Title

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Journal

International Journal of Osteoarchaeology, 19(2)

ISSN

1047-482X 1099-1212

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Publication Date

2009-03-19

DOI

10.1002/oa.1064

Peer reviewed

International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. **19**: 237–249 (2009)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/oa.1064

Palaeodietary Inferences Based on Isotopic Data for Pre-Hispanic Populations of the Central Mountains of Argentina

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ABSTRACT The aim of this study is to investigate spatial and temporal patterns of palaeodiet diversification through isotopic measurements ($\delta^{13}C_{COL}$ and $\delta^{15}N$) from individuals who inhabited the Central Mountains of Argentina during the Holocene. Isotopic measurements were obtained from bone and tooth samples from ten human skeletons, corresponding to the Middle and Late Holocene (4500–300 ^{14}C BP). Isotopic results show the consumption of C_3, C_4 and CAM plants, which reflects a mixed diet. Variation observed among hunter-gatherer sites could be associated with differences in the availability of animal resources. On the other hand, evidence from agricultural sites could be indicating a more omnivorous diet, with greater emphasis on vegetable resources. Regarding spatial variation, the $\delta^{13}C$ results suggest modest regional differences in diet in the later periods of the regional sequence. This study provides a first step to evaluating the role played by maize agriculture and the dietary variability in time and space for populations that inhabited the Central Mountains during the Holocene. Although preliminary, the evidence suggests that adoption of agriculture was complementary to hunter-gatherer subsistence strategies. However, the incorporation of cultigens seems to show regional differences. These results confirm the mixed character of the economy, previously inferred from other archaeological indicators.

Key words: Argentina; Córdoba; Central Mountains; diet; stable isotopes; hunter-gatherer subsistence system; pre-Hispanic agriculture; Holocene

Introduction

Archaeological research in the southern sector of the Central Mountains of Argentina has demonstrated the presence of human populations since approximately 10,000 years BP (Ameghino, 1885, 1889; Castellanos, 1943; Montes, 1960; González, 1960; D'Andrea & Nores, 2004). During this extensive period of time, human groups adapted to fluctuating environmental conditions and developed subsistence strategies based on hunting, mainly of deer and guanaco, and on the gathering of wild fruits such as the one from the carob tree (*Prosopis* sp.). By the middle of the first millennium of the Christian era, agriculture was incorporated as a complementary strategy, in addition to hunting and gathering, thus articulating an economic organisation centred on risk-avoidance in an environmental context of uncertainty (Laguens, 1999).

Research carried out in the Valley of Copacabana, in the northwest Central Mountains (Laguens & Bonnin, 1987; Laguens, 1997, 1999)

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Received 8 November 2008
Accepted 4 December 2008

of Córdoba, allowed us to propose a regional model of resource exploitation in farming societies which made use of different ecological floors, from hills to plains. This model has been verified in other sectors of the hills (Pastor, 2006) and it became of general use in defining subsistence strategies of highland populations (Berberián & Roldán, 2001). Based on this model, we have recently begun studying patterns of resource exploitation (Bonnin & Laguens, 2000; Laguens *et al.*, 2007; Laguens & Bonnin, 2008), since the region cannot be considered homogeneous in time and space. A common element arising in these studies is that the adoption of agriculture would not have induced a sharp change in the subsistence logic. Differences in the archaeological record allow us to infer an increasing process of regional differentiation for the Late Holocene, with a clear tendency toward diverse local modalities in different areas, with political autonomy and identity associated with different geopolitical units, just as it can be deduced from analysis of the ethnohistorical documentation of the 16th and 17th centuries (Laguens, 1994, 1999).

It is widely accepted that the rise of food production is associated with a series of irreversible changes in lifestyle, in the way individuals relate among themselves, in demography, and in technology, just as it has happened in Córdoba with regard to village lifestyle, population growth, pottery manufacture for domestic and ritual use, or the increasing regional interactions. Nevertheless, although agriculture replaced an important percentage of the subsistence resource income, its importance did not surpass 50% of diet, being complemented with hunting and gathering (Laguens, 1999). Even more remarkable is that its incorporation did not alter the previous ways of obtaining food, but its production was adjusted to the hunter-gatherer logic based on a long tradition of complementary exploitation of the differential resources of the caduceus forest of the Chaco Hills and the grassland vegetation of the Central Mountains' high prairies (Luti *et al.*, 1979; Cabido *et al.*, 2004).

