

Isotopic Evidence for Marine Consumption and Mobility in the Atacama Desert (Quillagua, Northern Chile)

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ABSTRACT Archaeological research in the Atacama Desert has recovered evidence of considerable cultural variability. This variability seems to have increased during the Late Intermediate Period (AD 950–1400). The oasis of Quillagua, located at the margins of the Loa River in northern Chile, between the Andes and the coast (70 km from the Pacific Ocean), has shown important evidence regarding this cultural diversity. The variety in the archaeological evidence found at Quillagua has been interpreted as the result of two different cultural influences at the oasis: the Pica-Tarapacá who occupied the coastal and inland regions to the north of Quillagua and the Atacama who occupied the oasis and fertile areas southeast of Quillagua. Here, we present the results of stable carbon, nitrogen and oxygen isotope analyses of 23 individuals recovered from the *Cementerio Oriente* in Quillagua, in order to test whether the observed cultural variability is also reflected in diet and mobility patterns. Results from carbon and nitrogen isotope measurements indicate the importance of marine protein, as well as a contribution of maize in the diet of some individuals. Four individuals show low $\delta^{18}\text{O}$ values, suggesting a possible highland or non-local origin, whereas values for the remaining individuals are consistent with lowland populations. Together, the results support the idea that the Quillagua oasis represented an important site of interaction between the Tarapacá and Atacama cultures, with close contacts with the coast but also with the presence of individuals from the highlands. Copyright © 2015 John Wiley & Sons, Ltd.

Key words: maize; marine resources; mobility; stable isotope analysis; Atacama Desert

Introduction

The oasis of Quillagua in northern Chile (Figure 1) has a considerable number of archaeological sites with occupations ranging from the Formative period (800 BC–AD 720) to the Late Intermediate Period (LIP) (AD 950–1400) (Gallardo *et al.*, 1993; Agüero *et al.*, 1995; Agüero *et al.*, 1999). One of the best explored sites in the oasis is the *Cementerio Oriente*, which is divided in two sectors, the Upper and the Lower Cemeteries, dated by thermoluminescence to AD 720–900 and AD 1150–1315, respectively (Gallardo *et al.*, 1993). The cemeteries show evidence of cultural contacts between different groups, comprising the

Atacama Culture from the regions close to the Andean highlands, southeast of Quillagua (Schiappacasse *et al.*, 1989; Núñez, 1995) and the Pica-Tarapacá Culture from the lower valleys and coastal plains north of Quillagua (Moragas, 1995; Uribe, 2006). Cultural contact evidence is reflected in funerary variability, notably in the provision of pottery and textiles from different groups (Gallardo *et al.*, 1993; Latcham, 1933, 1938; Agüero *et al.*, 1999).

The archaeological evidence from Quillagua suggests that the oasis served as an important point of interaction (whether for trade of goods or as a habitation site is not yet clear) and acted as a node in a network that connected different ecological zones of the region—the coast, valleys and mountains (Núñez, 1965; Agüero *et al.*, 1999). Because the two cultural groups had somewhat different connections to the coast and highlands, respectively, we expect them to show evidence for those direct connections among a

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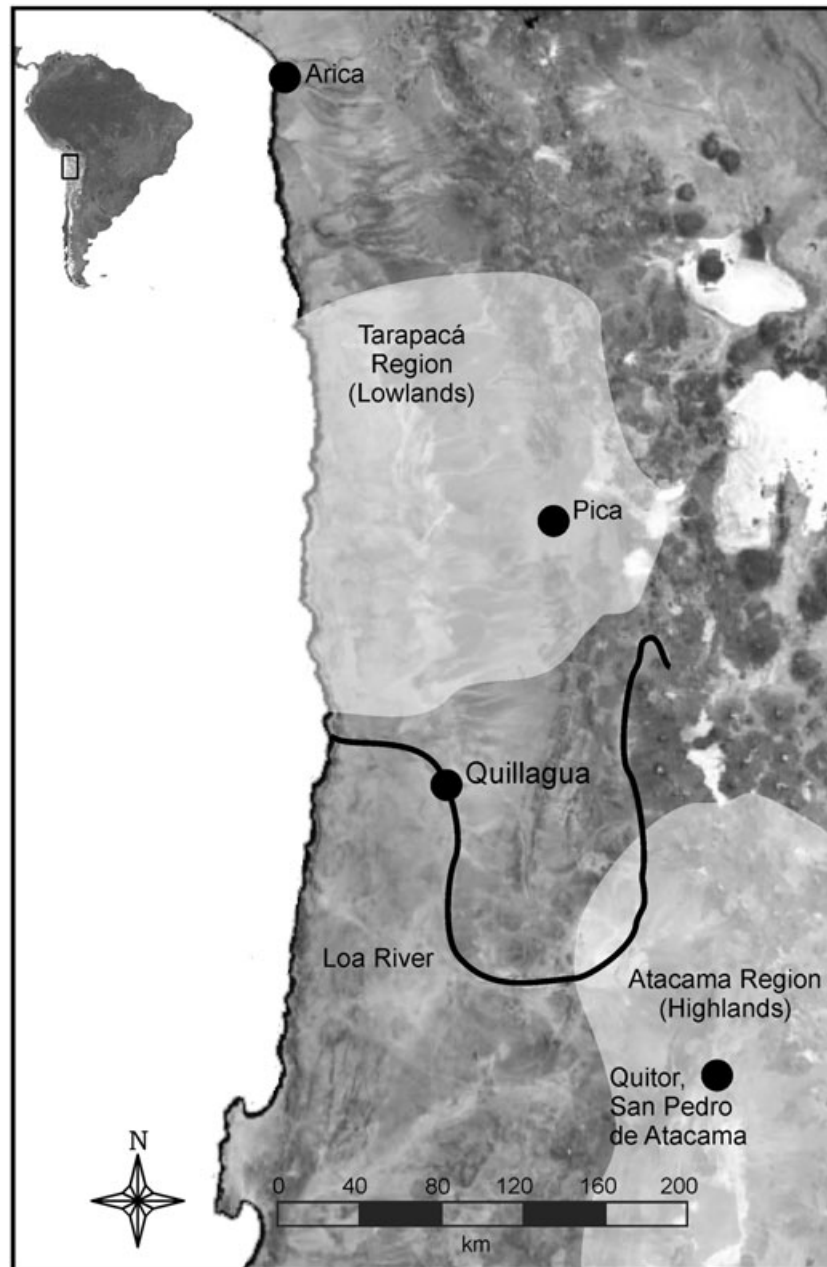


Figure 1. Location of the Quillagua oasis in northern Chile. The Pica-Tarapacá and Atacama cultural areas are also shown in the map.

few individuals at least and also for their diets to have differed. Here we tested the hypothesis that two cultural groups inhabited the Quillagua oasis during the LIP, through stable isotope analysis.

