Isotopic Evidence for Middle Horizon to 16th Century Camelid Herding in the Osmore Valley, Peru

E. K. THORNTON,[a]* S. D. DEFRANCE,[a] J. KRIGBAUM[a] AND P. R. WILLIAMS[b]

[a] Department of Anthropology, University of Florida, Gainesville, FL 32611, USA
[b] Department of Anthropology, The Field Museum, Chicago, IL 60605, USA

ABSTRACT   Archaeological and zooarchaeological data indicate that camelid pastoralism was a subsistence and economic mainstay of Middle Horizon and more recent cultures in the Osmore region of southern Peru. However, it is not known whether camelids were primarily herded in highland *puna* pastures or near lower elevation sites in the middle valley or along the coast. This research examines the elevation of archaeological camelid herding in the Osmore Valley using stable isotope analysis. Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios were measured on 28 archaeological camelid bone samples from the Middle Horizon sites of Cerro Baúl and Cerro Mejía, the Late Intermediate site of Yaral and the late pre-Hispanic to Colonial period site of Torata Alta. Twenty-three archaeological camelids have $\delta^{13}C$ and $\delta^{15}N$ values similar to five modern camelids maintained in highland *puna* pastures. In contrast, three camelids from the high status Wari site of Cerro Baúl, and two from Yaral have unexpectedly high $\delta^{13}C$ and/or $\delta^{15}N$ values outside the expected range for camelids pastured in highland *puna* habitats. The results may be explained by differences in foddering practices, altitudinal herding range or climatic conditions. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) were also assessed to infer pasture elevation using the camelid remains from Cerro Baúl ($n = 11$). One individual in this sub-sample exhibits a non-local $^{87}Sr/^{86}Sr$ value indicative of an origin in the highland *puna* region east or south of Lake Titicaca. It was not possible to further distinguish between camelids herded in lower to middle elevation habitats outside the Lake Titicaca basin using $^{87}Sr/^{86}Sr$ values. This study suggests that multiple isotope proxies may be used to identify animals primarily pastured in lowland coastal versus highland *puna* (>4000 masl (meters above sea level)) habitats, but are less useful at distinguishing between animals pastured in lower to middle elevation settings. Copyright © 2010 John Wiley & Sons, Ltd.

Key words: camelids; carbon; Middle Horizon; nitrogen; Peru; stable isotopes; strontium

Introduction

Since their domestication ~6000 years BP, llamas (*Lama glama*) and alpacas (*Lama pacos*) have played a key role in shaping systems of subsistence, settlement and exchange in prehistoric Andean societies. Domesticated New World camelids (Family Camelidae) served as reliable sources of products such as meat, bone, hide and fiber. They were also used in ritual sacrifice and for transport of goods and commodities to maintain extensive state systems and long distance trade networks (e.g. Dillehay & Nunez, 1988; Aldenderfer, 2001; Chepstow-Lusty *et al.*, 2007; Mengoni Goñalones, 2007). However, despite their importance in

Andean social and economic organisation, prehistoric foddering practices and the locations of pasturelands are not well established. In particular, we do not know whether camelids were primarily herded in high elevation habitats (e.g. > 3500 masl (meters above sea level)) and then transported to lower elevation sites shortly before butchery and use, or whether local herds were also maintained at sites near the coast (< 1000 masl) or at mid-valley elevations (1000–3500 masl).

Modern llama and alpaca herds graze at elevations > 3000 masl in the central Andean highlands, with the highest concentration of animals located within 350 km of Lake Titicaca (Franklin, 1982). Today, pasturelands are largely confined to high elevation habitats such as the *puna* grasslands and wetland *bofedales*, which occur between 3900–4500 masl. However, modern camelid distributions and ecological

* Correspondence to: Department of Anthropology, University of Florida, Gainesville, FL 32611, USA.
e-mail: kennedye@ufl.edu

affinities may be relatively recent phenomena. This is due to the historic displacement of camelid herds during colonial times (Bonavia, 2008: 443–448), and the possibility of extensive preconquest species hybridisation (Wheeler *et al.*, 1995; Kadwell *et al.*, 2001; Wheeler, 2003; Moore, 2006). The absence of modern camelid herding in lowland environments was used as negative evidence to support traditional models of prehistoric Andean exchange such as verticality (Murra, 1980, 1985) or ecological complementarity (Mujica, 1985), with the suggestion that ancient camelid herding was limited to upper elevation habitats. These models classified camelid products as highland commodities regardless of whether camelid remains were recovered from lowland or highland archaeological sites. In contrast to modern patterns of camelid distribution, both ethnohistorical sources (Rostoworowski de Ciez Canseco, 1988) and archaeological evidence (e.g. Shimada & Shimada, 1985; Wheeler, 1995; Wheeler *et al.*, 1995; Chávez, 1998; Umire & Miranda, 2001; Knudson, 2004; Lozada *et al.*, 2009) indicate that llamas and alpacas had greater vertical and horizontal distributions in the past than is evident today. The restriction of camelid herds to upper elevations in modern times is now attributed to human cultural practices and post-colonisation settlement patterns rather than camelid physiology (see Wheeler *et al.*, 1995). Although zooarchaeological and mortuary studies of animal remains (e.g. Wheeler *et al.*, 1995; Chávez, 1998; Lozada *et al.*, 2009) as well as spatial studies of corrals and caravan routes (e.g. Shimada & Shimada, 1985; Umire & Miranda, 2001) contribute to understanding ancient camelid herding, specific data to verify camelid diets and ancient pastureland elevations have not been available until recently.

This study explores the nature of ancient camelid herding in the Osmore Drainage of far southern Peru through stable isotope analysis of archaeological camelid remains and modern comparative data from highland pastured individuals. Bones sampled are from four archaeological sites dating from the Middle Horizon (AD 600–1000) to the second half of the 16th century. Stable carbon and nitrogen isotope ratios (δ^{13}C, δ^{15}N) derived from bone collagen provide dietary information on the types of plants consumed by camelids and the possible habitats and elevation zones used for natural foraging. This is possible because climatic and floristic differences between coastal and highland environments are isotopically distinct in plants and consumer tissues such as camelid bone. Moreover, camelids consuming large quantities of agricultural products such as maize, a C_4 plant, will be isotopically distinct from camelids feeding in pastures of natural C_3 vegetation. In the Andean region, stable isotope analysis of camelid remains has been applied to studies of animal diet and herding (DeNiro, 1988; Burger & van der Merwe, 1990; Van Buren, 1993; Finucane *et al.*, 2006; Mengoni Goñalones, 2007), and fiber production (Owen, 1993), but these previous studies analysed δ^{13}C and δ^{15}N values exclusively. In the present study, strontium isotope ratios (^{87}Sr/^{86}Sr), measured in a subset of camelid bone samples, serve as an independent test of herding location by identifying the primary geologic region where an animal fed. Analysis of ^{87}Sr/^{86}Sr ratios derived from archaeological camelids has been included in a few studies principally focused on past human migration patterns (e.g. Verano & DeNiro, 1993; Knudson & Buikstra, 2007), but this method has not yet been used to study camelid trade and pastureland location.

Our data suggest that bone isotopic signatures can be used to identify broad-scale differences in the elevational habitat in which some camelids were pastured in the Osmore region. Beyond identifying the diets and herding habitats of camelids, stable isotope analysis has the potential to elucidate the political and economic uses of animals including their use in trade, movement of goods and provisioning. We specifically examine the trade and political implications of identifying camelids whose diets indicate they may have been herded in coastal settings, but whose remains were found in high sierra contexts dating to the Middle Horizon. Results demonstrate that the isotopic analysis of animal remains from other Andean sites might provide insights into herd production as well as trade and exchange and possible political ramifications.

The Osmore Drainage: geographic and ecological setting

The Central Andes presents an appropriate system for exploring the elevation of prehistoric camelid herding through stable isotope analysis due to altitudinal variation in climate, geology and vegetation. The Osmore Drainage ranges from the highlands (3900–5100 masl) near Lake Titicaca to sea level at the Pacific Ocean near Ilo, Peru (Figure 1). Along its course there are significant altitudinal changes in annual precipitation, water regimes and temperature. These climatic changes result in vertically defined ecological and vegetation zones including coastal (0–1000 masl), low sierra (1000–2500 masl), high sierra (2500–4000 masl) and highland *puna* (> 4000 masl) habitats. Mean annual
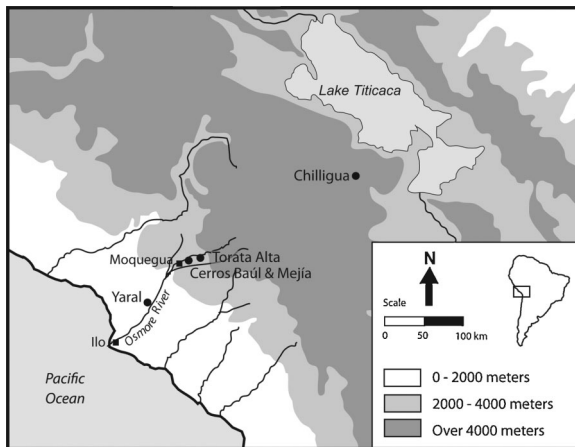
Figure 1. Map of Osmore Drainage, Peru showing elevation, study sites (circles) and modern cities (squares) mentioned in text.

temperature varies according to altitude, ranging from ~18.3°C along the coast to 3.3°C in the highlands.

The amount and sources of water vary within the basin. Most of the drainage's surface water flow originates as seasonal rainfall on the western slopes of the Andes, with only minor contributions from melting snow (ONERN, 1976; Rice 1989). Precipitation is heaviest during January to April with pronounced dryness from June to August. On average, the highlands (ca. 3900–4800 masl) receive ~350 mm of precipitation per year, while coastal areas (ca. 6 masl) receive ~5.3 mm. In the upper elevations of the basin the Osmore River branches into three tributaries, the Otoro, Torata and Tumilaca. At ~1500 masl the three channels unite to form the Osmore or Moquegua River that drains the fertile mid-valley. At ~1000 masl near the distal end of the low sierra habitat the main channel of the Osmore retreats underground (ONERN, 1976; Rice, 1989). A hyperarid gorge characterises the drainage until the river remerges in the coastal river valley at ~400 masl. The coastal valley is steep-sided and narrow, eventually opening to a broader fertile plain ~300 m wide (Owen, 1993). In addition to the main channel, freshwater is available in seeps and springs along the coastal plain, particularly north of the river (Clement & Moseley, 1991).

The coast of southern Peru is hyperarid constituting a central portion of the Peruvian Coastal Desert; therefore, vegetation is very restricted in distribution. In addition to springs, the coast acquires additional moisture from the seasonal accumulation of fog banks during the winter months (May–August). These dense coastal fogs (*garúa*) create seasonal, moisture-dependent *lomas* (small hills) vegetation zones that are characterised by mixed vegetation including scrub, cactus, airplants and wild potatoes (Dillon & Rundel, 1990). At the mouth of the Osmore near Ilo, Peru *lomas* vegetation occurs in a broad band parallel to the coast ranging from ~100 to 1000 masl ranging inland for several kilometers. *Lomas* vegetation can be used as grazing or pasture lands for domesticated camelids. In historic periods introduced Eurasian animals grazed in the lomas and highland camelids were sometimes brought to the lomas to feed, especially after El Niño-induced rainfall which fosters increased vegetation (Murra, 1965; Caviedes, 1975; Masuda, 1985); however, modern camelids have not been observed in the Osmore lomas region for at least the last 25 years. These fog oases were also inhabited by wild camelids, particularly guanacos (*Lama guanicoe*), as well as white-tailed deer (*Odocoileus virginianus*), small mammals (e.g. foxes) and terrestrial birds (e.g. Peruvian thick-knees), but these species are very rare in the Osmore region today.

Isotope analysis and south American camelids: diet and pastureland locations

Paleodietary reconstruction and sourcing of archaeological animal remains is possible because food and water resources vary predictably in the isotopic ratios of consumer tissues. Animals consume plants and water for food and it is the isotopic composition of their food and drink which is incorporated into their biological tissues (hair, skin, bone, tooth enamel, etc.). In this study, the variation in carbon ($^{13}C/^{12}C$), nitrogen ($^{15}N/^{14}N$) and strontium ($^{87}Sr/^{86}Sr$) isotope ratios of camelid bone are explored with respect to isotopic variation of plants, soil and water sources in the Andean highlands and lowlands. Natural variation in isotopic signatures across these ecological zones allows the reconstruction of ancient camelid diet and herding location.

Light stable isotope ratios of carbon and nitrogen are measured using isotope ratio mass spectrometry (IRMS) against the isotopic ratio of a known standard. Stable isotope ratios are reported in delta notation (δ) as parts per thousand (‰, per mil) which constitutes the difference of the sample from a standard reference material as outlined in the following equation:

$$\delta(\%) = [(R_{\text{sample}})/(R_{\text{standard}}) - 1] \times 1000$$

where R is the ratio of the heavier isotope to the lighter isotope. The established standard for stable carbon isotope ratios ($\delta^{13}C$) is Vienna Pee Dee Belemnite (v-PDB) and for stable nitrogen isotope ratios ($\delta^{15}N$) is atmospheric air (AIR).

Strontium is heavier and its ratio $^{87}Sr/^{86}Sr$ is measured using thermal ionisation mass spectrometry (TIMS) and reported as an absolute value against its established standard, NBS-987.

Carbon isotopes

Within terrestrial ecosystems, $\delta^{13}C$ values of the producers (plants) at the base of the foodchain are determined by their photosynthetic pathway (C_3, C_4 or CAM). Calvin-Benson (C_3) plants (e.g. trees, shrubs, root crops, most broadleaf plants and temperate and high altitude grasses) dominate temperate and high elevation environments such as those found in the Central and Southern Andes. C_3 plants produce a 3-carbon molecule during photosynthesis and have $\delta^{13}C$ values ranging from -20 to $-35‰$ with an average of $-27‰$ (O'Leary, 1981). In contrast, Hatch-Slack (C_4) plants produce a 4-carbon molecule and include tropical and arid-adapted grasses such as maize, millet and some amaranths and chenopodiums with less negative $\delta^{13}C$ values ranging from -9 to $-15‰$ (average $= -12.5‰$) (Bender, 1971; Smith & Epstein, 1971; van der Merwe, 1982). CAM (Crassulacean Acid Metabolism) plants including cacti, bromeliads and epiphytes, have $\delta^{13}C$ values intermediate to the $\delta^{13}C$ values of C_3 and C_4 plants because of how these plants store and assimilate CO_2 during day and night (Osmond *et al.*, 1973). Most CAM plants are succulents and do not contribute to camelid diets in the Andes (Bryant & Farfan, 1984; Reiner & Bryant, 1986; San Martin & Bryant, 1989; Genin *et al.*, 1994; Castellaro *et al.*, 2004; Castellaro *et al.*, 2008). Therefore, in terms

of terrestrial plant consumption by camelids, $\delta^{13}C$ values from bone collagen distinguish primarily between C_3 and C_4 plant consumption.

