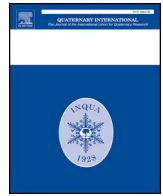




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## Social differentiation in the pre-Hispanic horticultural societies of central Chile (200–1500 AD). A stable isotope study



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### ARTICLE INFO

#### Keywords:

Central Chile  
Stable isotopes  
Social differentiation  
Mobility  
Pre-hispanic times

### ABSTRACT

The horticultural societies of the central zone of Chile in the first millennium AD and the first half of the second have been the subject of archaeological study for many years, and their cultural contexts have been described extensively. Their material culture, lifeways and settlement patterns present significant differences between the Bato and Llolleo groups in the Early Ceramic period (200–1200 AD) and between these and the Aconcagua groups of the Late Intermediate period (1000–1500 AD) (Falabella et al., 2016). Increasing complexity, social differentiation and changes in polity structure have been proposed, but robust data are still missing for many of these interpretations. The object of this work was to contribute to the identification of inter- and intra-group social differences in mobility, sex and age patterns and maize consumption, based on stable isotope analysis of human bones and a sub-sample of teeth. Analysis of the C, N and O stable isotopes in collagen and bioapatite extracted from the samples showed differences between the three groups studied in spatial mobility patterns and consumption of C<sub>4</sub> plants, suggesting that local communities organized themselves according to distinct social strategies at the regional level, and developed different horticultural practices and uses of maize. Among the Aconcagua groups a larger contribution of C<sub>4</sub> plants was found in children and in adult males, making visible sex and age categories. The results support archaeological data and contribute to a better understanding of gender issues and social organization in the groups studied.

### 1. Introduction

It is little more than a decade since stable isotope analysis was introduced as a new line of evidence on the diet of the pre-Hispanic populations of central Chile. The results have been fundamental for assessing the introduction and consolidation of horticulture, highlighting the low incidence of marine resources in the diets of the coastal populations of this zone and opening up discussion of occupation of the Andes Mountains (Falabella et al., 2007, 2008; Sanhueza and Falabella, 2010). Recent analyses by Swift (2017) in this zone and in the nearby Aconcagua valley confirm these results. As the authors' investigations have advanced, new samples have been analysed and the information has been used to address other archaeological questions and concerns. The purpose of this work was to explore the information delivered by stable isotopes on possible differences between the Bato and Llolleo groups during the Early Ceramic period (ECP), and the social changes associated with the transition to the Late Intermediate period (LIP) in central Chile.

In the prehistory of central Chile, Bato and Llolleo are two cultural entities considered to be different social groups – each with its own identity, practices and “way of doing things” (Falabella et al., 2016). The Bato groups (ca. 200 to 1200 AD) maintained lifeways similar to those of the hunter-gatherers of the previous period, with curated lithic technology and dispersed settlement in both permanent and temporary residential sites, indicating that they maintained some spatial mobility practices. In addition to wild resources, crops are found at their sites, especially quinoa (*Chenopodium quinoa*) and to a lesser degree – and in some sites only – maize (*Zea mays*). They produced and used pottery for their domestic activities, and some individuals, both male and female, used the *tembetá* as an adornment or visible distinguishing mark (Soto, 2010). No differences based on sex or age have been recognised, nor any evidence of hierarchies between individuals or settlements (Sanhueza, 2016). The Llolleo groups (ca. 400 to 1200 AD) cultivated maize, beans, squash and quinoa, with a dispersed settlement system based on permanent residential sites each containing only a few dwellings. Their pots and ceramic technology differ from those of the

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<https://doi.org/10.1016/j.quaint.2019.09.021>

Received 26 April 2019; Received in revised form 6 July 2019; Accepted 17 September 2019

Available online 19 September 2019

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Bato and extend to funerary as well as domestic use. Social differentiation between children and adults has been recognised in their funerary practices, and it has been suggested that gender distinctions were also made between males and females in the objects included as offerings (Falabella, 2000; Sanhueza, 2016). Nevertheless, stone bead necklaces were commonly used by both sexes and different age categories as distinguishing marks (Díaz, 2017). The two groups were contemporary, and their dwellings were interspersed in the same environments (Falabella et al., 2014; Sanhueza, 2016).

Towards 1000 AD, a substantial change occurred in the area, manifested in cultural expressions which differed radically from those described above. Pots and lithic instruments, personal adornments, the use of objects for smoking/inhaling and funerary practices all changed significantly. The settlement pattern remained dispersed, but occupation of spaces close to larger watercourses intensified while settlements associated with lakes and subterranean water-tables diminished (Sanhueza et al., 2019). Archaeobotanical, isotope and lithic material data indicate an intensification in maize consumption at the same time. Differences based on sex and age have been suggested in funerary spatial organization (Sánchez, 1997).

The archaeological information points to differences as well as similarities between groups and between periods (Falabella et al., 2016). In this study both inter- and intra-group analyses have been conducted to address the following questions: a) Were there differences in people's mobility? b) Were there differences defined by sex and age? c) Did patterns of maize consumption change, and how?

The study area is a sector of central Chile between the basins of the Maipo-Mapocho and Cachapoal rivers, including the coast, the valleys of the Coastal Range and the central valley (Fig. 1). The area has a mediterranean climate characterised by cold winters when precipitations are concentrated, and hot, dry summers. The landscape is dominated by four longitudinal geofoms which succeed one another from the Pacific Ocean in the west to the Andes Mountains in the east: the coastline; the Coastal Range containing numerous fertile valleys associated with streams and gullies; the flat central valley and the Andes Range. This east-west dimension is no wider than 150 km at the latitude of Santiago (33°26' S) and the furthest distance between the sites sampled is only 120 km. Although the area is small, the differences between the environments and their resources produce variations in the stable isotope ratios of C, N and O. Of these, the most important for this

work are the contrast between marine and terrestrial protein resources, the significant changes in the  $\delta^{18}\text{O}$  values in drinking water from the coast to the Andes, and the presence of maize as the only  $\text{C}_4$  resource among the plants which contributed significantly to diet.

## 2. Materials and methods

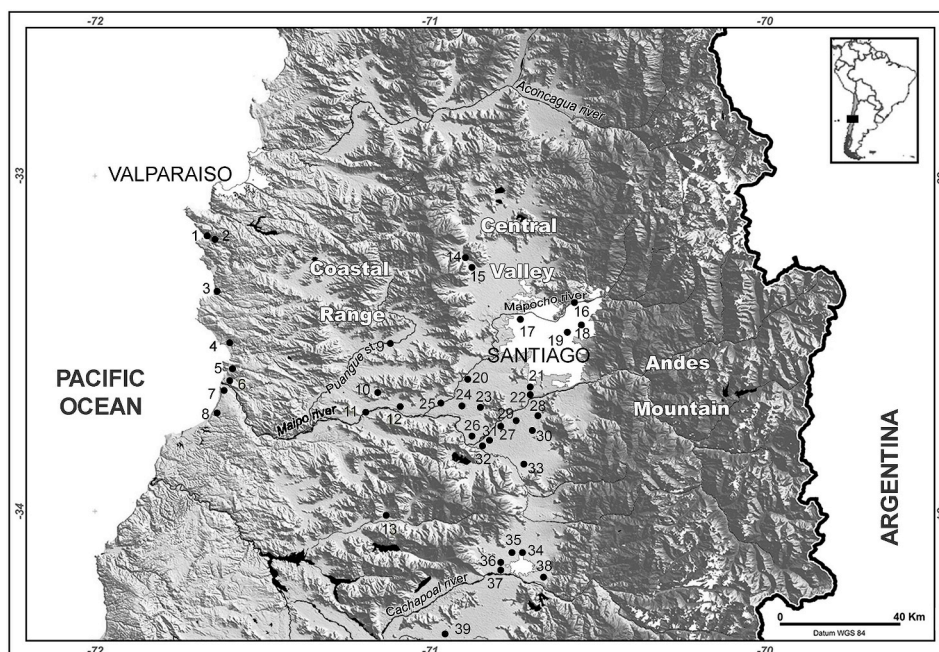
### 2.1. Materials

The archaeological sites studied are located on the coast, in the Coastal Range and in the central valley between latitudes 33°15' and 34°20' S (numbered dots in Fig. 1). One or more individuals were sampled from each site (maximum ten) depending on availability in collections, state of conservation and the search for a balance between male and female individuals (Table 1). Samples from 105 individuals, from both the ECP and LIP, have been submitted for stable isotope analysis; only 89 of them presented adequate collagen preservation but bioapatite could be analysed in all 105. Additionally, 45 included samples of one tooth, in most cases the third molar which should not be affected by breast-feeding. The bone samples, mostly cortical fragments, were taken from 103 adult individuals  $\geq 18$  years of age and 2 children 4–9 years. Sex determination for both this and earlier studies was carried out anew by the bio-anthropologist co-authors to avoid bias due to the application of differing criteria. In the comparative analyses, the probable males (pM) and probable females (pF) were treated as male ( $n = 48$ ) or female ( $n = 51$ ) respectively. The results were interpreted using local isotope baselines (Falabella et al., 2007; Tykot et al., 2009).

### 2.2. Stable isotope analysis

Stable isotope analysis has been used in archaeology for years to identify diet and mobility patterns, since the isotope composition of human tissues is derived from the isotope values of the resources that people eat. The relation between the isotope value of the resources and that of the human remains analysed is robust, as has been shown by many experimental studies (Katzenberg, 1992; van der Merwe, 1992; Ambrose and Norr, 1993; Passey et al., 2005).

Bone consists of an organic component or collagen, at least 75% of which is produced by the protein portion of diet, and a mineral



**Fig. 1.** Relief map of the study area and the archaeological sites from which samples were taken. 1: C. Golf-1; 2: Trébol SE; 3: Los Puquios; 4: LEP-C; 5: Arévalo-2; 6: Tejas Verdes (TV-1; TV-3; TV-4; TV-5); 7: Sto. Domingo-1; 8: Las Brisas 10–14; 9: María Pinto; 10: Pomaire; 11: El Bajo de Melipilla; 12: Chiñigüe-2; 13: Estero Alhué; 14: El Almendral; 15: Chicauma (RML-004); 16: El Mercurio; 17: Carrascal-3; 18: Parque La Quintrala; 19: Country Club; 20: Santo Toribio-2; 21: Carozzi; 22: Don Ladislao; 23: Lonquén; 24: S. Filomena; 25: Mateluna Ruz-1; 26: Las Mercedes; 27: Iglesia Maipo; 28: Santa Rita; 29: Villa Virginia; 30: Linderos; 31: Campusano; 32: Las Pataguas; 33: Hospital 8–9; 34: Las Coloradas; 35: Alto Jahuel; 36: La Granja-3; 37: La Granja ByPass; 38: Cond. Los Llanos; 39: Chamico.

