Brief Communication: Dietary Practices in Ancient Populations From Northern Chile during the Transition to Agriculture (Tarapacá Region, 1000 BC–AD 900)

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ABSTRACT

Objective: The goal of this research is to understand the relevance of diet diversity during the transition to agriculture, in ancient populations from northern Chile, especially considering the significance of marine resources and crops in a lesser degree.
Methods: A total of 14 human individuals were sampled from the Tarapacá 40 cemetery. Both bone and tooth samples were collected. Samples were studied from bone/dentine collagen for carbon and nitrogen isotopic analysis; and bone/enamel apatite for carbon isotope analysis. Inferential statistical analyses were performed in order to compare Tarapacá 40 stable carbon and nitrogen isotope values with other Formative and Late Intermediate Period groups. A nonparametrical hypothesis Kruskal–Wallis test was used.
Results: The results show that the individuals from Tarapacá 40 are intermediate to the values observed for terrestrial and marine fauna as well as C_3 and C_4 plants.
Conclusions: A gradual transition to crop consumption, especially maize, is suggested. This complemented the earlier hunter-gatherer tradition of marine resources and wild fruit consumption. Contrarily to the predictions made by some archaeologists, the results obtained for northern Chile contrast with the classical perspective of a "Neolithic Revolution" in which transition to agriculture occurred more abruptly and linearly. Am J Phys Anthropol 158:751–758, 2015.   © 2015 Wiley Periodicals, Inc.

The Formative Period is characterized as a moment of critical changes in the societies that inhabited the South-Central-Andes, around 1000 BC–AD 900 years. These transformations involved a series of innovations with the development of agriculture, domestic animal herding, and pottery-making (Muñoz, 1989). Archaeobotanical evidence (Núñez, 1982; Cohen and Armelagos, 1984) and paleopathological analyses (Cohen and Armelagos, 1984; Holden and Núñez, 1993; Watson et al., 2013) have been used to evaluate the transition to agriculture during this period in different parts of the world, including northern Chile.

Archaeological reconstructions for this period propose that the transition to agriculture in northern Chile followed a trend similar to Childe's "Neolithic Revolution" for Europe (Núñez, 1989; Núñez and Santoro, 2011). In this sense, the adoption of agricultural activities would have occurred abruptly and very soon after the transition from a hunter-gatherer life-way to an agriculturally based one. In fact, archaeologists suggest that, during the Formative Period, agricultural activities expanded and were consolidated (Muñoz, 1989). Hence, ancient Formative groups in Tarapacá and the Azapa Valleys likely based their diet on the newly introduced crops, such as maize (*Zea mays*) and squash (*Lagenaria siceraria*), complemented with marine foods and wild fruits (e.g. *Prosopis* sp., *Geoffroea decorticans*) (Muñoz, 1989; Núñez, 1989). It is worth noting that, throughout the

Formative Period, exchange of fisheries products between the coastal and inland groups remained important, as during the previous Archaic Period (Núñez, 1982; Muñoz, 1989; Núñez and Santoro, 2011; Santana et al., 2012; Uribe et al., 2015).

New research on Formative sites from northern Chile has shown that the presence of crops in the archaeological record is not homogeneous. Instead, the presence of maize and other crops seems quite variable, with higher frequencies in some sites and almost a complete absence in others (Torres-Rouff et al., 2012; García et al., 2014). In some cases, the most frequent vegetal food items observed are wild fruits, especially *algarrobo* (*Prosopis* sp.) rather than crops such as maize or squash (Torres-Rouff et al., 2012; García et al., 2014). Recent
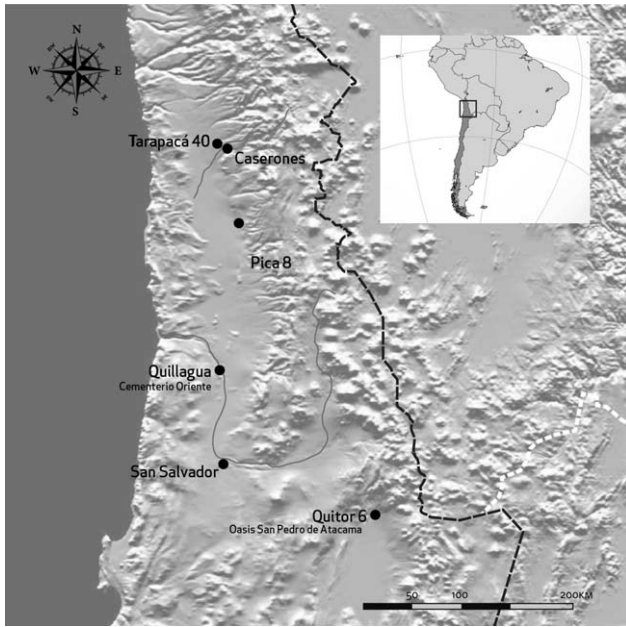
Fig. 1. Location of Tarapacá 40 in northern Chile.

