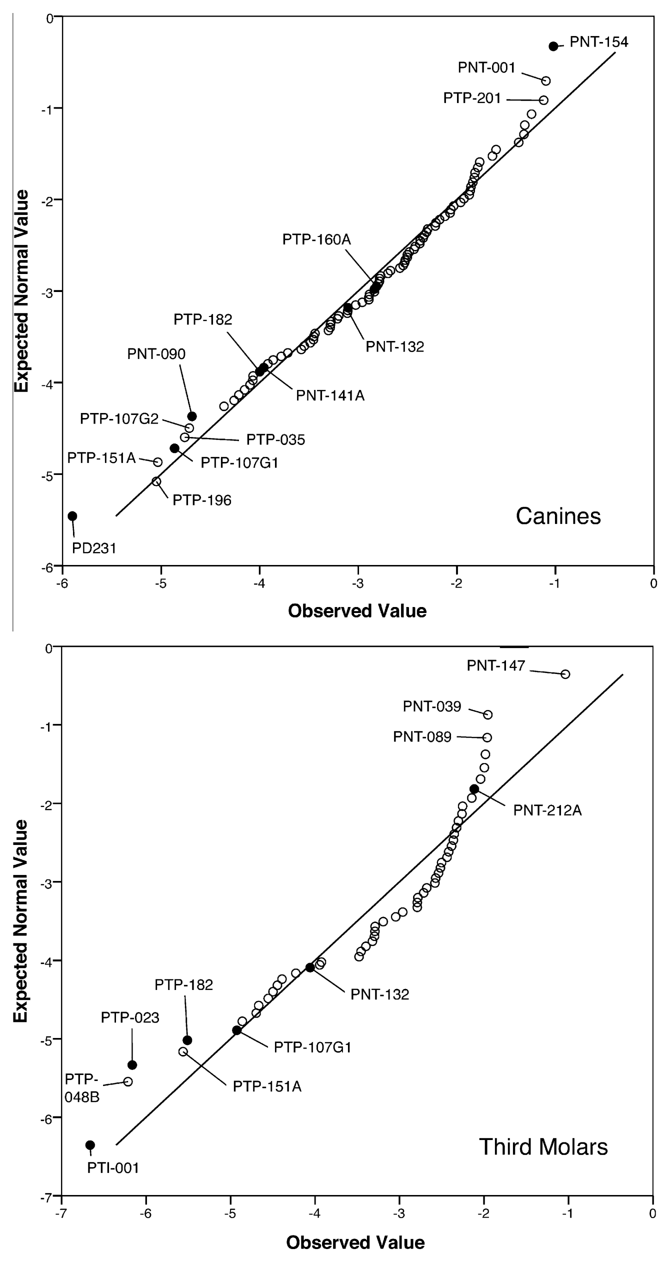

Fig. 5. Normal Q–Q probability plots for average $\delta^{18}O$ values in Tikal canine and third molar enamel. Filled circles are individuals with non-local strontium isotope ratios. Non-local skeletons are identified to burial.

(PTP-PD231, PNT-090). Since the canine distribution is fairly continuous, I am hesitant to exclude many individuals as non-local based on oxygen isotopes alone, however, the presence of non-local $^{87}Sr/^{86}Sr$ in the tails of the distribution suggests that some trimming is appropriate. A breakpoint in the distribution can be seen at −4.5‰ below which three $^{87}Sr/^{86}Sr$ outliers occur. I exclude these, together with the highest value (PNT-154, .7075) from a "local" canine range. At the upper extreme, there are few clear gaps in the data. I also exclude two Uolantun burials (PTP-209, PTP-214) from the local Tikal canine sample. Data within this local range are less skewed than in the sample as a whole (Table 2).

Most of the outlying $^{87}Sr/^{86}Sr$ values fall in the lower end of the third molar $\delta^{18}O$ distribution. Three individuals can be identified as non-local by excluding outliers below −5.0‰, where there is a break in the distribution that corresponds well with the lower bounds of the canine $\delta^{18}O$ local range when the mean difference between molar and canine $\delta^{18}O$ is considered. At the upper extreme, a large gap separates PNT-147 from the remaining data, and is consistent with the exclusion of the uppermost datum of the canine sample. Provisionally, I exclude only this burial, PNT-147 (for which Sr data was not obtained) and data below −5.0‰ from the local molar $\delta^{18}O$ sample. Eliminating these burials results in a more platykurtic distribution (Table 3), although both the complete and local molar datasets differ from a normal distribution. I also did not consider data from Uolantun burial PTP-214 in defining the local Tikal molar range.

Variability among the $\delta^{18}O$ of Tikal enamel may also derive from systematic patterning in the $\delta^{18}O$ of drinking water available to the Tikal population. Within the "local" sample, analyses of variance show statistically significant differences among Preclassic, Early Classic, Late Classic, and Terminal Classic samples for both canines ($F = 11.397$, $p = .002$) and molars ($F = 3.806$, $p = .017$). Comparing only the larger samples from the Early and Late Classic periods, mean $\delta^{18}O$ is 0.5‰ higher in Late Classic canines than Early Classic ones ($t = -2.79$, $p = .007$, 2 tailed) (see Fig. 3), and 0.7‰ higher in Late Classic molars ($t = -2.95$, $p = .005$, 2 tailed). This shift could be due to climate change, and is consistent with changes in ostracod carbonate $\delta^{18}O$ reported from Lake Salpetén sediment cores (Rosenmeier et al., 2002). However, rainwater catchment changes at Tikal due to the construction of reservoirs also merits consideration.

Tikal is located on the margins of the large seasonal swamp, the Bajo Santa Fe, however, there are no nearby streams or rivers that would have provided the city with water. Instead, a system of artificial reservoirs was constructed to capture rainwater for domestic uses as well as dry season irrigation (Scarborough and Gallopin, 1991). Although detailed analysis of water sources is beyond the scope of this paper, as a preliminary approach, I classified burials by proximity to water catchment facilities. I considered the "central precinct reservoirs" as a single unit, and assign burials in the main plaza and other major ceremonial architecture to these. Although Scarborough and Gallopin (1991) opine that the four major "bajo-margin reservoirs" were not used for drinking water, I did not exclude these. There is considerable shared range of canine and molar $\delta^{18}O$ among burials classified by reservoir, and no obvious differences among sectors of the city. Although smaller sample sizes may be responsible, $\delta^{18}O$ of burials close to the Aguada Las Chamacas and to the Inscriptions Reservoir are more tightly clustered than those assigned to the central precinct, Madeira or Tikal reservoirs. Given the extent of evaporative enrichment shown in the Petén Lakes, it is likely that reservoirs would differ slightly in $\delta^{18}O$, or that the $\delta^{18}O$ of reservoir water would fluctuate from year to year, and seasonally, depending on recharge and usage rates. This fluctuation may contribute to the broad range of enamel $\delta^{18}O$ measured at Tikal.

Patterns in migration to Tikal

For the sample as a whole, strontium isotopes allow us to identify eleven individuals as migrants to Tikal, some 11% of the individuals analyzed. Seven of these individuals lie in the tails of the oxygen isotope distribution, confirming a non-local origin; in the remaining four, $\delta^{18}O$ values are consistent with Tikal water, but do not necessarily contradict a foreign origin given the gradual change in $\delta^{18}O$ seen across the Maya area. The $\delta^{18}O$ data also lead us to suspect that an additional ten individuals were migrants, even though their $^{87}Sr/^{86}Sr$ are consistent with a childhood spent at Tikal. Thus some 15.7% (11 + 10 = 21/134) of individuals sampled derive either from geologically disparate zones or from regions with isotopically distinct water.