**Table 1**  
Isotope values for the samples discussed in the text, grouped by cultural context.

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	$\delta^{13}C_{col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	LAB-ID	$\delta^{13}C_{op}$ ‰ VPDB	$\delta^{18}O_{op}$ ‰ VPDB	Tooth	LAB-ID	$\delta^{13}C_{en}$ ‰ VPDB	$\delta^{18}O_{en}$ ‰ VPDB	C:N (d)	Data first published (e)
Bato	Arévalo-2 1	C	F	36-50		tibia	USF 8065 -17.8	11.7	USF 8138	-10.4	-4.1						& a
Bato	C. Golf-1 2	C	M	35-50		femur	USF 8057 -19.0	9.0	USF 8130	-12.1	-4.5	M3	USF 8173	-12.6	-3.2		& a
Bato	C. Golf-1 4	C	F	24-35		femur	USF 8058 -17.5	11.3	USF 8131	-9.7	-3.4						& a
Bato	C. Golf-1 5	C	M	24-35	1405 ± 47 BP (cal 550-690 AD) AA63823	femur	USF 8059 -17.4	11.2	USF 8132	-9.7	-3.1						& a
Bato	C. Golf-1 6	C	M	24-35		femur	USF 8060 -16.6	9.4	USF 8133	-8.3	-3.5						& a
Bato	Trébol SE 7	C	F	≥18		tibia	USF 8061 -17.4	9.8	USF 8134	-11.3	-3.0						& a
Bato	Trébol SE 9	C	pM	10-14		femur	USF 8062 -19.9	7.1	USF 8135	-11.5	-3.5						& a
Bato	Trébol SE 12	C	F	≥18		tibia	USF 8063 -18.7	8.2	USF 8136	-13.6	-2.2	M3	USF 8174	-12.5	-3.1		& a
Bato	Trébol SE 16	C	M	30-60		femur	USF 8064 -17.7	10.9	USF 8137	-11.1	-3.2						& a
Bato	Trébol SE 15	C	pF	≥18	1350 ± 25 BP (cal 664-767 AD) UGAMS 29856	ribs	UGAMS -18.6	9.8	UGAMS 29856	-14.7	-4.7	M3	UGAMS 29857	-12.9	-4.3	3.3	b
Bato	Campusano 1	V	nd	≥20	UGAMS 29856	long bone	UGAMS -20.6	5.2	UGAMS 6045	-14.1							n.r
Bato	Carozzi 3-1	V	M	25-30	1820 ± 25 BP (cal 127-252 AD) UGAMS 6045	n.r.	UGAMS -20.5	5.5	UGAMS 15237	-11.0	-8.2						2.9
Bato	Chamico 1	V	M	25-35	1770 ± 25 BP (cal 250-403 AD) UGAMS 15237	femur	USF -16.9	7.2	USF 10134	-8.4	-8.3						& c
Bato	Don Ladislao 1-1	V	M	24-50		tibia	USF -13.6	7.0	USF 10135	-7.5	-8.1	M3	USF 16820	-9.2	-6.0		& c
Bato	Don Ladislao 1-3/	V	F	≥20	1110 ± 20 BP (cal 900-1023 AD) UGAMS 15237	ulna	USF -16.0	4.8	USF 16831	-9.2	-9.3	M3	USF 16818	-6.2	-8.8		& c
Bato	Don Ladislao 3-1	V	F	20-30	UGAM 13590	radius	USF -15.8	5.3	USF 16832	-9.2	-9.2	M2	USF 16822	-11.4	-5.6		& c
Bato	Don Ladislao 4	V	F	17-24	1200 ± 20 BP (cal 782-977 AD) UGAM 13591	femur	USF -15.1	6.2	USF 16833	-7.6	-7.0						& c
Bato	Hospital 8-9 1	V	M	30-35	890 ± 20 BP (cal 1156-1257 AD) UGAM 13592	femur	USF -17.0	5.8	USF 8140	-8.8	-7.8	M3	USF 8176	-8.2	-7.2		& a

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Table 1 (continued)

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	LAB-ID	$\delta^{13}C_{col}$ VPDB ‰	$\delta^{15}N$ AIR ‰	LAB-ID	$\delta^{13}C_{cp}$ VPDB ‰	$\delta^{18}O_{op}$ VPDB ‰	Tooth	LAB-ID	$\delta^{13}C_{en}$ VPDB ‰	$\delta^{18}O_{en}$ VPDB ‰	C:N (d)	Data first published (e)
Bato	La Granja-3 1	V	M	23	1234 ± 52 BP (cal 660–900 AD) AA64986	femur	USF 8051	-19.7	6.3	USF 8124	-10.4	-7.3						& a
Bato	S. Filomena 1	V	F	30-35	1210 ± 20 BP (cal 780-969 AD) UGAM 13593	femur	USF 16834	-16.1	4.9	USF 16826	-7.7	-9.8						& c
Bato	S. Filomena 2	V	M	20-30		tibia	USF 16835	-18.9	4.2	USF 16827	-9.3	-7.6						& c
Bato	S. Toribio-2 U1	V	M	15-17	1170 ± 20 BP (cal 778-942 AD) UGAM 13594	femur	USF 16836	-17.1	4.3	USF 16828	-10.2	-8.3	M3	USF 16829	-8.8	-6.7		& c
Llolleo	LEP-C 9	C	F	35-39	1040 ± 27 BP (cal 1100-1398 AD) UGAMS 33358	femur	UGAMS 33358	-15.1	10.1	UGAMS 33358	-10.9	-5.4	M2	UGAMS 33364	-10.2	-4.1		3.2 b
Llolleo	LEP-C 11	C	F	25-29	1070 ± 28 BP (cal 1046-1332 AD) UGAMS 33359	femur	UGAMS 33359	-14.4	11.4	UGAMS 33359	-10.4	-5.6	M3	UGAMS 33365	-6.7	-2.9		3.2 b
Llolleo	LEP-C 17	C	M	25-29		femur	USF 8070	-13.5	12.6	USF 8143	-8.7	-2.6	M3	USF 8177	-8.4	-2.1		& a
Llolleo	LEP-C 19	C	F	30-34		femur	USF 8071	-14.8	11.3	USF 8144	-10.0	-2.9	M3	USF 8178	-9.7	-3.4		& a
Llolleo	LEP-C 22	C	M	40-50	1010 ± 29 BP (cal 1129-1422 AD) UGAMS 33360	femur	UGAMS 33360	-16.8	9.9	UGAMS 33360	-11.8	-4.3	M2	UGAMS 33366	-11.1	-3.1		3.2 b
Llolleo	Los Puquitos 2	C	F	45-55		femur	USF 8075	-16.2	12.3	USF 8148	-10.1	-2.5						& a
Llolleo	TV-1 12	C	M	39-45	1070 ± 25 BP (cal 981-1045 AD) UGAMS 29848	femur	UGAMS 29848	-15.6	10.5	UGAMS 29848	-10.6	-5.9	PM2	UGAMS 29849	-8.7	-8.7		3.3 b
Llolleo	TV-3 9	C	F	20-35	1090 ± 25 BP (cal 970-1030 AD) UGAMS 29850	femur	UGAMS 29850	-15.3	10.5	UGAMS 29850	-10.6	-8.6	M3	UGAMS 29851	-8.5	-5.2		3.3 b
Llolleo	TV-4 10/2	C	pF	25-29	1085 ± 33 BP (cal 890-1020 AD) AA64988	femur	USF 8073	-15.6	10.5	USF 8146	-10.8	-4.6						& a
Llolleo	TV-5 6/6	C	M	25-29		femur	USF 8074	-14.7	7.7	USF 8147	-8.9	-4.4						& a
Llolleo	Alto Jahuel 1	V	F	20-30		long bone	USF 8087	-13.2	6.2	USF 8160	-6.8	-8.1						& a
Llolleo	Carozzi 5-1	V	F	≥ 18	1150 ± 25 BP (cal 891-992 AD) UGAMS 15238	n.r.	UGAMS 15238	-15.3	5.0	UGAMS 15238	-8.4	-9.6						2.9 d

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Table 1 (continued)

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	LAB-ID	$\delta^{13}C_{cal}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	LAB-ID	$\delta^{13}C_{cp}$ ‰ VPDB	$\delta^{18}O_{op}$ ‰ VPDB	Tooth	LAB-ID	$\delta^{13}C_{en}$ ‰ VPDB	$\delta^{18}O_{en}$ ‰ VPDB	C:N (d)	Data first published (e)
Llolleo	Carozzi 5-2	V	M	25-30	1130 ± 25 BP (cal 895-1019 cal AD) UGAMS 15239	n.r.	UGAMS 15239	-13.8	5.5	UGAMS 15239	-7.5	-10.2		UGAMS 15239			2.9	d
Llolleo	Carozzi 5-3	V	nd	4-5	1060 ± 25 BP (cal 986-1132 AD) UGAMS 15240	n.r.	UGAMS 15240	-14.5	4.4	UGAMS 15240	-8.1	-11.2		UGAMS 15240			2.9	d
Llolleo	Carozzi 5-4	V	F	30-36	1130 ± 25 BP (cal 895-1019 AD) UGAMS 15241	n.r.	UGAMS 15241	-15.2	5.0	UGAMS 15241	-8.3	-11.9		UGAMS 15241			2.9	d
Llolleo	Carozzi 5-5	V	M	30-40	1110 ± 25 BP (cal 898-1025 AD) UGAMS 15242	n.r.	UGAMS 15242	-14.4	4.7	UGAMS 15242	-7.5	-11.3		UGAMS 15242			2.8	d
Llolleo	Cond Los Llanos 1	V	F	≥ 20	15242	humerus	USF 8088	-12.8	5.7	USF 8161	-8.1	-7.2		USF 8161			&	a
Llolleo	Country Club 1	V	pF	≥ 30	1169 ± 46 BP (cal 719-983 AD) AA68049	tibia	USF 8056	-13.7	5.0	USF 8129	-8.0	-9.0	M3	USF 8172	-4.9	-9.2	&	a
Llolleo	El Mercurio 6	V	M	25-29		cranium	USF 8077			USF 8150	-7.7	-10.6	M3	USF 8180	-6.5	-10.1	x	a
Llolleo	El Mercurio 7	V	M	25-29		long bone	USF 8078			USF 8151	-9.6	-10.7					x	a
Llolleo	El Mercurio 12	V	F	20-24		femur	USF 8079			USF 8152	-9.8	-9.6	M3	USF 8181	-8.9	-8.7	x	a
Llolleo	El Mercurio 13	V	F	20-24	Associated vessel TL 1080 ± 90 AD	femur	USF 8076	-17.6	4.9	USF 8149	-5.6	-4.7	M3	USF 8179	-8.2	-8.8	&	a
Llolleo	El Mercurio 16	V	M	30-34		long bone	USF 8080			USF 8153	-9.1	-9.6	M3	USF 8182			x	a
Llolleo	El Mercurio 17	V	F	30-34		tibia	USF 8081			USF 8154	-9.3	-9.3	M3	USF 8183	-7.9	-8.5	x	a
Llolleo	El Mercurio 18	V	F	25-29		long bone	USF 8082			USF 8155	-9.7	-9.2	M3	USF 8184	-7.9	-8.9	x	a
Llolleo	El Mercurio 20	V	F	25-29	Associated vessel TL 935 ± 100 AD	femur	USF 8083	-16.1	5.0	USF 8156	-10.3	-9.7					&	a
Llolleo	El Mercurio 25	V	F	35-39		long bone	USF 8084			USF 8157	-9.6	-10.0	M3	USF 8185	-11.1	-7.5	x	a
Llolleo	El Mercurio 26	V	F	20-24		femur	USF 8085			USF 8158	-9.7	-9.3	M3	USF 8186	-9.3	-8.4	x	a
Llolleo	Iglesia Maipo 2-2A	V	M	≥ 20	960 ± 20 BP (cal 1042-1181 AD) UGAMS 13149	long bone	UGAMS 13149	-13.6	5.3	UGAMS 13149	-8.0	-12.7					3.0	c

