

## The geographic origins of Nasca trophy heads using strontium, oxygen, and carbon isotope data

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### ABSTRACT

Scholars continue to debate the identity of individuals curated as trophy heads in the Nazca Drainage of southern Peru (c. 1–800 AD). What was the role of trophy heads in Nasca society? Were they victims of warfare or venerated ancestors? Strontium, oxygen, and carbon isotope data from archaeological human tooth enamel from Nasca trophy heads from Aja, Cahuachi, Cantayo, Majoro Chico and Paredones, and from individuals buried in Nasca cemeteries at Cahuachi, Cantayo, and Majoro Chico elucidate the geographic origins and paleodiet of trophy heads in the Nazca Drainage. The  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $\delta^{18}\text{O}_{\text{C}(V\text{-PDB})}$  data from both the trophy heads and the Nazca Drainage burials are all quite variable, and do not support the hypothesis that the Nasca trophy heads were obtained from a geographically-distinct population. Similarly, the  $\delta^{13}\text{C}_{\text{C}(V\text{-PDB})}$  data demonstrates that the individuals included in this study consumed similar diets. These data suggest that the Nasca trophy heads likely derive from the local Nasca population. Rather than obtain heads from enemy warriors through geographic expansion or warfare as seen in other parts of the world, this complex social practice existed within the Nasca polity throughout space and time.

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The role of trophy heads in the Nasca polity (c. 1–750 AD) of southern Peru, and the identities of the individuals transformed into trophy heads, has been the subject of debate for over 90 years (Tello, 1918; Uhle, 1914). Were the trophy heads venerated ancestors or victims of warfare-related activities? What was their role in Nasca society? We present strontium, oxygen, and carbon isotope data from archaeological human tooth enamel from Nasca trophy heads from Aja, Cahuachi, Cantayo, Majoro Chico and Paredones, and from individuals buried in Nasca cemeteries at Cahuachi, Cantayo, and Majoro Chico to elucidate the geographic origins, paleodiet, and, ultimately, the role of trophy heads in the Nazca Drainage. We begin with a discussion of the archaeological contexts of Nasca trophy heads and previous research on their role in the Nasca polity, with a focus on the trophy heads collected by Alfred Louis Kroeber in 1925 and 1926.<sup>1</sup> We then introduce the biogeochemical techniques we use to examine the geographic origins of a sample of Nasca trophy heads. We then discuss our archaeological human enamel strontium, oxygen, and carbon isotope results from individuals who were transformed into trophy heads and individuals

buried at the Nazca Drainage sites of Aja, Cahuachi, Cantayo, Majoro Chico, and Paredones (Fig. 1). This follows with our interpretations regarding the role of trophy heads in Nasca society. Finally, we conclude with a discussion of potential avenues for future research on the origins of Nasca trophy heads.

### Nasca trophy heads

#### The Nasca polity

The Nazca Drainage of the arid southern Peruvian coast was home to the archaeological Nasca culture beginning around AD 1 (Fig. 1). During the Early Nasca period (AD 1–450, Nasca ceramic phases 2–4), a complex regional polity arose, characterized by a distinctive art style, specific ritual and mortuary activities, and a change in settlement patterns (Schreiber, 1999; Schreiber and Lancha Rojas, 2003; Silverman, 1993, 2002; Silverman and Proulx, 2002; Van Gijsegheem, 2006; Vaughn, 2004, 2005; Vaughn and Linares Grados, 2006). The important ceremonial center of Cahuachi was built during this time, and was a focus of pilgrimage, ritual activities, and feasting events held by local elites (Silverman, 1993, 2002; Valdez, 1994; Vaughn, 2004; Vaughn and Van Gijsegheem, 2007). During the subsequent Middle Nasca period (AD 450–550, Nasca ceramic phase 5), Cahuachi ceased to be a major pil-

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<sup>1</sup> We refer to the archaeological people as “Nasca” and the region as “Nazca”, following other scholars (Silverman, 1993).

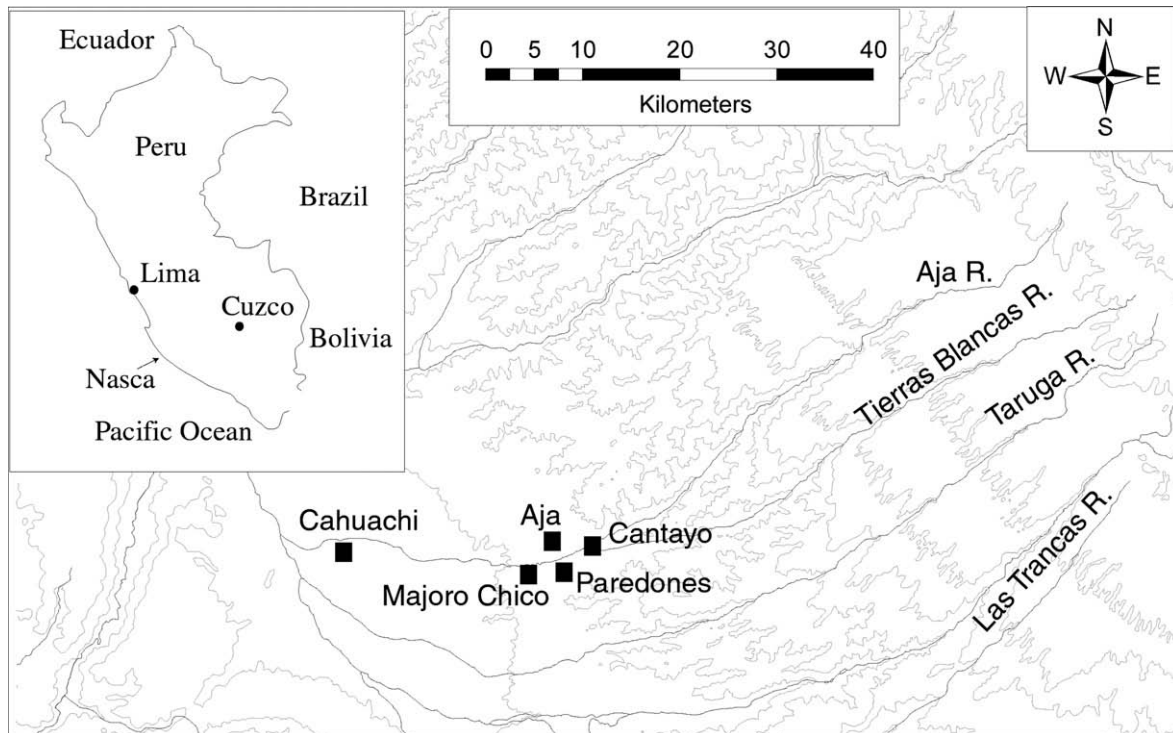


Fig. 1. Map of the Nazca Drainage of southern Peru with the sites included in this study.

grimage center and settlement patterns and irrigation practices changed, possibly as the result of a prolonged drought in the region (Isla and Reindel, 2006; Schreiber and Lancho Rojas, 2003; Silverman and Proulx, 2002). Finally, the Late Nasca period (AD 550–750, Nasca ceramic phases 6–7) is characterized by increasing sociopolitical complexity, warfare, and congregation into fewer larger sites (Schreiber, 1999; Schreiber and Lancho Rojas, 2003; Silverman and Proulx, 2002). During all of these periods, trophy heads were an important part of Nasca lifeways.

#### *An introduction to Nasca trophy heads*

Trophy heads, which we define here as human skulls that have been removed from the body after death and intentionally modified, often for display, have been documented at numerous Andean archaeological sites. Although iconographic depictions are more common, many modified human crania themselves have been documented in Paracas, Huarpa, and Wari contexts (Finucane, 2008; Pezzia Assereto, 1968; Tung, 2004, 2007, 2008; Tung and Cook, 2006; Tung and Owen, 2006; Verano, 1995). In addition, ethnohistoric data describes trophy taking in the Inka empire as well as the creation of drums, drinking cups, musical instruments and necklaces from the skin, skull, long bones, and teeth of conquered leaders (e.g. Betanzos, 1551 [1996]; Guaman Poma de Ayala, 1613 [1987]; Ogburn, 2006; Verano, 1995). Similarly, at least two modified human skulls have been documented at the Pyramids at Moche, and may have been transformed into drinking vessels (Verano, 2001; Verano et al., 1999).

However, the largest collection of trophy heads in the Andes comes from the Nasca polity. Since the first documentation of Nasca trophy heads (Tello, 1917, 1918; Uhle, 1914), more than 150 bioarchaeological examples have been discovered (Baraybar, 1987a; Browne et al., 1993, Carmichael, 1988; Carmichael, 1994, 1995; Drusini and Baraybar, 1989; Forgey and Williams, 2005; Kellner, 2002, 2006; Neira and Coelho, 1972; Proulx, 1971, 1989; Silverman, 1993; Tung, 2007; Ubbelohde-Doering, 1966; Verano, 1995, 2003; Williams et al., 2001). In addition, there are examples

of headless burials or burials with mortuary artifacts but no bodies (Carmichael, 1988; Conlee, 2007; DeLeonardis, 2000; Howell, 2007; Ubbelohde-Doering, 1966, p. 143). There is also a rich and well-documented record of Nasca iconography involving trophy heads, including the depiction of trophy heads associated with design elements like the Anthropomorphic Mythical Being, the Trophy Head Taster, the Mythical Killer Whale, and the Horrible Bird (see examples and discussion in Carmichael (1994), Carmichael (1995), Proulx (1970): plates 9, 23, 26, 31, 1971, 1989, 2001, 2006: 66, 68, 82, 84, 105–109, 114, 124, Quilter (2005, p. 71–73), Silverman and Proulx (2002), Verano (1995, p. 216, 231)).