These migrant individuals are not evenly distributed across the occupational history of the site. Considering strontium isotope ratios alone, the Early Classic period shows the greatest proportion—17.5% (7/40) of migrants from distant and geologically distinct regions. By contrast, 7.0% (3/43) of Late Classic skeletons analyzed for $^{87}Sr/^{86}Sr$ are non-local. Considering the oxygen isotope ratios, an additional four Early Classic skeletons with local $^{87}Sr/^{86}Sr$ may be immigrants, raising the total to 27.5% (11/40). Oxygen isotopes may identify four Late Classic skeletons as non-local, for most of whom strontium isotope ratios were not measured, thus, 10.2% (8/78) of Late Classic skeletons may be non-local. Comparing the proportion of migrants, the Fisher's Exact test is non-significant considering foreigners identified by strontium data alone ($p = .18$), but becomes significant if the oxygen data are also considered ($p = .03$), suggesting significantly greater immigration in the Early Classic than Late Classic periods.

Although reconstructions of population growth at Tikal vary significantly, it is not surprising that immigration to Tikal would be greater during the Early Classic period, when the city showed meteoric growth (Culbert et al., 1990; Haviland, 2003). The Early Classic period is also the time when epigraphic evidence for interaction with central Mexico is most abundant. However, skeletal sampling was not random, especially from the PTP remains. For strontium isotopes, I specifically targeted skeletons from contexts that might shed light on the issue of long distance interaction in the Early Classic period. The Early Classic sample contains predominantly PTP burials (27/40) largely from elite and ceremonial contexts, while the Late Classic sample is largely PNT burials (48/72), most of which are from domestic contexts, thus it is possible that sampling is responsible for some of the apparent decline of immigration in the Late Classic period. Since the isotopic measures will only highlight individuals from distant geological or meteorological regimes, these should be considered as low estimates. Presumably the majority of movement into a blossoming city would have been from nearby rural areas, or faltering cities that were not so distant, and cannot be detected isotopically.

Sex estimation is challenging at Tikal, and especially so for the PTP skeletons, for many of which the skeletal material was not curated. Combining "probable" and more securely sexed skeletons together and excluding indeterminate ones, it is appears that males migrants (11 migrants, 38 locals, defined considering both strontium and/or oxygen ratios) were perhaps more common than female ones (three migrants, 25 locals) in the sample as a whole, although the difference is not significant (Fisher Exact $p = .24$). Given that there are many unsexed skeletons (seven migrants, 50 locals), it is difficult to know if this is a meaningful pattern or not, even though many of the unsexed individuals are subadults. The data also hint at a chronological change in the pattern of migration by sex. The three female migrants include one Preclassic and two Early Classic women. Combining the Preclassic and Early Classic burials, there is no significant difference in the representation of migrants versus local skeletons between males and females (Fisher Exact $p = 1.00$). In the combined Late–Postclassic sample, however, there are no female migrants, and the likelihood of this being a random outcome is much smaller (Fisher Exact $p = .14$). However, there are a further four migrants among the 29 Late-Postclassic skeletons that could not be sexed.

Who are the migrants?

Fig. 6 shows δ^{18}O plotted against ^{87}Sr/^{86}Sr for the complete dataset. Open circles represent individuals sampled for δ^{18}O with mandibular canines. Filled circles represent third molar data for individuals from which no canine was sampled, thus only one oxygen isotope measurement is shown per individual, plotted against whichever tooth was sampled for strontium isotope analyses. Non-local individuals are identified to burial, as are a few burials with outlying data that were not excluded from the local sample above, but deserve consideration as possible immigrants.

To identify possible homelands for the outliers I consider published data on ^{87}Sr/^{86}Sr variability in Mesoamerican skeletons (Freiwald, 2011; Price et al., 2008, 2010; Wright and Bachand, 2009; Wright et al., 2010), as well as data from Hodell et al.'s (2004) environmental survey, Thornton's (2011) faunal study and general expectations based on the geological structure of the Maya area. These ^{87}Sr/^{86}Sr data are summarized in Fig. 1. Human skeletal δ^{18}O has not been studied systematically across the lowlands, and broad overlapping ranges of human data at most sites have led some to be skeptical about the utility of δ^{18}O for identifying migrants (Price et al., 2010). Published data on surface water δ^{18}O (Lachniet and Patterson, 2009) can also be used to infer human bone values in very broad terms, for areas where no human data are yet available. I use the equation $\delta^{18}O_{ap(PDB)} = .653 \bullet \delta^{18}O_{w(SMOW)} + 0.09$ (Wright et al., 2010, p. 169) to estimate enamel apatite δ^{18}O from surface water data, recognizing the pitfalls of this approach. Given the broad ranges measured at all sites, the considerable overlap among sites, and the various factors that can affect δ^{18}O from these expected values, such as evaporative enrichment and cultural behaviors as well as the documented intratooth variability in δ^{18}O (Wright, in press a,b), identifying homelands based on δ^{18}O is, thus, somewhat speculative.

As described above, eight individuals have strontium isotope ratios indicating a childhood spent in a geologically distinct zone, distant from Tikal. Three show ^{87}Sr/^{86}Sr consistent with a volcanic environment ($\sim$.704), either highland Guatemala or central Mexico (Price et al., 2000, 2008; Wright et al., 2010). Another two are consistent with an origin in the southeastern periphery of the Maya area (.7065) (Hodell et al., 2004; Price et al., 2010), while one can only come from the Maya Mountains (.7160) (Freiwald, 2011; Thornton, 2011). Two are slightly higher than the local Tikal range (.7090), and match values for the Quaternary coastal deposits in the Gulf coast, northern lowlands (Price et al., 2008) or the Belize River valley (Freiwald, 2011), while three skeletons come from Cretaceous limestone areas with strontium isotope ratios of .7075. This would include large areas of the Petén to the south of Tikal, as well as parts of Alta Verapaz and southern Belize (Hodell et al., 2004). Among other undocumented sites, Ceibal, Aguateca, Cancuen, Lubaantun, and Motul de San José show ^{87}Sr/^{86}Sr in this range (Krueger, 1985; Thornton, 2011; Wright and Bachand, 2009).

Many of these skeletons are also distinguished by outlying oxygen isotope ratios, which appear to highlight a larger number of burials in Fig. 6. At the low end of the δ^{18}O range are outliers that may be from highland or Pacific coastal contexts, having δ^{18}O consistent with the ranges at Kaminaljuyu and Teotihuacan illustrated in Fig. 3, and confirmed by nonlocal strontium isotopes. The Pacific coast shows δ^{18}O lower than at Kaminaljuyu or Teotihuacan (Metcalf et al., 2009), and one tooth from Middle Preclassic Tak'alik Ab'aj measures $-5.6‰_{PDB}$ in δ^{18}O and .70449 in ^{87}Sr/^{86}Sr (Wright, unpublished data), but was not in a primary context. For those with apparently local or Cretaceous ^{87}Sr/^{86}Sr, locations far to the south of Tikal and up into the highlands are possible homelands. Rainfall generated in Alta Verapaz, for instance, flows down to the lowlands, so surface water available at sites adjacent to the highlands may have low δ^{18}O. For instance, river water in Alta Verapaz has been measured at $-9‰_{SMOW}$ (Lachniet and Patterson, 2009) which corresponds to an apatite value of $-5.8‰_{PDB}$. Unfortunately there are as yet no human data from Cancuen, an important site in this region.