Quillagua oasis: landscape and archaeological background

The oasis of Quillagua (21°S; 69°W) is located in the dry valleys of the Atacama Desert, next to the lower

portion of the Loa River, 70 km away from the coast. The Atacama Desert is the driest desert in the world occupying a long extension of land from southern Peru (18°S) to northern Chile (27°S) (Latorre *et al.*, 2003; Latorre *et al.*, 2005). The extreme hyper arid conditions of the Atacama are mainly caused by the influence of the south Pacific anticyclone, the rain shadow effect of the Andes mountains that acts by blocking the advection of tropical moisture from the Amazon Basin and the influence of the Humboldt

Current (which limits the penetration of Pacific moisture inland, related to its very cold waters) (Gutiérrez et al., 1998, 1989; Latorre et al., 2003; Clarke, 2006; Houston, 2006).

The geographical and hydrological patterns of this desert are quite variable and complex, but they allow for the differentiation of at least four macro eco-geographical zones: coastal fringe or coastal cordillera; valleys and intermediate depressions known as *pampa* (desert landscape); sloping plains or canyons close to the pre-cordillera area (*quebradas* and *pre-cordillera*); and Andes Mountains (*Cordillera de los Andes*), which includes the highland plains (*altiplano*) (Uribe, 2006). From the coast to the Andes, the environment and climatic conditions change as altitude increases.

The Quillagua oasis is located at the intermediate depression or valleys-oases (*pampa*). The *pampa* is characterised by an expanded flat area located between the Coastal Cordillera and the pre-cordillera area at 800–1200 m above sea level (Gutiérrez et al., 1998; Houston, 2006). Rainfall here is almost non-existent being the most arid area in the Atacama Desert (Aravena, 1995; Latorre et al., 2005). There is an almost complete absence of vegetation. However, the presence of groundwater and springs, together with the Loa River, create the conditions for the development of vegetation and fauna, as well as human occupation, in this hyper arid area. The Loa River reaches the sea from the Andes leading to the formation of a series of oases, like Quillagua, Calama and Chiu Chiu. The most frequent flora species found at the Loa River and its oases are *Prosopis alba*, *Atriplex atacamensis* and *Geoffroea decorticans*, together with some shrubs and herbs (Gutiérrez et al., 1998).

The inhabitation of the Quillagua oasis dates from the Formative Period (800 BC–AD 720) to the LIP (AD 950–1450). The LIP represents a moment of intense development of localised, independent societies in the South-Central Andes, which is triggered by two major factors. The first is the collapse of the Tiwanaku State (ca. AD 1000) that influenced the whole South-Central Andes region and organised exchange networks throughout the area during the Middle Horizon (AD 450–1000) (Berenguer and Dauelsberg, 1989). The second is related to a period of relative aridity that may have increased social tensions (Schiappacasse et al., 1989; Zori & Brant, 2012). The result was a considerable expansion in the level of interaction between local groups and neighbour regions, and greater mobility between the coast and the highlands (Schiappacasse et al., 1989; Uribe et al., 2004). However, the ways by which this mobility was organised during the LIP is still under debate

(Murra 1972; Núñez & Dillehay, 1995 [1978]; Briones et al., 2005; Uribe, 2006; Knudson et al., 2010; Pimentel et al., 2011). Some of the classical hypotheses about mobility have proposed the presence of highland colonies in the lowlands, being the highland societies the ones controlling the trade of objects from the coast to the mountains and *vice versa*, complementing resources between the different ecological regions (Murra, 1972); whereas others have suggested that the mobility was dependent on llama caravans, with only a portion of the population actually moving and trading objects (Núñez and Dillehay, 1979).

In this context, the Quillagua oasis has been of longstanding interest to archaeologists because of its long cultural sequence. However, many of the oasis sites have been disturbed and looted by amateurs (Carrasco et al., 2003). Nevertheless, a large LIP cemetery, known as *Cementerio Oriente* (divided in two sectors: Upper and Lower), although being looted as well, has yielded evidence in the form of dispersed skeletal fragments, a few complete skeletons and dispersed grave goods. The *Cementerio Oriente* has been dated through thermoluminescence to between AD 900 and 1150 (Agüero et al., 1997, 1999). The most common grave goods found on the surface from both sectors are foodstuff such as maize (*Zea mays*), quinoa (*Chenopodium quinoa*), wild fruits such as *algarrobo* (*Prosopis* sp.) and dried fish, as well as pottery and textiles (Latcham, 1933, 1938). Based on this evidence, Latcham suggested that subsistence at Quillagua was based on farming, hunting of small game and fishing.

Agüero and colleagues (1999) suggested the presence of distinct cultural styles in the burials, based on the textiles and pottery recovered from both sectors of the cemetery. Many authors have suggested that the oasis functioned as a frontier area between different cultural groups from northern Chile, southern Bolivia, and northwest Argentina, becoming an important node in the regional interaction and exchange network (Vergara, 1901, 1905; Latcham, 1933, 1938; Gallardo et al., 1993; Agüero et al., 1999). Most of the objects found at *Cementerio Oriente* are associated with northern Chile cultural groups known as Atacama and Tarapacá. In fact, Agüero et al. (1999) performed the first and only excavation so far in the Lower sector of the *Cementerio Oriente*. There, they recovered three adult skeletons associated with Pica-Tarapacá pottery and textiles, as well as textiles typical from the Atacama Culture (Agüero et al., 1997, 1999). These are the only three skeletons for which there is information about their burial context.

For this reason, here we investigate whether the presence of objects from the Atacama and Pica-Tarapacá

cultures is also associated with the actual presence of individuals related to these cultural groups. Both cultural traditions had different economic and subsistence activities as well as mobility patterns. The Atacama cultural centre was the San Pedro oases and the Upper Loa River (200 km from the coast; Figure 1). The economy was focused on pastoralism and agriculture activities, with no evidence for exploitation or consumption of marine resources (Schiappacasse *et al.*, 1989; Núñez 1995). The almost complete absence of coastal resources on the diet of the Atacama groups has been reflected on the $\delta^{13}\text{C}$ (bone apatite and bone collagen) and $\delta^{15}\text{N}$ values obtained from bone samples associated with the Quitor 6 cemetery (Santana-Sagredo *et al.*, 2014), also dating to the LIP.

The Pica-Tarapacá cultural groups occupied coastal, inland and pre-cordilleran areas, north of Quillagua (Figure 1), but in all cases with a subsistence economy based on fishing and shellfish gathering, gathering of wild plants and agriculture (Moragas, 1995; Uribe, 2006). The reliance of Tarapacá groups on marine resources and maize has been supported by stable isotope analysis of carbon and nitrogen on individuals from the LIP cemetery Pica 8 (Santana-Sagredo *et al.*, 2014).