The majority of plants available to foraging camelids in the central and southern Andes follow the C_3 photosynthetic pathway. However, some C_4 plants were also available, depending on foddering practices and pastureland elevation. Archaeological and ethnographic evidence suggests that domesticated camelids may have consumed maize, the only C_4 cultigen available in the region during pre-Hispanic times (Shimada & Shimada, 1985; McCorkle, 1987; Burger & van der Merwe, 1990; Finucane *et al.*, 2006; Mengoni Goñalones, 2007; Bonavia, 2008; Izeta *et al.*, 2009). Maize could have been provided directly to camelids being kept in corrals, or herds could have been pastured on maize stubble after harvest. Wild C_4 grasses such as *Distichlis spicata* (saltgrass), *Eragrostis nigricans* (lovegrass), *Bouteloua simplexi* (matted gramma), *Muhlenbergia* sp. (muhly) and *Sporobolus rigens* (dropseed) are also consumed by wild and domestic camelids (Shimada & Shimada, 1985; Candia & Dealmasso, 1995; Fernandez & Panarello, 1999–2001; Panarello & Fernandez, 2002). With the exception of *Mulenbergia* sp., most C_4 plants in the region are found below 4000 masl (Figure 2). Altitudinal variation in the distribution of C_3 and C_4 plants is influenced by changes in temperature, sunlight and precipitation. In general, the percentage of C_4 plants increases with decreasing altitude due to increases in temperature, irradiance and aridity at lower elevations (Terri & Stowe, 1976; Tieszen, 1979; Ehleringer *et al.*, 1997; Connin *et al.*, 1998). Along altitudinal transects in central Argentina, few C_3 species were found growing
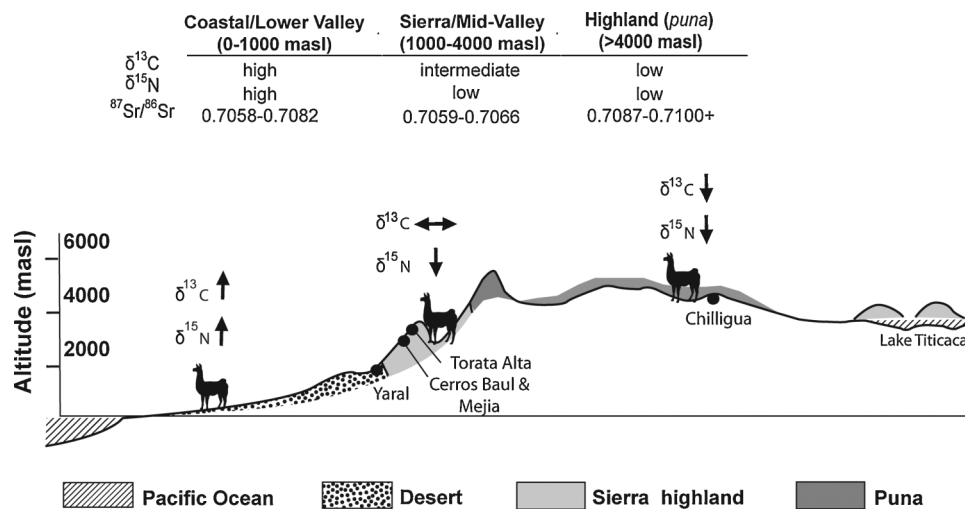

	Coastal/Lower Valley (0-1000 masl)	Sierra/Mid-Valley (1000-4000 masl)	Highland (*puna*) (>4000 masl)
$\delta^{13}C$	high	intermediate	low
$\delta^{15}N$	high	low	low
$^{87}Sr/^{86}Sr$	0.7058-0.7082	0.7059-0.7066	0.7087-0.7100+

Figure 2. Expected $\delta^{13}C$, $\delta^{15}N$ and $^{87}Sr/^{86}Sr$ values according to altitudinal variation within the Osmore Drainage, Peru.

below 1000 masl, and few C_4 grasses were found in high sierra altitudes over 2400 masl (Cavagnaro, 1988; Cabido et al., 1997; Llano, 2009). In the Azapa Valley of northern Chile, which is broadly similar in climate and ecology to the Osmore Drainage, Tieszen & Chapman (1992) also report an absence of C_4 species below 3500 masl.

Camelids feeding on natural pasture vegetation at coastal to low/high sierra elevations (< 3500 masl) therefore have increased access to wild C_4 plants compared to highland *puna* (> 4000 masl) camelids who would feed exclusively on C_3-based diets. Isotopic studies of modern camelids in northwestern Argentina verify that animals feeding on natural forage at lower elevations consume more C_4 vegetation and therefore have less negative $\delta^{13}C$ values. Fernandez & Panarello (1999–2001) report very negative $\delta^{13}C$ signatures (< − 19‰) for camelids feeding over 4000 masl, and less negative $\delta^{13}C$ values (−17.6 to −12.3‰) for individuals feeding below 4000 masl. The same pattern was observed in modern llamas studied by Yacobaccio et al. (2009) with mean $\delta^{13}C$ values of −18.0‰ reported over 3900 masl and −16.4‰ below 3900 masl[1]. No modern data are available for camelids feeding on natural forage at coastal or very low elevations (< 1000 masl) due to the scarcity of wild or domestic camelids in these habitats today. However, vegetation surveys suggest that camelid $\delta^{13}C$ values would be less negative with decreasing altitude.

Although camelids are terrestrial herbivores, it has been suggested that seaweed may also be occasionally eaten by wild guanacos, or provided to domesticated camelids as fodder, especially in coastal areas (Bonavia, 2008: 404; Yesner et al., 2003: 286). Most marine plants utilise the C_3 photosynthetic pathway and have average $\delta^{13}C$ values of −19‰, although less negative values (−12 to −6‰) have been observed in shallow water marine and estuarine species (Schoeninger & DeNiro, 1984; Walker & Deniro, 1986; Keegan & DeNiro, 1988; Ambrose et al., 1997). Limited numbers of modern seaweed specimens collected in northern and central Chile have $\delta^{13}C$ values ranging from −28.7 to −8.3‰, with most of the specimens falling towards the higher end of this range (−17.3 to −11.9‰) (Tieszen & Chapman, 1992; Aufderheide et al., 1994; Falabella et al., 2007). Camelids eating large quantities of seaweed may therefore have elevated carbon signatures similar to individuals consuming a mixed terrestrial C_3/C_4 diet.

Nitrogen isotopes

On average, consumers have $\delta^{15}N$ values 3−4‰ higher than their food resources (DeNiro & Epstein, 1981; Minagawa & Wada, 1984; Schoeninger & DeNiro, 1984; Schoeninger, 1985). Thus, $\delta^{15}N$ values may be used to determine trophic level or the amount of meat consumption in omnivorous and carnivorous species. However, $\delta^{15}N$ values can also be used to study herbivore diets containing nitrogen-enriched plants. They are particularly useful for distinguishing between marine and terrestrial diets because the $\delta^{15}N$ values of marine plants are on average 4‰ higher than terrestrial plants (Schoeninger et al., 1983; Walker & Deniro, 1986). Since carbon isotopes cannot necessarily distinguish between a camelid eating marine plants such as seaweed versus a camelid eating a terrestrial C_4 plant-based diet, $\delta^{15}N$ values provide an important component in camelid dietary reconstruction. To date, most studies of modern and archaeological camelid isotopes only report $\delta^{13}C$ values (for exceptions see: DeNiro, 1988; Tieszen & Chapman, 1992; Verano & DeNiro, 1993; Finucane et al., 2006; Falabella et al., 2007; Mengoni Goñalones, 2007).

$\delta^{15}N$ values also vary by local climate with less positive $\delta^{15}N$ values found in areas with increased rainfall and elevation, and more positive $\delta^{15}N$ values in arid, saline desert regions and in coastal soils (Virginia & Delwiche, 1982; Heaton, 1987; Ambrose, 1991). Terrestrial plants growing within coastal and low elevation portions (< 1000 masl) of the Osmore Drainage are expected, therefore, to have elevated $\delta^{15}N$ values in comparison to terrestrial plants growing at higher altitudes (Figure 2). This expectation is supported by four modern *lomas* plant samples tested as part of this study, which have $\delta^{15}N$ values similar to those reported by Evans & Ehleringer's (1994) study of *lomas* vegetation near the city of Paposo in northern Chile ($\delta^{15}N$ range: 6−12‰). The lomas vegetation overlaps with the normal range of terrestrial plants growing in non-arid or saline soils, but the upper end of this range (> 9‰) may indicate plant response to arid and saline conditions, or the input of ^{15}N from sea spray or fog. Camelids feeding extensively on coastal or low elevation forage should therefore have high $\delta^{15}N$ values in comparison to animals feeding primarily in the high sierra or *puna*.

Cultural practices, such as the use of compost, manure or guano to fertilise soils can also result in plants with higher $\delta^{15}N$ signatures (Mizutani et al., 1991; Choi et al., 2002; Choi et al., 2003; Bol et al., 2005; Commisso & Nelson, 2006; Bogaard et al., 2007). In

---

[1] All modern $\delta^{13}C$ values listed here have been adjusted by +1.5‰ to account for the fossil fuel effect (Friedli et al., 1986; Marino & McElroy, 1991). This adjustment makes the modern isotopic data comparable to archaeological $\delta^{13}C$ values reported in this paper.

some cases, fertilised plants have $\delta^{15}N$ values $> 10‰$ higher than plants grown in untreated soil (Choi *et al.*, 2002). Plants grown in manured or fertilised fields have higher $\delta^{15}N$ values due to the preferential loss of ^{14}N in gaseous ammonia from the organic materials applied to the soil. The remaining ammonia is enriched in ^{15}N and is subsequently converted to nitrate and taken up by plants, which in turn show elevated $\delta^{15}N$ values. Within the Osmore Valley, camelids feeding primarily on manured crops, or in fertilised fields could therefore exhibit elevated $\delta^{15}N$ values.

Strontium isotopes

Strontium isotope ratios ($^{87}Sr/^{86}Sr$) in rock, soil, groundwater and vegetation vary principally by the age and composition of a region's underlying bedrock (Sillen & Kavanagh, 1982; Sealy *et al.*, 1991). As an animal feeds and drinks in a particular area, the local $^{87}Sr/^{86}Sr$ value is recorded in its skeletal tissues. This occurs because Sr substitutes for Ca during mineralisation of bones and teeth (Likins *et al.*, 1960; Nelson *et al.*, 1986). Unlike light stable isotopes (e.g. $\delta^{13}C$, $\delta^{15}N$), $^{87}Sr/^{86}Sr$ is incorporated into animal tissues without fractionation, and $^{87}Sr/^{86}Sr$ signatures do not vary according to a species' size, diet or metabolism (Blum *et al.*, 2000; Price *et al.*, 2002), therefore they closely match local soil, plant and water signatures (Graustein, 1989).

Strontium isotope values recorded in human tooth enamel have been used to study past human migration throughout the Andes (e.g. Knudson, 2004; Knudson *et al.*, 2005; Knudson, 2007, 2008; Knudson & Buikstra, 2007; Knudson & Price, 2007; Knudson & Tung, 2007; Slovak *et al.*, 2009; Turner *et al.*, 2009). Similar methods may be used to identify non-local animals in archaeological contexts. Based on published baseline data for the region, $^{87}Sr/^{86}Sr$ values should broadly distinguish between animals residing primarily in the lower or middle versus upper reaches of the Osmore Valley, as well as those coming from isotopically distinct areas not within the immediate region. According to modern faunal specimens analysed by Knudson and colleagues (Knudson & Buikstra, 2007; Knudson & Price, 2007; Knudson, 2008), local $^{87}Sr/^{86}Sr$ values in the lowest reaches of the Osmore Drainage (near Ilo) (Figure 1) range from 0.7058 to 0.7082. Farther up the drainage (near Moquegua) and the site of Cerro Baúl, local $^{87}Sr/^{86}Sr$ values range from 0.7059 to 0.7067. The Moquegua Valley has a narrower strontium range than that observed near Ilo, but the values still fall within the broader lower

valley range. Due to this overlap, $^{87}Sr/^{86}Sr$ values do not distinguish between camelids herded primarily at lower sierra versus high sierra locations within the Osmore Drainage. However, $^{87}Sr/^{86}Sr$ values in the highland *puna* areas near Lake Titicaca (Figure 1) are distinct from those found at lower elevations in the region. Water samples from Lake Titicaca have $^{87}Sr/^{86}Sr$ values of 0.7082–0.7085 (Grove *et al.*, 2003) while modern fauna from the southeastern Lake Titicaca basin near the site of Tiwanaku have $^{87}Sr/^{86}Sr$ values of 0.7083–0.7112 (Knudson *et al.*, 2005; Knudson & Buikstra, 2007; Knudson & Price, 2007). Slightly higher $^{87}Sr/^{86}Sr$ values (> 0.7120) are observed in areas to the northeast and farther south of Lake Titicaca (Grove *et al.*, 2003; Knudson *et al.*, 2005). All of these baseline data conform to $^{87}Sr/^{86}Sr$ values reported in the geological literature (Hawkesworth *et al.*, 1982; James, 1982; Notsu & Lajo, 1984; Rogers & Hawkesworth, 1989; Carlier *et al.*, 2005).

Since bone apatite remodels over time, $^{87}Sr/^{86}Sr$ values recorded in camelid bone should reflect the average $^{87}Sr/^{86}Sr$ values of the plants and water consumed by the individual over the last several years before death (Ericson, 1985; Sealy *et al.*, 1991). Camelids feeding for extended periods of time on local plants and water in the coastal or lower sierra portion of the Osmore Drainage are expected to have $^{87}Sr/^{86}Sr$ values of 0.7058–0.7082. In this same context, camelids consuming large quantities of marine plants such as seaweed would be expected to show $^{87}Sr/^{86}Sr$ values approaching that of modern seawater ($^{87}Sr/^{86}Sr = 0.7092$) (Veizner, 1989). However, since these camelids would also be drinking from locally available freshwater sources and likely consuming some terrestrial plants their $^{87}Sr/^{86}Sr$ values are expected to fall somewhere in between seawater and the local geological and surface water signature. Camelids feeding and drinking in the high sierra habitats near the sites of Cerro Baúl and Torata Alta, are expected to have $^{87}Sr/^{86}Sr$ values ranging from 0.7059 to 0.7067, while those feeding in the highland *puna* areas in the Lake Titicaca region should have $^{87}Sr/^{86}Sr$ values > 0.7083. Animals moving extensively between the *puna* and low or high sierra portions of the Osmore Valley are expected to have intermediate or mixed $^{87}Sr/^{86}Sr$ signatures. They would still be distinguishable from animals feeding and drinking in one primary region. Based on these expected values, strontium isotopes are most useful for identifying camelids that fed on marine resources, or those animals imported to the coastal or low/high sierra portions of the valley from the *puna* habitats near Lake Titicaca. It is not expected that the Sr results will distinguish between

terrestrially-fed camelids raised on the coast rather than in the low/high sierra due to overlap in the ^{87}Sr/^{86}Sr ranges from these elevational regions.

