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THE USE OF STRONTIUM ISOTOPE ANALYSIS TO INVESTIGATE TIWANAKU MIGRATION AND MORTUARY RITUAL IN BOLIVIA AND PERU

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Strontium isotope analysis is applied in South America for the first time in order to investigate residential mobility and mortuary ritual from AD *500 to 1000. While Tiwanaku-style artefacts are spread throughout Bolivia, southern Peru and northern Chile during this time, the nature of Tiwanaku influence in the region is much debated. Human skeletal remains from the site of Tiwanaku and the proposed Tiwanaku colony of Chen Chen have been analysed to test the hypothesis that Tiwanaku colonies, populated with inhabitants from Tiwanaku, existed in Peru. Strontium isotope analysis supports this hypothesis by demonstrating that non-local individuals are present at both sites.*

KEYWORDS: ARCHAEOLOGICAL CHEMISTRY, ISOTOPE ANALYSIS, RESIDENTIAL MOBILITY, MIGRATION, MIDDLE HORIZON, ANDES

INTRODUCTION

During the Middle Horizon time period (AD 500–1000), the people of the South Central Andes were clearly influenced by the site of Tiwanaku, located on the Bolivian high plain, or *altiplano*, near Lake Titicaca (Fig. 1). During this time, Tiwanaku-style artefacts such as ceramics, textiles, and ritual objects are found throughout Bolivia, southern Peru and northern Chile. Myriad theories have been proposed to explain their widespread distribution. For example, Kolata and Ponce Sanginés envision Tiwanaku as an expansionist state that established colonies throughout the South Central Andes (Ponce Sanginés 1972; Kolata 1982, 1992, 1993a,b). Other scholars have hypothesized that Tiwanaku influence was characterized by the establishment of a 'vertical archipelago' of multi-ethnic productive colonies (Mujica *et al*. 1983) based on Murra's seminal work (Murra 1972). Finally, commercial influence through trade and llama caravans (Dillehay and Núñez A. 1988) and a shared religion and ideology spread by 'proselytizing merchant missionaries' (Browman 1978, 327) have also been used to describe the nature of Tiwanaku influence and political economy.

Figure 1 *A map of the South Central Andes, showing sites mentioned in text.*

In order to evaluate these hypotheses, strontium isotope analysis is being used to examine Tiwanaku residential mobility. More specifically, strontium isotope analysis of archaeological human tooth enamel is used to test the hypothesis that the individuals buried in the Peruvian cemetery of Chen Chen are members of a Tiwanaku colony and include immigrants from the site of Tiwanaku itself, which is approximately 250 km to the north-east (Fig. 1). In addition, strontium isotope analysis of individuals buried in the central monumental sector at the site of Tiwanaku is used to test the hypothesis that ritual sacrifices and dedicatory offerings included individuals from outside the Tiwanaku heartland. Here, preliminary data from the site of Tiwanaku, Bolivia, and the cemetery of Chen Chen, near the modern city of Moquegua in the Moquegua Valley, Peru, are presented in order to demonstrate the feasibility of this technique in the South Central Andes.

PREVIOUS RESEARCH ON TIWANAKU RESIDENTIAL MOBILITY IN THE MOQUEGUA VALLEY

Previous research on Tiwanaku residential mobility and the nature of Tiwanaku influence has been based on the analysis of artefacts, residential and public architecture, and genetic relationships (Berenguer *et al.* 1980; Berenguer and Dauelsberg 1988; Blom *et al.* 1998; Goldstein 1989, 1992; Oakland Rodman 1992; Blom 1999b; Varela and Cocilovo 2000; Rothhammer and Santoro 2001). In the Moquegua Valley (also known as the Osmore Drainage), much research has focused on mid-valley sites near the modern city of Moquegua (Goldstein 1989, 1992, 1993, 2000a,b; Moseley *et al.* 1991; Owen 1995; Blom *et al.* 1998; Blom 1999a,b). Various lines of evidence suggest that the site complexes of Omo, Río Muerto and Chen Chen were inhabited by individuals from or affiliated with the Tiwanaku heartland. For example, at the Omo M10 site, Goldstein (1989, 1992, 1993, 2000a) found that domestic and public architecture and material remains such as ceramics are clearly in the Tiwanaku style. In fact, Omo M10 contains the only Tiwanaku-style temple outside the Lake Titicaca Basin (Goldstein 1989, 1992, 1993, 2000a). Similarly, biodistance analysis of cranial non-metric traits of individuals from both the Tiwanaku heartland and the Moquegua Valley shows that the genetic distance between the two regions was smaller during the Middle Horizon than in any other period (Blom *et al.* 1998; Blom 1999a,b).