The agricultural practices of both groups were based on maize, squash and beans (Schiappacasse *et al.*, 1989; Núñez, 1995; Uribe 2006). Consequently, the main difference in terms of subsistence between the two traditions is the heavier dependence on coastal resources of Tarapacá groups (González, 2006; Uribe, 2006). The differences in their subsistence pattern can be tested using stable carbon and nitrogen isotope analysis of the individuals interred in the Quillagua oasis. Complementing paleodietary reconstruction, we also applied oxygen isotope analysis to explore the geographic origins of the interred individuals.

The archaeological evidence from Quillagua shows the presence of coastal resources (mainly fish) as well as maize (Latham, 1938). The consumption of these types of food can be tracked by the application of carbon and nitrogen isotope analysis on bone collagen (Schoeninger & DeNiro, 1984), but their presence together can be difficult to disentangle. Experimental studies on rats (Ambrose & Norr, 1993) have shown that dietary proteins are preferentially routed to bone collagen. However, marine resources are characterized by having a high protein content and ^{13}C -enriched composition, whereas maize, also ^{13}C -enriched, has low protein content. Thus, in the case of maize its $\delta^{13}\text{C}$ values will be poorly represented in the collagen isotopic composition, especially if there is also consumption of marine resources. By using only the $\delta^{13}\text{C}$ values from bone collagen, it is complicated to

differentiate between a marine diet and the consumption of C_4 plants, because they tend to overlap. Bioapatite $\delta^{13}\text{C}$ values, on the other hand, reflect the entire diet because bioapatite carbonate is formed directly from blood bicarbonate that in turn reflects a combination of all dietary components (lipids, carbohydrates and proteins) (Ambrose & Norr, 1993; Passey *et al.*, 2005). Therefore, we performed stable carbon isotope analysis on bone and tooth apatite, because bioapatite carbonate isotope values should reflect also the non-protein components of diet (Ambrose & Norr, 1993), allowing a better differentiation between maize and marine resources consumption. The use of bone apatite has been controversial because bone apatite is known to be more reactive than well-crystallised enamel and thus more susceptible to diagenesis. However, several studies have shown that the results for subfossil bone apatite from well-preserved material are reliable (e.g. Harrison & Katzenberg, 2003; Lee-Thorp & Sponheimer, 2003; Garvie-Lok *et al.*, 2004).

Oxygen isotopes from tooth and bone apatite will also be considered in this study, following the assumption that $\delta^{18}\text{O}$ values obtained from these tissues will reflect the values of the meteoric water that was consumed by the individuals during their infancy and last years of life, respectively (White *et al.*, 2004; Knudson, 2009). It is expected that oxygen isotopes of water from higher altitudes such as the Andes Mountains present values depleted in ^{18}O , whereas values enriched in ^{18}O are expected for the valleys and coast of the Atacama Desert (Knudson, 2009).

Materials and methods

The samples included in this study are human skeletal remains rescued from the surface of the Upper and Lower sectors of *Cementerio Oriente* during a rescue project performed in 2009. A total of 3900 bone fragments were collected (Upper sector $N = 1820$; Lower sector $N = 2080$). For both sectors of the cemetery, a minimum number of individuals of 114 and 137 were estimated for the Upper and Lower sectors, respectively.

Only 21 articulated skeletons were found, all of which lacked skulls and burial context. Apart from these 21 skeletons found on the surface, three burial contexts were excavated during the fieldwork carried out by Agüero and colleagues (Agüero *et al.*, 1999) and are now kept in the Instituto de Investigaciones Arqueológicas y Museo Gustavo Le Paige, in San Pedro de Atacama, Chile.

Twenty-three samples were taken from the skeletal remains: 10 from the Upper sector and 13 from the Lower

sector (Table 1 and Figure 2). In each sector, eight samples were obtained from long bones and two from teeth (three premolars and one canine). The samples were chosen from left long bones to avoid sampling the same individual. In addition, rib samples were taken from each of the only three articulated skeletons with burial contexts, recovered from the Lower sector. The rest of the samples come from dispersal skeletal remains rescued during fieldwork. For the long bones samples, age was estimated through the evaluation of their secondary centres of ossification (Buikstra and Ubelaker, 1994). Following this, it was possible to identify mainly adult individuals with the exception of one individual, who presents a range of age between 14 and 16 years, approximately. Age estimation of teeth samples was carried out as minimum ages (Buikstra and Ubelaker, 1994), because these were found isolated. Following the development stage of their roots, it was possible to estimate the age of sample I16 (Upper sector) at around 7 years. For the rest of the teeth samples, it was possible to observe that the root formation was complete, suggesting that the individuals were over 15 years old in the cases of samples I7 (Upper sector) and F11 (Lower sector) and over 12 years old for H7 (Lower sector). Although it is also possible that these teeth could be associated with one of the long bones analysed in this work, we believe this to be a remote possibility given the large number of individuals interred at the cemetery and the lack of clear signs of association

between the samples. Sex estimation was only possible in a limited number of cases, because of the disarticulated state of the material (Table 1).

Samples were cleaned, ground, prepared and analysed for carbon, nitrogen and oxygen stable isotope composition in the Cornell University Stable Isotope Laboratory. Samples were taken from bone and dentine collagen, and bone and enamel apatite. Stable oxygen isotopes were analysed from the carbonate fraction of bone and enamel apatite.

Collagen extraction followed an adapted version of the methodology used by Ambrose (1990). Apatite pre-treatment followed the methodology of Koch *et al.* (1997). Internal standards HCRN (corn standard) and trout standard (fish), calibrated against IAEA (International Atomic Energy Agency) standards, were used to calibrate carbon and nitrogen isotope ratios. IAEA standards CO-1 and CO-8 were used for the calibration of oxygen isotopes. Isotope ratios of carbon and nitrogen from collagen were measured on a Thermo Delta V isotope ratio mass spectrometer interfaced to a Gas Bench II. The analytical error was determined as $\pm 0.06\text{‰}$ for carbon and $\pm 0.22\text{‰}$ for nitrogen. Isotopic ratios for carbon and oxygen from apatite were measured on a Thermo Delta V isotope ratio mass spectrometer interfaced to an NC2500 elemental analyser. The analytical error was estimated as $\pm 0.07\text{‰}$ for carbon and $\pm 0.3\text{‰}$ for oxygen isotopes.