excavations performed by one of us (MU) in the Early Formative - Guatacondo archaeological site (875 BC–AD 75), located in southern Tarapacá—specifically at sites G-II and G-IV (Mostny, 1970; Rivera, 2005)—have shown a complete absence of maize. This situation contrasts with the considerable abundance of *algarrobo* (*Prosopis* sp.) and other wild fruits at the site, suggesting that preservation of plant materials cannot be the cause of maize's absence.

Considering that these diet reconstructions have largely been based on indirect zooarchaeological and archeobotanical evidence, the application of stable carbon and nitrogen analysis is a useful tool for evaluating the consumption of maize (a C_4 crop) and the contribution of marine fauna to the diets of Formative Period groups. The aim of this study is to apply stable isotope analysis to human remains from an inland cemetery in the Tarapacá region, Tarapacá 40, in order to better understand the nature of the transition to agriculture. Based on existing research (Torres-Rouff et al., 2012), we predict that bone and tooth apatite of the Tarapacá 40 individuals should be relatively depleted in ^{13}C indicating moderate consumption of maize, while relatively ^{15}N-enriched values are expected for bone and dentine collagen reflecting marine inputs to the diet.

TARAPACÁ 40: ARCHAEOLOGICAL BACKGROUND

The Tarapacá region is located in the Atacama Desert, delimited by the Camiña River to the north, the Loa River to the south, the Pacific Ocean to the west, and the Andes Mountains to the East (Fig. 1). This region has no rivers (apart from those delimiting the region) that actually reach the coast from the Andes. Ravines, oases, a complex system of groundwaters and salt lakes can be found in this area (Aravena, 1995; Uribe, 2006). In Tarapacá, areas of habitation were located on the arid coast and at the internal "*Pampa del Tamarugal*," a dry valley with oases in the middle of the Atacama

Desert, about 70 km inland and approximately 200 km from the Andean highlands (Fig. 1).

Two main sites (1000 BC–AD 900 years) are located in the inland region of *Pampa del Tamarugal*: the settlement of Caserones and its associated cemetery, Tarapacá 40, located 50–60 km from the coast. New radiocarbon dates obtained for Tarapacá 40 show occupations associated with the Early and Late Formative Period (Uribe et al., 2015). However, previous dates obtained from human bone and textiles suggest that the occupation of this cemetery was more-or-less continuous throughout the Formative, including limited evidence of the Middle Horizon (ca. AD 600) (Table 1). Hunting and gathering as well as agriculture and architecture became highly developed in the Caserones settlement (Núñez, 1982, 1984; Adán and Urbina, 2010). Archaeobotanical evidence from Caserones suggests intense collection of *algarrobo* (*Prosopis* sp.), in addition to a moderate presence of crops such as maize (*Zea mays*), squash (*Lagenaria* sp.*; Cucurbita maxima*), beans (*Phaseolus* sp.), potatoes (*Solanum tuberosum*), and quinoa (*Chenopodium quinoa*) (García and Vidal, 2006; García et al., 2014). Even though maize was recorded, its cultivation and consumption was, apparently, only completely adopted during the Late Intermediate Period or LIP (AD 900–1450). This suggestion is based on the considerably higher amount of maize recovered in the LIP Camiña 1 site around AD 1250–1450 (García and Vidal, 2006) compared to the Caserones village; and the high carbon isotopic values measured on LIP human remains from Pica 8, Quillagua's *Cementerio Oriente* (Santana-Sagredo et al., 2015b), Quitor 6 (Santana-Sagredo et al., 2015a), and Caspana cemeteries (Torres-Rouff and Knudson, 2009).

Remains of camelids and rodents have been found along with fish, shellfish, marine mammals, and birds. Marine resources at Caserones are abundant, with more than 48% of the vertebrate assemblage comprising ichthyofaunal remains (González, 2006). This evidence suggests that, during the Formative Period, connections and movements between the coast and interior were frequent and economically important (Núñez, 1982; Muñoz, 1989; Uribe et al., 2015). The nature of this coastal–inland interaction has been interpreted using two main hypotheses: one based on trade (Moragas, 1995; Núñez and Dillehay, 1995[1978]) and the other based on human mobility (Núñez and Santoro, 2011). However, is not yet clear how these interactions occurred. The present report aims to understand the relevance of dietary diversity in inland people during the transition to agriculture, especially considering the significance of marine resources and the potential consumption of crops.