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Table 1 (continued)

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	LAB-ID	$\delta^{13}C_{col}$ VPDB ‰	$\delta^{15}N$ AIR ‰	LAB-ID	$\delta^{13}C_{cp}$ VPDB ‰	$\delta^{18}O_{op}$ VPDB ‰	Tooth	LAB-ID	$\delta^{13}C_{en}$ VPDB ‰	$\delta^{18}O_{en}$ VPDB ‰	C:N (d)	Data first published (e)
Llolleo	Iglesia Maipo 4-4	V	pF	≥20	960 ± 20 BP (cal 1042-1181 AD) UGAMS 13150	long bone	UGAMS 13150	-13.7	4.2	UGAMS 13150	-7.8	-12.8					3.0	c
Llolleo	La Ganja ByPass 1	V	F	20-35		long bone	USF 8523	-14.0	5.6	USF 8556	-7.5	-9.8					&	a
Llolleo	Las Coloradas 3	V	M	≥20		femur	USF 8520	-13.9	6.4	USF 8553	-7.2	-8.6					&	a
Llolleo	Las Coloradas 6	V	nd	≤9		femur	USF 8521			USF 8554	-6.6	-9.6					x	a
Llolleo	Las Coloradas 7	V	pF	≥20		tibia	USF 8522	-14.7	5.1	USF 8555	-7.4	-9.2					&	a
Llolleo	Las Pataguas 1	V	F	35-40	910 ± 25 BP (cal 1035-1205 AD) UGAMS 6046	femur	USF 8089	-12.8	7.5	USF 8162	-8.3	-9.4	M3	USF 8187	-4.8	-6.9	&	a
Llolleo	Las Pataguas 2	V	M	30-40	880 ± 25 BP (cal 1045-1219 AD) UGAM6047	femur	USF 8090	-14.0	6.9	USF 8163	-9.2	-9.9	M3	USF 8188	-6.6	-9.1	&	a
Llolleo	Linderos (CDQ) 5	V	M	40-45	1090 ± 25 BP (cal 970-1030 AD) UGAMS 29846	ribs	UGAMS 29846	-14.5	5.0	UGAMS 29846	-8.8	-10.6	PM1	UGAMS 29847	-6.8	-12.1	3.3	c
Llolleo	Lonquén 3	V	M	≥20	1091 ± 46 BP (cal 784-1025 AD) AA68048	femur	USF 8055	-12.7	5.7	USF 8128	-7.3	-7.7					&	a
Llolleo	Mateluna Ruz-1 5	V	F	≥50	1290 ± 25 BP (cal 683-876 AD) UGAMS 29858	femur	UGAMS 29858	-15.0	5.7	UGAMS 29858	-9.0	-8.0					3.3	c
Llolleo	Mateluna Ruz-1 8	V	F	20-35	1040 ± 25 BP (cal 992-1142 AD) UGAMS 13148	femur	UGAMS 13148	-17.3	6.2	UGAMS 13148	-11.4	-10.7					3.1	c
Llolleo	Mateluna Ruz-1 10	V	M	35-50	1050 ± 20 BP (cal 990-1132 AD) UGAMS 13147	femur	UGAMS 13147	-16.1	6.9	UGAMS 13147	-11.1	-9.9					3.1	c
Llolleo	Parque La Quintrala T2	V	M	39-44	1250 ± 25 BP (cal 765-893 AD) UGAMS 29852	ribs	UGAMS 29852	-14.9	5.5	UGAMS 29852	-9.4	-10.5	M3	UGAMS 29853	-8.2	-9.1	3.2	c
Llolleo	Parque La Quintrala T7	V	F	≥23	1070 ± 25 BP (cal 981-1045 AD) UGAMS 29854	long bone	UGAMS 29854	-14.5	5.2	UGAMS 29854	-9.1	-10.4	Incisor	UGAMS 29855	-8.3	-8.9	3.3	c

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Table 1 (continued)

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	LAB-ID	$\delta^{13}C_{col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	LAB-ID	$\delta^{13}C_{cp}$ ‰ VPDB	$\delta^{18}O_{op}$ ‰ VPDB	Tooth	LAB-ID	$\delta^{13}C_{en}$ ‰ VPDB	$\delta^{18}O_{en}$ ‰ VPDB	C:N (d)	Data first published (e)
Llolleo	Santa Rita 2-3	V	F	24-29	950 ± 20 BP (cal 1045-1203 AD) UGAMS 13146	femur	UGAMS 13146	-14.5	4.4	UGAMS 13146	-9.2	-12.5					3.0	c
Llolleo	Santa Rita 1-1	V	M	40	940 ± 20 BP (cal 1046-1212 AD) UGAM 13145	femur	UGAMS 13145	-14.1	4.7	UGAMS 13145	-8.9	-10.4					2.9	c
Llolleo	Villa Virginia 1	V	pF	30-40		femur	USF 8086	-13.6	5.7	USF 8159	-8.0	-8.6					&	a
Aconcagua	Las Brisas 10-14	C	M	30-35	cal 1297-1699 AD (associated date)	femur	USF 8018	-13.6	8.4	USF 8091	-6.7	-3.7					&	a
Aconcagua	Las Brisas 10-14	C	F	24-30	A-12915 cal 1295-1526 AD (associated date)	femur	USF 8019	-14.3	8.5	USF 8092	-6.3	-4.3					&	a
Aconcagua	Las Brisas 10-14	C	M	45-59	A-12916	femur	USF 8021	-12.4	11.2	USF 8094	-6.2	-4.5	M3	USF 8164	-9.5	-9.5	&	a
Aconcagua	Las Brisas 10-14	C	F	24		femur	USF 8022	-12.3	10.3	USF 8095	-7.7	-3.9	M3	USF 8165	-5.2	-4.7	&	a
Aconcagua	Las Brisas 10-14	C	F	≥ 20		femur	USF 8023	-17.3	14.3	USF 8096	-12.7	-4.2					&	a
Aconcagua	Las Brisas 10-14	C	M	30-40		tibia	USF 8020	-13.5	8.1	USF 8093	-7.5	-5.1					&	a
Aconcagua	Sto. Domingo-1	C	M	≥ 20		femur	USF 8025	-10.7	11.6	USF 8098	-5.2	-4.2					&	a
Aconcagua	TV-5 8-1	C	F	≥ 20		femur	USF 8024	-13.2	8.2	USF 8097	-7.6	-4.8	M3	USF 8166	-4.1	-5.2	&	a
Aconcagua	Chinigué-2 2	CR	nd	≥ 20p		femur	USF 8033	-12.5	5.0	USF 8106	-6.2	-5.0					&	a
Aconcagua	El Bajo de Melipilla 1	CR	M	40-50		femur	USF 8032	-10.4	7.5	USF 8105	-6.5	-7.1					&	a
Aconcagua	Estero Alhué 12	CR	pF	25-33	450 ± 25 BP (cal 1439-1502 AD) UGAMS 29839	ribs	UGAMS 29839	-11.1	6.8	UGAMS 29839	-6.7	-8.0	Canine	UGAMS 29840	-4.0	-6.8	4.8	c
Aconcagua	Estero Alhué 13	CR	M	18-24	460 ± 25 BP (cal 1434-1499 AD) UGAMS 29843	ribs	UGAMS 29843	-14.0	8.2	UGAMS 29843	-6.3	-7.4	M3	UGAMS 29844	-2.5	-6.3	4.4	c
Aconcagua	Estero Alhué 3	CR	pF	22-28	440 ± 25 BP (cal 1443-1504 AD) UGAMS 29837	ribs	UGAMS 29837	-15.5	8.8	UGAMS 29837	-7.0	-6.8	M2	UGAMS 29838	-5.4	-6.0	4.3	c

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Table 1 (continued)

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	$\delta^{13}C_{col}$ VPDB ‰	$\delta^{15}N$ AIR ‰	LAB-ID	$\delta^{13}C_{cp}$ VPDB ‰	$\delta^{18}O_{op}$ VPDB ‰	Tooth	LAB-ID	$\delta^{13}C_{en}$ VPDB ‰	$\delta^{18}O_{en}$ VPDB ‰	C:N (d)	Data first published (e)
Aconcagua	Estero Alhué 9	CR	M	25-33	590 ± 25 BP (cal 1389-1432 AD) UGAMS 29841	cranium	-11.1	6.8	UGAMS 29841	-6.6	-7.7	M3	UGAMS 29842	-3.7	-6.8	3.3	c
Aconcagua	María Pinto 8	CR	pF	24-30	600 ± 25 BP (cal 1321-1427 AD) UGAMS 33362	clavicle	-11.8	7.7	UGAMS 33362	-8.0	-5.2	M3	UGAMS 33368	-5.4	-6.4	3.3	c
Aconcagua	María Pinto 11	CR	pF	20-25	430 ± 20 BP (cal 1449-1503 AD) UGAMS 33362	radius	-12.4	7.1	USF 8100	-7.6	-5.2	M3	USF 8167	-5.9	-4.6	&	a
Aconcagua	María Pinto 17	CR	F	40-45		femur	-12.0	6.3	USF 8101	-6.9	-3.9	M3	USF 8168	-2.8	-4.5	&	a
Aconcagua	María Pinto 15	CR	M	25-35	430 ± 20 BP (cal 1449-1503 AD) UGAMS 33363	vertebra	-12.5	9.9	UGAMS 33363	-9.6	-6.4	M3	UGAMS 33369	-3.6	-6.7	3.2	c
Aconcagua	María Pinto 1	CR	M	35-40		fibula	-10.6	7.6	USF 8102	-7.1	-5.6	M3	USF 8169	-4.2	-6.4	n.r.	a
Aconcagua	María Pinto 3	CR	M	35-40	600 ± 25 BP (cal 1321-1427 AD) UGAMS 33361	vertebra	-10.6	9.2	UGAMS 33361	-8.2	-6.4	M3	UGAMS 33367	-2.0	-5.1	3.3	c
Aconcagua	María Pinto 6	CR	M	35-40		ulna	-10.7	8.1	USF 8104	-7.5	-5.1					&	a
Aconcagua	Pomaire Carrascal-3 2	CR	M	≥20		femur	-10.3	7.5	USF 8573	-5.5	-8.2					&	a
Aconcagua	Carrascal-3 4	V	M	40-45		femur	-11.7	5.6	USF 8564	-6.4	-8.9					&	a
Aconcagua	Carrascal-3 4	V	M	35-45		femur	-11.9	5.7	USF 8563	-7.5	-8.7					&	a
Aconcagua	Chicauma (RML 004) T 102	V	M	20-24	650 ± 25 BP (cal 1301-1402 AD) UGAMS 29835	ribs	-12.2	8.2	UGAMS 29835	-7.6	-9.0	M3	UGAMS 29836	-4.0	-7.5	3.4	c
Aconcagua	Chicauma (RML 004) T 31-87	V	pF	36-50	640 ± 25 BP (cal 1305-1406 AD) UGAMS 29831	femur	-13.0	8.6	UGAMS 29831	-7.2	-9.6	M3	UGAMS 29832	-3.9	-9.0	3.7	c
Aconcagua	Chicauma (RML 004) T 80-91	V	pM	≥20	590 ± 25 BP (cal 1324-1432 AD) UGAMS 29833	cranium	-12.8	7.3	UGAMS 29833	-8.4	-10.3	PM2	UGAMS 29834	-4.3	-10.4	x	c
Aconcagua	El Almendral T1	V	F	30-48	467 ± 44 BP (cal 1328-1615 AD) AA68047	femur	-12.8	7.3	USF 8125	-7.7	-6.4					&	a
Aconcagua	Las Mercedes 1	V	pM	35-40		fibula	-12.0	5.8	USF 8126	-6.3	-8.4					&	a
Aconcagua	Las Mercedes 2	V	M	≥20	602 ± 33 BP (cal 1290-1410 AD) AA64987	humerus	-10.8	6.6	USF 8127	-6.1	-7.1					&	a

