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EXAMINING THE LIFE HISTORY OF AN INDIVIDUAL FROM SOLCOR 3, SAN PEDRO DE ATACAMA: COMBINING BIOARCHAEOLOGY AND ARCHAEOLOGICAL CHEMISTRY

EXAMINANDO LA VIDA DE UN INDIVIDUO DE SOLCOR 3, SAN PEDRO DE ATACAMA: COMBINANDO LA BIOARQUEOLOGÍA Y LA QUÍMICA ARQUEOLÓGICA

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Detailed life history information using multiple lines of evidence including the identification of geographic origins, health, and body use indicators, can be used to elucidate the complex process of acculturation in the San Pedro de Atacama oases of northern Chile during the Middle Horizon. This paper presents the results of bioarchaeological and archaeological chemical analyses of the skeletal remains of an adult male (tomb 50, catalog number 1948) from the cemetery of Solcor 3 (ca. AD 500-900). Strontium isotope ratios in human tooth enamel reveal information about where a person lived during their childhood, when enamel was being formed. Individual 1948 showed strontium isotope ratios decidedly outside the range of the local San Pedro de Atacama strontium isotope signature. Given these data implying that individual 1948 was originally from elsewhere, an examination of his health status, social role, and mortuary context provides insight into the treatment of foreigners in San Pedro de Atacama.

Our data support the argument that individual 1948's foreign birth did not hinder his later assimilation into Atacameño society. He was buried in a local cemetery with a typical mortuary assemblage for a male of this time and no strong evidence of possible foreign origin. Skeletal indicators of diet and activity patterns do not distinguish individual 1948 from the local population, suggesting that his lifestyle was similar to that of other Atacameños. Therefore, our analyses suggest that individual 1948's acculturation into Atacameño society during his adult life was nearly complete and he retained little to no indication of his probable foreign birth.

Key words: Tiwanaku, South Central Andes, acculturation, paleopathology, strontium isotope analysis, trace element analysis, bone chemistry.

Información detallada sobre la vida de un individuo, integrando múltiples líneas de evidencia que incluye identificación del origen geográfico, condiciones de salud e indicadores de usos funcionales del cuerpo, puede ser utilizada para aclarar el complejo proceso de la aculturación en los oasis de San Pedro de Atacama, norte de Chile durante el Horizonte Medio. Este trabajo presenta los resultados de análisis bioantropológicos y químicos de un individuo (tumba 50, número de catálogo 1948) del cementerio de Solcor 3 (ca. 500-900 d.C.) en San Pedro de Atacama. Las proporciones de los isótopos de estroncio en el esmalte dentario humano revelan información acerca de donde una persona vivió durante su niñez, cuando el esmalte se forma. El individuo 1948 muestra proporciones de isótopos de estroncio claramente fuera del rango que caracteriza a las poblaciones locales de San Pedro de Atacama. Estos datos muestran que el individuo 1948 fue originalmente de un lugar foráneo. El análisis de su salud, rol social y contexto mortuorio nos permite conocer el tratamiento social aplicado a los extranjeros en la región de San Pedro de Atacama durante el Horizonte Medio.

Nuestros datos sostienen la idea que la condición de extranjero del individuo 1948 no fue una limitación para su asimilación en la sociedad atacameña. Él fue enterrado en un cementerio local, a la moda local, sin que se resaltara su posible origen foráneo. Además, los datos con respecto a su salud y estilo de vida no lo distinguen del resto de la población local. Por lo tanto, nuestros análisis sugieren una total aculturación de este individuo en la sociedad atacameña durante su vida adulta, por lo que retuvo poca o ninguna indicación de su probable nacimiento en un área foránea.

Palabras claves: *Tiwanaku, Andes Surcentrales, aculturación, paleopatología, análisis de isótopos de estroncio, análisis de elementos traza, química ósea.*

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Although numerous archaeologists have addressed the effects of acculturation at a societal level, the impact of assimilation or non-assimilation by a group is rarely examined at the level of the individual. Acculturation is generally conceived of as smaller societies undergoing transformations resulting from contact with a more powerful group and ultimately “the loss of the smaller society’s cultural distinctiveness as its members adopt at the least the trappings, if not the basic value structure, of the dominant society” (Schortman and Urban 1998:104). Unfortunately, this understanding of acculturation often negates individual agency as well as the possibility for incorporation or transformation of cultural differences (Smith 2003). Bioarchaeology affords the opportunity to discern the individual in prehistory as well as to provide unique insights into the individual and his or her agency, a crucial element in exploring societal structures (Meskell 2000).

In this research we present detailed life history information using multiple lines of evidence, including the identification of geographic origins, health and body use indicators, to elucidate the complex process of acculturation in the San Pedro de Atacama oases of northern Chile during the Middle Horizon (AD 500-1,000). Here we combine two large sources of data, bioarchaeology and archaeological chemistry, in order to provide a more complete view into the life and death of one particularly interesting individual from the Middle Horizon cemetery of Solcor 3: individual 1948 from tomb 50. Excellent preservation allows us to examine him in great detail from osteological, chemical, and archaeological perspectives.

As part of a larger project investigating migration and the Tiwanaku state in the South-Central Andes (Figure 1), the second author examined strontium isotope ratios in numerous samples of dental enamel from three sites in the San Pedro de Atacama oases (Knudson 2007; Knudson and Price 2007). Strontium ratios of human tooth enamel reveal information about where a person lived during their childhood when enamel was being formed. Individual 1948 from Solcor 3 was one of the few outliers in this analysis, showing strontium ratios decidedly outside the range of the local San Pedro de Atacama strontium isotope signature. Given these data suggesting that this individual was originally from elsewhere, an examination of his health status, social role, and mortuary context provides us with a unique op-

Figure 1. Map of the South Central Andes.
Mapa de los Andes Surcentrales.

portunity to explore the treatment of foreigners in pre-Columbian San Pedro de Atacama. We will begin by discussing models of acculturation, provide a brief introduction to the San Pedro de Atacama oases during the Middle Horizon, and follow this with our interpretation of the bioarchaeological, mortuary, and archaeological chemical data from individual 1948.

Theoretical Considerations

Analyzing the life history of individual 1948 from Solcor 3 allows us the opportunity to examine the potential migration and integration of one individual into Atacameño society during the Andean Middle Horizon. As mentioned previously, some scholars posited that San Pedro de Atacama included a Tiwanaku colony during the Middle Horizon, while others viewed it as a place of interchange and more generalized population movement. Archaeologists use multiple lines of evidence to trace prehistoric migrations, which are notoriously hard to see in the archaeological record (Anthony 1990, 1992; Burmeister 2000; Feder 1981). Stein (2005:11) has argued that "the corporate nature of the foreign community and its formalized ties with its homeland are important elements that provide a significant distinction between colonies and episodes of migration by individuals or families". In the case considered here, the presence of a colonial settlement would imply a number of foreign individuals and likely distinctive mortuary goods that suggest a relationship with the Tiwanaku state. In contrast, small-scale migration of individuals or families would produce a different archaeological signature that suggests greater assimilation and dominance of the local community. Analyzing the life history of individual 1948 provides an opportunity for micro-scale analysis of a particular migrant's experience and to document the nuances of this process in the Middle Horizon Atacama.

Studies of acculturation formed the backbone of anthropological investigations of colonial encounters in the early and mid twentieth century. As Deagan (1998:28) notes, acculturation "was often used by anthropologists of the period to indicate an essentially unidirectional process of change in a recipient culture through contact with a donor culture". More contemporary work has integrated concepts of dynamism and agency for local groups and views the process as one of reformulation (Cusick 1998; Deagan 1998; Smith 2003). Cusick (1998:139) argues that acculturative models are particularly useful tools for examining undirected contact and syncretism. Acculturation studies in archaeology have generally focused on populations, however life history or osteobiographic studies can contribute to an understanding at the level of the individual. More closely tied to this project, examining the life history of this individual from Solcor 3 allows us to explore how a specific person lived and died in this prehistoric period.

San Pedro de Atacama and Tiwanaku

The series of oases that comprise San Pedro de Atacama are located at the confluence of the San Pedro and Vilama Rivers at an altitude of 2,430 masl (Figure 2). The oases are verdant and surrounded by the driest desert in the world. In this harsh environment there is a long history of settlement. The first evidence of a permanent human presence dates to ca. 2,000 BC at the site of Puripica, in the extreme north of the San Pedro River valley (Núñez 1989:86). Habitation is generally continuous from the time of this initial occupation, with sites established in the core of the oases, as well as in surrounding areas (Muñoz 1989). During the initial occupation there is a shift away from a nomadic, pastoralist lifestyle, towards the construction of agglutinated villages and a subsistence economy that is based not only on camelid pastoralism, but also on developing agricultural practices and burgeoning trade networks.

As these villages became more established there is evidence of increasing interactions with foreign groups. These included contacts with smaller societies in the northwest of Argentina, as well as larger political entities. Interactions with the Tiwanaku state, based in the Lake Titicaca Basin of highland Bolivia, are evident from at least AD 600, and are clearly seen at Solcor 3 (Berenguer and Dauelsberg 1989:156; Bravo and Llagostera 1986). Tiwanaku exerted a noticeable influence on the culture of the San Pedro peoples during the Middle Horizon, however it may have taken the form of a direct or indirect presence in the oases. Interpretations of the type of influence wielded by the Tiwanaku state in the Atacama range from colonizing forces and established po-

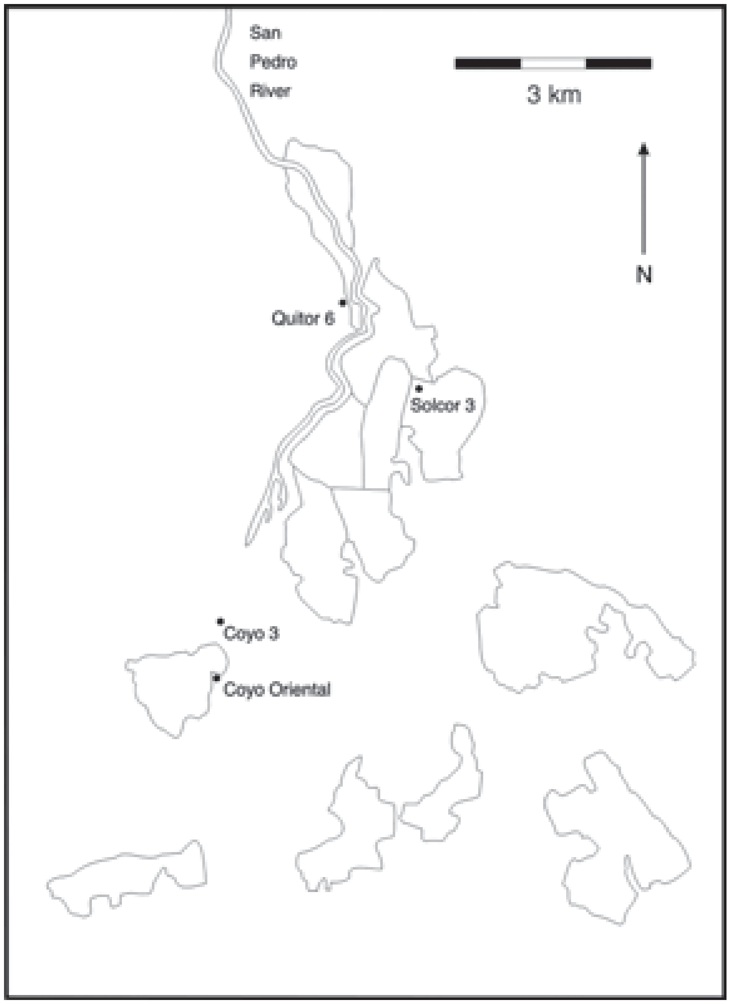

Figure 2. Map of the San Pedro de Atacama oases with sites mentioned in the text.
Mapa de los oasis de San Pedro de Atacama con los sitios mencionados en el texto.

litical presence to the sharing of an iconographic system and occasional traders who caravanned across the altiplano (Knudson 2007; Knudson et al. 2004; Kolata 1993; Llagostera 2004; Oakland Rodman 1992; Torres-Rouff 2002; Torres and Conklin 1995). Through either of these mechanisms of interaction, it is likely that foreign individuals passed through or settled in the San Pedro oases.