MATERIAL AND METHODS

A total of 14 human individuals were sampled from the Tarapacá 40 collection housed at the Department of Anthropology, Universidad de Chile. Both bone and tooth samples were collected, but it was only possible to analyze both tissues for three individuals in order to compare diets during their childhood and adulthood. Samples were studied from bone/dentine collagen for carbon and nitrogen isotopic analysis, and bone/enamel apatite for carbon isotope analysis.

Bone and enamel apatite analysis were included in this study in order to try and circumvent the ambiguity in bone collagen $\delta^{13}C$ due to two potential sources of

Lab number (Beta Analytic)	Sample	Conventional age	Calibrated age
355776	B0657 (Individual 1)	2840 ± 30 BP	1110–920 BC
370287	B0671	2750 ± 30 BP	970–830 BC
355778	B0666 (Individual 4)	2540 ± 30 BP	800–550 BC
370288	B0662	2470 ± 30 BP	760–410 BC
355779	B0678	1580 ± 30 BP	410–550 BC
355777	B0665	1610 ± 30 BP	390–540 BC

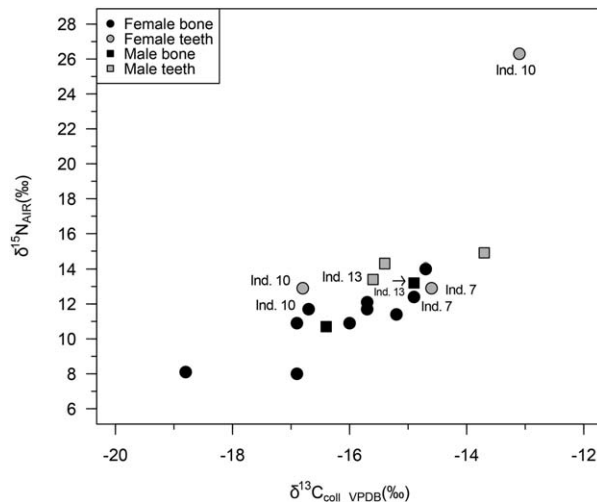**Fig. 2.** Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ values obtained from bone and dentine collagen. The data is presented by sex and tissue analyzed (bone and teeth). Individuals for whom both bone and teeth were analyzed are shown with the inscription "Ind." and their respective reference number.

Fig. 3. Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ values obtained from bone and enamel apatite. The data is presented by sex and tissue analyzed (bone and teeth). Individuals for whom both bone and teeth were analyzed are shown with the inscription "Ind." and their respective reference number.

^{13}C-enrichment. The $\delta^{13}C$ values for marine resources and maize (C_4 plant) tend to be high and overlap to a considerable degree, since they are both ^{13}C-enriched. Marine resources, however, are rich in protein while maize is not, and given the widely recognized preferential routing of protein carbon to collagen (Ambrose and Norr, 1993; Tieszen and Fagre, 1993), marine carbon is strongly represented in the $\delta^{13}C_{coll}$ values, in contrast to maize. On the other hand, bioapatite $\delta^{13}C$ values reflect the whole diet, including proteins, carbohydrates, and lipids (Ambrose and Norr, 1993; Tieszen and Fagre, 1993; Passey et al., 2005). Hence, bioapatite $\delta^{13}C$ values are more appropriate for distinguishing maize and marine dietary contributions.

The analyses were performed at Cornell University's Stable Isotope Laboratory in the Department of Ecology and Evolutionary Biology. Collagen extraction was done following Richard and Hedges (1999). Bone apatite was pretreated using the mild protocol developed by Smith (2005). Tooth enamel was prepared following the protocol described in Lee-Thorp et al. (1997).

