San José 520: An Unusual Teotihuacan Settlement System

Michael W. Spence, Karyn Olsen, M. Oralia Cabrera Cortés, and Fred J. Longstaffe

San José 520 is a Classic period hamlet of single-family residences in the urban periphery of Teotihuacan, just beyond the southeast edge of the city. Three burial features were associated with one of the residences, AF2. One of the features contained the burial of a single adult, another the successive burials of eight adults and one neonate, and the third held a neonate. We analyzed 29 bone and enamel samples from the adults for bioapatite phosphate oxygen-isotope composition; we also considered isotopic data for another five bone samples analyzed in a separate project. The isotopic results suggest a pattern of birth in the Teotihuacan region and then movement in early childhood to a "relocation" region, the geographic location of which is unknown. Later, probably in adolescence, the individuals returned to live, and eventually die, in San José 520. Without knowing more about the occupation of the relocation region, it is difficult to say what concerns or beliefs underlay this unusual but long-established settlement system.

Keywords: Teotihuacan, oxygen isotopes, urban periphery, burials, Classic period, San José 520

San José 520 es un sitio del Periodo Clásico, con residencias de familias nucleares, ubicado en la periferia sureste inmediata a la antigua ciudad de Teotihuacan. Las excavaciones en este sitio encontraron tres enterramientos asociados a una de las residencias, denominada como AF2. Uno de estos enterramientos consistió en la deposición sucesiva de ocho individuos adultos y un neonato. En primera instancia analizamos veintinueve muestras de hueso y esmalte de los individuos adultos para determinar la composición de isótopos de oxígeno de fosfato de bioapatita. Otras cinco muestras de hueso, tomadas por otro proyecto posterior, también fueron incluidas. Los resultados isotópicos en su conjunto sugieren un patrón de nacimiento en la región de Teotihuacan, luego un traslado durante la primera infancia a una región de "reubicación", cuya ubicación geográfica se desconoce. Más tarde, probablemente en la adolescencia, los individuos regresaron a vivir, y finalmente morir, en San José 520. Sin tener más datos acerca de la región de reubicación, es difícil decir qué intereses o creencias subyacen en este sistema de asentamiento inusual pero de larga tradición.

Palabres clave: Teotihuacan, isótopos de oxígeno, periferia urbana, entierros, periodo Clásico, San José 520

Teotihuacan was by far the largest urban center of its time in the Western Hemisphere. Situated in a side valley of the Valley of Mexico, with a population of about 100,000 and covering some 20 km^2, it dominated central Mexico during the Classic period (200–600 AD) and had a strong influence on the rest of Mesoamerica (Cowgill 2015; Millon 1973, 1981; Smith et al. 2019). The size of the city and its rapid growth raise the question of how it gathered, and retained, such a large population. Archaeologists have come to realize that ancient urban centers did not usually have stable populations, either in terms of numbers or composition (Smith 2014; Storey 1992). Individuals and groups were frequently mobile, just as they are in modern settings. The analysis of stable isotopes, particularly strontium and oxygen, is now allowing us to verify and track some of that movement into (and out of) Teotihuacan (e.g., Price et al. 2000; White et al. 1998).

Not surprisingly, the developing picture is complex. For the most part it is based on the large multifamily apartment compounds that

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Latin American Antiquity 31(4), 2020, pp. 720–732

doi:10.1017/laq.2020.59

housed the majority of Teotihuacan's residents (Manzanilla 1993; Millon 1981; Séjourné 1966). However, this leaves a significant gap in our understanding: we lack information on the nature, extent, and demographic history of insubstantial architecture in the city. Robertson (2008) states that there are some 800 insubstantial sites in Teotihuacan, perhaps holding up to 15% of the city's population. To remedy this shortcoming, Cabrera Cortés in 2004 excavated the San José 520 site, a small occupation area near the city's edge that lacked the large apartment compounds that characterized most of Teotihuacan (Cabrera Cortés 2005, 2011). Our concern here is to learn what we can about the people who occupied San José 520, their origins, and their movements through time. To this end, we conducted stable isotope analyses of the recovered human skeletal materials.

San José 520

San José 520, about 1 ha in size, is located some 500 m beyond the southeast edge of the city (Figure 1). Among other features, the excavation uncovered the remnants of Architectural Feature 2 (AF2), a single-room structure about 2.5 m on a side. Probably the residence of a single family, AF2 had a meager stone foundation with upper walls of adobe or perishable materials. The associated ceramics and radiocarbon dating indicate its occupation through nearly three centuries, including the Early Tlamimilolpa (170–250 AD), Late Tlamimilolpa (250–350 AD), and Early Xolalpan (350–450 AD) phases. An alternative chronology would reduce this span to 220 years from 200 to 420 AD (Manzanilla et al. 2012:457). The lower proportion of Xolalpan ceramics associated with the structure suggests that its use might not have extended through the latter part of the Xolalpan period.

Three burial features are associated with AF2. Data on these features are presented in Cabrera Cortés (2011), Driscoll (2005), and Nado and Cruz (2006). Burial 1, located about 2 m south of AF2, is the single burial of an adult of about 30–35 years, individual A. Poor preservation prevents an assessment of sex and also makes it difficult to determine the mode of burial. Some skeletal elements appear articulated, but a number of elements were either absent or too deteriorated for recognition. A large number of ceramic vessels accompanied the burial and indicate a date in the Tlamimilolpa period (Cabrera Cortés 2011:236–238).

Burial 2 was in a 75 cm deep pit in the northwest part of the AF2 residence. The pit contained artifacts and the skeletal remains of a number of individuals, deposited in multiple interment episodes over the Early Tlamimilolpa–Early Xolalpan span (ca.170–450 AD). Skeletal analyses indicate that eight adults and one subadult were present (Cabrera Cortés 2011:238; Nado and Cruz 2006). Minimum number of elements (MNE) counts show seven adults, based on seven left humeri and seven left femora.

The repeated entries into the feature had resulted in the displacement and mixture of earlier burials, so that the bones of any particular individual may be scattered among two or three of the five definable clusters ("lots") in the feature. Many of the skeletal elements cannot be assigned to any particular individual. The final individual to be placed in Burial 2, an adult woman here designated individual F (lot 5), was still complete and fully articulated in a seated position. A ceramic vessel placed with her is of a style known from the Xolalpan period (Cabrera Cortés 2011:Figure 6.13; see Rattray 2001:219, 251).

The skeletal analyses by Driscoll (2005) and by Nado and Cruz (2006) allowed the partial reconstruction of five of the adults in Burial 2: individuals B–F (Table 1). However, some of the sampled teeth and bones cannot be assigned to a particular adult. In addition, with the exception of individual F, the adults cannot be organized in a sequence of deposition in the feature.