This complementary exploitation operated since the Early Holocene, as can be deduced from the human occupation of the Intihuasi cave, for example, with exploitation of animal species from different ecological floors (González, 1960; Pascual, 1960; Bonnin & Laguens, 2000; Laguens & Bonnin, 2008). This strategy would last until the Middle Holocene, when changes were registered in landscape use which showed a marked preference for the occupation of ecotone stripes, as opposed to Early Holocene settlement patterns, which showed a more disperse tendency in landscape use, as well as innovation in the manufacturing processes of a different weapon system, all accompanied by geographical expansion and considerable population growth. Apparently these changes did not imply an abandonment of the complementary use of different types of vegetation, expanding at the same time the capture area of all types of resources, not only for food, but also for raw materials and personal and sumptuary objects (Laguens *et al.*, 2007).

The adoption of agriculture and pottery would have arisen as a gradual process, with an experimental phase clearly seen in dwelling sites under rocky refuges at around 2000 years BP (Austral & Rochietti, 1995a,b). Considering environmental and economic conditions in conjunction with the regional archaeological record, it is possible to suggest that plant domestication might be imported from northeastern populations of Argentina, having therefore a common origin (Laguens & Bonnin, 2008). We have not yet established its chronology on a firm basis, although the isotopic analyses of human diets presented here provide relevant information. These traditional ways of exploiting the environment can be understood as appropriate adjustments in a setting of semi-arid conditions characterised by low predictability, periodic cycles of slight variations in temperature, and intermittent rainfall pulses that vary in space and time, which establish a complex mosaic of potential ecological answers (Ferrio *et al.*, 2005). On a human scale, and particularly in an economy based on a production and exploitation system which is totally climate-dependent, populations can be subject to situations of considerable stress or periodic instability and vulnerability.

Despite these advances in the knowledge of food consumption based principally on Late Holocene archaeofaunistic and technological records, the role played by maize agriculture and its relative importance, as well as its

DOI: 10.1002/oa

chronology, is still not fully understood. In the present study we report the first results of palaeodiet based on analyses of stable isotopes obtained from archaeological human remains from different geographical regions of the Central Mountains of Argentina – the southern area of the Sierras Pampeanas hills – corresponding to the Middle and Late Holocene. The purpose of this paper is to analyse and discuss these results in terms of subsistence strategies associated with different ways of life, and of temporal and spatial aspects of regional variability. We ask then a key question for this study: what was the spatial and temporal variability in the diets of the pre-Hispanic populations who settled in the present territory of the province of Córdoba during the Holocene? This, in turn, raises a set of derived questions such as: When was the change towards a mixed diet produced? What are the regional differences in the conformation of the diets? Are these differences the result of palaeoenvironmental changes? In the following paragraphs we will briefly describe the study area, the palaeoenvironmental and geographical settings, the cases analysed and the results obtained, and we will finally integrate this information into the current state of knowledge.

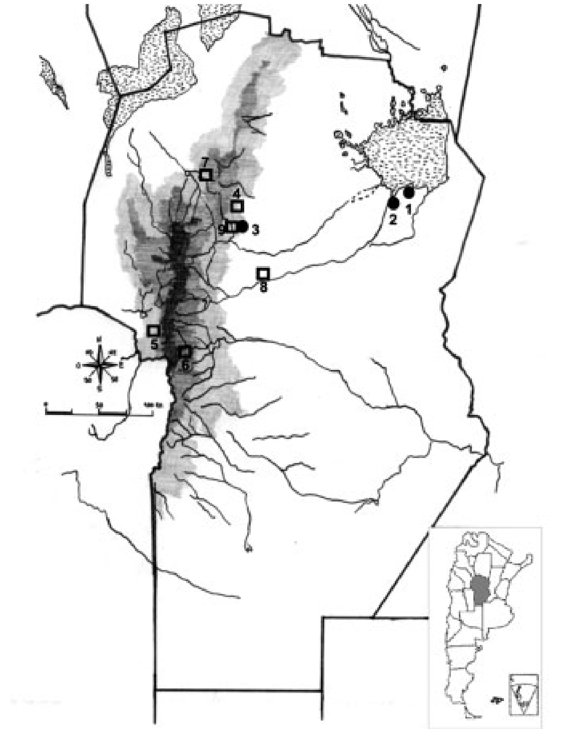

Figure 1. Archaeological sites considered in this study: 1, Miramar; 2, East Coast; 3 & 9, Agua de Oro; 4, La Granja; 5, Guasmara; 6, Amboy; 7, Ayampitin; 8, Rincon II.