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Table 1 (continued)

Cultural Group	Site Ind. #	Zone (a)	Sex (b)	Age (years)	Age BP (cal age 2 sigmas) LAB-ID	Bone (c)	LAB-ID	$\delta^{13}C_{col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	LAB-ID	$\delta^{13}C_{cp}$ ‰ VPDB	$\delta^{18}O_{op}$ ‰ VPDB	Tooth	LAB-ID	$\delta^{13}C_{en}$ ‰ VPDB	$\delta^{18}O_{en}$ ‰ VPDB	C:N (d)	Data first published (e)
Aconcagua	Carrascal-3 3	V	F	20-24	500 ± 25 BP (cal 1417-1458 AD) UGAMS 29845	ribs	UGAMS 29845	-11.1	6.0	UGAMS 29845	-7.5	-11.0					3.2	c
Aconcagua	Chicauma (RML 004) T 101-74	V	pF	20-24		femur	USF 8525			USF 8558	-5.7	-7.4	M3	USF 8575	-3.8	-6.0	x	a
Aconcagua	Chicauma (RML 004) T 37-84	V	F	≥ 40	(cal. 1415-1440 AD. 1 sigma). <a href="#">Sánchez 1997</a>	cranium	USF 8524			USF 8557	-6.1	-6.5					x	a
Aconcagua	Chicauma (RML 004) T 53-81	V	M	36-50		femur	USF 8527	-11.8	5.7	USF 8560	-5.9	-7.8					&	a
Aconcagua	Chicauma (RML 004) T 76-92	V	pM	30-48		long bone	USF 8529	-11.4	8.1	USF 8562	-6.7	-7.2					&	a
Aconcagua	Chicauma (RML 004) T 88-63	V	pF	36-50		femur	USF 8528	-10.6	7.4	USF 8561	-5.7	-6.6					&	a
Aconcagua	Chicauma (RML 004) T 98-71	V	pF	≥ 30		femur	USF 8526	-11.6	7.6	USF 8559	-5.8	-7.7					&	a

(a) C = Coast, CR = Coastal Range, V = Central Valley.

(b) F = female, pF = probable female, M = male, pM = probable male, nd = non-determined.

(c) long bone = diaphysis of long bones, n.r. = not reported.

(d) & = integral pseudomorph and collagen yield > 1%, X = collagen not preserved, n.r. = not reported. Collagen results with C:N above or below the acceptable range (2.9 and 3.6) are shown in italics and were discarded from analyses.

(e) a = Falabella et al., (2007), b = Falabella and Sanhueza (2019), c = this publication, d = Poch Ambiental, 2014.

component or hydroxyapatite, produced by the whole diet, i.e. the carbohydrates and lipids as well as the proteins (Norr, 1995; Fernandes et al., 2012). Both the collagen and the apatite in bones are replaced constantly during the individual's life and reflect the mean diet of recent years of life according to the turnover rate of the bone analysed and the individual's age (Ambrose, 1993; Richards and Hedges, 1999; Hedges et al., 2007). Dental enamel on the other hand reflects the diet during the period in which the tooth was forming (Wright and Schwarcz, 1998), between the ages of approximately 9 and 12 years in the case of third molars and between 3.8 and 6.8 years in the case of second molars and premolars.

Four lines of isotope evidence were used in the present work:

1) The consumption of marine vs. terrestrial resources. Marine and terrestrial ecosystems differ fundamentally in their nitrogen isotope values (Keegan and DeNiro, 1988; Schoeninger et al., 1983; Walker and DeNiro, 1986; Bocherens et al., 1995; Hedges and Reynard, 2007). On the one hand,  $\delta^{15}\text{N}$  values distinguish between different trophic levels, increasing due to fractionation by up to around 6‰, in each successive level of the trophic chain (O'Connell et al., 2012). As this chain is longer in aquatic organisms, the  $\delta^{15}\text{N}$  value of diets based on marine products is noticeably higher. On the other hand, nitrates at the base of the marine food chain are enriched relative to nitrates consumed by terrestrial organisms; as a result, marine resources have more positive  $\delta^{15}\text{N}$  values than terrestrial resources at similar trophic levels. Although many variables may affect  $\delta^{15}\text{N}$  values, such as aridity, stress or disease (Ambrose, 1991; Szpak, 2014; Makarewicz and Sealy, 2015), in their absence, N is a good indicator of marine/terrestrial resources. They are also indicated by the carbon isotope value ( $\delta^{13}\text{C}$ ) because seawater bicarbonate is more positive than atmospheric  $\text{CO}_2$  (Chisholm et al., 1982; Schoeninger and DeNiro, 1984). An exception to this is maize, the only  $\text{C}_4$  plant used as a food source in significant quantities by the groups in this study.

We have isotope analyses for 51 local resources, both plants and animals, which support this distinction in the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values between marine and terrestrial products in the study zone (Falabella et al., 2007; Tykot et al., 2009). In the case of proteins, the mean  $\delta^{15}\text{N}$  value by type of marine resource varies from 16.0‰ (invertebrates) to 20.2‰ (marine mammals), while the mean value for the guanaco, the principal terrestrial meat source, is  $\delta^{15}\text{N}$  5.5‰. In non-coastal sites in the study area, the archaeofaunal evidence presents no remains of marine resources which might have been consumed, at least not in quantities detectable by isotope analysis. Consequently, we can use the isotope values indicating a marine or terrestrial diet as probable indicators of residence of the individual in one of these environments.

2) The isotope composition of drinking water. The  $^{16}\text{O}/^{18}\text{O}$  ratio in the hydroxyapatite in bone and in dental enamel reflects the values of the water in the body, derived from drinking water and to a lesser degree from foodstuffs (Longinelli, 1984; Luz and Kolodny, 1985). Human beings need to consume water every day for their organism to function, thus the isotope value of the oxygen in the carbonates in bones and tooth enamel can be used as a proxy for the water available in the surroundings of the sites where individuals lived. The values of oxygen isotopes in the geography of central Chile diminish gradually from the Pacific Ocean to the Andes due to the accumulated effects of evaporation, increased altitude and lower temperatures. This enables us to distinguish between people who lived on the coast, in the valleys of the Coastal Range, in the central valley and in the Andes (GNIP/IAEA/WMO, 2019). A latitudinal transect, from Punta Angeles station at sea level in Valparaíso to the Infiernillo station at 4200 masl in the Andes opposite Santiago, published by Moser et al. (1972) shows a decline in the annual mean values of deuterium in rainwater equivalent to  $\delta^{18}\text{O}_{\text{VSMOW}}$  14‰, and of more than 5‰ from Valparaíso on the coast to Santiago at 680 masl in the central valley, where the reported value is  $-8.8$ ‰. A similar value ( $\delta^{18}\text{O}_{\text{VSMOW}} -8.7$ ‰  $\pm 1.8$ ) was obtained from the data collected between 1991 and 2015 from the GNIP rainwater station in Santiago (Sánchez-Murillo et al., 2018). The spring water at

this location presents similar values to the rainwater (Iriarte et al., 2004), however the water in the Mapocho and Maipo rivers presents lower values ( $-12.7$ ‰  $\pm 1.9$ ) due to the contribution of snow-melt water, increasing the difference between the coast and the central valley by at least  $\delta^{18}\text{O}_{\text{VSMOW}}$  9‰ (IAEA, 2009; Iriarte et al. 2009). North-south mobility is also expressed in isotope values, but the differences are of a very much smaller magnitude and unlikely to be noticed at the spatial scale of this work. Finally, no differences should exist due to climate changes as the temperature and precipitations remained stable during the study period (Villa Martínez et al., 2004).

One of the problems with the use of  $\delta^{18}\text{O}$  values in archaeology is the conversion of the carbonate values in the bone, expressed according to the VPDB standard, to isotope values expressed according to the VSMOW standard of local waters. To avoid this problem, we will use as a reference the set of  $\delta^{18}\text{O}_{\text{VPDB}}$  values of the human bones analysed in each zone in the study area, which is considered to be a robust method (Lightfoot and O'Connell, 2016).

3) Maize consumption. The three groups studied have been described as horticulturalists, however the type of crop and the intensity of use differ, as has been shown by isotope and archaeobotanical analysis. The principal crop among the Bato was quinoa; among the Llolleo maize, beans and squash in addition to quinoa; and among the Aconcagua a remarkable increase is found in dependence on maize, together with evidence of the manipulation of maize and quinoa (Planella et al., 2014). In stable isotopes, maize consumption (photosynthetic pattern  $\text{C}_4$ ) is clearly manifested in the carbon values in central Chile ( $\delta^{13}\text{C} -11.2$ ‰) as elsewhere; this distinguishes it from other plants of the region, both wild and cultivated (photosynthetic pattern  $\text{C}_3$ ) which have more negative values ( $\delta^{13}\text{C}$  between  $-30.4$  and  $-21.0$ ‰) (Falabella et al., 2007). Results presented by the authors in previous works were indicative of an increase in maize consumption over time, however the present work contains new data from Bato individuals which open a new perspective on the similarities and differences between this group and the Llolleo and Aconcagua groups. This line of evidence is also used to explore differences in maize consumption by sex and age.

4) Changes over the life histories of individuals. Comparison of nitrogen and oxygen isotopes in tooth-bone pairs from individuals was used to assess possible changes in subsistence and residence between childhood and adulthood, and thus determine whether the individual lived in isotopically different zones during his/her life (Wright and Schwarcz, 1998; White et al., 2004; Eerkens et al., 2014). The environmental and resource distribution conditions in the study area, as in the case of the other lines of evidence, allow us to distinguish principally the coast from the interior.

### 2.3. Analytical methods

The analyses were carried out in the Laboratory for Archaeological Science at the University of South Florida (USF) or in the Center for Applied Isotope Studies at the University of Georgia (CAIS-UGAM), each of which followed their own protocols for obtaining and analysing collagen and apatite; they did not necessarily use the same methodology.