The ninth individual in Burial 2 is a subadult, represented only by a few scattered and fragmentary elements. The sizes of two complete elements, a tibia and a first metacarpal, indicate a neonate. Another neonate, Burial 3, had been placed in a bowl at the southeast edge of AF2. None of the subadult bones were sampled for isotope analysis.

Given the even sex balance among the adult burials (Table 1) and assuming the continuous occupation of AF2 by lineally related families

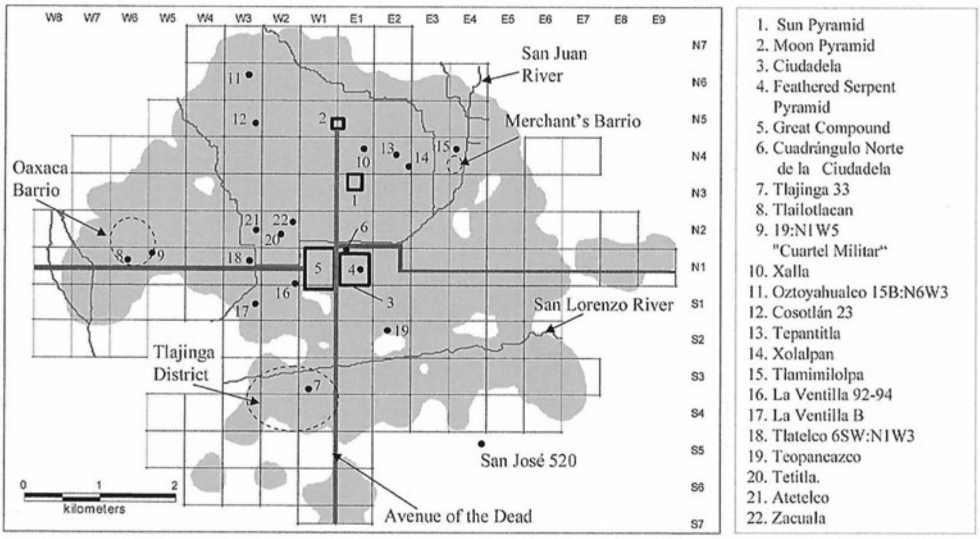

Figure 1. Map of Teotihuacan region (map by Ian Robertson).

Table 1. Adult Data.

Individual	Burial	Age (years)	Sex
A	1	30–35	unknown
B	2	20–24	female
C	2	55+	unknown
D	2	mid–30s	male
E	2	35–40	male
F	2	24–35	female

(as suggested by the repeated use of Burial 2), it seems likely that the adults buried there were the couples in residence over the two to three centuries of the structure's use. However, the life table constructed by Storey (1992:159, Table 6-1) for the Tlajinga 33 site suggests that the burials found at AF2 are not numerous enough to account for all those who would have lived and died there over the two to three centuries of occupation. Unfortunately, this sort of mortuary underrepresentation is a constant feature of Mesoamerican sites (Spence and White 2009:237). In particular, the number of subadults who died at birth or in their first year at AF2 should be considerably higher than the two neonates actually found there (Storey 1992:Table 6-1). Some older children would also be expected but, as becomes apparent later in the article, they probably lived, and sometimes died, elsewhere.

Materials and Methods

Twenty-nine bone and dental enamel samples, all from adults, were selected for analysis of bioapatite phosphate oxygen-isotope composition at the Laboratory for Stable Isotope Science at the University of Western Ontario. The enamel samples included the entire crown, thus providing a homogenized measure of the tooth's $\delta^{18}O_p$ over the 1.5–4.5 years of crown development. Four enamel and bone samples are from individual A of Burial 1, and 20 are from individuals B–F of Burial 2. The remaining five samples are also from Burial 2 but cannot be assigned to particular individuals. An additional five Burial 2 samples, all taken from adult ribs (one from each of the five lots), were analyzed in a separate project at Northern Arizona University (Nado 2017; Nado et al. 2017). These oxygen-isotope compositions were measured for bone structural carbonate, not phosphate, and the results were then converted to phosphate-equivalent oxygen-isotope compositions (Nado et al. 2017:122–123). With the exception of the sample from lot 5 (individual F), none of these rib samples can be associated with a particular Burial 2 individual. Given that all of the lots except lot 5 contained elements from more than one person, it is even possible that some rib samples may be duplicates from the same individual.

Phosphate oxygen was isolated from samples as silver phosphate (Ag_3PO_4) following Crowson and Showers (1991). About 30 mg of Ag_3PO_4 were then placed into nickel reaction vessels under dry nitrogen gas. Samples were then heated in vacuo for 2 hours at 300°C, followed by the addition of bromine pentafluoride (BrF_5) and reaction at 600°C for 18 hours, following Clayton and Mayeda (1963), Crowson and Showers (1991), Stuart-Williams and Schwarcz (1995), and Tudge (1960). The oxygen gas that was liberated was converted completely to CO_2 by reaction with red-hot carbon and was cryogenically transferred to evacuated gas tubes for analysis using a Micromass Optima dual-inlet stable-isotope-ratio mass spectrometer. Conventional δ-notation was used to report all oxygen-isotope results for the phosphate oxygen ($\delta^{18}O_p$) relative to Vienna Standard Mean Ocean Water (VSMOW). Reproducibility was normally better than ±0.2‰.

The $\delta^{18}O$ of most biomaterials, including bioapatite in bone and enamel, is derived from the oxygen-isotope composition of environmental (drinking) water (Longinelli 1984; Luz and Kolodny 1985). The $\delta^{18}O$ of water is influenced by both geography and climate, including variables such as distance from the sea, latitude, elevation, temperature, and humidity (Stuart-Williams et al. 1996; White et al. 2000). Combinations of these variables generally result in different $\delta^{18}O$ values for different bodies of water. As skeletal and dental mineral develop, the oxygen-isotope composition of the drinking water is incorporated, with some modification, through body water into the bioapatite of the bone and enamel (Longinelli 1984; Luz et al. 1984). Although a possible natural offset between enamel and bone oxygen-isotope compositions could potentially limit the usefulness of such data in tracing movement during an individual's lifetime, such effects have been shown elsewhere to be limited (Luz and Kolodny 1985:32; Webb et al. 2014;106; Wright and Schwarcz 1998:14–15). Webb and coauthors (2014:101), for example, report a median enamel-bone phosphate oxygen-isotope offset of −0.1‰ for a Maya sample suite (see the later discussion).

