Great House origins and population stability at Pueblo Bonito, Chaco Canyon,
New Mexico: The isotopic evidence

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Final Draft 3.1
10 August 2016

Revisions after submission and review
24 Oct 2016

Abstract

One of truly remarkable developments in the prehistory of North America was the construction of more than a dozen great houses--imposing multi-storied structures that were qualitatively different from the usual small, irregular, single-story homes—in Chaco Canyon in northwestern New Mexico from the early AD 800s to the 1100s. Beginning no later than AD 1000, scores of similar large pueblos, often referred to as Chacoan outliers, were erected throughout much of the southern Colorado Plateau in Arizona, Colorado, New Mexico, and Utah. A small number of these outliers were connected by formal roads and many others participated in a broad network of exchange and ritual. The largest and most unusual of the Chaco Great Houses and one of the earliest to be built was Pueblo Bonito situated in the heart of the canyon. Some of the most intriguing aspects of Pueblo Bonito are two clusters of the human burials, almost certainly elites, found within its sandstone walls. We present here isotopic proveniencing data (strontium, lead, and oxygen) that put these burials in a new and unexpected perspective. Our results suggest that the almost all individuals interred in Pueblo Bonito had been born in Chaco Canyon or in nearby parts of the southern San Juan Basin. All of these individuals, moreover, likely belonged to the elite component of Bonito society, given their placement in special burial crypts within the walls of the pueblo. These conclusions suggest that the origin of Chaco Canyon great houses and the hierarchical society that organized their construction was more likely a product of local sociocultural dynamics than a result of migration of a group of new people into the Canyon from the northern San Juan Basin.

Keywords

Southwest U.S., isotopic proveniencing, Chaco Interaction Network, Ancestral Pueblo, Great Houses, Pueblo Bonito, sociopolitical hierarchy

Introduction

This study focuses on human movement and interaction in Chaco Canyon in northwestern New Mexico in the Southwestern United States where the densest recorded concentration of large pueblos prior to AD 1300 was constructed in the ninth through early twelfth centuries AD. Chaco is the earliest example of marked social complexity and significant status differentiation in the Pueblo World. In addition to the great houses, other remarkable characteristics of the Canyon include unusual quantities of turquoise, shell, macaws, cacao, and other goods and materials either imported to the canyon or directly acquired by Chaco elites. Fascinating questions concern the origin, nature, and reasons for this development.

This study focuses on the humans buried in Pueblo Bonito, the largest of the Chaco great houses and one of the first constructed, where evidence from burial practices and human biology in two spatially discrete mortuary crypts suggests significant social inequality (Akins 2001; Akins and Schelberg 1984; Plog and Heitman 2010). During the era when Chacoans interred some of their dead in both crypts between roughly AD 800 and 1130, the northern Southwest region (northeastern Arizona, northwestern New Mexico, southwestern Colorado, and southeastern Utah; hereafter referred to as “northern Southwest”) witnessed both significant population increases and decreases along with both short- and long-distance migration and movement for various reasons. These reasons likely included colonization; significant internal, organizational dynamics; variation in the degree of conflict; and climate change (e.g., Bocinsky et al. 2016; Cordell and Gumerman 1989; LeBlanc 1999, 2000, 2007; Lekson and Cameron 1995; Schachner 2015; Schwindt et al. 2016; Spielmann 1998).

The geographic origin of the Chaco elites, the beginning of social differentiation in the Canyon and the concept of Chaco great house construction has been debated, with many scholars proposing individuals moved into Chaco Canyon from regions to the north, bringing with them the design of great house

construction (e.g., Judge and Cordell 2006:193-194; Wilshusen and Van Dyke 2006; Windes 2007; Windes and Van Dyke 2012.) The consensus view is thus that social inequality and complexity in Chaco was the product of historical trajectories that began more than a hundred miles to the north. In contrast, the analyses presented below suggest that Chaco cultural evolution resulted from local cultural dynamics that at times were reinforced by short- and long-distance contacts with areas such as southern Mesoamerica where high-status materials such as macaws were acquired

We report the results of our investigations of the origins of the individuals from the two elite burial crypts within Pueblo Bonito using new methods not employed by earlier researchers. Previously, scholars proposing the hypothesis that elites and great houses originated to the north have relied upon indirect proxies. Examples of such proxies include the architectural characteristics of the earliest great houses or a pronounced increase in the population of Chaco Canyon hypothesized to have occurred about the same time that significant demographic declines occurred in densely settled southwestern Colorado. For example, some have characterized the Canyon as a “relative backwater” prior to the migration from the north (Windes and Van Dyke 2012:72).

Instead of such indirect proxies for the origins of Chaco great houses, we use isotopes of strontium, oxygen, and lead in tooth enamel to directly investigate where the individuals interred in the two elite burial crypts were born. Isotopes in human tooth enamel provide a direct measure of mobility. The principle of the method is straightforward. Enamel forms in early childhood and incorporates the isotopic ratio of the place of birth. Enamel is inert and resistant to contamination and decomposition, thus providing an isotopic signature of place of birth after death and often long after burial. If the isotopic signal of the place of death differs from that of the enamel, the individual must have relocated to a different geological (isotopic) area.

In combination with a study by Marden et al. (n.d.), we have measured isotopic variation for 61 individuals from the elite burial crypts of Pueblo Bonito. We

analyze internal variation within the Pueblo Bonito samples and also compare them to about two dozen individuals who were buried in settlements north, northwest, or west of Chaco Canyon. The results indicate that there are at least two isotopic groups that can be identified in the burial crypts. Most of the individuals in both groups likely were born in or near Chaco Canyon. Only a small handful of individuals buried in the two crypts appear to have been born in more distant regions and then moved to Chaco.

The study is organized as follows. We first provide the archaeological background for Chaco Canyon in terms of time, space, major characteristics, and archaeological context. We then briefly summarize the results of new radiocarbon dates from the burial crypts that document the three-century long period in which the crypts were used for interments. Next we outline the methods of investigation, focused on the use of isotopic ratios in human tooth enamel to determine place of origin, and we present the results of our analyses. We conclude with a discussion of the isotopic analyses and their possible interpretation.

Archaeological Background

The network of Chacoan-style great houses that developed by the eleventh century was centered on the San Juan Basin of New Mexico and extended into southwestern Colorado, southeastern Utah, east and west-central New Mexico, and northeastern Arizona (Fig. 1). The archaeological focus of the densest concentration of great houses occurs along about 15 km in Chaco Wash, a largely dry tributary of the Chaco and San Juan Rivers. Ancestral Pueblo groups in the Chaco area created a dynamic regional culture between AD 800 – 1130, with subsistence based primarily on domesticated plants and wild animals. Corn, beans, and squash were cultivated, wild plants were gathered, and animals hunted included wild hare, deer, antelope, and some rodents such as prairie dogs (Akins 1986; Mathien 1986; Watson 2012). Domesticated turkeys were likely raised (primarily in the last 75 years before the abandonment of the site) (Beacham and Duran 2007; Grimstead et al. 2015)

Fig. 1. The San Juan Basin in northwestern New Mexico and southwestern Colorado. The distribution of some of the Great House pueblos (red dots) is also shown on the map.

