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Reconstructing Middle Horizon mobility patterns on the coast of Peru through strontium isotope analysis

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ABSTRACT

The pre-Columbian coastal site of Ancón, Peru frequently has been interpreted as an important outpost of the highland Wari Empire, inhabited by individuals from the sierra and the coast. In order to test this hypothesis, bone–tooth pairs from 35 Middle Horizon (550 AD–1000 AD) Ancón skeletons were analyzed for strontium isotopes, which vary by geologic provenance. Results indicate that 34 of the 35 individuals have $^{87}Sr/^{86}Sr$ enamel and bone values higher than Ancón's biologically available strontium isotope range. Nitrogen and carbon isotope data from a subset of the Ancón skeletons suggest that the higher than expected $^{87}Sr/^{86}Sr$ values among the Ancón sample likely reflects a diet rich in marine resources rather than migratory activity, and highlight the need to use multiple lines of evidence to track residence change at sites where individuals relied on resources other than locally grown terrestrial foods. The one remaining individual, a young female of elite status, has an enamel strontium isotope signature much lower than the available data for local fauna and soil indicating that she was not raised locally. Her enamel $^{87}Sr/^{86}Sr$ ratio fits well within the range of strontium isotope values established for the inland Wari site of Conchopata [Tung, T.A., Knudson, K.J. Social identities and geographical origins of Wari trophy heads from Conchopata, Peru. Current Anthropology, in press.], and suggests that highland, Wari immigrants may have been present at Ancón during the Middle Horizon.

1. Introduction

The Wari Empire was one of two major powers in the Andes during the Middle Horizon (550 AD–1000 AD). The polity was centered in the Ayacucho Valley, but its stylistic influence was far-reaching and extended well beyond the central highland region (Isbell and McEwan, 1991; Isbell and Schreiber, 1978; Lumbreras, 1999; Schreiber, 1992). While the extent of Wari's political power in the Peruvian highlands is well-documented (Isbell and McEwan, 1991; Schreiber, 1992), the empire's relationship to the coast remains ambiguous.

The site of Ancón, situated 40 km north of Lima on Peru's central coast, has traditionally been included within the Wari sphere of influence (Fig. 1). The site has been the object of intense archaeological inquiry for the last century (Kauffmann Doig, 1994; Kaulicke, 1997; Ravines, 1977, 1981; Slovak, 2007; Uhle, 1968[1912]), and the majority of research has focused on Ancón mortuary customs, as thousands of tombs have been excavated at the site.

Ancón traditionally has been divided into two major archaeological zones: the Necropolis of Ancón and the Early Ancón area (Fig. 2). The Necropolis of Ancón was in part an ancient cemetery, containing burials dating from the Early Intermediate Period to the Late Horizon (200 BC–1550 AD), while the Early Ancón zone contained the site's Preceramic through Early Horizon settlements (2250 BC–200 BC) (Kaulicke, 1997; Menzel, 1977; Muelle and Ravines, 1973; Ravines, 1977).

During the Middle Horizon, the time period associated with the expansion of the Wari Empire, Ancón transformed significantly. Site inhabitants completely abandoned the Early Ancón zone and established themselves permanently in the Necropolis (Uhle, 1968[1912]; Ravines, 1977). Ancón mortuary practices shifted from simple, single interments in shallow graves to elaborate burials in which multiple individuals were placed in deep-chambered tombs (Kaulicke, 1997; Menzel, 1977; Ravines, 1977, 1981; Slovak, 2007) Additionally, Middle Horizon grave goods displayed a marked degree of wealth absent in earlier burials. Gold and silver objects were included in some grave caches, and Wari style objects appear

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Fig. 1. Map of Peru showing sites mentioned in text.

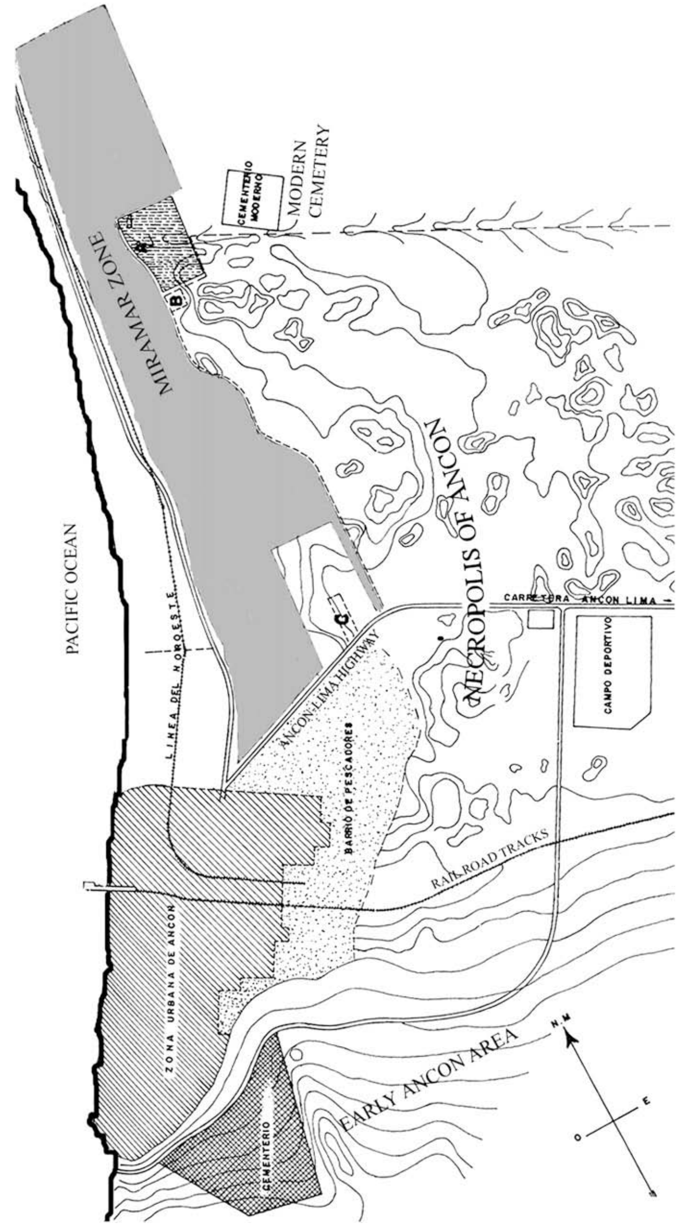

Fig. 2. Map of Ancón. All of the human skeletal material included in this study came from the Miramar Zone (highlighted in grey), located along the western edge of the Necropolis of Ancón. Map adapted from Ravines (1977).

among Ancón artifact assemblages for the first time (Kaulicke, 1997; Menzel, 1977).