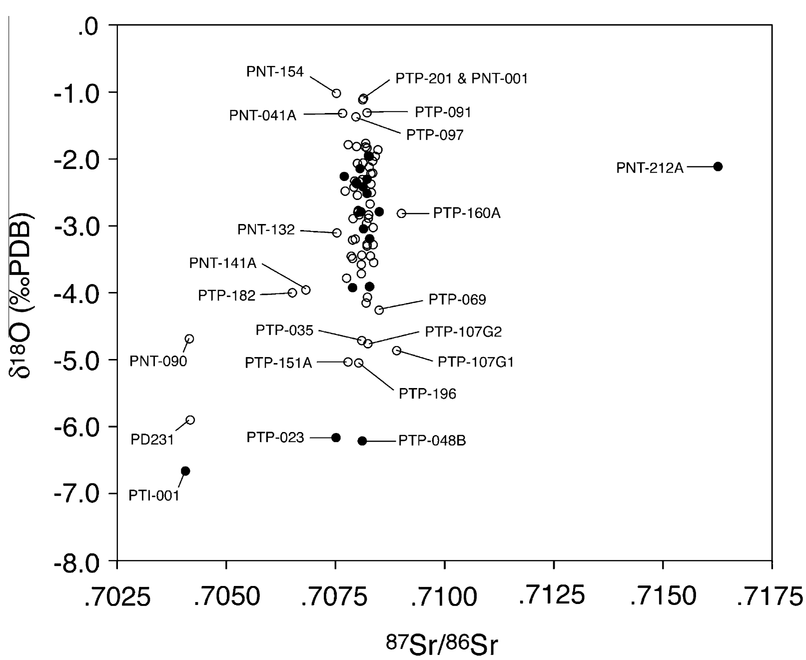

Fig. 6. Strontium and oxygen isotope ratios in Tikal tooth enamel. Oxygen isotope data is shown for canines preferentially if available (open circles); molar oxygen isotope ratios are shown for those teeth not sampled with canines (filled circles). Non-local individuals are identified to burial.

For data points at the high end of the $\delta^{18}O$ range, the evaporatively enriched Petén lakes should be considered as possible homelands. Petén lake waters range from 2.4 to 5.2‰$_{SMOW}$, corresponding to apatite of +1.6–3.5‰$_{PDB}$. Combined with intake of some rainwater, imbibing this water would raise apatite values to the near zero and positive values seen in some individuals at Topoxte (Wright et al., 2000). In theory, high $\delta^{18}O$ might be seen in coastal areas of Belize, where the first precipitation that falls onto land from Caribbean air is most enriched in ^{18}O. Stream water from southern Belize may be as enriched as −2.4‰$_{SMOW}$ (Lachniet and Patterson, 2009), giving an apatite value of −1.4‰$_{PDB}$, however, premolar enamel from Uxbenka averages −3.3‰$_{PDB}$, comparable to the Tikal means (Trask and Wright, 2011). Below, I discuss individual burials of probable migrants by time period, and consider the interpretation of possible homelands as well as archaeological implications of their migrant status. Key burials with local signatures are also discussed as they pertain to archaeological hypotheses about long distance interaction, especially in the Early Classic period.

Preclassic period (800 BC–AD 250)

Relatively few Preclassic burials were analyzed for either isotope, nine in all. Only PNT-001 may be non-local. It has a high $\delta^{18}O$ value for both teeth sampled, which might suggest that the individual hailed from the central Petén lakes region. Although I did not exclude it from the local sample in the above discussion, it is the highest canine $\delta^{18}O$ retained (−1.1‰$_{PDB}$). The third molar, measured at M^c^Master is higher still (−.1‰$_{PDB}$). This Chuen phase (350BC–AD1) primary burial was recovered from below the axial stairway of an early version of Str. 5C-54, the central temple of the Mundo Perdido astronomical complex (E group) (Fialko and Laporte, 1986). Two other Preclassic burials from the same structure show lower canine $\delta^{18}O$ and were probably local children (PNT-003, 004). However, the high molar $\delta^{18}O$ (−1.0‰$_{PDB}$) for PNT-003 does raise the possibility that this individual also spent his adolescence elsewhere.

Local values are also shown in two high status skeletons from the North Acropolis. First is the important Cimi phase tomb, PTP-125, from structure 5D-22 (Coe, 1990b). Although Coe reports just two skeletons, the remains curated from this tomb include at least three robust individuals. Two show slight wear on the teeth, suggesting a youthful adult age. The sampled right maxillary canine is from an individual with central incisors filed to Romero Molina's (1986) type C5, presumably the articulated primary skeleton. Despite its location deep in the center of the North Acropolis, the remains were not accompanied by any artifacts, though it is generally accepted to be that of an early ruler (Harrison, 1999). Similarly, the Chuen phase Burial PTP-164, in the supporting Platform 5D-4 that underlies the North Acropolis, shows local values for both isotopes.

Early Classic period (AD 250–550)

Early Classic deposits show both the largest proportion of migrants, and the greatest diversity of source areas. Moreover, many of the Early Classic migrants are from elite or royal contexts. In addition to those skeletons that do appear to be migrants, equally important are those who do not, since several key royal burials show local signals. Table 4 summarizes the results of strontium and oxygen isotope ratios for these elite individuals.

Interest in an Early Classic foreign presence at Tikal arises from the epigraphic evidence suggesting the installation of a foreign born king in AD 379. Yax Nuun Ahiin I is described as the son of a Spearthrower Owl, perhaps a ruler at Teotihuacan in Central Mexico, who was sent to Tikal, in the care of an emissary named Sihyaj K'ahk'. Although he may have been a member of Tikal's local dynasty through maternal connections, Yax Nuun Ahiin is interpreted as a foreign child (Martin and Grube, 2008; Stuart, 2000). Burial PTP-010 is the undisputed tomb of this individual (Coe, 1990b; Coggins, 1975; Martin and Grube, 2008). Although the tomb had collapsed, and some remains in it were intermingled, the only canine recovered from this tomb that could belong to the central adult skeleton shows a local $^{87}Sr/^{86}Sr$, .70832 (Wright, 2005b). The subadult and young adult skeletons that accompanied the ruler also have local $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values (Table 1). Although some might be tempted to discount this outcome as due to diagenetic contamination, it is not possible

Table 4
Migrant or local status of key elite burials from Tikal.