Nasca trophy heads are characterized by the perforation of the frontal bone, which allowed the trophy head to be suspended with a woven cord (Verano, 1995, 2003; Williams et al., 2001). In addition, the foramen magnum was generally widened to enable the removal of the brain and other soft tissues (Forgey and Williams, 2005; Verano, 1995, 2003; Williams et al., 2001). However, despite these unifying characteristics, there was much variability in the creation of Nasca trophy heads. For example, the position and size of the frontal perforation varies and the enlargement of foramen magnum varies widely (Williams et al., 2001). In addition, the suspensory cord through the frontal bone could be made of cotton, vegetable fibers, or human hair (Verano, 1995, 2003). The variability in Nasca trophy heads is also seen in iconographic depictions (Proulx, 2006, p. 105–109). This is in contrast to Wari trophy heads, for example, which are perforated at the osteological point of bregma on the top of the cranium and are very standardized in their preparation (Tung, 2004, 2007, 2008).

The contexts in which Nasca trophy heads have been found, and the contexts in which they were used, also varies widely. Both iconographic and archaeological evidence depicts the placement of multiple trophy heads in large caches of as many as 48 individual heads (Browne et al., 1993; Proulx, 2001). A number of trophy heads have been included as mortuary offerings in burials at Nasca sites such as Cantayo, Majoro Chico, and Chaviña (Kroeber and Collier, 1998; Ubbelohde-Doering, 1966, p. 142), though there is not a correlation between burial type and the presence or absence of a

trophy head (see Nasca mortuary information in Carmichael (1995), DeLeonardis (2000), Isla and Reindel (2006), Silverman and Proulx (2002)). Iconographically, trophy heads have been depicted in a burial scene on a Nasca 5 or 6 ceramic vessel, which depicts individuals playing panpipes and, in the case of one individual, holding a trophy head, next to a large mummy bundle (Proulx, 2001, p. 135, 2006, plate 23). Finally, some trophy heads were excavated in the context of architectural spaces. For example, Kowta (1987, p. 66) excavated a row of five cooking vessels at the site of Tambo Viejo, each of which contained a trophy head. At Cahuachi, Silverman (1993, p. 156, 220) excavated a trophy head placed into a cist located inside a room at the top of Mound 19 while at Majoro Chico, Kroeber found two trophy heads buried along the walls of a structure (Kroeber and Collier, 1998, p. 49, 50). However, trophy heads are not found at all Nasca sites, particularly residential sites (e.g., Conlee, 2007; Vaughn and Linares Grados, 2006).

#### *Trophy heads from the Kroeber collection at the Field Museum of Natural History*

Here, we focus on the trophy heads of the Kroeber collection at the Field Museum of Natural History. Alfred Louis Kroeber collected 18 trophy heads as well as burials from the Nazca Drainage sites of Aja, Cahauchi, Cantayo, Las Cañas, Majoro Chico, and Paredones in 1925 and 1926 (Fig. 1) (Kroeber and Collier, 1998; Williams et al., 2001). These trophy heads have been the subject of detailed osteological analyses, which have documented variability in preparation, such as the size and placement of the perforation of the frontal bone, as well as the diverse age and sex distribution of the individuals, the presence of anterioposterior cranial modification styles, and relatively little evidence of trauma or poor health (Fig. 2) (Forgey and Williams, 2003, 2005; Williams et al., 2001).

The trophy heads in the Kroeber collection were discovered in a variety of archaeological contexts, including in caches of trophy heads, in burials of other individuals, where they were presumably



**Fig. 2.** An example of one of the trophy heads collected by Alfred Louis Kroeber from the site of Cahuachi and included in this study (FMNH-171097, ACL-0278). The perforation of the frontal bone is clearly visible, as well as a suspensory cord. (Photograph courtesy of The Field Museum, negative number A113639 (object number 171097).

mortuary artifacts, and in architectural features (Kroeber and Collier, 1998; Williams et al., 2001). In addition, the archaeological contexts of these trophy heads represent a variety of Nasca sites, from the massive pilgrimage and ceremonial center of Cahuachi (Silverman, 1993) to the early Nasca cemeteries of Aja and Cantayo (Kroeber and Collier, 1998; Williams et al., 2001). Paredones is also a Nasca cemetery, although the later Inka occupation has obscured any possible traces of Nasca habitation, and the site of Majoro Chico consists of burials associated with adobe walls (Carmichael, 1988; Kroeber and Collier, 1998; Williams et al., 2001).

#### **The role of trophy heads in the Nasca polity**

The role of Nasca trophy heads has been a subject of debate since the first trophy heads were documented, and Uhle (1914) and Tello (1918) first postulated a primarily militaristic or ritual function, respectively, of the trophy heads (Forgey and Williams, 2003, 2005; Williams et al., 2001). Here, we first discuss the iconographic, archaeological and ethnographic evidence for the ritual role of Nasca trophy heads in agricultural fertility. We then discuss the militaristic functions of the Nasca trophy heads, followed by a discussion of the geographic origins of the trophy heads. However, we note that these roles are not mutually exclusive, and may also represent temporal or spatial variability in Nasca trophy heads (DeLeonardis, 2000; Forgey and Williams, 2005).

#### *Nasca trophy heads and agricultural fertility*

In Nasca iconography, there is clear evidence for a relationship between trophy heads and agricultural fertility (Browne et al., 1993; Carmichael, 1994, 1995; Conlee, 2007; DeLeonardis, 2000; Proulx, 2006; Roark, 1964, 1965; Silverman, 1993). For example, Proulx (2006, p. 109–110) writes that, “[i]n the Nasca worldview, the taking of trophy heads provides the supernatural power necessary for the growth of plants, and plants and trophy heads are often seen as interchangeable. Indeed we can see the transformation of “morphing” of trophy heads into plants on some of the pottery vessels. A good example is the presence of trophy head features (eyes, mouth, hair hanks) on the exposed ears of corn emerging from their husks.” Other scholars have emphasized the ritual role of the trophy heads as well, including the role of ritualized warfare to obtain the trophy heads (e.g. Baraybar, 1987b; Neira and Coelho, 1972). Finally, burial treatment and placement of headless bodies who had been transformed into trophy heads demonstrates the linkages between the decapitation and trophy heads and the ancestors, agricultural fertility, regeneration and rebirth (Conlee, 2007). These themes are common throughout the Andean archaeological and ethnographic record, and are intimately related to rituals concerning rainmaking (Arnold and Hastorf, 2008).

The importance of human trophies in ritual activities is demonstrated by this excerpt from *The Huarochirí Manuscript*, which addresses the role of *huayos*, or masks made from the skin and bones that retained the facial characteristics of the individual after death (Salomon and Urioste, 1991, p. 120–121).

If they captured a man in warfare, they would first flay his face, and then make it dance, saying “This is our valor!”

And when a man was taken prisoner in war, that man himself would say, “Brother, soon you’ll kill me. I was a really powerful man, and now you’re about to make a *huayo* out of me. So before I go out onto the plaza, you should feed me well and serve me drinks first.”

Obedying this, they’d offer food and drinks to the other *huayos*, saying, “This day you shall dance with me on the plaza.”

They actually used to bring out the *huayos* and carry them in a litter for two days. On the following day, they'd hang them up together with their maize, potatoes, and all the other offerings. About the hanging of the *huayos*, people remarked, "The *huayos* will return to the place where they were born, the place called Uma Pacha, carrying these things along with them."

While we recognize the danger of incautiously applying ethno-historic and ethnographic data to understand Andean archaeology, this passage demonstrates the relationship between *huayos*, ritual offerings, feasting, and display of human trophies. It is possible that Nasca trophy heads, with their clear relationship to agricultural fertility, were used in similar ways.

#### *The militaristic functions of Nasca trophy heads*

Despite the clear ritual importance of Nasca trophy heads, and particularly their associations with fertility, regeneration, and rebirth, there is also iconographic evidence for their association with warfare and violence. A predominately militaristic function for the Nasca trophy heads was first hypothesized by Uhle (1914), who have been joined by other scholars as well (e.g. Metraux, 1949; Pezzia Assereto, 1968; Roark, 1964, 1965; Zuidema, 1971). In addition, some scholars have argued that, while the trophy heads came from individuals killed or taken in battle, the trophy heads ultimately had a ritual function (Baraybar, 1987a; Proulx, 1989, 2001; Tello, 1918), as has been hypothesized for the Moche of northern Peru (see overview in Sutter and Cortez, 2005). Other scholars have argued that the warfare itself was primarily ritual in nature, and undertaken in order to obtain the trophy heads (Neira and Coelho, 1972). Ritual warfare may have been similar to the contemporary Andean *tinku*, in which members of the same community or neighboring communities engage in ritual battles (e.g., Allen, 1988; Arkush and Stanish, 2005; Platt, 1986). Heads taken in warfare could be important political symbols, actively used to generate political change, modify or expand territorial borders, or acting as a symbolic basis of power and authority (see detailed discussion in Arnold and Hastorf (2008)).