Materials and methods

The study area

The Central Mountains of Argentina are located in the southern region of the Sierras Pampeanas, between 30° and 35°S and 62° and 66°W, covering the mountainous ranges of the provinces of Córdoba and San Luis and the eastern and western adjoining plains, a region traditionally known as the *Sierras Centrales* (González & Pérez Gollán, 1976; Figure 1). This area is characterised as a landscape with low mountains located northwest of the Argentine pampas, where two main physiographical units can be distinguished: the oriental plains (lowlands) and the western hills. Between the two main ranges (Sierras de Cordoba and Sierras de San Luis) a second plain develops. These ranges are separated by an extensive intermontane valley, occasionally interrupted by lower hills in San Luis province.

The subtropical location of the region generates dry winters and humid summers. There are two large wetlands in the northern sector: Mar Chiquita Lagoon in the northeast and Salinas Grandes in the northwest. Toward the southwest in southern San Luis there is another important wetland with more than 180 bodies of fresh and salty water.

In relation to vegetation, a series of floral physiognomies are oriented in northeastern-southwestern bands, from the pasture lands in the steppe of the pampas in the southwestern extreme, to low forests with dominance of acacias in a middle zone corresponding to the Espinal phytogeographical province – the ecotone between the Pampas and Chaqueña phytogeographical provinces – up to the stepped vegetation of the Chaco mountain forest, with shrubs and pasture lands at higher altitudes (Luti *et al.*, 1979; Cabido *et al.*, 2004).

In terms of faunal communities, this region is located on the edge of the two South American biogeographical regions (the North and Eastern,

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and the South and Western, according to the divisions of Ruggiero *et al*., 1998). This transition is characterised by rapid changes in the values of environmental resistance,[1] defining an area with the continents' lowest values of anisotropy,[2] pertaining to the Chaco-pampean plains (Ruggiero *et al*., 1998). It is noted that its lower border merges approximately with the NW–SE arid diagonal, which has fluctuated over time (Páez *et al*., 2003). This zone presents a varied spectrum of prey animals, like guanaco (*Lama guanicoe*), pampas deer (*Ozotocerus bezoarticus*), corzuela (*Mazama guazoubira*), huemul (*Hippocamelus bisulcus*), peccary (*Tayassu tajacu*), as well as jaguar (*Felis concolor*) and Chacoan Mara (*Dolichotis salinicola*), quirquincho (*Chaetophractus* sp.), the ñandú flightless bird (*Rhea americana*), and other smaller prey.

Palaeoenvironmental history

Recent research has demonstrated a series of Holocene palaeoclimatic changes which occurred in the Córdoba province (Carignano, 1997). In the Early Holocene, as well as in the Late Pleistocene, a semi-arid and cold climate was dominant. These conditions gradually changed towards a subtropical climate, with higher temperatures and humidity. Between 9000 and 4200 years BP these climatic conditions favoured the development of meadows in the high prairies of the Central Mountains, and lagoons and swamps in the lowest areas (Carignano, 1999; Piovano, 2005).

An abrupt change towards dry and semi-arid conditions and high temperatures occurred at 4200 years BP, lasting for 2000 years and causing the erosion and deflation of soils, deficit of water, diminution of the lakes, development of the Salinas Grandes, and a decrease in the volume of the large rivers. These changes suggest not only a different distribution of the food resources potentially exploited, but also changes in environmental offerings (Laguens *et al*., 2007). Since 1000 years BP this event slightly modified towards sub-humid and temperate conditions, which would have lasted without great variation until the 16th century (Cioccale, 1999).