Burial	Skeleton	Phase	$^{87}Sr/^{86}Sr$	Canine $\delta^{18}O$	M3 $\delta^{18}O$	Possible attributions	Reign	Dates (AD)	Source
PTP-125	A?	Cimi	Local	Local		**?**			Coe (1990b)
PTP-022	B?	Manik		Local		Sihyaj K'ahk'			Freidel pers. comm. 2010
PNT-019	A	Manik	Local		Local	Chak Tok Ich'aak I/Great Jaguar Paw	14th	360–378	Laporte and Fialko (1995)
PTP-010	A	Manik	Local	Local		**Yax Nuun? Ahiin I**[a]/Curl Nose	15th	379–404?	Martin and Grube (2008)
PTP-048C	C	Manik	Local			**Sihyaj Chan K'awiil II**/Stormy Sky	16th	411–456	Martin and Grube (2008)
PNT-212A	A	Manik	Maya Mountains		local	K'an Chitam/Kan Boar	17th	458–486?	Laporte (2001)
						Chak Tok Ich'aak II/Jaguar Paw Skull	18th	486–508	Possibility raised in this study
PTP-PD231		Manik	Volcanic	Highland		Sihyaj K'ahk'			Possibility raised in this study
PTP-177		Manik	Local	Local	Local	?			Coggins (1975)
PTP-162		Manik	Quaternary?		Local	Ix-Kalomte' Ix-Yo-K'in?/Lady of Tikal		511–527	Haviland (1997a, p. 3)
PTP-160		Manik	Quaternary?	Local		Kaloomte' Bahlam	19th	c. 511–527	Haviland (1997a, p. 3)
PTV-002		Ik	Local		Local	Unknown		600 ± 50	
PTP-023		Ik	Cretaceous		Highland	K'inich Muwaan Jol II ?	23rd		Haviland (2003)
						Nuun Ujol Chaak/Shield Skull	25th	>657–679>	Martin and Grube (2008)
PTP-196		Imix	Local	Highland		**Yik'in Chan K'awiil**/Ruler B	27th	734–746>	Martin and Grube (2008)
PTP-077		Imix	Local	Local		?			

[a] Attributions in bold are supported by epigraphic data associated with the grave.

that a postmortem process could have transformed a central Mexican strontium isotope ratio to exactly match a Tikal signal. This would require the addition of a much larger quantity of strontium to the tooth than it initially contained. If dramatic diagenesis had occurred, an intermediate value would be expected. If Yax Nuun Ahiin's claim to Tikal's throne rested in part on his maternal heritage, it is likely that he spent his childhood years at his mother's family home. Thus, the AD 378 intervention brought about a change in the dynastic line, installing a local child, who was legitimized both by his maternal ancestry and his foreign paternal connections. The local result does not necessarily contradict the parentage indicated in the inscriptions.

The grave accepted to be that of Yax Nuun Ahiin's son, Sihyaj Chan K'awiil II, is Burial PTP-048, a hieroglyphic-painted tomb over which the central temple, Structure 5D-33, of the North Acropolis was raised (Coe, 1990a; Coggins, 1975; Martin and Grube, 2008). The ruler, Skeleton A, appears to have been buried without his head. Shook and Kidder (1961) speculated that he was captured in battle and beheaded, but that only his body was returned to Tikal for burial. Thus, samples could only be collected from the two subadults who accompanied Sihyaj Chan K'awiil in the grave. Both are adolescents, evidenced by their incomplete dental development. Skeleton B is aged 15 ± 3 years, while Skeleton C is aged 11 years ± 30 months by dental development (Ubelaker, 1989). Both show local $^{87}Sr/^{86}Sr$ values. The $\delta^{18}O$ for PTP-048C is also local, but the third molar values for PTP-048C are very low ($-6.2‰_{PDB}$), and excluded from the local range, suggesting a highland water source, perhaps an origin in Alta Verapaz.

PNT-212 was an important tomb found in structure 3D-43, in the North Zone of Tikal, that contained the skeleton of a ±15 year old female and a ±42 year old male, both aged by transition analysis using the pubic symphysis (Boldsen et al., 2002). The male skeleton, PNT-212A, shows a very high $^{87}Sr/^{86}Sr$ value of .71626, that could only correspond to an origin in the metamorphic Maya Mountains of Belize. Hodell et al. (2004) report stream water values in this range surrounding the Mountain Pine Ridge, and *Odocoileus* from Tipu average .7140 (Thornton, 2011). To date, the known only sites with human values in this range are from sites near the Chalillo dam over the Macal river, and average .7142 (Freiwald, 2011, p. 348). Although it is not far from the Chalillo sites, Caracol is not a possible origin for this skeleton, as human $^{87}Sr/^{86}Sr$ values are much lower there (.7078) (Freiwald, 2011). PTP-212A's M3 $\delta^{18}O$ value ($-2.1‰_{PDB}$) is consistent with a lowland Maya origin. The female skeleton, PNT-212B, who accompanied this elite male in his grave had a local Tikal signal for both isotopes.

Although the excavation of the PNT-212 tomb was poorly recorded, Laporte (2001) dated it to just before 500 AD on ceramic grounds, thus, it would correspond to the reign of the 17th or 18th ruler. The famous sculptural bust, known as "Ximba" or "Hombre de Tikal," was found in this tomb, which contained abundant jade and shell jewelry and mosaic pieces, jade ear flares, three hematite mirrors, and 21 ceramic vessels. The glyph-decorated sculpture depicts the Early Classic ruler Chak Tok Ich'aak I, however, a secondary text was added to the back of the sculpture during the time of Yaax Nuun Ahiin I (Fahsen, 1988), approximately 70 years before it was deposited in the tomb. The burial is clearly of very high status, and should perhaps be considered a dynastic candidate, although it lacked the *Spondylus* valves typically found in royal tombs at Tikal (Laporte, 2001). Yet, the 17th ruler, K'an Chitam (AD 458–486?), was the son of Sihyaj Chan K'awiil II, and the 18th, Chak Tok Ich'aak II (AD 486?-508), was his grandson; both firmly within the local dynasty (Martin, 2003). Although burial with a monument commemorating an earlier namesake might be logical for Chak Tok Ich'aak II, other monuments from his reign demonstrate that Chak Tok Ich'aak II's maternal grandfather was from the site of Naranjo (Martin and Grube, 2008), where isotopic baselines should be quite similar to Tikal.

The early 6th century was marked by political transition and turmoil at Tikal; many monuments from this time were intentionally defaced, hindering reconstruction of the dynastic sequence. Group 7F-1 is an elite group located near the Temple of Inscriptions; its occupants have been interpreted as members of a royal lineage that briefly held and then was ousted from power during this period, which has been referred to as the "troubled Middle Classic" (Martin and Grube, 2008), the hiatus (Moholy-Nagy, 2003a), or "Complex Times" (Martin, 2003). The most elaborate burial from this group, PTP-160, was placed in a painted bedrock chamber beneath the largest structure, Str. 7F-30, and resembles royal graves from the city center. The defaced Stelae 23 and 25 were set in front of 7F-30, having been moved from an earlier central location (Coe and Broman, 1958). Haviland (1981, 1997b) identifies Burial PTP-160A as that of Tikal's 19th ruler, Kaloomte' B'alam. This noble was associated with a "Lady of Tikal" whose birth is described on Stela 23, and was perhaps his spouse, who carried the line of succession (Martin, 2003; Martin and Grube, 2008).

The canine from PTP-160A's skeleton shows a non-local $^{87}Sr/^{86}Sr$ value, .70901, that is consistent with either the Miocene/Pliocene and Quaternary deposits of the modern state of Yucatan, the Gulf coastal lowlands, or with Belize or Macal River valley sites, such as Cahal Pech and Baking Pot (Freiwald, 2011). This result accords well with the suggestion that Kaloomte' B'alam would have been an outsider to the city, who came to power by marriage into the royal family (see also Coggins, 1975; Harrison, 1999). The "local" canine $\delta^{18}O$ value of PTP-160A ($-2.8‰_{PDB}$) does not contradict an origin in these lowland Maya areas. Two children accompanied PTP-160A in the grave, aged 7 years ± 24 months and 11 years ± 36 months. Only the younger was sampled, PTP-160B, and shows a local signature for both isotopes.