Based on these changes, some scholars have speculated that Ancón functioned as an imperial outpost of the Wari polity, occupied partially by settlers from the Wari heartland and coast (Menzel, 1977; Uhle, 1968[1912]). This designation is not without problems, however. The classification of Ancón as a Wari colony has been based almost exclusively on the appearance and distribution of Wari style objects such as ceramics and textiles, which have been used as proxies for population movement and Wari political control. The presence of Wari style artifacts at Ancón, however, may reflect cultural and/or economic influence and not Wari migration. As an alternative, this study reports the results of strontium isotope analysis of human skeletons from Ancón. Strontium isotope analysis of bones and teeth provides direct evidence for prehistoric residence change (Bentley, 2006; Grupe et al., 1997; Price et al., 1998; Wright, 2005) and potentially can be used to detect highland immigrants to the site of Ancón.

2. Strontium isotope analysis

The principles of strontium isotope analysis in archaeology are relatively straightforward. Strontium is a trace element that occurs in igneous, metamorphic, and sedimentary rock, as well as within groundwater, soil, plants, and animals. Strontium has four naturally occurring stable isotopes (^{88}Sr, ^{87}Sr, ^{86}Sr, ^{84}Sr). The relative abundance of ^{87}Sr and ^{86}Sr (expressed as the atomic ratio ^{87}Sr/^{86}Sr) varies depending upon local geology (Faure, 1986; Faure and Powell, 1972). This natural variability has been capitalized upon by archaeologists who have used strontium isotope ratios in human bone and tooth enamel to test hypotheses about prehistoric mobility, colonization, and ritualized warfare in regions such as the American Southwest (Ezzo et al., 1997; Ezzo and Price, 2002; Farnsworth et al., 1985; Price et al., 1994), the Andes (Knudson, 2008; Knudson et al., 2004, 2005; Tung and Knudson, in press), Mexico and Guatemala (Price et al., 2000; Wright, 2005), Central Europe (Bentley et al., 2003; Grupe et al., 1997; Price et al., 1998; Schweissing and Grupe, 2003), and the Nile Valley (Buzon et al., 2007).

It has been suggested that ^{87}Sr/^{86}Sr values are transferred through the ecosystem largely unmodified such that the strontium isotope ratios of soil, groundwater, vegetation, and fauna in a given geologic zone should primarily reflect ^{87}Sr/^{86}Sr values in the parent bedrock (Blum et al., 2000). Assuming humans were eating only local foods, then ^{87}Sr/^{86}Sr ratios found in human hard tissue should reflect the strontium composition of an individual's diet, which in turn mirrors the geologic environment (Ericson, 1985; Grupe et al., 1997; Price et al., 1998; Sealy et al., 1991).

Tooth enamel of the permanent dentition forms in early childhood and is laid down as a series of layers. Once formed, mature enamel is almost entirely mineral and undergoes little change (other than mechanical wear) during an individual's lifetime (Hillson, 1996). Human bone, on the other hand, continuously regenerates its chemical constituents (Parfitt, 1983). On average, the rate of strontium turnover in human bone is 2.0–3.0 percent per year (Kulp and Schulert, 1962). Measurements of strontium in human tooth enamel, therefore, reflect the first years of an individual's life while measurements of strontium in human bone reflect the isotopic composition of the geologic region in which a person lived in the last few years before death (Ericson, 1985; Sealy et al., 1991). Differences in strontium isotope ratios between human bone and teeth from the same individual indicate change in geologic environment, and thus residence change (Ericson, 1985; Price et al., 1998).

In order to detect prehistoric mobility using strontium isotope ratios, there must be significant geologic variation between the different regions under study (Ericson, 1985). Baseline geologic signatures for an area can be determined by calculating regional $^{87}Sr/^{86}Sr$ ratios in exposed bedrock and soil. However, the strontium isotope composition of geologic substrate often differs from $^{87}Sr/^{86}Sr$ in plant and available Sr, and human $^{87}Sr/^{86}Sr$ signatures tend to reflect these latter values rather than strontium isotope ratios in bedrock and whole soil (Sillen et al., 1998). As a result, archaeological studies of human migration should be based on biologically available strontium isotope levels (Price et al., 2002; Sillen et al., 1998). Biologically available strontium isotope signatures can be measured using the skeletal remains of local archaeological and modern small fauna such as guinea pig, mice, and snails. Strontium isotope ratios from these types of animals tend to reflect a regional average $^{87}Sr/^{86}Sr$ value and have been shown to correlate strongly with $^{87}Sr/^{86}Sr$ levels among indigenous archaeological human populations (Price et al., 2002).

The effectiveness of strontium isotope signatures as an analytical tool rests on the premise that individuals consumed only locally grown foods during their lifetimes such that strontium isotope ratios in their bones and teeth will reflect underlying bedrock values (Ericson, 1985). However at archaeological coastal sites such as Ancón where individuals likely consumed a high degree of marine resources, strontium isotope analysis is more complicated. This is because strontium isotope ratios in marine foods reflect the $^{87}Sr/^{86}Sr$ signature of the ocean, not that of the land. If ancient coastal inhabitants consumed mostly foods from the sea, their $^{87}Sr/^{86}Sr$ values will reflect the strontium composition of the present day ocean which is $^{87}Sr/^{86}Sr = 0.7092$ (Veizer, 1989). Similarly if individuals consumed mostly imported foods, then their strontium isotope ratios will reflect the $^{87}Sr/^{86}Sr$ of the geologic region where the food was grown rather than the local area in which they lived. In these cases, individuals may erroneously be identified as migrants, despite having lived locally. Understanding the composition of local diets for study populations is therefore critical to strontium isotope research (Knudson, 2008).