Bone remodels throughout life and therefore reflects the last 10 or so years of life. Enamel oxygen-isotope compositions reflect conditions only over the 1.5–4.5 years of formation of the crown. Because the crowns of different tooth categories develop at different times during an individual's early lifespan, the comparison of the $\delta^{18}O$ of different teeth in a single dental arcade can help track that individual's movements and changing conditions through time (e.g., White et al. 2000). However, this requires that we know the timing of crown development for each tooth category. For the San José 520 sample, we adapted the data of the London Atlas of Tooth Development and Eruption (AlQahtani et al. 2010). In particular, we used the median age columns presented by AlQahtani and colleagues in their Tables 3–8, defining crown formation as the period spanning the "cusp outline complete" (Coc) to "crown complete" (Crc) stages (Table 2). In the few cases where they do not provide ages for those stages, ages were extrapolated from those assigned to the preceding and subsequent stages.

An isotopic correction was applied to the earlier developing teeth to compensate for the trophic level increase associated with breastfeeding. Breastfeeding in Mesoamerican societies often continued into the third or fourth year of life (White, Spence, et al. 2004:393). Given the varying times of crown formation (Table 2), we decided to reduce the $\delta^{18}O_p$ of the maxillary central incisors (UI1), the mandibular central and lateral incisors (LI1, LI2), and the first molars (UM1, LM1) by 0.7‰ (White, Spence, et al. 2004:543, 545; White, Storey, et al. 2004:177–178; see also Britton et al. 2015:231; Wright and Schwarcz 1998:13). Because the maxillary lateral incisors (UI2) and the canines (UC, LC) develop somewhat later (Table 2), we reduced their $\delta^{18}O_p$ by only 0.35‰. The measured $\delta^{18}O_p$ of the later forming premolars, second molars, and third molars were left unchanged.

The samples were tested for diagenetic recrystallization using Fourier transform infrared spectroscopy (FTIR; see Webb et al. 2014 and references therein). The calculated crystallinity indices, with one exception, fit within the range expected for unaltered bone and enamel. The exception occurred for sample 28, but its value fell below, rather than above, the expected range for apatite-retaining original oxygen-

Table 2. Dental Development Ages.

Maxilla (U)		Mandible (L)	
Tooth Category	Crown Formation[a]	Tooth Category	Crown Formation[a]
Central incisors (UI1)[b]	0.6–4.5 yrs	Central incisors (LI1)[b]	0.6–3.5 yrs
Lateral incisors (UI2)[c]	1.5–5.5 yrs	Lateral incisors (LI2)[b]	1.0–4.0 yrs
Canines (UC)[c]	1.5–5.5 yrs	Canines (LC)[c]	1.5–5.5 yrs
1st premolars (UP1)	3.5–6.5 yrs	1st premolars (LP1)	3.0–6.5 yrs
2nd premolars (UP2)	5.0–6.5 yrs	2nd premolars (LP2)	4.5–6.5 yrs
1st molars (UM1)[b]	0.9–3.5 yrs	1st molars (LM1)[b]	0.6–3.0 yrs
2nd molars (UM2)	4.5–8.0 yrs	2nd molars (LM2)	4.5–8.0 yrs
3rd molars (LM3)	9.5–14.0 yrs	3rd molars (LM3)	11.5–14.0 yrs

Note: Adapted from AlQahtani et al. (2010:Tables 3–8, median columns).

[a] Cusp outline complete (Coc) to crown complete (Crc).

[b] 0.7‰ was subtracted from the measured $\delta^{18}O_p$ to compensate for breastfeeding.

[c] 0.35‰ was subtracted from the measured $\delta^{18}O_p$ to compensate for breastfeeding.

isotope signatures. The significance of a low value is unclear, so the sample was retained in the analysis.

Results

Distribution of Oxygen-Isotope Compositions

There are two distinct clusters of $\delta^{18}O_p$, one for bone from +14.2 to +14.7‰ ($n = 12$; mean and *s*: +14.4 ± 0.2‰) and one for enamel from +16.2 to +16.8‰ ($n = 13$; mean and *s*: +16.6 ± 0.2‰; Figure 2). Between these clusters there are a number of $\delta^{18}O_p$ whose affiliations are less clear. We believe that the two clusters identified here represent residence in two distinct geographic regions, given the 2.2‰ difference between their means (see Webb et al. 2014). The +14.2 to +14.7‰ cluster strongly suggests residence in the Teotihuacan region, which has a range of +14.0 to +16.0‰ (White, Storey, et al. 2004). A number of the $\delta^{18}O_p$ values from Tlajinga 33, a Teotihuacan apartment compound 2.4 km to the northwest of San José 520 (Figure 1), fall in the +14.2 to +14.7‰ range (White, Storey, et al. 2004:Table 1). The location of the region producing the cluster of oxygen-isotope data for the enamel is less clear. For want of a better term we refer to it as the "relocation region."

Some of the ambiguous oxygen-isotope compositions can be tied to one or another of the two regions by examining the other $\delta^{18}O_p$ values for those individuals. The +15.2‰ bone value, for example, is from a tibia of individual B (Table 3). Three other bones of individual B have $\delta^{18}O_p$ of +14.3 to +14.5‰, so the tibia composition may just represent part of the bone cluster's range of variation, and thus residence in the Teotihuacan region. However, the bone $\delta^{18}O_p$ of +13.3, +15.9, and +16.0‰ are from skeletal elements that cannot be assigned to a particular individual. As such, their geographic reference remains uncertain, although the +15.9‰ and +16.0‰ values are within (but at the high end of) the Teotihuacan range. These last two values are from two of the five ribs analyzed by Nado and colleagues (2017). The three other rib $\delta^{18}O_p$ values are all within the +14.2 to +14.7‰ Teotihuacan cluster (Table 3). Nado (2017:187–189, Appendix B) also reports strontium ($^{87}Sr/^{86}Sr$) values for the five ribs. They form a tight cluster, 0.7046–0.7047, within the Teotihuacan range for $^{87}Sr/^{86}Sr$.

The five ambiguous enamel $\delta^{18}O_p$ values can be approached in the same way. The +15.3‰ value represents the lower right second premolar (LRP2) of individual A from Burial 1 (Table 3; Figure 3). It and the +15.7‰ value from the earlier-developing lower first molar crown (LM1) contrast with the +16.5‰ value for the second molar crown. This pattern suggests that the two lower values of $\delta^{18}O_p$ represent residence in the Teotihuacan region, whereas the second molar developed after movement to the relocation region. The relocation may have occurred around the age of 5.0–5.5 years. There are two other $\delta^{18}O_p$ values of +15.7‰ for enamel, one for an upper lateral incisor of individual C and