Table 1. Samples selected for stable isotope analyses

Sector	Quadrant	Element sampled	Sex	Age
Upper	C9	Humerus	Unknown	Adult
Upper	E10	Tibia	Unknown	Subadult (16 years approximately)
Upper	F8	Femur	Unknown	Adult
Upper	F10	Femur	Unknown	Adult
Upper	K8	Femur	Unknown	Adult
Upper	K16	Femur	Unknown	Adult
Upper	I16	Lower first molar	Unknown	Subadult (7 years approximately)
Upper	I7	Lower second premolar	Unknown	Unknown
Upper	H16 (skeleton 8)	Femur	Unknown	Unknown
Upper	K16 (skeleton 6)	Femur	Male	Adult
Lower	G5	Femur	Unknown	Adult
Lower	H5	Tibia	Unknown	Adult
Lower	H11	Femur	Unknown	Adult
Lower	I11	Tibia	Unknown	Adult
Lower	L4	Femur	Unknown	Adult
Lower	F11	Upper second premolar	Unknown	Unknown
Lower	H7	Upper canine	Unknown	Unknown
Lower	F11 (skeleton 15)	Femur	Female	Adult
Lower	F11 and F10 (skeleton 14)	Femur	Male	Adult
Lower	H11 (skeleton 11)	Femur	Unknown	Adult
Lower	Funerary context 1	Rib	Female	Adult
Lower	Funerary context 2	Rib	Male	Adult
Lower	Funerary context 3	Rib	Female	Adult

With the exception of the funerary contexts (1, 2 and 3), the rest of the samples come from different quadrants of the ossuary.

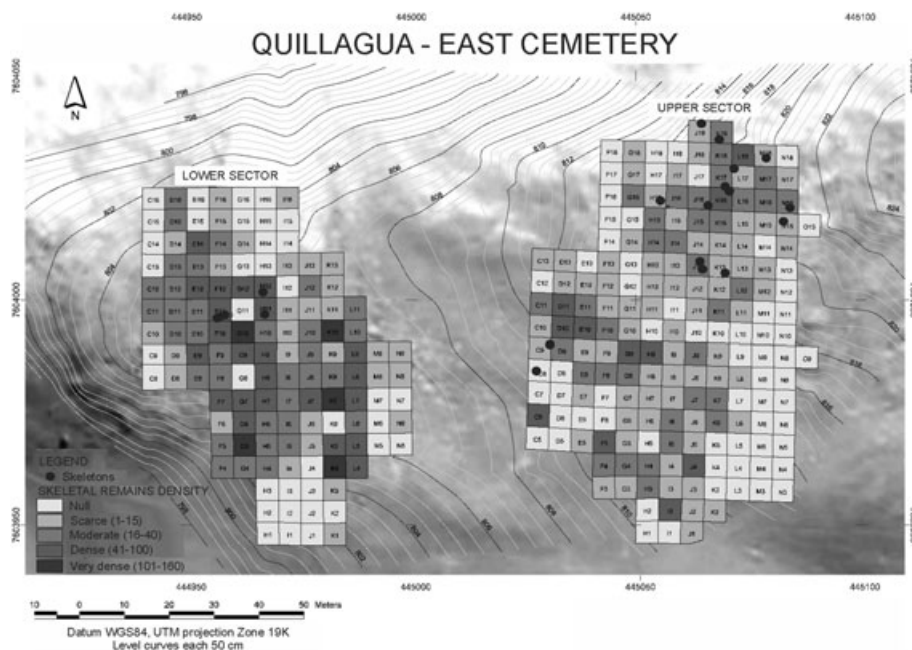


Figure 2. Map of the Upper and Lower sectors of Quillagua's Cementerio Oriente.

All isotope ratios are expressed in the delta (δ) notation relative to international standards, in parts per mil (‰) according the generalised formula

$$\delta X(^0/_{00}) = \left(\frac{\text{Isotope ratio}_{\text{sample}}}{\text{Isotope ratio}_{\text{standard}}} - 1 \right) * 1000$$

where the standards are Vienna Pee Dee Belemnite (VPDB) for $^{13}\text{C}/^{12}\text{C}$, AIR for $^{15}\text{N}/^{14}\text{N}$ and VPDB for $^{18}\text{O}/^{16}\text{O}$ (Sharp, 2007).

We compared the carbon, nitrogen and oxygen stable isotopes composition of the two sectors of *Cementerio Oriente* through the application of descriptive and inferential statistics, the latter using a Mann–Whitney test, because the data were not normally distributed. To explore if individuals clustered in two different groups according to $\delta^{18}\text{O}$ values, individuals were represented in a cluster (Ward's minimum variance method), constructed from the matrix of pairwise absolute differences in $\delta^{18}\text{O}$ between individuals. The significance of the clusters observed was estimated using permutations, given the impossibility of knowing *a priori* if the outlier individuals should be considered as part of the population or not (which affects the calculations of the parameters used to test the null hypothesis in more traditional statistical tests). The difference between the averages of the two clusters was contrasted with a distribution of differences between all possible combinations of the individuals assuming different number of

individuals in the smaller cluster (2–6). This strategy allowed us to test if the results observed in the cluster were statistically significant and if the cluster analysis identified significant clustering patterns. This test is especially important in this case, because clusters can generate imprecise representation of dissimilarity matrices (Hair *et al.*, 2009). The number of combinations of the data that generated differences higher than or equal to the observed clusters were divided by the total of permutations for each set of individuals, and the result provides the probability that the differences observed between cluster can derive from a single population (i.e., that our null hypothesis is wrong). Cluster and permutation analysis were carried out in R (R Core Team, 2013).

Results

Results for both sectors of the cemetery are presented in Table 2 and descriptive statistics in Table 3. Bivariate plots of the data are presented in Figure 3. Three of the 23 samples analysed were discarded because their C/N ratios fell above the accepted range of 2.9–3.6 for well-preserved collagen (DeNiro, 1985; Ambrose, 1990). As can be seen (Figure 3a), values observed for $^{13}\text{C}_{\text{col}}$ are enriched in both sectors of *Cementerio Oriente* with a mean of $-12.5 \pm 1.7\text{‰}$ for both sectors.