The Chaco region is best known for its architecture. Chaco Canyon, the center of this network, witnessed the construction of more than a dozen Great House pueblos and as many as 200 were built in the larger region of the San Juan Basin. Great House architecture consists of many-roomed, multi-storied structures with core-and-veneer masonry and great underground kivas (e.g., Lekson 2006, Kantner and Mahoney 2000, Marshall et al. 1982, Vivian 1990). These structures included some of the largest buildings in North America prior to the 19th century. Both Pueblo Bonito and population in the canyon as a whole grew rapidly in the 11th and early 12th centuries. Existing great houses were expanded and at least 10 new great houses were constructed, followed by a rapid decline in construction activity and the almost complete depopulation of the canyon by AD 1130 (Lekson 1984; Vivian 1990; Windes and Ford 1996).

The dramatic expansion of population and construction in the canyon during the mid-11th century was associated with population growth across the Colorado Plateau as a whole as well as the appearance of tens of outlying settlements in that region that adopted the Chacoan architectural style (Kantner and Mahoney 2000; Kohler and Reese 2014; Lekson 2007; Schachner 2015). In addition, numerous road segments (most 1–5 km, but some 40–50 km in length) radiate out from Chaco and represent a significant investment in infrastructure.

One of the intriguing aspects of the Chaco phenomena lies in the seemingly desolate nature of the landscape. As one of the first archaeologists to visit the area, A.V. Kidder (1924) remarked, “How so large a population could have supplied itself with the mere necessities of life, and still had time and energy left for the development of so remarkable a civilization, has puzzled every observer who has visited the Chaco Country.” A dynamic and impressive prehistoric society emerged in one of the more arid and non-productive regions of the northern Southwest. Chaco Canyon is a desert-scrub grassland, with relatively poor soils for farming and modern annual precipitation averaging less than 23 cm, insufficient in most years for agriculture unless supplemented by water control

methods (Benson 2010; but see Dorshow 2012; Tankersley et al. 2016; Wills and Dorshow 2012; Vivian and Watson 2015 for contrary opinions). Water sources are largely confined to several springs and Chaco Wash carries water primarily after mountain snow melt in the spring or heavy summer thunderstorms.

Other investigators, however, have argued that more fertile soils supported intensive irrigation agriculture (e.g., Tankersley et al. 2016; Vivian 1990; Vivian and Watson 2015), likely a result of capturing rainfall draining from the large bedrock outcrops on the northern rim of the canyon, and at times building dams and reservoirs to store water.

A variety of food, goods, and other resources were transported substantial distances to the Great Houses in Chaco Canyon beginning as early as the late 9th century, including some corn (Benson et al. 2008; Benson et al. 2003; Cordell et al. 2001; Cordell et al. 2008), venison (Benson et al. 2003; Grimstead et al. 2014; Watson 2012), pottery (Mills et al. 1997; Shepard 1939; Toll and McKenna 1997), lithic raw materials (Cameron 2001; Mathien 1997), ornaments and minerals such as marine shells, turquoise, and copper (Mathien 1997; Thibodeau et al. 2013; Vargas 1995), macaws (Watson et al. 2015) and construction timber (Betancourt et al. 1986; English et al. 2001; Guiterman et al. 2016; Reynolds et al. 2005). Several of these studies are discussed in more detail in the Supplementary Material.

The relationship between Chaco and the outlying areas and communities, and the general nature of sociopolitical organization, are major, unresolved, and hotly debated questions in Southwestern prehistory (e.g., Lekson 2009; Van Dyke 2007; Plog and Watson 2012). Several models have been proposed, ranging from Chaco as the center of a military state (Wilcox 1993), as a benevolent redistribution center (Judge 1979), or as a place of ritual and cosmological power visited and used during pilgrimage (Judge 1989; Renfrew 2001; Stein and Lekson 1992; Toll 1985; Van Dyke 2007).

Pueblo Bonito and the Burial Clusters

Sometime near the beginning of the ninth century AD, a unique structure was built in the center of Chaco Canyon at the site known as Pueblo Bonito (Fig. 2). This structure grew in a series of construction stages to be the largest stone walled structure in prehistoric North America prior to AD 1300 with more than 650 rooms and 40 kivas. At its zenith, this ancient complex potentially housed as many as 500 people, although lower estimates have been suggested. This sandstone walled, multi-story building was very different from the contemporary architecture of the region and the northern Southwest as a whole, particularly at the beginning of the 9th century. At the time most people lived in pithouses or single story pueblos, with room numbers typically less than 50. The cessation of construction and significant depopulation of Pueblo Bonito took place around AD 1130, following an occupation of some 300-350 years.

Fig. 2. Air photo of Pueblo Bonito in Chaco Canyon.

In the southwest corner of the original core of Pueblo Bonito a unique space, known as Room 33, was built at an early stage in the construction (Fig. 3). This room was small, roughly 2.0 x 1.8 m in size and 2.4 m from floor to ceiling. After the interment of two individuals with perhaps the richest set of grave goods known in the prehistoric northern Southwest, a floor of wooden planks was laid across the entire room. The only doorway into the room was very small and high up on the east wall less than 0.6 m from the ceiling. It is clear that this odd room was intended as a burial crypt from its inception.

Room 33 and three adjacent rooms (Rooms 32, 53, and 56) were used for the burial of ca. 25 adult individuals based on our analysis of original, but unpublished field notes available from the Chaco Research Archive (www.chacoarchive.org), as well as our inspection of skeletal collections from multiple repositories. No infants or children were recovered during the excavations. We refer to this group of four rooms as the North Cluster. Initially, two adult males were interred beneath a wooden plank floor in Room 33. The earliest male was laid on the original floor of the room and covered with a 70 cm

thick layer of sand. This individual had been buried with almost 15,000 turquoise and shell beads and pendants. The second male was buried higher in the sand layer, with additional wealth. Just above this second individual the wood plank floor was installed and eventually 12 more individuals (6 males and 6 females) were sequentially placed in this room (Pepper 1909, 1920). Between 6 and 11 phases of interment are evident during the ca. 350 year use of the room, suggesting generational continuity in the use of the crypt (Kennett et al. 2016). At least nine individuals (early and poorly recorded excavations provide incomplete information) were interred in rooms 53 and 56.

Fig. 3. Location of the northern and western burial clusters in Pueblo Bonito.

The construction of the North Cluster, and its use over approximately 10 generations is completely unique in the American Southwest. The only parallels are West Mexican shaft tombs, although none of those are known to have been used for so many generations, and their construction and use ended in West Mexico just prior to the construction of Room 33, although the tradition of keeping ancestral remains, especially those of leaders, in sacred buildings continued (Nelson et al. 1992).

These four burial rooms appear to have part of the initial construction of a set of irregularly shaped rooms that formed the northern core of the original pueblo (Judd 1954; Kennett et al. 2016). Shortly thereafter, arcs of larger, more regularly shaped rooms were added to the east and west of the original core (Fig. 3). While the initial construction involved a group of rooms with little internal regularity in their shape or layout, this new addition was planned. It primarily consisted of a series of suites of rooms, with one large room and two small rooms behind. This pattern was repeated 5 times to form the western arc. At the corner of this arc, four rooms – 320, 326, 329 and 330 — were converted into a burial area. Tree-ring dates indicate construction of these rooms began by AD 852 (Windes and Ford 1996), but unpublished ¹⁴C AMS dates suggest construction may have begun a few decades earlier. Some of the initial burials were sub-floor, and subsequent burials were placed on the room floors and in the

fill. It is clear that these rooms had been converted into burial crypts, not purposely built for that reason as was Room 33. Nevertheless, radiocarbon dates on the burials suggest that the conversion occurred fairly soon after construction. Thus, while their origins did not directly parallel that of Room 33, the rooms took on the same function. We refer to this group of four rooms as the West Cluster. That both the North and West Cluster each consisted of four rooms and that each cluster was at the extreme southern corner of an episode of major construction at Pueblo Bonito does not seem coincidental.