At USF (Tykot, 2004) the whole bone sample is demineralized for collagen in 2% hydrochloric acid, base-soluble contaminants are removed using 0.1 M sodium hydroxide (24 h each before and after demineralization), and residual lipids are dissolved in a 2:1:0.8 mixture of methanol, chloroform, and water (24 h). One milligram samples of the resulting collagen pseudomorphs are analysed in a continuous flow mode using a CHN analyser coupled with a Finnigan MAT stable isotope ratio mass spectrometer. Sample integrity is visually evaluated with the pseudomorphs and confirmed through collagen yield above 1% and C:N ratios. For bone apatite and enamel the sample is cleaned ultrasonically and crushed, sifted and sorted centrifugally. Approximately 10 mg of powder are immersed in 2% sodium hypochlorite to dissolve organic

components (24 h for enamel, 72 h for bone apatite). Non-biogenic carbon is treated with this method tested to be successful in removing diagenetic contaminants (Koch et al., 1997). The integrity of apatite and enamel samples is assessed through yields obtained in each stage of the pre-treatment process. Samples are analysed on a Finnigan MAT mass spectrometer equipped with a Kiel III individual acid bath carbonate system. Samples are measured against reference gases and several standard samples are analysed at the beginning of each run and then after every six or seven archaeological samples to ensure the reliability of the results. The analytical precision for stable isotope ratio mass spectrometry is better than ca. 0.1‰ for  $\delta^{13}\text{C}$  and 0.2‰ for  $\delta^{15}\text{N}$ .

At CAIS (Cherkinsky, 2009) bone samples are broken into small particles and demineralized for collagen with cold (4 °C) 1 N HCL for 24 h, filtered and washed with deionized water. The samples are then rinsed with 0.1 M NaOH, washed, rinsed with 1 N HCL and washed in deionized water at pH 4 and heated at 80 °C for 8 h. The solutions are filtered through fiberglass filters to isolate the total acid-insoluble fractions (collagen) and freeze-dried. Isotope ratios are measured using an elemental analyser isotope ratio mass spectrometer (EA\_IRMS). Bone apatite and enamel samples are pre-treated following the acetic acid hydrolysis protocol. The samples are crushed and reacted with 1 N acetic acid which is evacuated and re-pressurized periodically, allowing them to react overnight. Then the samples are rinsed repeatedly in deionized water and dried. Stable isotope ratios are measured using a GasBench-IRMS and report an error of less than 0.1‰. In both laboratories, results are reported as  $\delta$  values with respect to international standards: Vienna Pee Dee Belemnite (VPDB) for carbon and atmospheric nitrogen (AIR) for nitrogen.

Working with values derived from two laboratories does not represent a major problem in the case of collagen, to judge by the results of an inter-laboratory study which showed that in the analysis of stable isotopes of bone collagen the differences between laboratories are insignificant. Apatite, on the other hand, showed variability under analysis which might be confused with biological differences, and it is recommended that data of this type should be viewed with great caution (Pestle et al., 2014). Only the samples with adequate collagen preservation are included in the results (C:N between 2.9 and 3.6 in the case of the UGAM samples and/or integral pseudomorphs with collagen yield  $\geq 1\%$  in the case of the USF samples). Two-sample and paired t-tests were performed for testing intra- and inter-group differences using Mstat 12.

### 3. Results and discussion

#### 3.1. Mobility and socio-spatial organization

The isotope values obtained from the samples discussed in this work are detailed in Table 1. The samples from coastal sites, both from the Early Ceramic and from the Late Intermediate periods, systematically show higher  $\delta^{15}\text{N}$  values than those from inland sites due to marine proteins in their diet (Fig. 2). Additionally, most of the individuals analysed, from both the Early Ceramic and the Late Intermediate periods, exhibit  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values in their bones consistent with their place of burial (Figs. 3 and 4). They suggest that most people either remained in their places of residence or moved between isotopically similar environments.

As may be seen in Fig. 3, Bato and Llolleo individuals from the ECP buried inland (white symbols) have oxygen isotope profiles compatible with the central valley, while the  $\delta^{15}\text{N}$  values show that they did not consume marine resources; those buried on the coast on the other hand (black symbols) exhibit higher  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values consistent with water from environments close to the sea and diets which included marine resources. As shown in Table 2, where we have compiled all the data available to date on  $\delta^{18}\text{O}$  values in human bones ( $n = 129$ ), significant differences exist between the environments under analysis (pooled variance two sample t-test coast vs coastal range,  $t = 5.337$ ,

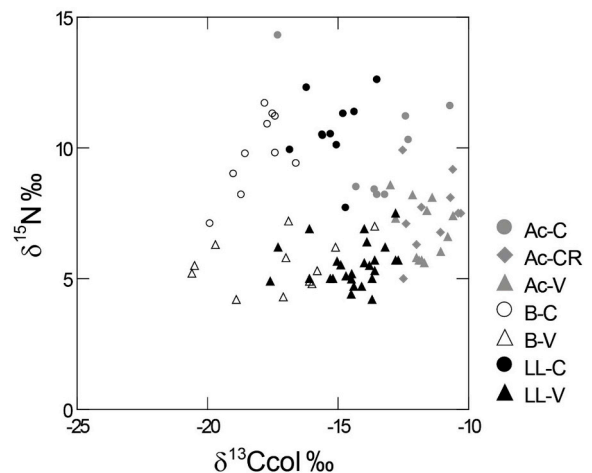


Fig. 2. Biplot showing  $\delta^{13}\text{C}_{\text{col}}$  and  $\delta^{15}\text{N}$  values from all the analysed samples according to cultural group and geographical zone. Ac = Aconcagua, B = Bato, LL = Llolleo, C = Coast, CR = Coastal Range, V = Valley. Number of individuals: Bato = 21; Llolleo = 37; Aconcagua = 31.

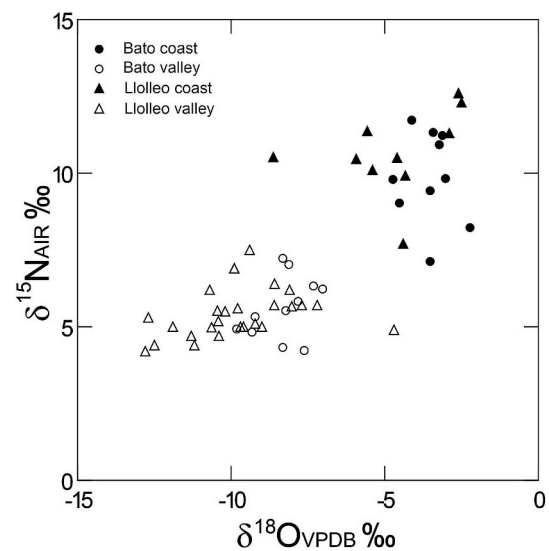


Fig. 3. Biplot showing Early Ceramic Period  $\delta^{18}\text{O}$  (proxy for drinking water) and  $\delta^{15}\text{N}$  (proxy for consumption of marine resources) values. Number of individuals: Bato  $n = 21$ ; Llolleo  $n = 37$ .

$df = 43.000$ ,  $p\text{-value} = 0.000$ ; coastal range vs valley,  $t = 4879$ ,  $df = 100.000$ ,  $p\text{-value} = 0.000$ ). These data are used as a reference for the oxygen isotope values of the drinking water in the different locations.

An interesting difference from the other groups is observed among the Aconcagua groups of the LIP (Fig. 4): the samples from the Puangué valley in the Coastal Range show higher  $\delta^{18}\text{O}$  values than would be expected for this zone (Table 2), which we interpret as possibly representing water drunk from sources close to the coast. Moreover, half of the individuals buried on the coast and with coastal water  $\delta^{18}\text{O}$  values exhibit  $\delta^{15}\text{N}$  values which reflect scarce marine resources and consumption of foodstuffs of terrestrial origin. These data suggest mobility between the coast and the valleys of the Coastal Range, since many of those buried both on the coast and in the interior show oxygen isotope values for drinking water and oxygen and nitrogen values for food consumed which do not fully match expected isotope values for their burial place.

Following another line of evidence for mobility, the graph in Fig. 5 shows the  $\delta^{18}\text{O}$  value pairs for bone and tooth enamel in the same

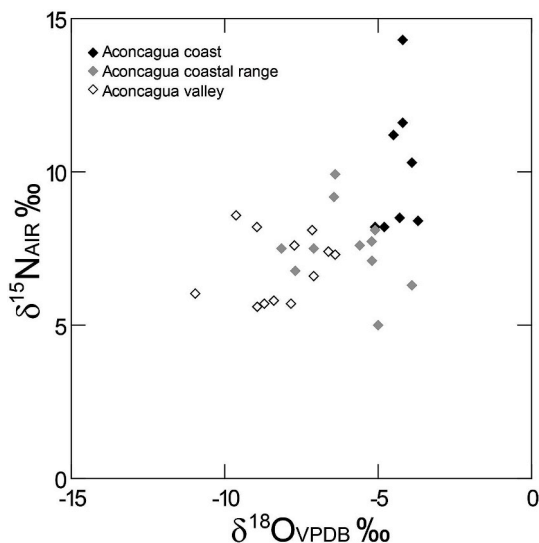


Fig. 4. Biplot showing Late Intermediate period  $\delta^{18}\text{O}$  (proxy for drinking water) and  $\delta^{15}\text{N}$  (proxy for consumption of marine resources) values. Number of Aconcagua individuals: Coast  $n = 8$ , Coastal Range  $n = 11$ , Valley  $n = 12$ .

Table 2  
Mean  $\delta^{18}\text{O}_{\text{PDB}}$  values of human bones analysed by geographic zone.

Geographic Zone	Zone	n	mean $\delta^{18}\text{O}_{\text{PDB}} \text{‰}$	SD
COAST	Coast	25	-3.780	0.921
	River Maipo Coast	5	-4.786	0.677
COASTAL RANGE	Maipo middle	7	-7.480	1.474
	valley			
VALLEYS	Puangue valley	7	-5.407	0.870
	Alhué valley	4	-7.492	0.510
CENTRAL VALLEY	Northern Santiago	51	-8.496	1.601
	Southern Santiago	22	-9.752	1.767
	Rancagua	8	-8.506	0.973

individual. Most of them differ by less than 1.6‰, which can be assumed to reflect the physiological variation expected in a human being without implying a change of residence. As some studies have established a range of 2‰ for this variation (White et al., 2004) in the present study an intra-individual isotope spacing  $\geq 2\text{‰}$  was considered as evidence of a change of residence from childhood to adulthood. Other studies have proposed that the intra-population variation in oxygen isotope values may be greater (Lightfoot and O’Connell, 2016).

The Llolleo are the group with more individuals presenting intra-individual isotope spacing  $\geq 2\text{‰}$  in the  $\delta^{18}\text{O}$  value. Six individuals moved from their childhood place of residence, some towards the coast and some towards the central valley, representing 30% of the Llolleo individuals for whom tooth-bone pairs exist. It should be noted that in five cases the individuals are female (38.5% of females) and in only one case a male (14.3% of males). Two of them (El Mercurio #25 and Las Pataguas #1) must have lived in Coastal Range environments as children and then moved to the central valley. Sample LEP-C #9, with coastal  $\delta^{18}\text{O}$  value but a spacing greater than 2‰ between bone and tooth and a marine diet, must have moved between different coastal environments; while the male who lived in the interior as a child (TV1 #12), later moved to the coast where he consumed a marine diet and was buried. Two cases are more complex. For one of them, a female buried in a coastal site (TV3 #9), the bone nitrogen isotope value indicates that she consumed marine products, and the  $\delta^{18}\text{O}$  value in her tooth reflects consumption of coastal waters. Nevertheless, her bone exhibits an oxygen isotope value in accordance with the central valley. The reverse is the case of El Mercurio #13, a female buried in the central valley, whose tooth  $\delta^{18}\text{O}$  indicates consumption of inland waters, i.e. she lived inland as a child, but whose bone oxygen isotope value shows that she lived on the coast as an adult. We have no tooth sample for TV-5 #6-6, a male individual buried on the coast, however his bone values show that marine fauna did not constitute his main protein source.