Some scholars have argued that colonies from the altiplano site were physically present in San Pedro de Atacama (Kolata 1993; Oakland Rodman 1992). Oakland Rodman's (1992:326) analysis of textile patterns and weaving structures from the Middle Horizon cemetery of Coyo Oriental demonstrated that a "strong Tiwanaku influence did disrupt the San Pedro cultural sequence, [and that] there were most likely people physically present whose original home was the Bolivian altiplano". She also posits that locals and foreigners were buried together in the Coyo Oriental cemetery (Oakland Rodman 1992:335). Kolata (1993:277) concords with this argument, citing "the presence of substantial colonies of altiplano people from the Tiwanaku core area".

In contrast, Torres and Conklin (1995:1-2) argue that the Tiwanaku/San Pedro de Atacama relationship was based on exchange of both goods and ideas but not the physical presence of Tiwanaku colonists. They support this with a variety of data including the absence of architectural features or pure Tiwanaku burials and the occurrence of Tiwanaku iconography on objects that are mainly of a portable form. Recent data from metallurgical studies indicate that axes in San Pedro were made from altiplano ores, suggesting an expansive trade network (Lechtman and MacFarlane 2005). Similarly, arguments based on material culture and bioarchaeological data suggest that changes resulting from the spread of Tiwanaku did not radically alter health and lifestyle and most likely did not involve colonists (Costa Junqueira et al. 2004; Llagostera 2004:135-137). While these debates over the nature of San Pedro de Atacama's interaction with the Tiwanaku state are unlikely to be easily resolved, they do support the notion that peoples from this area were mobile and that Tiwanaku figured prominently in their worldview.

The Cemetery of Solcor 3

The Solcor 3 cemetery is located in the core of the San Pedro oases and was one of the major burial locations of the Middle Horizon in the Atacama. Of the sites in the area, it provides very strong evidence of an interaction with Tiwanaku. Bravo first excavated the site in 1983 under the auspices of the *Instituto de Investigaciones Arqueológicas* in San Pedro de Atacama. This excavation yielded 93 tombs. Subsequent excavations occurred in 1987, directed by Llagostera. This second excavation was a salvage operation necessitated by impending construction in the area. Approximately 50 more tombs were opened as a result of this work. A substantial portion of these remains was not examined here as a result of preservation - either excellent, resulting in mummification, or poor or disturbed resulting in fragmentary remains. The cemetery was in use from AD 400-900 and covers both a pre-Tiwanaku phase and a later phase that shows evidence of Tiwanaku influence (Bravo and Llagostera 1986; Llagostera et al. 1988). The burials from Solcor 3 were in cylindrical pits with flat floors between 1 and 2 meters in depth (Bravo and Llagostera 1986:323). The majority of these burials are of single individuals (n = 49). Individuals were generally buried in a flexed and seated position, fully wrapped in textiles and surrounded by grave goods. In using these mortuary arrangements the people of Solcor 3 followed well-established Atacameño funerary customs and does not appear to have been influenced by outside groups (Bravo and Llagostera 1986:324).

Bioarchaeology: A Brief Introduction

A bioarchaeological approach can help to elucidate the nature of Tiwanaku influence in San Pedro de Atacama and in the burials from Solcor 3. Briefly, bioarchaeology is the study of prehistoric human behavior through the analysis of human skeletal remains from archaeological contexts. It attempts to provide a biological perspective to archaeological examinations (Buikstra 1977; Larsen 1997:3). The study of human remains has generally been incorporated into biological anthropology; however the bioarchaeological approach uses these methods and techniques to answer questions of archaeological significance. The Andes is one of the foundational research areas for bioarchaeology because of the excellent preservation of human remains and a long history of research (Arriaza 1995; Blom 1999; Blom et al. 1998; Sutter 2000; Verano 1995; Verano and Ubelaker 1992). As an integrative approach, bioarchaeological analyses are particularly appropriate for an examination of individual life histories. By focusing on one individual we hope to provide information akin to a life history, and as such fall within the paradigm of contemporary bioarchaeological or osteobiographic studies as well as some post-processual archaeological approaches (e.g. Meskell 2002; Saul 1972).While the modern emphasis in bioarchaeology is on larger populations studies, individual case studies have formed the basis of the field and contribute to an understanding of biological variation (Larsen 1997:3).

Using an interdisciplinary approach that incorporates methods and data from biological anthropology, archaeology, cultural anthropology, medical science, geography, history, and other related disciplines, bioarchaeologists analyze human adaptation and change (Buzon et al. 2005). This approach enables more accurate assessment and interpretation of osteological data (Walker 1996). Human skeletal remains are a valuable source of information for addressing issues of social organization and state involvement in individual lives. A more complete picture of the past results from combining multiple data sources and helps to counter the biases and limitations inherent in skeletal data (Goodman 1993; Steckel and Rose 2002; Wood et al. 1992; Wright and Yoder 2003). Most significantly, bioarchaeology focuses on both the social and biological dimensions of a lived human experience. It allows for a unique opportunity to understand the dynamic interaction between environment, culture, and human biology.

An array of bioarchaeological data was collected on individual 1948 from the Solcor 3 cemetery. Methods were based on the *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker 1994). This investigation is framed by demographic and paleopathological data, together with information on cultural modifications of the body. Age determinations by the first author were based on dental development, tooth wear, cranial suture closure and the Suchey-Brooks method for aging the pelvis (Brooks and Suchey 1990; Buikstra and Ubelaker 1994:15-20; Ubelaker 1989:63-65). Sex was determined using cranial and pelvic features (Buikstra and Ubelaker 1994:21-38).

The skeletal remains were also examined for numerous indicators of health status by the first author. Traumatic injuries, either accidental or due to intentional violence, can provide information about one's environment including social conditions and activity patterns (Buikstra and Ubelaker 1994:119-120; Walker 1989). It has been argued that cranial trauma and weapon wounds provide the strongest evidence for interpersonal violence (e.g. Alvrus 1999). Data on osteoperiostitis, an indicator of systemic infections and/or trauma (Aufderheide and Rodriguez-Martin 1998) and patterns of osteoarthritis, which reveal occupational stressors and gender-based division of labor (Hollimon 1991), were examined as well. Osteoarthritis, evidenced by lipping, porosity and eburnation, was recorded by location, severity and extent.

An investigation into dietary stress was conducted through the documentation of the expression of lesions associated with nutritional deficiencies, including porotic hyperostosis of the cranial vault and cribra orbitalia (Stuart-Macadam 1985; Stuart-Macadam and Kent 1992; Walker 1985). Porotic hyperostosis has been linked to iron deficiency anemia, possibly stemming from nutritional deficiencies, inadequate absorption of iron, parasitic infection, and as an "adaptation" to disease and microorganism invasion (El-Najjar et al. 1976; Kent 1986; Lallo et al. 1977; Stuart-Macadam and Kent 1992; Walker 1985, 1986). Porotic hyperostosis was recorded as present when porosity with coalescing foramina were apparent on the ectocranial surfaces of the cranial vault and/or on the superior surface of the orbits (cribra orbitalia) and with remodeled and unremodeled lesions noted as well as the degree of severity (porosity, coalescing foramina, thickening). Finally, data was collected on stature based on femoral length (Buikstra and Ubelaker 1994).

Dental observations were also recorded; caries, abscesses, antemortem tooth loss, and enamel hypoplasia provide direct evidence for nutrition and health (Cohen and Armelagos 1984; Hillson 1996). The prevalence of caries, for example, tends to increase with the consumption of carbohydrate-rich foods and may provide information about shifts in diet (Cohen and Armelagos 1984; Hillson 1979; Walker and Erlandson 1986). Carious lesions were identified based on the presence of dark eroded regions of enamel. Antemortem tooth loss is linked to caries as well as overall health status and was identified based on the absence of teeth and the extent of alveolar remodeling. The presence of a drainage channel in the alveolar bone was taken to indicate an abscess. Together, these dental indicators provide evidence of both diet and overall health status.

Incidences of hypoplasia were recorded to document acute stress during growth. Hypoplasia is a deficiency in enamel thickness resulting from a disruption in the secretory/matrix formation phase of amelogenesis. This pathological condition is frequently associated with the presence of systemic metabolic stress (Dobney and Goodman 1991; Goodman and Armelagos 1985; Goodman et al. 1980; Holland and O'Brien 1997). Enamel hypoplasia was determined by the presence of a continuous linear horizontal groove or series of pits on the buccal surface of the tooth. This provides a permanent record of dietary stress, as enamel cannot be remodeled.

Data was also collected on cultural modifications of the body, which manifest archaeologically in the Atacama as cranial modification and the use of labrets (lip plugs); these practices respond to changes in the social environment. Labret use leaves not only the material artifact itself, often as a grave inclusion, but also results in abrasion of the dental enamel that is visible after death (Cybulski 1974; Torres-Rouff 2003b). Cranial vault modification is the intentional reshaping of the head through the use of binding fabrics and/or stiff pads. This is typically done during infancy and early childhood, while the bones of the skull are still malleable, in order to attain a desired head shape. In the Andes, these head shapes are culturally proscribed and are related to group identity (Antón 1989; Blom 1999; Blom et al. 1998; Cocilovo and Zavattierri 1994; Dembo and Imbelloni 1938; Hoshower et al. 1995; Munizaga 1969; Torres-Rouff 2002, 2003a). The head shape of the individual buried in tomb 50 was compared to others buried in the same cemetery. The final set of data used in this analysis is also cultural. Archaeological data based on the grave structure and the mortuary assemblage that accompanied this individual in his death was collected. Data concerning material culture, type and origin was compared to others in the Solcor 3 cemetery.

Tomb 50: The Bioarchaeological Data

The male (1948) (Figure 3) buried in tomb 50 was between 40 and 50 years old at death, an age at death that was typical for this area. He was accompanied by the fragmented remains of an infant of approximately 1.5 years of age with no observable pathologies or exclusive grave offerings. Paleopathological data reveal an individual with little evidence of stress. He had slight osteoperiostitis on his tibias with no visible cause. Moreover, he also had osteoarthritic developments in his jaw with porosity and remodeling of both temporomandibular joints; these are in keeping with his age and the expected body use that he would have endured to this point. This pattern of degenerative joint disease was common in the adult portion of the sample, being visible in nearly 20% (n = 18/92) of the individuals from this cemetery. This indicates a lifestyle in keeping with that of other members of his group.

Figure 3. Cranium, individual 1948.
Cráneo, individuo 1948.