However, while the biodistance analysis of cranial non-metric traits demonstrates a close genetic relationship between the *altiplano* and possible colonies, neither the direction of population movement nor the source of the genetic similarities has been determined. In addition, while Tiwanaku material culture is clearly evident at the Moquegua Valley sites, the possibility remains that local peoples adopted it as they were incorporated into or affiliated with the Tiwanaku polity. Strontium isotope analysis of human skeletal remains can be used to identify migrants and the geological regions from which they migrated.

STRONTIUM ISOTOPE ANALYSIS: PRINCIPLES AND METHODS

Strontium geochemistry

In the environment, strontium (Sr) is found in rock, groundwater, soil, plants and animals. This strontium is composed of different percentages of the following four isotopes: ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), ^{87}Sr (~7.04%) and ^{88}Sr (~82.53%) (Faure and Powell 1972). Of these four isotopes, only ^{87}Sr is radiogenic; it is formed over time by radioactive decay from rubidium (^{87}Rb), which has a half-life of ~4.88×10^{10} years (Faure 1986). The strontium concentration of plant or animal tissue will vary according to its trophic position (Faure and Powell 1972). However, the isotopic composition of strontium is not changed or fractionated by biological processes during strontium transport through the ecosystem, because the mass differences between the four strontium isotopes are relatively small (Faure and Powell 1972; Elias *et al.* 1982). The strontium concentrations and isotope ratios in the soil, plants and bedrock vary according to local geology. The bulk composition of the Earth's surface at a specific location, which affects the ^{87}Rb/^{87}Sr ratios, and the age of the Earth's surface ensure that the ^{87}Sr/^{86}Sr ratios are quite variable (Turekian and Kulp 1956). Very old (greater than one million years) rocks that had very high Rb/Sr ratios will have the highest ^{87}Sr/^{86}Sr ratios today (Faure 1986). Examples of geological deposits that have high Rb/Sr ratios include clay-rich rocks such as shale, or igneous rocks that have high silica contents, such as granite (Faure and Powell 1972). On the other hand, geologically young rocks will have low Rb/Sr ratios and typically have ^{87}Sr/^{86}Sr ratios less than 0.706, while rocks that have very low Rb/Sr ratios, such as basalt, can have ratios of less than 0.704 (e.g., Rogers and Hawkesworth 1989). In addition, the isotopic composition of the ocean is characterized by an ^{87}Sr/^{86}Sr ratio of 0.7092 (Veizer 1989).

Strontium isotope analysis in archaeology

Since the strontium present in soil and groundwater is incorporated into the plants and animals of the region, the strontium isotopic composition of an individual's diet will be reflected in her or his hard tissue (Ericson 1985; Sealy *et al.* 1991, 1995; Price *et al.* 1994; Carlson 1996). Because its chemical behaviour and atomic radius are similar to that of calcium, strontium commonly substitutes for calcium in the crystalline lattice of hydroxyapatite in teeth and bone (Likins *et al.* 1960; Schroeder *et al.* 1972; Nelson *et al.* 1986).