Camelid diet, altitude and multi-proxy expectations

Since bone remodels at a rate of $\sim$2–10% per year, the isotopic signature recorded in bone reflects the average dietary input over the course of 10–30 years (Ambrose, 1993). Wild and domesticated camelids live on average 10–12 and 15–20 years, respectively (Flannery et al., 1989; Bonavia, 2008). The δ^{13}C, δ^{15}N and ^{87}Sr/^{86}Sr values recorded in their bones should therefore approximate the lifetime dietary average of the individual.

Although some individuals likely moved extensively between habitat zones, camelids habitually feeding on different resources in coastal, low/high sierra or *puna* habitats in the Osmore Drainage should differ in their isotopic signatures based on the underlying geology, surface water, and types of plants available for consumption (Figure 2). Camelids feeding on natural forage for extended periods of time at coastal or low/high sierra altitudes should yield less negative δ^{13}C values than those feeding in the *puna* due to the increased availability of C_4 plants below 4000 masl. However, camelids feeding on maize or marine plants such as seaweed would also be expected to exhibit less negative δ^{13}C values.

Camelids primarily residing at low or coastal elevations would also be expected to have higher δ^{15}N values due to increased aridity, salinity and nitrogen input from sea spray or fog. Animals feeding on marine plants such as seaweed, would also have elevated δ^{15}N values compared to individuals feeding exclusively on terrestrial plants at higher altitudes. The extensive use of compost, manure or guano as crop fertiliser could also raise the δ^{15}N values in camelids feeding primarily on human cultigens, or on weeds growing in fallow fields.

As a final proxy of camelid diet and residency, strontium isotope values should distinguish between camelids pastured primarily in the *puna* versus those being kept in the low/high sierra or near the coast. Mixed isotopic signatures intermediate between the *puna* and sierra or coast would indicate extensive movement of animals between these habitat zones. Elevated strontium values approaching that of modern seawater would also indicate extensive camelid consumption of marine or estuarine plants.

Site and sample descriptions

A sample of 28 archaeological camelids and 5 modern alpacas (Table 1) was analysed for δ^{13}C and δ^{15}N derived from bone collagen. Bones from four archaeological sites and three culture periods were included in the study to assess camelid dietary variation between different time periods and between sites located at different altitudes within the Osmore Valley. In addition, a sample of five modern alpacas from the community of Chilligua (4850 masl) was used to establish baseline δ^{13}C and δ^{15}N data for animals feeding on natural forage in the highland *puna* habitat. Four modern plant samples collected in the coastal *lomas* formations growing near Ilo, Peru were also isotopically assessed for δ^{13}C and δ^{15}N. Strontium isotope analysis was only conducted on archaeological camelid remains from Cerro Baúl.

The archaeological samples for this analysis include camelids from the Middle Horizon Wari sites of Cerro Baúl and Cerro Mejía located in the upper sierra at elevations of 2600 masl and 2450 masl, respectively. Samples are also included from the Late Intermediate Period, Chiribaya culture site of Yaral located at ca. 1000 masl, and the Late Horizon/Early Spanish Colonial site of Torata Alta located at 2700 masl. Although the archaeological samples are all from sites

Table 1. Summary of modern and archeological camelid bone samples

Site	Dates	Elevation (masl)	*Lama glama* N	*Lama pacos* N	*Lama* sp. N	Total
Cerro Baúl	AD 600–1000	2500	3	—	8	11
Cerro Mejía	AD 650–800	2500	—	—	1	1
Yaral	AD 1000–1200	1000	4[a]	2	1	7
Torata Alta	16–17th Century AD	2500	—	1[b]	8	9
Chilligua, Peru	Modern	4850	—	5	—	5
Totals			7	8	18	33

[a] One individual was eliminated from the analysis due to an unacceptable C/N ratio.
[b] Species identification based on metacarpal measurements (Kent 1982).

located in low (1000–2500 masl) and high sierra (2500–4000 masl) settings and none are from coastal (< 1000 masl) archaeological contexts, the data provide preliminary results that can be used to gauge the utility of isotopic analyses to identify past herding locales in the Osmore basin.

Taxonomic identification of archaeological camelids is limited by the difficulty of distinguishing between the four camelid species based on post-cranial osteological evidence alone (Kent, 1982; Wheeler *et al.*, 1995; Aldenderfer, 2001). Although wild camelids cannot be ruled out, the context and general size of the camelids from Cerros Baúl and Mejía and Torata Alta strongly suggest that the camelids were either domesticated llamas or alpacas. The Yaral samples came from complete mummified camelids identified as either llamas or alpacas by Dr Jane Wheeler (San Marcos University, Lima).

Cerro Baúl and Cerro Mejía

The ceremonial/administrative site of Cerro Baúl, along with its smaller associated sites, represents the farthest southern expansion of the Wari Empire during the Middle Horizon (Moseley *et al.*, 1991; Williams, 2001, 2009). Located in the Moquegua middle sierra, Cerro Baúl was constructed on the summit of a large, sheer-sided mesa rising 600 m above the valley floor. The site served as a regional capital for several smaller Wari sites located nearby including Cerro Mejía, a residential and/or craft production site (Nash, 2002). Cerro Baúl's engagement in long distance trade or tribute networks with coastal areas is evidenced by the presence of imported coastal resources such as several species of marine fish and shellfish (Moseley *et al.*, 2005). The Wari occupied Cerros Baúl and Mejía and the upper part of the Osmore Valley from roughly AD 600 to 1000 after which the colony was abandoned (Williams, 2001, 2002, 2006).

Land appropriate for prolonged camelid herding does not appear to be available in the area directly around the site, but Feldman (1989) notes the presence of rectangular, 'corral-like' structures on nearby hillsides that may be contemporaneous with Cerro Baúl. Preliminary zooarchaeological analysis indicates that camelids served as the sites' main source of animal protein (deFrance, 2004; Moseley *et al.*, 2005; Williams *et al.*, 2008). The camelid remains ($n = 12$) used in this study come from various architectural features located on the summits of Cerro Baúl and Cerro Mejía. Only one sample was used from Cerro Mejía because most

camelid bones at the site were burnt, which makes them unreliable and inappropriate for isotopic analysis.

Five of the Cerro Baúl camelids were recovered from a palace complex (Unit 9). Significantly, the camelid bones and other faunal remains found in association with the palace's interior patio may represent the remains of a mortuary feasting event (deFrance & Nash, 2007). Four other camelid samples were excavated from two separate D-shaped temple structures (Units 5 and 10) located southwest of the palace. The final two camelid samples came from Unit 2, a residential structure located northeast of the palace, and Unit 8, a structure situated between the residential and ceremonial sectors of the site (Williams, 2001).

Yaral

Yaral (ca. 1000 masl) is located ∼50 km from the coast at the distal elevation of the low sierra. Dating to ca. AD 1000–1200, the Late Intermediate Period site represents a Chiribaya agricultural settlement established along the lowest reaches of arable land within the Moquegua Valley (Rice, 1993). Faunal remains indicate the importance of camelids to both ritual and subsistence activities at Yaral (Buikstra, 1995; Chávez, 1998). Twenty-six intact, naturally mummified llamas and alpacas were excavated from the floors of domestic structures. Bone samples from seven of the camelid mummies (2 alpacas, 5 llamas) are analysed in this study. Since Chiribaya settlements have only been identified in the coastal and middle valley portions of the Osmore Drainage, camelids herded in the highlands would have been acquired through trade with outside cultural groups. However, an expanse of flat river valley suitable for lower elevation agriculture, or possibly camelid herding, lies just north of the site (Wheeler *et al.*, 1995).

Torata Alta

The Late Horizon/Early Colonial site of Torata Alta (ca. 2700 masl) is situated along the Torata River, an upper tributary of the Osmore Drainage. Although the site may have been established during the Late Horizon (Van Buren, 1993; Van Buren *et al.*, 1993), the faunal materials included here are from 16th century contexts associated with indigenous inhabitants (deFrance, 1993). Extensive prehistoric and modern agricultural terracing surrounds the site where native and introduced crops such as corn, wheat, alfalfa, potatoes and other vegetables are grown (Van

Buren *et al.*, 1993). Zooarchaeological data indicate that camelids were the principal source of dietary protein during the 16th century, and that camelid herds were possibly locally maintained (deFrance, 1993). However, 16th century colonial documents also claim that the residents of the Moquegua Valley (and probably the Torata Valley as well) traded agricultural products for camelids and camelid wool from highland populations living within the Titicaca Basin (Murra, 1965).

Camelid samples ($n = 9$) were selected from proveniences sealed under a layer of volcanic ash deposited during the AD 1600 volcanic eruption of the Huaynaputina volcano. This serves to reduce the possibility that these were camelids fed on C_3 colonial cultigens such as wheat and alfalfa; however, it is still possible that the diet of indigenous animals had shifted to introduced crops. The zooarchaeological data from Torata Alta indicate that juvenile to adult animals were present and butchered on the site, thus suggesting that the animals either were pastured locally or were obtained from herding specialists on the hoof (deFrance, 1993). However, a previous $\delta^{13}C$ analysis of camelid remains from the site conducted concluded that the site's camelids were of highland origin (Van Buren, 1993).

Modern animal and plant samples

Modern alpaca bone specimens ($n = 5$) were collected from *puna* and *bofedales* pasturelands near the town of Chilligua, Peru (4850 masl). At the time of collection, local herds contained only alpacas and no definitive llama remains were available in the local refuse deposits. Since llamas and alpacas feeding in highland pastures are expected to have similar $\delta^{13}C$ and $\delta^{15}N$ values, the modern specimens may be used as comparative data for all of the archaeological camelids. We also analysed four modern *lomas* plant samples collected near the coastal city of Ilo, Peru. The plants include two C_3 plants (*Astragalus triflorus* and *Spergularia congestifolia*) and two C_4 grasses (*Cenchrus humilis* and *Eragrostis peruviana*).

Methods

Sample preparation and analysis was conducted in the University of Florida Bone Chemistry Lab and Stable Isotope Lab in the departments of Anthropology and Geological Sciences, respectively. Bone samples were manually cleaned and sonicated in distilled water

to remove visible dirt and debris. After cleaning, archaeological bone samples were gently crushed with a mortar and pestle. Modern bone samples were resistant to manual breakage and were therefore ground using a Spex 6700 freezer/mill.

Lipids were removed from both modern and archaeological bone samples using a Dionex Accelerated Solvent Extractor (ASE). Samples were infused with petroleum ether, heated to $100°C$, soaked for 5 min, rinsed, and dried with compressed nitrogen. The removal of lipids was a necessary step due to their abundance in well-preserved modern remains and possible presence in archaeological remains. Residual lipids may skew bone collagen $\delta^{13}C$ values by up to 7‰ (Evershed *et al.*, 1995; Liden *et al.*, 1995). Bone collagen isolation procedures for $\delta^{13}C$ and $\delta^{15}N$ isotope analysis followed the methods outlined in previous publications (Ambrose, 1990; Norr, 1995). Sample quality was evaluated using percent collagen yield and atomic C:N ratio (DeNiro, 1985).

Isotopic analysis of organic material (bone collagen and modern plant samples) was conducted on a Finnigan-MAT DeltaPlus isotope ratio mass spectrometer. Precision of analysis was $\pm 0.2‰$ for $\delta^{13}C$ and $\delta^{15}N$. Collagen samples were also combusted in a Carlo Erba NA 1500 CNS elemental analyser to measure the volume of CO_2 and N_2 preserved in the sample. All modern $\delta^{13}C$ values are reported with a $+1.5‰$ correction factor to account for modern enrichment of atmospheric ^{12}C caused by the burning of fossil fuels (Friedli *et al.*, 1986; Marino & McElroy, 1991).

Strontium isotope analysis was done in a class 1000 clean lab in the University of Florida's Department of Geological Sciences. Ground bone samples were pretreated for 30 min in a 5% acetic acid solution to remove post-depositional contaminants, and rinsed to neutral with 4x distilled water. The samples were then transferred to sterile Teflon beakers and hot-digested in 3 ml of 50% HNO_3 (optima). Once digested, the samples were uncapped and left overnight in a sterile laminar flow fumehood to evaporate. Dried samples were re-dissolved in 3.5N HNO_3 the following day and loaded into cation exchange columns packed with strontium-selective crown ether resin to isolate strontium from other ions. Dissolved samples (200 μl each) were added to each column and rinsed through four times with 100 μl of 3.5N HNO_3. After a final rinse with 1ml HNO_3, the isolated strontium as collected in 1.5 ml 4x distilled H_2O. Sample $^{87}Sr/^{86}Sr$ was measured with at Micromass Sector 54 thermal ionisation mass spectrometer (TIMS). Multiple samples of the strontium standard NBS-987 were run to confirm

instrument accuracy. External precision of analysis was ± 0.00002 (2 sigma absolute) based on 314 analyses of NBS-987.