He bore few signs of violent traumatic injury despite the inclusion of an axe with a copper blade, bows and arrows in his tomb. However, his left second rib showed a healed fracture that did not affect other ribs (Figure 4). Post-cranial trauma is commonly caused by accidents, and unlike cranial trauma, is not usually associated with violence (Alvrus 1999). Trauma was not unusual at Solcor 3, and nearly 11% (n = 11/107) of the remains from this cemetery showed evidence of healed cranial injuries, mostly in the form of depressed fractures of the parietals and broken nasal bones. Previous studies have indicated that 15.6% of the Solcor 3 burials had post-cranial trauma, primarily in the form of parry fractures, although three other individuals (all adult males) had rib fractures caused by arrow penetrations (Lessa and Mendonça de Souza 2004). This is not the case for individual 1948, whose healed wound shows no evidence of cause.

Paleopathological indicators suggest that this individual generally led a healthy life. He showed no indication of dietary stress in the form of porotic hyperostosis, cribra orbitalia or enamel hypoplasia. Porotic hyperostosis and cribra orbitalia were very rare in this sample (1.87%; 2/107 and 4.63%; 5/108, respectively), as would be expected during a prosperous period. The enamel hypoplasia data is complicated by the high rate of antemortem tooth loss in the Atacama. While individual 1948 did not have evidence of hypoplasia, 16.67% (n = 10/60) of the population did indicating that his nutrition was not severely compromised in infancy and early childhood. Also supporting this idea is the length of his femur, a proxy for stature. His femoral length of 424 mm approximates the average for all adult males from Solcor 3 (421.23 mm) also suggesting that his nutrition was not compromised during childhood.

In keeping with patterns of poor dental health in the Atacama, individual 1948 had lost 10 of his teeth[1] before death, showing evidence of substantial resorption and remodeling of the alveolar process. In the remaining 22 teeth he showed no evidence of calculus or abscesses and had only one large carious lesion on his left upper canine. Previous examinations of dental health at Solcor 3 show that 35% of the population had caries (Murphy et al. 1991). Moreover, more than half of the population suffered from antemortem tooth loss (52%) and abscesses were present in 7.4% of the population (Murphy 1993). Similar results were obtained from contemporary cemeteries (Kelley et al. 1991; Murphy et al. 1991). Against this back-

Figure 4. Healed fracture of left second rib, inferior view, individual 1948.
Fractura cicatrizada de la segunda costilla izquierda, vista del inferior, individuo 1948.

ground, individual 1948's poor dental health is not unusual and likely reflects the local diet, which is high in carbohydrate-laden foods such as maize, algarrobo and chañar nuts. In addition, Langsjoen's (1996) study of north Chilean populations suggests that high rates of ante-mortem loss of posterior teeth could be associated with coca chewing; this may also be a contributing factor here since coca chewing was practiced in the region.

In relation to cultural modifications to the body, individual 1948 was not buried with a labret, an adornment seen with only in two adult males (2/52 males) in this sample. Moreover, he does not appear to show evidence of intentional cranial modification although his skull evidences some slight lambdoidal flattening. This is of particular interest if this individual moved to the San Pedro oases as a child or young adult. Head shaping must be performed during infancy, when the bones of the head can be modified and retain their new shape, and as such is a signifier of origin. Head shaping was a common practice in the pre-Columbian Atacama (Munizaga 1969). At Solcor 3, over half the population (51.4%) showed evidence of cranial modification, the majority in the tabular erect style that is considered a local form (Munizaga 1969; Torres-Rouff 2002). This is a rate that is consistent with contemporary cemeteries (Torres-Rouff 2003a).

Tomb 50: The Mortuary Context

While the bioarchaeological data provides much useful information about this individual's life, information about the mortuary context is also vital. Like most tombs in the cemetery, tomb 50 was a cylindrical pit burial, oriented towards the Andean range, east of the oases. The 1.5-year-old infant was found at the side of the adult. The burial was also accompanied by a camelid offering. As such, the individual considered here was buried according to the established mortuary patterns for individuals in this area. Although the individual buried in tomb 50 was not buried with any Tiwanaku-style artifacts, a thermoluminescence date for his tomb is 720±95 AD placing it squarely in the time of Tiwanaku influence in the San Pedro oases (Bravo and Llagostera 1986:329; Llagostera 1995).

Grave goods in tomb 50 are typical of a male from this period in San Pedro de Atacama (Bravo and Llagostera 1986:329). His burial included a wooden snuff tablet carved with a three-dimensional sacrificer figure with a trophy head in his left hand, a wooden tube carved with a condor figure, and a spoon (Llagostera et al. 1988). The snuff complex is ubiquitous during this period in the Atacama. The weapons in his grave included a copper bladed axe, and a fragmented bow and arrow. Again, in keeping with local burial traditions, his bow and arrow were broken before they were interred with him. These types of grave inclusions, snuffing paraphernalia and weapons, are also highly gendered grave goods in the Atacama, being found nearly exclusively with males (Torres et al. 1991). Individual 1948 also had five coiled baskets, three gourds, and six ceramic vessels - both *negro pulido* (a local form typical of the Middle Horizon that is a fine, highly burnished, blackware) and *gris grueso pulido* (a thick gray variant of the same). Llagostera et al. (1988:95) have described this assemblage as atypical because it includes these two ceramic variants in addition to one fragmented vessel from an earlier period. In addition to these containers individual 1948 also had a ceramic box, a wooden box and a number of collections of organic materials. While nothing in his tomb was out of the ordinary for this cemetery it should be noted that he had no foreign goods, from Tiwanaku or elsewhere, and displayed an abundance of grave wealth similar to others at Solcor 3.

Archaeological Chemistry and Human Remains

Finally, we used archaeological chemistry to identify where this individual lived during enamel and bone formation. Briefly, strontium isotope analysis is becoming an increasingly common way for archaeologists and bioarchaeologists to answer questions about human migration (e.g. Bentley et al. 2002; Grupe et al. 1997; Knudson et al. 2004; Montgomery et al. 2003; Price et al. 2001; Price et al. 1994; Sealy et al. 1995; Wright 2005a). Although geologists initially used the natural variation of strontium isotopes in the environment to date igneous and sedimentary rocks, researchers in archaeology, biology, geology and paleontology have begun to utilize the fact that different geologic environments have different strontium isotope ratios to answer a wide variety of questions, such as the identification of animal migration patterns (Hoppe 2004; Hoppe et al. 1999; Ingram and Weber 1999; Kennedy et al. 1997). However, most strontium isotope analyses in archaeology have been used to answer questions about human migration (Bentley 2006; Bentley et al. 2003; Bentley et al. 2002; Ezzo et al. 1997; Ezzo and Price 2002; Farnum et al. 2003; Grupe et al. 1997; Knudson 2004; Knudson et al. 2004; Montgomery et al. 2000; Montgomery et al. 2003; Montgomery et al. 2005; Price et al. 2001; Price et al. 1998; Price et al. 1994; Price et al. 2000; Price et al. 2006; Schweissing and Grupe 2003a, b; Sealy et al. 1995; Sealy et al. 1991; Sillen et al. 1995; Sillen et al. 1998; Wright 2005a, b).

Differences in strontium isotope ratios in human tooth enamel and bone can be used to identify migration and the geologic origins of immigrants (Ericson 1985, 1989; Krueger 1985; Price et al. 1994; Sealy et al. 1991; Sillen et al. 1989). Humans incorporate strontium into their bodies mainly through the consumption of food and water (Schroeder et al. 1972). Because their atomic radii are similar, strontium substitutes for calcium in hydroxyapatite during the development of teeth and bones (Carr et al. 1962; Dolphin and Eve 1963; Elias 1980; Elias et al. 1982; Hodges et al. 1950; Kulp and Schulert 1962; Lowenstam and Weiner 1989; Schroeder et al. 1972). Unlike lighter isotopes, substantial fractionation does not occur between different isotopes of strontium as the elements are incorporated into hydroxyapatite because the mass differences between the various isotopes of strontium are so small (Price et al. 2002).

Therefore, the isotope ratios of strontium found in an individual's bone and teeth reflect the isotopic ratios found in the plants, animals and water that she or he consumed, which in turn reflect the isotope ratios found in the soil and bedrock of that geologic region. Since bone continually regenerates, the strontium isotope ratios in human bone will reflect the geologic region in which a person lived before death. The exact number of years before death that are represented will depend on the skeletal element analyzed. However, tooth enamel does not regenerate after it has formed, so the strontium isotopes in tooth enamel will reflect the geologic region in which a person lived while her or his tooth enamel formed.

In contrast, archaeologists have traditionally used the *concentration* of strontium in human tooth enamel and bone to determine paleodiet, not migration. As previously discussed, strontium substitutes for calcium in biological systems (Carr et al. 1962; Dolphin and Eve 1963; Elias 1980; Elias et al. 1982; Hodges et al. 1950; Kulp and Schulert 1962; Lowenstam and Weiner 1989; Schroeder et al. 1972). However, the amount of strontium *relative* to calcium decreases as one moves up the food chain because of biopurification of calcium (Balter 2004; Dolphin and Eve 1963; Elias 1980; Elias et al. 1982; Schroeder et al. 1972). Therefore, the ratio of strontium to calcium (Sr/Ca) in bones is lowest for carnivores, slightly higher for herbivores, and the highest Sr/Ca ratios are found in plant materials (Balter 2004; Dolphin and Eve 1963; Elias et al. 1982; Price et al. 1985; Price et al. 1986; Schroeder et al. 1972). This information has been used by archaeologists to determine the amounts of plant and animal material in an individual's diet (Baraybar 1999; Brown 1974; Burton 1996; Ezzo 1992a; Ezzo et al. 1995; Farnum and Sandford 2002; Schoeninger 1979; Schutkowski et al. 1999; Sillen 1981, 1992; Sillen et al. 1995; Tomczak 1995). In addition, the ratio of barium to calcium has been used to identify marine food consumption when used in conjunction with strontium concentration data (Burton and Price 1990, 1991).

However, a number of researchers have identified various limitations of using strontium and barium concentrations to determine paleodiet (Burton 1996; Burton and Price 2000; Elias 1980; Fuchs 1987; Pate and Brown 1985; Radosevich 1993; Sandford and Katzenberg 1992; Sandford and Weaver 2000; Schoeninger 1978, 1979, 1989; Sillen 1981, 1992; Sillen et al. 1995; Sillen and Kavanagh 1982; Sillen et al. 1989). For example, the strontium and barium concentrations in different geologic zones vary widely, which ensures that the strontium and barium concentrations in human bone from different geologic zones also vary widely (Odum 1951; Schoeninger 1979, 1989; Schroeder et al. 1972; Sillen and Kavanagh 1982; Turekian and Kulp 1956a, b). By utilizing the variability of strontium and barium concentrations in different geologic zones, archaeologists may be able to identify migration (Burton et al. 2003).