The $\delta^{15}\text{N}$ values are remarkably high, averaging $18.6 \pm 4.1\text{‰}$ and $17.9 \pm 3.0\text{‰}$ for the Upper and Lower sectors, and reaching maximum values of 25.1‰ and

Table 2. Isotopic values for the Upper and Lower sectors of Cementerio Oriente, including C/N ratios, %C and %N

Sector	Quadrant	$\delta^{13}\text{C}_{\text{col}}$ VPDB	$\delta^{15}\text{N}_{\text{AIR}}$	$\delta^{13}\text{C}_{\text{ap}}$ VPDB	$\delta^{18}\text{O}_{\text{VPDB}}$	C/N	%C	%N
Upper	C9	-12.3	23.4	-7.5	-4.8	3.3	36.1	12.5
Upper	E10	-12.4	20.4	-7.1	-4.3	3.1	40.8	14.8
Upper	F8	-11.1	20.1	-5.1	-4.7	3.3	43.0	14.8
Upper	F10	-12.5	20.7	-6.1	-4.8	3.9	35.8	10.5
Upper	K8	-12.4	17.3	-6.8	-4.7	3.2	42.5	15.0
Upper	K16	-12.0	15.4	-6.2	-5.6	3.5	37.6	12.4
Upper	I16	-11.4	18.4	-6.0	-4.1	3.1	27.6	10.1
Upper	I7	-16.3	12.5	-10.0	-8.3	3.1	31.0	11.6
Upper	H16 (skeleton 8)	-10.7	14.9	-5.1	-8.4	3.3	38.1	13.3
Upper	K16 (skeleton 6)	-13.8	25.1	-9.8	-5.4	3.3	39.2	13.6
Lower	G5	-11.1	16.7	-5.8	-4.4	3.1	33.5	12.4
Lower	H5	-10.9	20.7	-5.1	-4.6	3.6	35.6	11.4
Lower	H11	-12.1	15.7	-5.5	-5.2	3.7	36.7	11.3
Lower	I11	-11.2	14.4	-5.3	-4.2	3.3	38.7	13.3
Lower	L4	-12.6	22.4	-7.9	-4.9	3.3	39.1	13.3
Lower	F11	-16.8	14.5	-10.7	-10.0	3.1	35.1	13
Lower	H7	-12.8	19.5	-7.7	-4.4	3.2	31.4	11.2
Lower	F11 (skeleton 15)	-12.6	16.7	-7.3	-5.2	3.2	37.8	13.3
Lower	F11 and F10 (skeleton 14)	-11.9	16.3	-6.4	-5.3	3.3	37.9	12.9
Lower	H11 (skeleton 12)	-14.1	17.7	-7.3	-4.7	4.0	37.7	10.7
Lower	Funerary context 1	-13.9	15.7	-7.3	-6.5	3.6	33.6	10.6
Lower	Funerary context 2	-11.4	18.6	-5.9	-6.9	3.6	13.1	4.10
Lower	Funerary context 3	-12.1	16.8	-7.2	-8.3	3.3	33.5	11.3

Samples with bad collagen preservation are shown in italics for the C/N ratios.

22.4‰, respectively. The $\delta^{15}\text{N}$ values are also quite variable. The lowest $\delta^{15}\text{N}$ value (12.5‰) is a tooth (I7) from the Upper sector.

Values obtained for bone apatite are also enriched in ^{13}C (Figure 3b), with the exception of two individuals (K16-6 and I7) from the Upper sector and one from the Lower sector (F11). The averages are very similar, with $-7.1 \pm 1.8\text{‰}$ and $-7.2 \pm 1.8\text{‰}$ for the Upper and Lower sectors, respectively. The lowest values come from two of the four teeth analysed (I7 from the Upper sector and F11 from the Lower sector). These two samples show the lowest values in $\delta^{13}\text{C}_{\text{col}}$, $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{ap}}$ (Figure 3). When the values of $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ were compared between both sectors of the cemetery, no significant differences were observed ($\delta^{13}\text{C}_{\text{col}}$ values

$Z = 0.1522$, $p = 0.8790$; $\delta^{13}\text{C}_{\text{ap}}$ values $Z = 0.1554$, $p = 0.8765$; $\delta^{15}\text{N}$ values $Z = 0.6080$, $p = 0.5432$).

Stable oxygen isotopes are relatively high for most of the samples (Table 3 and Figure 4). Most of the results range from -5.5‰ to -4.1‰ in the Upper sector and -6.9‰ to -4.2‰ for the Lower sector. No significant differences were observed between the two sectors ($Z = 0.2820$, $p = 0.7779$). However, four individuals show low values compared with the others: H16-SK8 (-8.4‰) and I7 (-8.3‰) from the Upper sector, and F11 (-10.1‰) and FC-3 (-8.3‰) from the Lower sector. Two of these individuals (I7 and F11) also show low $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ values. These individuals form a discrete cluster when compared with the other samples (Figure 5), and the differences between clusters are significant; When compared with all possible combinations of two clusters with the smallest composed of two to six individuals in the sample, the four clustered individuals are significantly different than the rest of the individuals ($p = 0.015$ for recombinations of two individuals; $p < 0.0001$ for recombinations of three, four, five and six individuals).

Table 3. Descriptive statistics of isotopic values from the Upper and Lower sectors of Cementerio Oriente

	N	Mean	SD	Max.	Min.
Upper sector					
$\delta^{13}\text{C}_{\text{col}}$	9	-12.5	1.7	-10.8	-16.3
$\delta^{15}\text{N}$	9	18.6	4.1	25.1	12.5
$\delta^{13}\text{C}_{\text{ap}}$	10	-6.7	1.7	-5.1	-10.0
$\delta^{18}\text{O}_{\text{ap}}$	10	-5.6	1.6	-4.1	-8.4
Lower sector					
$\delta^{13}\text{C}_{\text{col}}$	11	-12.5	1.7	-11.0	-16.8
$\delta^{15}\text{N}$	11	17.5	2.5	22.4	14.4
$\delta^{13}\text{C}_{\text{ap}}$	13	-6.9	1.5	-5.1	-10.7
$\delta^{18}\text{O}_{\text{ap}}$	13	-5.8	1.8	-4.2	-10.1

SD, standard deviation.

Discussion

Diet in Cementerio Oriente

The elevated $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ bone collagen values obtained for the Upper and Lower sectors of Cementerio