Finally, reliable strontium isotope results can only be obtained if diagenetic processes can be ruled out. Skeletal material, once interred, is subjected to both physical and chemical alteration that may affect original biogenic signatures in teeth and bone (Hoppe et al., 2003; Nelson et al., 1986; Price et al., 1992; Sillen, 1986; Sillen and Sealy, 1995). Bone, which is relatively porous, highly organic (~30%), and composed of tiny hydroxyapatite crystals (20 × 4 nm), is highly susceptible to diagenetic change. Enamel, on the other hand, contains less than 2% organics, is non-porous, more crystalline, and has larger crystals (130 × 30 nm) with fewer defects and substitutions (Hillson, 2005; Koch et al., 1997). Not surprisingly, enamel hydroxyapatite is much more retentive of original isotopic signatures than either bone or dentine (Koch et al., 1997; Quade et al., 1992; Wang and Cerling, 1994). While the loss of biological isotope signatures is inevitable in some cases, significant amounts of diagenetic contamination in archaeological bone and teeth potentially can be removed following appropriate sampling and pretreatment procedures (Hoppe et al., 2003).

3. The geology of Ancón

The site of Ancón is situated on an arid, sandy plain along Peru's central coast. The region is bounded to the north and east by the foothills of the Andes and to the west by the Bay of Ancón, a small, protected horseshoe shaped bay rich in marine life that served, and continues to serve, as an important fishing center (Menzel, 1977). The southern edge of Ancón is less rugged, and stretches relatively uninterrupted to the lower reaches of the Chillón Valley.

The Necropolis of Ancón, the sector of the site from which the materials in this study originated, is situated in an alluvial floodplain formed from numerous deposition events throughout the Pleistocene (Fig. 3). The alluvial deposit is composed of a heterogeneous mix of materials, including tertiary rock, Mesozoic volcanics, and coastal batholiths that date to the Cretaceous period (Palacios Moncayo et al., 1992). Baseline strontium isotope values from soil for the Necropolis' northwestern sector were reported previously (Slovak, 2006) and ranged from $^{87}Sr/^{86}Sr = 0.7076$ to 0.7079 (Table 1). Additionally, biologically available strontium isotope ratios for the region were determined prior to this study using skeletal and enamel material from modern and archaeological *cuyes*, or guinea pig, from the Ancón region (Slovak, 2007). Strontium isotope results from archaeological and modern *cuyes* were very similar, ranging from $^{87}Sr/^{86}Sr = 0.7064$ to 0.7065 for archaeological *cuyes* and $^{87}Sr/^{86}Sr = 0.7066–0.7067$ for modern representatives (Table 1). Based on the faunal data, the biologically available strontium isotope range for Ancón was determined to be $^{87}Sr/^{86}Sr = 0.7063–0.7068$.

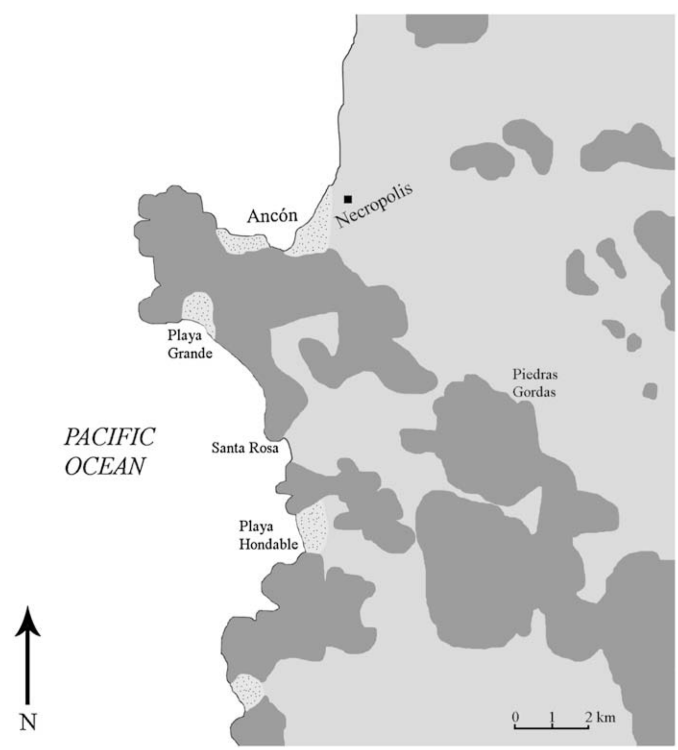

Fig. 3. Simplified geologic map of the Ancón region. Dark grey, Mesozoic volcanics; light grey, alluvial soil; stippled grey, marine deposit. Adapted from Palacios Moncayo et al. (1992).

Table 1
Strontium isotope ratios for Ancón soil (ammonium acetate extractable fraction) and fauna

Site	Lab number	Specimen number	Material	$^{87}Sr/^{86}Sr$
Ancón	Soil 1A	CF-18-3	Soil	0.70786
Ancón	Soil 1B	CF-18-3	Soil	0.70761
Ancón	ACT1	CF-20-009a	*Cuy* tooth (archaeological)	0.70638
Ancón	ACT2	CF-20-009b	*Cuy* tooth (archaeological)	0.70648
Ancón	*Cuy* A	*Cuy* A	*Cuy* bone (modern)	0.70661
Ancón	*Cuy* B	*Cuy* B	*Cuy* bone (modern)	0.70657
Ancón	*Cuy* C	*Cuy* C	*Cuy* bone (modern)	0.70668

Data from Slovak (2006, 2007).