Finally, one of the most important aspects of biogeochemical analysis of archaeological human remains is ensuring that the chemical signatures do not reflect post-depositional contamination. It is well established that bone is susceptible to diagenetic contamination from the burial environment (Budd et al. 2000; Edward and Benfer 1993; Ericson 1993; Ezzo 1992b; Grupe et al. 1999; Hancock et al. 1989; Horn and Muller-Sohnius 1999; Lambert et al. 1991; Nelson et al. 1986; Nielsen-Marsh and Hedges 2000a, b; Pate and Brown 1985; Price et al. 1992; Sillen 1989; Sillen and Sealy 1995; Stuart-Williams et al. 1996; Waldron 1981, 1983; Waldron et al. 1979). However, tooth enamel is resistant to diagenetic contamination (Budd et al. 2000; Budd et al. 1998; Chiaradia et al. 2003; Grupe et al. 1997; Hillson 1996; Kohn et al. 1999; Lee-Thorp and Sponheimer 2003; Molleson 1988; Montgomery et al. 1999; Price et al. 1994; Shellis and Dibdin 2000; Vernois et al. 1988). Mechanical and chemical cleaning of archaeological tooth enamel and bone can eliminate much of the diagenetic contamination that occurs (Lambert et al. 1991; Nielsen-Marsh and Hedges 2000b; Price et al. 1992; Price et al. 1994; Sillen and LeGros 1991; Sillen and Sealy 1995). In addition, a number of different techniques, including monitoring the ratio of calcium to phosphorus (Ca/P) can identify contaminated samples during sample analysis (Bentley 2001; Edward and Benfer 1993; Hancock et al. 1989; Knudson 2004; Kohn et al. 1999; Kyle 1986; Nielsen-Marsh and Hedges 2000a, b; Price et al. 2002; Price et al. 1994; Sillen 1989; Wright and Schwarcz 1996).

Strontium Isotope and Trace Element Concentration Data from Tomb 50, Solcor 3

Strontium isotope results

The strontium isotope ratios in exposed bedrock in the San Pedro de Atacama region are $^{87}Sr/^{86}Sr = 0.7062\text{-}0.7068$ (Rogers and Hawkesworth 1989). Strontium isotope ratios in modern and archaeological fauna from the San Pedro de Atacama region are similar, although slightly higher. The local range of the San Pedro de Atacama region is $^{87}Sr/^{86}Sr = 0.7074\text{-}0.7079$, and is the mean of three bone samples from local San Pedro de Atacama fauna, plus or minus two standard deviations (Figure 5, Table 1) (Price et al. 2002). The majority of the archaeological human samples from three San Pedro cemeteries are between $^{87}Sr/^{86}Sr = 0.7074\text{-}0.7079$, which suggests that the fauna bone samples more accurately reflect the local range of the San Pedro inhabitants than the geologic data (Knudson 2004).

In general, the strontium isotope data from human tooth enamel from the cemetery of Solcor 3 shows that many of the individuals buried in Solcor 3 likely came from the same geographic area (Knudson 2004). Of the 153 individuals buried at Solcor 3, ninety-two individuals were included in previous biodistance and cranial modification studies (Torres-Rouff 2002). Of these 92 individuals, strontium isotope analysis

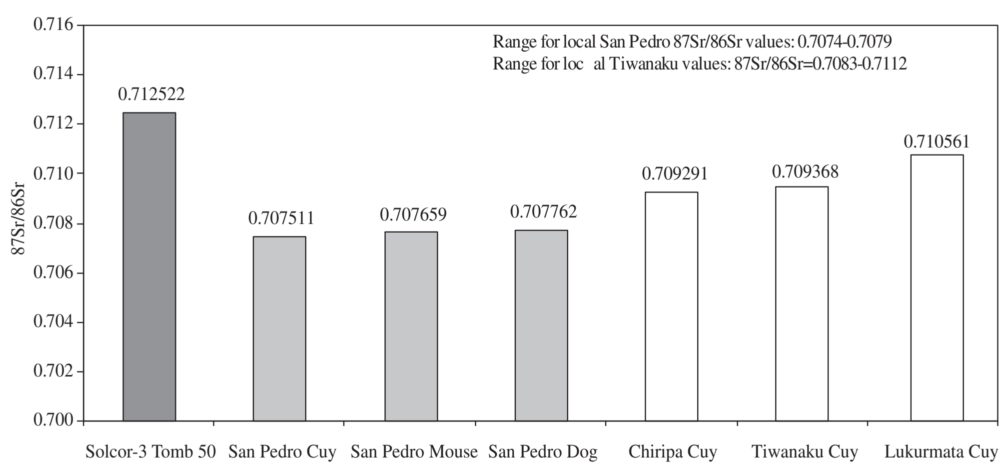

Figure 5. Strontium isotope data from first molar tooth enamel from individual 1948 as well as modern and archaeological fauna from the San Pedro de Atacama oasis and the southeastern Lake Titicaca Basin where Tiwanaku is located.
Datos de isótopo de estroncio del esmalte del primer diente molar del individuo 1948, de la fauna moderna y arqueológica de los oasis de San Pedro de Atacama y el sudeste de la cuenca del Lago Titicaca donde se localiza Tiwanaku.

Table 1. Strontium isotope and trace element concentration data for archaeological human remains from Solcor 3 Tomb 50 and archaeological and modern fauna from San Pedro de Atacama and the southeastern Lake Titicaca Basin.
Datos de isótopo de estroncio y de la concentración de elementos traza de restos humanos de la tumba 50 de Solcor 3, y de la fauna moderna y arqueológica de los oasis de San Pedro de Atacama y el sudeste de la cuenca del Lago Titicaca.

Site (Region)	Lab Number	Specimen Number	Material	Corrected $^{87}Sr/^{86}Sr$	Log (Ba/Ca)	Log (Sr/Ca)
Solcor 3 (San Pedro de Atacama)	F1681	SC3–50	human URM1	0.712522	NA	NA
Solcor 3 (San Pedro de Atacama)	F1683	SC3–50	human rib	NA	–4.01	–2.75
Quitor–6 (San Pedro de Atacama)	F1635	QT6–18	mouse bone (archaeological)	0.707659	–3.76	–2.49
Quitor–6 (San Pedro de Atacama)	F1636	QT6–33	dog bone (archaeological)	0.707762	–3.84	–2.62
Quitor–6 (San Pedro de Atacama)	F1714	SPA1	*cuy* bone (modern)	0.707511	–3.86	–2.23
Chiripa (Titicaca Basin)	F1024	Ch1A	*cuy* bone (modern)	0.709291	NA	NA
Lukurmata (Titicaca Basin)	F1025	L2A	*cuy* bone (modern)	0.710561	NA	NA
Tiwanaku (Titicaca Basin)	F1026	T1A	*cuy* bone (modern)	0.709368	–3.72	–2.58
Tiwanaku (Titicaca Basin)	F1715	T3A	*cuy* bone (modern)	NA	–3.43	–2.66
Tiwanaku (Titicaca Basin)	F1913	T3B	*cuy* bone (modern)	NA	–3.48	–2.64
Tiwanaku (Titicaca Basin)	F1716	T4A	*cuy* bone (modern)	NA	–3.48	–2.64
Tiwanaku (Titicaca Basin)	F1914	T4B	*cuy* bone (modern)	NA	–3.48	–2.67
Tiwanaku (Titicaca Basin)	F1912	T5A	*cuy* bone (modern)	NA	–3.30	–2.51
Tiwanaku (Titicaca Basin)	F1915	T5B	*cuy* bone (modern)	NA	–3.34	–2.51
Tiwanaku (Titicaca Basin)	F1717	T6A	*cuy* bone (modern)	NA	–3.31	–2.47
Tiwanaku (Titicaca Basin)	F1916	T6B	*cuy* bone (modern)	NA	–3.35	–2.48
Tiwanaku (Titicaca Basin)	F1718	T7	*cuy* bone (modern)	NA	–3.18	–2.41

was performed on tooth enamel from 16 individuals in order to test the hypothesis that the individuals buried with Tiwanaku-style artifacts were immigrants from the Lake Titicaca Basin (Knudson 2004).

Compared to the strontium isotope ratios in individuals buried in the cemeteries of Coyo 3 and Coyo Oriental, there is more variability in the strontium isotope ratios seen in tooth enamel at Solcor 3 (Knudson 2004). In fact, out of the 16 individuals analyzed, nine individuals had strontium isotope ratios in their first or second molar enamel that were outside of the local San Pedro de Atacama signature of $^{87}Sr/^{86}Sr$ = 0.7074-0.7079 (Knudson 2004). However, eight of these individuals were only slightly outside of the local range of $^{87}Sr/^{86}Sr$ = 0.7074-0.7079 (Knudson 2004). This implies that individuals buried at Solcor 3 had access to foods from agricultural fields in a slightly different location, or ate a different or more varied diet, than the individuals buried at Coyo 3 and Coyo Oriental.

Only one individual buried at Solcor 3 had a strontium isotope ratio that is clearly non-local. Individual 1948 exhibited strontium isotope ratios in his upper right first molar that were well outside of the local San Pedro de Atacama strontium isotope ratios (SC3-50, $^{87}Sr/^{86}Sr$ = 0.712522) (Figure 5, Table 1, Appendix 1). This implies that this individual did not live in the San Pedro de Atacama oasis during the first three years of his life. Despite the hypothesis that some individuals buried at Solcor 3 were immigrants from the Lake Titicaca Basin, the strontium isotope ratio in this individual's tooth enamel is not within the local strontium isotope signature in the southeastern Lake Titicaca Basin ($^{87}Sr/^{86}Sr$ = 0.7083-0.7112). Individual 1948 does have a strontium isotope signature that is similar to the northeastern Lake Titicaca Basin, where strontium isotopes in surface water from the Río Suches were $^{87}Sr/^{86}Sr$ = 0.712002-0.713458 (Grove et al. 2003). However, it is possible that this individual came from a region for which we do not yet have strontium isotope ratio data.

Finally, it is unlikely that the non-local strontium isotope signature in this individual's tooth enamel was caused by the consumption of strontium in non-local foods. If this individual's diet, or his mother's diet, during breastfeeding, consisted of locally-grown terrestrial products and locally-procured camelids and freshwater products, the strontium in the diet would have come predominately from high-strontium parts of terrestrial plants rather than the low-strontium meat or fish products. Grave goods in the cemeteries of Coyo 3, Coyo Oriental and Solcor 3 include maize, algarrobo, camelid bones and freshwater shells (Costa-Junqueira and Llagostera 1994; Oakland Rodman 1992). These foodstuffs could be raised or procured near the oases and it is unlikely that large quantities were imported.

Trace element concentrations results

Trace element analysis on a rib fragment from individual 1948 was initially used to determine the amount of diagenetic, or post-depositional, contamination in the bone (Knudson 2004). Monitoring the ratio of calcium to phosphorus (Ca/P) in skeletal material can identify contaminated samples because contaminated bone will have a much higher Ca/P ratio that the biogenic ratio of Ca/P = 2.1:1 (Price et al. 1994; Sillen 1989). For this individual, there is little evidence of diagenetic contamination because Ca/P = 2.25.

In addition, modern and archaeological faunal bones from San Pedro de Atacama and the southeastern Lake Titicaca Basin were analyzed using inductively coupled plasma atomic emission spectrometry (ICP-AES) in order to determine the regional differences in strontium to calcium and barium to calcium ratios in the South Central Andes (Appendix 1). Barium, calcium and strontium concentrations show that most fauna from the southeastern Lake Titicaca Basin and the San Pedro de Atacama oasis do not cluster together (Figure 6, Table 1). The trace element concentrations from the bone of individual 1948 are closer to the San Pedro fauna than the Lake Titicaca Basin fauna (Figure 6, Table 1). This implies that individual 1948 lived in or near the San Pedro de Atacama oasis in the years before death.