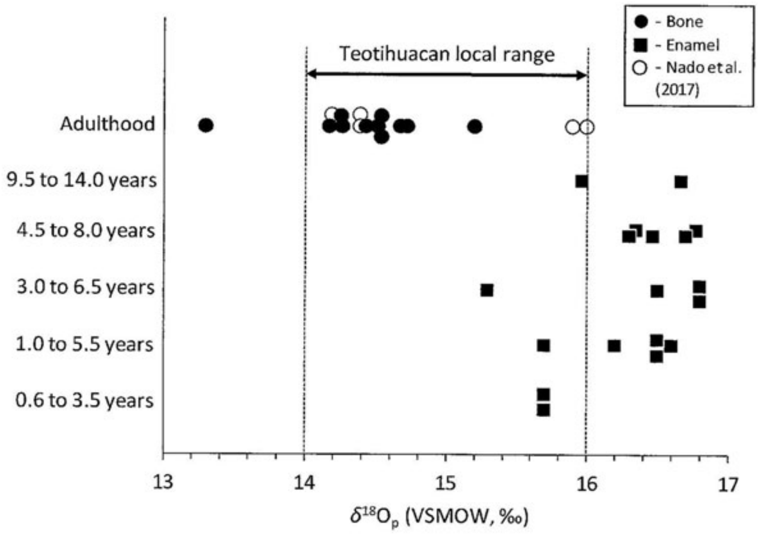

Figure 2. Oxygen-isotope compositions from San José 520 burials. Additional bone data compiled from Nado and colleagues (2017).

the other for a lower central incisor of individual E. In both individuals these $\delta^{18}O_p$ values contrast with the oxygen-isotope compositions of later developing teeth that are securely in the enamel cluster (Table 3).

These four enamel $\delta^{18}O_p$ of +15.3 to +15.7‰ have a mean of +15.6‰, which is within the Teotihuacan range (White, Spence, et al. 2004; White, Storey, et al. 2004) but 1.2‰ higher than the mean (+14.4‰) of the +14.2 to +14.7‰ Teotihuacan bone cluster. For contemporaneous tissue formation, Webb and coauthors (2014) found a mean bone-enamel offset in $\delta^{18}O_p$ of ±0.7‰ with a standard deviation of 0.5‰. However, there is considerable inconsistency in both the magnitude and direction of the offsets in their small sample, leaving it unclear whether they represent situational or inherent factors. The authors suggest that differences of less than 1.0‰ are not meaningful and that differences of 1.0 to 1.5‰ require some caution in interpretation (Webb et al. 2014:102). We shall assume, then, that these four enamel $\delta^{18}O_p$ and the bone cluster both represent Teotihuacan residence.

The +16.0‰ enamel value is from sample 28, for the lower right third molar of individual F. Sample 28 has a low crystallinity index but was retained in this analysis. The three other individual F enamel $\delta^{18}O_p$ values are in the range of +16.3 to +16.5‰. The +16.0‰ value may represent the lower end of the enamel cluster's range, or it might include some degree of equilibration toward Teotihuacan oxygen-isotope compositions, indicating that individual F returned to Teotihuacan during the formation of her third molar crowns.

Individual Histories

Despite these uncertainties, patterning is visible in the results when individual histories are examined (Table 3; Figure 3). Individual A of Burial 1 has bone and enamel isotopic compositions in the Teotihuacan range but also a second molar crown that formed in the relocation geographic region (Figure 3), suggesting movement there at about 5.0–5.5 years of age.

In Burial 2 we have no samples from the earliest teeth of individual B (Figure 3). She may have moved from Teotihuacan to the relocation region before the development of the UI2 crown, which forms at 1.5–5.5 years and has a relocation region composition. Individual C (Figure 3) may have relocated sometime during UI2 formation.

We have no samples for individual D from his earlier-forming teeth (Figure 3). It is possible that he was not born in Teotihuacan, or he may have moved from Teotihuacan to the relocation region

Table 3. Oxygen-Isotope Compositions of Bioapatite Phosphate.

Burial	Individual	Sample	Lot	Element	$\delta^{18}O_p$‰ VSMOW
1	A (30–35 yr)	3	—	LRM1	+15.7[a]
		2	—	LRP2	+15.3
		4	—	LRM2	+16.5
		29	—	R tibia	+14.5
2	B (♀, 20–24 yr)	11	2	ULI2	+16.5[b]
		7	1	LRM2	+16.8
		30	1	L tibia	+15.2
		31	1	L humerus	+14.5
		34	2	R humerus	+14.4
		36	4	L femur	+14.3
2	C (55+ yr)	5	1	ULI2	+15.7[b]
		6	1	ULC	+16.6[b]
		32	1	R humerus	+14.7
2	D (♂, mid-thirties)	16	3	ULP1	+16.8
		17	3	URM2	+16.4
		18	3	URM3	+16.7
		35	3	cranial fragment	+14.3
2	E (♂, 35–40 yr)	20	4	lower I1	+15.7[a]
		21	4	lower P1	+16.8
		22	4	lower M2	+16.7
2	F (♀, 24–35 yr)	26	5	LRI2	+16.5[a]
		27	5	LRP1	+16.5
		25	5	LLM2	+16.3
		28	5	LRM3	+16.0
		Nado et al. 2017	5	rib	+14.2
2	unassigned (♂)	13	3	ULI2	+16.2[b]
2	unassigned	33	2	R humerus	+14.7
2	unassigned	37	4	L femur	+14.6
2	unassigned	38	4	R femur	+14.2
2	unassigned	39	4	L femur	+13.3
2	unassigned	Nado et al. 2017	1	rib	+15.9
2	unassigned	Nado et al. 2017	2	rib	+14.4
2	unassigned (♂)	Nado et al. 2017	3	rib	+16.0
2	unassigned	Nado et al. 2017	4	rib	+14.4

[a] 0.7‰ was subtracted from the measured $\delta^{18}O_p$ to compensate for breastfeeding.

[b] 0.35‰ was subtracted from the measured $\delta^{18}O_p$ to compensate for breastfeeding.

before formation of the UP1 crown; that is, before the age of 3.5–4.0 years. Individual E (Figure 3) may have moved sometime during the formation of the LI1 crown (0.6–3.5 years) and before the development of his LP1 crown (3.0–6.5 years). All of the tested teeth of individual F produced isotopic compositions in the enamel cluster, suggesting that she was living in the relocation region during her second year (Figure 3). Like individuals B and D, it is possible that F was not born in Teotihuacan. Without isotopic evidence from the earliest teeth, the central incisors and first molars, we cannot identify the region of birth of these three individuals.