The difference in $^{87}Sr/^{86}Sr$ values between Ancón soil (ammonium acetate extractable fraction) and Ancón fauna is striking and warrants further discussion (mean soil $^{87}Sr/^{86}Sr = 0.7077$; mean *cuy* $^{87}Sr/^{86}Sr = 0.7065$). The geologic $^{87}Sr/^{86}Sr$ values for Ancón were based on two soil samples taken from a single Middle Horizon burial context, CF-18, along the western edge of the Necropolis in an area designated as the Miramar Zone (Fig. 2). The remains of the ancient *cuyes* were found in Middle Horizon tomb CF-20, also in the Miramar Zone. On the other hand, the modern *cuyes* sampled here were raised in the town of Ancón, just south of the Necropolis, and fed locally grown alfalfa from a small patch of arable terrain nearby. Despite the difference in provenance between the modern and ancient *cuyes*, it seems that the latter consumed food from the same general vicinity as the former based on the remarkable consistency in $^{87}Sr/^{86}Sr$ values through time (Table 1).

It is important to remember that although Ancón's Middle Horizon settlement was concentrated in the Necropolis, it is unlikely that site inhabitants practiced agriculture there owing to the lack of water in the immediate vicinity (Kaulicke, 1997; Menzel, 1977). Instead, small amounts of vegetation could have been sustained in or near the modern town of Ancón where underground wells and springs lay close to the surface (Lanning, 1963; Menzel, 1977). Thus the discrepancy between strontium isotope ratios from Ancón soil and fauna likely reflects underlying geologic differences in the $^{87}Sr/^{86}Sr$ of the Necropolis and that of the surrounding Ancón region.

Finally, it was hypothesized that strontium isotope values among Ancón individuals may be higher than the biologically available strontium isotope range reported here owing to the consumption of marine foods by Ancón's inhabitants. A diet rich in marine resources would shift $^{87}Sr/^{86}Sr$ ratios towards the modern seawater signature ($^{87}Sr/^{86}Sr = 0.7092$, Veizer, 1989). If this is the case, Ancón individuals potentially will have markedly higher strontium isotope signatures in their bones and teeth than either the $^{87}Sr/^{86}Sr$ levels established for Ancón soil or site fauna.

4. Materials and methods

Thirty-five adult individuals from 28 Middle Horizon Ancón tombs were selected for analysis. The skeletal sample spans three different excavation projects – Cirilo Huapaya Manco's 1947 excavations sponsored by the Museo Nacional de Antropología y Arqueología, Luis Ccosi Salas and Marino Gonzalez's 1950–1953 Inspección de Monumentos Arqueológicos project, and Federico Kauffmann Doig's Proyecto Tumbas de Ancón in 1992. The remains from Huapaya's project are held at the Museo Nacional de Antropología, Arqueología, e Historia (MNAAH) in Lima, Peru, as are a portion of the materials from Ccosi Salas and Gonzalez's excavations. Kauffmann's collections currently are housed at the Museo de Ancón in Ancón, Peru (Fig. 2).

Ten milligrams of tooth enamel and 50 mg of cortical bone were obtained from 26 of the skeletons for which both cranial and postcranial remains were present. For the remaining 9 individuals who lacked post-cranial material, only tooth enamel was collected. Enamel samples were taken from an individual's mandibular or maxillary third molar if possible. Third molars initially form between 7 and 13 years of age and crown completion occurs between 12 and 16 years (Hillson, 1996). Third molars form well after the period of weaning and therefore are the least likely of all teeth to be affected by maternal strontium isotope levels. Third molars are not always available for archaeological study, however, in part because not every individual develops them (Garn et al., 1962). If no third molars were present or if the integrity of the tooth or surrounding jawbone was at risk, priority was given to mandibular or maxillary second molars followed by first molars. Second molars initially begin to form in an individual's second or third year and crown completion takes place at 7 or 8 years. First molars begin their initial formation *in utero* and crown completion generally occurs at 3 years (Hillson, 1996). Cortical bone samples were taken from the diaphyseal shaft of individuals' long bones (see Table 3 for a complete list of teeth and bones sampled).

Samples were prepared for strontium isotope analysis at the Paytan Biogeochemistry Lab and the Stanford–USGS Micro-Isotopic Analytical Center. Samples initially were cleaned through abrasion using a Dremel Multipro drill (Model 395) outfitted with a 0.5 mm inverted cone tip. This eliminated any adhering materials present on the teeth and bones and removed the outer levels of enamel and bone that generally are more susceptible to diagenetic contamination (Hillson, 1996; Price et al., 1992).

Enamel samples were soaked in 1 mL of H_2O_2 (30%) for 24 h after which they were sonicated with deionized water. One mL of 0.1 N acetic acid was added to each sample and left overnight. Archaeological bone samples were subjected to a more rigorous pretreatment protocol generally following the methods laid out in Sillen (1986) and Hoppe et al. (2003). Bone samples were sonicated with 1 mL of 0.1 N buffered acetic acid (pH = 4.5) for 90 s, followed by a second aliquot of 0.1 N acetic acid. This process was repeated 21 times after which bone samples were rinsed and sonicated with deionized water for 5 min. Both enamel and bone samples were dissolved in 2.5 N HCl.

Separation of strontium from other cations was carried out using ion chromatography columns packed with Biorad AG50 $\times$ 8 (200–400 mesh) resin and Sr was eluted with 2.5 N HCl. Only distilled or trace metal grade reagents were used for chemical sample preparation. The purified Sr fractions were loaded onto outgassed Ta single filaments using 0.25 N H_3PO_4 and measured on a Finnigan MAT262 Mass Spectrometer at the Stanford–USGS Micro-Isotopic Analytical Center. A few samples (4 enamel and 5 human bone samples) were analyzed by Thomas Bullen at the USGS in Menlo Park using a Finnigan MAT261 Mass Spectrometer in dual collector dynamic mode. Samples were loaded onto outgassed Ta single filaments using 40 μl of 0.5 N phosphoric acid as the loading medium. $^{87}Sr/^{86}Sr$ ratios were corrected for instrumental fractionation by normalizing to $^{86}Sr/^{88}Sr = 0.1194$. The average NBS-987 during the time when the samples were run is 0.71033 ± 0.00002 (two-sigma; $n = 60$) at Stanford and 0.71023 ± 0.00002 (two-sigma) at the USGS. Blanks are less than 0.5 ng for Sr.