For collagen samples, the analyses were performed in a Thermo Delta V isotope mass spectrometer interfaced to a NC2500 elemental analyzer. Measurement errors of better than 0.10 and 0.25‰ were estimated for $\delta^{13}C$ and $\delta^{15}N$, respectively, based on multiple replicates of internal standards (HCRN-corn standard; and CBT-trout standard). A two-point calibration was applied to the drift corrected data using the internal standards. All internal standards were calibrated against IAEA
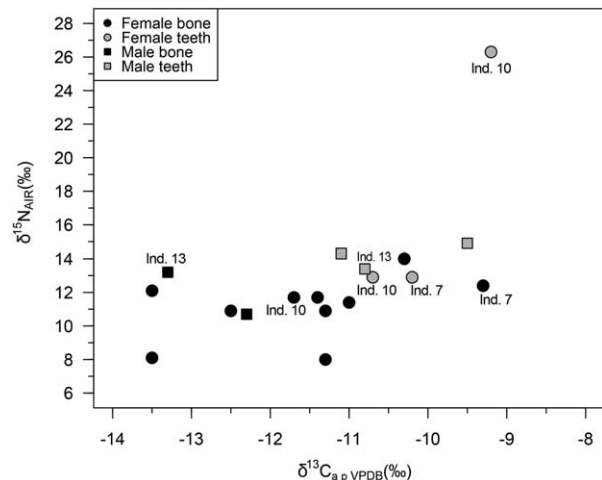
standards. Apatite sample measurements were carried out on a Thermo Delta V isotope mass spectrometer interfaced to a Temperature Conversion Elemental Analyzer (TC/EA). Observed error for $\delta^{13}C$ was better than 0.1‰. A two-point calibration based on international standards NBS18 and NBS19 was applied to the drift-corrected data.

Inferential statistical analyses were performed in order to compare Tarapacá 40 stable carbon (from bone and dentine collagen; and bone and enamel apatite) and nitrogen (bone and dentine collagen) isotope values with other Formative and Late Intermediate Period groups. Because some of the results were not normally distributed, nonparametric Kruskal–Wallis tests were used.

RESULTS

The collagen and apatite isotope data are given in Table 2. Bivariate plots of $\delta^{13}C$ and $\delta^{15}N$ for bone and dentine collagen and for bone and enamel apatite are shown in Figures 2 and 3, respectively. All samples had C/N ratios within the range expected for well-preserved collagen (DeNiro, 1985; Ambrose, 1990). Maximum and minimum values for $\delta^{13}C_{coll}$ are −13.1 and −18.8‰ (mean −15.7 ± 1.3‰), while for $\delta^{15}N$, values range from 8.0 to 26.3‰ (mean +12.8 ± 3.9‰). Maximum and minimum values for bioapatite ($\delta^{13}C_{ap}$) are −9.2 and −13.5‰ (mean −11.3 ± 1.3‰). The means and standard deviations for $\delta^{13}C_{coll}$ and $\delta^{15}N$ are plotted against isotopic values from modern flora and fauna, as well as archaeological fauna of northern Chile (Tieszen and

TABLE 2. Stable isotope results for Tarapacá 40 individuals

Individual number	Inventory number	Sex	Age	Sample	$\delta^{13}C_{coll}$ (‰)	$\delta^{13}C_{ap}$ (‰)	$\delta^{15}N$ (‰)	C/N ratios
1	B0657	F	Adult	Rib	−16.9	−12.5	10.9	3.2
2	B0659	F	Adult	Fibula	−15.2	−11.0	11.4	3.2
3	B0660	F	Adult	Ulna	−15.7	−13.5	12.1	3.5
4	B0666	F	Adult	Humerus	−16.9	−11.3	8.0	3.2
5	B0667	M	Adult	Third molar	−15.4	−11.1	14.3	3.3
6	B0669	M	Adult	Second molar	−13.7	−9.5	14.9	3.4
7	B0672	F	Adult	Third molar	−14.6	−10.2	12.9	3.3
	B0672	F	Adult	Humerus	−14.9	−9.3	12.4	3.3
8	B0674	M	Adult	Fibula	−16.4	−12.3	10.7	3.3
9	B0675	F	Adult	Rib	−16.0	−11.3	10.9	3.2
10	B0677*	F	Adult	Second premolar	−13.1	−9.2	26.3	3.4
	B0677	F	Adult	Third Molar	−16.8	−10.7	12.9	3.3
	B0677	F	Adult	Clavicle	−16.7	−11.7	11.7	3.2
11	B0680	F	Adult	Radius	−15.7	−11.4	11.7	3.3
12	B0684	F	Adult	Radius	−18.8	−13.5	8.1	3.3
13	B0688	M	Adult	Fibula	−14.9	−13.3	13.2	3.4
	B0688	M	Adult	Third Molar	−15.6	−10.8	13.4	3.4
14	B0691	F	Adult	Phalange	−14.7	−10.3	14	3.3