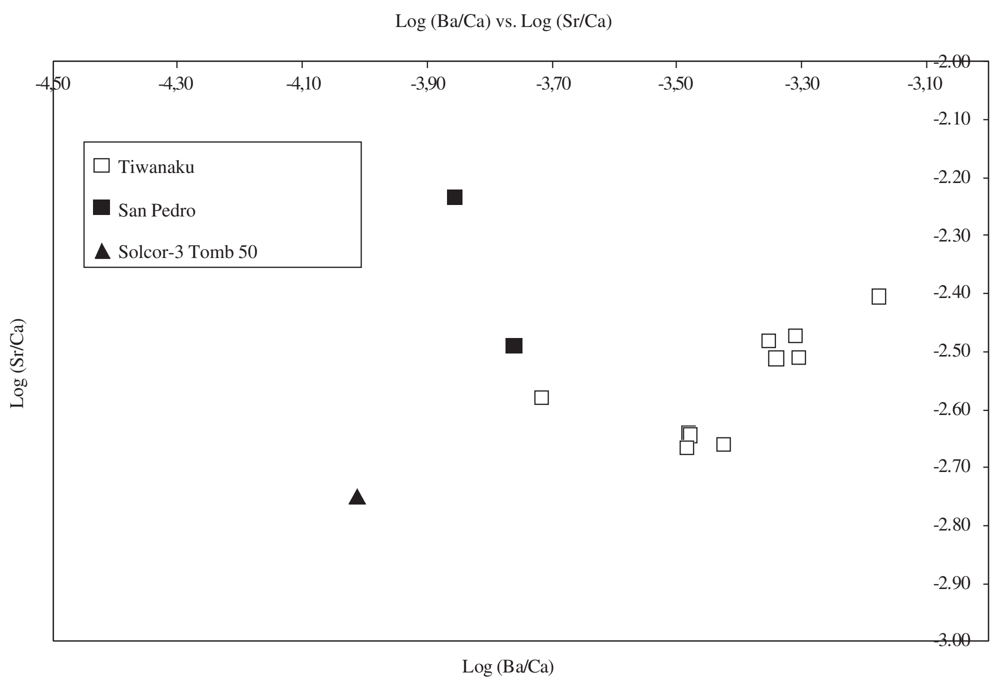

Figure 6. Trace element concentration data of modern and archaeological fauna from the San Pedro de Atacama oasis and the southeastern Lake Titicaca Basin where Tiwanaku is located, as well as trace element concentration data on a rib fragment from the adult male buried in Tomb 50.

Datos de la concentración de los elementos traza de la fauna moderna y arqueológica de los oasis de San Pedro de Atacama y el sudeste de la cuenca del Lago Titicaca donde se localiza Tiwanaku, y datos de la concentración de los elementos traza en un fragmento de costilla del individuo 1948.

Discussion and Conclusion

This in-depth analysis has allowed us to explore the life of one individual in the prehistoric San Pedro oases. Doing so has provided a glimpse into patterns of body use, cultural relationships, and mobility and how this individual was assimilated into Atacameño society. Strontium isotope and trace element concentration analysis shows that despite being buried there, individual 1948 likely lived outside of the San Pedro de Atacama oases for the first years of life. Scholars have argued that initial migrant populations tend to be young and male (Anthony 1990:905; Burmeister 2000:545, 549) a finding that concords with our investigation. However, if individual 1948 was born and spent the early years of his life away from the San Pedro oases, our data imply that this did not necessarily hinder his later inclusion into Atacameño society. In contrast, our data show that he likely underwent a process of acculturation.

Individual 1948 was buried in a local cemetery, in local fashion, with no indication of his possible foreign origin. Even his grave goods were local in origin, without any evidence of trade goods from the Tiwanaku state or elsewhere. Moreover, he had the typical accoutrements of a man of his era including weapons and snuffing paraphernalia, objects found in many adult male graves at Solcor 3 and more typically throughout the San Pedro oases.

Beyond the mortuary data, analyses of his skeleton support these conclusions. Like most inhabitants of the oases during this period, his nutrition, as seen through indicators of nutritional deficiency and stature, was not compromised. Dental data support the idea that he spent his adult life in the oases consuming a diet akin to that of others, since he suffered similarly high rates of dental disease and ante-mortem tooth loss. Moreover, his patterns of body use indicate assimilation into the regular work regimen of this population. Examination of head shape raises some interesting issues in this analysis. Individual 1948's unmodified head shape may have facilitated his ability to integrate successfully into Atacameño society since he was not marked with a sign of belonging to a foreign group. Blom (2005:17) has noted, "the benefits of not being identified as belonging to a particular group might have been seen if they were, for example, members of llama caravans, who were thought to have traveled throughout the Tiwanaku realm". The ability to cross-boundaries and present a fluid identity could have been advantageous for a migrant into San Pedro de Atacama.

These data come together to present an image of a man born outside the San Pedro oases who, over the course of his life, became an Atacameño in those material traces left in the archaeological record. In conclusion, our analyses indicate that his acculturation into Atacameño society during his adult life was nearly complete and he retains little to no indication of his probable foreign birth.

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References Cited

Alvrus, A.
1999 Fracture patterns among the Nubians of Semna South, Sudanese Nubia. *International Journal of Osteoarchaeology* 9:417-429.

Anthony, D.W.
1990 Migration in archaeology: The baby and the bathwater. *American Anthropologist* 92:895-914.
1992 The bath refilled: Migration in archaeology again. *American Anthropologist* 94:174-176.

Antón, S.C.
1989 Intentional cranial vault deformation and induced changes of the cranial base and face. *American Journal of Physical Anthropology* 79:253-268.

Arriaza, B.T.
1995 *Beyond Death: The Chinchorro Mummies of Ancient Chile*. Smithsonian Institution Press, Washington, DC.

Aufderheide, A.C. and C. Rodriguez-Martin
1998 *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge University Press, New York.

Balter, V.
2004 Allometric constraints on Sr/Ca and Ba/Ca partitioning in terrestrial mammalian trophic chains. *Ecosystem Ecology* 139:83-88.

Baraybar, J.P.
1999 Diet and death in a fog oasis site in Central Coastal Peru: A trace element study of Tomb 1 Malanche 22. *Journal of Archaeological Science* 26:471-482.

Bentley, R.A.
2001 *Human Migration in Early Neolithic Europe: A Study by Strontium and Lead Isotope Analysis of Archaeological Skeletons*. Doctoral Dissertation, Department of Anthropology, University of Wisconsin, Madison.
2006 Strontium isotopes from the earth to the archaeological skeleton: A review. *Journal of Archaeological Method and Theory* 13:135-187.

Bentley, R.A., R. Krause, T.D. Price and B. Kaufmann
2003 Human mobility at the Early Neolithic settlement of Vaihingen, Germany: Evidence from strontium isotope analysis. *Archaeometry* 45:471-487.

Bentley, R.A., T.D. Price, J. Luning, D. Gronenbron, J. Wahl and P.D. Fullagar
2002 Prehistoric migration in Europe: Strontium isotope analysis of Early Neolithic skeletons. *Current Anthropology* 34:799-804.

Berenguer, J. and P. Dauelsberg
1989 El Norte Grande en la órbita de Tiwanaku (400 a 1200 d.C.). In *Culturas de Chile. Prehistoria desde sus Orígenes hasta los Albores de la Conquista*, edited by J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate and I. Solimano, pp. 129-180. Andrés Bello, Santiago.

Blom, D.E.
1999 *Tiwanaku Regional Interaction and Social Identity: A Bioarchaeological Approach*. Doctoral Dissertation, Department of Anthropology, University of Chicago, Chicago.
2005 Embodying borders: Human body modification and diversity in Tiwanaku Society. *Journal of Anthropological Archaeology* 24:1-24.

Blom, D.E., B. Hallgrimsson, L. Keng, M.C. Lozada and J.E. Buikstra
1998 Tiwanaku 'Colonization': Bioarchaeological implications for migration in the Moquegua Valley, Peru. *World Archaeology* 30:238-261.

Bravo, L. and A. Llagostera
1986 Solcor-3: Un aporte al conocimiento de la cultura San Pedro. Periodo 500 al 900 d.C. *Chungara* 16-17:323-332.

Brooks, S.T. and J.M. Suchey
1990 Skeletal age determination based on the Os Pubis: A comparison of the Acsadi-Nemeskeri and Suchey-Brooks methods. *Human Evolution* 5:227-238.

Brown, A.B.
1974 Bone strontium as a dietary indicator in human skeletal populations. *Contributions to Geology* 13:47-48.

Budd, P., J. Montgomery, B. Barreiro and R.G. Thomas
2000 Differential diagenesis of strontium in archaeological human dental tissues. *Applied Geochemistry* 15:687-694.

Budd, P., J. Montgomery, A. Cox, P. Krause, B. Barreiro and R.G. Thomas
1998 The distribution of lead within ancient and modern human teeth: Implications for long-term and historical exposure modeling. *The Science of the Total Environment* 220:121-136.

Buikstra, J.E.
1977 Biocultural dimensions of archaeological study: A regional perspective. *Southern Anthropological Society. Proceedings* 11, pp. 67-84, Athens.

Buikstra, J.E. and D.H. Ubelaker
1994 Standards for data collection from human skeletal remains. *Arkansas Archaeological Survey Research Series* No. 44. Arkansas Archaeological Survey, Fayetteville.

Burmeister, S.
2000 Archaeology and migration: Approaches to an archaeological proof of migration. *Current Anthropology* 41:539-567.

Burton, J.H.
1996 Trace elements in bone as paleodietary indicators. In *Archaeological Chemistry*, edited by M.V. Orna, pp. 327-333. American Chemical Society, Washington, DC.

Burton, J.H. and T.D. Price
1990 The ratio of barium to strontium as a paleodietary indicator of consumption of marine resources. *Journal of Archaeological Science* 17:547-557.
1991 Paleodietary applications of barium values in bone. In *International Symposium on Archaeometry, 2-6 April, 1990, Heidelberg, Germany*, edited by G.A. Wagner and E. Pernicka, pp. 787-795. Birkhauser Verlag Basel, Basel.
2000 The use and abuse of trace elements for paleodietary research. In *Biogeochemical Approaches to Paleodietary Analysis*, edited by S.A. Ambrose and M.A. Katzenberg, pp. 159-171. Kluwer Academic/ Plenum Publishers, New York.

Burton, J.H., T.D. Price, L. Cahue and L. Wright
2003 The use of barium and strontium abundances in human skeletal tissues to determine their geographic origins. *International Journal of Osteoarchaeology* 13:88-195.

Buzon, M.R., J.T. Eng, P.M. Lambert and P.L. Walker
2005 Bioarchaeological methods. In *Handbook of Archaeological Methods*, edited by H.D.G. Maschner and C. Chippendale, vol. II, pp. 871-918. Altamira Press, Walnut Creek.

Carr, T.E.F., G.E. Harrison, J.F. Loutit and A. Sutton
1962 Movement of strontium in the human body. *British Medical Journal* 2:773-775.

Chiaradia, M., A. Gallay and W. Todt
2003 Different contamination styles of prehistoric human teeth at a Swiss Necropolis (Sion, Valais) inferred from lead and strontium isotopes. *Applied Geochemistry* 18:353-370.

Cocilovo, J.A. and M.V. Zavattierri
1994 Biología del grupo prehistórico de Coyo Oriental (San Pedro de Atacama, Norte de Chile): II deformación craneana artificial. *Estudios Atacameños* 11:135-143.