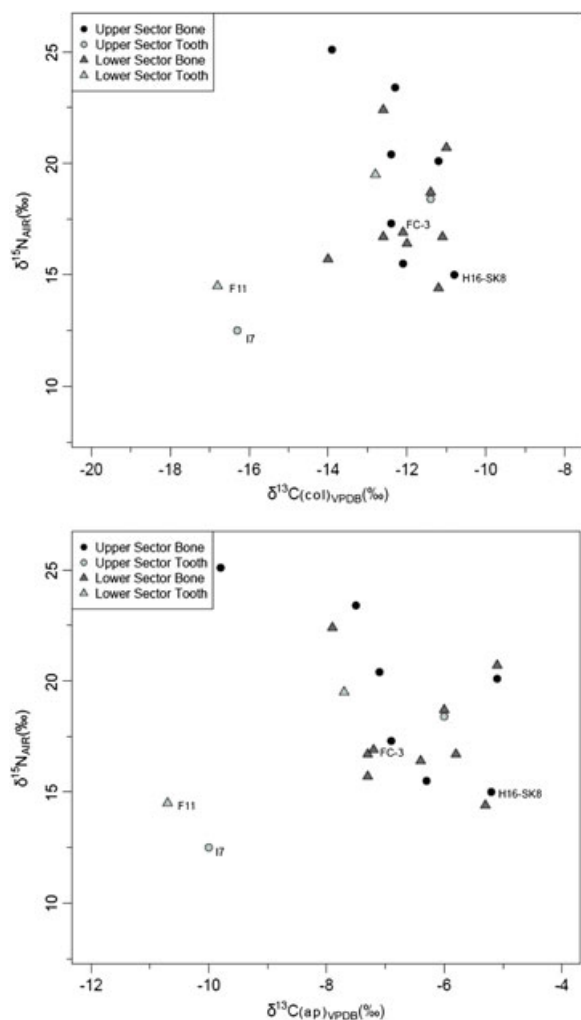


Figure 3. Bivariate plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the Upper and Lower sectors of Cementerio Oriente. (a) $\delta^{13}\text{C}$ from bone collagen, (b) $\delta^{13}\text{C}$ from bone apatite.

Oriente suggest the importance of marine foods, despite the site's location some 70 km from the sea. A marine diet may have been complemented by the consumption of C_4 plants, most likely maize, by some individuals, as indicated by the relatively high $\delta^{13}\text{C}_{\text{ap}}$ values, reaching a maximum of -5.1‰ . To characterise the local diversity in diet habits, our results were compared with reference values of fauna and flora from northern Chile (Figure 6). To date, the most complete reference study for the region has been made by Tieszen and Chapman (1992), on modern flora and fauna from Arica, approximately 600 km north of Quillagua, but sharing the same ecological characteristics. In addition, values of archaeological llama samples from the Quitor 6 cemetery (associated with the Atacama Culture) were included in the figure.

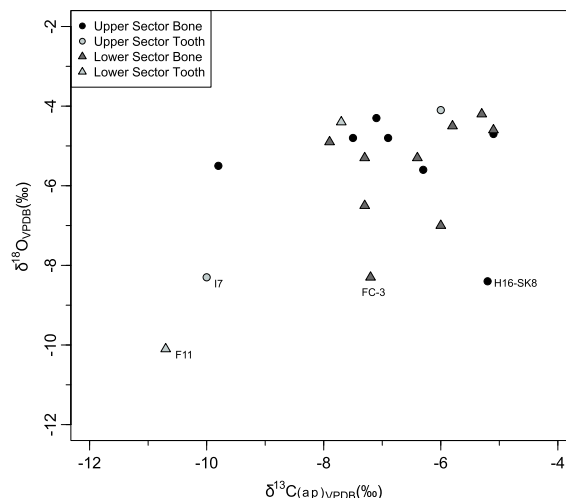


Figure 4. Bivariate plot of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}_{\text{ap}}$ values from the Upper and Lower sectors of Cementerio Oriente.

These results are directly related to the evidence observed in the archaeological record from *Cementerio Oriente* (such as complete corn cobs and fish vertebra). In addition, Latcham (1933) reported evidence of maize flour in ceramic pots, maize in the form of popcorn, as well as marine resources such as dry fish and shellfish.

Additional subsistence data were derived from the nearby and broadly contemporary settlement of La Capilla (AD 720–1315), also located in Quillagua. From the evidence found at La Capilla, López (1979) and Cervellino and Téllez (1980) suggested that fish and shellfish might have represented a major part of the diet for the Quillagua population during the LIP, with a secondary reliance on the consumption of domesticated plants such as maize and *quinoa*, and wild fruits.

Furthermore, Núñez (1965) emphasized the strong connections existing between the Quillagua oasis and the coast, noting many objects associated with the latter, such as tunics and hats made with sea mammal leather, as well as decorations using feathers from coastal birds. This evidence suggests that the connection between Quillagua and the coast was very important and probably persistent. The stable isotope results reported here strongly support the importance of marine resources, presumably traded from the coast in bulk, complemented by maize agriculture. However, as no differences were observed between the two sectors of the cemetery, any purported cultural divisions at the site apparently did not extend to the diets. Our results are consistent with the idea that despite the distance from the coast (70 km in a straight line), Quillagua should be seen as part of the coastal occupation node.

Nonetheless, two cases (I7 from the Upper sector and F11 from the Lower sector) show distinct $\delta^{13}\text{C}_{\text{col}}$,

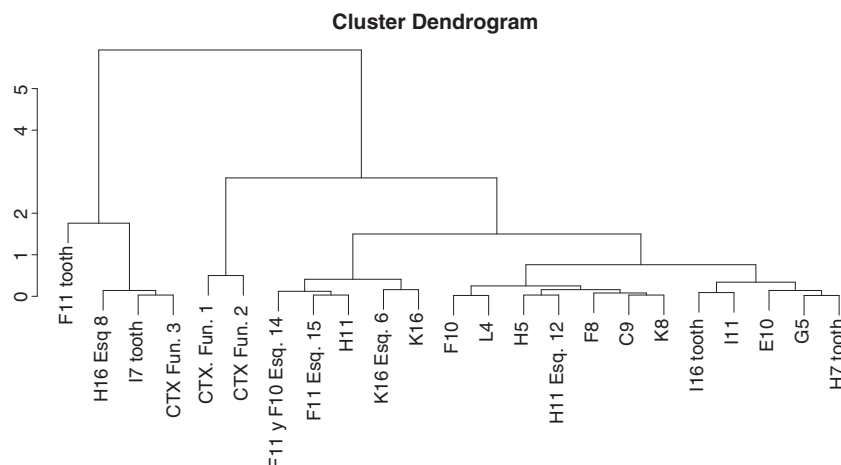


Figure 5. Ward's cluster of sample individuals based on $\delta^{18}\text{O}$ absolute differences.

$\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ values, suggesting a more terrestrial diet, but one which did not include significant amounts of maize when compared with the rest of the group (following their $\delta^{13}\text{C}_{\text{ap}}$ values). These two samples were teeth, indicating that this was the diet that characterised these individuals during their childhood (between 2 and 7 years old, following the age of

formation for second premolars), showing that their diet was different from Quillagua's population at that particular moment of their lives (see succeeding text).

Consequently, from the dietary point of view, our results suggest that the individuals buried in both sectors of the *Cementerio Oriente* of Quillagua were more closely related to the Pica-Tarapacá than the Atacama Culture, because the former showed stronger ties with the coast (Moragas, 1995; González, 2006; Uribe, 2006; Santana *et al.*, 2012). The isotopic values obtained for Quillagua are remarkably similar to the ones observed for the Pica-Tarapacá site of Pica 8, rather than the ones from the Atacama cultural groups, such as Quitor 6 (Figure 7). This similarity reinforces the interpretation about the tightest links of Quillagua with the Tarapacá Culture, at least in terms of diet.