Results

The $\delta^{13}C$, $\delta^{15}N$ and $^{87}Sr/^{86}Sr$ data of the faunal and botanical samples are listed in Table 2. Figure 3 illustrates the faunal sample's $\delta^{13}C$ and $\delta^{15}N$ distribution. The boxes in Figure 3 represent the estimated ranges of herbivore bone collagen based on Tieszen

and Chapman's (1992) modern survey of plant and animal resources in the Azapa Valley of northern Chile. This study provides the best reference sample for the isotopic composition of available plant resources in the Osmore Valley, due to its geographic proximity and similar altitudinal climatic variation. However, the $\delta^{15}N$ range for terrestrial plants has been expanded upwards to account for the elevated $\delta^{15}N$ values (6.3–10.7‰) identified in the four modern *lomas* plants we tested from within the Osmore Valley (Table 2). The elevated plant $\delta^{15}N$ values are likely due to the highly arid and saline soil conditions found in the

Table 2. Stable isotope ratios of modern and archaeological samples from the Osmore Drainage, Peru

Taxon	Unit/feature	$\delta^{13}C$	$\delta^{15}N$	C/N	$^{87}Sr/^{86}Sr$
Cerro Baúl (archaeological):					
Lama sp.	Unit 9B	−10.23	14.27	3.4	0.70587
Lama sp.	Unit 9B	−11.80	12.62	3.4	0.70654
Lama sp.	Unit 9B	−13.34	10.10	3.3	0.70676
Lama sp.	Unit 9B	−16.09	7.59	3.3	0.70685
Lama sp.	Unit 5	−17.32	6.35	3.3	0.70612
Lama sp.	Unit 9	−18.03	7.87	3.3	0.70683
Lama glama	Unit 8	−18.12	9.15	3.3	0.70669
Lama sp.	Unit 10A	−18.62	4.24	3.4	0.71164
Lama glama	Unit 5G	−18.83	7.81	3.3	0.70612
Lama sp.	Unit 2	−19.01	7.10	3.4	0.70660
Lama glama	Unit 5G	−19.53	4.65	3.4	0.70638
Cerro Mejía (archaeological):					
Lama sp.	Unit 145	−18.93	6.30	3.3	—
Yaral (archaeological):					
Lama pacos	Feature 314	−17.20	9.79	3.3	—
Lama glama	Feature 227	−18.13	6.96	3.3	—
Lama glama	Feature 235	−18.43	7.77	3.3	—
Lama glama	Feature 273	−18.80	7.23	3.3	—
Lama pacos	Feature 317	−19.35	10.25	3.3	—
Lama sp.	Feature 236	−20.44	7.43	3.4	—
Lama glama[a]	Feature 844	−26.41[a]	−1.86[a]	5.4[a]	—
Torata Alta (archaeological):					
Lama sp.	0N/3E	−16.46	4.97	3.2	—
Lama sp.	2N/0E	−17.67	8.23	3.3	—
Lama sp.	0N/1E	−17.84	8.20	3.3	—
Lama sp.	0N/1E	−18.03	7.76	3.3	—
Lama sp.	0N/1E	−18.47	8.78	3.4	—
Lama pacos	0N/4E	−18.49	7.63	3.3	—
Lama sp.	0N/5.5E	−18.66	6.78	3.3	—
Lama sp.	3.5N/1E	−18.83	7.63	3.3	—
Lama sp.	0N/5.5E	−19.69	8.59	3.3	—
Chilligua, Peru (modern):					
Lama pacos	—	−19.46 [b]	5.41	3.3	—
Lama pacos	—	−19.22 [b]	4.99	3.3	—
Lama pacos	—	−19.08 [b]	5.74	3.3	—
Lama pacos	—	−19.00 [b]	5.34	3.3	—
Lama pacos	—	−18.99 [b]	5.20	3.3	—
Lomas plants (modern)—collected near Ilo, Peru:					
Cenchrus humilis	—	−12.02 [b]	6.33	—	—
Eragrostis peruviana	—	−12.11 [b]	8.33	—	—
Astragalus triflorus	—	−22.21 [b]	9.33	—	—
Spergularia congestifolia	—	−22.91 [b]	10.63	—	—

[a] Sample not included in graphs or calculation of means due to an unacceptable C/N ratio.
[b] Modern $\delta^{13}C$ values adjusted by $+ 1.5$ per mil (‰) to account for modern enrichment of atmospheric ^{12}C caused by the burning of fossil fuels (Friedli *et al.*, 1986; Marino & McElroy, 1991).
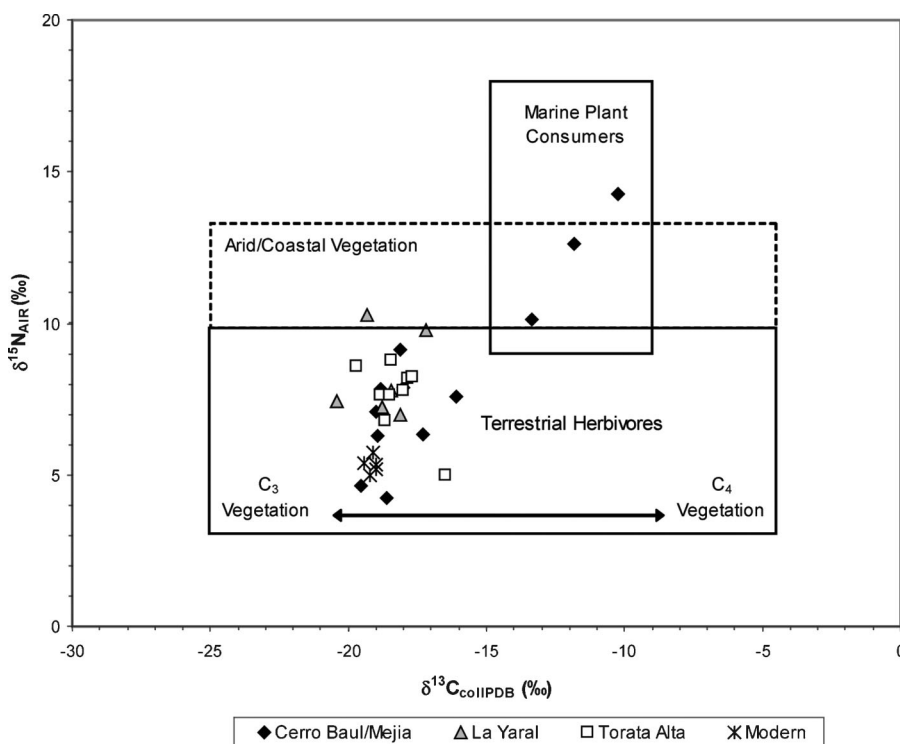
Figure 3. Archaeological and modern $\delta^{13}C$ and $\delta^{15}N$ values from bone collagen. Isotopic ranges denoted by solid lines are based on Tieszen & Chapman (1992). Dotted lines represent extended $\delta^{15}N$ ranges based on modern lomas plants tested from within the Osmore Drainage.

lower reaches of the drainage. Table 3 and Figure 4 draw comparisons between the current dataset and previously published $\delta^{13}C$ and $\delta^{15}N$ values from South American camelids. $^{87}Sr/^{86}Sr$ values for archaeological camelids from Cerro Baúl are presented in Figure 5.

Carbon and nitrogen isotopes

The Cerro Baúl camelids have $\delta^{13}C$ values ranging from -19.53 to $-10.23‰$ ($\bar{x} = -16.45‰ \pm 3.2$). The single camelid from Cerro Mejía has a $\delta^{13}C$ value of $-18.93‰$. Most of these individuals have $\delta^{13}C$ values consistent with a diet of mainly C_3 vegetation but three camelids from Cerro Baúl have significantly less negative $\delta^{13}C$ values (-13.34 to $-10.23‰$) indicating a mixed C_3/C_4 diet and/or consumption of marine vegetation. Yaral camelid results are more homogeneous with $\delta^{13}C$ values ranging from -20.44 to $-17.20‰$ ($\bar{x} = -18.73‰ \pm 1.1$), within the range of terrestrial C_3 herbivores. Camelids from Torata Alta have $\delta^{13}C$ values similar to those from Yaral, ranging from -19.69 to $-16.46‰$ ($\bar{x} = -18.24‰ \pm 0.9$). In a previous isotopic study of camelids from Torata Alta,

bone collagen $\delta^{13}C$ ratios ranged between -21.7 to -18.2 ‰ (Van Buren, 1993). Based on their low $\delta^{13}C$ values, all of the camelids in this previous study were interpreted as being pastured in highland *puna* habitats before being transported to Torata Alta shortly before slaughter.

Modern highland alpacas exhibit little variation in $\delta^{13}C$ value, ranging between -19.46 to $-18.99‰$ ($\bar{x} = -19.15‰ \pm 0.2$). The sample's homogeneity may be due to the selection of modern samples from a single flock feeding year-round in a *bofedales* habitat. However, the $\delta^{13}C$ values are similar to data reported by Schoeninger & DeNiro (1982) for modern highland camelids at La Raya Research Station ($\sim$4500 masl) near Cuzco, Peru ($\delta^{13}C = -19.3$ to $-18.7‰$). Overall, modern highland camelids fall within the lower range of $\delta^{13}C$ values, suggesting a greater reliance on C_3 plants.

The three Cerro Baúl camelids with less negative $\delta^{13}C$ values also have elevated $\delta^{15}N$ values between 10.10 and 14.27‰. This result is supported by a correlation between $\delta^{13}C$ and $\delta^{15}N$ within the Cerro Baúl sample ($r^2 = 0.798$, $p < 0.001$). The remaining nine camelids from Cerro Baúl and Cerro Mejía have $\delta^{15}N$ values between 4.24 and 9.15‰, within the

Table 3. Comparative camelid light stable isotope data from published sources organised by country and publication date

Data Source	Site/Location (Country)	N	Range δ13C	Mean δ13C	SE δ13C	Range δ15N	Mean δ15N	SE δ15N	Age (years BP)	Elevation (masl) or Habitat Zone
Archaeological samples:										
Aufderheide et al. (1988)	Pachamachay and Wari (Peru)	2	−19.5 to −19.8	−19.7	0.1	—	—	—	4500–3750	>3000
DeNiro (1988)	Chilca (Peru)	5	−13.8 to −18.8[a]	−15.4	2.1	7.2 to 15.0[a]	11.0	3.4	2100–260	Coastal
DeNiro (1988)	La Paloma (Peru)	3	−11.4 to −19.4[a]	−15.4	4.0	8.5 to 16.2[a]	12.1	3.9	5800–1200	Coastal
DeNiro (1988)	Pucara (Peru)	18	−16.2 to −19.5[a]	−18.3	1.0	4.5 to 8.4[a]	6.2	1.0	2800–1800	>3000
DeNiro (1988)	Upper Mantaro Valley (Peru)	3	−16.9 to −17.8[a]	−17.4	0.5	6.0 to 6.5[a]	6.2	0.3	800–450	>3000
Burger & van der Merwe (1990)	Chavin de Huantar (Peru)	3	−12.8 to −19.4	−17.0	3.6	—	—	—	2850–2460	3150
Van Buren (1993)	Torata Alta (Peru)	21	−18.2 to −21.7	−19.7	0.9	—	—	—	700–400	2500
Verano & DeNiro (1993)	Pacatnamu (Peru)	9	−9.1 to −16.2	−12.9	2.6	4.5 to 11.1	7.4	2.0	1400–1100	Coastal
Finucane et al. (2006)	Conchopata (Peru)	17	−8.2 to −19.5	−13.0	4.4	4.6 to 9.6	6.6	1.5	1450–1000	2700
Aufderheide et al. (1988)	Northern Chile	1	−17.5	−17.5	—	9.7	9.7	—	1600	Coastal
Falabella et al. (2007)	Central Chile	6	−18.6 to −20.2	−19.5	0.6	4.0 to 6.4	5.0	0.9	1800–1100	Coastal
Olivera & Yacobaccio (1998)	La Puna de Atacama (Argentina)	1	−17.5	−17.5	—	—	—	—	—	2500–4100
Fernandez & Panarello (1999–2001)	Pozuelos (Jujuy, Argentina)	6	−16.1 to −17.4	−16.5	0.5	—	—	—	745–455	3500–3900
Mengoni Gonalons (2007)	Tolombon and Pucara de Volcan (Argentina)	16	−9.0 to −19.0	−14.6	2.4	2.5 to 11.8	6.1	2.5	700–350	1700–2100
Izeta et al. (2009)	Salta Province (Argentina)	4	−11.0 to −19.6	−13.7	4.1	—	—	—	1600–670	Yunga
Izeta et al. (2009)	Catamarca Province (Argentina)	4	−10.1 to −18.3	−15.6	3.8	—	—	—	1990–735	~3000
Modern samples:										
Schoeninger and DeNiro (1982)	La Raya (Peru)	6	−18.7 to −19.3[b]	−19.0[b]	0.2	—	—	—	0	4500
Schoeninger & DeNiro (1984)	Peru	5	−18.7 to 19.1[b]	−19.0[b]	0.2	4.1 to 6.6	5.8	1.0	0	?
Tieszen & Chapman (1992)	Northern Chile	7	−17.0 to −20.6[bd]	−18.4[bd]	1.1	4.0 to 8.9[e]	5.5[e]	1.6	0	>3500
Aufderheide et al. (1994)	Pisagua (Chile)	?	−21.5[bc]	−21.5[b]	—	6.0	6.0	—	0	100
Fernandez et al. (1991)	Jujuy Province (Argentina)	2	−12.6 to −15.3[b]	−14.0[b]	1.9	—	—	—	0	3600–4400
Fernandez et al. (1991)	Jujuy Province (Argentina)	4	−17.7[bc]	−17.7[b]	—	—	—	—	0	4000–4500
Fernandez et al. (1991)	Jujuy Province (Argentina)	5	−17.8[bc]	−17.8[b]	—	—	—	—	0	4000–4700
Olivera & Yacobaccio (1998)	La Puna de Atacama (Argentina)	2	−17.0 to −16.0[ab]	−16.5[b]	0.7	—	—	—	0	2500–4100
Fernandez & Panarello (1999–2001)	Jujuy Province (Argentina)	13	−12.3 to −20.1[bf]	−16.3[bf]	1.9	—	—	—	0	3550–3750
Fernandez & Panarello (1999–2001)	Jujuy Province (Argentina)	18	−17.6 to −20.1[b]	−18.7[b]	0.8	—	—	—	0	4000–4600
Panarello & Fernandez (2002)	Jujuy Province (Argentina)	2	−18.5 to −18.6[b]	−18.5[b]	0.1	—	—	—	0	4500
Yacobaccio et al. (2009)	Cieneguillas and Lapao (Argentina)	12	−15.5 to −17.7[b]	−16.4[b]	0.8	—	—	—	0	3600–3653
Yacobaccio et al. (2009)	Agua Chica and Taire (Argentina)	4	−17.8 to −18.4[b]	−17.8[b]	0.3	—	—	—	0	3940–4021