[1]The effects of the physical barriers on the size of the species' geographical distribution (Ruggiero *et al*., 1998).
[2]Measure from which the geographical range's perimeter of several species derives from a circular perimeter (Ruggiero *et al*., 1998).

The archaeological record of food resources

In relation to the pre-Hispanic food resources known from the archaeological record, the animal species include, in order of predominance, guanaco, deer, corzuela, peccary and quirquincho, in addition to the rhea represented by egg shells. With regard to vegetal resources, remains of corn (*Zea mays*), cucurbita (Lopez, 2007), acacia (Laguens & Bonnin, 1987) and *algarroba* (*Prosopis* sp.) have been identified, the latter mainly in the ethnohistorical record. Finally, *Opuntia* sp. has been recorded near domestic areas. Human diets may also have included beans and other wild fruits like chañar (*Geoffrea decorticans*), mistol (*Zyzyphus mistol*) and tala (*Celtis tala*).

As a consequence of contact with Europeans, the indigenous wildlife resources were replaced by European cattle, horses, sheep and goats (Laguens, 1999). In the absence of isotopic measurement of local species, information was selected from published studies for southern Mendoza (Table 2). Figure 2 illustrates the isotopic relationships between δ^{13}C and δ^{15}N for these resources (solid squares).

The sample

The samples analysed in this study come from archaeological sites located in both eastern and western sides of the Central Mountains, as well as from the oriental plain and the Mar Chiquita Lagoon in the northeast (Figure 1). The samples were sent to Keck Carbon Cycle -University of California, Irvine (KCCAMS/UCI, USA) for stable isotope analyses and ^{14}C accelerator mass spectrometry (AMS) age determinations. The isotopic measurements were performed on five bone and five tooth samples from ten human skeletons. These samples belong to one juvenile and nine male and female adults (Table 1). Five of the samples are from burial sites excavated during archaeological rescues, and are stored at the

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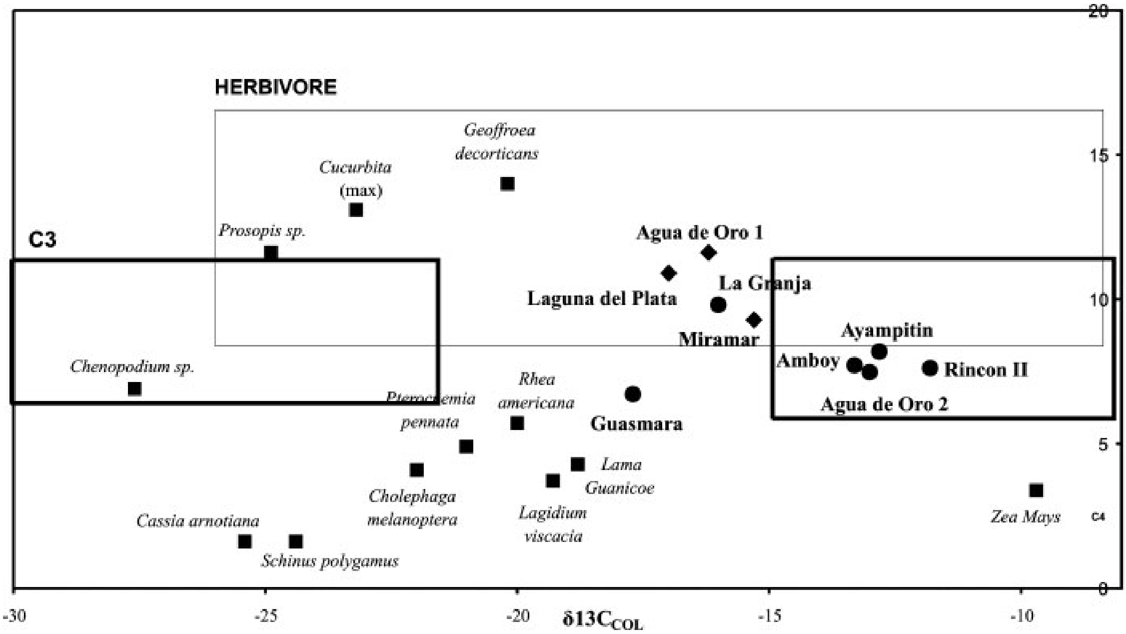

Figure 2. Isotopic relations.