Potential Limitations of the Method

There are a number of possible reasons for variability in enamel $\delta^{18}O_p$. For one, dental crowns

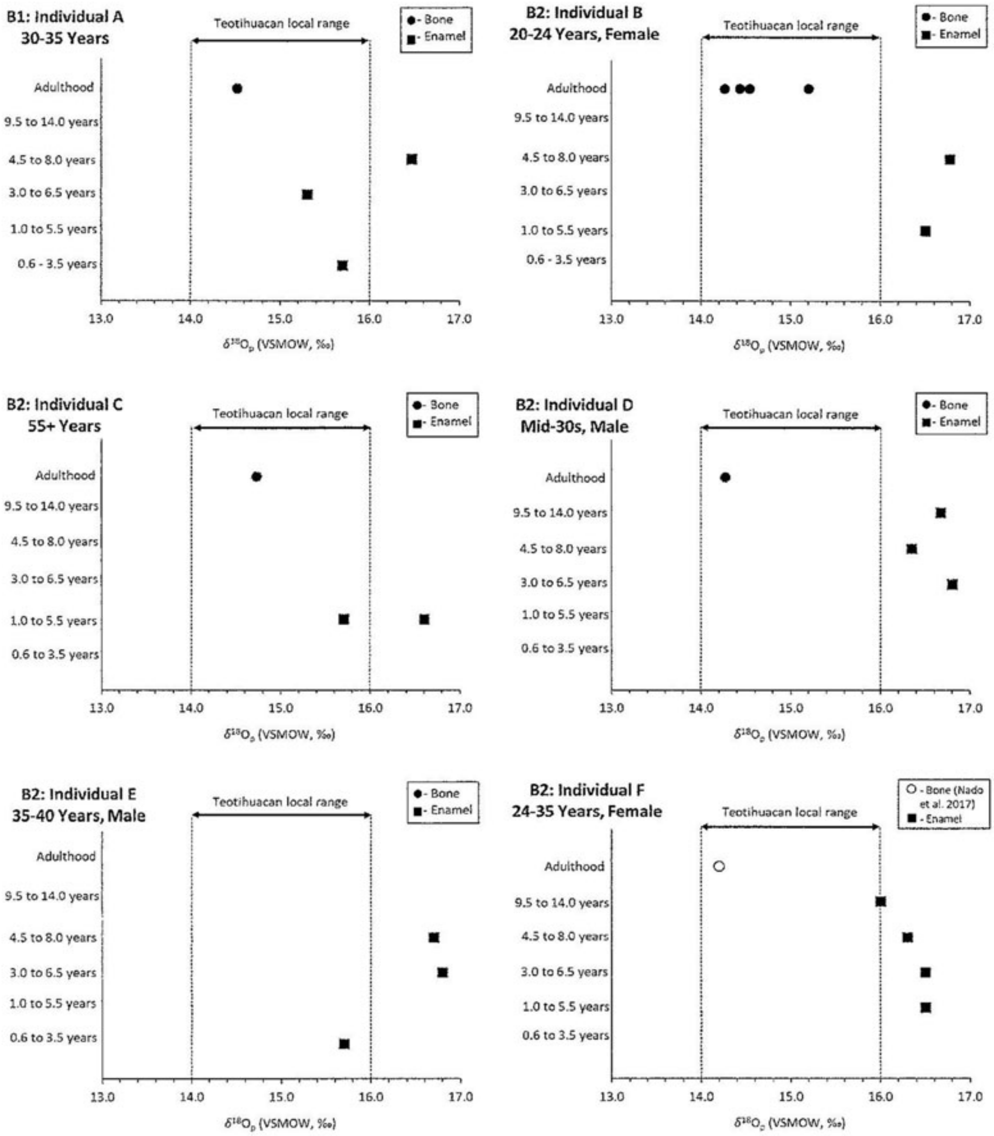

Figure 3. Oxygen-isotope compositions for individuals A–F. For individual F, the oxygen-isotope composition for bone was acquired from Nado and colleagues (2017).

commonly take 1.5–4.5 years to form (Table 2), so an enamel sample taken for isotopic analysis may encompass time spent in more than one location, as we suggested for the M3 of individual F. In addition, weaning is a process rather than an event, and its timing can be affected by a number of factors. A competing younger sibling may hasten it, or a lack of a suitable transition food may prolong it. Furthermore, the breastfeeding reductions applied to particular dental categories may not be fully accurate. There is also the possibility that the dental development ages taken from AlQahtani and colleagues (2010) may require some modification. Ubelaker (1978:46) suggests that Amerindian dental development may have been more rapid than the European standards used by most investigators, including AlQahtani and colleagues.

Some investigators have suggested that enamel oxygen-isotope compositions may be affected by seasonal or other short-term fluctuations (e.g., Britton et al. 2015:236; White, Longstaffe, et al. 2004:243), although these variations would not significantly affect the results for bone (Ayliffe and Chivas 1990:2603). Use of the whole tooth crown in this study should also have homogenized any limited intra-tooth variation in δ^{18}O values. We also note that the water consumed by the residents of San José 520 probably came from local runoff and perhaps also from the San Lorenzo River, which passes only 1.2 km north of the site. The δ^{18}O values of local runoff would have varied seasonally similar to precipitation, and hence should be reflected in bulk enamel and bone similarly, notwithstanding that the multiyear record is shorter in bulk tooth enamel. The San Lorenzo River is small and slow moving. As such, it may very well have been enriched in ^{18}O relative to precipitation because of evaporation; again, however, this enrichment would have affected the bone and enamel of local inhabitants more or less equally. Local groundwater would have been relatively homogeneous in terms of oxygen-isotope composition (Scherer et al. 2015) and therefore not a strong factor in producing variation in inter- or intraindividual δ^{18}O values. Some variation in δ^{18}O values might have also been introduced by evaporation if water was stored uncovered over long periods in small reservoirs or ceramic vessels (Scherer et al. 2015). Again, however, any such variation would presumably have affected the AF2 household uniformly and should not have led to an enamel-bone offset in δ^{18}O values.

Later Postclassic communities in marginal areas like that of San José 520 also used aguamiel and pulque (unfermented and fermented maguey sap products) as potable liquids, particularly in the dry season when they may have become important resources (Evans 1990; Parsons and Parsons 1990; Robertson and Cabrera Cortés 2017). Pulque residues have been identified in Teotihuacan period ceramics (Correa-Ascencio et al. 2014). There is the potential for these drinks to become enriched in ^{18}O relative to precipitation during these processes: (1) evaporation of soil water, (2) transpiration during sap development, (3) heating or boiling during their preparation, and (4) fermentation during pulque formation (e.g., McCool and Coltrain 2018). If these liquids were consumed in significant quantities, and differentially by subadults and adults, an offset between enamel and adult bone δ^{18}O values could conceivably result. The probability, however, is that such ^{18}O-enrichment would be more likely expressed in adult bone than subadult tooth enamel, thus decreasing rather than increasing the difference between bone and tooth δ^{18}O values.

Pathological conditions might affect metabolism and, by extension, δ^{18}O values (Webb et al. 2014:102). An analysis of Nubian skeletons by White, Longstaffe, and colleagues (2004:243), however, found no changes, with cases of iron-deficiency anemia and only slightly lower bone δ^{18}O values in females with osteopenia. Pathology at San José 520 is difficult to evaluate, given the poor condition of the remains. The only clear case beyond the usual arthritis and oral pathology is some slight evidence of healed porotic hyperostosis, an anemia-related condition, in the cranium of individual A (Driscoll 2005).