Figures interpreted as Nasca warriors are depicted on Nasca ceramics with clubs, spears, slings, and trophy heads; these objects are found archaeologically as well (Proulx, 2001, 2006). In addition, there are rare examples of battle scenes on Nasca pottery (Proulx, 2001, 2006). Finally, Kellner (2002) documented evidence for trauma and violent conflict throughout all Nasca phases, but found that it peaked during the Late Nasca period and corresponded with an increase in trophy taking.

Although trophy heads are depicted in Nasca iconography in all ceramic phases, the number and variety of trophy head images may increase in phases 5–7 (Proulx, 1989, 1994, 2006). During these ceramic phases, trophy heads are increasingly associated with figures identified as warriors (Browne et al., 1993; Proulx, 2006; Roark, 1964, 1965; Silverman and Proulx, 2002). During the subsequent Middle Horizon (Loro phase), the iconographic representations of trophy heads decrease (Proulx, 2006, p. 105), although the osteological evidence for the preparation of trophy heads is not different from earlier phases (Kellner, 2002, 2006).

#### *The geographic origins of Nasca trophy heads*

The debate over the ritual or militaristic functions of the Nasca trophy heads is an integral aspect of the debate over the geographic origins of the trophy heads. More specifically, some scholars have argued that the trophy heads were derived from individuals who were vanquished warriors, either from Nasca populations (e.g. Proulx, 2001) or populations perceived as foreign (e.g. Proulx, 1989). Alternatively, the trophy heads may have derived from victims of raiding (Williams et al., 2001). Finally, Neira and

Coelho (1972) argue that the trophy heads were obtained purely for ritual functions and were objects of ancestor veneration (see also Carmichael, 1995; DeLeonardis and Lau, 2004; Tello, 1918), while Conlee (2007, p. 442) has argued that a headless burial at La Tiza represented a local, although low-status, individual.

Were the individuals transformed into trophy heads enemy warriors from other parts of the Andes, or were they drawn from the same population as the individuals buried in Nasca graves at Nasca sites? Proulx (2001, p. 129) argues that, "it seems most likely that the various Nasca chiefdoms were fighting among themselves for access to resources, particularly water and additional land for agriculture. In the battle scenes on the pottery, little difference in dress, weaponry, and bodily depiction is shown...". However, it is also possible that the individuals transformed into trophy heads were from populations perceived as non-local or "foreign", and Proulx (2001, p. 129) points out that there is iconographic evidence for both local and non-local enemies.

The age and sex distribution of the Nasca trophy heads consists predominately of adult males but contains adult females and subadults as well (Kellner, 2006; Verano, 1995; Williams et al., 2001). Some scholars have argued that the predominately adult males who were transformed into trophy heads were vanquished warriors (Tello, 1917; Verano, 1995). However, the trophy heads may have been primarily ritual offerings or objects of ancestor veneration given the presence of adult females and males as well as juveniles (Forgey and Williams, 2005; Tello, 1918).

When present, cranial modification styles of Nasca trophy heads are anteroposterior (also called fronto-occipital), which is associated with the Nasca and has been used to argue for a predominately local, Nasca origin of the individuals transformed into trophy heads (Tello, 1918; Verano, 1995). However, cranial modification styles vary widely in the Andes (e.g. Blom, 2005a,b; Gerszten, 1993; Hoshower et al., 1995; Lozada Cerna and Buikstra, 2002; Lozada Cerna and Buikstra, 2005; Torres-Rouff, 2002, 2007), and in the Nazca Drainage (Kellner, 2002). In addition, cranial modification style does not always correspond to geographic origin (Knudson and Blom, in press; Knudson and Buikstra, 2007; Torres-Rouff and Knudson, 2007).

Therefore, despite much research on the origins of the Nasca trophy heads and their role, many questions remain. In fact, Forgey and Williams (2005, p. 274) wrote that, "...standard osteological analyses cannot resolve adequately the question of whether Nasca trophy heads were made from heads taken from enemies or ancestors. Previous researchers attempted to use indirect information to infer trophy head origins, basing their arguments on demography, cause of death, burial context, shared cultural traits, and preparation methods. Unfortunately, none of these arguments can answer the fundamental questions about the source of the heads." Here, we use biogeochemistry to identify the geographic origins of trophy heads in the Kroeber collection to elucidate the role that they played in the Nasca polity. The techniques used are described in more detail below.

#### **Biogeochemical approaches to residential mobility and paleodiet**

Biogeochemical techniques have increasingly been used to identify the movement of animals (e.g. Ashford and Jones, 2006; Dufour et al., 2007; Hoppe et al., 1999; Ingram and Weber, 1999; Killingley, 1980; Schweissing and Grupe, 2003; Sykes et al., 2006) and plants (e.g. Benson et al., 2006; English et al., 2001). In archaeology, these techniques can identify residential mobility and geographic origins in past populations (e.g. Bentley et al., 2007; Buzon et al., 2007; Evans et al., 2006; Knudson et al., 2005; Montgomery et al., 2005; Price et al., 2006; Prowse et al., 2007; Wright,

2005). Here, we use strontium, oxygen, and carbon isotope analyses of archaeological human tooth enamel from the Nazca Drainage to compare the geographic origins of individuals buried in the cemeteries at Cahuachi, Cantayo, and Majoro Chico with the geographic origins of individuals transformed into trophy heads at the Nasca sites of Aja, Cahuachi, Cantayo, Majoro Chico, and Paredones. The advantages and disadvantages of each technique are discussed below.

Briefly, strontium isotope signatures ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) vary according to the age and initial composition of the bedrock in a given region, with smaller inputs from atmospheric and other sources (see Bentley, 2006; Bern et al., 2004; Faure, 1986). The  $^{87}\text{Sr}/^{86}\text{Sr}$  signature is not fractionated as it moves from the bedrock, soil, plants and animals in an ecosystem (Aberg, 1995; Blum et al., 2000), so the strontium consumed and imbibed by an individual will reflect the strontium isotope signatures in the geologic regions in which the plants, animals and water originated (see Bentley, 2006). Strontium then substitutes for calcium in hydroxyapatite in enamel and bone (Carr et al., 1962; Dolphin and Eve, 1963; Hodges et al., 1950; Kulp and Schulert, 1962). Since bone is continually remodeling, bone strontium isotope signatures reflect the place of residence during the period of bone formation before death. On the other hand, enamel strontium isotope signatures reflect place of residence during enamel formation in the first years of life. Therefore, if local strontium sources were consumed, strontium isotope signatures in human enamel and bone can be used to identify migration and residential mobility in the past (Ericson, 1985, 1989; Krueger, 1985; Price et al., 1994; Sealy et al., 1991; Sillen et al., 1989).

In contrast, oxygen isotope signatures ( $\delta^{18}\text{O}$ ) vary according to a number of environmental factors such as distance from the ocean, latitude, temperature, and altitude because of differential treatment of  $^{18}\text{O}$  and  $^{16}\text{O}$  during processes like evaporation (Bowen and Wilkinson, 2002; Craig, 1961a; Dansgaard, 1964; Epstein and Mayeda, 1953; Gat, 1996; Gonfiantini et al., 2001; Koch, 1998; Pogue and Chamberlin, 2001; Scholl et al., 2002; Stern and Blisniuk, 2002). This variability is useful to archaeologists since the oxygen from drinking water and food sources is incorporated into human enamel and bone hydroxyapatite phosphate and carbonate, and  $\delta^{18}\text{O}$  in body water will equilibrate with the  $\delta^{18}\text{O}$  in hydroxyapatite, if body temperature is constant (Longinelli, 1984; Luz and Kolodny, 1985; Luz et al., 1984). As in strontium isotope analysis, oxygen isotope signatures in tooth enamel will reflect the oxygen isotope sources imbibed or consumed during enamel formation in childhood, while bone  $\delta^{18}\text{O}$  will reflect the oxygen sources from the last years of life. When drinking water is from local sources that reflect place of residence, oxygen isotope analysis can identify residential mobility (e.g. Prowse et al., 2007; White et al., 1998, 2000, 2001, 2002, 2004a,b, 2007). However, the weaning process can affect oxygen isotope results in enamel that formed while the individual was still consuming breast milk because human breast milk is enriched in  $^{18}\text{O}$  relative to imbibed water (Roberts et al., 1988). As discussed below, multiple lines of evidence, including carbon isotope signatures, can be used to elucidate the weaning process and interpret oxygen isotope results.

Finally, carbon isotope signatures ( $\delta^{13}\text{C}$ ) reflect variability in diet. Plants utilize carbon according to  $\text{C}_4$ ,  $\text{C}_3$ , or CAM photosynthetic pathways, which result in different carbon isotope signatures for different plant types (see overviews in Katzenberg, 2000; Lee-Thorp and Sponheimer, 2006; Schoeninger and Moore, 1992; Tykot, 2006). Carbon isotope analysis has become a very useful tool in archaeology, and has been used to understand the differential consumption of  $\text{C}_4$  plants, like maize (*Zea mays*), and, when used with nitrogen isotope analysis, marine resource consumption (e.g. Bourbou and Richards, 2007; Finucane, 2007; Müldner and Richards, 2007; Richards et al., 2007). Many carbon isotope

studies focus on the carbon isotope signatures in bone collagen ( $\delta^{13}\text{C}_{\text{collagen}}$ ), which largely reflect the carbon in the protein sources in the diet (Ambrose and Norr, 1993; Jim et al., 2004). Some researchers also utilize the carbon isotope signatures in bone and enamel hydroxyapatite ( $\delta^{13}\text{C}_{\text{apatite}}$ ) in addition to or instead of  $\delta^{13}\text{C}_{\text{collagen}}$ , which allows a better understanding of the carbon sources in the whole diet (Ambrose and Norr, 1993; Jim et al., 2004; Kellner and Schoeninger, 2007). In addition,  $\delta^{13}\text{C}_{\text{apatite}}$  in tooth enamel can be used to examine childhood diet and the weaning process (Dupras et al., 2001; Dupras and Tocheri, 2007; Fuller et al., 2006a, 2006b; Herring et al., 1998; Katzenberg et al., 1996; Richards et al. 2002; Turner et al. 2007; Williams et al. 2005; Wright and Schwarcz 1998, 1999).