More than 80 individuals were interred in the four rooms in the West Cluster over a considerable span of time. The adult burials in the North Cluster have a sex ratio slightly skewed toward males (Table 1). In the West Cluster, there are three rooms with many women and few or no males, and one room with the reverse, a number of men and few women. This pattern in the West Cluster is thus very different from the North Cluster. There are also more than 2-3 times as many burials than in the North Cluster. Clearly, different criteria were used to determine who was buried where.

Table 1. Sex and location of burials in the North and West Cluster at Pueblo Bonito.

Cluster	Room	Males	Females	Unknown	Children	Sub Floor or Planks
North	33	8	6			2 males
	56	5	4			1 male (another?)
West	320	0	8	1	4	
	326	1	10	1	1	
	329	2	9	2	7	
	330	11	3	5	4	2 males
Total		27	40	9	16	

As noted earlier, the population size of Pueblo Bonito has long been debated (e.g., Benardini 1999, Plog and Watson 2012, Windes 1984), but regardless of the estimates for the huge pueblo, it is clear that not all the inhabitants were buried in the two clusters. This is not surprising, because at this time in the northern Southwest, individuals were not typically buried in rooms or below floors. Normally their bodies were placed in extra-mural midden deposits adjacent to

habitation structures. Such burials are well known elsewhere in Chaco Canyon and the larger region. Thus, the burials in the two clusters at Pueblo Bonito contain only a small proportion of the total site population and are exceptional as intra-mural (Plog and Heitman 2010).

The burials of the North and West clusters at Pueblo Bonito are therefore unique in almost every way. We present here more details on the isotopic analyses that provide information on the origins of these individuals and the similarities and differences between individuals interred in the North and West Clusters.

Dating

The collection of samples for this study was a large and complex undertaking. The North Cluster samples come from four different museums, while the West Cluster remains were all housed at the Smithsonian National Museum of Natural History. There are radiocarbon dates for more than 35 individuals and isotopic proveniencing data for 61 individuals from these two burial clusters.

Either a small sample of cortical bone or tooth was used for ^{14}C dating a number of individuals from the North and West Clusters. In addition to the 24 samples dated for this project, Marden et al. (n.d.) dated bone collagen from 23 individuals in the West Cluster and arranged for several of the same isotope measurements as in our analysis (Sr, C, O). Samples from specific individuals were easily identified and obtained, except those from Room 33. There, the crania of most of the individuals had been stored separately from the remaining skeletal elements with no information to allow re-association prior to the detailed forensic study of Marden (2012). In most cases we were able to obtain bone from the crania, but in a few instances we had to use long bones for the ^{14}C samples.

The radiocarbon dates will be the focus of another paper although, where relevant, individual dates will be discussed below. To summarize briefly, however, burials in the Western crypt did not occur quite as early as in the Northern crypt, but a few took place soon after the construction of the early western wing of the pueblo. Also, like the North Cluster, interment in the West Cluster continued into

the late eleventh and early twelfth centuries. Interments in both crypts thus took place over several generations.

Isotopic Analysis

The isotopic analysis of the burials from the two clusters included strontium ($^{87}\text{Sr}/^{86}\text{Sr}$), oxygen ($\delta^{18}\text{O}$), carbon ($\delta^{13}\text{C}$), and three lead ratios ($^{208}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$) in tooth enamel. Carbon isotope ratios showed little variation in our samples and are not discussed further in this study. For the remaining isotopic ratios we outline the basic principles involved and background information from the northern Southwest in the Supplementary Material for this study. A summary of information on expected ratios is provided here; the isotopic measures from the two Pueblo Bonito burial clusters are then discussed in the following section.

Background Isotopic Information from the Region: $^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{18}\text{O}$, and Pb

Benson and others (Benson 2010; Benson et al. 2003, 2006, 2009, 2012) have measured bioavailable strontium data for the Chaco Canyon region, as well as a series of areas within the San Juan Basin using weak acetic-acid extracts of soils and modern mice to approximate biologically available $^{87}\text{Sr}/^{86}\text{Sr}$. Soil samples from the San Juan Basin averaged 0.7095 ± 0.0005 . Twelve samples of soil and mice from archaeological sites in Chaco Canyon had a mean of 0.7092 ± 0.0003 and 0.7095 ± 0.0002 respectively. Although there is little variation in $^{87}\text{Sr}/^{86}\text{Sr}$ in either the mice or soils from Chaco, there is a hint of a pattern, slightly lighter $^{87}\text{Sr}/^{86}\text{Sr}$ in soil samples from drainages north of the river and slightly heavier $^{87}\text{Sr}/^{86}\text{Sr}$ in samples from drainages south of the river (Fig. 4). This is consistent with a slight radiogenic input from the continental Menefee formation exposed in the south and with strontium to the north coming more from either eolian carbonate or limestone in the slightly younger, marine Lewis Shale (Craig 2001). Nonetheless the pattern is faint and there is considerable overlap within the range of 0.7087 to 0.7104, with a strong central tendency among soils in the San Juan Basin toward 0.7092 overall, similar to that of the Chaco sites (Fig. 4).

Fig. 4. Distribution of $^{87}\text{Sr}/^{86}\text{Sr}$ values in the San Juan Basin based on soil extracts (Benson et al. 2009). Chaco Canyon is the long rectangle in the right center of the map. The hatched line mark the state lines between New Mexico, Colorado, Utah, and Arizona.

Grimstead et al. (2014) report $^{87}\text{Sr}/^{86}\text{Sr}$ values for a range of archaeological fauna excavated from Pueblo Bonito. While the deer exhibit some elevated ratios indicating distant origin, the turkey, prairie dog and leporid values (Table 2) were tightly constrained within the expected range for Chaco Canyon (0.70912–0.70951).

Table 2. $^{87}\text{Sr}/^{86}\text{Sr}$ values for small mammals from Pueblo Bonito (Grimstead et al. 2014).

	Cottontail	Jackrabbit	Prairie Dog
count	6	4	9
average	0.7093	0.7093	0.7093
sd	0.0001	0.0000	0.0001
min	0.7092	0.7092	0.7092
max	0.7094	0.7093	0.7095

We believe that while there are overlaps in $^{87}\text{Sr}/^{86}\text{Sr}$ values across Chaco Canyon and the larger San Juan Basin region, there are also some distinctive differences that are useful for isotopic proveniencing. Moreover, the application of multi-isotope analyses using oxygen and lead supplements the potential limitations of the more homogeneous strontium isotope ratios.

Average $\delta^{18}\text{O}$ for modern precipitation measured at field stations throughout the northern Southwest show significant correlation with elevation ($n=12$, $r = -0.621$, $p<.05$). Converting these $\delta^{18}\text{O}_{\text{SMOW}}$ rainfall values to PDB apatite (our enamel values) yields a range of $\delta^{18}\text{O}_c$ from approximately -11.0‰ to -4.5‰ (Chenery et al. 2012). In general, more negative oxygen isotope ratios in the San Juan Basis are likely to reflect higher altitudes. However, there is substantial variation in $\delta^{18}\text{O}$ values that is not well understood. This isotopic system should be used with caution in discussions of past human mobility.