Sex is indicated by F, Female; and M, Male. Individual 10 (B0677*) second's premolar was analyzed in a previous study by Santana et al. (2012).
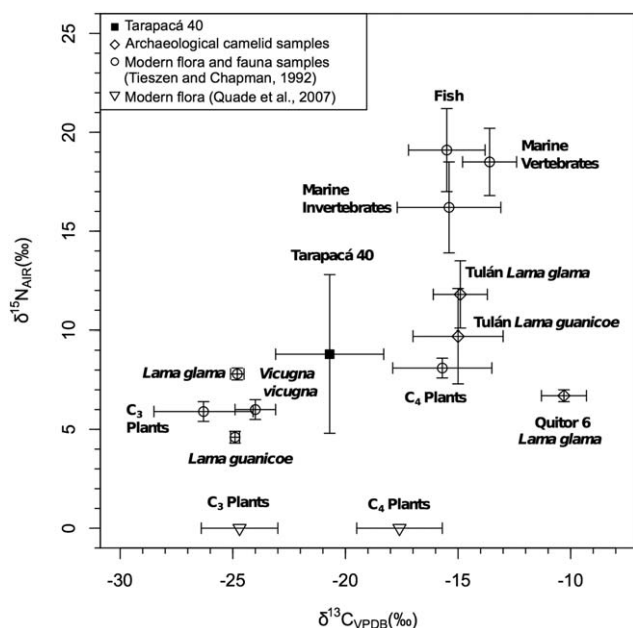

Fig. 4. Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ as means and standard deviations for modern floral and faunal resources analyzed by Tieszen and Chapman (1992); modern flora analyzed by Quade et al. (2007); as well as archaeological fauna from the sites Tulan 54 and Tulan 58 (Lopez et al., 2013), and Quitor 6 (Santana-Sagredo et al., 2015a), compared with dietary $\delta^{13}C$ and $\delta^{15}N$ values for Tarapaca 40. Diet values were estimated using an offset of +5‰ for $\Delta^{13}C_{diet-collagen}$ and +4‰ for $\Delta^{15}N_{diet-collagen}$ in humans. The $\delta^{13}C$ values of modern C_3 and C_4 plants from Northern Chile (Calama/Paso Jama, Socompa, and Paposo) (Quade et al., 2007) are shown as means and standard deviations immediately above the X-axis; $\delta^{15}N$ values were not reported. All $\delta^{13}C$ values for modern terrestrial samples were corrected for the fossil fuel effect to preindustrial (1750 AD) $\delta^{13}C$ CO_2 values, using a correction of −1.6‰ for 2007 and −1.9‰ for 1992 (CO_2 data from CDIAC http://cdiac.ornl.gov/trends/co2/iso-sio/iso-sio.html). No corrections were applied to the marine fauna.

Chapman, 1992; Quade et al., 2007; López et al., 2013) in Figure 4. The results show that the individuals from Tarapacá 40 are intermediate to the values observed for

terrestrial and marine fauna as well as C_3 and C_4 plants.

DISCUSSION

Although it is possible to propose consumption of maize for Tarapacá 40, it did not form the bulk of the diet. The data suggest that there was a moderate and gradual increase in the consumption of maize during the Formative Period. Similar results for $\delta^{13}C_{coll}$ and $\delta^{13}C_{ap}$ values were observed for another inland cemetery in southern Tarapacá, known as San Salvador (Torres-Rouff et al., 2012) also dating to the Formative Period, located in the middle Loa River area.

Compared with Late Intermediate Period groups from northern Chile (Pica 8 in Tarapacá, Quillagua's Cementerio Oriente in the middle Loa River and Quitor 6 in the highlands at San Pedro de Atacama), the consumption of maize during the Formative Period was much lower (Fig. 5a,b). Values for $\delta^{13}C_{coll}$ and $\delta^{13}C_{ap}$ during the LIP are very high, strongly suggesting a considerable consumption of maize in their diets. Significant differences were observed for Tarapacá 40 when compared to the $\delta^{13}C_{coll}$ values of LIP sites (Kruskal–Wallis test, Pica 8 $P = 0.00005$; Quillagua Oriente Alto $P = 0.0003$; Quillagua Oriente Bajo $P = 0.009$). No significant differences were found with the Formative site of San Salvador (Kruskal–Wallis test, $P = 0.488$) and the LIP site Quitor 6 (Kruskal–Wallis test, $P = 0.184$). The absence of a significant difference in the $\delta^{13}C_{coll}$ values between Tarapacá 40 and Quitor 6 could be explained by the consumption of marine resources by the former group, which will tend to increase their $\delta^{13}C_{coll}$ values; and the ingestion of maize by the Quitor 6 individuals, who based their diet on terrestrial resources. In this sense, the values of Tarapacá 40 and Quitor 6 are similar because the $\delta^{13}C_{coll}$ values for a marine diet tend to overlap the ones observed for C_4-based diets, as previously mentioned in the materials and methods section.