## Isotope signatures in the Central Andes

### Baseline strontium isotope data from the Central Andes

The Nazca Drainage system is predominately composed of Quaternary sedimentary geologic formations with alluvial and riverine soils (Bellido et al., 1956). The adjacent highlands, which are composed primarily of Cenozoic volcanic rocks, contribute to the alluvial and riverine soils (Bellido et al., 1956). Strontium isotope data from exposed bedrock in the Nazca Drainage is not yet available. However, it is expected that the values will be similar to the Cenozoic volcanic rocks in the adjacent highlands, which are approximately  $^{87}\text{Sr}/^{86}\text{Sr} = 0.706$  in the Central Andes, based on isotope analyses of exposed bedrock and modern and archaeological fauna (Hawkesworth et al., 1982; James, 1982). There is a north–south trend in strontium isotope signatures in the Cenozoic volcanic rocks of the Andes, with higher strontium isotope signatures in the south (Francis et al., 1977; Hawkesworth et al., 1982; James, 1982; Klerkx et al., 1977). The terrestrial, coastal values are in contrast to the strontium isotope signature of seawater, which is  $^{87}\text{Sr}/^{86}\text{Sr} = 0.7092$  (Veizer, 1989). Seawater may contribute its strontium isotope signature through the consumption of strontium in marine products or through sea spray (e.g. Whipkey et al., 2000).

Although understanding the underlying bedrock geology of the Nazca Drainage, and the Central Andes more generally, is an important first step in understanding strontium isotope values, it is important to examine the bioavailable strontium isotope signatures in the study region as well. In the Andes, small modern and archaeological faunal samples have been used to estimate the bioavailable strontium isotope signatures in given areas, particularly when the animals obtain their strontium from the same sources, and in some cases the same field systems, as were used in the past. The faunal values represent the bioavailable strontium in small, well-defined regions. In the Andes, faunal strontium isotope signatures have generally supported the expected strontium isotope signatures based on the geologic literature (Knudson and Buikstra, 2007; Knudson and Price, 2007; Knudson et al., 2004). In the southern Nazca Drainage, Buzon et al. (2008) analyzed archaeological and modern rodent bones from the sites of La Tiza and Pajonal Alto. One way to define the “local” strontium isotope range is by the faunal mean plus and minus two standard deviations (Price et al. 2002); using this definition, the local range for the southern Nazca Drainage is  $^{87}\text{Sr}/^{86}\text{Sr} = 0.70559\text{--}0.70727$  (Buzon et al., 2008).

### Baseline oxygen isotope data from the Central Andes

Worldwide,  $\delta^{18}\text{O}$  in precipitation, or meteoric water ( $\delta^{18}\text{O}_{\text{mw}}$ ), decreases with increasing altitude, increasing distance from the coast, decreasing temperature, and increasing latitude (Bowen and Wilkinson, 2002; Craig, 1961a; Dansgaard, 1964; Epstein and Mayeda, 1953; Gat, 1996; Gonfiantini et al., 2001; Koch, 1998; Po-

age and Chamberlin, 2001; Scholl et al., 2002; Stern and Blisniuk, 2002). The altitudinal and environmental variability in the Andes ensures that  $\delta^{18}\text{O}_{\text{mw}}$  is similarly variable. For example, precipitation near Puno, Peru exhibited  $\delta^{18}\text{O}_{\text{mw}(V-SMOW)} = -13.3 \pm 5.3$  ( $n = 20$ ,  $1\sigma$ ) between 2001 and 2002 (IAEA/WMO, 2006), while  $\delta^{18}\text{O}_{\text{mw}} = -5.6 \pm 2.3$  ( $n = 16$ ,  $1\sigma$ ) on the coast in La Serena, Chile, between 1988 and 2002 (IAEA/WMO, 2006, see also Squeo et al., 2006). Similar altitudinal effects are seen  $\delta^{18}\text{O}$  from springs located at different altitudes but at the similar latitudes and longitudes, where  $\delta^{18}\text{O} = -5.1$  (105 m.a.s.l.),  $\delta^{18}\text{O} = -6.1$  (990 m.a.s.l.),  $\delta^{18}\text{O} = -7.1$  (1450 m.a.s.l.), and  $\delta^{18}\text{O} = -8.6$  (2020 m.a.s.l.) (IAEA/WMO, 2006).

#### Baseline carbon isotope data from the Central Andes

Since maize (*Zea mays*) fixes carbon using a different photosynthetic pathway (the  $\text{C}_4$  or Hatch–Slack pathway) than most other plants, which use the  $\text{C}_3$ , or Calvin, photosynthetic pathway,  $\text{C}_4$  plants generally exhibit  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})} = -9\text{‰}$  to  $-14\text{‰}$  while  $\text{C}_3$  plants exhibit  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})} = -20\text{‰}$  to  $-35\text{‰}$  (Katzenberg, 2000). In the Andes, isotopic analyses of both modern and archaeological plant materials have shown that maize (*Zea mays*) exhibits  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})} = -10\text{‰}$  to  $-14\text{‰}$  (DeNiro and Hastorf, 1985; Tieszen and Chapman, 1992). Commonly-consumed  $\text{C}_3$  plants such as beans (*Phaseolus* sp.), squash (*Cucurbita* sp.), and potatoes (*Solanum* sp.) exhibit much more negative carbon isotope signatures and  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})} = -22\text{‰}$  to  $-29\text{‰}$  (DeNiro and Hastorf, 1985; Tieszen and Chapman, 1992). Marine foodwebs investigated by Tieszen and Chapman (1992) exhibited  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})}$  values that were intermediate between those of  $\text{C}_3$  and  $\text{C}_4$  plants. Finally, terrestrial animals, including camelids, had more negative values, and averaged  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})} = -22\text{‰}$  (Tieszen and Chapman, 1992), although other camelid populations in the Andes consumed more  $\text{C}_4$  plants like maize and exhibited more positive  $\delta^{13}\text{C}_{\text{C}(\text{VPDB})}$  values (e.g. Finucane et al., 2006). On average, hydroxyapatite carbonate in the humans and other animals that consume the plants will reflect the isotopic composition of the diet, plus 9.4‰ (Ambrose and Norr, 1993).

#### Dietary strontium, oxygen, and carbon sources in the Central Andes

Based on iconography and archaeology, the Nasca subsistence economy was based on irrigation agriculture with supplemental products from the rich marine ecosystem and domesticated animals such as guinea pigs (*Cavia porcellus*) and camelids (*Lama glama* and *Lama alpaca*). Nasca ceramic iconography depicts beans (*Phaseolus lunatus*, *Phaseolus vulgaris* and *Canavalia plagioperma*), squash (*Cucurbita* sp.), chile peppers (*Capsicum* sp.), maize (*Zea mays*), peanuts (*Arachis hypogaea*), root crops like jicama (*Pachyrhizus tuberosus*), achira (*Canna edulis*) and manioc (*Manihot esculenta*), and fruits like lucuma (*Pouteria lucuma*), and pepino (*Solanum muricatum*) (Proulx, 2006). Archaeologically, these were all recovered in Silverman's (1986, 1993) excavations at Cahuachi, as were other tubers such as sweet potatoes (*Ipomoea batatas*) and potatoes (*Solanum* sp.) and fruits like *paca* (*Inga feuillei*) and *guayaba* (*Psidium guajava*); a similar botanical assemblage at the site of Pajonal Alto, whose occupation spanned the Middle Horizon through the Late Horizon periods, shows little temporal variation in Nazca Drainage subsistence patterns (Conlee, 2000). The rich marine ecosystem of the Pacific Ocean was also important in the Nasca polity. Iconographically, a large number of fish and crustaceans were portrayed (Proulx, 2006), and archaeological evidence exists for the exploitation of fish like *corvina* (*Sciaena gilberti*) and various mollusk species (Isla, 1992, Rodríguez de Sandweiss, 1993). However, at the Early Nasca village site of Marcaya, the small quantities of shellfish remains lead Vaughn (2000, p. 464) to write that, "these resources would have amounted to only an ex-

tremely small portion of the diet." Finally, the iconographic and archaeological data have been confirmed by recent isotopic analyses of Nasca paleodiet in the Las Trancas Valley, which demonstrates dietary breadth and access to a wide variety of terrestrial resources (Kellner and Schoeninger, 2008).