We cross plotted our $\delta^{18}\text{O}$ data and site elevation for 33 enamel values from 12 prehistoric sites in the San Juan Basin and adjacent areas. These values ranged from -1.8‰ to -9.1‰ for $\delta^{18}\text{O}$ with a mean and s.d. of $-5.6\text{‰} \pm 1.9$, and from

1581 to 2048 m in elevation, with a mean and s.d. of $1806 \text{ m} \pm 124$. Pearson's r correlation coefficient for these data was only 0.17. The elevational differences among settlements in this region are minor. In fact comparison of elevations between Chaco Canyon and the higher geographic features of the San Juan Basin reveals that only the highest ranges (La Plata Mountains, San Juan Mountains, San Mateo Mountains) have maximum elevations more than 1000 m above Chaco Canyon. Most of the San Juan Basin is slightly lower than Chaco.

Grimstead et al. (2015) report $\delta^{18}\text{O}$ in surface water in the San Juan Basin and faunal remains from Pueblo Bonito. Water values (VSMOW) averaged $-10.5\text{‰} \pm 3.5$ with a minimum of -13.8‰ and a maximum of 0.8‰ . The values were skewed to the left in the distribution and the modal value was between -12‰ and -13‰ . The only obligate drinking species comparable to humans was deer. Fifteen samples of archaeological deer tooth enamel (carbonate, PDB) from Pueblo Bonito ranged from -11.8‰ to -5.0‰ with a mean and 1 s.d. of $-8.3\text{‰} \pm 1.8$. These values cover the range for modern rainfall for the northern Southwest as described above. Grimstead et al. (2015) argue that oxygen values indicate that all of the food animals (rabbit, prairie dog, and deer) came from higher altitudes at least 50 km from Bonito. The range of $\delta^{18}\text{O}_{\text{en}}$ in humans from Bonito measured for this project was between -2.8‰ and -8.3‰ with a mean and 1 s.d. of $-4.8\text{‰} \pm 1.1$. If Grimstead et al. (2015) are correct with respect to the relationship between oxygen isotope ratios and elevation in the northern Southwest (an issue best considered in another context), then it would seem that the inhabitants of the North and West crypts were not from higher elevations.

Very little information on lead isotope ratios in human tooth enamel is available from the San Juan Basin, or North America in general for that matter. Fortunately, Dudás et al. (2016) report strontium and lead isotope ratios for five teeth from Pueblo Bonito. Several samples were measured for each tooth. Strontium isotope ratios in tooth enamel from Pueblo Bonito range between 0.7090 and 0.7093 and fit the expected local baseline. Lead isotope ratios reported by Dudás et al. (2016) are presented in Table 3. Sample numbers are the same as listed in

our Table 4. As these strontium isotope ratios these samples are within the local range, similar lead isotope ratios could be expected for local individuals from Pueblo Bonito.

Table 3. Lead isotope ratios in human enamel from Pueblo Bonito (Dudás et al. 2016).

Sample No	206/204	207/204	208/204
F5403	20.318	15.768	39.430
F5403	20.450	15.771	39.425
F5400	20.861	15.816	39.553
F5400	20.706	15.779	39.548
F5400	21.264	15.830	39.787
F5399	20.222	15.755	39.212
F6171	19.967	15.743	39.173
F6171	20.254	15.746	39.337
F6173	18.845	15.647	38.560

It is important to recognize that there are two kinds for lead isotopes in human enamel. Lead ores occur at fixed points on the landscape and have distinctive isotopic decay signatures that reflect geological formation age. These data are available on various lead sources in the northern Southwest. Thibodeaux et al. (2013) have examined these lead isotope data in New Mexico as a way of identifying turquoise sources. Thibodeaux et al. (2013) also plotted turquoise lead isotope values from Pueblo Bonito and we have added the human values from the North and West Clusters (Fig. 5). The distributions of both turquoise and human enamel appear similar and two groups can be distinguished. The location of the two groups on the graph reflect age differences in the lead and copper sources of the turquoise with the values from younger geological deposits to the upper right. Because Pb and Cu behave similarly in hydro-thermal fluids, they are often used to infer the sources of metals in ore deposits (e.g., Bouse et al. 1999). This pattern fits with the geological ages of the deposits in the north and south San Juan Basin as described above. The older group with lower values for both isotope ratios resembles lead sources at the Cerillos mines 150 km to the east near Santa Fe. The second group in the graph has 07/04Pb values above 15.7 and 08/04Pb values greater than 39.1. Most of the individuals buried in the North Cluster (15

of 21) have 208/204Pb ratios above 39.1. The isotope ratios in the second, higher group do not have a known turquoise source in New Mexico. This missing source raises the possibility that there may be an unknown turquoise/lead source north of Chaco Canyon. If that is the case it might help explain the geographic origins of some of the individuals buried in the Bonito crypts.

Fig. 5. Comparison of lead isotope ratios between turquoise and human tooth enamel from Pueblo Bonito (red is turquoise, green = North Cluster, blue = West Cluster).

However, it is also the case that the geological mixing of rock types and/or lead sources can confound decay signatures and make source identification difficult. The term anomalous is used to describe the lead in those mixed rocks and sediments which do not follow normal decay curves. This ambient or anomalous lead is often the primary type that humans ingest as they breath, eat, and form enamel.

In sum, we can define expected isotope ratios for Chaco Canyon based on previous work and first principles. Strontium isotope ratios in Chaco Canyon should fall between 0.7092 and 0.7095. Oxygen isotope ratios in Chaco should be in the mid range for the northern Southwest (perhaps around -8.0‰) and more negative values could be expected at higher elevations. Lead Isotope ratios are more difficult to predict, but the values reported by Dudás et al. (2016) provide a first approximation for comparison.

Each of the isotopic ratios has some interpretive limitations either due to potential overlapping areas with the same values, difficulties in interpreting results because of many confounding variables, or poor knowledge of the background variability. However, we believe that in aggregate they provide a more powerful tool set to evaluate place of origin for the prehistoric inhabitants of the San Juan Basin.

Pueblo Bonito Enamel Isotope Measurements

For the isotopic samples in the present study a tooth was selected, an M2 when possible but, if unavailable, an M1, PM2 or PM1 were chosen in that order. A key

priority in tooth selection was the presence of the same tooth on the opposite side of the dentition, so an examination of a similar tooth could be done in the future. The crown of each tooth was used for enamel isotope ratios.

It is essential to note here that these samples are a combination of two research projects. Marden et al. (n.d.) examined 19 burials from the West Cluster, obtained strontium and oxygen isotope ratios in enamel from 15 teeth, and dated a number of bone samples which also provided carbon and nitrogen isotope ratios in collagen. By agreement, the tooth samples from the West Cluster were then provided to this project for lead isotope analysis. The other values listed in this study from the West Cluster come from Marden et al. (n.d.).

We first use our isotopic data for an interregional comparison of Pueblo Bonito with sites north, west, and northwest of Chaco Canyon, and then we examine on the samples from the two Pueblo Bonito burial clusters.

Interregional Comparison

The results of the isotopic analysis of human tooth enamel from Pueblo Bonito are provided in Table 4. There are 61 samples with values for all the isotopes. Table 5 provides summary descriptive statistics for the various ratios in the samples of human enamel. In the following discussion we initially consider all of the data from Chaco Canyon compared to settlements north of Chaco. We then focus on the North and West Clusters in Pueblo Bonito.