When the $\delta^{13}C_{ap}$ values (Fig. 5b) of Tarapacá 40 were compared versus the LIP sites significant differences were invariably observed (Kruskal–Wallis test, Pica 8 $P = 0.00001$; Quillagua Oriente Alto $P = 0.0003$;
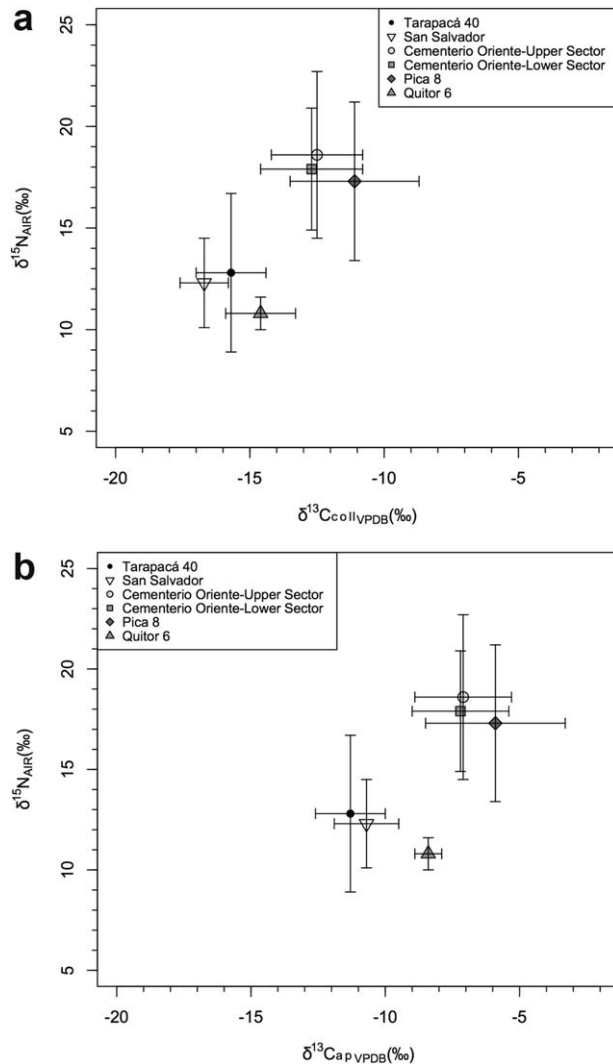
Fig. 5. (a) Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ values from bone and dentine collagen for the Formative Period sites Tarapaca 40 and San Salvador (Torres-Rouff et al., 2012), as well as the Late Intermediate Period sites Pica 8, Quitor 6 (Santana-Sagredo et al., 2015a), and Quillagua's Cementerio Oriente Sector Alto and Sector Bajo (Santana-Sagredo et al., 2015b). (b) Bivariate plot showing $\delta^{13}C$ and $\delta^{15}N$ values from bone apatite for the Formative Period sites Tarapaca 40 and San Salvador (Torres-Rouff et al., 2012), as well as the Late Intermediate Period sites Pica 8, Quitor 6 (Santana-Sagredo et al., 2015a), and Quillagua's Cementerio Oriente Sector Alto and Sector Bajo (Santana-Sagredo et al., 2015b). We are aware that by comparing tooth and bone collagen and apatite samples we are dealing with different times in the life of the individuals. As such, both tissues were included together in the graph to show the general trend of their $\delta^{13}C$ and $\delta^{15}N$ values when compared to the LIP.

Quillagua Oriente Bajo $P = 0.001$; Quitor 6 $P = 0.00008$). The LIP sites are considerably enriched in ^{13}C values (up to $-5\permil$) compared to Tarapacá 40. In contrast, no significant differences were observed when comparing Tarapacá 40 to San Salvador (Kruskal–Wallis test, $P = 1$). These comparisons suggest that, for these two Formative sites, the consumption of maize was very low compared to the LIP diets. This evidence is also supported by bioanthropological analyses made on the oral health of Tarapacá 40 showing a lower frequency of caries when compared to late populations (Herrera, 2010).