[a] Values estimated from data plot in publication.
[b] Modern δ13C values reported with a +1.5‰ correction factor to account for modern enrichment of atmospheric ^{12}C caused by the burning of fossil fuels (Friedli et al., 1986; Marino & McElroy, 1991).
[c] Average value cited in original publication, no range of values available.
[d] δ13C values reported from muscle in original publication are presented here +3.7‰ to make the values comparable to bone collagen δ13C values.
[e] δ15N values reported from muscle in original publication are presented here −0.6‰ to make the values comparable to bone collagen δ15N values.
[f] δ13C values for camelid neonates cited in original publication are not included in the sample ranges and averages reported here.
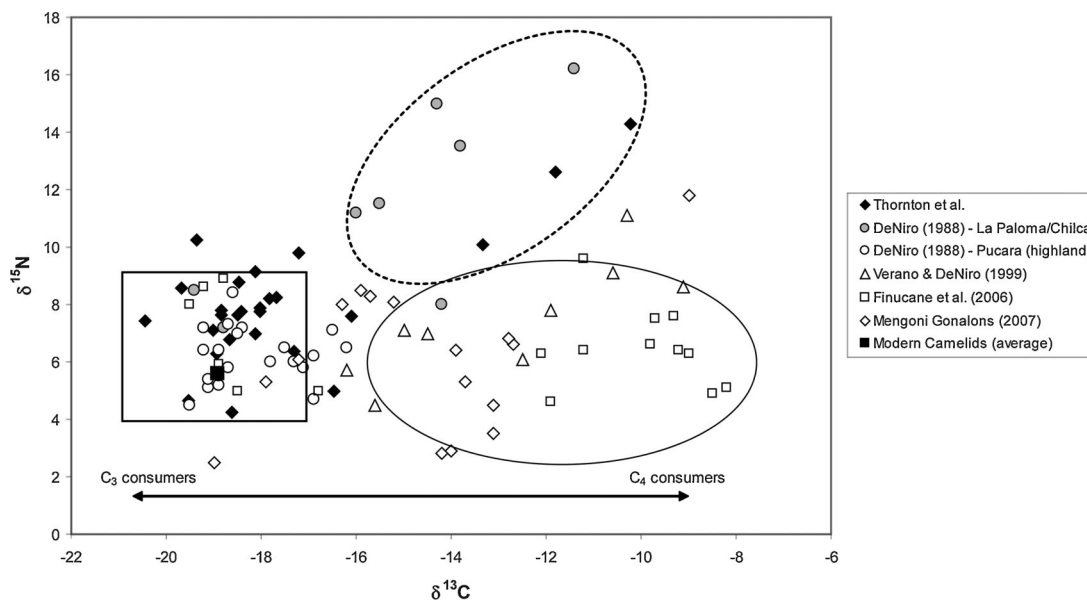
Figure 4. Archaeological camelid bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope ratios from this study compared to those reported from other archaeological sites in Peru and northwestern Argentina. The solid black box designates the isotopic range of modern highland camelids based on our original data and that published by Aufderheide *et al.* (1994), Tieszen & Chapman (1992) and Schoeninger & DeNiro (1984). The dashed circle represents camelids with mixed C_3/C_4 diets and elevated $\delta^{15}N$ values, while the solid circle represents camelids with mixed C_3/C_4 diets and $\delta^{15}N$ values similar to those of modern highland camelids.

estimated range for terrestrial herbivores outside of coastal/low elevation habitats.

Yaral camelids have $\delta^{15}N$ values between 6.96 and 10.25‰, with a mean of 8.24‰ ± 1.41. When combined with the $\delta^{13}C$ results, most of the Yaral camelids fall within the range of C_3 terrestrial herbivores. Two alpacas from Yaral have slightly elevated $\delta^{15}N$ values of 9.79 and 10.25‰, which fall at the lower end of the

expected $\delta^{15}N$ range for herbivores feeding in arid or coastal environments.

Camelids from Torata Alta have more homogeneous $\delta^{15}N$ values than those found at Cerro Baúl or Yaral. Individuals range from 4.97 to 8.78‰ with a mean $\delta^{15}N$ value of 7.62‰ ± 1.16. The highland modern alpacas from Chilligua have significantly lower mean $\delta^{15}N$ values (5.34‰ ± 0.28) than the archaeological samples from Cerro Baúl ($t = 3.22$, $p < 0.01$), Yaral ($t = 4.92$, $p < 0.01$) and Torata Alta ($t = 5.63$, $p < 0.01$).
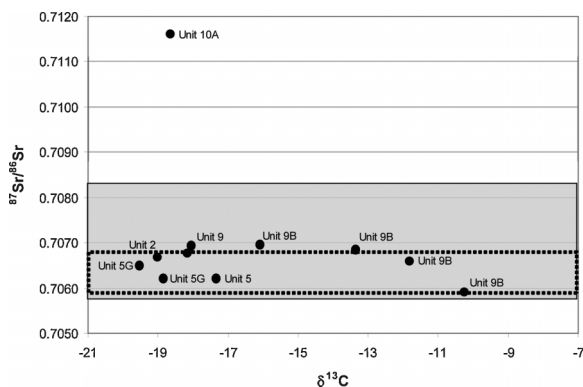

Figure 5. $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ isotope values from Cerro Baúl archaeological camelid bone samples. The shaded grey box represents the local $^{87}Sr/^{86}Sr$ range for the Ilo Valley, while the dashed box represents the $^{87}Sr/^{86}Sr$ range for the Moquegua Valley (based on values from Knudson & Buikstra, 2007; Knudson & Price, 2007; Knudson, 2008).

Strontium isotopes

Ten of the 11 camelids analysed from Cerro Baúl have $^{87}Sr/^{86}Sr$ values within the overlapping local ranges for the Ilo and Moquegua Valleys, which includes both the coastal and low/high sierra portions of the Osmore Drainage (Figure 5). Of these 10 camelids, seven had $^{87}Sr/^{86}Sr$ values within the narrower local range defined for the Moquegua Valley near Cerro Baúl ($^{87}Sr/^{86}Sr = 0.7059–0.7067$). The three camelids from Cerro Baúl with elevated $\delta^{13}C$ and $\delta^{15}N$ values had $^{87}Sr/^{86}Sr$ values of 0.7059, 0.7065 and 0.7068, which identifies them all as local to either the coastal/low sierra portions of the Osmore Drainage near Ilo or the high sierra habitats near Moquegua and Cerro Baúl.

Only a single outlier was identified in the sample ($^{87}Sr/^{86}Sr = 0.7116$). This camelid came from one of two D-shaped temple structures located in the ceremonial sector of the site. Based on its strontium ratio, this camelid was likely imported to the site from somewhere east or south of Lake Titicaca. The individual's $\delta^{13}C$ ($-18.62‰$) and $\delta^{15}N$ ($4.24‰$) values are consistent with an animal pastured for extended periods of time in the highland *puna*.

Discussion

Our results contribute to the growing body of data on isotopic variation in modern and archaeological South American camelids. We interpret the results independently, and in comparison to previous isotopic studies. Methodologically, the results support the potential for using multi-proxy isotopic analyses to reconstruct past camelid diets and herding locations. We also seek to move beyond a purely methodological discussion and towards a cultural interpretation of what the data mean in terms of past political and economic organisation and trade and tribute networks.

Comparative analyses: camelid isotope studies throughout the Andes

The light stable isotope results may be compared to other datasets of archaeological camelids from Peru and northwestern Argentina (Figure 4, Table 3) (e.g. DeNiro, 1988; Verano & DeNiro, 1993; Finucane *et al.*, 2006; Mengoni Goñalones, 2007). The three Cerro Baúl camelids with elevated $\delta^{13}C$ and $\delta^{15}N$ values fall within the upper range of camelids reported by DeNiro (1988) from the coastal sites of Chilca ($2100 - 260$ BP) and La Paloma ($\sim5800 \pm 1200$ BP). The remaining camelids from Cerro Baúl, Cerro Mejía, Yaral and Torata Alta compare best with modern camelids sampled from high elevation habitats (> 3500 masl) in Chile and Peru, and DeNiro's (1988) highland archaeological camelids from the site of Pucara ($\delta^{13}C = -16.2$ to $-19.5‰$; $\delta^{15}N = 4.5$ to $8.4‰$) located in the Lake Titicaca basin. DeNiro (1988) attributes the high $\delta^{13}C$ and $\delta^{15}N$ signatures in camelids at Chilca and La Paloma to the consumption of non-terrestrial resources such as marine plants, or aquatic vegetation growing along lagoons, riverbanks or the shores of saltwater lakes. The use of organic fertiliser on maize fields cannot account for DeNiro's (1988) elevated $\delta^{13}C$ and $\delta^{15}N$ values because maize was not used as a dietary resource at these maritime

adapted sites (Weir & Dering, 1986; Weir, 1988). Also, the camelids identified at La Paloma are thought to be wild guanacos rather than domesticated llamas or alpacas (Reitz, 1988) and as such, were unlikely to have been feeding in agricultural fields close to human settlements. It is therefore likely the Chilca and La Paloma camelids with high $\delta^{13}C$ and $\delta^{15}N$ values represent individuals feeding on natural forage in coastal or arid, low elevation habitats. Single $\delta^{13}C$ and $\delta^{15}N$ isotopic outliers also appear in the samples reported by Verano & DeNiro (1993) and Mengoni Goñalons (2007); however, these studies do not address these data points in detail. For example, Verano & DeNiro (1993) use a camelid with high $\delta^{13}C$ and $\delta^{15}N$ values simply as baseline data in their isotopic study on human diet and mobility, and Mengoni Goñalons (2007) interprets elevated $\delta^{13}C$ values as indicative of maize-feeding, but he does not comment on the potential source of the elevated $\delta^{15}N$ value.

Previous studies have also identified archaeological camelids exhibiting elevated $\delta^{13}C$ values that are not accompanied by high $\delta^{15}N$ values (Verano & DeNiro, 1993; Finucane *et al.*, 2006; Mengoni Goñalones, 2007). These camelids appear to have mixed C_3/C_4 diets that were not enriched in ^{15}N due to the use of fertiliser, the consumption of marine plants, or the presence of highly arid and saline growing conditions. These values have been interpreted as a result of maize fodder (Finucane *et al.*, 2006; Mengoni Goñalones, 2007), or mixed C_3/C_4 feeding by camelids on natural forage at elevations below 2500 masl (Verano & DeNiro, 1993; Mengoni Goñalones, 2007). Both the Finucane *et al.* (2006) and Mengoni Goñalons (2007) datasets also contain several camelids with lower $\delta^{13}C$ and $\delta^{15}N$ values similar to modern highland camelids.

At the Wari site of Conchopata, Finucane *et al.* (2006) further use heterogeneity in camelid isotopic signatures to argue for specialised herd management of llamas and alpacas. The authors argue that camelids with elevated $\delta^{13}C$ values are maize-consuming llamas that were herded near site under human control for probable caravan trade. In contrast, all camelids with more negative $\delta^{13}C$ values are alpacas that derive from highland settings where rangestock grazing on C_3 *puna* grasses was the norm. Although this a possible explanation, the interpretations from Conchopata ignore ancient DNA evidence as well as zooarchaeological data indicating extensive patterns of camelid hybridisation in the precolonial past (see Kadwell *et al.*, 2001; Wheeler, 2003; Moore, 2006). Also, because controlled breeding programs collapsed following the conquest, and skeletal pathologies from colonial sites

indicate that Spaniards pushed llamas into more intensive caravan work (deFrance, in press), fine-fleeced llamas, such as those documented at Yaral (Wheeler et al., 1995), ceased to exist. Therefore, the interpretation of alpaca rearing as an exclusive high-land activity for textile production warrants reconsideration.

Several other studies of archaeological camelids can only be partially compared to our data because they do not report $\delta^{15}N$ values (Table 3). As previously mentioned, Van Buren's (1993) sample of pre and postcolonial camelids from Torata Alta had $\delta^{13}C$ values between -21.7 and -18.2‰. Slightly higher $\delta^{13}C$ values have been reported from archaeological sites in northwestern Argentina. In the altiplano of Jujuy, $\delta^{13}C$ ranges from -16.1 to -17.4‰, with the slightly elevated values being attributed to mixed C_3/C_4 feeding on lower elevation forage (< 4000 masl) (Fernandez & Panarello, 1999–2001; Panarello & Fernandez, 2002). Farther to the south, a small sample ($n = 8$) of camelids drawn from seven different archaeological sites had even less negative $\delta^{13}C$ values ranging from -19.6 to -10.1‰ (Izeta et al., 2009). In this study, all but one of the camelids with elevated carbon values (> -15‰) comes from sites located in yungas or mountain rainforest habitats. This makes the dataset less comparable to the high sierra and altiplano or puna samples previously discussed. The authors of this study also do not specify whether they believe the elevated carbon values are indicative of maize foddering, or consumption of wild C_4 plants.

Previous datasets disagree whether less negative $\delta^{13}C$ values in camelids should be attributed to maize consumption, or foraging on wild C_4 vegetation found in coastal or lower elevation habitats. In many cases, the elevated $\delta^{13}C$ values are not accompanied by high $\delta^{15}N$ values. However, certain individuals do appear similar to the three Cerro Baúl camelids with elevated $\delta^{13}C$ and $\delta^{15}N$ values. The possible explanations for variation in camelid $\delta^{13}C$ and $\delta^{15}N$ must be explored in more detail through further isotopic sampling.

Isotopic evidence for camelid diet and herding location within the Osmore Valley

Isotopic variation in archaeological camelids from the Osmore Valley suggests heterogeneity in pre-Hispanic camelid diet, which has implications for prehistoric pastureland locations and foddering practices. Based on modern isotopic sampling, highland camelids pastured primarily on natural forage at altitudes greater than 4000 masl should have low $\delta^{13}C$ values (< -17‰) and

moderate $\delta^{15}N$ values (4–9‰). Twenty-three of the 28 archaeological camelids analysed in this study have $\delta^{13}C$ and $\delta^{15}N$ values indicative of a primarily C_3-based terrestrial diet similar to modern camelids feeding on highland puna vegetation. Five camelids in our sample (three from Cerro Baúl and two from Yaral) have $\delta^{13}C$ values and/or $\delta^{15}N$ values outside the expected range for highland-herded individuals that may be explained by differences in foddering strategy, or altitudinal herding range.

The three camelids with the highest $\delta^{13}C$ and $\delta^{15}N$ values are from the high status Wari administrative centre of Cerro Baúl. The elevated $\delta^{13}C$ values indicate substantial consumption of C_4 and/or marine vegetation, which is incompatible with the natural forage available in the highland puna bunchgrass or bofedales habitats (Bryant & Farfan, 1984; Reiner & Bryant, 1986; San Martin & Bryant, 1989; Genin et al., 1994; Castellaro et al., 2008). These less negative $\delta^{13}C$ values could be derived from substantial consumption of wild C_4 grasses and/or aquatic rushes prevalent at lower elevations, or human-provided foods such as maize or seaweed. Based on the combined $\delta^{13}C$, $\delta^{15}N$ and $^{87}Sr/^{86}Sr$ data, we argue that the three elevated $\delta^{13}C$ values in the Cerro Baúl sample result from long-term coastal or lower elevation grazing. The high $\delta^{15}N$ values in these samples suggest consumption of marine plants such as seaweed, or terrestrial plants enriched in ^{15}N due to coastal or highly arid climatic conditions. However, since none of the Cerro Baúl camelids have $^{87}Sr/^{86}Sr$ ratios indicative of a marine or mixed marine/terrestrial diet, the high $\delta^{15}N$ values in the three Cerro Baúl camelids are more likely due to consumption of terrestrial plants growing in coastal or highly arid regions. Support for this interpretation comes from the fact that high nitrogen values were found in two modern lomas plants collected in the Osmore Valley as part of this study.