Cohen, M.N. and G.J. Armelagos
1984 *Paleopathology at the Origins of Agriculture*. Academic Press, Orlando.

Costa-Junqueira, M.A. and A. Llagostera
1994 Coyo-3: momentos finales del período Medio en San Pedro de Atacama. *Estudios Atacameños* 11:73-143.

Costa Junqueira, M.A., W.A. Neves and M. Hubbe
2004 Influencia de Tiwanaku en la calidad de vida biológica de la población prehistórica de San Pedro de Atacama. *Estudios Atacameños* 27:103-116.

Cusick, J.G.
1998 Historiography of acculturation: An evaluation of concepts and their application in archaeology. In *Studies in Cultural Contact: Interaction, Culture Change, and Archaeology*, edited by J.G. Cusick, pp. 126-145. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Cybulski, J.
1974 Tooth wear and material culture: Precontact patterns in the Tsimshian Area, British Columbia. *Syesis* 7:31-35.

Deagan, K.
1998 Transculturation and Spanish American ethnogenesis: The archaeological legacy of the quincentenary. In *Studies in Cultural Contact: Interaction, Culture Change, and Archaeology*, edited by J.G. Cusick, pp. 29-43. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Dembo, A. and J. Imbelloni
1938 *Deformaciones Intencionales del Cuerpo Humano de Carácter Étnico*. J. Anesi, Buenos Aires.

Dobney, K. and A.H. Goodman
1991 An epidemiological study of enamel defects. In *Health in Past Societies*, edited by H. Bush and M. Zvelebil, pp. 81-100. vol. 567. BAR International, Oxford.

Dolphin, G.W. and I.S. Eve
1963 The metabolism of strontium in adult humans. *Physics of Medical Biology* 8:193-203.

Edward, J.B. and R.A. Benfer
1993 The effects of diagenesis on the Paloma skeletal material. In *Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology*, edited by M.K. Sandford, pp. 183-268. Gordon and Breach Science Publishers, New York.

El-Najjar, M.B., M.D. Ryan, C. Turner and B. Lozoff
1976 The etiology of porotic hyperostosis among the prehistoric and historic Anasazi Indians of the Southwestern United States. *American Journal of Physical Anthropology* 44:477-488.

Elias, M.
1980 The feasibility of dental strontium analysis for diet-assessment of human populations. *American Journal of Physical Anthropology* 53:1-4.

Elias, R.W., Y. Hirao and C.C. Patterson
1982 The circumvention of the natural biopurification of calcium along nutrient pathways by atmospheric inputs of industrial lead. *Geochimica et Cosmochimica Acta* 46:2561-2580.

Ericson, J.E.
1985 Strontium isotope characterization in the study of prehistoric human ecology. *Journal of Human Evolution* 14:503-514.
1989 Some problems and potentials of strontium isotope analysis for human and animal ecology. In *Stable Isotopes in Ecological Research*, edited by R.W. Rundel, J.R. Ehleringer and K.A. Nagy, pp. 254-269. Springer-Verlag, New York.
1993 Ba/Ca as a diagenetic indicator for evaluating buried bone tissues: Advances in tissue selection, reducing contamination, and data evaluation. In *Prehistoric Human Bone: Archaeology at the Molecular Level*, edited by J.B. Lambert and G. Grupe, pp. 157-171. Springer-Verlag, New York.

Ezzo, J.A.
1992a Dietary change and variability at Grasshopper Pueblo, Arizona. *Journal of Anthropological Archaeology* 11:219-289.
1992b A test of diet versus diagenesis at Ventana Cave, Arizona. *Journal of Archaeological Science* 19:23-37.

Ezzo, J.A., C.M. Johnson and T.D. Price
1997 Analytical perspectives on prehistoric migration: A case study from East-Central Arizona. *Journal of Archaeological Science* 24:447-466.

Ezzo, J.A., C.S. Larsen and J.H. Burton
1995 Elemental signatures from the Georgia Bight. *American Journal of Physical Anthropology* 98:471-481.

Ezzo, J.A. and T.D. Price
2002 Migration, regional reorganization, and spatial group composition at Grasshopper Pueblo, Arizona. *Journal of Archaeological Science* 29:499-520.

Farnum, J. and M.K. Sandford
2002 Trace element analyses of the skeletal remains and associated soils from the Tutu Site. In *Human Adaptations at the Tutu Archaeological Village Site: A Multidisciplinary Case Study*, edited by E. Righter, pp. 250-262. Routledge, London.

Farnum, J., R.J. Speakman, K. Lienhop and I. Shimada
2003 Diet, status and health at Sican: A test of ICP-MS as a tool for paleodietary reconstruction. Paper presented at the *66th Annual Meeting of the Society for American Archaeology*, Milwaukee.

Feder, K.L.
1981 The Archaeology of trade, migration and diffusion: How can you really tell? *Bulletin of the Archaeological Society of Connecticut* 44:51-99.

Fuchs, A.
1987 Strontium calcium ratios in bone: An assessment of their use in paleodietary research. *MASCA Journal* 1:10-11.
Goodman, A.H.
1993 On the interpretation of health from skeletal remains. *Current Anthropology* 34:281-288.
Goodman, A.H. and G.J. Armelagos
1985 Factors affecting the distribution of enamel hypoplasias within the human permanent dentition. *American Journal of Physical Anthropology* 68:479-493.
Goodman, A.H., G.J. Armelagos and J.C. Rose
1980 Enamel hypoplasias as indicators of stress in three prehistoric populations from Illinois. *Human Biology* 52:515-528.
Grove, M.J., P.A. Baker, S.L. Cross, C.A. Rigsby and G.O. Seltzer
2003 Application of strontium isotopes to understanding the hydrology and paleohydrology of the Altiplano, Bolivia-Peru. *Paleogeography, Paleoclimatology, Paleoecology* 194:281-297.
Grupe, G., T.D. Price, P. Schroter, F. Sollner, C.M. Johnson and B.L. Beard
1997 Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: A study of Southern Bavarian skeletal remains. *Applied Geochemistry* 12:517-525.
Grupe, G., T.D. Price and F. Sollner
1999 Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: A study of Southern Bavarian skeletal remains: A reply to the comment by Peter Horn and Dieter Muller-Sohnius. *Applied Geochemistry* 14:271-275.
Hancock, R.G.V., M.D. Grynpass and K.P.H. Protzker
1989 Abuses of bone analysis for archaeological dietary studies. *Archaeometry* 31:169-179.
Hillson, S.
1979 Diet and dental disease. *World Archaeology* 2:147-162.
1996 *Dental Anthropology*. Cambridge University Press, Cambridge.
Hodges, R.M., N.S. MacDonald, R. Nusbaum, R. Stearns, F. Ezmirlian, P. Spain and C. MacArthur
1950 The strontium content of human bones. *Journal of Biological Chemistry* 185:519-524.
Holland, T.D. and M.J. O'Brien
1997 Parasites, porotic hyperostosis, and the implications of changing perspectives. *American Antiquity* 62:183-193.
Hollimon, S.E.
1991 Health consequences of divisions of labor among the Chumash Indians of Southern California. Paper presented at the *Chacmool Conference: Archaeology of Gender*, Calgary.
Hoppe, K.A.
2004 Late Pleistocene mammoth herd structure, migration patterns, and Clovis hunting strategies inferred from isotopic analyses of multiple death assemblages. *Palaeobiology* 30:129-145.
Hoppe, K., P.L. Koch, R.W. Carlson and S.D. Webb
1999 Tracking mammoths and mastodons: Reconstruction of migratory behavior using strontium isotope ratios. *Geology* 25:439-442.
Horn, P. and D. Muller-Sohnius
1999 Comment on 'Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: A study of Southern Bavarian skeletal remains' by Gisela Grupe, T. Douglas Price, Peter Schroter, Frank Sollner, Clark M. Johnson, and Brian L. Beard. *Applied Geochemistry* 14:263-269.
Hoshower, L., J.E. Buikstra, P.S. Goldstein and A.D. Webster
1995 Artificial cranial deformation at the Omo M10 site: A Tiwanaku complex from the Moquegua Valley, Peru. *Latin American Antiquity* 6:145-164.
Ingram, B.L. and P.K. Weber
1999 Salmon origin in California's Sacramento-San Joaquin River system as determined by otolith strontium isotopic composition. *Geology* 27:851-854.
Kelley, M.A., D.R. Levesque and E. Weidl
1991 Contrasting patterns of dental disease in five early northern Chilean groups. In *Advances in Dental Anthropology*, edited by M. Kelley and C.S. Larsen, pp. 203-213. Wiley-Liss, New York.
Kennedy, B.P., C.L. Folt, J.D. Blum and C.P. Chamberlain
1997 Natural isotope markers in Salmon. *Nature* 387:766.
Kent, S.
1986 The influence of sedentism and aggregation on porotic hyperostosis and anaemia: A case study. *Man* 21:605-636.
Knudson, K.J.
2004 *Tiwanaku Residential Mobility in the South Central Andes: Identifying Archaeological Human Migration through Strontium Isotope Analysis*. Doctoral Dissertation, Department of Anthropology, University of Wisconsin, Madison.
2007 La influencia de Tiwanaku en San Pedro de Atacama: Una investigación por los isótopos del estroncio. *Estudios Atacameños* 33:7-24.
Knudson, K.J. and T.D. Price
2007 The Utility of multiple chemical techniques in archaeological residential mobility studies: Case studies from Tiwanaku- and Chiribaya-Affiliated sites in the Andes. *American Journal of Physical Anthropology* 132:25-39.
Knudson, K.J., T.D. Price, J.E. Buikstra and D.E. Blom
2004 The use of strontium isotope analysis to investigate Tiwanaku migration and mortuary ritual in Bolivia and Peru. *Archaeometry* 46(1):5-18.
Kohn, M.J., M.J. Schoeninger and W.W. Barker
1999 Altered states: Effects of diagenesis on fossil tooth chemistry. *Geochimica et Cosmochimica Acta* 63:2737-2747.
Kolata, A.L.
1993 *The Tiwanaku: Portrait of an Andean Civilization*. Blackwell, Oxford.
Krueger, H.W.
1985 Sr Isotopes and Sr/Ca in Bone. Poster paper presented at *Biomineralization Conference, Airlie House*, Warrenton.
Kulp, J.L. and A.R. Schulert
1962 Strontium-90 in Man V. *Science* 136(3516):619-632.
Kyle, J.H.
1986 Effect of post-burial contamination on the concentrations of major and minor elements in human bones and teeth-the implications for paleodietary research. *Journal of Archaeological Science* 13:403-416.