Therefore, the bone strontium content and isotopic composition will reflect the isotopic composition of the geological region in which a person lived before death. While the average rate of mature adult bone regeneration is 7–11 years, the actual rate of bone turnover varies from 2 to 20 years, and turnover rates of 3% per year in cortical bone and 26% per year in trabecular bone have been estimated (Parfitt 1983). Tooth enamel, on the other hand, forms during early childhood but is considered dead tissue because it is not penetrated by any organic structures (Steele and Bramblett 1988). Tooth enamel will not recrystallize or absorb elements from the environment after it has formed (Hillson 1986), and this ensures that tooth enamel will reflect the strontium content and isotopic composition of the environment in which a person lived while the tooth was being formed (Ericson 1985; Sealy *et al*. 1991, 1995; Price *et al*. 1994; Carlson 1996).

Although strontium isotope analysis is a relatively new technique, successful research has already illustrated the feasibility of the technique and the potential of strontium isotope analysis to elucidate residential mobility in the archaeological record. For example, strontium isotope analysis has identified migration in the North American Southwest (Price *et al*. 1994; Ezzo *et al*. 1997), in Bell Beaker and Linearbandkeramik populations in Central Europe (Grupe *et al*. 1997; Bentley 2001; Price *et al*. 2001; Bentley *et al*. 2002), and in Teotihuacan *barrios* in Mesoamerica (Price *et al*. 2000). Strontium isotope analysis has also been used to identify individuals buried in a mass grave as shipwrecked slaves (Cox and Sealy 1997), to reconstruct hominid habitat utilization (Sillen *et al*. 1995, 1998) and to determine the last domicile of Ötzi, the famed Iceman of the Alps (Hoogewerff *et al*. 2001).

The geology of the study areas and field methodology

Before analysing archaeological tooth and bone samples, the geology of the South Central Andes was examined in order to determine the feasibility of the application of strontium isotope analysis in this region (Fig. 2). Geological analyses of the late Cenozoic volcanics of the South Central Andes, which includes the Moquegua Valley where Chen Chen is located, show that the $^{87}Sr/^{86}Sr$ ratios in exposed bedrock range from 0.7055 to 0.7068 (Hawkesworth *et al*. 1982; James 1982; Rogers and Hawkesworth 1989). In contrast, the Tiwanaku and Katari

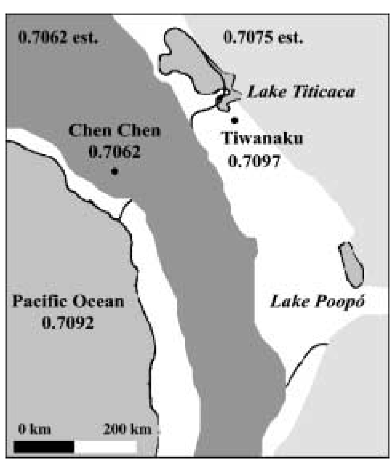

Figure 2 *A map of $^{87}Sr/^{86}Sr$ isotope ratios in the South Central Andes, including estimated averages for Cenozoic volcanics and volcanic-derived sediments (dark grey), Palaeozoic marine sedimentary rocks (light grey) and seawater (Hawkesworth et al. 1982; James 1982; Rogers and Hawkesworth 1989; Veizer 1989). Values for Chen Chen and Tiwanaku are based on analysis of modern fauna (Knudson et al. 2001).*

River Basins, on the southeastern edge of Lake Titicaca, are bordered by mountain ranges composed of Palaeozoic andesites, sandstones and red mudstones (Argollo *et al*. 1996; Binford and Kolata 1996). In the river basins, the bedrock is composed of igneous basalts and andesites, and is overlain by up to 10–20 m of Quaternary fluvial and lacustrine sediments (Argollo *et al*. 1996; Binford and Kolata 1996).

However, since strontium isotope ratios in bedrock, soil and water within a given region can vary widely, the biologically available strontium isotope ratios for the regions included in this study were determined using modern fauna (Price *et al*. 2002). Modern guinea pigs or *cuy* were collected from markets in Moquegua, Peru, during the summers of 1999 and 2000. The *cuyes* were raised in private homes and informants reported that they were fed only locally grown produce such as alfalfa. The strontium isotope ratios of the femora of the Moquegua *cuyes* were compared with those of wild *cuyes* collected from three sites in the southeastern Lake Titicaca Basin, including the site of Tiwanaku. The mean $^{87}Sr/^{86}Sr$ ratio for the three *cuy* bone samples from Moquegua is 0.7063 ± 0.0002 (1σ, $n = 3$), which supports the geological estimates (Knudson *et al*. 2001). In addition, this value is significantly lower than the mean $^{87}Sr/^{86}Sr$ ratio for the three *cuy* bone samples from the Lake Titicaca Basin, which have a mean value of 0.7097 ± 0.0007 (1σ, $n = 3$) (Table 1 and Fig. 3 (Knudson *et al*. 2001)).