Among the Bato, only two individuals (25% of the total Bato paired samples), one female (Don Ladislao #3-1) and one male (Don Ladislao #1-1) buried at the same site in the central valley, originally came from areas closer to the coast judging by their  $\delta^{18}\text{O}$  tooth values; both

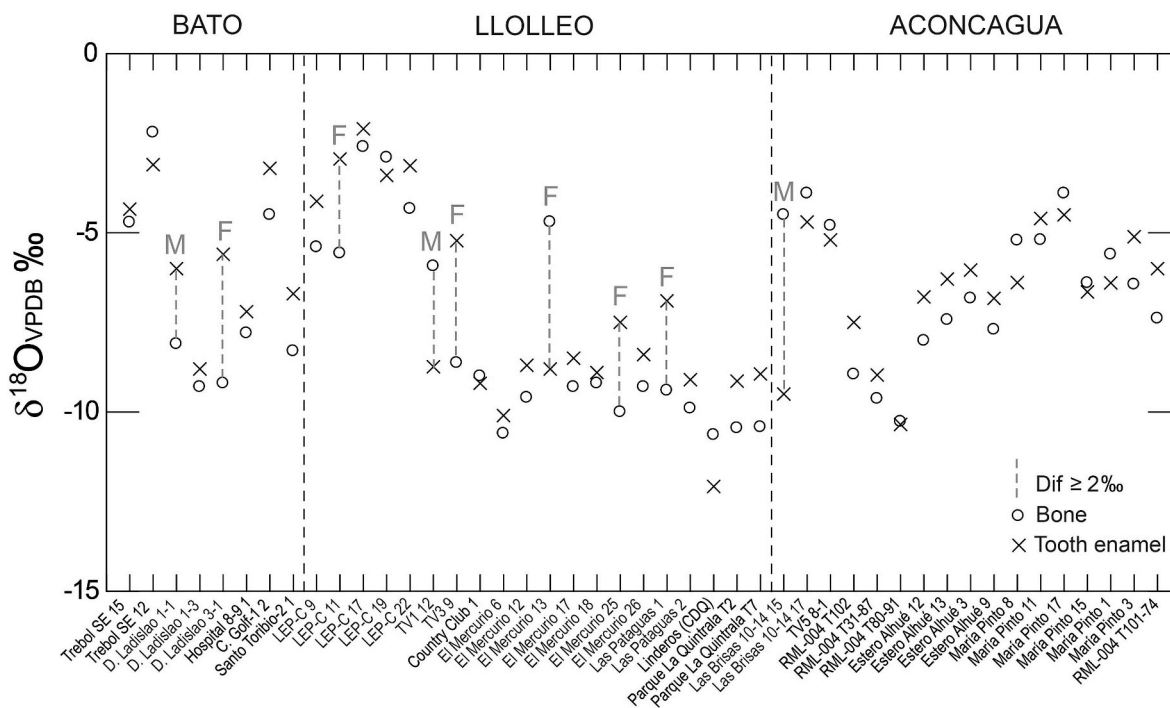


Fig. 5. Intra-individual spacing of  $\delta^{18}\text{O}$  values from paired samples of tooth and bone. Cases with spacing larger than 2‰ between tooth and bone are linked with a gray discontinuous line. Sex is coded as F (female) or M (male). Number of individuals: Bato  $n = 8$ ; Llolleo  $n = 20$ ; Aconcagua  $n = 17$ .



present an enriched  $\delta^{13}\text{C}$  value from their diet, suggesting increased maize consumption as adults. In the LIP, there is only one case of an Aconcagua male who lived in the central valley as a child and later moved to live on the coast where he was buried (Las Brisas 10–14 #15). The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values in his bone show that he adopted a marine diet. He represents 5.9% of Aconcagua individuals with paired samples and 11.8% of male individuals.

These results provide a new perspective on mobility in sedentary and semi-sedentary communities in central Chile, despite the limitations of the number of samples and the sometimes uneven distribution between males and females or between sites and locations. The data confirm that certain persons moved away from their places of residence temporarily or permanently, and that how they did so differed between the three groups studied. As movements between isotopically similar locations remain obscured, this mobility may have involved more individuals than we can identify here.

Unfortunately, we have few samples for the Bato; however the data suggest movement by at least 25% of the population, perhaps family groups, and following a different pattern from that of the Llolleo and Aconcagua groups. These results are consistent with and support the archaeological data, based on pottery, subsistence and the structure of residential sites, based on which it has been hypothesised that the Bato were quite mobile, with the whole group changing residence occasionally (Planella and Falabella, 1987; Rodríguez et al., 1991; Sanhueza, 2016).

The case of the Llolleo is more robust. According to the archaeological evidence, the Llolleo lived in co-residential communities which were permanent for at least several generations (Falabella et al., 2014; Sanhueza, 2016). The isotope data reveal a pattern of mobility by sex and age: some adult women moved to other communities from where they grew up. This pattern is consistent with socio-spatially institutionalised forms of movement in patrilocal systems typical of some small-scale societies, as a mechanism for consolidating networks and alliances in which women play an active role in regional integration and knowledge transfer (Service, 1962; Faron, 1969; Ember and Ember, 1983).

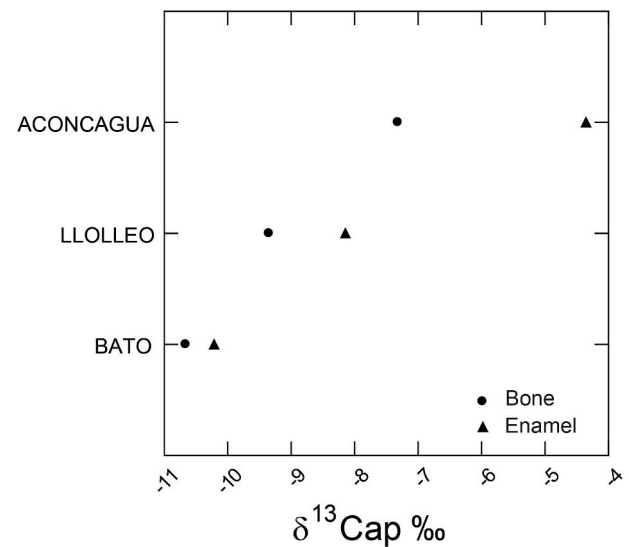
The Aconcagua group does not reflect these practices, showing minimal residential mobility. Nevertheless, the isotope data show other integrating mechanisms on a smaller spatial scale. This is a pattern in which persons of both sexes circulated between the valleys of the Coastal Range and the coastal plains. We believe that these may have been temporary movements in a socially recognised, shared territorial space. As in the previous cases, this interpretation is in line with the archaeological evidence. Based on pottery studies it has been proposed that some pots found in coastal sites were produced in the Puangue area, denoting exchange or access to the coast by people from the Coastal Range (Falabella and Andonie, 2011), a pattern of economic and spatial integration that still existed in the 16th century (Contreras, 2009).

### 3.2. Age and sex differences

Between the ECP and the LIP an important change can be seen in the diet of children vs adults (pooled two-sample *t*-test,  $t = -3.982$ ,  $df = 43.000$ ,  $p\text{-value} = 0.000$ ) (Table 3, Fig. 6). In both the Bato and the Llolleo groups the mean  $\delta^{13}\text{C}$  values of adult individuals ( $> 18$

**Table 3**  
Mean  $\delta^{13}\text{C}$  values for  $\delta^{13}\text{Cap}$  bone samples (adulthood) and  $\delta^{13}\text{Cen}$  tooth samples (childhood) in paired samples.

CONTEXT	n	$\delta^{13}\text{Cap}$ ‰	SD	$\delta^{13}\text{Cen}$ ‰	SD	$\Delta$
Bato	8	-10.664	0.897	-10.215	0.874	0.449
Llolleo	20	-9.351	0.298	-8.147	0.394	0.927
Aconcagua	17	-7.320	0.227	-4.355	0.409	2.965



**Fig. 6.** Graph showing mean  $\delta^{13}\text{Cap}$  values in pairs of teeth and bones by cultural context.

years) is very similar to that in their childhood ( $< 12$  years) (mean difference 0.449 and 0.927, respectively); in contrast, in the Aconcagua population the children's diet presents a remarkably higher mean  $\delta^{13}\text{Cap}$  value, indicating greater  $\text{C}_4$  foods consumption (mean difference = 2.965; paired *t*-test  $t = -5.898$ ,  $df = 16$ ,  $p\text{-value} = 0.000$ ).

Although these differences exist in the quantity of  $\text{C}_4$  resources consumed during childhood by individuals of the LIP compared with those of the ECP, in both cases and in the three contexts analysed we find no differential treatment between boys and girls for this type of resources. The *t*-tests show that there is no significant difference by sex during childhood in either the Bato, the Llolleo or the Aconcagua groups ( $p\text{-values}$  0.487, 0.471 and 0.547 respectively).

This situation changes for adults. During the ECP, in the Bato and Llolleo samples, there are no major differences in behaviour between men and women in the consumption of  $\text{C}_4$  resources, as reflected either in the collagen or the apatite isotope values (Table 4). In the LIP on the other hand, although there are no differences in apatite between men and women above 18 years, there are differences in collagen with adult males presenting higher carbon isotope values suggesting greater consumption of  $\text{C}_4$  protein resources (pooled variance  $t = -2.093$ ,  $df = 27$ ,  $p = 0.046$ ), in line with the ideas on sex differentiation proposed by Sánchez (1997). We believe that it is an interesting result which could suggest new gender-based functions in roles and hierarchies during this period. The difference may well be due to the greater consumption of maize-fed guanaco meat by men, rather than more consumption of maize or maize *chicha*. This difference would not appear to be due to marine resources since the  $\delta^{15}\text{N}$  values are not higher among males. The archaeofaunal records of domestic sites in central Chile provide evidence of a change in human-animal relations in the LIP. Unlike the ECP, when the edible parts of guanacos were generally brought to the residential site, in the LIP the whole animal is found (Becker, 1994). This has led to the proposal that at this time animal-raising practices were adopted, with animals kept close to residences and crop fields, perhaps being fed partly on maize (Soto, 2018). The isotope data available indicate consistently that guanacos in the LIP exhibit higher collagen isotope values ( $\delta^{13}\text{Ccol} -17.9 \pm 2.1$ ) than those in the same region during the ECP ( $\delta^{13}\text{Ccol} -19.9 \pm 0.5$ ) (Tykot et al., 2009), suggesting that the carbon isotope enrichment of the male population may be influenced by higher consumption of guanaco meat. Some dimensions of social organization seem to have changed in the Late Intermediate period, possibly related with the commensalism and hospitality practices associated with the creation

**Table 4**

Mean  $\delta^{13}\text{C}_{\text{col}}$ ,  $\delta^{13}\text{C}_{\text{ap}}$  and  $\delta^{15}\text{N}$  values for female and male bone samples (adult individuals) with results of pooled variance two sample T-test to test differences by sex.