Also from Group 7F-1, I sampled Burial PTP-162, which was placed in a repurposed chultun covered by a low platform added to Structure 7F-30. Haviland (1997b) interprets the female skeleton as the spouse of the man in Burial PTP-160. At .7085, the strontium isotope result for this skeleton is at the upper margin of the local Tikal range, and may be consistent with a local Tikal origin (and the consumption of marine Sr), though it would also be consistent with results obtained at sites further east in the upper Belize River valley, such as Xunantunich (Freiwald, 2011), or the Northern Yucatan (Price et al., 2008). The $\delta^{18}O$ of the molar ($-2.8‰_{PDB}$) is also consistent with a local Petén childhood. The possibly foreign $^{87}Sr/^{86}Sr$ raises some doubt either about the attribution of PTP-162 or the spousal relationship of the burials, since a lower central Petén $^{87}Sr/^{86}Sr$ might be expected for the presumably local "Lady of Tikal." Of course, Kaloomte' B'alam could have had multiple wives (Houston and Stuart, 2001).

Another important elite burial from this time period is PTP-177, placed beneath the axial stairway of Str. 5D-71, a Central Acropolis range structure that forms the south side of the Main Plaza (Coggins, 1975; Culbert, 1993). This young adult, probable male shows local values for all isotopic measures.

Also from elite contexts, two Early Classic skeletons have $^{87}Sr/^{86}Sr$ consistent with Copan and the eastern Paleozoic province (~.7065). Both are adult females. Burial PTP-182 was placed below the stairway of the Central Acropolis palace of the Early Classic ruler Chak Tok Ich'aak, Str. 5D-46. It was accompanied by a Fama Buff bowl (Culbert, 1993: Fig. 38d). The second, Burial PNT-141A, is from group 6C-XVI (Str. Sub 50), a group with considerable iconographic and artifactual links to Teotihuacan (Laporte, 1989). PNT-141 was a very well furnished grave, with some 14 ceramic vessels, and a large quantity of jade and shell jewelry (Laporte et al., 1992). The two skeletons have equivalent average canine

$\delta^{18}O$, −4.0‰$_{PDB}$, and closely match the expected value for domestic skeletons at Copan (Price et al., 2010), corroborating the $^{87}Sr/^{86}Sr$ provenance measured on the P^3. However, the third molar $\delta^{18}O$ for PTP-182 is considerably lower, −5.5‰$_{PDB}$. The individual sample $\delta^{18}O$ measurements for this tooth are −6.2 (cuspal), −6.8, and −3.6‰$_{PDB}$ (cervical). This dramatic shift suggests an early adolescence residence in a highland environment, perhaps enroute to arrival at Tikal by mid adolescence.

Several non-elite skeletons from the Early Classic period are those of migrants. Burial PNT-132, of indeterminate sex, from a small domestic group in the southwestern part of the city (Str. 7B-18) (Laporte et al., 1992), shows a $^{87}Sr/^{86}Sr$ value of .7075 and has $\delta^{18}O$ values of −3.1 and −4.1‰$_{PDB}$ that are consistent with that expected for river water from the Pasión or Subín rivers. However, many other parts of the lowlands would have comparable $\delta^{18}O$, thus caution is due in identifying a homeland from this data alone. The grave is from the eastern structure (7B-18) of the group, and is both the earliest and most well furnished grave from the group, indicating that it may be that of the group's founder.

Another non-elite skeleton who may be an immigrant is Burial PTP-035, also an adult of indeterminate sex. This burial was placed in a chamber excavated beneath an eastern shrine building in Group 4F-1, a low status domestic group near the Tikal Reservoir. It is the most elaborately-furnished of graves associated with the structure (Haviland, 1985), and like PNT-132, could plausibly be the grave of the group's founder. Despite a local $^{87}Sr/^{86}Sr$ value, .70824, the canine $\delta^{18}O$ is low (−4.8‰$_{PDB}$), suggesting intake of water from a highland origin, perhaps in modern Alta Verapaz.

Human remains were also recovered in contexts at Tikal that were designated as "problematic deposits" (PDs), either because they were found in unusual locations, or because they contain non-articulated jumbles of remains and artifacts. Moholy-Nagy (1999) refers to problematic deposits containing substantial quantity of human bone and artifacts as "Burial-like Problematic Deposits (BPDs)," and suggests that some may be burials encountered during architectural remodeling that were moved and reburied, while others represent some kind of patterned desecratory behavior. The boundary between PDs and burials is somewhat arbitrary (Becker, 1987). A number of PTP deposits were first identified as burials and later reassigned to PDs. Iglesias Ponce de León (2003) notes that the artifacts found in Early Classic PDs are comparable to those in funerary assemblages from that time. Many PDs are deposits in chultuns, although a few chultun deposits were also designated as burials. I sampled a small number of such contexts, primarily for strontium isotope measurement.

One interesting case is PTP-PD231. This Early Classic skeleton is from a deposit in Chultun 6C-11, located to the northeast of the Perdido Reservoir, near Group 6C-5. It may be a redeposited royal tomb (Becker, 1987, p. 52), as it was accompanied by a quantity of ceramic vessels as well as a large number of shell ornaments, ground stone, chert and obsidian bifaces. Some of the obsidian bifaces are from the central Mexican Otumba source (Moholy-Nagy, 2003b; Moholy-Nagy and Coe, 2008). Culbert (1993: Fig. 153) speculates that one of the vessels may have been imported; comparable vessels were found in tombs at Uaxactun and Kaminaljuyu. A canine sampled from PTP-PD231 is one of just two individuals in this study found to have $^{87}Sr/^{86}Sr$ values derived from volcanic soils, .70417. The $\delta^{18}O$ value is an outlier at the low end of the scale, −5.9‰$_{PDB}$, also indicating a highland environment, but lies at the interface between the ranges reported for Kaminaljuyu and Teotihuacan. Both ratios are also consistent with the only data available from Tak'alik Ab'aj (Wright, unpublished data). This is a canine sample, presumably enriched by nursing. Individual samples show a decline of .6‰ from cusp to cervix in this tooth, reflecting gradual weaning from breast milk, with the cervical data below −6‰$_{PDB}$. Since local values for third molars at Kaminaljuyu are all above −6‰ (Wright et al., 2010), this may well be a central Mexican skeleton. Given the chronology, artifacts, and redeposited nature of the context, it is tempting to speculate that this may be one of the Teotihuacano participants of the AD 378 *entrada*, perhaps Sihyaj K'ahk', himself.

Strontium isotope ratios were also measured for three other Early Classic problematic deposits. Two skeletons from PTP-PD111 were sampled, both showing local strontium values. This deposit was recovered from Chultun 5C-1, located in the Tozzer Causeway, some 100 m from the base of Temple IV, Str. 5C-4. It contained an odd assortment of artifacts, including an obsidian ear flare, chert scrapers, hammerstone, and one worked human bone (Moholy-Nagy, 2003b). Ceramics in this deposit appear to have been local in origin (Culbert, 1993; Iglesias Ponce de León, 2003). A similar late Manik deposit, PTP-PD274, contained alabaster ear flares, shell pendants, chert bifaces, ground stone artifacts, bone rasps, and polished-end (probably human) long bone shafts (Moholy-Nagy, 2003b). It came from quadrant 7C of the Carr and Hazard (1961) map, but was not associated with a mapped structure. A strontium isotope ratio measured on a canine from this deposit shows a local Tikal signature. Similarly, local $^{87}Sr/^{86}Sr$ values were obtained for three individuals whose decapitated heads were interred below outflaring-side cache vessels in PTP-PD170 (Culbert, 1993), a deposit placed below the stairway of the Temple of the Inscriptions, Structure 6F-27.