The high variability observed for the $\delta^{15}\text{N}$ values could be related to multiple reasons. Gender could be playing a role in the variation of $\delta^{15}\text{N}$ values. However, because the cemetery was looted and there is almost no information regarding sex of the sampled individuals, it is difficult to make inferences about this aspect. So far, no gender differences have been observed in northern Chile during the LIP in terms of diet (Santana-Sagredo *et al.*, 2014). Social status could be having an influence on the variation observed for stable nitrogen isotopes. Again, the lack of information on the burial contexts for *Cementerio Oriente* makes it very difficult to evaluate this situation. In any case, the LIP cemeteries of Pica 8 (Pica-Tarapacá Culture) and Quitor 6 (Atacama Culture) do not show evidence that could suggest status differences in terms of diet. It is probable that the *Cementerio Oriente* of Quillagua had followed a similar trend, although it is impossible at the moment to explore this further. Finally, ethnic and/or identity aspects might have had a role in the variation observed in the

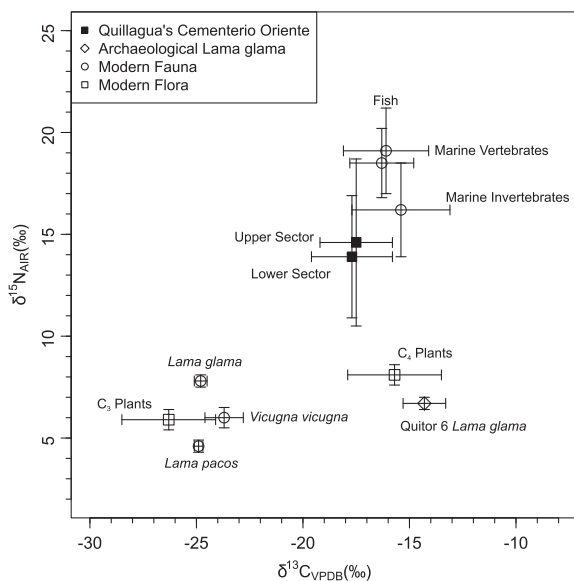


Figure 6. Bivariate plot showing $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ average and standard deviation values for modern flora and fauna from northern Chile (Tieszen & Chapman, 1992), and archaeological llama values from the Quitor 6 cemetery (Santana-Sagredo *et al.*, 2014), compared with dietary $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ average values for the Upper and Lower sectors of Quillagua's *Cementerio Oriente*. Diet values were estimated using an offset of +5‰ for $\Delta\delta^{13}\text{C}_{\text{diet-collagen}}$ and +4‰ for $\Delta\delta^{15}\text{N}_{\text{diet-collagen}}$ in human samples. All modern $\delta^{13}\text{C}$ values for plants and terrestrial animals have been corrected for the Suess effect (no corrections were applied to marine fauna), using a correction of -1.9‰ for the year 1992 (CO₂ data from CDIAC (Carbon Dioxide Information Analysis Center) <http://cdiac.ornl.gov/trends/co2/iso-sio/iso-sio.html>).

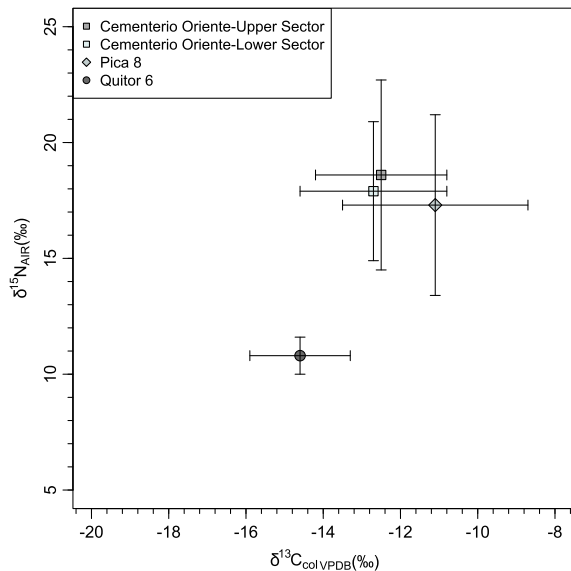


Figure 7. Bivariate plot of $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ values for the Upper and Lower sectors of Cementerio Oriente compared with the LIP sites of Pica 8 (Tarapacá Culture) and Quitor 6 (Atacama Culture) (Santana-Sagredo *et al.*, 2014).

sample. In this sense, the data obtained for the Pica 8 cemetery (Santana-Sagredo *et al.*, 2014) suggest that identity could have been related to the type of diet consumed by the individuals. Because Quillagua is closely related to the Pica 8 cemetery in terms of diet, it could be possible that identity/ethnic factors could also be playing a role here. However, it is impossible to make further interpretations with the lack of information we have for the site.

A chronological factor could also explain the differences in the $\delta^{15}\text{N}$ values observed in Quillagua. The only available dates for the cemetery come from the application of thermoluminescence on pottery fragments recollected on the surface of the site (Gallardo *et al.*, 1993) showing dates between AD 900 and 1150 for the whole cemetery. Because this information is very diffuse, together with the lack of radiocarbon dates for the sites, it is again, very complicated to make any inferences about possible variation in the $\delta^{15}\text{N}$ values regarding chronology.

The lowest values observed for $\delta^{15}\text{N}$ in Quillagua could be suggesting lower consumption of marine resources or also a non-consumption of this type of food. However, as presented in Figure 6 the $\delta^{15}\text{N}$ values observed for modern marine fauna of northern Chile show averages above 15‰ for shellfish, fish and marine mammals. Hence, it is unlikely that the individuals with lower $\delta^{15}\text{N}$ values were consuming marine resources. Even though the values are lower compared with the maximum $\delta^{15}\text{N}$ values observed for the

Cementerio Oriente, they are still high compared with populations consuming terrestrial diets (such as in Quitor 6; Santana-Sagredo *et al.*, 2014). In this sense, other factors might have had an influence on their $\delta^{15}\text{N}$ values, such as the use of manure in agriculture or the aridity effect (see succeeding text).