Context	Female n	Male n	Female Mean $\delta^{13}\text{C}$ (SD)	Male Mean $\delta^{13}\text{C}$ (SD)	T-test	
					t	p-value
Bato $\delta^{13}\text{C}_{\text{col}}$ ‰	9	12	-17.306 (1.377)	-17.625 (1.918)	0.423	0.677
Bato $\delta^{13}\text{C}_{\text{ap}}$ ‰	9	12	-10.557 (2.287)	-9.725 (1.557)	-0.993	0.333
Bato $\delta^{15}\text{N}$ ‰	9	12	7.919 (2.875)	7.383 (2.272)	0.477	0.638
Llolleo $\delta^{13}\text{C}_{\text{col}}$ ‰	22	14	-14.787 (1.283)	-14.472 (1.099)	-0.758	0.454
Llolleo $\delta^{13}\text{C}_{\text{ap}}$ ‰	27	17	-9.036 (1.382)	-8.895 (1.336)	-0.332	0.742
Llolleo $\delta^{15}\text{N}$ ‰	22	14	6.929 (2.679)	6.949 (2.424)	-0.023	0.982
Aconcagua $\delta^{13}\text{C}_{\text{col}}$ ‰	12	17	-12.698 (1.755)	-11.651 (1.054)	-2.093	<b>0.046</b>
Aconcagua $\delta^{13}\text{C}_{\text{ap}}$ ‰	16	20	-7.261 (1.646)	-6.889 (1.052)	-0.825	0.415
Aconcagua $\delta^{15}\text{N}$ ‰	12	18	8.278 (2.202)	7.871 (1.775)	0.560	0.580

and maintenance of relations outside the domestic unit. Although the sample is small, and in some cases the sex of the individuals is only probable, the isotope data support a change in the Aconcagua groups, pointing to explicit gender categories, that might have involved social activities and specific roles. Age categories were also distinguished in dietary practices, giving credit to the ideas of a radical overturning of earlier traditions (Cornejo, 2010).

### 3.3. Consumption pattern of C<sub>4</sub> resources

Another area in which stable isotopes have contributed to our study problem is the C<sub>4</sub> resource consumption behaviour of individuals from the ECP and the LIP. Earlier works have indicated that the Aconcagua samples from the LIP presented more enriched carbon isotope values than the previous period, reflecting an increase in maize consumption (Falabella et al., 2007, 2008). Looking at the results from a broader sample, this difference is statistically robust (t = -8955, df = 95.000, p-value = 0.000 for  $\delta^{13}\text{C}_{\text{col}}$ ; t = -7502, df = 110.000, p-value = 0.000 for  $\delta^{13}\text{C}_{\text{ap}}$ ) (Fig. 7).

For the ECP, the larger number of samples of Bato individuals allows a more substantiated comparison between this group and the Llolleo group. On the one hand, both groups continue to show a pattern of greater C<sub>4</sub> contribution in the inland population than in the coastal. On the other, the data show a greater enrichment of collagen than apatite in the Llolleo samples when compared to the Bato. This may be due to

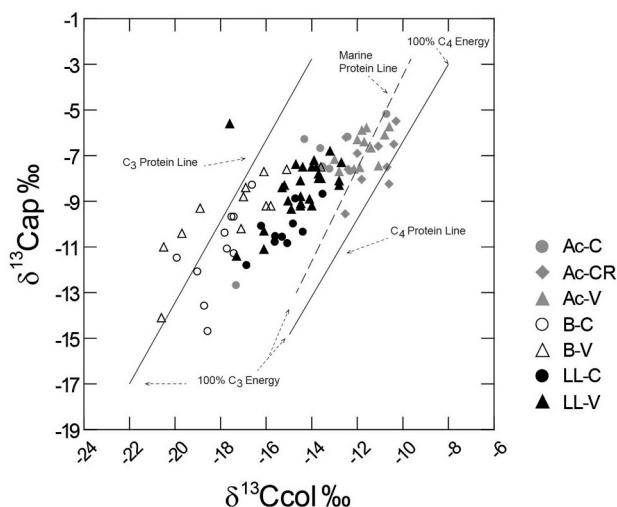
the consumption of animals with a C<sub>4</sub> diet in the Llolleo sites as described above for the Aconcagua. Nevertheless, no available zooarchaeological or isotope data for the fauna support this interpretation. Another possibility is that the Llolleo population consumed very little animal protein, so that maize proteins supplied what would otherwise be provided by the fauna. This interpretation is more in line with the archaeological data, which indicate a decrease in the number of lithic artefacts for hunting and the consolidation of a complex of crops which position the Llolleo as an eminently horticultural population, in contrast to the Bato who maintained their hunting practices strongly (Planella et al., 2014).

Finally, the intra-site variation of C<sub>4</sub> resource consumption shows differences between individuals who inhabited the same residential grouping. In general, there is greater internal variation among the Bato, i.e. some individuals eat maize, others do not. In the Llolleo group, sites differ greatly: some are quite homogeneous, while in others individuals differ considerably; moreover, not all the communities depended on maize horticulture in the same way, irrespective of the chronology. Something similar is found for the Aconcagua: it was expected that a maize-based diet would be consolidated, however variations are found between individuals and sites. In any case, uniform sampling and a larger number of individuals per site would be necessary to validate these results.

### 4. Conclusions

The results presented above, and the inferences proposed on that basis, expand knowledge about the prehistory of central Chile during the first millennium AD and the first half of the second, suggesting a more complex and diversified view. Although these conclusions must not be treated as definitive, since they will be validated or modified as new data are incorporated, the inclusion of more lines of isotope evidence has marked real progress in integrating social issues which are hard to grasp from artefacts.

On the one hand, differences are found in the mobility patterns and maize consumption of the three groups studied. In these societies, described as sedentary or semi-sedentary, the movements of individuals were previously scarcely examined. Stable isotope analysis has enabled us to support the idea that Bato groups practised residential mobility, probably involving the family group. In the Llolleo groups, the evidence points mainly to changes of residence by women. In the Aconcagua population, only one case of permanent transfer from one location to another was found, however the evidence indicated a pattern of circulation, probably temporary, between the valleys of the Coastal Range and the coastline by both females and males. Turning to maize consumption, during the Early Ceramic period the increase is uneven, and the results show differences between individuals and residential complexes. Greater regularity and intensity of consumption is found in the Llolleo group than among the Bato, but with definite evidence that some Bato individuals also included maize in their diet, in differing



**Fig. 7.** Early Ceramic and Late Intermediate periods  $\delta^{13}\text{C}$  values in apatite and collagen as proxies for the consumption of C<sub>3</sub> vs C<sub>4</sub> energy and protein resources, according to cultural group and geographical zone. Line references as proposed by Kellner and Schoeninger (2007) model. Ac = Aconcagua, B = Bato, LL = Llolleo, C = Coast, CR = Coastal Range, V = Valley.

proportions. The Aconcagua groups differ from the other two, with markedly higher consumption.

Details of social differentiation associated with age and sex were also found, affecting only the Aconcagua population in the Late Intermediate period. In terms of age, male and female children present a higher level of maize in their diet than adults. In relation to sex, adult males present greater  $^{13}\text{C}$  enrichment of their collagen, which is interpreted as being related with consumption of  $\text{C}_4$  enriched meat.

This work is not free of problems and limitations. One of the greatest problems is the number of samples, which is still too small for some intra-group comparisons, together with the unequal representation of the samples in the sites and the different locations. Moreover, the gender determination of individuals is subject to ambiguities, and this generates biases in the recognition of possible differences between males and females over time. This is an important issue for planned future work focusing on social questions. It is hoped that further stable isotope analysis in this region will produce increasingly reliable results.

### Formatting of funding sources

This work was supported by Fondecyt [grant numbers 1160511, 1090200, 1040553] and POCH Ambiental for analyses of samples from the Carozzi site. Analysis of the recent samples was authorized by the Chilean Council for National Monuments (CMN) Ord. N°2578-17 and N°0385-18.

### Acknowledgements

Our thanks to the archaeologists responsible for investigations at the sites analysed, those responsible for the EIA and the reports used. The authors thank the various institutions for permission to take samples and analyse bio-anthropological material from their collections. We are grateful for the contribution of the three anonymous reviewers whose observations helped to improve the text and clarify the results.