Lallo, J., R.P. Mensforth and G.J. Armelagos
1977 The role of diet, disease and physiology in the origin of porotic hyperostosis. *Human Biology* 49:471-483.
Lambert, J.B., J.M. Weydert, S.R. Williams and J.E. Buikstra
1991 Inorganic analysis of excavated human bone after surface removal. *Journal of Archaeological Science* 18:363-383.
Langsjoen, O.
1996 Dental effects of diet and coca-leaf chewing on two prehistoric cultures of Northern Chile. *American Journal of Physical Anthropology* 101:475-489.
Larsen, C.S.
1997 *Bioarchaeology: Interpreting Behavior from the Human Skeleton*. Cambridge studies in biological anthropology. Cambridge University Press, New York.
Lechtman, H. and A. Macfarlane
2005 La metalurgia del bronce en los Andes Sur Centrales: Tiwanaku y San Pedro de Atacama. *Estudios Atacameños* 30:7-27.
Lee-Thorp, J. and M. Sponheimer
2003 Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for paleodietary studies. *Journal of Anthropological Archaeology* 22:208-216.
Lessa, A. and S. Mendonça de Souza
2004 Violence in the Atacama Desert during the Tiwanaku period: Social tension? *International Journal of Osteoarchaeology* 14:374-388.
Llagostera, A.
1995 Art in the snuff trays of San Pedro de Atacama (Northern Chile). In *Andean Art: Visual Expression and Its Relation to Andean Beliefs and Values*, edited by P. Dransart, pp. 51-77. Avebury, Aldershot.
2004 *Los Antiguos Habitantes del Salar de Atacama: Prehistoria Atacameña*. Editorial Pehuén, Antofagasta.
Llagostera, A., C.M. Torres and M.A. Costa
1988 El complejo psicotrópico en Solcor-3 (San Pedro de Atacama). *Estudios Atacameños* 9:61-98.
Lowenstam, H.A. and S. Weiner
1989 *On Biomineralization*. Oxford University Press, Oxford.
Meskell, L.
2000 Writing the body in archaeology. In *Reading the Body: Representations and Remains in the Archaeological Record*, edited by A.E. Rautman, pp. 13-21. University of Pennsylvania Press, Philadelphia.
2002 *Private Life in New Kingdom Egypt*. Princeton University Press, Princeton.
Molleson, T.
1988 Trace elements in human teeth. In *Trace Elements in Environmental History*, edited by G. Grupe and B. Herrmann, pp. 67-82. Springer-Verlag, Berlin.
Montgomery, J., P. Budd, A. Cox, P. Krause and R.G. Thomas
1999 LA-ICP-MS evidence for the distribution of lead and strontium in Romano-British, medieval and modern human teeth: Implications for life history and exposure reconstruction. In *Metals in Antiquity*, edited by S.M.M. Young, A.M. Pollard, P. Budd and R.A. Ixer, pp. 290-296. BAR International Series, Oxford.
Montgomery, J., P. Budd and J. Evans
2000 Reconstructing the lifetime movements of ancient people: A Neolithic case study from Southern England. *European Journal of Archaeology* 3:370-385.
Montgomery, J., P. Budd and T. Neighbour
2003 Sr isotope evidence for population movement within the Hebridean Norse community of NW Scotland. *Journal of the Geological Society* 160:649-653.
Montgomery, J., J.A. Evans, D. Powlesland and C.A. Roberts
2005 Continuity or Colonization in Anglo-Saxon England? Isotope Evidence for Mobility, Subsistence Practice, and Status at West Heslerton. *American Journal of Physical Anthropology* 126:123-138.
Munizaga, J.
1969 Deformación craneana intencional en San Pedro de Atacama. Paper presented at the *V Congreso Nacional de Arqueología Chilena*, La Serena.
Muñoz, I.
1989 El período formativo en el norte grande. In *Culturas de Chile. Prehistoria desde sus Orígenes hasta los Albores de la Conquista*, edited by J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate and I. Solimano, pp. 107-128. Andrés Bello, Santiago.
Murphy, S.P.
1993 Dental disease in the pre-Hispanic Agroalfarero Period of San Pedro de Atacama, Chile (abstract). *American Journal of Physical Anthropology* Supplement 16:150.
Murphy, S.P., M.A. Costa-Junqueira and M.K. Marks
1991 Dental disease in the Agroalfarero Medio Period of San Pedro de Atacama: Highest caries rate in prehistoric Chile (abstract). *American Journal of Physical Anthropology* Supplement 12:136.
Nelson, B.K., M.J. DeNiro, M.J. Schoeninger, D.J. DePaolo and P.E. Hare
1986 Effects of diagenesis on strontium, carbon, nitrogen, and oxygen concentration and isotopic concentration of bone. *Geochimica et Cosmochimica Acta* 50:1941-1949.
Nielsen-Marsh, C.M. and R.E. Hedges
2000a Patterns of diagenesis in bone I: The effects of site environments. *Journal of Archaeological Science* 27:1139-1150.
2000b Patterns of diagenesis in bone II: Effects of acetic acid treatment and the removal of Diagenetic CO3. *Journal of Archaeological Science* 27:1151-1159.
Núñez, L.
1989 Los primeros pobladores (20.000? a 9.000 aC). In *Culturas de Chile. Prehistoria desde sus Orígenes hasta los Albores de la Conquista*, edited by J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate and I. Solimano, pp. 13-32. Andrés Bello, Santiago.
Oakland Rodman, A.
1992 Textiles and ethnicity: Tiwanaku in San Pedro de Atacama, North Chile. *Latin American Antiquity* 3:316-340.
Odum, H.T.
1951 The stability of the World Strontium cycle. *Science* 114(2964):407-411.
Pate, D. and K.A. Brown
1985 The stability of bone strontium in the geochemical environment. *Journal of Human Evolution* 14:483-491.
Price, T.D., R.A. Bentley, J. Luning, D. Gronenborn and J. Wahl
2001 Prehistoric human migration in the *Linearbankeramik* of Central Europe. *Antiquity* 75:593-603.
Price, T.D., J. Blitz, J.H. Burton and J. Ezzo
1992 Diagenesis in prehistoric human bone: Problems and solutions. *Journal of Archaeological Science* 19:513-529.

Price, T.D., J.H. Burton and R.A. Bentley
2002 The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* 44:117-136.

Price, T.D., M. Connor and J.D. Parsen
1985 Bone chemistry and the reconstruction of diet: Strontium discrimination in White-Tailed Deer. *Journal of Archaeological Science* 12:419-442.

Price, T.D., G. Grupe and P. Schroter
1998 Migration in the Bell Beaker Period of Central Europe. *Antiquity* 72:405-411.

Price, T.D., C. M. Johnson, J.A. Ezzo, J. Ericson and J.H. Burton
1994 Residential mobility in the prehistoric Southwest United States: A preliminary study using strontium isotope analysis. *Journal of Archaeological Science* 21:315-330.

Price, T.D., W.D. Middleton and L. Manzanilla
2000 Immigration and the ancient city of Teotihuacan in Mexico: A study using strontium isotope ratios in human bone and teeth. *Journal of Archaeological Science* 27:903-913.

Price, T.D., R.W. Swick and E. Chase
1986 Bone chemistry and prehistoric diet: Strontium studies of laboratory rats. *American Journal of Physical Anthropology* 70:365-375.

Price, T.D., V. Tiesler and J.H. Burton
2006 Early African diaspora in colonial Campeche, Mexico: Strontium isotopic evidence. *American Journal of Physical Anthropology* 130:485-490.

Radosevich, S.C.
1993 The six deadly sins of trace element analysis: A case of wishful thinking in science. In *Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology*, edited by M.K. Sandford, pp. 269-332. Gordon and Breach Science Publishers, New York.

Rogers, G. and C.J. Hawkesworth
1989 A geochemical traverse across the North Chilean Andes: Evidence for crust generation from the mantle Wedge. *Earth and Planetary Science Letters* 91:271-285.

Sandford, M.K. and M.A. Katzenberg
1992 Current status of and methods for trace mineral analysis of archaeological tissue. In *Proceedings of the First World Congress on Mummy Studies*, pp. 535-542.

Sandford, M.K. and D.S. Weaver
2000 Trace element research in anthropology: New perspectives and challenges. In *Biological Anthropology of the Human Skeleton*, edited by M.A. Katzenberg and S.R. Saunders, pp. 329-350. Wiley-Liss, New York.

Saul, F.P.
1972 *The Human Skeletal Remains of Altar de Sacrificios: An Osteobiographic Analysis*. The Peabody Museum, Cambridge.

Schoeninger, M.J.
1978 Bone strontium and diet: Methods and some possible sources of error. *American Journal of Physical Anthropology* 48:435.
1979 Diet and status at Chalcatzingo: Some empirical and technical aspects of strontium analysis. *American Journal of Physical Anthropology* 51:295-310.
1989 Reconstructing prehistoric human diet. In *The Chemistry of Prehistoric Human Bone*, edited by T.D. Price, pp. 38-67. Cambridge University Press, Cambridge.

Schortman, E.M. and P.A. Urban
1998 Culture contact structure and process. In *Studies in Culture Contact: Interaction, Culture Change, and Archaeology*, edited by J.G. Cusick, pp. 102-125. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Schroeder, H.H., I.H. Tipton and A.P. Nason
1972 Trace metals in Man: Strontium and barium. *Journal of Chronic Diseases* 25:491-517.

Schutkowski, H., B. Herrmann, F. Wiedemann, H. Bocherens and G. Grupe
1999 Diet, status and decomposition at Weingarten: Trace element and isotope analyses on Early Mediaeval skeletal materials. *Journal of Archaeological Science* 26:675-685.

Schweissing, M.M. and G. Grupe
2003a Stable strontium isotopes in human teeth and bone: A key to migration events of the Late Roman Period in Bavaria. *Journal of Archaeological Science* 30:1373-1383.
2003b Tracing migration events in Man and Cattle by stable strontium isotope analysis of appositionally grown mineralized tissue. *International Journal of Osteoarchaeology* 13:96-103.

Sealy, J., R. Armstrong and C. Schrire
1995 Beyond lifetime averages: Tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity* 69:290-300.

Sealy, J.C., N.J. van der Merwe, A. Sillen, F.J. Kruger and H.W. Krueger
1991 87Sr/86Sr as a dietary indicator in modern and archaeological bone. *Journal of Archaeological Science* 18:399-416.

Shellis, R.P. and G.H. Dibdin
2000 Enamel microporosity and its functional implications. In *Development, Function and Evolution of Teeth*, edited by M.F. Teaford, M.M. Smith and M.W.J. Ferguson, pp. 242-251. Cambridge University Press, Cambridge.

Sillen, A.
1981 Strontium and diet at Hayonim Cave. *American Journal of Physical Anthropology* 56:131-137.
1989 Diagenesis of the inorganic phase of cortical bone. In *The Chemistry of Prehistoric Human Bone*, edited by T.D. Price, pp. 211-228. Cambridge University Press, Cambridge.
1992 Strontium-calcium ratios (Sr/Ca) of *Australopithecus robustus* and associated fauna from Swartkrans. *Journal of Human Evolution* 23:495-516.

Sillen, A., G. Hall and R. Armstrong
1995 Strontium-calcium ratios (Sr/Ca) and strontium isotope ratios (87Sr/86Sr) of *Australopithecus robustus* and *Homo* sp. from Swartkrans. *Journal of Human Evolution* 28:277-285.

Sillen, A., G. Hall, S. Richardson and R. Armstrong
1998 87Sr/86Sr ratios in modern and fossil food-webs of the Sterkfontein Valley: Implications for Early Hominid habitat preferences. *Geochimica et Cosmochimica Acta* 62(14):2463-2473.

Sillen, A. and M. Kavanagh
1982 Strontium and paleodietary research: A review. *Yearbook of Physical Anthropology* 25:67-90.

Sillen, A. and R. LeGros
1991 Solubility profiles of synthetic apatites and of modern and fossil bone. *Journal of Archaeological Science* 16:661-672.

Sillen, A. and J.C. Sealy
1995 Diagenesis of strontium in fossil bone. *Journal of Archaeological Science* 22:313-320.