Five bone samples were set aside for Fourier transform infrared spectroscopy (FTIR). FTIR analysis measures the absorption of infrared radiation by a bone or tooth sample at its molecular level, permitting an assessment of the overall mineralogy and crystallinity of skeletal materials (Hoppe et al., 2003; Shemesh, 1990; Sillen, 1989; Wright and Schwarcz, 1996). In order to monitor the degree of potential diagenesis in archaeological bone mineral from Ancón, the crystallinity index (CI) was evaluated. On an infrared spectrum, the CI refers to the extent of phosphate peak splitting at 565–605 cm^{-1} and is measured by calculating the relative depth of the valley between the two peaks. Poorly crystallized apatites such as those found in fresh human bone will exhibit a greater degree of overlap between the two peaks than highly crystallized apatites, and as a result will yield lower CI's than more crystalline apatite (Shemesh, 1990). The reported CI for both modern human and animal bone ranges from 2.8 to 3.1 (Garvie-Lok et al., 2004; Weiner and Bar-Yosef, 1990; White et al., 1998; Wright and Schwarcz, 1996). Archaeological samples that exhibit CI's above the modern range likely have been diagenetically altered, either by recrystallization (growth in size) of original bone crystals or the selective dissolution of less crystallized bone (Wright and Schwarcz, 1996).

Untreated, powdered bone was analyzed by Dr. Guanchao Li at Stanford University. Approximately 0.01 g of bone powder from each sample was mixed with 0.1 g KBr, ground to a very fine powder, and placed in an FTIR pellet device. The spectra were collected on a Nicolet 470 FTIR Spectrometer with a DTGS detector. KBr was used as background in this measurement. Peak absorbance was measured at wave-number 565 and 605 cm^{-1} and at the valley between both of these peaks, wave-number 595 cm^{-1}. The crystallinity index (CI) for each bone sample was determined by the following equation:

$$CI = \{A_{565} + A_{605}\}/A_{595}$$

where A_x represents the absorbance at wave-number x (Shemesh, 1990; Wright and Schwarcz, 1996). Samples with CI values greater than 2.8–3.0, the CI range in modern bone (White et al., 1998) were considered diagenetically altered. Samples with CI values that fell within or slightly below the modern range were considered unaltered.

5. Results

FTIR analysis indicates that the Ancón samples are well preserved and their apatite composition resembles that of modern bone. All 5 samples have a crystallinity index (CI) similar to fresh bone (2.8–3.0) with a mean of 2.7 and a range of 2.6–3.0 (Table 2). Though bone samples from all 35 individuals were not tested for diagenesis using FTIR, it is suggested that the absence of contamination among the 5 samples tested here likely is reflective of the sample as a whole given that all of the skeletons were interred in the same geologic area for roughly the same amount of time and uniformly appeared well preserved. Furthermore it is worth emphasizing that the Ancón region is hyper-arid. The cool Humboldt Current, which runs northwards along Peru's coast, creates nutrient-rich water conducive to marine life while simultaneously inhibiting coastal precipitation (Moseley, 1992). As a result, Ancón maintains stable year-round temperatures and experiences little, if any, rainfall. While diagenetic contamination among the Ancón samples cannot be ruled out absolutely, drier conditions like those at Ancón generally are more favorable to the preservation of biogenic signatures in organisms than are moist depositional environments (Nielsen-Marsh and Hedges, 2000; Price et al., 1992; Sillen, 1989).

Table 2
Crystallinity indexes for 5 Middle Horizon Ancón individuals

Material	Specimen number	Skeletal element	CI (FTIR)
Cow (modern)			2.9[a]
Peccary (modern)		Femur	2.9[b]
Human (modern)		Femur	3.1[b]
Human	CF-08-Y	Tibia	2.6
Human	CF-08-I	Fibula	2.6
Human	CF-14-I	Humerus	3.0
Human	CF-14-III	Radius	2.8
Human	CF-14-X	Fibula	2.6

Peak absorbance was measured at wave-number 565 and 605 cm^{-1} and at the valley between both of these peaks, wave-number 595 cm^{-1}. All CI values fall within or slightly below the CI range for modern human and animal bone, suggesting that the Ancón samples are not diagenetically altered.

[a] Garvie-Lok et al. (2004).

[b] Wright and Schwarcz (1996).

Table 3 shows strontium isotope ratios from archaeological tooth enamel and bone from thirty-five individuals buried at Ancón. The majority of strontium isotope values fall between $^{87}Sr/^{86}Sr = 0.7075$ and 0.7081, with a mean enamel value of $^{87}Sr/^{86}Sr = 0.7078$ and a mean bone value of $^{87}Sr/^{86}Sr = 0.7079$. Fig. 4 illustrates the distribution of strontium isotope values relative to biologically available strontium levels established for the site. The present day seawater value and local soil values also are plotted on the figure. As can be seen, all of the individuals have $^{87}Sr/^{86}Sr$ enamel and bone values higher than Ancón's biologically available strontium range and lower than seawater, except for one individual – A1-P8247 – whose enamel strontium isotope signature ($^{87}Sr/^{86}Sr = 0.7056$) is much lower than local terrestrial values. Additionally, three other individuals (A1-P6504, A1-1461, and CF-14-X) exhibit either tooth or bone $^{87}Sr/^{86}Sr$ values slightly outside of those exhibited by most other Ancóñeros (Fig. 5). However, unlike individual A1-P8247, these three individuals' $^{87}Sr/^{86}Sr$ signatures are well above Ancón's biologically available $^{87}Sr/^{86}Sr$ range.