More problematic is the possibility of an inherent enamel-bone offset in oxygen-isotope compositions for coevally formed tissues, perhaps due to metabolic differences between subadults and adults. Despite the results of some analyses (Luz and Kolodny 1985; Webb et al. 2014; White, Longstaffe, et al. 2004; Wright and Schwarcz 1998:14–15), such an offset cannot yet be entirely dismissed. However, the variability in offset direction (Webb et al. 2014) and the wide range of offset values reported elsewhere in the literature cannot be explained solely by an inherent difference. For example, the Tlailotlacan and Tlajinga series of Teotihuacan show almost equal frequencies of higher enamel and higher bone δ^{18}O values (White, Spence, et al. 2004 White, Storey, et al. 2004). A Chapantongo series (see the later discussion) of 25 enamel-bone pairs includes only two in which the bone value is higher, but the mean offset is only 1.6 ± 0.9‰ and the range is large, 0.2‰–4.1‰ (Spence et al. 2011). Rather than seeking some inherent cause, it might be more fruitful to look for an explanation in variability introduced through weaning practices, dietary shifts, changes in local water sources (Scherer et al. 2015) or, as suggested here, geographic relocation.

Discussion

The oxygen-isotope evidence points to a long-standing pattern of individual movement between two distinct geographic regions, the Teotihuacan region (in particular, residence AF2 of the San José 520 settlement) and the relocation region, the latter characterized by oxygen-isotope compositions in the +16.2 to +16.8‰ range. The location of this region is not known. Moreiras Reynaga (2019) developed a map of $\delta^{18}O_p$ values for Mesoamerica, showing that values in the relocation region enamel cluster would be expected in the southern highlands. However, +16.2 to +16.8‰ values are also found closer to Teotihuacan. In a series from the Epiclassic site of Chapantongo, some 90 km northwest of Teotihuacan, 10 of the 32 enamel $\delta^{18}O_p$ values are in that range (Spence et al. 2011). Isolated $\delta^{18}O_p$ values in the range have also been noted from sites in Puebla and Michoacán.

Individuals A, C, and E were born in Teotihuacan and passed their earliest years there, moving to the relocation region sometime between one and six years of age. Perhaps this movement was initiated when the child passed a stage in development that made the journey easier, like weaning or walking. The two neonates in burials 2 and 3, of course, died before any movement was possible. Individuals B, D, and F may also have followed this relocation pattern, but with no samples from their earliest teeth, we cannot be sure of their birth location. They may have been born in Teotihuacan or in the relocation region after the family moved there.

All of the tested individuals passed the rest of their childhood in the relocation region. Almost all of the canine, premolar, and second and third molar oxygen-isotope compositions, and even most of the lateral incisor compositions, fall in the range associated with the relocation region. The +16.0‰ value of individual F's third molar may include some degree of equilibration toward Teotihuacan oxygen-isotope compositions. If so, relocation to Teotihuacan, at least for that individual, would have taken place in adolescence. Most of the bone isotopic compositions are in the $\delta^{18}O_p$ range of +14.2 to +14.7‰ characteristic of Teotihuacan, with a few exceptions. The +13.3‰ value is below the Teotihuacan range, but because it cannot be assigned to an individual, it cannot be fully assessed. The +15.9‰ and +16.0‰ values are also from unidentified individuals and thus difficult to evaluate. However, both values are in the general Teotihuacan range. and both samples have $^{87}Sr/^{86}Sr$ values typical of Teotihuacan (Nado 2017:Appendix B).

Conclusions

Together, the evidence suggests a pattern, continuing over some centuries, of birth in the area of the San José 520 settlement, movement (presumably as part of a family) to a different region, and then return to San José 520 during the teen or young adult years. This is a highly unusual pattern. Stable isotope analyses in other Teotihuacan sites frequently show the movement of individuals to Teotihuacan (e.g., Manzanilla 2012; Spence et al. 2004; White, Storey, et al. 2004) but not the back-and-forth pattern suggested by the San José 520 data. One comparable situation may be the sojourning of Tlailotlacan infants and their parents in other Zapotec communities, although their stays were of much briefer duration (White, Spence, et al. 2004).

Perhaps a better example of long-term relocation is presented by Estructura 19 (E19), an apartment compound a short distance east of Tlailotlacan. E19 contains evidence of occupants of both Zapotec and Michoacán affiliation (Begun 2013; Gómez Chávez 2002). Some 20 m south of the structure is a deep well that contained the articulated skeletons of some 30 people. The dental enamel and bones of eight of these skeletons were analyzed for their oxygen-isotope composition (Spence et al. 2006). The enamel $\delta^{18}O_p$ values are for the most part in the Teotihuacan range, whereas the bone values are all below it. The enamel-bone offset has a mean of 3.0‰ but varies widely, from 1.7 to 5.2‰. Oxygen-isotope compositions similar to those of the bone samples are found in the Valley of Oaxaca and the Lake Patzcuaro region of Michoacán. It may be, then, that these individuals were born and grew up in Teotihuacan but then moved to Oaxaca or Michoacán, returning to Teotihuacan only late in their lives.

The relocation region apparently played a very important role in the lives of the people of San José 520 or, at least, the lives of those living in the AF2 residence. Unfortunately, we cannot define that role without knowing where that region is located and something about the lives of the people there. Perhaps it was the original homeland of the San José 520 people, one to which they returned to ensure that their children were immersed in the homeland culture during their formative years. Or perhaps the purpose of this unusual settlement system was to send young adults (with their children) there to maintain some sort of exchange, provisioning, or social relationship with Teotihuacan that was conducted through San José 520. Identification of the relocation/homeland region will help in resolving these questions, but it will require further isotopic research in Mexico, both in and beyond San José 520, and the additional evidence that can be provided by other isotopic systems, such as strontium (Spence and White 2009:237–238).

Acknowledgments. We are very grateful to Christine White, who initiated the isotopic analysis of the San José 520 series. Dr. White's work on Teotihuacan and other Mesoamerican sites has had a profound impact on our understanding of the structure and volatility of these ancient populations. We also thank the Consejo de Arqueología of the Instituto Nacional de Antropología e Historia for permission to conduct the project, and the INAH-Zona de Monumentos Arqueológicos for their support. We are grateful to the Foundation for the Advancement of Mesoamerican Studies, the Wenner-Gren Foundation, and Arizona State University for their financial support of the San José 520 excavation, as well as the ASU-Teotihuacan Research Laboratory and their staff for facilitating laboratory work. Kristin Nado kindly allowed use of her dissertation data. We also thank the reviewers for their helpful suggestions. The Canada Research Chairs program, Canada Foundation for Innovation, and Ontario Research Fund provided financial support for analytical costs and the infrastructure that supported the isotopic measurements. This is the University of Western Ontario's Laboratory for Stable Isotope Science Contribution #377.