Based on the isotopic, archaeological, and iconographic evidence for Nasca subsistence, we argue that the main sources of strontium in the Nasca diet would have likely come from high-calcium terrestrial products such as beans and leafy green vegetables, since strontium concentrations are highest in plant leaves (e.g. Burton and Wright, 1995; Comar et al., 1957; Elias et al., 1982; Lee, 1959; Runia, 1987). While maize was an important crop and was likely consumed as *chicha*, or corn beer (Kellner and Schoeninger, 2008), maize kernels are low in calcium, and hence strontium, and so would not have contributed large amounts of strontium to the diet (e.g. Burton and Wright, 1995; Runia, 1987). However, maize consumption will be visible in the carbon isotope signatures in archaeological human remains, as documented in hydroxyapatite collagen and apatite from other parts of the Andes (Burger and van der Merwe, 1990; Falabella et al., 2007, 2008; Fernández et al., 2003; Finucane, 2007, 2008; Finucane et al., 2006; Gil et al., 2006; Gil, 2003; Hastorf, 1990; Kellner and Schoeninger, 2008; Knudson et al., 2007; Slovak, 2007; Tomczak, 2001, 2003; Turner et al., 2006; Tykot et al., 2006; Tykot and Staller, 2002; Ubelaker et al., 1995; Verano and DeNiro, 1993; Wilson et al., 2007).

Camelids were likely valuable for their meat as well as their wool. While these animals are associated with the high-altitude *puna* region, there is evidence that camelids were raised on the coast as well. They are common in iconographic representations in Nasca ceramics (Proulx, 2006), where they are portrayed being lead with tethers (Carmichael, 1988: plate 26, Proulx, 2006, p. 145), as well as in archaeological contexts (Silverman, 1993; Valdez, 1988, 1994). Additionally, Valdez (1994) has argued that their age and sex distribution points to local control of the herds. Therefore, it is most likely that consumed domesticated camelids were raised locally. However, unless the bones were consumed, camelid meat would be relatively low in calcium, and therefore low in strontium (e.g. Elias et al., 1982). Individuals who consumed domesticated camelids that consumed maize would exhibit a carbon isotope signature consistent with  $\text{C}_4$  plant consumption (e.g. Finucane et al., 2006).

Marine products were likely consumed by inhabitants of Nasca sites, but were likely not a large source of strontium if only the flesh was consumed. If small fish like anchovies were consumed whole, the strontium in the bones would contribute the strontium isotope signature of seawater ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.7092$  (Veizer, 1989)). While nitrogen isotope data to evaluate Nasca consumption of marine products has not yet been generated for the Kroeber collection, carbon and nitrogen isotope analyses of bone collagen from the Las Trancas Valley shows little consumption of marine products (Kellner and Schoeninger, 2008). Paleodiet data from other populations on the South Coast of Peru has demonstrated variable consumption of marine products (Knudson et al., 2007; Slovak, 2007; Tomczak, 2003) and some populations on the South Coast, like the Chiribaya, were clearly consuming marine products yet obtained their strontium from terrestrial sources rather than marine sources (Knudson and Buikstra, 2007; Knudson and Price, 2007).

While there is no evidence that inhabitants of Nasca sites consumed large amounts of imported foods, it is possible that salt was imported from the highlands. Although not a large part of the diet, salt can contribute a large number of minerals and strontium to the diet (Wright, 2005). While salt can be obtained through solar evaporation from sea water (e.g. McKillop, 2002; Williams, 2002), there is no evidence for this process on the southern Peruvian coast, to our knowledge (but see northern coastal sources in Weismantel, 1988). Instead, it is more likely that the salt was ob-

tained from the highlands, where large *salares*, or salt pans, are an important source of salt (e.g. Broman, 1983; Harris, 1985). Alternatively, salt could have been obtained from evaporation of surface and spring water (e.g. Santley, 2004).

Finally, drinking water sources for inhabitants at Nazca Drainage sites ultimately derive largely from precipitation in the highlands to the east. Most of the water used for drinking and irrigation is obtained from *pukios*, which are complex horizontal wells that access subsurface water, generally derived from rainfall in the highlands (Clarkson and Dorn, 1995; Schreiber and Lancho Rojas, 2003; Silverman, 2002). While the Nazca Drainage also contains rivers that bring precipitation from the adjacent highlands down to the Pacific Ocean, the rivers go underground or dry up in parts and river output is very low most years (Schreiber and Lancho Rojas, 2003). In general, the oxygen isotope signatures in the Nazca Drainage will derive from highland rainfall, which will exhibit relatively low  $\delta^{18}\text{O}_{\text{mw}}$  values that reflect the altitude and distance from the ocean (Craig, 1961a; Dansgaard, 1964; Epstein and Mayeda, 1953; Gat, 1996; Gonfiantini et al., 2001; Poage and Chamberlin, 2001). However, the evaporation that occurs in the *pukios* will ensure that the water is enriched in  $^{18}\text{O}$  relative to  $^{16}\text{O}$ , which will result in a higher  $\delta^{18}\text{O}$  signature. For example, surface water from coastal rivers in northern Peru exhibit  $\delta^{18}\text{O}_{(\text{V-SMOW})} = -3.3$  to  $-5.7$  (IAEA/WMO, 2006).

## Methodology for strontium, oxygen, and carbon isotope analysis

### Sampling strategy

All individuals included in this study had been included in previous osteological analyses and are currently part of the Kroeber collection at the Field Museum of Natural History (Table 1) (Wil-

liams et al., 2001). We collected enamel samples from all individuals with teeth, for a total of 16 out of 18 trophy heads from the sites of Aja, Cahuachi, Cantayo, Majoro Chico and Paredones. This represents an approximately 10–15% sample of known Nasca trophy heads. One tooth enamel sample was collected from each individual (Table 2). Comparative samples were collected from burials from the sites of Cahuachi, Cantayo, and Majoro Chico. When possible, a first molar was collected, although other dental elements were analyzed when necessary. These dental elements will reflect the isotope signature incorporated during enamel formation between approximately 10 weeks before birth for the first molar and 15–20 years of age for the third molar, although third molar crown formation times are highly variable (Hillson, 1996).

### Laboratory methods

At the Field Museum of Natural History, the teeth were mechanically cleaned by abrasion and then approximately 20 mg of tooth enamel was removed as has been described elsewhere (Knudson and Price, 2007; Knudson et al., 2004; Knudson et al., 2005). Radiogenic strontium isotope analyses of archaeological enamel ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) were performed at the Isotope Geochemistry Laboratory in the Department of Geological Sciences at the University of North Carolina at Chapel Hill. Strontium was separated from the sample matrix using EiChrom SrSpec resin, a crown-ether Sr-selective resin (50–100  $\mu\text{m}$  diameter) loaded into the tip of a 10 mL Bio-Rad polypropylene column. The UNC VG Sector 54 thermal ionization mass spectrometer (TIMS) instrument was in quintuple-collector dynamic mode using the internal ratio  $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$  to correct for mass fractionation. Recent analyses of strontium carbonate standard SRM 987 yielded  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710245 \pm 0.000018$  (2), while long term analyses over approximately 24 months yielded an average of  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710242$  for SRM 987. Internal

**Table 1**  
Individuals from the Kroeber collection at the Field Museum of Natural History included in this study.

Site	Laboratory number	Specimen number	Burial number	Age (years) <sup>a</sup>	Sex <sup>a</sup>	Cranial modification <sup>b</sup>	Context
Aja	ACL-0272	FMNH-170912	8	YA	PM	Anterioposterior	Trophy head
Cahuachi	ACL-0260	FMNH-171240	12	YA	M	Anterioposterior	Burial
Cahuachi	ACL-0263	FMNH-171263	13	YA (20–21)	M	Anterioposterior	Burial
Cahuachi	ACL-0266	FMNH-171300	2	YA	F	Anterioposterior	Burial
Cahuachi	ACL-0267	FMNH-171307	5	A (45–50)	M	Anterioposterior	Burial
Cahuachi	ACL-0270	FMNH-171187	10	YA	I	Anterioposterior	Burial
Cahuachi	ACL-0271	FMNH-171135	2	A	M	Anterioposterior	Burial
Cahuachi	ACL-0273	FMNH-170222		YA	M	Anterioposterior	Trophy head
Cahuachi	ACL-0276	FMNH-171096	1	YA	M	Anterioposterior	Trophy head
Cahuachi	ACL-0277	FMNH-170224	1	YA	I	Anterioposterior	Trophy head
Cahuachi	ACL-0278	FMNH-171097	1	YA	M	Anterioposterior	Trophy head
Cahuachi	ACL-0280	FMNH-171098	1	YA	I	Anterioposterior	Trophy head
Cahuachi	ACL-0282	FMNH-171136	2	YA	F	Anterioposterior	Trophy head
Cahuachi	ACL-0283	FMNH-171186	9	SA (15–16)	I	Anterioposterior	Trophy head
Cahuachi	ACL-0284	FMNH-171099	1	YA	I	Anterioposterior	Trophy head
Cahuachi	ACL-0286	FMNH-171185	9	YA	F	Anterioposterior	Trophy head
Cahuachi	ACL-0287	FMNH-171100	1	C (4–6)	I	Anterioposterior	Trophy head
Cantayo	ACL-0262	FMNH-170998	3	YA	M	Anterioposterior	Burial
Cantayo	ACL-0264	FMNH-171025	5	A (30–45)	M	Anterioposterior	Burial
Cantayo	ACL-0265	FMNH-170993	3	YA	F	Anterioposterior	Burial
Cantayo	ACL-0269	FMNH-171023	5	A (30–40)	M	Anterioposterior	Burial
Cantayo	ACL-0275	FMNH-171008	2	SA (14–18)	I	Anterioposterior	Trophy head
Cantayo	ACL-0285	FMNH-171058	17	C (8–10)	I	Anterioposterior	Trophy head
Majoro Chico	ACL-0259	FMNH-170469	7a	A, Y-M	M	Anterioposterior	Burial
Majoro Chico	ACL-0261	FMNH-170493	14b	YA (20–21)	F	Anterioposterior	Burial
Majoro Chico	ACL-0268	FMNH-170499	15	A, Y-M	M	Anterioposterior	Burial
Majoro Chico	ACL-0279	FMNH-170489	11	YA	M	Anterioposterior	Trophy head
Majoro Chico	ACL-0281	FMNH-170463	6	YA	M	Anterioposterior	Trophy head
Paredones	ACL-0274	FMNH-170157	3	YA	M	Anterioposterior	Trophy head

<sup>a</sup> The age and sex of the individuals included in this study were determined by Drs. Sloan R. Williams, Kathleen Forgey and Elizabeth Klarich (Forgey, in press; Williams et al., 2001). Here, the following abbreviations are used: A, Y-M, adult (young-middle); C, child; F, female; I, indeterminate; M, male; PM, probable male; SA, subadult; and YA, young adult.