Table 1 *Results of strontium isotope analysis of archaeological human tooth enamel samples from Chen Chen and Tiwanaku and modern guinea pig bone samples from Moquegua, Peru and the southern Lake Titicaca Basin, Bolivia. Strontium isotope data were obtained on the TIMS at the Isotope Geochemistry Laboratory at the University of North Carolina at Chapel Hill by P. Fullagar*

Specimen	*Site*	*Sample type*	*Age (years)*	*Sex*	$^{87}Sr/^{86}Sr$
MI-0681	Chen Chen	Human LRC	50–80	M	0.706786
MI-1600	Chen Chen	Human LLM1	40–45	M	0.706932
M1-3660-1	Chen Chen	Human LRM1	30–44	F	0.706726
M1-3718	Chen Chen	Human LRC	50–80	F	0.706992
M1-3154	Chen Chen	Human LRM1	40–59	M	0.706921
M1-S/NK380	Chen Chen	Human LLM1	40–50	F	0.707422
M1-3840	Chen Chen	Human LLM1	35–39	F	0.708843
M1-S/NB092	Chen Chen	Human LRM1	25–35	F	0.709995
AKE-20727	Tiwanaku	Human LRM1	18–21	F	0.710334
AKE-8908	Tiwanaku	Human LRM1	18–21	PM	0.710907
CJ-35250	Tiwanaku	Human URI1	30–39	F	0.709674
MK-29412	Tiwanaku	Human LLM1	22–24	F	0.70832
MK-39788	Tiwanaku	Human LLM1	40–60	F	0.708478
PUT-24106	Tiwanaku	Human LRM1	20–29	M	0.711303
PUT-25785-1	Tiwanaku	Human LLM1	18–21	F	0.711758
PUT-20995	Tiwanaku	Human ULM1	20–24	F	0.709523
AK-12149	Tiwanaku	Human LRM1	50–59	M	0.709513
AK-4931	Tiwanaku	Human URI2	17–30	PF	0.716256
M5A	Moquegua	Modern *cuy* femur	NA	NA	0.706184
M9A	Moquegua	Modern *cuy* femur	NA	NA	0.706452
M14A	Moquegua	Modern *cuy* femur	NA	NA	0.706121
T1A	Tiwanaku	Modern *cuy* femur	NA	NA	0.709368
L2A	Lukurmata	Modern *cuy* femur	NA	NA	0.710561
Ch1A	Chiripa	Modern *cuy* femur	NA	NA	0.709291