Another possible explanation for the anomalous $\delta^{13}C$ and $\delta^{15}N$ values is that the three Cerro Baúl camelids represent animals feeding on maize grown in fields fertilised with guano (marine bird excrement) or manure. Historical documents from the Colonial period report that guano was used as fertiliser in lower and middle valley agricultural fields within the Osmore Valley (Murra, 1965; Julien, 1985). The documents do not mention the use of fertilis in highland contexts, but camelid dung was also likely spread on agricultural fields based on modern ethnographic evidence. However, we reject this explanation because other isotopic studies have identified camelids that may have been maize-fed, but which do not show elevated $\delta^{15}N$ values similar to those found at Cerro Baúl

(Verano & DeNiro, 1993; Finucane *et al.*, 2006; Mengoni Goñalones, 2007). Moreover, if it were common practice to heavily fertilise crops with large amounts of manure, we would expect to see higher $\delta^{15}N$ signatures in human populations throughout the Andes, since humans would be eating both fertilised crops, and animal protein. Although this practice is suggested by Finucane (2007) for the Ayacucho Valley, this interpretation has not been suggested for sites in southern Peru where archaeological human $\delta^{13}C$ and $\delta^{15}N$ values have been studied (e.g. Tomczak, 2003; Knudson, 2004; Knudson *et al.*, 2007; Knudson & Buikstra, 2007; Kellner & Schoeninger, 2008). Therefore, we are confident that the combined $\delta^{13}C$ and $\delta^{15}N$ data from Cerro Baúl indicate herding of select camelids outside of highland *puna* habitats.

Strontium isotope ratios assessed for the Cerro Baúl camelids identified an additional isotopic outlier within the sample. This single non-local $^{87}Sr/^{86}Sr$ value indicates good preservation of a biogenic strontium value in at least one of the camelid samples. Since $^{87}Sr/^{86}Sr$ ratios were measured from bone rather than tooth enamel, which was not available for individuals sampled in this study, there is greater potential for diagenetic contamination from strontium in the burial environment (Nelson *et al.*, 1986; Sealy *et al.*, 1991; Sillen & Sealy, 1995; Koch *et al.*, 1997). However, if the samples were diagenetically altered, we would expect to see completely homogenous $^{87}Sr/^{86}Sr$ values across the entire sample, or more individuals with mixed signatures between the local strontium values and those found outside the region. Since this is not observed, we have confidence that we are measuring intact biogenic strontium signatures.

The non-local $^{87}Sr/^{86}Sr$ value, along with the individual's low $\delta^{13}C$ and $\delta^{15}N$ values, suggest that this individual was pastured somewhere in the highland *puna* habitats east or south of Lake Titicaca near the homeland of the Tiwanaku culture (a Middle Horizon imperial culture contemporary with the Wari who colonised and primarily occupied the middle Moquegua Valley). Since the non-local camelid comes from a D-shaped temple structure in the site's ceremonial sector, the animal may represent a special trade or tribute item brought into the site. The rest of the Cerro Baúl camelids have $^{87}Sr/^{86}Sr$ values broadly indicative of herding locations outside the Lake Titicaca basin. However, due to the high degree of overlap in local $^{87}Sr/^{86}Sr$ values found in the coastal and low and high sierra portions of the Osmore Valley, the data cannot distinguish between camelids herded in these different habitats.

Cultural implications: trade, tribute and political relations

The isotopic heterogeneity of the Cerro Baúl camelids has implications for cultural interpretations regarding Wari trade, tribute and political relations. The occupants of Cerro Baúl appear to be extracting camelid resources from both coastal and highland settlements, possibly in the form of tribute. Camelid resources at this high status administrative site therefore fit into a pattern of extended resource extraction, rather than local production. The possible presence of coastal-herded camelids at this sierra site also suggests the existence of cultural and trade connections between the Wari state and coastal localities. However, the political and social dynamics of the relations that fostered access to camelids from coastal or lower-elevation settlements are not known. All of the possible coastal-herded camelids were recovered from the central patio of an elite palatial residence (Unit 9) constructed in the Wari Ayacuchano style. The three non-local (coastal) camelids may represent a single tribute payment or ritual event, perhaps associated with a diacritical mortuary feast (deFrance & Nash, 2007). In support of this hypothesis, a large quantity of marine fish (NISP = 1358) are present in this context including eight species of finfish of which jack mackerel (*Trachurus murphyi*, NISP = 192) are most numerous. This quantity and diversity of marine fauna is greater than for other similarly elaborate summit contexts (deFrance, 2004). Following the consumption of the camelids, fish and other food items, the residential palace of Cerro Baul was 'ceremonially closed' in ~ AD 800 despite the site remaining in use for roughly 200 years more. Additional analysis is needed to assess whether non-local camelids were imported regularly for general elite and non-elite consumption, or on a more limited basis for high status ritual or tribute payments.

Despite the proximity of Yaral to the coast and its cultural affiliation with complex Late Intermediate Period Chiribaya coastal polities, none of the camelids sampled in this study exhibit isotopic signatures indicative of prolonged coastal herding. The $\delta^{13}C$ values are consistent for llamas and alpacas feeding on C_3 vegetation in highland environments. The slightly elevated $\delta^{15}N$ values of the two alpacas ($\delta^{15}N = 9.79$, 10.25) require further explanation. These samples could indicate lower elevation herding either on the coast or near the site of Yaral, even though they are not coupled with elevated $\delta^{13}C$ values. It is possible that these individuals were eating primarily C_3 vegetation growing in highly arid areas of the coast or low sierra. Alternative explanations for

the elevated $\delta^{15}N$ values include the use of organic fertiliser on fields of C_3 crops used to feed or pasture the animals, or substantial movement of these individuals between resource zones.

Other lines of archaeological evidence from the site of Yaral, including camelid mortality profiles and stomach content analysis, suggest local systems of pastoral production. Zooarchaeolgical analysis found camelids of all age classes (fetal, neonates, juveniles and adults) present in the Yaral assemblage (Rofes Chávez, 1998). Moreover, the stomachs of mummified camelids found at the site contained low sierra vegetation found at or near the site of Yaral (Jane Wheeler, Personal Communication). Together, the faunal data and the stomach contents strongly suggest that camelids were herded on-site. However, stomach content data only represent short-term dietary patterns, while bone stable isotopes record the lifetime average of an individual's diet. It is therefore possible that the sacrificial Yaral camelids were pastured at higher elevations and kept for a shorter period of time at Yaral's lower-middle valley location before being sacrificed. Although it is possible that the complete sacrificial camelids analysed for this study originated from a different source than those used for dietary purposes at the site, it is also possible that the diets of camelids feeding in low sierra habitats near Yaral are isotopically indistinguishable from the diets of camelids feeding in the high sierra or *puna*. Additional multi-proxy isotopic analysis of modern plants as well as archaeological camelids from sites ranging from coastal to high sierra should resolve this question. In particular, it would be useful to test the $\delta^{13}C$ and $\delta^{15}N$ values of camelids from low elevation sites such as Chiribaya Alta, where Knudson & Buikstra (2007) report $^{87}Sr/^{86}Sr$ values and conclude that some camelids were herded locally, rather than imported from the highlands.

The majority of the deposits from Torata Alta date to the late 16th century period of cultural upheaval following the Spanish conquest. Although the site may have functioned as a colonial *reducción* where the native population was forced to resettle in conjunction with the disruption of traditional agro-pastoral economic systems, the sample of Torata Alta camelids shows the least amount of isotopic variability. The samples conform more closely to the expected isotopic range of highland camelids than the samples from either Yaral or Cerro Baúl. A preliminary analysis of $\delta^{13}C$ values of camelid bones from Torata Alta by Van Buren (1993) concludes that the site's camelids were likely drawn from highland (*puna*) populations. Along with the results presented here, these isotopic data support

historical accounts describing the exchange of middle valley agricultural products for domesticated camelids pastured in the altiplano (Murra, 1965). However, as previously discussed, it may not be possible to distinguish between camelids feeding in the high sierra versus *puna* if middle valley camelids feed almost exclusively on C_3 vegetation. Zooarchaeological evidence lends some support to the possibility that camelids were herded on-site at Torata Alta without resulting in anomalous isotopic signatures. Camelid faunal remains analysed by deFrance (1993) included the remains of multiple age classes, including several fetal and juvenile individuals. If camelids only entered the site for use as meat, or as part of caravans, we would expect to find a more homogeneous sample dominated by the remains of young adult individuals. Future $^{87}Sr/^{86}Sr$ ratio analysis of Torata Alta camelids may be able to resolve this question since the residents of Torata Alta may have been trading with herders within the Lake Titicaca basin or elsewhere.

The Osmore camelid isotopic signatures have interesting political ramifications that warrant further investigation. During the Wari period the inhabitants of Cerro Baúl may have traded with coastal populations; however, the inhabitants of the coastal region during the early sequence of the Middle Horizon are not known (Owen, 1993). In addition, any trade between the coast and highlands during Wari times would have traversed the mid-valley which was densely populated with rival Tiwanaku settlements. Since there are no known coastal sites that are contemporaneous with Cerro Baúl we do not know if or what types of sierra products or commodities might have been traded to the coast, or if resources only moved from the coast to the highlands as tribute or for ritual purposes (deFrance, 2004). By Chiribaya times we have no archaeological knowledge of cultural interaction with highland populations other than these isotopic data, which possibly indicate that highland-pastured animals were used by inhabitants of the low sierra. There is no irrefutable evidence for Chiribaya interaction with the contemporary mid-valley inhabitants know as the Estuquiña culture. The Torata Alta samples indicate homogeneity in the camelid population. The Late Horizon and/or Colonial period inhabitants may have been engaged in extensive interactions with Lupaqa populations residing in the Lake Titicaca basin to obtain camelid resources (Murra, 1968; Stanish & Rice, 1989). Ethnohistorical accounts and abundant remains of weaving paraphernalia suggest that the female inhabitants of Torata Alta were required to provide colonial overlords with tribute or taxation demands in the form of textiles (see Van Buren 1993). Therefore,

one might expect the camelid remains to have originated from a variety of locations in contrast to the isotopic signatures indicating relatively uniform highland origins.

Future research and multi-proxy analyses

Additional isotopic studies of modern fauna and vegetation along altitudinal gradients in the Andes may help resolve ambiguity in the isotopic data we currently have for archaeological camelid populations. Future studies of archaeological camelid remains involving multi-proxy analyses of $\delta^{13}C$, $\delta^{15}N$ and $^{87}Sr/^{86}Sr$ ratios have great potential to identify past camelid diets and where camelids were herded. Other isotopic proxies of climate (e.g. oxygen), residence (e.g. lead) and marine product consumption (e.g. sulphur) could also greatly expand our understanding of these issues. To address the key question of camelid mobility, it is also necessary for future studies to compare isotopic values between tissues such as tooth enamel, which forms early in life and does not remodel, with bone collagen and bone apatite, which record average dietary intake over the lifetime of an individual. Cold and/or highly arid conditions in the Andes also provide additional possibilities for the isotopic sampling of materials such as hair, skin and scat, which often do not preserve in archeological contexts.

Conclusions

Stable carbon, nitrogen and strontium isotope ratios of camelid remains from four archaeological sites located in the Osmore Valley of southern Peru suggest that past camelids were pastured both in the highlands and on the coast beginning in the Middle Horizon. However, a site's proximity to the coast does not necessarily correspond to the source of its camelid resources. The Yaral data indicate that the coastal-oriented Chiribaya culture obtained camelids from the highlands, as did the Late Horizon sierra residents of Torata Alta. In contrast, Wari elites living at the sierra site of Cerro Baúl imported select camelids from the coast and the highland, including one from the Lake Titicaca region. These data support previous isotopic and zooarchaeological research in the Osmore region suggesting the expansion of camelid herding to habitats outside of the highlands, thus raising significant questions regarding pre-Hispanic land use, and

the nature of political relationships, trade and tribute between coastal and highland settlements.

Methodologically, this study demonstrates the use of multiple isotopic proxies as a promising means of distinguishing between camelids pastured in highland and coastal environments, here focused on $\delta^{13}C$, $\delta^{15}N$ and $^{87}Sr/^{86}Sr$ data derived from camelid bone. Less direct evidence for lower elevation herding, such as the presence of mortuary sacrifices, corral structures, dung heaps and zooarchaeological remains does not provide information regarding whether the animals were herded on-site, or imported from the highlands and tended for a shorter period of time before slaughter. In contrast, isotopic studies are able to identify animals that were herded in one habitat zone for a significant portion of their lives before possibly being transported to another shortly before or after slaughter. Additional isotopic analyses in other areas of the Andes may be able to identify the temporal and spatial extent of pre-Hispanic coastal or low/high sierra herding.

Distinguishing between camelids pastured in low or middle sierra locations versus *altiplano* (*puna*) habitats may be more difficult due to greater overlap in the temperature ranges, and plant $\delta^{13}C$ and $\delta^{15}N$ values found at these varied elevations. Camelids feeding at sierra and *altiplano* locations may therefore differ in their isotopic ratio by only a few per mil (‰) making it difficult to formulate a finer-grained assessment of the elevation of camelid herding beyond a coastal-highland dichotomy. More botanical research is needed to quantify the degree of isotopic separation between the plant and water resources available in coastal, sierra and *puna* habitats.

The isotopic variation found in these camelid remains also has implications for human paleodietary studies. As a domesticated animal, camelids may have diets that are highly modified by human intervention, thus yielding unexpected isotopic signatures. Camelids are assumed to be terrestrial C_3 food resources, but consumption of some individuals may in fact contribute C_4, or marine-like $\delta^{13}C$ and $\delta^{15}N$ signatures to human bone collagen. Greater knowledge of the range of isotopic variation of this important dietary resource is suggested to further refine human dietary isotope interpretations.

Future research that combines multiple lines of archaeological evidence including animal and human isotopes, zooarchaeology and habitats of animal rearing and corralling has the greatest potential to elucidate past herding practices and camelid management strategies. As more regional research is conducted in circumscribed geographic areas such as this one and more samples from different cultural periods are

amassed, researchers will be able to reconstruct spatial as well as diachronic changes in Andean herding practices.

Acknowledgements

References

Aldenderfer M. 2001. Andean pastoral origins and evolution: the role of ethnoarchaeology. In *Ethnoarchaeology of Andean South America: Contributions to Archaeological Method and Theory* Kuznar LA (ed.). International Monographs in Prehistory: Ann Arbor; 19–30.

Ambrose SH. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* **17**: 431–451.

Ambrose SH. 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* **18**: 293–317.

Ambrose SH. 1993. Isotopic analysis of paleodiets: methodological and interpretive considerations. In *Investigations of Ancient Human Tissue* Sandford MK (ed.). Gordon and Breach Science Publishers: Langhorne, PA; 59–130.