### References

- Ambiental, Poch, 2014. Informe Final: Rescate Arqueológico Sitio Carozzi. Consejo de Monumentos Nacionales, Santiago Unpublished report.
- Ambrose, S.H., 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *J. Archaeol. Sci.* 18, 293–317.
- Ambrose, S.H., 1993. Isotopic analysis of paleodiets: methodological and interpretive considerations. In: Stanford, M.K. (Ed.), *Investigations of Ancient Human Tissue. Chemical Analysis in Anthropology*. Breach Science Publishers, Pennsylvania, USA, pp. 59–130.
- Ambrose, S.H., Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert, J.B., Grupe, G. (Eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level*. Springer-Verlag, New York, pp. 1–37.
- Becker, C., 1994. Desde el período Alfarero Temprano al Medio-Tardío a través de la lectura de sus restos faunísticos. *Boletín Museo Regional de la Araucanía* 5, 41–52.
- Bocherens, H., Fogel, M.L., Tuross, N., Zeder, M., 1995. Trophic structure and climatic information from isotopic signatures in a Pleistocene cave fauna of Southern England. *J. Archaeol. Sci.* 22, 327–340.
- Cherkinsky, A., 2009. Can we get a good radiocarbon age from “bad bone”? Determining the reliability of radiocarbon age from bioapatite. *Radiocarbon* 51, 647–655.
- Chisholm, M.S., Nelson, D.E., Schwarcz, H.P., Knyf, M., 1982. Carbon isotope measurement techniques for bone collagen: notes for the archaeologist. *J. Archaeol. Sci.* 10, 335–360.
- Contreras, H., 2009. Encomienda y servicio personal entre las comunidades indígenas de Chile central. PhD thesis. Facultad de Filosofía y Humanidades, Universidad de Chile, Santiago, pp. 1541–1580.
- Cornejo, L., 2010. Hacia una hipótesis sobre el surgimiento de la cultura Aconcagua. *Actas XVII Congreso Nacional de Arqueología Chilena I*, pp. 341–350.
- Díaz, G., 2017. Cuentas, collares e identidades en el complejo cultural Lillo: período Alfarero Temprano de Chile central. *Archaeological Title thesis*, Universidad de Chile, Santiago.
- Eerkens, J.W., Barford, G.H., Jorgenson, G.A., Peske, C., 2014. Tracing the mobility of individuals using stable isotope signatures in biological tissues: “locals” and “non-locals” in an ancient case of violent death from Central California. *J. Archaeol. Sci.* 41, 474–481. <https://doi.org/10.1016/j.jas.2013.09.014>.
- Ember, M., Ember, C.R. (Eds.), 1983. *Marriage, Family, and Kinship*. HRAF Press, New Haven.
- Falabella, F., 2000. El sitio arqueológico de El Mercurio en el contexto de la problemática cultural del período alfarero temprano en Chile central. *Actas Segundo Taller de Arqueología de Chile Central 1993*. <http://www.arqueologia.cl/actas2/falabella.pdf>.
- Falabella, F., Andonie, O., 2011. Análisis por activación neutrónica instrumental de alfarería Aconcagua en el valle del río Maipo, Chile. In: Vetter, L., Vega-Centeno, R., Olivera, P., Petrick, S. (Eds.), *II Congreso Latinoamericano de Arqueometría*. IPEN, UNI, OEI, Lima, Perú, pp. 215–228.
- Falabella, F., Sanhueza, L., 2019. Living on the coast without depending on coastal resources. Isotopic evidence in Central Chile. *J. Archaeol. Sci.: Rep.* 26, 101890. <https://doi.org/10.1016/j.jasrep.2019.101890>.
- Falabella, F., Planella, M.T., Aspillaga, E., Sanhueza, L., Tykot, R.H., 2007. Dieta en sociedades alfareras de Chile central: aporte de análisis de isótopos estables. *Chungara, Revista de Antropología Chilena* 39, 5–27.
- Falabella, F., Planella, M.T., Tykot, R.H., 2008. El maíz (*Zea mays*) en el mundo prehispánico de Chile central. *Lat. Am. Antiq.* 19, 25–46.
- Falabella, F., Cornejo, L., Correa, I., Sanhueza, L., 2014. Organización espacial durante el período Alfarero Temprano en Chile central: un estudio a nivel de la localidad. In: Falabella, F., Sanhueza, L., Cornejo, L., Correa, I. (Eds.), *Distribución espacial en sociedades no aldeanas: del registro arqueológico a la interpretación social*. Monografías N°4. Sociedad Chilena de Arqueología, Santiago, pp. 51–88.
- Falabella, F., Pavlovic, D., Planella, M.T., Sanhueza, L., 2016. Diversidad y heterogeneidad cultural y social en Chile durante los períodos Alfarero Temprano e Intermedio Tardío (300 a.C. A 1450 d.C.). In: Falabella, F., Uribe, M., Sanhueza, L., Aldunate, C., Hidalgo, J. (Eds.), *Prehistoria en Chile. Desde sus primeros habitantes hasta los Incas*. Editorial Universitaria, Sociedad Chilena de Arqueología, Santiago, pp. 365–399.
- Faron, L., 1969. Los Mapuche. Su Estructura Social. Instituto Indigenista Interamericano, México.
- Fernandes, R., Nadeau, M.-J., Grootes, P.M., 2012. Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. *Archaeol. Anthropol. Sci.* 4, 291–301.
- GNIP/IAEA/WMO, 2019. Global Network of Isotopes in Precipitation and Global Network of Isotopes in River. The GNIP Databases Accessible at: <http://www.iaea.org/water>. Last, Accessed date: 15 March 2019.
- Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *J. Archaeol. Sci.* 34, 1240–1251.
- Hedges, R.E.M., Clement, J.G., Thomas, D.L., O’Connell, T.C., 2007. Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. *Am. J. Phys. Anthropol.* 133, 808–816. <https://doi.org/10.1002/ajpa.20598>.
- IAEA, 2009. Atlas of isotope hydrology. The Americas. RLA8031-CHI Santiago de Chile area. IAEA, Vienna.
- Iriarte, S., Tore, C., Pardo, M., Aguirre, E., Aravena, E.R., 2004. Use of environmental isotopes to evaluate natural and anthropic sources of groundwater in an area with multiple land uses, Santiago Norte Basin, Chile. In: *International Symposium on Isotope Hydrology and Integrated Water Resources Management. Book of Extended Synopses*, pp. 30–32 IAEA-CN-104/51.
- Iriarte, S., Atenas, M., Aguirre, E., Torres, C., 2009. Aquifer recharge and contamination determination using environmental isotopes: Santiago basin, Chile. A study case. In: *Estudios de Hidrología Isotópica en América Latina*. IAEA, Viena, pp. 97–112.
- Katzenberg, M.A., 1992. Advances in stable isotope analysis of prehistoric bones. In: Saunders Shelly, R., Anne, Katzenberg M. (Eds.), *Skeletal Biology of Past Peoples: Research Methods*. Wiley-Liss, Inc., USA, pp. 105–119.
- Keegan, W.F., DeNiro, M.J., 1988. Stable carbon and nitrogen-isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. *Am. Antiq.* 53, 320–336.
- Kellner, C.M., Schoeninger, M.J., 2007. A simple carbon isotope model for reconstructing prehistoric human diet. *Am. J. Phys. Anthropol.* 133, 1112–1127.
- Koch, P.L., Tuross, N., Fogel, M.L., 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. *J. Archaeol. Sci.* 24, 417–429.
- Lightfoot, E., O’Connell, T.C., 2016. On the use of biomineral oxygen isotope data to identify human migrants in the archaeological record: intra-sample variation, statistical methods and geographical considerations. *PLoS One* 11 (4), e0153850. <https://doi.org/10.1371/journal.pone.0153850>.
- Longinelli, A., 1984. Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research. *Geochim. Cosmochim. Acta* 48, 385–390.
- Luz, B., Kolodny, Y., 1985. Oxygen isotope variations in phosphate of biogenic apatites. *Earth Planet. Sci. Lett.* 75, 29–36.
- Makarewicz, C.A., Sealy, J., 2015. Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: expanding the prospects of stable isotope research in archaeology. *J. Archaeol. Sci.* 56, 146–158.
- Moser, H., Silva, C., Stichler, W., Stöwhas, L., 1972. Measuring the isotope content in precipitation in the Andes. *Proc. Banff Symp.* 1, 15–23 UNESCO-WMO-IAHS.
- Norr, L., 1995. Interpreting dietary maize from bone stable isotopes in the American Tropics: the state of the art. In: Stahl, P.W. (Ed.), *Archaeology in the Lowland American Tropics*. Cambridge University Press, Cambridge, pp. 198–233.
- O’Connell, T.C., Kneale, C.J., Tasevska, N., Kuhnle, G.G.C., 2012. The diet-body offset in human nitrogen isotopic values: a controlled dietary study. *Am. J. Phys. Anthropol.* 149, 426–434. <https://doi.org/10.1002/ajpa.22140>.
- Passes, B.H., Robinson, T.F., Ayliffe, L.K., Cerling, T.E., Sponheimer, M., Dearing, M.D., Roeder, B.L., Ehleringer, J.R., 2005. Carbon isotope fractionation between diet, breath  $\text{CO}_2$ , and bioapatite in different mammals. *J. Archaeol. Sci.* 32, 1459–1470.
- Pestle, W.J., Crowley, B.E., Weirauch, M.T., 2014. Quantifying inter-laboratory variability in stable isotope analysis of ancient skeletal remains. *PLoS One* 9, e102844. <https://doi.org/10.1371/journal.pone.0102844>.
- Planella, M.T., Falabella, F., 1987. Nuevas perspectivas en torno al Período Alfarero

- Temprano en Chile central. *Clava* 3, 43–110.
- Planella, M.T., Falabella, F., Belmar, C., Quiroz, L., 2014. Huertos, chacras y sementeras. Plantas cultivadas y su participación en los desarrollos culturales de Chile central. *Rev. Española Antropol. Am.* 44, 495–522.
- Richards, M.P., Hedges, R.E.M., 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *J. Archaeol. Sci.* 26, 717–722.
- Rodríguez, J., Avalos, H., Falabella, F., 1991. La tradición Bato al norte del Aconcagua. In: *Actas XI Congreso Nacional de Arqueología Chilena*. T.3. MNHN, SCHA, Santiago, pp. 69–79.
- Sánchez, R., 1997. Muerte, vida, mujeres y hombres en la cultura Aconcagua. *Actas Segundo Congreso Chileno de Antropología* 155–159.
- Sánchez-Murillo, R., Aguirre-Dueñas, E., Gallardo-Amestica, M., Moya-Vega, P., Birkel, C., Esquivel-Hernández, G., Boll, J., 2018. Isotopic characterization of waters across Chile. In: Rivera, D.A., Godoy-Faundez, A., Lillo Saavedra, M. (Eds.), *Andean Hydrology*. CRC Press, Boca Raton, pp. 205–230.
- Sanhueza, L., 2016. Comunidades prehispánicas de Chile Central. *Organización social e ideológica (0-1200 d.C.)*. Editorial Universitaria, Santiago.
- Sanhueza, L., Falabella, F., 2010. Analyses of stable isotopes: from the archaic to the horticultural communities in Central Chile. *Curr. Anthropol.* 51, 127–136. <https://doi.org/10.1002/oa.2437>.
- Sanhueza, L., Ardiles, F., Miranda, C., Correa, I., Falabella, F., Cornejo, L., 2019. Ni muy lejos ni muy cerca: patrón de asentamiento de los periodos alfareros en la microregión de Angostura, Chile central. *Lat. Am. Antiq.* (in press).
- Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochem. Cosmochim. Acta* 48, 625–639.
- Schoeninger, M.J., DeNiro, M.J., Tauber, H., 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220, 1381–1383.
- Service, E.R., 1962. *Primitive Social Organization. An Evolutionary Perspective*. Random House, New York.
- Soto, C., 2010. Sobre las identidades en el Alfarero Temprano de Chile Central: un acercamiento desde los objetos ornamentales. *Revista Werken* 12, 77–90.
- Soto, M., 2018. Explotación de camélidos durante el periodo Intermedio Tardío en la cuenca del Maipo-Mapocho. *Archaeological Title thesis*. Universidad de Chile, Santiago.
- Swift, J., Oyanedel, J., López, L., 2017. Dieta prehispánica en la región de Valparaíso, Chile central: evidencia del análisis de isótopos estables de carbono y nitrógeno de colágeno óseo humano de las colecciones del Museo de Historia Natural de Valparaíso. *An. Mus. Hist. Nat. Valpo.* 30, 22–39.
- Szpak, P., 2014. Complexities of nitrogen isotope biogeochemistry in plant-soil systems: implications for the study of ancient agricultural and animal management practices. *Front. Plant Sci.* 5, 1–19. <https://doi.org/10.3389/fpls.2014.00288>.
- Tykot, R.H., 2004. Stable isotopes and diet: you are what you eat. In: Martini, M., Milazzo, M., Piacentini, M. (Eds.), *Physics Methods in Archaeometry. Proceedings of the International School of Physics "Enrico Fermi"*. Società Italiana di Fisica, Bologna, Italia, pp. 433–444.
- Tykot, R.H., Falabella, F., Planella, M.T., Aspillaga, E., Sanhueza, L., Becker, C., 2009. Stable isotopes and archaeology in Central Chile: methodological insights and interpretative problems for dietary reconstruction. *Int. J. Osteoarchaeol.* 19, 156–170.
- van der Merwe, N.J., 1992. Light stable isotopes and the reconstruction of prehistoric diets. *Proc. Br. Acad.* 77, 247–264.
- Villa-Martínez, R., Villagrán, C., Jenny, B., 2004. Pollen evidence for late-Holocene climatic variability at Laguna de Aculeo, Central Chile (lat. 34 S). *Holocene* 14, 361–367.
- Walker, P.L., DeNiro, M.J., 1986. Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in Southern California. *Am. J. Phys. Anthropol.* 71, 51–61.
- White, C.D., Spence, M.W., Longstaffe, F.J., Law, K.R., 2004. Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. *J. Anthropol. Archaeol.* 23, 385–403.
- Wright, L.E., Schwarcz, H.P., 1998. Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. *Am. J. Phys. Anthropol.* 106, 1–18.