Sillen, A., J.C. Sealy and N.J. van der Merwe
1989 Chemistry and paleodietary research: No more easy answers. *American Antiquity* 54:504-512.

Smith, S.T.
2003 *Wretched Kush: Ethnic Identities and Boundaries in Egypt's Nubian Empire, c. 2000-1000 BC*. Routledge, New York.

Steckel, R. H. and J. C. Rose, editors
2002 *The Backbone of History*. Cambridge University Press, Cambridge.

Stein, G.J.
2005 Introduction: The comparative archaeology of colonial encounters. In *The Archaeology of Colonial Encounters: Comparative Perspectives*, edited by G.J. Stein, pp. 3-32. School of American Research Press, Santa Fe, New Mexico.

Stuart-Macadam, P.
1985 Porotic hyperostosis: Representative of a childhood condition. *American Journal of Physical Anthropology* 66:391-398.

Stuart-Macadam, P. and S. Kent, editors
1992 *Diet, Demography and Disease: Changing Perspectives on Anemia*. Aldine de Gruyter, Hawthorne.

Stuart-Williams, H.L.Q., H.P. Schwarcz, C.D. White and M.W. Spence
1996 The isotopic composition and diagenesis of human bone from Teotihuacan and Oaxaca, Mexico. *Paleogeography, Paleoclimatology, Paleoecology* 126:1-14.

Sutter, R.
2000 Prehistoric genetic and culture change: A bioarchaeological search for Pre-Inka Altiplano colonies in the coastal valleys of Moquegua, Peru, and Azapa, Chile. *Latin American Antiquity* 11:43-70.

Tomczak, P.
1995 *Paleodietary Analysis of Chiribaya Alta: The Stable Isotope and Trace Element Analysis*. Masters thesis, University of Chicago, Chicago.

Torres-Rouff, C.
2002 Cranial vault modification and ethnicity in Middle Horizon San Pedro de Atacama, Chile. *Current Anthropology* 43:163-171.
2003a *Shaping Identity: Cranial Vault Modification in the pre-Columbian Andes*. Doctoral Dissertation, Department of Anthropology, University of California, Santa Barbara.
2003b Oral implications of labret use: A case from pre-Columbian Chile. *International Journal of Osteoarchaeology* 13:247-251.

Torres, C.M. and W.J. Conklin
1995 Exploring the San Pedro de Atacama/ Tiwanaku relationship. In *Andean Art: Visual Expression and Its Relation to Andean Beliefs and Values*, edited by P. Dransart, pp. 78-108. Avebury, Aldershot.

Torres, C.M., D.B. Repke, K. Chan, D. McKenna and A. Llagostera
1991 Snuff powders from pre-Hispanic San Pedro de Atacama: Chemical and contextual analysis. *Current Anthropology* 32:640-647.

Turekian, K.K. and J.L. Kulp
1956a The geochemistry of strontium. *Geochimica et Cosmochimica Acta* 10:245-296.
1956b Strontium content of human bone. *Science* 124:405-407.

Ubelaker, D.H.
1989 *Human Skeletal Remains: Excavation, Analysis, Interpretation*. Taraxacum, Washington DC.

Verano, J.W.
1995 Where do they rest? The treatment of human offerins and trophies in ancient Peru. In *Tombs for the Living: Andean Mortuary Practices*, edited by T.D. Dillehay, pp. 189-228. Dumbarton Oaks, Washington DC.

Verano, J.W. and D.H. Ubelaker
1992 *Disease and Demography in the Americas*. Smithsonian Institution Press, Washington DC.

Vernois, V., M. Ung Bao and N. Dechamps
1988 Chemical analysis of human dental enamel of archaeological sites. In *Trace Elements in Environmental History*, edited by G. Grupe and B. Herrmann, pp. 83-90. Springer-Verlag, Berlin.

Waldron, H.A.
1981 Postmortem absorption of lead by the skeleton. *American Journal of Physical Anthropology* 55:395-398.
1983 On the post-mortem accumulation of lead by skeletal tissues. *Journal of Archaeological Science* 10:35-40.

Waldron, H.A., A. Khera, G. Walker, G. Wibberly and C.J.S. Green
1979 Lead concentrations in bones and soil. *Journal of Archaeological Science* 6:295-298.

Walker, P.L.
1985 Anemia among prehistoric indians of the American Southwest. In *Health and Disease in the Prehistoric Southwest*, edited by C.F. Merbs and R.J. Miller, pp. 139-164. vol. 34. Arizona State University Anthropological Research Papers.
1989 Cranial injuries as evidence of violence in prehistoric southern California. *American Journal of Physical Anthropology* 70:313-323.
1996 Integrative approaches to the study of ancient health: An example from the Santa Barbara Channel area of southern California. In *Notes on Populational Significance of Paleopathological Conditions: Health, Illness and Death in the Past*, edited by A. Perez-Perez, pp. 97-105. Fundacio Uriach, Barcelona.

Walker, P.L. and J. Erlandson
1986 Dental evidence for prehistoric dietary change on the Northern Channel Islands. *American Antiquity* 51:375-383.

Wood, J., G. Milner, H. Harpending and K. Weiss
1992 The osteological paradox: Problems of inferring prehistoric health from skeletal samples. *Current Anthropology* 33:343-370.

Wright, L.E.
2005a Identifying immigrants to Tikal, Guatemala: Defining local variability in strontium isotope ratios of human tooth enamel. *Journal of Archaeological Science* 32:555-566.
2005b In search of Yax Nuun Ayiin I: Revisiting the Tikal Project's Burial 10. *Ancient Mesoamerica* 16:89-100.

Wright, L.E. and H.P. Schwarcz
1996 Infrared and isotopic evidence for diagenesis of bone apatite at Dos Pilas, Guatemala: Paleodietary implications. *Journal of Archaeological Science* 23:933-944.

Wright, L.E. and C.J. Yoder
2003 Recent progress in bioarchaeology: Approaches to the osteological paradox. *Journal of Archaeological Research* 11:43-70.

Note

1 Individual 1948 had ante-mortem loss of his LM3, LM2, LI2, LI1, RI1, RM3, and his LM1, RM1, RM2, RM3.

APPENDIX 1

Laboratory Methodology for Analysis of Strontium, Carbon and Nitrogen Isotopes and Trace Element Concentrations

All tooth and bone samples for strontium isotope and trace element concentrations were initially prepared in the Laboratory for Archaeological Chemistry by Kelly J. Knudson. Modern fauna samples for strontium isotope analysis were placed in a crucible and ashed at approximately 800º C for 10 hours. The bone samples were then crushed in an agate mortar and pestle. The teeth were removed from modern fauna mandibles after ashing and crushed and stored separately from the bone.

Archaeological teeth samples were mechanically cleaned before analysis. The samples were first mechanically cleaned by abrasion with a Patterson NC-350 dental drill equipped with an inverted-cone carbide burr (White burrs HP-59 type 2 class 2). This removed any adhering organic matter or contaminants as well as the outermost layers of tooth, which are most susceptible to diagenetic contamination (Budd et al. 2000; Montgomery et al. 1999; Waldron 1981, 1983; Waldron et al. 1979). Approximately 5-10 mg of tooth enamel was then removed with a Patterson NC-350 dental drill equipped with a carbide burr or, in the field, with a Dremel Minimite-750 cordless drill equipped with an engraving cutter.

Archaeological bone samples were treated for diagenesis before sample analysis. The bone samples were first mechanically cleaned with the Patterson NC-350 dental drill equipped with a carbide burr to remove any organic matter or contaminants. The mechanical cleaning also removed the layers of cortical bone most susceptible to diagenetic contamination, as well as all traces of trabecular bone. If the bone sample taken from the museum was large, the bone sample was cut with the Patterson NC-350 dental drill equipped with a diamond disc saw. The bone samples were then chemically cleaned in an ultrasonic bath in order to remove diagenetic contaminants. The samples were first sonicated in water for 30 minutes, then rinsed and sonicated in 5% acetic acid for 30 minutes, and finally rinsed and sonicated with 5% acetic acid for 5 minutes (Nielsen-Marsh and Hedges 2000b; Price et al. 1992; Price et al. 1994; Sillen 1989). The bone samples were dried in the oven for approximately 1 hour at approximately 80º C for. Then, the bone samples were placed in a crucible and ashed at approximately 800º C for 10 hours.

Strontium isotope ratios were obtained at the Isotope Geochemistry Laboratory in the Department of Geological Sciences at the University of North Carolina at Chapel Hill by Paul Fullagar and by Kelly J. Knudson under the direction of Paul Fullagar. Three to six milligrams of bone ash or powdered tooth enamel were dissolved in 15 mL Savillex PFA vials using 500 μL of twice distilled 5N HNO_3 in a class 100 filtered air environmental hood. The samples were then evaporated and redissolved in 250 μL of 5N HNO_3. The strontium was separated from the sample matrix using EiChrom SrSpec resin, a crown-ether Sr-selective resin (50-100 μm diameter) loaded into the tip of a 10 mL BioRad polypropylene column. Total resin volume was approximately 50 μL. The SrSpec resin was pre-soaked and flushed with H_2O to remove Sr present from the resin manufacturing process. The resin was further cleaned in the column with repeated washes of deionized H_2O and conditioned with 5N HNO_3. Resin was used once for sample elution and discarded. The dissolved sample was loaded and washed in 750 μL of 5N HNO_3, then Sr was eluted with 1 mL of H_2O. Total procedural blanks for Sr are typically 100-to-200 picograms. The sample was then evaporated, dissolved in 2 μL of 0.1 M H_3PO_4 and 2 μL of $TaCl_5$, and loaded onto degassed Re filaments. Isotopic ratios were measured on a VG Sector 54 thermal ionization mass spectrometer at the University of North Carolina-Chapel Hill in quintuple-collector dynamic mode, using the internal ratio $^{86}Sr/^{88}Sr = 0.1194$ to correct for mass fractionation. Recent analyses of strontium carbonate standard SRM 987 yield $^{87}Sr/^{86}Sr = 0.710245 \pm 0.000018$ (2σ). Long term analyses over approximately 24 months of SRM 987 yield an average of $^{87}Sr/^{86}Sr = 0.710242$. Internal precision for Sr carbonate runs is typically 0.0006 to 0.0009 % standard error, based on 100 dynamic cycles of data collection.

Trace element analysis of archaeological human bone was obtained through by Kelly J. Knudson and James H. Burton using an Applied Research Labs Model 3520 inductively coupled plasma-atomic emission spectrometer (ICP-AES). For the trace element analysis using an ICP-AES, approximately 50 mg of powdered bone ash was dissolved in 1.0 mL ultrapure concentrated HNO_3 and heated to 100ºC for one hour. Each sample was then diluted with 17 mL deionized water. Calcium, strontium, barium and phosphorus concentrations were analyzed. Analyses of Laboratory for Archaeological Chemistry standard reference 9511 yielded the following trace element concentrations in ppm: Ca = $3.12 x 10^4 \pm 1.42 x 10^3$ (2σ, n = 7), Sr = 142.9 ± 10.0 (2σ, n = 7), Ba = 211.6 ± 7.1 (2σ, n = 7) and P = $5.39 x 10^3 \pm 2.24 x 10^2$ (2σ, n = 7). Long-term analyses of laboratory standards and international bone standard reference material have determined accuracy of ± 5% and precision of ± 2% (Burton et al. 2003).