Ambrose SH, Butler BM, Hanson DB, Hunter-Anderson RL, Krueger HW. 1997. Stable isotopic analysis of human diet in the Marianas Archipelago, western Pacific. *American Journal of Physical Anthropology* **104**: 343–361.

Aufderheide AC, Kelley MA, Rivera M, Gray L, Tieszen LL, Iverson E, Krouse HR, Carevic A. 1994. Contributions of chemical dietary reconstruction to the assessment of adaptation by ancient highland immigrants (Alto Ramirez) to coastal conditions at Pisagua, North Chile. *Journal of Archaeological Science* **21**: 515–524.

Aufderheide AC, Tieszen LL, Allison MJ, Wallgren J, Rapp GJ. 1988. Chemical reconstruction of components in complex diets: a pilot study. In *Diet and Subsistence: Current Archaeological Perspectives: Proceedings of the Nineteenth Annual Conference of the Archaeological Association of the University of Calgary* Kennedy BV, LeMoine GM (eds). University of Calgary Archaeology Association: Calgary; 301–306.

Bender MM. 1971. Variations in the $^{13}C/^{12}C$ ratios of plants in relation to the pathway of photosynthetic carbon dioxide fixation. *Phytochemistry* **10**: 1239–1244.

Blum J, Taliaferro E, Weisse M, Holmes R. 2000. Changes in Sr/Ca, Ba/Ca, and $^{87}Sr/^{86}Sr$ ratios between trophic levels in two forest ecosystems in the northeastern USA. *Biogeochemistry* **49**: 87–101.

Bogaard A, Heaton THE, Poulton P, Merbach I. 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* **34**: 335–343.

Bol R, Eriksen J, Smith P, Garnett MH, Coleman K, Christensen BT. 2005. The natural abundance of ^{13}C, ^{15}N, ^{34}S and ^{14}C in archived (1923–2000) plant and soil samples from the Askov long-term experiments on animal manure and mineral fertilizer. *Rapid Communications in Mass Spectrometry* **19**: 3216–3226.

Bonavia D. 2008. *The South American Camelids*. Cotsen Institute of Archaeology Press, University of California: Los Angeles.

Bryant FC, Farfan RD. 1984. Dry season forage selection by alpaca (Lama pacos) in southern Peru. *Journal of Range Management* **37**: 330–333.

Buikstra J. 1995. Tombs for the living or for the dead: the Osmore ancestors. In *Tombs for the Living: Andean Mortuary Practices* Dillehay TD (ed.). Dumbarton Oaks: Washington, DC; 229–280.

Burger RL, van der Merwe N. 1990. Maize and the origin of Chavin civilization: an isotopic perspective. *American Anthropologist* **92**: 85–95.

Cabido M, Ateca N, Astegiano ME, Anton AM. 1997. Distribution of C_3 and C_4 grasses along an altitudinal gradient in central Argentina. *Journal of Biogeography* **24**: 197–204.

Candia R, Dealmasso AD. 1995. Dieta del guanaco (*Lama guanicoe*) y productividad del pastizal en la Reserva La Payunia, Mendoza (Argentina). *Multequina* **4**: 5–15.

Carlier G, Lorand JP, Liégeois M, Soler P, Carlotto V, Cárdenas J. 2005. Potassic-ultrapotassic mafic rocks delineate two lithospheric mantle blocks beneath the southern Peruvian altiplano. *Geology* **July**: 601–604.

Castellaro GG, Squella NF, León CF, Raggi SA. 2008. Botanical composition of alpaca (*Lama pacos* Linn.) diet in a central Mediterranean range of Chile. *Chilean Journal of Agricultural Research* **68**: 136–145.

Castellaro GG, Ullrich RT, Wackwitz B, Raggi SA. 2004. Composición botánica de la dieta de alpacas (*Lama pacos* L.) y llamas (*Lama glama* L.) en dos estaciones del año, en praderas altiplánicas de un sector de la Provincia de Parinacota, Chile. *Agricultura Técnica (Chile)* **64**: 353–364.

Cavagnaro JB. 1988. Distribution of C_3 and C_4 grasses at different altitudes in a temperate arid region of Argentina. *Oecologia* **76**: 273–277.

Caviedes CN. 1975. El Niño 1972: its climatic, ecological, human and economic implications. *Geographical Review* **65**: 493–509.

Chávez JR. 1998. *Utilización de Recursos Faunísticos en El Yaral, Asentamiento Chiribaya en la Cuenca del Osmore, Sierra Baja de Moquegua*. Tésis de Licenciado en Arqueología, Pontificia Universidad: Católica del Perú: Lima.

Chepstow-Lusty AJ, Frogley MR, Bauer BS, Leng MJ, Cundy AB, Boessenkool KP, Gioda A. 2007. Evaluating socioeconomic change in the Andes using oribatid mite abundances as indicators of domestic animal densities. *Journal of Archaeological Science* **34**: 1178–1186.

Choi W-J, Lee S-M, Ro H-M, Kim K-C, Yoo S-H. 2002. Natural ^{15}N abundances of maize and soil amended with urea and composted pig manure. *Plant and Soil* **245**: 223–232.

Choi W-J, Roa H-M, Hobbie EA. 2003. Patterns of natural ^{15}N in soils and plants from chemically and organically fertilized uplands. *Soil Biology and Biochemistry* **35**: 1493–1500.

Clement CO, Moseley ME. 1991. The spring-fed irrigation system of Carrizal, Peru: a case study of the hypothesis of agrarian collapse. *Journal of Field Archaeology* **18**: 425–443.

Commisso RG, Nelson DE. 2006. Modern plant δ^{15}N values reflect ancient human activity. *Journal of Archaeological Science* **33**: 1167–1176.

Connin SL, Betancourt J, Quade J. 1998. Late Pleistocene C_4 dominance and summer rainfall in the southwestern United States from isotopic study of herbivore teeth. *Quaternary Research* **50**: 179–193.

deFrance SD. 1993. Ecological imperialism in the South-Central Andes: faunal data from Spanish colonial settlements in the Moquegua and Torata Valleys. *Unpublished Ph.D. Dissertation*, Department of Anthropology, University of Florida, Gainesville.

deFrance SD. 2004. The ordinary and the exotic: Wari diet in Moquegua. *Symposium paper presented at the 69th Annual Meeting of the Society for American Archaeology*, Montreal, Canada.

deFrance SD. (in press). Paleopathology and health of native and introduced animals on southern Peruvian and Bolivian Spanish colonial sites. *International Journal of Osteoarchaeology*. DOI: 10.1002/oa.1074

deFrance SD, Nash DJ. 2007. A final feast: surf and turf at the Wari site of Cerro Baul, Peru. *Paper presented at the 2007 Annual Meeting of the Chacmool Association*, University of Calgary, Canada.

DeNiro MJ. 1985. Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to paleodietary reconstruction. *Nature* **317**: 306–309.

DeNiro MJ. 1988. Marine food sources for prehistoric coastal Peruvian camelids: isotopic evidence and implications. In *Economic Prehistory of the Central Andes* Wing ES, Wheeler JC (eds). BAR International Series: Oxford; 119–129.

DeNiro MJ, Epstein S. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* **45**: 341–351.

Dillehay TD, Nunez LA. 1988. Camelids, caravans, and complex societies in the south-central Andes. In *Recent Studies in Pre-Columbian Archaeology* Saunders NJ, de Montmollin O (eds). BAR International Series: Oxford; 603–634.

Dillon MO, Rundel PW. 1990. The botanical response of the Atacama and Peruvian desert flora to the 1982–83 El Niño event. In *Global Ecological Consequences of the 1982-83 El Niño-Southern Oscillation* Glynn PW (ed.). Elsevier: New York; 478–504.

Ehleringer JR, Cerling TE, Helliker BR. 1997. C_4 photosynthesis, atmospheric CO_2 and climate. *Oecologia* **112**: 285–299.

Ericson JE. 1985. Strontium isotope characterization in the study of prehistoric human ecology. *Journal of Human Evolution* **14**: 503–514.

Evans RD, Ehleringer JR. 1994. Plant δ^{15}N values along a fog gradient in the Atacama Desert, Chile. *Journal of Arid Environments* **28**: 189–193.

Evershed RP, Turner-Walker G, Hedges REM, Tuross N, Leyden A. 1995. Preliminary results for the analysis of lipids in ancient bone. *Journal of Archaeological Science* **22**: 277–290.

Falabella F, Planella MT, Aspillaga E, Sanhueza L, Tykot RH. 2007. Dieta en sociedades alfareras de Chile central: Aporte de análisis de isótopos estables. *Chungara* **39**: 5–27.

Feldman RA. 1989. A speculative hypothesis of Wari southern expansion. In *The Nature of Wari: A Reappraisal of the Middle Horizon Period in Peru* Czwarno RM, Meddens FM, Morgan A (eds). BAR International Series 525: Oxford; 72–97.

Fernandez J, Markgraf V, Panarello HO, Albero M, Angiolini FE, Valencio S, Arriaga M. 1991. Late Pleistocene/Early Holocene environments and climates, fauna, and human occupation in the Argentine altiplano. *Geoarchaeology* **6**: 251–272.

Fernandez JC, Panarello HO. 1999–2001. Isótopos del carbono en la dieta de herbívoros y carnívoros de los Andes Jujeños. *Xama* **12–14**: 71–85.

Finucane BC. 2007. Mummies, maize, and manure: multitissue stable isotope analysis of late prehistoric human remains from the Ayacucho Valley, Peru. *Journal of Archaeological Science* **34**: 2115–2124.

Finucane BC, Agurto PM, Isbell WH. 2006. Human and animal diet at Conchopata, Peru: stable isotope evidence for maize agriculture and animal management practices during the Middle Horizon. *Journal of Archaeological Science* **33**: 1766–1776. DOI: 10.1016/j.jas.2006.03.012

Flannery K, Marcus J, Reynolds RG. 1989. *The Flocks of Wamani: A Study of Llama Herders on the Punas of Ayacucho, Peru*. Academic Press: San Diego.

Franklin WL. 1982. Biology, ecology, and relationship to man of the South American camelids. In *Mammalian Biology in South America* Mares MA, Genoways HH (eds). Pymatuning Laboratory of Ecology: Pittsburgh; 457–488.

Friedli H, Lotscher H, Oeschger H, Siegenthaler U, Stauffer B. 1986. Ice core record of the $^{13}C/^{12}C$ ratio of atmospheric CO_2 in the past two centuries. *Nature* **324**: 237–238.

Genin D, Villca Z, Abasto P. 1994. Diet selection and utilization by llama and sheep in a high altitude-arid rangeland of Bolivia. *Journal of Range Management* **47**: 245–248.

Graustein WC. 1989. $^{87}Sr/^{86}Sr$ ratios measure the sources and flow of strontium in terrestrial ecosystems. In *Stable Isotopes in Ecological Research* Rundel PW, Ehleringer JR, Nagy KA (eds). Springer: New York; 491–512.

Grove MJ, Baker PA, Cross SL, Rigsby CA, Seltzer GO. 2003. Application of strontium isotopes to understanding the hydrology and paleohydrology of the altiplano, Bolivia-Peru. *Palaeogeography, Palaeoclimatology, Palaeoecology* **194**: 281–297.

Hawkesworth CJ, Hammill M, Gledhill AR, van Calsteren P, Rogers G. 1982. Isotope and trace element evidence for late-stage intra-crustal melting in the high Andes. *Earth and Planetary Science Letters* **58**: 240–354.

Heaton THE. 1987. The $^{15}N/^{14}N$ ratios of plants in southern Africa and Namibia. *Oecologia* **74**: 236–246.

Izeta AD, Laguens AG, Marconetto MB, Scattolin MC. 2009. Camelid handling in the meridional Andes during the first millennium AD: a preliminary approach using stable isotopes. *International Journal of Osteoarchaeology* **19**: 204–214.

James DE. 1982. A combined O, Sr, Nd, and Pb isotopic and trace element study of crustal contamination in central Andean lavas. I. Local geochemical variations. *Earth and Planetary Science Letters* **57**: 47–62.

Julien CJ. 1985. Guano and resource control in Sixteenth Century Arequipa. In *Andean Ecology and Civilization: An Interdisciplinary Perspective on Andean Ecological Complementarity* Masuda S, Shimada I, Morris C (eds). University of Tokyo Press: Tokyo; 185–231.

Kadwell M, Fernandez M, Stanley HF, Baldi R, Wheeler JC, Rosadio R, Bruford MW. 2001. Genetic analysis reveals the wild ancestors of the llama and the alpaca. *Proceedings of the Royal Society of London Series B-Biological Sciences* **268**: 2575–2584.

Keegan WF, DeNiro MJ. 1988. Stable carbon and nitrogen isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. *American Antiquity* **53**: 320–336.

Kellner CM, Schoeninger MJ. 2008. Wari's imperial influence on local Nasca diet: the stable isotope evidence. *Journal of Anthropological Archaeology* **27**: 226–243.

Kent JD. 1982. The domestication and exploitation of the South American Camelids: methods of analysis and their application to Circum-Lacustrine archaeological sites in Bolivia and Peru. *Unpublished Ph.D. Dissertation*, Department of Anthropology, Washington University, St. Louis.

Knudson KJ. 2004. Tiwanaku residential mobility in the south central Andes: identifying archaeological human migration through strontium isotope analysis. *Unpublished Ph.D. Dissertation*, Department of Anthropology, University of Wisconsin, Madison.

Knudson KJ. 2007. La influencia de Tiwanaku en San Pedro de Atacama: Una investigación utilizando el análisis de isótopos del estroncio. *Estudios Atacameños: Arqueología y Antropología Surandinas* **33**: 7–24.

Knudson KJ. 2008. Tiwanaku influence in the south central Andes: strontium isotope analysis and Middle Horizon migration. *Latin American Antiquity* **19**: 3–23.

Knudson KJ, Aufderheide AE, Buikstra JD. 2007. Seasonality and paleodiet in the Chiribaya polity of southern Peru. *Journal of Archaeological Science* **34**: 451–462.

Knudson KJ, Buikstra JD. 2007. Residential mobility and resource use in the Chiribaya polity of southern Peru: strontium isotope analysis of archaeological tooth enamel and bone. *International Journal of Osteoarchaeology* **17**: 563–580.

Knudson KJ, Price TD. 2007. Utility of mulitple 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 KJ, Tung TA. 2007. Using archaeological chemistry to investigate the geographic origins of trophy heads in the central Andes: strontium isotope analysis at the Wari site of Conchopata. In *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation* Glascock MD, Speakman RJ, Popelka-Filcoff RS (eds). American Chemical Society: Washington, DC; 99–113.