Data Availability Statement. The San José 520 collection is temporarily maintained in the Arizona State University Teotihuacan Research Laboratory, Teotihuacan, Mexico.

References Cited

AlQahtani, Sakher J., Mark P. Hector, and Helen M. Liversidge
2010 Brief Communication: The London Atlas of Human Tooth Development and Eruption. *American Journal of Physical Anthropology* 142:481–490.

Ayliffe, Linda K., and Allan R. Chivas
1990 Oxygen Isotope Composition of the Bone Phosphate of Australian Kangaroos: Potential as a Palaeoenvironmental Recorder. *Geochimica et Cosmochimica Acta* 54:2603–2609. DOI:10.1016/0016-7037(90)90246-H.

Begun, Erica
2013 Detecting Ethnicity at Teotihuacan through Archaeology: The West Mexican Presence at Structure N1W5:19. PhD dissertation, Department of Anthropology, University of Iowa, Iowa City.

Britton, Kate, Benjamin T. Fuller, Thomas Tütken, Simon Mays, and Michael Richards
2015 Oxygen Isotope Analysis of Human Bone Phosphate Evidences Weaning Age in Archaeological Populations. *American Journal of Physical Anthropology* 157:226–241.

Cabrera Cortés, Mercedes Oralia
2005 Craft Production and Socio-Economic Marginality: Living on the Periphery of Teotihuacán, México. Report to the Foundation for the Advancement of Mesoamerican Studies. http://www.famsi.org/reports/03090/index.html, accessed July 23, 2020.
2011 Craft Production and Socio-Economic Marginality: Living on the Periphery of Urban Teotihuacan. PhD dissertation, School of Human Evolution and Social Change, Arizona State University, Tempe.

Clayton, Robert N., and Toshiko K. Mayeda
1963 The Use of Bromine Pentafluoride in the Extraction of Oxygen from Oxides and Silicates for Isotopic Analysis. *Geochimica et Cosmochimica Acta* 27:43–52.

Correa-Ascencio, Marisol, Ian G. Robertson, Oralia Cabrera Cortés, Rubén Cabrera Castro, and Richard P. Evershed
2014 Pulque Production from Fermented Agave Sap as a Dietary Supplement in Prehispanic Mesoamerica. *Proceedings of the National Academy of Sciences of the United States of America* 111:14223–14228.

Cowgill, George L.
2015 *Ancient Teotihuacan: Early Urbanism in Central Mexico*. Cambridge University Press, Cambridge.

Crowson, Roy A., and William J. Showers
1991 Preparation of Phosphate Samples for Oxygen Isotope Analysis. *Analytical Chemistry* 63:2397–2400.

Driscoll, Laura
2005 Análisis preliminar de los entierros de San José 520. Manuscript on file, Proyecto San José 520.

Evans, Susan T.
1990 The Productivity of Maguey Terrace Agriculture in Central Mexico during the Aztec Period. *Latin American Antiquity* 1:117–132.

Gómez Chávez, Sergio
2002 Presencia del occidente de México en Teotihuacan. Aproximaciones a la política exterior del estado teotihuacano. In *Ideología y política a través de materiales, imágenes y símbolos*, edited by María Elena Ruiz Gallut, pp. 563–625. CONACULTA, Instituto Nacional de Antropología e Historia, Mexico City.

Longinelli, Antonio
1984 Oxygen Isotopes in Mammal Bone Phosphate: A New Tool for Paleohydrological and Paleoclimatological Research? *Geochimica et Cosmochimica Acta* 48:385–390. DOI:10.1016/0016-7037(84)90259-x.

Luz, Boaz, and Yehoshua Kolodny
1985 Oxygen Isotope Variations in Phosphate of Biogenic Apatites, IV: Mammal Teeth and Bones. *Earth and Planetary Science Letters* 75:29–36.

Luz, Boaz, Yehoshua Kolodny, and Michael Horowitz
1984 Fractionation of Oxygen Isotopes between Mammalian Bone-Phosphate and Environmental Drinking Water. *Geochimica et Cosmochimica Acta* 48:1689–1693. DOI:10.1016/0016-7037(84)90338-7.

Manzanilla, Linda R. (editor)
1993 *Anatomía de un conjunto residencial teotihuacano en Oztoyahualco*. Universidad Nacional Autónoma de México, Mexico City.
2012 *Estudios arqueométricos del centro del barrio de Teopancazco en Teotihuacan*. Universidad Nacional Autónoma de México, Mexico City.

Manzanilla, Linda R., Gabriela Mejía, Gerardo Jiménez, Peter Schaaf, Becket Lailson, Gabriela Solís, Pedro Morales, and Edith Cienfuegos
2012 Caracterización de la población multiétnica de Teopancazco por isótopos estables, isótopos de estroncio y elementos traza. In *Estudios arqueométricos del centro del barrio de Teopancazco en Teotihuacan*, edited by Lina R. Manzanilla, pp. 449–465. Universidad Nacional Autónoma de México, Mexico City.

McCool, Weston C., and Joan B. Coltrain
2018 A Potential Oxygen Isotope Signature of Maize Beer Consumption: An Experimental Pilot Study. *Ethnoarchaeology* 10:56–67. DOI:10.1080/19442890.2018.1439300.

Millon, René
1973 *The Teotihuacan Map, Part I: Text. Urbanization at Teotihuacan, Mexico*, Vol. 1. University of Texas Press, Austin.
1981 Teotihuacan: City, State, and Civilization. In *Supplement to the Handbook of Middle American Indians,* Vol. 1: *Archaeology*, edited by Jeremy A. Sabloff, pp. 198–243. University of Texas Press, Austin.

Moreiras Reynaga, Diana K.
2019 The Life Histories of Aztec Sacrifices: A Stable Isotope Study (C, N, and O) of Offerings from Tlatelolco and the Templo Mayor of Tenochtitlan. PhD dissertation, Department of Anthropology, University of Western University, London, Canada.

Nado, Kristin Lynn
2017 Dietary Practices, Socioeconomic Status, and Social Mobility at Teotihuacan, Mexico. PhD dissertation, School of Human Evolution and Social Change, Arizona State University, Tempe.

Nado, Kristin, and Stephanie Cruz
2006 Final Report on Burials 1–3 from Proyecto San José 520, Teotihuacan, Mexico. Manuscript of file. Proyecto San José 520.