<sup>b</sup> The cranial modification styles of the individuals included in this study were determined by Drs. Sloan R. Williams, Kathleen Forgey and Elizabeth Klarich (Forgey, in press; Williams et al., 2001).

**Table 2**

Strontium, carbon and oxygen isotope data from archaeological human enamel samples.

Site	Laboratory number	Specimen number	Material <sup>a</sup>	Context	<sup>87</sup> Sr/ <sup>86</sup> Sr	δ <sup>13</sup> C <sub>c(VPDB)</sub> <sup>b</sup>	δ <sup>18</sup> O <sub>c(VPDB)</sub> <sup>b</sup>	δ <sup>18</sup> O <sub>dw(VSMOW)</sub> <sup>b</sup>
Aja	ACL-0272	FMNH-170912	LLM3	Trophy head	0.706653	-9.5	-9.1	-12.1
Cahuachi	ACL-0260	FMNH-171240	LLM1	Burial	0.706692	-7.4	-8.7	-12.5
Cahuachi	ACL-0263	FMNH-171263	LRM2	Burial	0.706251	-7.6	-8.7	-12.4
Cahuachi	ACL-0266	FMNH-171300	LLP1	Burial	0.706995	-7.8	-7.9	-11.4
Cahuachi	ACL-0267	FMNH-171307	LLP1	Burial	0.706627	-10.0	-6.6	-9.8
Cahuachi	ACL-0270	FMNH-171187	LRM2	Burial	0.706134	-6.7	-8.9	-12.7
Cahuachi	ACL-0271	FMNH-171135	LRM3	Burial	0.706594	-7.0	-9.2	-13.1
Cahuachi	ACL-0273	FMNH-170222	URP1	Trophy head	0.708669	-8.3	-3.8	-6.1
Cahuachi	ACL-0276	FMNH-171096	URM3	Trophy head	0.706328	-9.2	-9.6	-13.5
Cahuachi	ACL-0277	FMNH-170224	URM1	Trophy head	0.707524	-9.9	-6.1	-9.1
Cahuachi	ACL-0278	FMNH-171097	ULM1	Trophy head	0.706493	-7.7	-7.8	-11.2
Cahuachi	ACL-0280	FMNH-171098	ULP2	Trophy head	0.706486	-8.3	-4.1	-6.4
Cahuachi	ACL-0282	FMNH-171136	ULJ2	Trophy head	0.706593	-7.9	-8.6	-12.3
Cahuachi	ACL-0283	FMNH-171186	LRM2	Trophy head	0.706405	-8.8	-9.0	-12.9
Cahuachi	ACL-0284	FMNH-171099	URM3	Trophy head	0.706950	-8.9	-10.6	-14.9
Cahuachi	ACL-0286	FMNH-171185	LRM2	Trophy head	0.707490	-9.2	-8.0	-11.5
Cahuachi	ACL-0287	FMNH-171100	URM1	Trophy head	0.706156	-7.6	-8.2	-11.8
Cantayo	ACL-0262	FMNH-170998	LRM1	Burial	0.707803	-5.2	-7.9	-11.3
Cantayo	ACL-0264	FMNH-171025	LLM3	Burial	0.706856	-8.2	-10.0	-14.1
Cantayo	ACL-0265	FMNH-170993	LRM2	Burial	0.706273	-6.7	-7.8	-11.3
Cantayo	ACL-0269	FMNH-171023	LLM2	Burial	0.706314	-6.8	-8.9	-12.7
Cantayo	ACL-0275	FMNH-171008	LLM1	Trophy head	0.708860	-6.7	-1.8	-3.6
Cantayo	ACL-0285	FMNH-171058	LRM1	Trophy head	0.706586	-9.2	-8.3	-11.9
Majoro Chico	ACL-0259	FMNH-170469	LLM1	Burial	0.706575	-7.8	-8.3	-11.9
Majoro Chico	ACL-0261	FMNH-170493	LRM1	Burial	0.706323	-5.7	-8.8	-12.5
Majoro Chico	ACL-0268	FMNH-170499	LRM3	Burial	0.707318	-7.9	-7.2	-10.5
Majoro Chico	ACL-0279	FMNH-170489	URM1	Trophy head	0.706340	-10.3	-4.8	-7.3
Majoro Chico	ACL-0281	FMNH-170463	LRM2	Trophy head	0.707024	-7.8	-9.7	-13.8
Paredones	ACL-0274	FMNH-170157	LLM1	Trophy head	0.706437	-7.2	-8.5	-12.2

<sup>a</sup> All archaeological tooth enamel samples are identified by position in the maxilla or mandible (U or L), side (L or R) and dental element, so that, for example, URM3 refers to an upper right third molar and LLP1 refers to a lower left first premolar.

<sup>b</sup> Here, the subscript "c" in δ<sup>18</sup>O<sub>c(VSMOW)</sub> and δ<sup>13</sup>C<sub>c(VPDB)</sub> refers to bone carbonate data reported relative to the Vienna Standard Mean Ocean Water (V-SMOW) or Vienna PeeDee Belemnite (V-PDB) standards.

precision for strontium carbonate runs is typically 0.0006–0.0009% standard error, based on 100 dynamic cycles of data collection.

Oxygen and carbon isotope analyses of archaeological hydroxyapatite carbonate (δ<sup>18</sup>O<sub>c</sub>, δ<sup>13</sup>C<sub>c</sub>) were performed using the ThermoFinnigan MAT 253 stable isotope ratio mass spectrometer (IRMS) in the W.M. Keck Foundation Laboratory for Environmental Biogeochemistry in the School of Earth and Space Exploration at Arizona State University. Sample preparation was performed in the Archaeological Chemistry Laboratory by Andrew Somerville under the direction of Kelly J. Knudson according to established methodologies (Koch et al., 1997). Replicates of NBS-19 resulted in a reproducibility of ±0.15‰ for δ<sup>18</sup>O and ±0.04‰ for δ<sup>13</sup>C. Oxygen and carbon isotope ratios (δ<sup>18</sup>O<sub>c</sub>, δ<sup>13</sup>C<sub>c</sub>) are reported relative to the V-PDB (Vienna PeeDee belemnite) carbonate standard and are expressed in per mil (‰) using the following standard formula: δ<sup>18</sup>O = (((<sup>18</sup>O/<sup>16</sup>O<sub>sample</sub>)/(<sup>18</sup>O/<sup>16</sup>O<sub>standard</sub>))-1) × 1000 (Coplen, 1994; Craig, 1961b). When necessary to compare the observed δ<sup>18</sup>O<sub>c(VPDB)</sub> values with the observed δ<sup>18</sup>O<sub>mw</sub> values in the Andes, the conversion equations listed below were used.

$$\delta^{18}\text{O}_{\text{VSMOW}} = (1.03091 \times \delta^{18}\text{O}_{\text{VPDB}}) + 30.91 \text{ (Coplen et al., 1983)}$$

$$\delta^{18}\text{O}_{\text{VPDB}} = (0.97002 \times \delta^{18}\text{O}_{\text{VSMOW}}) - 29.98 \text{ (Coplen et al., 1983)}$$

$$\delta^{18}\text{O}_{\text{c(VSMOW)}} = (8.5 + \delta^{18}\text{O}_{\text{p}})/0.98 \text{ (Iacumin et al., 1996)}$$

$$\delta^{18}\text{O}_{\text{p(VSMOW)}} = (0.78 \times \delta^{18}\text{O}_{\text{dw}}) + 22.70 \text{ (Luz et al., 1984)}$$

#### Strontium, oxygen, and carbon isotope results from the Kroeber collection

Results of strontium isotope analysis of archaeological human tooth enamel samples using TIMS are shown in Table 2. Mean enamel <sup>87</sup>Sr/<sup>86</sup>Sr = 0.706819 ± 0.000686 (n = 29, 1σ) for all samples. Mean <sup>87</sup>Sr/<sup>86</sup>Sr = 0.707115 ± 0.001021 (n = 6, 1σ) for all samples from Cantayo and mean <sup>87</sup>Sr/<sup>86</sup>Sr = 0.70706716 ± 0.000440 (n = 5, 1σ) for all samples from Majoro Chico. At Cahuachi, the trophy

head samples exhibited mean <sup>87</sup>Sr/<sup>86</sup>Sr = 0.706909 ± 0.000776 (n = 10, 1σ) while the burial samples exhibited mean <sup>87</sup>Sr/<sup>86</sup>Sr = 0.706549 ± 0.000313 (n = 6, 1σ). Finally, for the trophy head samples, mean <sup>87</sup>Sr/<sup>86</sup>Sr = 0.706937 ± 0.000814 (n = 16, 1σ) while mean <sup>87</sup>Sr/<sup>86</sup>Sr = 0.706673 ± 0.000477 (n = 13, 1σ) for the burials in the Kroeber collection.