Museo de Antropología (Córdoba city); the remaining samples belong to different public and private museums of Córdoba. In those cases where samples were obtained by archaeological rescues (Agua de Oro, Guasmara and La Granja sites) we had information about mortuary practices and associated archaeological materials that allowed us to infer their relative chronology before performing ^{14}C dating. The remaining samples (Amboy, East Coast, Rincon II, Ayampitin and Miramar sites) were not obtained from systematic archaeological surveys, so there was no contextual information. Overall visual inspection of the samples indicated that they were very well preserved, except for the tooth samples UCIAMS# 22279 [61B, Agua de Oro site ("I2,CB")] and 22286 [64B, Agua de Oro Site, ("I1, CD")] in which roots were no longer attached, leaving the dentine exposed (Table 1).

Sample processing for stable isotopes and ^{14}C dating

Radiocarbon dating and isotopic analyses were performed by a member of our team (GMDS) at KCCAMS/UCI. In the case of bone samples, the surface was scraped off using stainless steel cutters attached to a Dremel tool to help remove any extraneous material. After the surface was removed, the sample was broken into small fragments about 0.5 to 2 mm in diameter to speed up the demineralisation process. Around 100 to 160 mg of material was used depending on the initial inspection of the bone. In the case of tooth samples, a more complex extraction process was required to allow the preservation of the tooth enamel for the preparation of moulds to produce replicas of the samples. To avoid any contamination by extraneous carbon, the stable isotope analyses and ^{14}C dating measurements were done before any contact of tooth samples with moulding materials. To reach the dentine (the organic dating material) and leave the enamel intact, the crown and roots were separated using a thin flexible diamond wheel. Dentine was then extracted from the inner part of the tooth using a diamond burr. Diamond wheels and burrs were fully cleaned between each sample processing to avoid any cross-contamination. It was not possible to keep the enamel from sample UCIAMS# 22286 intact. When this sample was held to be drilled it shattered at once. In this case, dentine was taken from the broken fragments.

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Table 1. Chronology and isotopic information about the samples included in this study

Site	UCIAMS no.	Sample name	Sample type	Hardness and smell	Initial weight (mg)	Gelatin colouration	$\delta^{15}N$ (‰)	IRMS $\delta^{13}C_{COL}$ (‰)	C/N	±	^{14}C age (BP)	±
3	22279	61B, Agua de Oro site (“I2,CB”)	Tooth; lower second premolar	Dentine/no smell	160	Pure white	11.6	−16.2	2.9	0.0014	3360	20
9	22280	62B, Agua de Oro site, (“I1, CC”)	Bone; postcranial –fragment of scapula	Hard bone/smell	105	Light tan	7.5	−13.0	2.7	0.0019	345	20
5	22281	66B, Guasmara Site, (″I2)	Bone; postcranial – left rib proximal epiphysis	Hard bone/smell	137	Light tan	6.7	−17.7	2.7	0.0017	920	20
4	22282	67, La Granja Site, (″I1)	Bone; postcranial – right foot medial phalange	Hard bone/smell	100	Light tan	9.8	−16.0	2.8	0.0019	1280	20
6	22283	14B, Amboy Site, (“I2”)	Bone; postcranial	Avoid spongy area/no smell	158	Light tan	7.7	−13.3	2.9	0.0019	830	20
2	22284	72A, East Coast Site, (I1)	Bone; cranial fragments – sphenoid	Avoid spongy area/no smell	152	Tan	10.9	−17	2.8	0.0012	3805	20
8	22285	1B, Rincon II Site (SI, I2607)	Tooth; lower right first premolar	Dentine/smell	63	Pure white	7.6	−11.8	2.9	0.0017	520	15
3	22286	64B, Agua de Oro Site, (“I1, CD”)	Tooth; upper right canine	Dentine/no smell	110	Light tan	—	—	—	0.0022	2980	30
7	22287	17B, Ayampitin Site, (I1)	Tooth; upper left second molar	Dentine/smell	122	Light tan	8.2	−12.8	3.0	0.0018	600	20
1	22288	56B, Miramar Site, (MIR5 ZS2)	Tooth; lower right second molar	Dentine/smell	83	Pure white	9.3	−15.3	2.8	0.0011	4525	20
	22289	Local dentist office	Modern tooth	Dentine/smell	63	Pure white	10.7	−16.1	2.8	0.0019	Modern	—