Table 5. Descriptive statistics for isotope ratios in human tooth enamel from Pueblo Bonito.

	⁸⁷ Sr ⁸⁶	δ ¹⁸ O	²⁰⁸ Pb ²⁰⁴	²⁰⁷ Pb ²⁰⁴	²⁰⁶ Pb ²⁰⁴
<i>n</i>	61	61	61	61	61
<i>Mean</i>	0.7092	-4.75	38.01	15.71	19.75
<i>± 1 s.d.</i>	0.0001	1.11	0.38	0.06	0.71
<i>Minimum</i>	0.7090	-8.29	38.44	15.61	18.85
<i>Maximum</i>	0.7094	-2.75	39.89	15.85	21.48

To provide an initial assessment of the similarity and differences between the Chaco isotope ratios, we compared the Pueblo Bonito isotope measures with comparable measurements for 22 individuals from settlements in southeastern

Utah, southwestern Colorado, extreme northeastern Arizona, and northwestern New Mexico (i.e., all north, northwest or west of Chaco Canyon) using descriptive statistics, basic univariate tests, and principal components analysis. Although not all these settlements are contemporary with Pueblo Bonito, they nevertheless are either Chacoan outliers or lie within areas where outlier communities developed. They thus should provide accurate isotope values for individuals who were almost certainly born at the sites sampled.

Table 6 provides descriptive statistics for these 22 samples, as well as the results of t-tests comparing the Pueblo Bonito means with the means of the samples from settlements north of Chaco.

Table 6. Descriptive statistics for isotope ratios in human tooth enamel from settlements north of Chaco Canyon and t-tests comparing Pueblo Bonito with northern samples.

	$^{87}\text{Sr}/^{86}\text{Sr}$	$\delta^{18}\text{O}$	$^{208}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{206}\text{Pb}/^{204}\text{Pb}$
<i>n</i>	22	22	22	22	22
<i>Mean</i>	0.70968	-6.39	38.78	15.67	19.17
<i>± 1 s.d.</i>	0.00075	1.61	0.34	0.034	0.40
<i>Minimum</i>	0.70885	-9.08	38.37	15.63	18.74
<i>Maximum</i>	0.71173	-4.16	39.61	15.76	20.33
<i>T-tests comparing Pueblo Bonito and Non-Chaco Samples</i>					
<i>t</i>	-5.11	5.23	2.48	3.35	3.61
<i>p</i>	0.000	0.000	0.015	0.001	0.001

The t-tests all show strong, statistically significant differences, suggesting the Chaco Canyon burials are not from the same population as the individuals interred elsewhere in the northern Southwest.

Box-and-whisker plots (Figure 6) further illustrate the differences between Chaco interments and those from the north. These basic plots show the clear differences in the central tendencies and ranges of the isotope values for the two areas. Not surprisingly, variation among interments from the multiple sites north of Chaco differ not only in central tendency as shown by the t-tests, but also have greater ranges for strontium and oxygen compared to interments from Pueblo Bonito. What is surprising, however, is that the lead isotopes variation within

Pueblo Bonito is greater than variation in the lead isotope values from the north, suggesting perhaps there is an aspect of the geology of Chaco Canyon that is important and needs to be studied. This variation will become important in subsequent analysis presented below.

Fig. 6. Box-and-whisker plots of isotope ratios at Bonito compared to other sites in the northern Southwest.

To provide a further comparison of the Pueblo Bonito burials with the non-Chaco samples, we used a scatter plot of $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ (Figure 7), eliminating the lead isotope ratios given our lack of understanding of lead variation, particularly in Chaco Canyon. The majority of the Pueblo Bonito samples cluster fairly strongly in the scatter plot, although there is a somewhat negative linear pattern with $^{87}\text{Sr}/^{86}\text{Sr}$ increasing as $\delta^{18}\text{O}$ decreases. Eighteen (82%) of the northern samples fall well outside the Pueblo Bonito cluster, some (3) with much lower $^{87}\text{Sr}/^{86}\text{Sr}$ values and others (15) with higher $^{87}\text{Sr}/^{86}\text{Sr}$ values than any of the Pueblo Bonito samples. One non-Chaco sample, an individual interred at the Viets Site, a small Chacoan outlier in southwestern Colorado near Cortez excavated in the 1890s, falls close to the Pueblo Bonito cluster near a group of individuals from the Pueblo Bonito West Cluster. A second non-Chaco sample from Battle Cave lies on the right edge of the Pueblo Bonito samples, near two individuals interred in the Bonito North Cluster. Finally, two additional individuals from the Viets Site lie somewhat outside the linear distribution of the Pueblo Bonito samples. Overall, only two of the 22 (90.9%) non-Chaco samples fall clearly within the Pueblo Bonito individuals. We conclude the scatterplot shows the Pueblo Bonito individuals differ significantly from the non-Chaco samples as suggested by the graphs and statistics already presented. There are, however, a few outliers among the Pueblo Bonito individuals and these will be discussed in more detail below.

Fig. 7. Scatter plot of $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ values for tooth enamel from the North and West Pueblo Bonito Clusters compared to the samples from settlements to the north, northwest, and

west. Note that four non-Chaco Canyon samples have $^{87}\text{Sr}/^{86}\text{Sr}$ values that exceed 0.710 and are so different they do not fall within the range shown in this figure.

The Pueblo Bonito Samples

The descriptive statistics for the burials in the two Bonito burial clusters are presented below (Table 7). Both the North and West Cluster have the same mean value and standard deviations for $^{87}\text{Sr}/^{86}\text{Sr}$, with very similar ranges. The mean oxygen isotope ratio is slightly lower in the North Cluster, but the standard deviation for the Northern samples is much higher. Although the descriptive statistics for the 07/04 lead ratio are very similar, there are greater differences between the clusters for the 08/04 and 06/04 ratios, with the means, standard deviations, and ranges all higher in the North Cluster.

Table 7. Descriptive statistics for strontium, oxygen, and lead isotope ratios for North and West Clusters.

Isotope & Cluster	Mean	s.d.	min	max	N
North Sr	0.70922	0.0001	0.70903	0.70939	21
West Sr	0.70922	0.0001	0.70904	0.70940	40
North O	-4.86	1.45	-7.58	-2.75	21
West O	-4.69	0.90	-8.29	-3.41	40
North 08/04	39.22	0.42	38.44	39.87	21
West 08/04	38.90	0.31	38.57	39.63	40
North 07/04	15.74	0.07	15.61	15.85	21
West 07/04	15.70	0.04	15.63	15.80	40
North 06/04	20.14	0.84	18.85	21.48	21
West 06/04	19.09	0.54	19.09	20.97	40

For all the interments from Pueblo Bonito, histograms of the isotopes reveal a dominant mode (Fig. 8), and show two other characteristics. First, the histograms of strontium and lead 208/204 and 207/204 suggest minor secondary modes as well. Strontium in particular, has a strong second mode to the extreme right of the distribution. Second, most of the histograms are skewed either to the left (oxygen) or to the right (particularly Pb 206/204), with the dominant modes

occurring near the far right or left of the distributions. The latter characteristic suggests some type of transformation should be used to create more normal distributions prior to the use of any multivariate analyses.

Figure 8. Histograms of isotopic ratios in human tooth enamel at Pueblo Bonito.