Even though the consumption of marine resources played a role in Tarapacá 40, this was not as important as in coastal populations or LIP groups such as Pica 8 or the *Cementerio Oriente* of Quillagua. When $\delta^{15}N$ values were compared versus these LIP sites, significant differences were observed for Tarapacá 40 (Kruskal–Wallis test, Pica 8, $P = 0.0007$; Quillagua Oriente Alto, $P = 0.001$; Quillagua Oriente Bajo, $P = 0.001$). There were no significant differences when comparing Tarapacá 40 versus San Salvador and the LIP site, Quitor 6 for which a terrestrial diet has been suggested (Santana-Sagredo et al., 2015a). Following these comparisons and the results obtained, a consumption of a moderate marine diet is proposed for the individuals of Tarapacá 40. A similar situation is suggested for San Salvador. Some coastal populations from northern Chile, such as Cáñamo 1 and Caleta Huelén (also dating to the Formative Period), show a much stronger dependence on marine resources with higher values for carbon and nitrogen isotopes compared to Tarapacá 40. In fact, $\delta^{15}N$ values of individuals from these coastal sites are as high as 26‰ (Santana et al., 2012). High $\delta^{15}N$ values, above 20‰, in ancient human populations are also observed for early and later periods in northern Chile including the Archaic (7000–2950 BP), Late Intermediate (1050–550 BP) and Late Periods (550–410 BP) (Tieszen et al., 1992; Roberts et al., 2013; Santana-Sagredo et al., 2015a; Santana et al., 2015b). In contrast to Tarapacá 40, these populations, with $\delta^{15}N$ values above 20‰, were heavily dependent on the consumption of marine resources.

Another important conclusion that can be drawn from our data is the impact that mobility from the coast to the inlands and vice versa had on the population of Tarapacá during the Formative Period. Even though we only have one individual that shows evidence of mobility from its infancy to its adulthood, the changes in its diet were drastic. Individual 10 (Figs. 2 and 3) was analyzed for its third molar and a clavicle fragment. In a previous study (Santana et al., 2012), the second premolar of the same individual was analyzed. As it can be seen, during her first years of life (the second premolar starts to form around Age 2), this female individual probably lived on the coast following its extremely high $\delta^{15}N$ value of 26.3‰ and $\delta^{13}C_{coll}$ value of $-13.1\permil$. Afterwards, around the age of 12 years (following the data obtained from her third molar), a drastic change in her diet occurred, with a dramatic drop in her nitrogen and carbon values (to 12.9 and $-16.8\permil$). These values were retained until the final years of her life, as shown in her clavicle nitrogen and carbon values of 11.7 and $-16.7\permil$. So, the isotopic evidence suggests that individual 10 lived on the coast during the first years of life and then moved inland where she lived until her death.

Other individuals such as number 7 (female) and number 13 (male) were also analyzed for their third molars and bone. However, no important changes in their diets were observed over the course of their lives (between 12 years and their last years of life). These individuals' diets (7 and 13) were also characterized by the consumption of fish and moderate ingestion of maize, despite individual 13 showing a decrease in maize consumption during adulthood.

In order to address the transition to and its impact on the paleodiet through time, $\delta^{13}C_{coll}$ values for Individuals 1 and 4 were plotted versus their calibrated
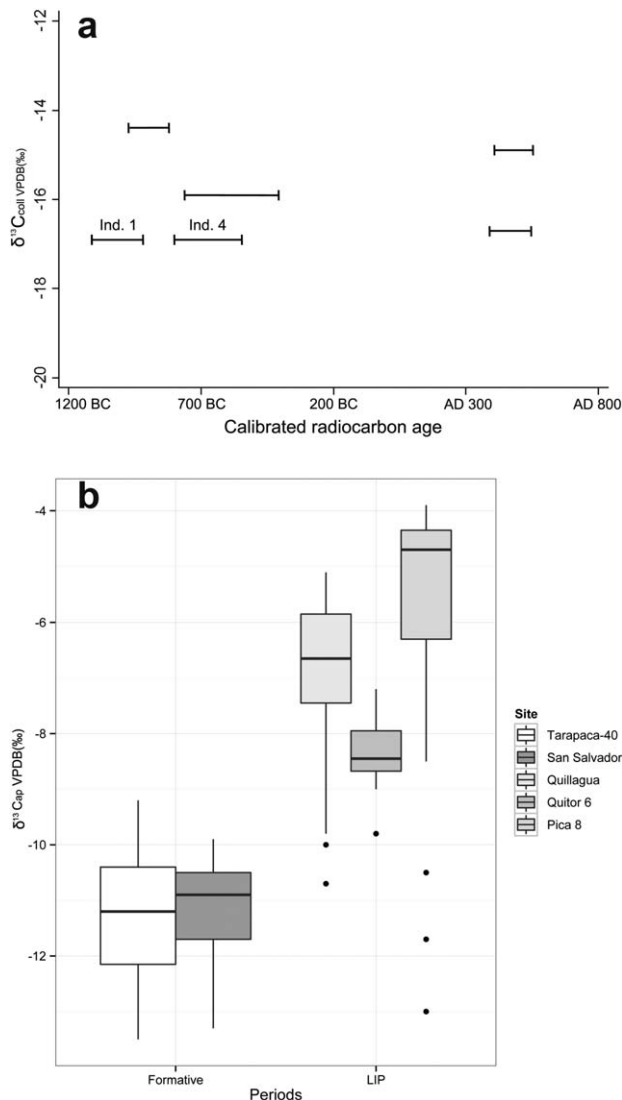
of marine resources. We discard a possible association between the higher values in $\delta^{13}C_{coll}$ and an increase in maize consumption, following the previous comparisons between the Formative and LIP carbon values for collagen and apatite fractions. As previously mentioned, a reliance on maize as a dietary staple leads to values of $\delta^{13}C_{coll}$ values between -11 and $-8‰$, while for $\delta^{13}C_{ap}$ values fall between -8 and $-5‰$; this range of values for both bone fractions are seen at Pica 8, Quillagua's Cementerio Oriente and Quitor 6, but not at Tarapacá 40. Figure 6b shows this important difference in the $\delta^{13}C_{ap}$ values with a clear temporal trend between the Formative and LIP cemeteries, showing the later period the highest values for carbon apatite.