In the small residential group 4H-1, a chultun beneath Structure 4H-4 contained the remains of at least 14 individuals together with Early Classic ceramics, designated as Burial PTP-107 (Becker, 1999). Among them, one individual (PTP-107G1) has canine enamel with a nonlocal $^{87}Sr/^{86}Sr$ of .70890, similar to Burial PTP-160A. Both its canine (−4.9‰$_{PDB}$) and third molar $\delta^{18}O$ (also −4.9‰$_{PDB}$) are near the lower extreme of the Tikal distribution, and suggest a different point of origin than PTP-160A. However, three other crania in this deposit show local strontium values (PTP-107G2, PTP-107E, PTP-107A). Average canine $\delta^{18}O$ for PTP-107G2 (−4.7‰$_{PDB}$) is close to that for G1, and may imply a nonlocal origin, but from a different source with $^{87}Sr/^{86}Sr$ equivalent to Tikal. Several individual burials were sampled from this group, (PTP-091, 097, 103, 101, and 109), most of which are from the Late Classic occupation. Excluding the clearly non-local PTP-107G1, the remaining three PTP-107 individuals average slightly higher in $^{87}Sr/^{86}Sr$ than non-chultun burials from the group, although the sample size is small. In addition, the $\delta^{18}O$ average is much higher for the non-chultun burials than for the individuals in Burial PTP-107 (by 1‰ for canines, 2‰ for third molars), suggesting that they imbibed water from a different source. Although climate change may explain part of the discrepancy, it is greater than the average difference between Early and Late Classic $\delta^{18}O$ in the complete Tikal dataset. Thus it is likely that several of the PTP-107 burials were not local Tikal children.

Burial PNT-022 has characteristics similar to PDs in that it contained the remains of numerous non-articulated individuals, including adults of both sexes and children, interred together below a low platform on the east plaza of Mundo Perdido, in front of Str. 5D-86. Due to the poor preservation of the remains it is unclear if this was a primary or secondary deposit, although it has been interpreted as a sacrificial context, dating to the early part of the Manik phase (Laporte and Fialko, 1995). Three individuals sampled from this deposit —a mid adult male, an adolescent of unknown sex, and an 8-year-old child—all show local Tikal values for both isotopes.

Late Classic period (AD 550–850)

Several key Late Classic burials were sampled for isotope analyses. The recently excavated PTV-002 was recovered from a small bedrock chamber at the heart of Temple V (Str. 5D-5), and is dated to approximately AD 600 (Gómez, 1999). The skeleton was not articulated, but was tightly bundled, and missing small bones of the hands and feet, indicating a secondary burial. The young adult (18–22 years) male was quite tall, 162 ± 3 cm, and showed elaborate dental decoration as well as marked tabular oblique cranial deformation. Both strontium and oxygen stable isotopes identify this individual as a local Tikal child (.70822, $-2.5‰_{PDB}$). The skeleton was accompanied only by a bowl and an incense burner and thus falls short of that expected for a ruler. However, the grave's clearly planned location below the axis of the temple room implies that its occupant was an important personage, for whom the funerary temple was planned and constructed in a single event. A second burial, PTV-001, containing the articulated skeleton of an adolescent, probable female, was recovered at the base of the temple stairs (Gómez, 1998), and shows comparable local strontium and oxygen isotope ratios. Given the youth of PTV-002 and his secondary interment, it is worth considering that the individual might have been an otherwise poorly documented and short-lived ruler who died at some distance from Tikal, whose remains were repatriated to the city for burial. For instance, little is known of the father of Animal Skull, the first Late Classic ruler during whose reign Temple V was probably constructed. Unfortunately, I could not sample several key Late Classic elite remains, among them, Animal Skull's grave, thought to be PTP-195.

Burial PTP-023 was a royal tomb intruded into Structure 5D-33 immediately to the south of PTP-048 some two centuries later, around AD 650. While it was once identified as the tomb of the 25th Ruler Nuun Ujol Chaak (Coe, 1990c; Jones, 1991), Haviland now interprets the grave as that of the unnamed 23rd ruler (Haviland, 2003), though there is no direct epigraphic information to identify the individual (Martin, pers. comm. 2010). The epigraphically known K'inich Muwaan Jol II may have been either the 23rd or 24th ruler, and was the father of both Tikal's 25th ruler and Bahlaj Chan K'awiil, the first documented ruler of Dos Pilas (Martin, 2003; Martin and Grube, 2008). Given both chronological and epigraphic uncertainties, the same are also candidates for PTV-002.

PTP-023 is one of the three skeletons with $^{87}Sr/^{86}Sr$ of .7075 excluded from the local range, that correspond to a Cretaceous geological context, and it has a very low M3 $\delta^{18}O$ value, $-6.2‰_{PDB}$. Coggins (1975, pp. 372–380) and Coe (1990b, pp. 539–540) speculate that the person in PTP-023 may have been a foreigner to Tikal because of the inclusion of three large plates decorated with Ahau glyphs, which Coggins compares to altars at Caracol. However, Culbert (1993: Fig. 39) cites a similar plate found at Altar de Sacrificios. For Caracol, Freiwald (2011, p. 343) defines a local $^{87}Sr/^{86}Sr$ average of .70776 ± .00012, based on a small sample of human and faunal remains, which is not inconsistent with the value for PTP-023 (.70751). A better match is with Ceibal and Aguateca (Krueger, 1985; Wright and Bachand, 2009), however, $^{87}Sr/^{86}Sr$ has not been measured at Altar, which we might expect to differ from nearby sites like Ceibal and Aguateca due to the sandstone substrate at Altar (Wright, 2006). Yet waters from the Pasión and Subín Rivers should correspond to apatite values of just $-2.5‰_{PDB}$ and human bone apatite from Dos Pilas and the Petexbatun sites averages $-3.5‰_{PDB}$ (Wright and Schwarcz, 1996, Wright, unpublished data). The extremely low mean $\delta^{18}O$ value ($-6.2‰_{PDB}$) for PTP-023 suggests water from a highland origin, thus a site further south in Alta Verapaz is a more likely origin. Faunal remains from Cancuen show $^{87}Sr/^{86}Sr$ consistent with this individual (Thornton, 2011), though Cancuen humans have not been studied for either isotope. Individual isotope measurements from this third molar show a marked rise in $\delta^{18}O$ from cusp to cervix (−6.6, −7.3, $-4.5‰_{PDB}$), suggesting a shift in water sources in early adolescence, perhaps the age of migration. If so, some change in $^{87}Sr/^{86}Sr$ after migration would also be expected, raising the possibility of a lower natal $^{87}Sr/^{86}Sr$.

A single Late Classic skeleton shows a "volcanic" $^{87}Sr/^{86}Sr$ signature, .70415: PNT-090 was recovered from a patio grave adjacent to Str. 7B-11, the eastern shrine in a small domestic group located at the southwestern margin of the map (Carr and Hazard, 1961). The canine $\delta^{18}O$ of this individual, $-4.7‰_{PDB}$, matches the local range from Kaminaljuyu (Wright et al., 2010), and suggests that an origin in highland Guatemala is more likely than in central Mexico. Critically, it shows that non-elite long distance migration occurred during the Late Classic period.