When we turn our attention to scatter plots showing the relations between pairs of isotopes in the two burial clusters, however, other patterns begin to appear. For example, the scatter plot of $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\delta^{18}\text{O}$ (Fig. 9) shows while interments in the West Cluster concentrate in the upper-left quadrant, they follow a rather continuous contribution from the upper-left to the lower-right. In contrast, individuals from the North Cluster are distributed in a discontinuous manner, with two-thirds of the burials in the upper-left and a gap between the remainder in the lower right. The latter cluster overlaps somewhat with a few of the West burials, but overall forms a distinct portion of the distribution. These two northern groups suggest the presence of two sets of individuals at Chaco with two somewhat different places of origin although both likely are within or near Chaco Canyon based on the significant differences with isotope values for the individuals north of Chaco discussed previously. Also, as with the box-and-whisker plots, there appear to be at least one and possibly a few more outliers to the overall distribution.

Fig. 9. Scatter plot of $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\delta^{18}\text{O}$ for tooth enamel in the North and West Bonito Burial Clusters.

Given the use of 5 different isotope measurements, the demonstrated value of examining variation among the isotopes, and the rather strong correlations ($r > 0.95$) among the three lead isotope ratios, principal components analysis (PCA) was used to reduce the measurements to two primary axes that account for 89% of the variation in the isotope measurements. For this analysis we also included three individuals from sites in Chaco Canyon other than Pueblo Bonito for comparative purposes. Two individuals are from Pueblo del Arroyo, a great house within 0.5 km of Pueblo Bonito, and one individual is from Smith Ranch Ruin, a small house pueblo ca. 15 km east of Pueblo Bonito. Prior to running the

PCA, all five isotope measures were transformed using natural logs to increase normality and reduce the likelihood of non-linear relationships among the isotopes.

The scatter plot showing the distribution of all samples on the first two PCA axes is shown in Figure 10. One primary pattern that emerges from the scatter plot is that the vast majority (75%) of the burials from the West Cluster have x-axis values (Component 1) less than 0, whereas most of the individuals from the North Cluster (67%) have values greater than 0. This difference is summarized in a simple 2x2 table (Table 8).

Fig. 10. Distribution of individuals from the North and West burial clusters on the first two axes of the principal components analysis.

Table 8. Distribution of North and West Cluster individuals on the x-axis of the PCA plot.

	North Cluster	West Cluster	Totals
x-axis < 0	7	30	37
x-axis > 0	14	10	24
Totals	21	40	61

This cross tabulation can be evaluated using Fischer's Exact test which results in $p = .002$, a strong statistically significant difference. Alternatively, a Pearson's chi-square test produces $\chi^2 = 10.02$ with $p = .002$ and $\phi = 0.41$. The tests thus show a marked, statistically significant difference in Component 1 scores for the North and West Burial cluster individuals. There is also some overlap, however, and the two clusters are not totally distinct.

One might also suggest the possibility of three groups within the PCA distribution: (1) the large, lineal cluster with values on the x-axis less than zero, (2) a group in the upper right quadrant of Components 1 and 2 ($y > 0$ and $x > 0$), and (3) a group in the lower right quadrant ($x > 0$, $y < 0$) (Table 9). The first

group primarily consists of individuals who were interred in the West Cluster as well as one of the individuals from Pueblo del Arroyo and the burial from Smith Ranch Ruin. The second group includes primarily individuals ($n = 7$) from the North Cluster along with along with four individuals from the West Cluster. Finally, the third group is an equal mix of interments in the North ($n = 8$) and West ($n = 6$) clusters, along with one sample from Pueblo del Arroyo. Individuals from the North Cluster are almost equally distributed among these three groups, but 75% of the West Cluster burials occur in the first group. This distribution is also statistically significant, with $\chi^2 = 12.39$, $p = .002$ and Cramer's $V = .451$. Viewing the PCA plot as composed of three groups is thus equally supported from a statistical perspective. This grouping provides less support, however, for distinct West and North populations given that the North Cluster burials are almost equally distributed in the three groups, although the heavy concentration of the West Cluster interments in Group 1 is nevertheless noteworthy. Both cross-tabulations, however, suggest there is greater homogeneity in the West Cluster than the North. One might propose that the West Cluster largely consists of one segment of the variation observed in the North Cluster.

Table 9. Three possible groups within the distribution of individuals in the PCA plot.

Groups	West Cluster	North Cluster	Totals
(1) $x\text{-axis} < 0$	30	6	36
(2) $x\text{-axis} > 0$, $y\text{-axis} > 0$	4	7	11
(3) $x\text{-axis} > 0$, $y\text{-axis} < 0$	6	8	14
Totals	40	21	61

The PCA analysis of the five isotope measures reveals only one clear outlier and two others that lie slightly separated from the overall distribution. The most obvious outlier is catalog no. 327071 from room 326 in the West Cluster dated prior to AD 1020 by ^{14}C AMS. A somewhat less notable outlier is H/3659 from Room 33 in the North Cluster with a radiocarbon date in the late 10th and early

11th centuries. A third individual slightly outside the general distribution is H/9167 from Room 361 in the North Cluster (although this skeleton it may have been thrown into Room 361 during the haphazard excavation of adjacent Rooms 56 and 53 by Moorehead 1906). This individual dates to the earliest decades of the construction of Pueblo Bonito. All three of these samples thus date to the initial period in the construction of Pueblo Bonito and prior to the marked expansion of great house construction in the canyon. However, these three individuals constitute only 5% of a sample of 61 individuals.

Two of these three individuals are noteworthy beyond their location on the periphery of the PCA plot. The third individual whose isotopic information falls slightly apart from the PCA scatter plot has no unusual skeletal characteristics. First, the most significant outlier is a female (NMNH catalog no. 327071 (labeled “71” on the PCA plot) referred to by Judd (1954) as Skeleton 7 in Room 326 of the West Cluster who is surprisingly interesting for two additional reasons. She has occipital cranial deformation. Cranial deformation was widely practiced in the northern Southwest from sometime in the AD 700s onward. There were two general forms, lambdoidal and occipital deformation. At Pueblo Bonito we have a striking pattern. The West Cluster has 52 individuals for whom there are deformation information; of these 49 had lambdoidal deformation. One of the three exceptions was Skeleton 7 in Room 326. Equally, if not more interesting, she had six toes Crown et al (2016). Crown et al. (2016) argue that individuals with polydactyly were rare in the northern Southwest and considered a positive and special trait based on the a variety of characteristics, including their presence in rock art, rubbings on room walls at Bonito, and artifacts. These data together suggest that this individual may not have been born in the Canyon, but may have been brought into the Bonito community, perhaps at marriage, given her unusual skeletal traits.

AMNH catalog no. H/9167, another of the three individuals who are somewhat peripheral to the PCA scatter plot, also had occipital deformation. While lambdoidal deformation was the dominant form in Room 33, the situation was

more nuanced. The two early interments in Room 33, H/3671 (also a six-toed individual, Crown et al. 2016) and H/3672 who were born in the canyon based on our isotopic analyses, both had occipital deformation. However, the remaining individuals in the room for whom we have information all had lambdoidal deformation (Marden 2012: 419, citing T. Dale Stewart). Also, there were two very early burials in the adjacent rooms 53-56. Skeletons 37-121-10/N3075 and H/9167 both had very early ^{14}C dates and at least one was a subfloor. Both of these two individuals also had occipital deformation. One can make a strong argument that lambdoidal deformation was not the norm at the time of the birth of these individuals, then later became ubiquitous.