5.1. Potential explanations for the elevated strontium isotope signatures

The near ubiquitous presence of elevated strontium isotope signatures among Ancón tooth and bone samples is notable and potentially can be explained four ways: 1. Strontium isotope signatures were diagenetically altered; 2. Bodies were brought to Ancón for burial from elsewhere; 3. Ancón's inhabitants practiced agriculture in the Necropolis; or 4. Consumption of marine foods by Ancón's inhabitants led to elevated strontium isotope signatures.

Based on the results of FTIR analysis discussed above, diagenetic contamination of bones and teeth likely can be ruled out. Of the 5 specimens subjected to FTIR analysis, all exhibited crystallinity indexes identical to that found in modern bone. Thus it seems likely that the correspondence between some skeletal $^{87}Sr/^{86}Sr$ values and soil extracts is coincidental and due to a factor(s) other than diagenesis.

Another possibility to explain the elevated strontium isotope values among the Ancón sample is that deceased individuals were brought to the site for burial from geologically distinct locales; however this phenomenon probably does not account for the situation at Ancón. The Necropolis of Ancón contained mortuary and non-mortuary components (Kaulicke, 1997; Menzel, 1977; Ravines, 1977; Uhle, 1968[1912]), indicating that the site hosted a year-round population. It is unlikely that outside groups would bury their dead in someone else's territory. Furthermore, the relative uniformity among most Ancón strontium signatures (Table 3) suggests that the majority of individuals were from the same place, rather than brought in for burial from multiple locales.

A third explanation for the high $^{87}Sr/^{86}Sr$ signatures exhibited by most Ancóñeros is that ancient people ate foods grown in the Necropolis. The range of strontium isotope values established from Necropolis soil samples partially overlaps with human $^{87}Sr/^{86}Sr$ values (Fig. 4). If Ancóñeros mostly consumed plants or plant-fed animals from this sector of the site, we would expect their $^{87}Sr/^{86}Sr$ signatures to mimic the underlying geologic value(s). This scenario, however, is unlikely. As mentioned earlier, the lack of an abundant freshwater source in or near to the Necropolis would have prohibited agricultural production in the sector. Additionally no archaeological evidence has yet been found to suggest that crops were cultivated in the Necropolis in ancient times.

Table 3
Strontium isotope results from tooth enamel and bone apatite and carbon and nitrogen isotope results from bone collagen for Middle Horizon Ancón individuals

Specimen number	Sex	Tooth	$^{87}Sr/^{86}Sr$ tooth	Standard error	Bone	$^{87}Sr/^{86}Sr$ bone	Standard error	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N
A1/1333	M	LM$_3$	0.70792	±0.00002	Radius	0.70785	±0.00002			
A1/1345	F	LM^2	0.70800	±0.00002	Tibia	0.70776	±0.00002	−9.2	14.5	3.34
A1/1461	?	LM$_1$	0.70744	±0.00001	Ulna	0.70835	±0.00007	−10.7	13.6	3.44
A1/1509	?	RM$_2$	0.70810	±0.00001	Tibia	0.70785	±0.00002	−10.4	14.0	3.59
A1/1554	?	RM^1	0.70810	±0.00002						
A1/1569	F	LM^3	0.70808	±0.00002	Fibula	0.70783	±0.00002			
A1/1572	?	LM$_2$	0.70811	±0.00002	Fibula	0.70761	±0.00001	−9.9	14.1	3.37
A1/1645	M	LM^3	0.70798	±0.00002	Radius	0.70794	±0.00001			
A1/1703	F	LM$_3$	0.70807	±0.00002	Fibula	0.70791	±0.00002	−11.2	13.1	3.40
A1/1939	F	RM^2	0.70800	±0.00002	Radius	0.70796	±0.00002			
A1/1979	F	LM$_3$	0.70796	±0.00001	Humerus	0.70813	±0.00003	−10.7	13.4	3.42
A1/2092	M	RM^2	0.70798	±0.00001						
A1/2250	F	LM$_3$	0.70841	±0.00002						
A1/2252	F	LM$_3$	0.70760	±0.00001						
A1/2257	M	LM$_3$	0.70767	±0.00002	Humerus	0.70777	±0.00001			
A1/2271	?	LM^2	0.70783	±0.00002	Radius	0.70774	±0.00002			
A1/2277	?	LM$_2$	0.70778	±0.00001						
A1/P6136	M	RM$_3$	0.70823	±0.00002	Tibia	0.70799	±0.00002	−11.8	15.0	3.37
A1/P6504	M	RM$_2$	0.70703	±0.00003	Humerus	0.70812	±0.00003	−10.8	14.8	3.29
A1/P6677	M	RM$_1$	0.70758	±0.00002	Radius	0.70789	±0.00003	−12.2	13.0	3.31
A1/P6865	F	RM$_3$	0.70784	±0.00001	Humerus	0.70801	±0.00005	−9.6	14.9	3.31
A1/P7224	?	LM$_2$	0.70770	±0.00002						
A1/P7854	M	RM^3	0.70785	±0.00002	Humerus	0.70766	±0.00005	−8.5	14.7	3.22
A1/P7968	F	RM$_2$	0.70818	±0.00002	Tibia	0.70795	±0.00001	−12.4	15.0	3.40
A1/P8247	F	LM^2	0.70555	±0.00002	Radius	0.70776	±0.00004			
A1/P8375	M	LM$_3$	0.70742	±0.00002						
A1/P8406	F	LM^2	0.70761	±0.00002	Humerus	0.70792	±0.00002			
CF-03-II	F	LM$_3$	0.70782	±0.00002	Fibula	0.70769	±0.00004	−10.0	13.5	3.34
CF-08-I	M	RM$_3$	0.70764	±0.00005	Fibula	0.70782	±0.00005	−10.1	14.9	3.33
CF-08-II	M	LM$_2$	0.70775	±0.00004	Radius	0.70804	±0.00005	−10.2	14.1	3.31
CF-08-Y	F	LM^2	0.70780	±0.00005	Tibia	0.70804	±0.00005	−10.5	14.0	3.28
CF-14-I	F	RM$_3$	0.70745	±0.00002	Humerus	0.70785	±0.00005			
CF-14-III	F	LM^3	0.70796	±0.00002	Radius	0.70769	±0.00005			
CF-14-X	F	RM$_2$	0.70824	±0.00005	Fibula	0.70724	±0.00005	−11.0	13.3	3.29
CF-18	M	RM^2	0.70746	±0.00002						