Results of oxygen isotope analysis of archaeological human tooth enamel samples using IRMS are also shown in Table 2. Mean enamel δ<sup>18</sup>O<sub>c(VPDB)</sub> = -7.8‰ ± 2.0‰ (n = 29, 1σ). At Cahuachi, mean enamel δ<sup>18</sup>O<sub>c(VPDB)</sub> = -7.9‰ ± 1.9‰ (n = 16, 1σ). Mean enamel δ<sup>18</sup>O<sub>c(VPDB)</sub> = -7.4‰ ± 2.9‰ (n = 6, 1σ) for all samples from Cantayo while mean enamel δ<sup>18</sup>O<sub>c(VPDB)</sub> = -7.8‰ ± 1.9‰ (n = 5, 1σ) for all samples from Majoro Chico. For the trophy head samples, mean enamel δ<sup>18</sup>O<sub>c(VPDB)</sub> = -7.4‰ ± 2.5‰ (n = 16, 1σ). The enamel samples from burials exhibited mean enamel δ<sup>18</sup>O<sub>c(VPDB)</sub> = -8.4‰ ± 0.9‰ (n = 13, 1σ).

For all sites, mean enamel δ<sup>13</sup>C<sub>c(VPDB)</sub> = -8.0‰ ± 1.2‰ (n = 29, 1σ) (Table 2). At Cahuachi, mean enamel δ<sup>13</sup>C<sub>c(VPDB)</sub> = -8.3‰ ± 1.0‰ (n = 16, 1σ) for all samples and mean enamel δ<sup>13</sup>C<sub>c(VPDB)</sub> = -7.1‰ ± 1.4‰ (n = 6, 1σ) for all samples from Cantayo. Mean enamel δ<sup>13</sup>C<sub>c(VPDB)</sub> = -7.9‰ ± 1.6‰ (n = 5, 1σ) for all samples from Majoro Chico. For the trophy head samples from all sites, mean enamel δ<sup>13</sup>C<sub>c(VPDB)</sub> = -8.5‰ ± 1.0‰ (n = 16, 1σ) while the burial samples exhibited mean enamel δ<sup>13</sup>C<sub>c(VPDB)</sub> = -7.3‰ ± 1.2‰ (n = 13, 1σ).

#### Interpretations of strontium, oxygen, and carbon isotope data from the Kroeber collection

Given the resistance of enamel to diagenetic contamination (e.g. Budd et al., 2000; Chiaradia et al., 2003; Ericson, 1993; Hedges, 2002; Lee-Thorp, 2002; Montgomery et al., 1999; Shellis and Dibdian, 2000; Sillen, 1989) and the exceptional preservation of the

Kroeber collection, in which many individuals are naturally-mummified, we argue that our data most likely represent biogenic isotope signatures rather than post-depositional contamination. Mechanical cleaning, as described above, removed the outermost layers of tooth, which are most susceptible to diagenetic, or post-depositional, contamination (Budd et al., 2000; Montgomery et al., 1999; Waldron, 1981, 1983; Waldron, et al. 1979). Although we were not able to collect additional samples for the analysis of post-depositional contamination, given the importance of these irreplaceable archaeological human remains, we note that other populations from similar environments on the Peruvian coast exhibited biogenic isotope signatures in both tooth enamel and bone (e.g. Buzon et al., 2008; Knudson and Buikstra, 2007; Knudson and Price, 2007; Slovak, 2007).

As previously discussed, one definition of the local range of the Nazca Drainage is  $^{87}\text{Sr}/^{86}\text{Sr}=0.70559\text{--}0.70727$ , based on strontium isotope analyses of small mammals (Buzon et al., 2008). However, these animals from the southern Nazca Drainage may or may not adequately reflect the bioavailable strontium isotope signatures at the study sites. There are only two individuals whose strontium isotope signatures are higher than the other individuals analyzed (ACL-0273, FMNH-170222, ( $^{87}\text{Sr}/^{86}\text{Sr}=0.708669$ ) and ACL-0275, FMNH-171008 ( $^{87}\text{Sr}/^{86}\text{Sr}=0.708860$ ) (Table 2, Fig. 3); these values may be caused by consuming strontium from, and living in, a different geologic zone. However, these values may also represent the consumption of calcium, and strontium, from marine sources; future carbon and nitrogen analyses of collagen from these individuals could test this hypothesis. Interestingly, there is no definitive artifactual or temporal data that distinguishes these individuals from others in this dataset, although we note that the Kroeber collection spans a large temporal range from the Early Intermediate period to the Middle Horizon. In fact, the two individuals buried in a grave described as “highland-derived” (Kroeber and Collier, 1998, p. 71) cannot be distinguished from other individuals in this dataset based on their isotopic signatures. Finally, there is, in fact, no statistically significant difference between the strontium isotope signatures of the trophy head samples and the burial samples,

either when comparing all trophy heads to all burials ( $t=1.03$ ,  $df=27$ ,  $p=0.31$ ) or when comparing the trophy heads and burials at Cahauchi ( $t=-1.07$ ,  $df=14$ ,  $p=0.30$ ), Cantayo ( $t=-1.04$ ,  $df=4$ ,  $p=0.36$ ), or Majoro Chico ( $t=0.12$ ,  $df=3$ ,  $p=0.91$ ).

The oxygen isotope data from the Kroeber collection reflects the water sources consumed during enamel formation as well as the enriched isotopic signature of breast milk if the enamel formed before or during the weaning process. The oxygen isotope signatures from the Kroeber collection are highly variable. However, this variability, in part, is the result of  $^{18}\text{O}$  enrichment in enamel that formed before and during the weaning process; for example, the oxygen isotope signatures in third molars, which formed after weaning, are lower, or isotopically lighter, than the first molar values (Table 2). More specifically, mean first molar enamel  $\delta^{18}\text{O}_{\text{C(VPDB)}}=-7.2\text{‰}\pm 2.2\text{‰}$  ( $n=11$ ,  $1\sigma$ ) while mean third molar enamel and bone  $\delta^{18}\text{O}_{\text{C(VPDB)}}=-9.3\text{‰}\pm 1.2\text{‰}$  ( $n=6$ ,  $1\sigma$ ). In other datasets that examined changes in oxygen isotope signatures in enamel series, the early-forming teeth were enriched (Wright and Schwarcz, 1998). Therefore,  $^{18}\text{O}$  enrichment in breast milk clearly accounts for some of the variability in the oxygen isotope signatures (Table 2, Fig. 4).

Converting the third molar  $\delta^{18}\text{O}_{\text{C(VPDB)}}$  signatures to the drinking water  $\delta^{18}\text{O}_{\text{dw(V-SMOW)}}$  signatures will then allow a discussion of the geographic origins of these individuals without any weaning effects in the dataset. Mean third molar enamel and bone  $\delta^{18}\text{O}_{\text{dw(V-SMOW)}}=-13.2\text{‰}\pm 1.5\text{‰}$  ( $n=6$ ,  $1\sigma$ ) (Table 2). When  $\delta^{18}\text{O}_{\text{dw(V-SMOW)}}$  values from all enamel and bone samples are combined, mean  $\delta^{18}\text{O}_{\text{dw(V-SMOW)}}=-11.3\text{‰}\pm 2.6\text{‰}$  ( $n=29$ ,  $1\sigma$ ) (Table 2). The mean  $\delta^{18}\text{O}_{\text{dw(V-SMOW)}}$  values are much lower than the expected values based on observed  $\delta^{18}\text{O}_{\text{mw(V-SMOW)}}$  in coastal precipitation. However, given the low quantities of precipitation on the coast, it is more likely that the drinking water of the inhabitants of Nasca sites incorporated water from higher-altitudes, as discussed above.