Nado, Kristin L., Natalya Zolotova, and Kelly J. Knudson
2017 Paleodietary Analysis of the Sacrificial Victims from the Feathered Serpent Pyramid, Teotihuacan. *Archaeological and Anthropological Sciences* 9:117–132.

Parsons, Jeffrey R., and Mary H. Parsons
1990 *Maguey Utilization in Highland Central Mexico. An Archaeological Ethnography*. Anthropological Papers No. 82. University of Michigan, Ann Arbor.

Price, T. Douglas, Linda Manzanilla, and William D. Middleton
2000 Immigration and the Ancient City of Teotihuacan in Mexico: A Study Using Strontium Isotope Ratios in Human Bone and Teeth. *Journal of Archaeological Science* 27:903–913.

Rattray, Evelyn C.
2001 *Teotihuacan: Ceramics, Chronology and Cultural Trends / Teotihuacan: Cerámica, cronología y tendencias culturales*. Instituto Nacional de Antropología e Historia, Mexico City; University of Pittsburgh, Pittsburgh, Pennsylvania.

Robertson, Ian G.
2008 "Insubstantial" Residential Structures at Teotihuacán, Mexico. Report to the Foundation for the Advancement of Mesoamerican Studies. http://www.famsi.org/reports/06103/index.html, accessed July 23, 2020.

Robertson, Ian G., and M. Oralia Cabrera Cortés
2017 Teotihuacan Pottery as Evidence for Subsistence Practices involving Maguey Sap. *Archaeological and Anthropological Sciences* 9:11–27. DOI:10.1007/s12520-016-0415-z.

Scherer, Andrew K., Alyce de Carteret, and Sarah Newman
2015 Local Water Source Variability and Oxygen Isotopic Reconstructions of Mobility: A Case Study from the Maya Area. *Journal of Archaeological Science: Reports* 2:666–676. DOI:10.1016/jasrep.2014.11.006.

Séjourné, Laurette
1966 *Arquitectura y pintura en Teotihuacan*. Siglo Veintiuno Editores, Mexico City.

Smith, Michael E.
2014 Peasant Mobility, Local Migration and Premodern Urbanization. *World Archaeology* 46:516–533.

Smith, Michael E., Abhishek Chatterjee, Angela C. Huster, Sierra Stewart, and Marion Forest
2019 Apartment Compounds, Households, and Population in the Ancient City of Teotihuacan, Mexico. *Ancient Mesoamerica* 30:1–20.

Spence, Michael W., and Christine D. White
2009 Mesoamerican Bioarchaeology: Past and Future. *Ancient Mesoamerica* 20:233–240.

Spence, Michael W., Christine D. White, Patricia Fournier, Emily Webb, and Fred J. Longstaffe
2011 The Chapantongo Site: Oxygen Isotope Analysis and Epiclassic Population Mobility in the Valley of Mezquital. Paper presented at the 76th Annual Meeting of the Society for American Archaeology, Sacramento, California.

Spence, Michael W., Christine D. White, Julie Gazzola, Sergio Gómez Chávez, and Fred J. Longstaffe
2006 Oxygen-Isotope Values and Population Movement in Structure 19, Teotihuacan. Paper presented at the 71st Annual Meeting of the Society for American Archaeology, San Juan, Puerto Rico.

Spence, Michael W., Christine D. White, Fred J. Longstaffe, Evelyn C. Rattray, and Kimberley R. Law
2004 Un análisis de las proporciones de los isótopos del oxígeno en los entierros del barrio de los Comerciantes. In *La costa del Golfo en tiempos teotihuacanos: Propuestas y perspectivas: Memoria de la segunda Mesa Redonda de Teotihuacan*, edited by María Elena Ruiz Gallut, and Arturo Pascual Soto, pp. 469–492. Instituto Nacional de Antropología e Historia, Mexico City.

Storey, Rebecca
1992 *Life and Death in the Ancient City of Teotihuacan: A Modern Paleodemographic Synthesis*. University of Alabama Press, Tuscaloosa.

Stuart-Williams, Hilary LeQ., and Henry P. Schwarcz
1995 Oxygen Isotope Analysis of Silver Orthophosphate

Using a Reaction with Bromine. *Geochimica et Cosmochimica Acta* 59:3837–3841.

Stuart-Williams, Hilary LeQ., Henry P. Schwarcz, Christine D. White, and Michael W. Spence

1996 The Isotopic Composition and Diagenesis of Human Bone from Teotihuacan and Oaxaca, Mexico. *Palaeogeography, Palaeoclimatology, Palaeoecology* 126:1–14.

Tudge, A.P.

1960 A Method of Analysis of Oxygen Isotopes in Orthophosphate—Its Use in the Measurement of Paleotemperatures. *Geochimica et Cosmochimica Acta* 18:81–93.

Ubelaker, Douglas H.

1978 *Human Skeletal Remains: Excavation, Analysis, Interpretation*. Aldine Publishing, Chicago.

Webb, Emily C., Christine D. White, and Fred J. Longstaffe

2014 Investigating Inherent Differences in Isotopic Composition between Human Bone and Enamel Bioapatite: Implications for Reconstructing Residential Histories. *Journal of Archaeological Science* 50:97–107.

White, Christine D., Fred J. Longstaffe, and Kimberley R. Law

2004 Exploring the Effects of Environment, Physiology and Diet on Oxygen Isotope Ratios in Ancient Nubian Bones and Teeth. *Journal of Archaeological Science* 31:233–250.

White, Christine D., Rebecca Storey, Fred J. Longstaffe, and Michael W., and Spence

2004 Immigration, Assimilation and Status in the Ancient City of Teotihuacan: Isotopic Evidence from Tlajinga 33. *Latin American Antiquity* 15:176–198.

White, Christine D., Michael W. Spence, Fred J. Longstaffe, and Kimberley R. Law

2000 Testing the Nature of Teotihuacán Imperialism at Kaminaljuyú Using Phosphate Oxygen-Isotope Ratios. *Journal of Anthropological Research* 56:535–558.

2004 Demography and Ethnic Continuity in the Tlailotlacan Enclave of Teotihuacan: The Evidence from Stable Oxygen Isotopes. *Journal of Anthropological Archaeology* 23:385–403.

White, Christine D., Michael W. Spence, Hilary Stuart-Williams, and Henry P. Schwarcz

1998 Oxygen Isotopes and the Identification of Geographical Origins: The Valley of Oaxaca versus the Valley of Mexico. *Journal of Archaeological Science* 25:643–655.

Wright, Lori E., and Henry P. Schwarcz

1998 Stable Carbon and Oxygen Isotopes in Human Tooth Enamel: Identifying Breastfeeding and Weaning in Prehistory. *American Journal of Physical Anthropology* 106:1–18.

Submitted November 17, 2019; Revised April 14, 2020; Accepted June 25, 2020