Knudson KJ, Tung TA, Nystrom KC, Price TD, Fullagar PD. 2005. The origin of the Juch'uypampa cave mummies: strontium isotope analysis of archaeological human remains from Bolivia. *Journal of Archaeological Science* **32**: 903–913.

Koch PL, Tuross N, Fogel ML. 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. *Journal of Archaeological Science* **24**: 417–429.

Likins RC, McCann HG, Possner AS, Scott DB. 1960. Comparative fixation of calcium and strontium by synthetic hydroxyapatite. *Journal of Biological Chemistry* **235**: 2152–2156.

Liden K, Takahashi C, Nelson DE. 1995. The effects of lipids in stable carbon isotope analysis and the effects of NaOH treatment on the composition of extracted bone collagen. *Journal of Archaeological Science* **22**: 321–326.

Llano C. 2009. Photosynthetic pathways, spatial distribution, isotopic ecology, and implications for pre-Hispanic human diets in central-western Argentina. *International Journal of Osteoarchaeology* **19**: 130–143.

Lozada MC, Buikstra JE, Rakita G, Wheeler J. 2009. Camelid herders: the forgotten specialists in the coastal senorio of

Chiribaya, southern Peru. In *Andean Civilization: A Tribute to Michael E. Moseley* Marcus J, Williams PR (eds). Cotsen Institute of Archaeology: Los Angeles; 351–364.

Marino BD, McElroy MB. 1991. Glacial-to-interglacial variations in the carbon isotopic composition of atmospheric CO_2. *Nature* **349**: 127–131.

Masuda S. 1985. Algae collectors and lomas. In *Andean Ecology and Civilization* Masuda S, Shimada I, Morris C (eds). University of Tokyo Press: Tokyo; 233–250.

McCorkle CM. 1987. Punas, pastures and fields: grazing strategies and the agropastoral dialectic in the indegenous Andean community. In *Arid Land Use Strategies and Risk Management in the Andes: A Regional Anthropological Perspective* Browman DL (ed.). Westview Press: Boulder; 57–80.

Mengoni Goñalones, GL., 2007. Camelid management during Inca times in N.W. Argentina: models and archaeozoological indicators. *Anthropozoologica* **42**: 129–141.

Minagawa M, Wada E. 1984. Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between $\delta^{15}N$ and animal age. *Geochimica et Cosmochimica Acta* **48**: 1135–1140.

Mizutani H, Kabaya Y, Moors PJ, Speir TW, Lyon GL. 1991. Nitrogen isotope ratios identify deserted seabird colonies. *The Auk* **108**: 4.

Moore KM. 2006. Camelid pastoralism and early complex society in the southern Lake Titicaca Basin. *Paper presented at the 2006 Meeting of the International Council for Archaeozoology*, Mexico City, Mexico.

Moseley ME, Feldman RA, Goldstein PS, Watanabe L. 1991. Colonies and conquest: Tihuanaco and Huari in Moquegua. In *Huari Administrative Structure: Prehistoric Monumental Architecture and State Government* Isbell WH, McEwan GF (eds). Dumbarton Oaks: Washington DC; 121–140.

Moseley ME, Nash DJ, Williams PR, deFrance SD, Miranda A, Ruales M. 2005. Burning down the brewery: establishing and evacuating an ancient imperial colony at Cerro Baúl, Peru. *Proceedings of the National Academy of Sciences* **102**: 17264–17271.

Mujica E. 1985. Altiplano-coast relationships in the south-central Andes: from indirect to direct complementarity. In *Andean Ecology and Civilization* Masuda S, Shimada I, Morris C (eds). Univerity of Tokyo Press: Tokyo; 103–140.

Murra J. 1968. An Aymara kingdon in 156. *Ethnohistory* **15**: 115–151.

Murra JV. 1965. Herds and herders in the Inca state. In *Man, Culture and Animals: The Role of Animals in Human Ecological Adjustments* Leeds A, Vayda AP (eds). American Association for the Advancement of Science: Washington, DC; 185–216.

Murra JV. 1980. *The Economic Organization of the Inka State.* JAI Press: Greenwich, CT.

Murra JV. 1985. 'El archipelago vertical' revisited. In *Andean Ecology and Civilization* Masuda S, Shimada I, Morris C (eds). Univerity of Tokyo Press: Tokyo; 3–14.

Nash DJ. 2002. The Archaeology of Space: Places of Power in the Wari Empire. *Unpublished Ph.D. Dissertation*, Department of Anthropology, University of Florida, Gainesville.

Nelson BK, DeNiro MJ, Schoeninger MJ, De Paolo DJ. 1986. Effects of diagenesis on strontium, carbon, nitrogen and oxygen concentration and isotopic composition of bone. *Geochimica et Cosmochimica Acta* **50**: 1941–1949.

Norr L. 1995. Interpreting dietary maize from bone isotopes in the New World tropics: the state of the art. In *Archaeology of the Lowland American Tropics: Current Analytical Methods and Applications* Stahl PW (ed.). Cambridge University Press: New York; 198–223.

Notsu K, Lajo JA. 1984. Regional variation of $^{87}Sr/^{86}Sr$ in the late Cenozoic volcanic rocks from southern Peru. *Geochemical Journal* **18**: 241–250.

O'Leary MH. 1981. Carbon isotope fractionation in plants. *Phytochemistry* **20**: 553–567.

Olivera DE, Yacobaccio HD. 1998. Estudios de paleodieta en poblaciones humanas de los Andes del sur a través de isótopos estables. *Actas del V Congreso. Nacional de Paleopatologías. Alcalá La Real, España.* Available at: http:www.ucm.es/info/aep/boletin/actas/24.pdf

ONERN. 1976. *El mapa Ecológico del Perú.* ONERN (Oficina Nacional de Evaluacion de Recursos Naturales), Lima, Peru.

Osmond CB, Allaway WG, Sutton BG. 1973. Carbon isotope discrimination in photosynthesis of CAM plants. *Nature* **246**: 41–42.

Owen BD. 1993. A model of multiethnicity: state collapse, competition, and social complexity from Tiwanaku to Chiribaya in the Osmore Valley, Peru. *Unpublished Ph.D. Dissertation*, Department of Anthropology, University of California, Los Angeles.

Panarello HO, Fernandez JC. 2002. Stable carbon isotope measurements on hair from wild animals from altiplanic environments of Jujuy, Argentina. *Radiocarbon* **44**: 709–716.

Price TD, Burton JH, Bentley RA. 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* **44**: 117–135.

Reiner RJ, Bryant FC. 1986. Botanical composition and nutritional quality of alpaca diets in two Andean rangeland communities. *Journal of Range Management* **39**: 424–427.

Reitz EJ. 1988. Faunal remains from Paloma, an archaic site in Peru. *American Anthropologist* **90**: 310–322.

Rice DS. 1989. Osmore Drainage, Peru: the ecological setting. In *Ecology, Settlement and History in the Osmore Drainage, Peru* Rice DS, Stanish C, Scarr PR (eds). BAR International Series: 545: Oxford; 17–33.

Rice DS. 1993. Late Intermediate Period domestic architecture and residential organization at La Yaral. In *Domestic Architecture, Ethnicity, and Complementarity in the South-Central Andes* Aldenderfer MS (ed.). University of Iowa Press: Iowa City; 66–82.

Rofes Chávez J. 1998. *Utilización de Recursos Faunísticos en El Yaral, Asentamiento Chiribaya en la Cuenca del Osmore, Sierra Baja de Moquegua.* Tésis de Licenciado en Arqueología, Pontificia Universidad: Católica del Perú: Lima.

Rogers G, Hawkesworth CJ. 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.

Rostoworowski de Ciez Canseco M. 1988. *Historia del Tahuantisuyu*. Instituto de Estudios Peruanos: Lima.

San Martin F, Bryant FC. 1989. Nutrition of domesticated South American llamas and alpacas. *Small Ruminant Research* **2**: 191–216.

Schoeninger MJ. 1985. Trophic level effects on $^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios in bone collagen and strontium levels in bone mineral. *Journal of Human Evolution* **14**: 515–525.

Schoeninger MJ, DeNiro MJ. 1982. Carbon isotope ratios of apatite from fossil bone cannot be used to reconstruct diets of animals. *Nature* **297**: 577–578.

Schoeninger MJ, DeNiro MJ. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* **48**: 625–639.

Schoeninger MJ, DeNiro MJ, Tauber H. 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* **220**: 1381–1383.

Sealy JC, van der Merwe NJ, Sillen A, Kruger FJ, Krueger HW. 1991. $^{87}Sr/^{86}Sr$ as a dietary indicator in modern and archaeological bone. *Journal of Archaeological Science* **18**: 399–416.

Shimada M, Shimada I. 1985. Prehistoric llama breeding and herding on the north coast of Peru. *American Antiquity* **50**: 3–26.

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

Sillen A, Sealy JC. 1995. Diagenesis of strontium in fossil bone: a reconsideration of Nelson *et al.*, 1986. *Journal of Archaeological Science* **22**: 313–320.

Slovak NM, Paytan A, Wiegand BA. 2009. Reconstructing Middle Horizon mobility patterns on the coast of Peru through strontium isotope analysis. *Journal of Archaeological Science* **36**: 157–165.

Smith BN, Epstein S. 1971. Two categories of $^{13}C/^{12}C$ ratios for higher plants. *Plant Physiology* **47**: 380–384.

Stanish C, Rice DS. 1989. The Osmore Drainage, Peru: an introduction to the work of Programa Contisuyu. In *Ecology, Settlement and History in the Osmore Drainage, Peru* Rice DS, Stanish C, Scarr PR (eds). BAR International Series: Oxford; 1–14.

Terri J, Stowe L. 1976. Climatic patterns and distributions of C_4 grasses in North America. *Oecologia* **23**: 1–12.

Tieszen LL. 1979. The distribution of C_3 and C_4 grasses and carbon isotope discrimination along an altitudinal and moisture gradient in Kenya. *Oecologia* **37**: 337–350.

Tieszen LL, Chapman M. 1992. Carbon and nitrogen isotopic status of the major marine and terrestrial resources in the Atacama Desert of northern Chile. *Paper presented at the First World Congress on Mummy Studies*, Puerto de la Cruz, Canary Islands, Spain.

Tomczak PD. 2003. Prehistoric diet and socioeconomic relationships within the Osmore Valley of southern Peru. *Journal of Anthropological Archaeology* **22**: 262–278.

Turner BL, Kamenov GD, Kingston JD, Armelagos GJ. 2009. Insights into immigration and social class at Machu Picchu, Peru based on oxygen, strontium, and lead isotope analysis. *Journal of Archaeological Science* **36**: 317–332.

Umire A, Miranda A. 2001. *Chiribaya de Ilo*. Imprenta Eskann: Arequeipa, Peru.

Van Buren M. 1993. Community and empire in Southern Peru: the site of Torata Alta under Spanish rule. *Unpublished Ph.D. Dissertation*, Department of Anthropology, University of Arizona, Tucson.

Van Buren M, Burgi PT, Rice PM. 1993. Torata Alta: a late highland settlement in the Osmore Drainage. In *Domestic Architecture: Ethnicity, and Complementarity in the South-central Andes* Aldenderfer MS (ed.). University of Iowa Press: Iowa City; 136–146.

van der Merwe NJ. 1982. Carbon isotopes, photosynthesis, and archaeology. *American Scientist* **70**: 596–606.

Veizner J. 1989. Strontium isotopes in seawater through time. *Annual Review of Earth and Planetary Science* **1**: 141–167.

Verano JW, DeNiro MJ. 1993. Locals or foreigners? Morphological, biometric and isotopic approaches to the question of group affinity in human skeletal remains recovered from unusual archaeological contexts. In *Investigations of Ancient Human Tissue: Chemical Analysis in Anthropology* Sandford MK (ed.). Gordon and Breach: Langhorne, PA; 361–386.

Virginia RA, Delwiche CC. 1982. Natural ^{15}N abundance of presumed N_2-fixing and non-N_2-fixing plants from selected ecosystems. *Oecologia* **54**: 317–325.

Walker PL, Deniro MJ. 1986. Stable nitrogen and carbon isotope ratios in bone collagen as indexes of prehistoric dietary dependence on marine and terrestrial resources in southern-California. *American Journal of Physical Anthropology* **71**: 51–61.

Weir G. 1988. Preceramic to Early Formative subsistence on the central coast. In *Economic Prehistory of the Central Andes* Wing ES, Wheeler JC (eds). BAR International Series: Oxford; 56–94.

Weir GH, Dering PJ. 1986. The lomas of Paloma: human-environment relations in a central Peruvian fog oasis: archaebotany and palynology. In *Andean Archaeology: Papers in Memory of Clifford Evans* Matos R, Turpin SA, Eling HHJ (eds). Institute of Archaeology, University of California: Los Angeles; 18–44.

Wheeler J. 2003. Evolution and origin of the domestic camelids. *International Lama Registry Report* **8**: 1–9.

Wheeler JC. 1995. Evolution and present situation of the South-American Camelidae. *Biological Journal of the Linnaean Society* **54**: 271–295.

Wheeler JC, Russel AJF, Redden H. 1995. Llamas and alpacas: preconquest breeds and postconquest hybrids. *Journal of Archaeological Science* **22**: 833–840.

Williams PR. 2001. Cerro Baul: a Wari administrative center on the Tiwanaku frontier. *Latin American Antiquity* **12**: 67–83.

Williams PR. 2002. Re-examination of disaster induced collapse in the case of the Andean highland states: Wari and Tiwanaku. *World Archaeology* **33**: 361–374.

Williams PR. 2006. Agricultural innovation, intensification, and sociopolitical development: the case of highland irrigation agriculture on the Pacific Andean watersheds. In *Agricultural Strategies* Marcus J, Stanish C (eds). Cotsen Institute of Archaeology, UCLA: Los Angeles; 309–333.

Williams PR. 2009. Wari and Tiwanaku borderlands. In *Tiwanaku: Papers from the 2005 Mayer Center Symposium* Young-Sanchez M (ed.). Denver Art Museum: Denver; 211–224.

Williams PR, Nash DJ, Moseley ME, deFrance SD, Ruales M, Miranda A, Goldstein D. 2008. Encuentros en el reino Wari. *Boletin de Arqueología PUCP* **9**: 207–232.

Yacobaccio HD, Morales MR, Samec CT. 2009. Towards and isotopic ecology of herbivory in the puna ecosystem: new results and patterns on *Lama glama*. *International Journal of Osteoarchaeology* **19**: 144–155.

Yesner DR, Figuerero Torres, MJ, Guichon RA, Borrerod LA. 2003. Stable isotope analysis of human bone and ethnohistoric subsistence patterns in Tierra del Fuego. *Journal of Anthropological Archaeology* **22**: 279–291.