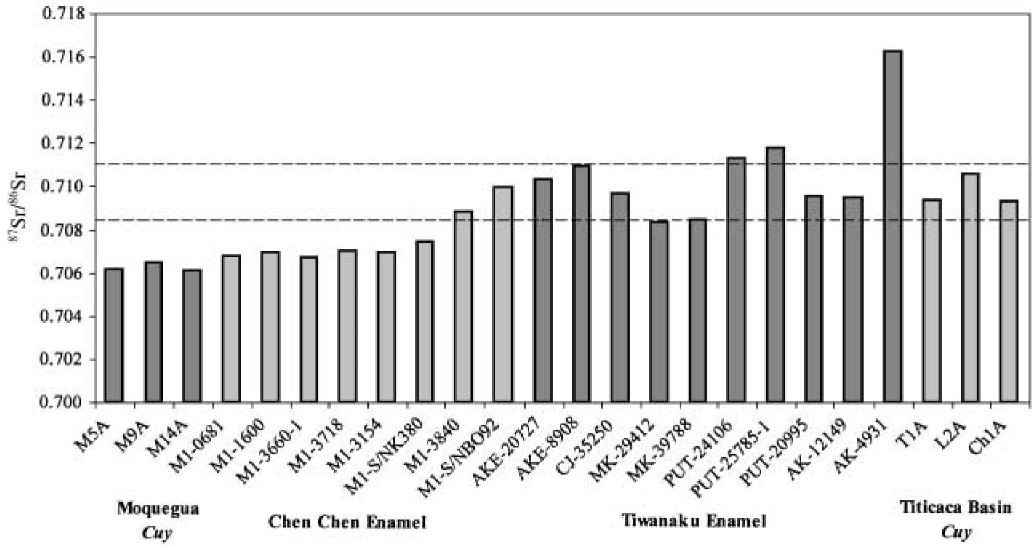

Figure 3 *Strontium isotope ratios for archaeological human tooth enamel from individuals buried at the sites of Chen Chen and Tiwanaku, and for modern cuy bone collected in Moquegua and the sites of Chiripa, Lukurmata and Tiwanaku in the southern Lake Titicaca Basin. The two dotted lines show the mean ± 2 s.d. of the strontium isotope ratios for modern cuy from the southern Lake Titicaca Basin ($^{87}Sr/^{86}Sr$ = 0.7083 −0.7111); the three individuals from Tiwanaku whose strontium isotope ratios are outside of this range are considered non-local. In addition, two individuals at Chen Chen identified as immigrants through strontium isotope analysis are well within the range of local strontium isotope ratios for Tiwanaku.*

Laboratory methodology

All bone and tooth samples were first mechanically cleaned and abraded using an inverted-cone carbide burr fitted to a high-rpm dental drill. For the bone samples, all trabecular, or spongy, bone was removed with the carbide drill. For the tooth samples, a wedge-shaped sample of the crown was cut using the drill fitted with a diamond disc saw. The pulp and dentine were then removed with the carbide burr, leaving only the intact enamel. All archaeological bone and teeth samples were then sonicated with deionized water for 30 minutes, 5% acetic acid for 30 minutes, and a second aliquot of 5% acetic acid for 5 minutes. Once rinsed, the samples were then ashed at 750°C for 8 hours and powdered. Since modern bone from freshly butchered animals is not subject to the same diagenetic contamination as the archaeological bone, modern *cuy* bone samples were mechanically cleaned and ashed, but not acid washed.

For the strontium isotope analysis, approximately 5 mg of powdered tooth enamel or bone ash was dissolved in 500 µl of 5M HNO_3 and evaporated. The sample was then dissolved in 250 µl of 5M HNO_3 and then purified through cation exchange columns filled with approximately 50 µl of Sr exchange resin. After the purified samples were dried down, they were redissolved in 2 µl of 0.1M H_3PO_4 and 2 µl of $TaCl_5$, and loaded on to degassed Re filaments for analysis by thermal ionization mass spectrometry (TIMS). All strontium isotope data presented here were obtained through thermal ionization mass spectrometry (TIMS) by P. Fullagar at the Isotope Geochemistry Laboratory at the University of North Carolina at Chapel Hill, using a MicroMass Sector 54. Based on 100 dynamic cycles of data collection, the internal precision at the University of North Carolina at Chapel Hill was between ±0.000006 and

±0.000010 for each sample. Total procedural blanks for strontium were 100–200 pg (picograms). All $^{87}Sr/^{86}Sr$ ratios were corrected for mass fractionation in the instrument using $^{86}Sr/^{88}Sr = 0.1194$. At the University of North Carolina at Chapel Hill, $^{87}Sr/^{86}Sr$ analyses of strontium carbonate standard NIST SRM 987 yielded a value of 0.710258 ± 0.000015 (2σ, $n = 9$), while long-term analyses of NIST SRM 987 over approximately the last 24 months yielded an average $^{87}Sr/^{86}Sr$ value of 0.710242 (Paul Fullagar, pers. comm. 2002).