Burial PNT-154, from the Late Classic Group 6C-XVI shows a strontium isotope value of .70752, suggesting an origin on Cretaceous limestone soils. The $\delta^{18}O$ value is quite enriched, $-1.0‰_{PDB}$, and matches human enamel from Topoxte (Wright et al., 2000). It is possible that this individual is a migrant from the central Petén lakes, however, the inadequacy of $\delta^{18}O$ mapping in the Maya area requires caution in identifying a homeland.

Five skeletons in the tails of the $\delta^{18}O$ distribution should be considered as possible immigrants, and were excluded from the local sample. The skeleton with the second lowest canine $\delta^{18}O$ (only PTP-PD231 is lower) is PTP-196, $-5.0‰_{PDB}$, which shows a local $^{87}Sr/^{86}Sr$ signal, .70803. This grave is generally considered to be the Late Classic, 27th ruler, Yik'in Chan K'awiil, but it could also contain his less industrious son, the 28th ruler (Martin and Grube, 2008, p. 50). As with Early Classic PTP-023, the only way to reconcile these values is to search for a site located on limestone, but with highland-sourced water, such as in the far southern Petén or Alta Verapaz. However, there is little epigraphic reason to suspect that either of the contenders for this burial were not local children, since they are firmly in the dynastic line. It is possible that the child was raised at the home of his mother, who perhaps came from a distant site.

Burial PTP-151A from Structure 6E-1 also shows low $\delta^{18}O$ ratios comparable to PTP-196 (−5.0, $-5.6‰_{PDB}$), and a local $^{87}Sr/^{86}Sr$ (.70779), so may have hailed from the same area. This skeleton was interred in a triple burial in a small platform, with no ceramic offerings. It was probably a young adult male, and shows dental filing. Other individuals from the grave were not available for study.

At the upper end of the $\delta^{18}O$ distribution, two Late Classic burials (PTP-091 and 097) from the small *bajo*-margin Group 4H-1 lie close to the local cut off, with canine mean $\delta^{18}O$ respectively, −1.3 and $-1.4‰_{PDB}$. Values are quite variable among burials in this group, so migration from a nearby site is not impossible (see earlier discussion of PTP-107). By contrast, another bajo margin burial, PTP-069 from Group 3F-26, a probable male, shows the lowest of the canine $\delta^{18}O$ ratios that was not excluded from the local range,

Fig. 7. Burial PTI-001, a probable Postclassic migrant excavated by the IDAEH-AECI Temple I project (Muñoz Cosme, 2006).

$-4.3‰_{PDB}$. Its strontium isotope ratio is at the upper limit of the local range, .70850; together these marginal values raise the possibility that this too is a migrant. However, variability among household water sources should also be kept in mind, and is difficult to test with small sample sizes. A well-furnished burial, PNT-009, was placed on the axis of the *talud-tablero* temple 5C-49; the adolescent skeleton shows a local average canine $\delta^{18}O$, $-2.1‰_{PDB}$, but an enriched bulk third molar $\delta^{18}O$ $-1.0‰_{PDB}$, consistent with an adolescence spent near the Petén lakes, comparable to the Preclassic burials from nearby Str. 5C-54. By contrast, Burial PNT-006, a looted burial also from 5C-49 shows a local $\delta^{18}O$ value in the third molar, $-2.8‰_{PDB}$.

Terminal Classic (AD 850–950) and Postclassic periods (AD 950–1200)

Burial PTI-001 (Fig. 7) was excavated by the IDAEH/Cooperación Espanola Temple I restoration project in 1996, in the collapsed rubble between Structures 5D-1, 5D-29 and 5D-38. The burial dates to the Terminal Classic or Postclassic period, after the collapse and abandonment of the city center. The $^{87}Sr/^{86}Sr$ value, .70406, of the young adult male skeleton is consistent with both central Mexico and highland Guatemala, while the very low third molar $\delta^{18}O$, $-6.7‰_{PDB}$, is a better match with central Mexico or the Pacific piedmont than the Guatemalan highlands. This skeleton demonstrates that Tikal continued to be a locus of long distance pilgrimage long after the dynasty had collapsed.

Oxygen isotopes shed light on two further possible migrants from the Terminal Classic sample. Burial PTP-201 was intruded into an earlier reused grave atop Structure 5D-22, the central temple at the top of the North Acropolis (Coe, 1990b). The building does not appear to have seen considerable repair or use after the interment. Accompanied by two Eznab phase vessels (Culbert, 1993: Fig. 98), the skeleton was that of an adolescent, of unknown sex. The canine enamel shows a high $\delta^{18}O$, $-1.1‰_{PDB}$, not excluded from the local sample, but of uncertain local provenance. Neither the strontium (.70812) nor the oxygen values would be out of place in the Petén Lakes region.

Burial PNT-041A also shows ^{18}O-enriched canine enamel, $-1.3‰_{PDB}$, though it is debatable whether or not this value is local. The strontium isotope ratio is the lowest value retained in the local sample, .70766. This Eznab phase burial was from Str. 5C-46, within a range structure group on the north side of the Mundo Perdido plaza. The skeleton is that of a young adult male. Values more typical of Tikal are shown in a second adult from the grave, PNT-041B.

Discussion

Both strontium and oxygen isotopes provide some measure of the immigration to and within the Maya area, confirming that a significant number of both Early and Late Classic burials at Tikal contain the remains of individuals born some distance from where they came to be buried. For both isotopes, however, there is considerable uniformity in values across the lowlands, which hinders detection of migration within this region. Hence, the "local" ranges identified here certainly overlap the ranges expected for key Maya polities of interest in study of migration within the Maya area. For instance, current data suggests that immigrants from Piedras Negras, Yaxchilan, Tulum, Colha, Palenque, Tonina, or Becan (Price et al., 2010) would not be readily identified amid data from Tikal. Since oxygen isotope patterns in drinking water is poorly characterized, it is perhaps feasible to distinguish only individuals who imbibed highland-sourced water, Pacific piedmont rainfall, or ^{18}O-enriched water from the Petén lakes from other lowland children with confidence. For $\delta^{18}O$, the effect of evaporative enrichment of reservoirs and the varied sources of drinking water exploited both within and among sites may have measureable implications for human $\delta^{18}O$ that demand further study. For both isotopes, very few published studies include large numbers of burials, and the burial samples analyzed differ in social and chronological composition, thus it is difficult to know if they adequately capture local variability. Additional study of large samples of skeletons from other lowland sites may improve mapping of both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ in the future, and permit more detailed resolution of the homelands of those individuals reported here.

Despite these limitations, the data shed light on changing patterns of migration between Early and Late Classic periods. Given the non-random sampling strategy, caution is appropriate when interpreting the estimated number of migrants. Nonetheless, it is reasonable to conclude that the Early Classic period was a time of relatively greater immigration that presumably contributed to the rapid growth of the city in the 6th century AD. Early Classic migrants were perhaps more likely to hail from distant areas than those of the Late Classic period. Women appear to have migrated to Tikal with somewhat greater frequency during the Preclassic and Early Classic periods, perhaps as elite brides, whereas they are absent from the sexed Late Classic migrant sample. Only two possible central Mexican skeletons were identified: the Early Classic PTP-PD231 and the post-collapse PTI-001. Migration from other parts of the Maya area is evident, including the southeastern periphery, the Belize Valley, the Maya Mountains, highland Guatemala, and perhaps Alta Verapaz.