Table 2. Isotopic information from resources of southern Mendoza

Taxa	Common name	Environment/provenance	δ^{15}N‰	$\delta^{13}C_{COL}$ ‰
Zea Mays	Maize	Archaeological, lowland, southern Mendoza	3.9	−9.6
Geoffroea decoticans	—	Archaeological, lowland, southern Mendoza	14.0	−20.2
Lama guanicoe	Guanaco	Archaeological, highlands, southern Mendoza	4.3	−18.8
Cholephaga melanoptera	Andine goose	Actual, southern Mendoza	4.1	−22.0
Rhea americana	Rhea	Archaeological, footplain, southern Mendoza	5.7	−20.0
Pterocnemia pennata	Andean rhea	Archaeological, southern Mendoza	4.9	−21.0
Lagidium viscacia	—	Archaeological, southern Mendoza	3.7	−19.3
Cucurbita	Pumpkin	Archaeological, southern Mendoza	13.1	−23.2
Chenopodium sp.	Quinoa	—	6.9	−27.6
Prosopis sp.	—	Archaeological, southern Mendoza	11.6	−24.9
Cassia arnotiana	—	Actual, fruit, southern Mendoza	1.6	−25.4
Schinus polygamus		Actual, fruit, southern Mendoza	1.6	−24.4

All data from Gil *et al*. (2006).

Overall amounts of 63 to 122 mg of material were used from the tooth samples, depending on the amount of dentine available.

For ^{14}C measurements, clean aliquots of bone and tooth samples were converted to collagen by decalcification, gelatinisation and ultra-filtration (Brown *et al*., 1988); then the chemically extracted freeze-dried ultra-filtered collagen was combusted and graphitised (Santos *et al*., 2004) to produce 1 mg samples of graphite. Samples of ^{14}C-free bone and a secondary standard of known-age whale bone (for background correction and accuracy checks, respectively) accompanied the unknown samples through the entire sample preparation process. An extra tooth sample obtained in a local dentist's office was also added to the batch to be used as a modern quality control sample. Complete results are shown in Table 1, corrected for isotopic fractionation by on-line AMS-$\delta^{13}C_{COL}$ measurements. Radiocarbon concentrations are given as conventional radiocarbon ages (years BP), following the conventions of Stuiver and Polach (1977). Aliquots of 0.5 to 0.6 mg of freeze-dried ultra- filtered collagen were sent to the elemental analyser-IRMS for $\delta^{13}C_{COL}$, δ^{15}N and C/N ratio measurements. Samples were measured to a precision of <0.1‰ based on the scatter of several standards.

Results

The C/N ratio for all samples for which we have data was close to 2.8 (Table 1), indicating that they were well preserved (DeNiro, 1985; Ambrose, 1990). The yield for sample UCIAMS #22286 was low, and it did not produce enough ultra-filtered collagen for an EA/IRMS determination in addition to ^{14}C-AMS measurement. A $\delta^{13}C_{COL}$ value of -13.2 ± 0.4‰ was obtained on prepared graphite using the AMS spectrometer, but AMS-measured $\delta^{13}C_{COL}$ values can differ from 1–3‰ from those of the original material. Due to the fact that this sample did not fulfill the selected criteria for quality control, the final age result should be treated with caution.

Isotopic values for nine samples analysed are presented in Table 1. $\delta^{13}C_{COL}$ values range between -17.7‰ and -11.8‰ (average $= -14.8$‰). δ^{15}N values range between 11.6‰ and 6.7‰ (average = 9.2‰). These values are expected for mixed diets of C_3, C_4, CAM and/or herbivores' meat (Pate, 1994). Figure 2 shows measurements of $\delta^{13}C_{COL}$ and δ^{15}N values from the samples analysed in this study, and values for animal and plants from central-western Argentina published by other authors (Gil *et al*., 2006). The overall carbon stable isotope results show that the local inhabitants consumed mixed diets (C_3, C_4, CAM), as expected on the basis of the previous archaeological data. The diamonds symbolise samples from hunter-gatherer archaeological contexts (H-G) and the triangles symbolise samples from agricultural contexts (A). We see that both cases are distributed between the ranges of the C_4 plants and the herbivores. Two of the samples from the hunter-gatherer sites are located in the area of the herbivores, while the third is in the superimposed fields of herbivores and C_4