STRONTIUM ISOTOPE RESULTS

The Moquegua Valley, Peru

As previously discussed, the strontium isotope ratios of modern *cuy* from Moquegua and Tiwanaku are distinct and non-overlapping, and provide estimates of the biologically available strontium isotope values in the two regions. The modern fauna data were then used to determine the local strontium isotope values. Individuals whose strontium isotope ratios were within the range of the mean of the *cuy* isotope ratio ±2 s.d. were identified as local to the region (Price *et al.* 2002). Therefore, individuals at Chen Chen are considered local if their strontium isotope ratios ($^{87}Sr/^{86}Sr$) fall between 0.7059 and 0.7067, as determined by modern Moquegua fauna.

According to this criterion, all eight individuals analysed from Chen Chen exhibit non-local strontium isotope ratios in their tooth enamel (Table 1 and Fig. 3). Because the local range as defined by the strontium isotope ratios in modern fauna is so narrow, the diet of the prehistoric inhabitants of Chen Chen came from an area wider than that of the *cuy*. As will be discussed in more detail below, it is also possible that individuals at Chen Chen were consuming small amounts of marine foods, which would raise their strontium isotope ratios slightly. However, two of the eight individuals have strontium isotope ratios in their tooth enamel that are much higher than the other six Chen Chen individuals sampled [M1-3840 ($^{87}Sr/^{86}Sr = 0.708843$), and M1-S/NB092 ($^{87}Sr/^{86}Sr = 0.709995$)]. In fact, as will be discussed below, the strontium isotope ratios found in the tooth enamel of these two individuals are well within the local range of the Lake Titicaca Basin (Table 1 and Fig. 3). Both of these individuals are women and exhibit fronto-occipital cranial modification. These two women cannot be distinguished from other individuals buried at Chen Chen on the basis of grave goods or burial location within the larger cemetery. Despite the lack of characteristics that distinguish these two burials from others at Chen Chen, these two women clearly did not live in the Moquegua area while the enamel of their permanent first molars was forming; that is, during the first 3–4 years of life.

Tiwanaku, Bolivia

Strontium isotope analysis has also identified non-local individuals at the site of Tiwanaku. The range of the mean of the strontium isotope ratios of the modern *altiplano cuy* ±2 s.d. is shown by the dotted lines in Fig. 3. Using this criterion, tooth enamel from three of the ten individuals analysed exhibits strontium isotope values outside the local strontium isotope signature at Tiwanaku ($^{87}Sr/^{86}Sr$ between 0.7083 and 0.7111). All three non-local individuals were buried in the central monumental district at Tiwanaku. More specifically, two non-local individuals (PUT-25785-1 and PUT-24106) were buried in the Putuni sector, an elite residential and ceremonial complex west of the Kalasasaya platform, and have been identified by the excavators as dedicatory offerings (Couture and Sampeck 2003). One of the non-local individuals, a female between the ages of 18 and 21 (PUT-25785-1, $^{87}Sr/^{86}Sr = 0.711758$), was a particularly elaborate dedicatory offering, buried in a shaft-and-side chamber tomb below the southeastern corner of the Palace of the Multicoloured Rooms (Couture and Sampeck 2003). The tomb also contained the remains of two children, each 7–10 years old, and part of a human foetus, as well as a silver pin, beads and a deer antler. The other non-local individual (PUT-24106, $^{87}Sr/^{86}Sr$ = 0.711303) in the Putuni sector was also interpreted as a dedicatory offering (Couture and Sampeck 2003). This individual was buried as an offering for the closing of Late Tiwanaku IV occupation of the sector and the construction of the Palace of the Multicoloured Rooms. The individual, a male aged between 20 and 29, was placed near a large drainage canal just south of the kitchen structure in the North Compound. Future strontium isotope analysis of bone from these two non-local individuals will be used to determine place of residence 7–10 years before death, and may help to determine whether the individuals buried as dedicatory offerings were brought in from outside the Tiwanaku heartland shortly before death.