Despite the iconographic and epigraphic information suggesting that Teotihuacan directly manipulated Tikal's dynastic lineage, there are no confirmed Early Classic central Mexican migrants among the primary burials I sampled, including the probable remains of Yax Nuun Ahiin I, the purported Teotihuacano child ruler (Wright, 2005b). However, the remains interred in the Early Classic PTP-PD231 could well be central Mexican, and raise the possibility that this individual may have been a participant in the AD 378 *entrada*.

The isotope data both answer and raise questions about the identity of several key elite skeletons. The putative skeleton of the 19th ruler, Kaloomte' B'alam is shown to have been an immigrant to the city as might be expected, and the strontium isotopes give us reason to look toward the Belize valley or the Gulf coastal lowlands as his point of origin. However, the probable skeletons of several other rulers who are thought to have been secure members of the local dynasty appear to have spent their childhoods elsewhere, including the 23rd ruler (PTP-023) and perhaps Yik'in Chan K'awill (PTP-196). If the North Zone tomb PNT-212 proved to be that of Chak Tok Ich'aak II, he would be a third ruler in the Tikal dynastic line who spent his infancy elsewhere. Likewise, a local Petén origin for Yax Nuun Ahiin I does not necessarily contradict the glyphic evidence for his central Mexican paternity. It is worth considering the possibility that polygamous kings may have not moved all of their consorts to their home city, and that royal offspring were at times raised in the court of their maternal family. Both ethnographic and epigraphic records provide some evidence for court mobility and for palace schools among the Maya. Martin (2001) describes one case where the heir-apparent to a subordinate kingdom spent several years at Calakmul, perhaps as hostage or guest, prior to his father's death and his own accession (Houston, 2001; Martin, 2001). Similarly, palace schools are more likely to have enrolled older children, rather than infants. However, residential histories of female consorts and children are poorly documented in the epigraphic record (Houston, 2001) so it is worth entertaining scenarios of residential mobility both for consorts and children. Evidently both adult males and females born at other polities came to be buried at Tikal in what appear to be high ranking contexts, indicating that they retained and/or achieved high status after their arrival at Tikal. Although epigraphic evidence for the importance of elite marriage as a political mechanism linking distant cities might lead one to suspect that women were the commodities in this system (Molloy and Rathje, 1974) it is evident that elite males also lived and died far from their natal region.

Several elite Early Classic burials are multiple, and typically interpreted as high ranking males accompanied by youthful sacrificial victims, as in burials PTP-010, PTP-048, PTP-160, and PNT-212. With the possible exception of PTP-048B, who may be from the area of modern day Alta Verapaz, all of the juveniles in such Tikal burials were local children. This contrasts sharply the case at Kaminaljuyu, where the peripheral juveniles in the Mound A and B tombs include foreign children. Indeed the $\delta^{18}O$ of the nonlocal skeletons at Kaminaljuyu is consistent with the local range at Tikal, although the $^{87}Sr/^{86}Sr$ is not (Wright et al., 2010). Further scrutiny of comparative data (Hodell et al., 2004) raises the possibility that the Kaminaljuyu foreigners may have come from the Motagua River valley, perhaps near Quirigua. By contrast, individuals in problematic deposits at Tikal who died in adulthood are as likely to be non-local, as seen in PTP-107 and PTP-PD231.

That migration must have contributed to the meteoric growth of the Late Classic Tikal is not surprising, however, isotope data clearly shows that this migration occurred at both elite and lower social statuses, and that migrants arrived from quite distant and disparate parts of the lowlands. In the Early Classic period, the migrant females who arrived at Tikal may well have been elite brides, however, the Late Classic migrants appear to be predominantly males. These patterns confirm that migration was common in the Classic period at all levels of the social hierarchy, as suggested by Inomata (2004). However, the apparent absence of Late Classic female migrants raises the possibility that this migration occurred on a small scale, with small numbers of individuals moving, rather than through the relocation of entire families.

Additional stable isotopic research on migration in the Maya area will no doubt necessitate revision of the ideas proposed here, especially the identification of homelands based on the spotty mapping of both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ across Mesoamerica. Although key regions that are consistent with the ratios measured in Tikal skeletons are likely candidates for the origin of skeletons with outlying values, it is critical to remember that many sites show equivalent local ranges, that local ranges for most sites have not been statistically characterized, and many other sites have yet to be studied. Statistical analysis of the larger Tikal dataset permits a better understanding of the local range for both isotopes, but also tends to identify skeletons near the extremes of the distributions as local, when in fact they may not be, and a narrower range may be accurate. For instance, the use of either the mean and standard deviation or interquartile ratios (Freiwald, 2011), which would exclude the upper and lower 25th percent of the data sampled, would identify a larger proportion of migrants from these data. For strontium isotopes, consumption of sea salt or other imported foods may explain the broad range (Wright, 2005a), however, the presence of undetected migrants from the east or north may also be a factor. For $\delta^{18}O$ in particular, seasonal interannual, and intratooth variability in $\delta^{18}O$ make methods of isotopic sampling a further consideration that contributes uncertainty about local signatures. Ultimately, no single statistical approach is likely to be successful in all archaeological and geological contexts, and to some degree the issue of identifying local and migrant signals for either isotope is an interpretive problem, aided only by the largest possible volume of data. Further development of analytic methods for the study of migration would clearly be helpful, as additional scales of geographic variability would better allow us to pinpoint homelands.

Acknowledgments

This research was made possible by financial support from a variety of sources. The Ahau Foundation funded the strontium isotope measurements, while the Wenner Gren Foundation for Anthropological Research and Texas A&M's Office of the Vice President for Research funded oxygen stable isotope analyses. NSF (BCS-9870351) funded skeletal inventory and sample collection at Tikal and the University of Pennsylvania. Preliminary research on Tikal osteology and stable isotopes was funded by the Foundation for the Advancement of Mesoamerican Studies, Inc. I thank Ethan Grossman for assistance with the oxygen isotope work, and Doug Price, Jim Burton and Paul Fullagar for the strontium isotope laboratory work. This work also benefitted from NSF grants awarded to Doug Price and colleagues, SBR-0075231 and BCS-0413047. Thanks are also due to Chris Jones, Sharon Misdea, William Wierzbowski, and Jerry Sabloff at the University Museum of the University of Pennsylvania, the staff of the Museo Nacional de Antropología e Historia and the Parque Nacional Tikal for their kind assistance during my study of the collections. Permission to analyze the samples and study the collections was granted by the Instituto de Antropología e Historia de Guatemala. I thank Oswaldo Gómez, Rafael Chang and Gaspar Muñoz for access to the Cooperación Española remains, and for their company at Tikal. I thank Peter Harrison, William Haviland, Marshall Becker, Pat Culbert, Chris Jones, Hattula Moholy-Nagy, Juan Antonio Valdés and Juan Pedro Laporte for their assistance at various stages of the work. Mariana Valdizón, Nancy Monterroso, Mario Vásquez, Miguel Morales, Alejandro Gillote, Andy Scherer, Jennifer McCaskill, Cassady Yoder, Joel Braby, Maria Parks, and Kai Tao provided assistance in the lab and field.

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