It is also of interest to note the isotopic context of the two primary burials (Burials 13 and 14) of males with rich grave goods buried below the wooden floor in the lower deposits of Room 33, North Cluster. H/3671 lies in the lower right corner and H/3672 is in the lower left corner in Fig. 9. Both have similar values for strontium and oxygen, but are distinguished on the plot based by the lead isotope ratios, primarily $^{208}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$.

CONCLUSIONS

The primary goal of our effort to measure isotope frequencies in a sample of 83 individuals from the northern Southwest, including 61 individuals from two unusual burial clusters in Pueblo Bonito, was to assess the extent to which the remarkable cultural developments centered upon Chaco Canyon between AD 800 and 1130 were a result of the movement of new people to the Canyon in the ninth century or a product of internal sociocultural dynamics.

Several aspects of the evidence we have presented in combination with other recent studies favor internal cultural processes. First, the two burials in Room 33 in the North Cluster with the remarkable assemblages of grave goods date to the very beginning of the construction of Pueblo Bonito (Plog and Heitman 2010; Kennett et al. 2016), a great house that likely was among the first few constructed in the Canyon in the first half of the ninth century. There is no

evidence of similar levels of social differentiation elsewhere in the Pueblo Southwest at that time, particularly in the southwestern Colorado area (Kohler and Higgins 2016) that has often been proposed as the origin of the people who moved into Chaco Canyon and initiated great house constructions.

Second, strontium and oxygen isotopes values for the 61 individuals we studied from the two burial crypts show rather minimal variation and our t-tests demonstrate the Chaco samples differ in strontium and oxygen measures compared to the set of non-Chaco burials. The relatively minimal variation within Pueblo Bonito and the strong, statistically significant differences between Pueblo Bonito interments and burials from settlements located to the north, northwest, and west are more consistent with relatively local origins for the Chaco burials. These data further suggest a large percentage of the high-status individuals interred in the two Pueblo Bonito burial crypts were born either in Chaco Canyon or the nearby southern San Juan Basin—an area not considered in this study, but worthy of study—where there are some strong early ceramic similarities with sites in Chaco dating to the ninth century.

We acknowledge that variation in the three lead isotope ratios is greater in Chaco, but we suggest that this may be due to differences in the geological strata exposed on the northern and southern sides of Chaco Wash. That is, significant variation in lead could be a signature of Chaco Canyon. However, the study of lead isotopes in human dental enamel is comparatively new and much needs to be done before we can fully understand this variation in lead.

Finally, a third aspect of our analysis favoring relatively local origins of the Chaco elites is the lack of differentiation within the PCA scatter plot using the two primary principal components when the sample is viewed collectively. We have highlighted some possible groups within the scatter plot that suggest some statistically significant differences between the North and West Burial Clusters in diet. However, whether we isolate two or three statistically significant clusters in the scatter plot, the values of either *phi* or Cramer's V are low enough that the groups account for less than half of the observed variation. Although burials from

the West Cluster have a tendency to be concentrated in one of the possible groups, individuals from the North Cluster often are more equally distributed. The cross tabulations thus demonstrate both differences and similarities between the two clusters rather than mutually distinct populations. The overlap between the two clusters is also clear from the very similar respective means for strontium (North = 0.70922; West = 0.70916) and oxygen (North = -4.86; West = -4.69). We propose the best interpretation of the isotope evidence based on the data presented in this study is that the West Cluster represents one segment of the North Cluster, possibly, for example, one branch of the same matriline. This conclusion differs from the results of earlier studies that have argued for more marked differences between the North and West Clusters based on non-metric cranial characteristics (e.g., Akins 1986, 2003; Schillaci et al. 2001). Our isotopic analysis, however, focuses on a different question than the phylogenetic relationships of interest in these other studies. The two different conclusions are thus not necessarily mutually exclusive.

Given the evidence we have presented and our analyses, we hypothesize that the initial construction of Chaco Canyon great houses *likely resulted more from sociocultural dynamics in the Canyon and nearby locales than from the migration into the canyon by people from the northern Southwest as has often been proposed*. Over time, sociocultural processes in the Canyon very likely attracted people from outside the Canyon, but few, if any, of those individuals were interred in the two unusual burial crypts in the largest and best known great house, Pueblo Bonito.

Acknowledgements

A number of individuals and institutions contributed to this research. We would particularly like to thank the following. Kerriann Marden sorted through the mass and mess of human remains from Pueblo Bonito at the Smithsonian NMNH and the American Museum of Natural History and spent months reuniting crania and their lower remains as part of her Doctoral Thesis at Tulane University. Kerriann also began a project with the remains from the West Cluster involving radiocarbon dating and isotope analysis as part of her research. The strontium isotope analysis was done though the Price Laboratory for Archaeological Chemistry at the University of Wisconsin-Madison. Our project on Pueblo Bonito and other burials in the northern Southwest began about the same time and we agreed that the strontium isotope data from Marden's project could be used in our study as well. We also measured lead isotopes on those same samples with Marden's permission. Our sincere thanks to Kerriann for her collaboration.

We also thank Fraser Neiman for running the principal components analysis for us and helping us with some of the interpretations of the data, not only the PCA scatter plot but also the histograms and the box-and-whisker plots, and Jakob Sedig for additional statistical assistance. In addition, we received good advice and suggestions from several individuals who kindly agreed to read the manuscript, including Larry Benson, Jay Quade, Alyson Thibodeaux, and Adam Watson. Much appreciated. We would also like to thank Paul Fullagar and the team at the Department of Geological Sciences at UNC, David Dettman at Arizona, and James Burton at the University of Wisconsin-Madison for their care in sample preparation and measurement for this project.

Samples for this project came from collections at the Peabody Museum at Harvard University, the American Museum of Natural History in New York City, the Field Museum in Chicago, and the National Museum of Natural History, Washington D.C. These repositories released samples following each institutions' internal policies and in accordance with all legal requirements governing research on human skeletons (NAGPRA). At the Peabody Curator Michele

Morgan was a great help. At the AMHN, Gisselle Garcia provided assistance and information for the sample collection. At the Field Museum, Jamie Kelly and Jonathan Haas were important liaisons for our sampling. Application for the samples and the actual sampling at NMNH was greatly facilitated by Doug Owsley and David Hunt, and Chris Dudar provided additional assistance. Chris also graciously shared data with us and focused our attention on cranial deformation as an important characteristic. Finally, we thank Jane Rousseau for her help with collecting the samples curated at NMNH.

This research was funded by the archaeology program at the US National Science Foundation and that support is gratefully acknowledged (Grant BCS-095705).

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Figure Captions

Fig. 1. The San Juan Basin in northwestern New Mexico and southwestern Colorado. The distribution of some of the Great House pueblos (red dots) is also shown on the map.

Fig. 2. Air photo of Pueblo Bonito in Chaco Canyon.

Fig. 3. Location of the northern and western burial clusters in Pueblo Bonito.

Fig. 4. Distribution of $^{87}\text{Sr}/^{86}\text{Sr}$ values in the San Juan Basin based on soil extracts (Benson et al. 2009). Chaco Canyon is the long rectangle in the right center of the map. The hatched line mark the state lines between New Mexico, Colorado, Utah, and Arizona.

Fig. 5. Comparison of lead isotope ratios between turquoise and human tooth enamel from Pueblo Bonito (red = turquoise, green = North Cluster, blue = West Cluster).

Fig. 6. Box-and-whisker plots of isotope ratios at Bonito compared to other sites in the northern Southwest.