Instead, it seems likely that the high $^{87}Sr/^{86}Sr$ values relative to bioavailable Sr among almost all Ancón individuals resulted from a heavy reliance on seafood. Earlier it was hypothesized that the heavy consumption of marine foods by Ancón inhabitants would elevate $^{87}Sr/^{86}Sr$ ratios towards the modern seawater signature ($^{87}Sr/^{86}Sr = 0.7092$, Veizer, 1989). While none of the Ancón individuals display strontium isotope signatures as high as $^{87}Sr/^{86}Sr = 0.7092$, the majority of human $^{87}Sr/^{86}Sr$ values fall between Ancón's mean terrestrial value as established by local fauna ($^{87}Sr/^{86}Sr = 0.7065$) and the seawater signature ($^{87}Sr/^{86}Sr = 0.7092$) (Fig. 4), suggesting a mixed diet of marine foods and terrestrial resources.

This hypothesis is well-supported by nitrogen and carbon isotope data from Ancón. As reported in greater detail elsewhere (Slovak, 2007), $\delta^{15}N$ and $\delta^{13}C$ values were generated for a subset of the Ancón skeletal sample. Carbon and nitrogen isotope ratios in human bone collagen have been used to assess the relative amounts of marine and terrestrial foods in prehistoric diets (DeNiro and Epstein, 1978, 1981; Schoeninger and DeNiro, 1984; Walker and DeNiro, 1986) and are important to migration studies because they can identify potential dietary biases that might affect strontium isotope signatures, such as the ingestion of marine foods discussed above.

As can be seen in Table 3, $\delta^{15}N$ values from 17 of the Ancón skeletons range from 13.0‰ to 15.0‰ with a mean value of 14.1‰. These results are well within the range reported for marine food source eaters elsewhere (DeNiro, 1987; Schoeninger et al., 1983),

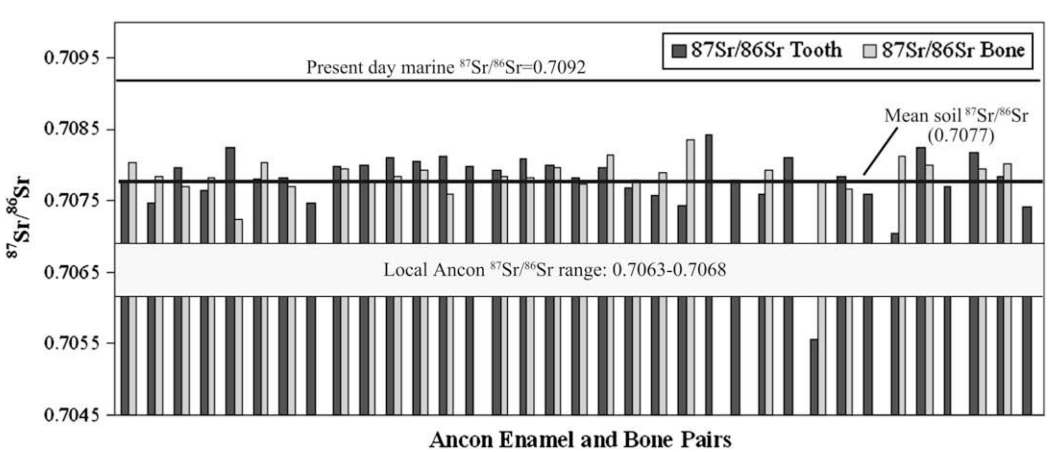

Fig. 4. Strontium isotope ratios in human tooth enamel and bone from 35 Middle Horizon Ancón skeletons. Local bioavailable $^{87}Sr/^{86}Sr$ values are based on strontium isotope signatures from modern and archaeological Ancón fauna. The present day marine $^{87}Sr/^{86}Sr$ signature is based on Veizer (1989).

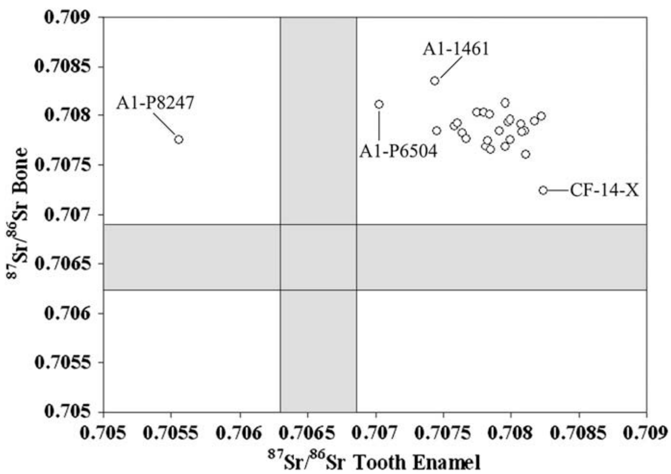

Fig. 5. Strontium isotope ratios from human tooth enamel and bone from 27 Middle Horizon Ancón individuals. The shaded area between the horizontal and vertical lines indicates Ancón's biologically available strontium isotope range as determined by local fauna: $^{87}Sr/^{86}Sr = 0.7063–0.7068$.

including the Andes (Tomczak, 2003; Ubelaker et al., 1995). Carbon isotope data from the same individuals vary from −8.4‰ to −12.4‰ with a mean value of −10.5‰. These results likely reflect a mixed diet composed primarily of marine foods and C_4 plants.