It is also likely that this range of oxygen isotope signatures reflects both temporal changes in precipitation patterns in the Nazca Drainage, as the samples in the Kroeber collection date from the Early Intermediate Period (EIP 1–3) through the Middle Horizon

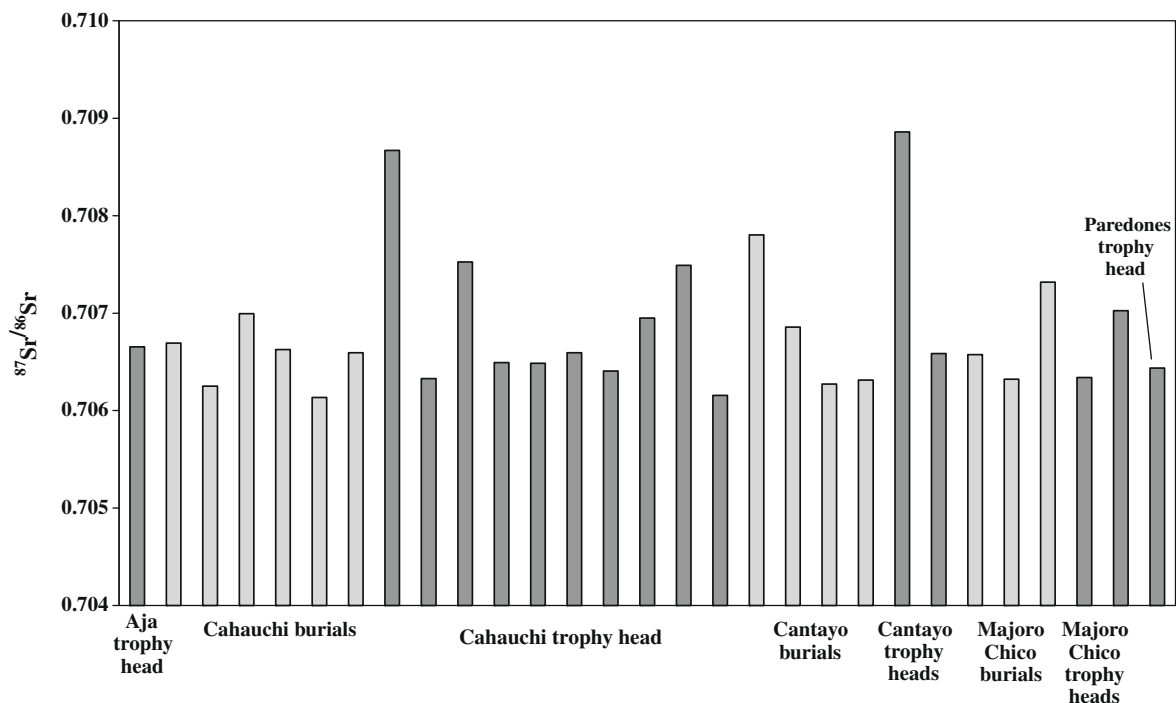
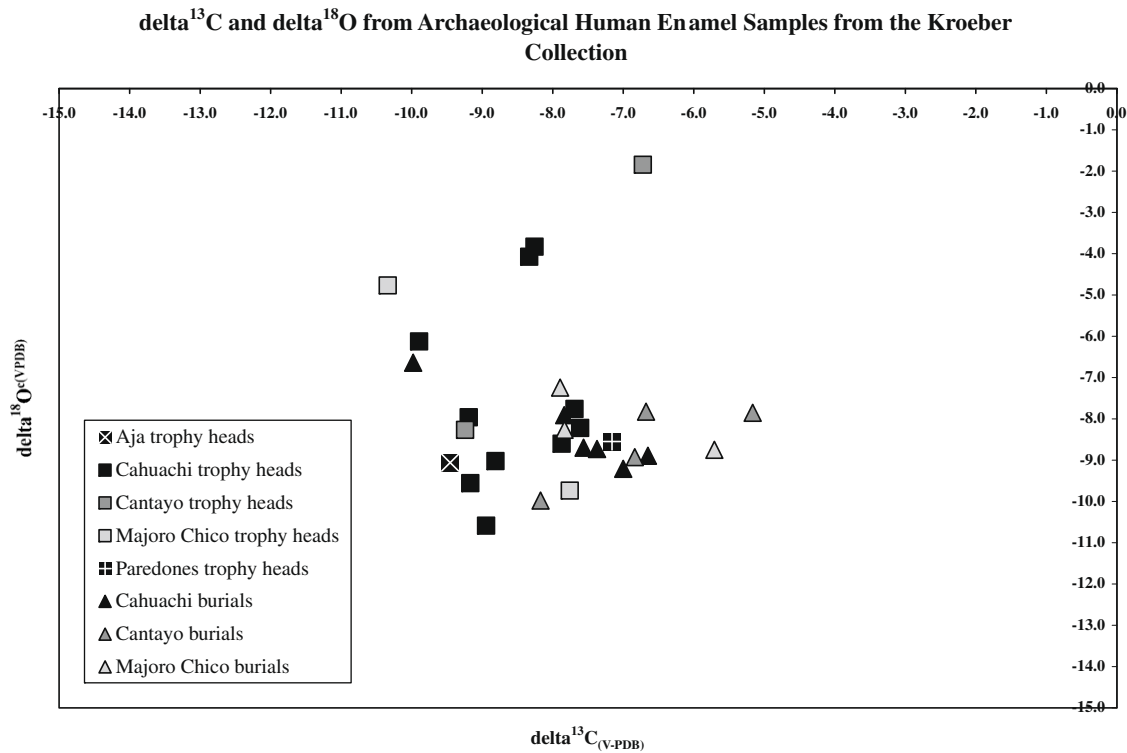


Fig. 3. Strontium isotope signatures from archaeological human tooth enamel from the Kroeber collection.



**Fig. 4.** Carbon and oxygen isotope signatures from archaeological human tooth enamel from the Kroeber collection.

and Late Intermediate Period (Kroeber and Collier, 1998; Williams et al., 2001), as well as spatial variability in water sources throughout the Nazca Drainage. Finally, as in the strontium isotope signatures, there is no statistically significant difference between  $\delta^{18}\text{O}_{\text{C(V-PDB)}}$  in the individuals who were transformed into trophy heads and the individuals interred in burials in the Kroeber collection ( $t = 1.38$ ,  $df = 27$ ,  $p = 0.18$ ).

The carbon isotope data hydroxyapatite carbonate in archaeological human enamel from the Kroeber collection reflect the carbon isotopic composition of the whole diet, plus 9.4‰ (Ambrose and Norr, 1993). Plants that use the  $\text{C}_4$  metabolic pathway exhibit  $\delta^{13}\text{C}_{\text{C(V-PDB)}} = -9\text{‰}$  to  $-14\text{‰}$  while  $\text{C}_3$  plants exhibit  $\delta^{13}\text{C}_{\text{C(V-PDB)}} = -20\text{‰}$  to  $-35\text{‰}$  (e.g. Tieszen and Chapman, 1992). Therefore, the carbon isotope signatures observed in the Kroeber collection reflect a mix of predominately  $\text{C}_4$  carbon sources, like maize (*Zea mays*) or animals that consumed maize, with smaller amounts of  $\text{C}_3$  carbon sources or animals that consumed them (Table 2, Fig. 4). There are no clear differences between enamel that formed during and after weaning, although the carbon isotope signatures document the introduction of solid foods during the weaning process (e.g. Wright and Schwarcz, 1998). Finally, the lack of differences between the carbon isotope signatures in the tooth enamel of trophy heads or individuals in burials suggests that these individuals did not consume substantially different carbon sources in their diets (Table 2, Fig. 4).

Since there are no statistically significant differences between the isotope signatures of the individuals who were transformed into trophy heads and the individuals buried in Nasca sites, we argue that the trophy heads were not taken from a different or non-local population. This conclusion is supported by aDNA data on archaeological human remains from the Kroeber collection; Foregy's (2006, p. 216) mtDNA analyses lead her to conclude that, "the trophy heads belonged to members of the Nazca Valley population." Interestingly, this is in contrast to the Wari trophy heads of Middle Horizon Conchopata (c. 500–1000 AD), where it is clear

that the individuals transformed into trophy heads exhibit much more heterogeneity in geographic origins than the individuals buried at the site of Conchopata, implying that the Wari trophy heads are in fact from a different population or populations (Knudson and Tung, 2007; Tung and Knudson, 2006, 2008).

In conclusion, the Nasca trophy heads in the Kroeber collection do not come from a geologically-distinct zone from the individuals buried at these sites. Instead the trophy heads derive from populations within the Nazca Drainage. Therefore, our data do not support the hypothesis that Nasca trophy heads were taken from enemy warriors from foreign locales. Although trophy heads of individuals perceived as local or foreign could have important ritual functions, we argue that transforming local Nasca individuals into trophy heads highlights their ritual role. For example, Proulx (2006, p. 76) writes that in Nasca iconography, "[m]any of these [trophy] heads are also decorated with a zigzag red stripe running across the cheek and down the nose. This is a common motif found on enemy warriors in the art. It reinforces the concept that the heads of these decapitated enemy soldiers have taken on the aspects of a mythical being."

Importantly, we note that we have identified biogeochemical indicators of origins, which may not reflect what the inhabitants of the Nazca Drainage identified as local or non-local. For example, when Browne (1993, p. 291) and his colleagues write that, "[w]e are particularly interested in determining who lost whose heads and why," they also ask, "[d]id it depend on the cultural definition of local and foreign populations?". However, the homogeneity in cranial modification and material culture styles indicate a shared community identity at these sites.

#### Directions for future research and conclusion

In conclusion, we have demonstrated that the individuals transformed into trophy heads and interred at the Nazca Drainage sites of Aja, Cahuachi, Cantayo, Majoro Chico, and Paredones did not in

fact exhibit enamel isotopic signatures consistent with living in a different geologic or environmental zone or consuming substantially different diets from the individuals interred in burials at the sites of Cahuachi, Cantayo, and Majoro Chico during enamel formation in the first years of life. We hope that future work will elucidate the changing role of trophy heads in the context of the changing role of iconographic representations of trophy heads. For example, as discussed above, there is a change in Nasca 5–7 iconography with evidence of increasingly militarism and depictions of trophy heads with warriors rather than ritual specialists (Browne et al., 1993; Proulx, 2006; Roark, 1964, 1965; Silverman and Proulx, 2002). However, our data demonstrate that the mortuary population and the trophy head population in the Kroeber collection are likely derived from the same group of people.

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