Fig. 7. Scatter plot of $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ values for tooth enamel from the North and West Pueblo Bonito Clusters compared to the samples from settlements to the north, northwest, and west. Note that four non-Chaco Canyon samples have $^{87}\text{Sr}/^{86}\text{Sr}$ values that exceed 0.710 and do not fall within the range shown in this figure.

Fig. 8. Histograms of isotopic ratios in human tooth enamel at Pueblo Bonito.

Fig. 9. Scatter plot of $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\delta^{18}\text{O}$ for tooth enamel in the North and West Bonito burial clusters.

Figure 10. Distribution of individuals from the North and West burial clusters on the first two axes of the principal components analysis.

Table Captions

Table 1. Sex and location of burials in the North and West Cluster at Pueblo Bonito.

Table 2. $^{87}\text{Sr}/^{86}\text{Sr}$ values for small mammals from Pueblo Bonito (Grimstead et al. 2014).

Table 3. Lead isotope ratios in human enamel from Pueblo Bonito (Dudás et al. 2016).

Table 4. Pueblo Bonito Tooth Samples and Isotope Data

Table 5. Descriptive statistics for isotope ratios in human tooth enamel from Pueblo Bonito.

Table 6. Descriptive statistics for isotope ratios in human tooth enamel from settlements north of Chaco Canyon and t-tests comparing Pueblo Bonito with northern samples.

Table 7. Descriptive statistics for strontium, oxygen, and lead isotope ratios for North and West Clusters.

Table 8. Distribution of North and West cluster individuals on the x-axis of the PCA plot.

Table 9. Three possible groups within the distribution of individuals in the PCA plot.

Table 4. Pueblo Bonito Tooth Samples and Isotope Data. The sample marked with an asterisk is likely from Room 56 and thus has been included for completeness, but archival information on the provenience of the sample creates some ambiguity about its original provenience.

Lab #	Location	Museum#	Sex	Room	Sr	O	208/204	207/204	206/204
F5403	North 33	H/3668	M	33	0.7091	-4.7	39.430	15.768	20.318
F5404	North 33	H/3671	M	33	0.7091	-4.3	39.721	15.833	21.316
F5402	North 33	H/3666	F	33	0.7091	-3.7	39.593	15.808	21.103
F6173	North 33	H/3665	F	33	0.7093	-7.6	39.337	15.746	20.254
F5401	North 33	H/3663	F	33	0.7091	-4.8	39.584	15.805	21.011
F5405	North 33	H/3672	M	33	0.7091	-3.1	38.648	15.638	19.078
F6176	North 33	H/3670	M	33	0.7092	-3.7	38.713	15.636	19.282
F5399	North 33	H/3659	F	33	0.7093	-6.8	39.886	15.847	21.484
F6172	North 33	H/3664	M	33	0.7092	-4.4	38.582	15.636	19.101
F5400	North 33	H/3660	F	33	0.7092	-3.9	39.462	15.772	20.547
F6171	North 33	H/3661	M	33	0.7092	-4.2	39.192	15.749	19.994
F6952	North 56	1905.917.42543*	?	56	0.7092	-3.9	38.733	15.656	19.010
F6948	North 56	1897.513.42533	?	56	0.7090	-6.9	38.784	15.637	18.903
F6944	North 56	1987.513.42520	F	56	0.7093	-5.8	39.181	15.724	19.949
F6928	North 56	1897.513.42535	M	56	0.7092	-2.7	39.363	15.774	20.632
F6956	North 56	1897.513.42534	?	56	0.7094	-6.6	39.123	15.710	19.938
F6931	North 56	1897.513.42519	F	56	0.7094	-5.4	39.655	15.805	20.944
F6174	North 56	H/9167	M	56	0.7092	-3.1	38.442	15.611	18.855
F6180	North 56	H/5620	?	56	0.7091	-3.6	39.418	15.775	20.632
F6177	North 56	H/5621	?	56	0.7094	-6.9	39.206	15.728	20.041
F6179	North 56	H/5636	M	56	0.7094	-5.8	39.533	15.777	20.655
F9286	West	327059	F	320	0.7090	-3.8	38.687	15.640	19.109
F9287	West	327060	F	320	0.7091	-3.7	39.459	15.743	20.276
F9288	West	327061	F	320	0.7091	-4.7	39.050	15.689	19.525
F9289	West	327063	F	320	0.7093	-5.5	39.225	15.714	19.927
F9290	West	327063-A	F	320	0.7092	-4.7	38.672	15.668	19.165
F9291	West	327067	F	320	0.7091	-4.4	38.691	15.671	19.174
F8248	West	327058	F	320	0.7091	-3.9	38.651	15.649	19.168
F8252	West	327111	F	325	0.7091	-3.8	38.610	15.671	19.099
F8255	West	327077	F	326	0.7094	-4.3	38.791	15.693	19.433
F8249	West	327069	F	326	0.7094	-6.1	38.717	15.684	19.270
F9292	West	327068	M	326	0.7091	-4.9	39.334	15.741	20.306
F9293	West	327072	F	326	0.7090	-3.7	38.619	15.668	19.112
F9294	West	327073	F	326	0.7091	-4.6	38.675	15.677	19.178
F9295	West	327075	F	326	0.7091	-4.8	38.968	15.682	19.594
F8267	West	327066	F	326	0.7093	-4.1	38.572	15.661	19.102
F8260	West	327071	F	326	0.7094	-8.3	38.627	15.672	19.095
F8264	West	327076	F	326	0.7091	-5.2	38.972	15.685	19.431
F9296	West	327082	?	330	0.7091	-4.3	39.028	15.687	19.646
F9297	West	327084	M	330	0.7091	-4.0	38.657	15.671	19.154

F9298	West	327085	?	330	0.7091	-5.4	38.642	15.673	19.146
F9299	West	327087	?	330	0.7093	-5.3	39.521	15.776	20.634
F9300	West	327089	F?	330	0.7093	-5.1	39.284	15.734	20.162
F9301	West	327090	M	330	0.7092	-5.3	38.711	15.683	19.248
F9303	West	327096	F	330	0.7091	-5.3	39.218	15.740	20.198
F9304	West	327099	M	330	0.7091	-3.4	38.665	15.677	19.197
F8256	West	327100	M	330	0.7093	-5.0	38.773	15.676	19.246
F8261	West	327094	M	330	0.7091	-4.6	38.708	15.683	19.237
F8266	West	327088	M	330	0.7090	-4.8	38.645	15.677	19.156
F8250	West	327081	M	330	0.7092	-5.2	38.867	15.707	19.607
F8251	West	327101	M	330	0.7091	-3.4	38.675	15.682	19.209
F9305	West	320106	F	329	0.7091	-4.0	39.118	15.736	20.048
F9306	West	327112	M	329	0.7091	-4.0	39.539	15.803	20.965
F9307	West	327113	F	329	0.7092	-5.2	38.770	15.664	19.358
F9308	West	327117	F	329	0.7090	-5.2	39.369	15.764	20.471
F9309	West	327118	F	329	0.7091	-4.2	38.882	15.677	19.416
F9310	West	327112	F	329	0.7092	-4.6	39.024	15.676	19.498
F9311	West	327126	M	329	0.7094	-6.0	39.627	15.803	20.971
F8257	West	327104	C	329	0.7091	-5.2	38.645	15.671	19.145
F8258	West	327106	F	329	0.7092	-3.7	38.634	15.671	19.090
F8259	West	327130	DA	21	0.7091	-4.1	38.632	15.676	19.113