The $\delta^{15}\text{N}$ values obtained for both sectors of Cementerio Oriente (averaging 17‰ and 18‰) are among the highest values observed in human groups anywhere in the world, higher even than sites in Patagonia (Barberena, 2002) and Tierra del Fuego (Guichón *et al.*, 2001; Yesner *et al.*, 2003). Similarly high values have been observed, however, in other archaeological human remains and dental calculus from northern Chile (Tieszen *et al.*, 1992; Aufderheide *et al.*, 1994; Knudson *et al.*, 2010; Santana *et al.*, 2012; Torres-Rouff *et al.*, 2012; Poulson *et al.*, 2013), southern Peru (Tomczak, 2003) and coastal Brazil (Colonese *et al.*, 2014).

The high values observed for nitrogen isotopes in humans could be related to different factors affecting the plants and animals consumed by them. Factors that are known to lead to relatively high $\delta^{15}\text{N}$ values in plants and animals include the 'aridity' effect (e.g., Ambrose, 1991) and the effect of manure on plants (Bogaard *et al.*, 2007), in this case possibly guano (Szpak *et al.*, 2012), although it has been suggested that factors associated with the upwelling system of the Pacific Ocean may account for some of the very high $\delta^{15}\text{N}$ values observed for fish (Tieszen & Chapman, 1992). It is very likely that a combination of these factors influenced the $\delta^{15}\text{N}$ of plants, animals and ultimately humans at Quillagua.

Mobility patterns in Cementerio Oriente

From the $\delta^{18}\text{O}$ values in bone and tooth apatite, it is possible to suggest that most of the individuals buried in Cementerio Oriente inhabited the Quillagua oasis at least during their last decade of life, and at least two of them during their childhood (from tooth enamel values). The $\delta^{18}\text{O}$ values for these individuals are consistent with the values reported by Knudson (2009) for human enamel samples from northern Chile's valley and oases, such as San Pedro de Atacama to the southwest of Quillagua (range between -2‰ and -7‰ approximately). However, four individuals (17% of the sample) show unusually low $\delta^{18}\text{O}$ values, which are similar to those reported for ancient human remains from the *altiplano* region (Knudson, 2009). Values for $\delta^{18}\text{O}$ in ancient human enamel samples from Tiwanaku, Bolivia show an average of $-13.3 \pm 4.2\text{‰}$ (Knudson, 2009). The data for the four outlier's individuals from Quillagua suggest a possible highland origin. Two of these individuals seem to have spent part

of their childhood (between 2 and 7 years old) in higher areas, based on their tooth enamel values (second premolars), whereas the other two individuals spent their last decade or more outside of Quillagua, based on their bone apatite values. The two individuals (I7 and F11) that show low $\delta^{18}\text{O}$ values for their tooth enamel, also present very low $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ values for their dentine (Figure 3a). These values indicate lower consumption of marine foods and maize, which is in agreement with a diet expected for highland people, mainly based on terrestrial fauna (e.g. camelids) and C_3 plants (*quinoa* and potatoes) (Núñez, 1984). However, the diet of the other two 'non-locals', exhibit similar values to the rest of the group from both sectors of the *Cementerio Oriente*, contrasting with the values expected for a highland diet. Thus, these two individuals could have had another origin, different from the *altiplano*. Oxygen isotope values in the Atacama Desert can be quite variable because its hydrology is very complex (Magaritz et al., 1990; Aravena, 1995). The groundwater systems present in the Atacama Desert carry water directly from the mountains and come up to the surface to form springs. For this reason, the $\delta^{18}\text{O}$ values of spring waters can be quite low, being similar to the ones in the high Andes (Magaritz et al., 1990). Different oases in the valleys located to the north of Quillagua share similar characteristics and have low $\delta^{18}\text{O}$ values as well (Magaritz et al., 1990; Aravena, 1995). For instance, the springs present at the Pica oases present low $\delta^{18}\text{O}$ in their water composition (Aravena, 1995). Human $\delta^{18}\text{O}$ values from enamel apatite analysed for the Pica 8 cemetery also show values depleted in ^{18}O , in accordance with the water spring values (Santana-Sagredo et al., 2014). This situation could explain the presence of the two bone apatite outliers (H16-SK8 and FC-3) with low $\delta^{18}\text{O}$ values but a similar diet to *Cementerio Oriente*. The Pica oases to the north of Quillagua have occupations dating to the LIP showing plenty of fish and maize evidence (Núñez, 1984; Uribe, 2006), being a potential place of origin for the outlier individuals.

More oxygen stable isotope composition analyses in northern Chile are needed to better explain this situation. At present, we can only suggest that the two bone apatite outliers observed for Quillagua may have been 'non-local', and we cannot be certain about their exact geographic origin.

Conclusions

The individuals buried at *Cementerio Oriente* in Quillagua had a diet strongly influenced by the consumption of

marine resources, as seen in both the elevated collagen $\delta^{13}\text{C}$ values and high $\delta^{15}\text{N}$ values. The contribution of maize is seen more strongly in bone or enamel apatite $\delta^{13}\text{C}$ values. The stable isotope results presented here are largely consistent with the archaeological evidence, indicating that the majority of the individuals at Quillagua showed evidence for consumption of marine resources and thus were more closely aligned with the Pica-Tarapacá than with the Atacama Culture. However, the material culture differences that suggest the co-existence of different groups in the *Cementerio Oriente* (Agüero et al., 1999) was not observed in our analyses, suggesting that, if the Quillagua groups were associated with different cultural traditions, these were not reflected in different diets or mobility patterns.

Even though Quillagua was apparently more closely related to the Pica-Tarapacá cultural tradition (from the coast and *pampa*), there are at least four non-local individuals: two whose isotope data are more consistent with highland origins and two others unknown origin. This concurs with previous archaeological research that suggests mobility between different regions/cultural groups during the LIP (Schiappacasse et al., 1989; Núñez & Dillehay, 1995; Agüero et al., 1997). What the isotope information adds is a new line of evidence regarding the movement of specific individuals. This allows both an investigation of how these individuals were treated in death compared with long-term residents and an element of quantification in terms of how many people at the site can be designated as outsiders. However, it is still unknown how this contact and interaction occurred. In contrast to the main theories proposed for the LIP about a dominant presence of highland peoples in the lowlands (Murra, 1972; Schiappacasse et al., 1989), the *Cementerio Oriente* presents a different picture. Rather than having stronger ties to Atacama or other *altiplano* groups, we observe the presence of only a small number of immigrants at the site (17% of the sample). This situation opens the discussion towards the type of mobility and interaction that was occurring during the LIP in northern Chile, especially between the coast and oases of the Atacama Desert.

This study represents an initial effort to explore bioanthropological aspects of the cultural diversity in Quillagua. Despite the looted and decontextualized nature of the archaeological remains, our results indicate that relevant data can still be used to study the social dynamics characterising this small oasis in the Loa River, in the arid north of Chile. More bioanthropological and stable isotopes analyses will undoubtedly help us refine the conclusions drawn here.

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