The third non-local individual (AK-4931, $^{87}Sr/^{86}Sr$ = 0.716256) identified at Tiwanaku was buried in the Akapana, a stepped platform that is the largest monumental structure at the site (Manzanilla 1992; Kolata 1993a). Found on the platform of the first terrace of the Akapana, this individual, aged between 17 and 30, was splayed across a massive ceramic 'smash' that consisted of hundreds of purposely broken polychrome vessels (Manzanilla and Woodward 1990; Blom *et al*. 2003). Initially, the Akapana offerings were interpreted as secondary interments, which may have been the work of a mummy cult at Tiwanaku (Manzanilla and Woodward 1990). However, recent re-analysis of the human remains from the Akapana platform has yielded evidence for defleshing, exposure and dismemberment (Blom *et al*. 2003). On the non-local individual discussed here (AK-4931), weathering was evident on the cranium, on a foot phalanx, on various hand bones, and on the vertebrae and sternum, and this implies that the victim was publicly displayed on the pyramid for some time after death (Blom *et al*. 2003).

STRONTIUM ISOTOPE RESULTS: DISCUSSION

The presence of individuals buried at Chen Chen who did not live there during the first years of their lives is not surprising. Excavations in both the residential and mortuary sectors at Chen Chen have yielded overwhelmingly Tiwanaku-style artefacts (Vargas V. 1994; Goldstein 1995; Owen 1997; Blom 1999b). Moreover, the site complexes of Chen Chen, Omo and Río Muerto have been interpreted as colonies associated with, and perhaps controlled by, the site of Tiwanaku (Goldstein 1989, 1992, 1993, 1995). By combining the data from both Chen Chen and Tiwanaku, it is apparent that two individuals at Chen Chen identified as immigrants through strontium isotope analysis are well within the range of local strontium isotope ratios for Tiwanaku (Fig. 3). Although this preliminary data set is too small to draw definitive conclusions on the status of Chen Chen as the cemetery of a Tiwanaku colony, it is likely that strontium isotope analysis has identified two immigrants from the Tiwanaku heartland at Chen Chen.

At Tiwanaku, multiple lines of evidence suggest that individuals moved into the site from the Lake Titicaca Basin and beyond. For example, cranial modification styles in the Moquegua Valley were predominately fronto-occipital between AD 500 and 1000, and were predominately annular, or circumferential, in the *altiplano* east of Tiwanaku. However, individuals from the site of Tiwanaku exhibit both styles of cranial modification (Blom *et al*. 1998; Blom 1999a,b). Janusek (1994, 1999, 2002) has hypothesized, on the basis of ceramic evidence, that the urban centre of Tiwanaku may have been arranged by *barrios* that were settled by non-local groups; for example, the Ch'iji Jawira sector may have been settled by a group from the far eastern Bolivian valleys.

It is important to remember, however, that the individuals interred as sacrificial offerings in the Putuni sector and Akapana pyramid may not represent the average inhabitant of Tiwanaku. Kolata (1993a) hypothesizes that ancestral mummy bundles of conquered ethnic groups were incorporated into the Akapana as an intensely powerful symbol of Tiwanaku's domination. Alternatively, if the predominately male victims of sacrifice at the Akapana were captured warriors, symbolic or real, they may have been foreign individuals (Blom *et al.* 2003).

Of course, it is possible that food such as maize, and not individuals, was moving from Moquegua to Tiwanaku or vice versa. However, the palaeodiet reconstruction, based on carbon and nitrogen isotope evidence, of both pre-Tiwanaku and Tiwanaku sites in Moquegua, including the site of Chen Chen, shows a shift to high levels of maize consumption from a predominately marine subsistence base (Sandness 1992; Tomczak 2001). In fact, nitrogen isotopes in bone collagen were measured for four of the Chen Chen individuals included in this study (MI-0681, MI-1600, MI-3718 and MI-S/NK3840) (Tomczak 2001). For these four individuals, $\delta^{15}N = 4.79–8.93$, which is well within the range of a predominately terrestrial isotopic signature, and is much lower than either a predominately marine signature or an *altiplano* signature, on the basis of analysis of individuals from Tiwanaku (Tomczak 2001). Therefore, it is unlikely that the very high strontium isotope ratios seen at Chen Chen are the result of marine food consumption, although it is possible that small amounts of seafood are slightly increasing the strontium isotope ratios for local individuals. In addition, since the mid-valley region contains prime agricultural land for mid-altitude crops such as maize, it is highly unlikely that either maize was imported or that significant amounts of strontium were coming from foods traded in from regions outside the Moquegua Valley.