DOI: 10.1002/oa

plants. A similar situation occurred with the individuals of Laguna Mar Chiquita (Miramar site) and Traslasierra Valley (Guasmara site). In the case of Guasmara site, the sample is in the superimposed fields of herbivores and the CAM plants (e.g. between the C_3 and C_4 fields). These results allow us to suggest that: (a) the dietary differences observed between the hunter-gatherer sites (diamonds) can be associated with a possible emphasis on animal resources (at one end of the local trophic chain); and (b) that the samples from agricultural contexts (triangles) can be interpreted as more omnivorous, with greater emphasis on vegetal resources, as expected from the models.

When considering $\delta^{13}C_{COL}$ results (Figure 3), we notice different isotopic values at the beginning and the end of the Holocene. Neither of the samples are totally consumers of C_3 (carob tree and wild fruits) or C_4 (maize) plants (following the standard of Pate, 1994). Samples with older ^{14}C ages show more negative $\delta^{13}C_{COL}$ values, suggesting mixed diets with emphasis on C_3 food consumption. For younger or more recent ^{14}C ages the average $\delta^{13}C_{COL}$ value suggests a tendency towards more intense C_4 food consumption. The most likely explanation is that the isotopic shift observed in the diet of these populations from the southern portion of the Sierras Pampeanas reflects the introduction of maize during the Late Holocene. A similar conclusion was reported for the western region of the country (Novellino *et al.*, 2004). The combination of hunter-gatherer and agricultural strategies implies a detailed knowledge of local resources and their regional and seasonal variations. If we analyse these results by combining $\delta^{13}C_{COL}$ values and time as a variable, we can observe some interesting temporal tendencies in diet composition during the Holocene. The samples from the early Late Holocene are grouped into the range expected for diets with more consumption of C_3 species and/or herbivorous consumers of those resources. Furthermore, samples from the Late Holocene have isotopic values expected for diets based on the consumption of C_4 plants. Two of these samples, from La Granja and Guasmara sites, present isotopic values more representative of a hunter-gatherer subsistence strategy.

Regarding spatial variation, the $\delta^{13}C_{COL}$ results suggest that Late Holocene diets were similar among the different regions, except for one sample from Traslasierra Valley (Guasmara) and one sample from Sierras Chicas (La Granja), which show $\delta^{13}C_{COL}$ values similar to Middle Holocene values from other sites. Neither Guasmara nor La Granja sites present enough

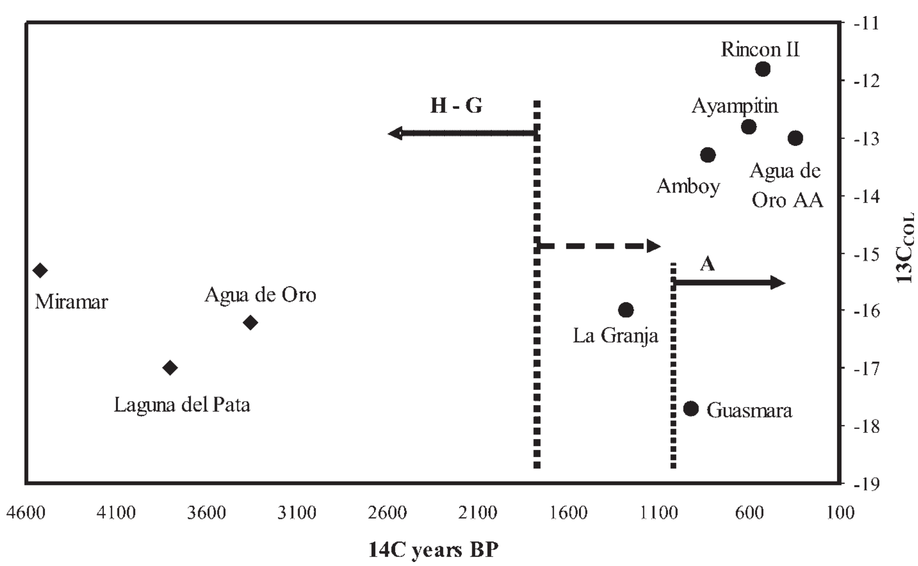

Figure 3. Temporal trends.