Similar C and N isotope results to those found at Ancón have been reported for Middle Horizon Site 71 in the lower Viru Valley on Peru's north coast (Ericson et al., 1989). According to the Viru study, Site 71's local inhabitants likely consumed a mix of marine fish, shellfish and C_4 plants, with the latter composing approximately 40–65% of individual's total diet. Based on the nearly identical isotope data from Ancón, it is easy to imagine a similar scenario. Importantly, the carbon and nitrogen isotope results presented here suggest that Ancón individuals relied heavily, although not exclusively, on marine foods. The high consumption of seafood likely raised local inhabitants' $^{87}Sr/^{86}Sr$ ratios towards the seawater signature, resulting in the elevated strontium isotope values exhibited by the Ancón skeletons.

Ancient Ancóñeros reliance on seafood is supported by osteological and dietary evidence as well. External auditory exostoses (EAE), a pathological condition that develops as a result of prolonged exposure of the ear canal to cold water (DiBartolomeo, 1979; Filipo et al., 1982), were exhibited by 4 males in the Ancón sample. EAE are found most frequently among habitual fishers, divers, swimmers, and surfers (Fowler and Osmun, 1942; Harrison, 1962; Kennedy, 1986), and its presence among some Ancón individuals suggests that marine foods were harvested and likely eaten during the Middle Horizon. Furthermore fishing paraphernalia such as fishing hooks and nets have been documented in Ancón graves (Huapaya Manco and Zagarra, 1947a,b; Kauffmann Doig, 1994; Kaulicke, 1997) and the remains of various shellfish and marine mammals are found throughout the Middle Horizon strata (Leon del Val, 1994).

5.2. Potential origins for the one non-local individual

While higher strontium isotope values can be explained as a result of marine food consumption, low strontium isotope values cannot. As mentioned above, individual A1-P8247 – a female – has an anomalously low enamel signature ($^{87}Sr/^{86}Sr = 0.7056$) compared with the remainder of the Ancón sample (Fig. 5). In fact, A1-P8247's enamel strontium isotope value falls well within the range of local $^{87}Sr/^{86}Sr$ established for the Wari heartland ($^{87}Sr/^{86}Sr = 0.7051–0.7065$, Tung and Knudson, in press), and her enamel strontium isotope value is virtually identical to $^{87}Sr/^{86}Sr$ enamel and bone values reported for Middle Horizon individuals living at the Wari site of Conchopata in the Ayacucho Valley (Tung and Knudson, in press) (Table 4; Fig. 1).

Table 4
Strontium isotope values for the South Central Andes, the Ayacucho region, and the Wari site of Conchopata

Region (site)	Material	Range of $^{87}Sr/^{86}Sr$
South Central Andes	Geologic Data	0.7054–0.7067[a]
Ayacucho	Modern Fauna	0.705762–0.707204[b]
Ayacucho (Conchopata)	Archaeological human tooth enamel from 5 adults	0.705480–0.705647[b]
Ayacucho (Conchopata)	Archaeological human bone from 5 adults and 1 infant	0.705663–0.706734[b]

[a] Hawkesworth et al. (1982).
[b] Tung and Knudson (in press).

Individual A1-P8247, a female, was a teenager at the time of her death. She had been buried in one of three elite tombs that date to the onset of the Middle Horizon. Unlike other individuals from the same time period, she had been wrapped elaborately in a number of dyed and embellished textiles and buried with decorative ceramics, including one Wari style vessel and two *keros* (flared drinking cups) containing maize. Given the elaborateness of her burial relative to others of that time period, the Wari influenced artifacts interred with her, and her non-local strontium isotope value, individual A1-P8247 is likely a migrant from the Wari polity.

However it is also possible that individual A1-P8247 was raised not in Ayacucho but in a region with strontium isotope signatures similar to those in Ayacucho. Bethard et al. (2008), for example, reported biologically available strontium isotope ratios for the northern Peruvian coastal site of Santa Rita B to be $^{87}Sr/^{86}Sr = 0.7050–0.7056$, while Buzon et al. (2008) defined the biologically available strontium isotope range for the site of La Tiza in the Nasca region as $^{87}Sr/^{86}Sr = 0.70559–0.70727$. Both of these ranges partially overlap with Ayacucho's range (Tung and Knudson, in press) and are potential places of origin for individual A1-P8247.

6. Discussion and conclusion

Strontium isotope results from an analysis of 35 Middle Horizon Ancón skeletons indicate that at least one individual, A1-P8247, was raised non-locally. Individual A1-P8247 likely was from the Ayacucho area based upon her low enamel strontium isotope signature as well as the inclusion of Wari influenced artifacts in her grave and the elite nature of her tomb. Her young age at death, approximately 15–19 years of age, coupled with her local bone $^{87}Sr/^{86}Sr$ signature indicates that she lived at Ancón for several years before death and likely migrated to Ancón as a young child.

If we assume that individual A1-P8247 was indeed a Wari migrant, then her presence at Ancón raises interesting questions about the nature of Wari influence at the site. As discussed at the start of this paper, one of the major debates surrounding Ancón's role during the Middle Horizon was whether or not it served as a Wari colony. Admittedly the presence of one migrant from Ayacucho is not absolute confirmation for a large-scale migration and/or colonization event at Ancón; however, on the basis of these findings, the possibility that Wari exercised political control over the site cannot be ruled out.

Although the comparative data used to establish baseline signatures for Ancón (2 archaeological soil samples and 5 guinea pigs) were not exhaustive, it is clear that almost all human Sr isotope values fall above the local, terrestrial range. While these results might appear to indicate that all of the individuals analyzed were non-local, we argue that elevated strontium isotope ratios among Ancón's population are due to the regular consumption of marine foods by site inhabitants rather than to migratory activity. The presence of ancient fishing paraphernalia, marine mammal bones, and shellfish debris at Ancón supports this hypothesis. More importantly, nitrogen and carbon isotope data from a subset of the Ancón skeletons indicate that individuals consumed a marine-heavy diet. The results of this study demonstrate that the ingestion of marine resources and/or imported foods by ancient populations must be considered in applications of strontium isotope analysis. Furthermore, the use of local terrestrial fauna to establish biologically available Sr isotope levels at coastal sites should be used cautiously and augmented by additional classes of isotopic and paleodietary data.

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