At the site of Tiwanaku, on the other hand, there is evidence that both lower-altitude crops and far-ranging camelids augmented a diet of local plant foods such as tubers and quinoa (Webster 1993; Wright *et al.* 2003). The maize found at the site of Tiwanaku may be from the Moquegua Valley or from Cochabamba, Bolivia, and so the variability in strontium isotope ratios in the Tiwanaku samples may reflect the importation of food from these regions. Since the three Tiwanaku individuals identified as non-local have strontium isotope ratios that are much higher than that of Moquegua, these individuals are not identified as non-local because of Moquegua maize consumption.

SUGGESTIONS FOR FURTHER RESEARCH

The preliminary data presented here have demonstrated that strontium isotope analysis can potentially identify population movement between the site of Tiwanaku in the Bolivian *altiplano* and the proposed Tiwanaku colony of Chen Chen in the Peruvian valley of Moquegua. However, more archaeological human samples will be needed before we can thoroughly test the hypothesis that the site complex of Chen Chen was a Tiwanaku colony that was established by individuals from the Tiwanaku heartland. The samples currently being analysed will provide a 10% sample of both the individuals buried at Tiwanaku and of undisturbed burials at Chen Chen. In addition, an examination of the age and sex composition of immigrant groups at Chen Chen may elucidate the complex mechanisms of Tiwanaku residential mobility.

Although it seems highly probable that Tiwanaku colonies were present in the Moquegua Valley, where they would have provided *altiplano* inhabitants with direct access to maize and other important low-altitude crops, Tiwanaku influence was not limited to lower-altitude valleys such as the Moquegua in Peru and Cochabamba in Bolivia (Berenguer 1978; Berenguer *et al.* 1980; Kolata 1982, 1993a,b; Caballero 1984; Berenguer and Dauelsberg 1988; Goldstein

1989, 1992; Higueras-Hare 1996). Investigating Tiwanaku residential mobility from a wider range of geographical and archaeological zones will provide a more nuanced view of Tiwanaku influence throughout the South Central Andes.

For example, at the San Pedro de Atacama oasis in north central Chile, there is no evidence of Tiwanaku residential or public architecture, although grave goods commonly include Tiwanaku-style textiles, ceramics and ritual objects such as hallucinogenic snuff kits (Berenguer 1978; Berenguer *et al*. 1980; Serracino 1980; Orellana 1984, 1985; Thomas Winter *et al*. 1985; Torres 1985, 1987; Oakland 1986; Berenguer and Dauelsberg 1988; Rivera 1991; Torres *et al*. 1991). On the coast of Peru, near the modern city of Ilo, Tiwanaku or Tiwanaku-derived artefacts have been identified in sites of the Chiribaya culture (Owen 1992, 1993; Buikstra 1995; Tomczak 1995; Sutter 1997, 2000; Lozada Cerna 1998; Burgess 1999; Lozada Cerna and Buikstra 2002). Although the Chiribaya have traditionally been identified as a post-Tiwanaku development, new radiocarbon dates demonstrate the contemporaneity of these two cultures and raise the possibility that Tiwanaku people were also present on the coast of Peru (Owen 1992, 1993; Buikstra 1995; Tomczak 1995; Sutter 1997, 2000; Lozada Cerna 1998; Burgess 1999; Lozada Cerna and Buikstra 2002). Analysis of the strontium isotope ratios of archaeological teeth and bone, as well as of modern and archaeological fauna, from cemeteries in the San Pedro de Atacama region and Chiribaya sites will provide valuable information on the nature of Tiwanaku influence throughout the South Central Andes, and may show how immigration patterns varied spatially and were region-dependent.

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