In addition, the archaeobotanical evidence does not support an important role of maize for the Formative sites in northern Chile. For instance, the sites of Guatacondo and San Salvador in the *Pampa del Tamarugal* and the middle Loa River area, respectively, show almost a complete absence of this crop in their contexts. In this sense, the chronological evidence supports the interpretation of a gradual transition to maize agriculture. If the situation were different, assuming and accepting the model of a "Neolithic Revolution" in Tarapacá, we would have expected much higher $\delta^{13}C$ values during the Early Formative Period (~1000 years BC), which is not the case. It can be seen that from around 1100 years BC until around AD 500, the individuals still present low values of $\delta^{13}C_{coll}$ compared to the LIP.

CONCLUSIONS

Our results indicate a moderate consumption of maize by the community represented by the cemetery of Tarapacá 40. This suggests that agricultural crops, specifically maize, were not yet staple crops in the Formative Period. The relatively modest consumption of maize contrasts with observations for greater reliance on maize in later periods. Thus, our data are consistent with the hypothesis of a gradual transition to agriculture, rather than with a sharp and radical shift. Therefore, we do not observe a "Neolithic Revolution" in northern Chile, (Núñez and Santoro, 2011).

Isotopic data obtained for Tarapacá 40 are more consistent with hypothesis of strong coast–inland contacts during the Formative Period. The isotopic results support the archaeological evidence of fish found in the Tarapacá 40 cemetery (Núñez, 1982; Núñez and Santoro, 2011) and its associated domestic site Caserones (González, 2006). Comparison of the small group of individuals for which we have both bone and enamel data suggests that one individual at least, a female, moved inland from the coast during childhood. This observation provides direct evidence for movement and co-residentially of individuals, in addition to the exchange of food resources and goods visible in the archaeological record. The foundation for these patterns (mobility and co-residence) was thus laid as early as the Formative Period, being crucial for the development of agriculture in the driest desert of the world.

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Fig. 6. (a) Bivariate plot showing $\delta^{13}C_{coll}$ values and their respective radiocarbon date ranges (calibrated). The values were obtained for the six Tarapaca 40 individuals dated so far. From these six individuals, only two were considered for the present stable isotope analysis (individuals 1 and 4), being their carbon collagen values plotted in the figure. As for the rest of the individuals, carbon collagen values given by Beta Analytic were used. (b) Boxplot showing the $\delta^{13}C_{ap}$ values and their trend in time for the Formative Period sites Tarapaca 40 (1110 BC–AD 540 years, Uribe et al., 2015) and San Salvador (511 BC–AD 67 years Torres-Rouff et al., 2012), as well as the Late Intermediate Period sites Quillagua's Cementerio Oriente (AD 720–AD 1315, Gallardo et al., 1993), Quitor 6 (AD 899–AD 1211, Hubbe et al., 2012), and Pica 8 (AD 900–1300, Nunez 1979; Uribe et al., 2007).

radiocarbon dates. In addition, another four individuals were included in Figure 6a, for comparing their $\delta^{13}C_{coll}$ values (values from Beta Analytic, since these individuals were not analyzed for stable isotope analysis here) with their calibrated dates. From a comparison of Figures 6a and 3, it can be seen that the variation in the $\delta^{13}C_{coll}$ values for the six dated individuals is similar to that presented in Figure 3. This variation in $\delta^{13}C_{coll}$ values could be attributed to the differential consumption

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