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associated evidence to infer that they correspond to agricultural contexts. They correspond to isolated burials recovered through archaeological rescues, with fragmented pottery in proximity but not directly associated. Chronology would associate Guasmara as synchronous with an agricultural context in Calamuchita Valley (920 ± 20 BP), based on the oldest radiocarbon date obtained for agricultural societies: the Los Molinos site at 903 ± 150 BP (Marcellino *et al.*, 1967). The radiocarbon date of La Granja (1280 ± 20 BP) could be seen as corresponding to an agricultural context, but the isotopic information does not correspond to that subsistence strategy. Ecologically, both sites are located in the highland region, but Guasmara is on the occidental hillside of the Sierras Grandes, in Traslasierra Valley, and La Granja is in the Chaco mountain forest. These different ecological locations might explain the 2‰ difference between the two samples (Table 1). Furthermore, these values would not explain the difference with other sites, because hunter-gatherer occupation of Agua de Oro site is located a few km south from La Granja. We interpret these sites as corresponding to a transitional stage in the process of adoption of maize agriculture, as we stated in our model, with a diet based principally on a high consumption of faunal and C_3 species, such as the carob tree.

If we group the samples into temporal blocks of 1000 years (Figure 4) we find that the average $\delta^{13}C_{COL}$ values between 4000 and 1000 calendar years BP (−16.2‰ and −16‰) are higher than the global average, being closer to the lower end expected for diets rich in C_3 plants or their herbivore consumers. Besides, the average for later periods is lower (−13.6‰) than the total average obtained, so this is coherent with the incorporation of C_4 plants into the diet during the last thousand years. The latest period shows the widest isotopic dispersion, with negative values for diets with more consumption of C_3 resources, as expected (Guasmara site, −17.7‰), and positive values that might suggest low incidence of C_4 plants, as also expected (Rincon site II, −11.8‰).

In order to investigate temporal and spatial variations in $\delta^{13}C_{COL}$ and $\delta^{15}N$, we classified the results in chronological order and considered archaeological regions (Figure 5). The La Granja and Guasmara sites share the same range of variation as hunter-gatherer sites, clearly separated from agricultural ones. This result led us to question whether we are dating and characterising the first transitional stages through an agricultural way of life (or the last hunter-gatherers for the region), and if this were to be the case, whether this result could help dating of this transitional stage.

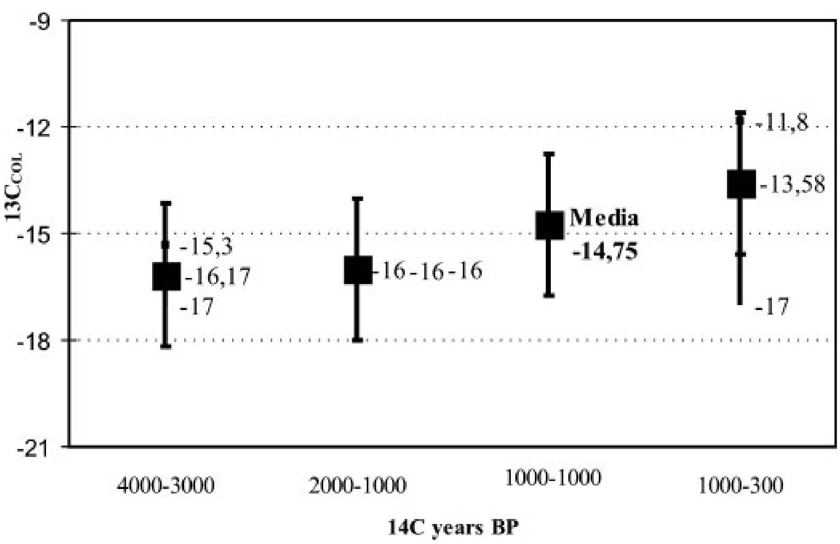

Figure 4. Temporal trends (thousand years).

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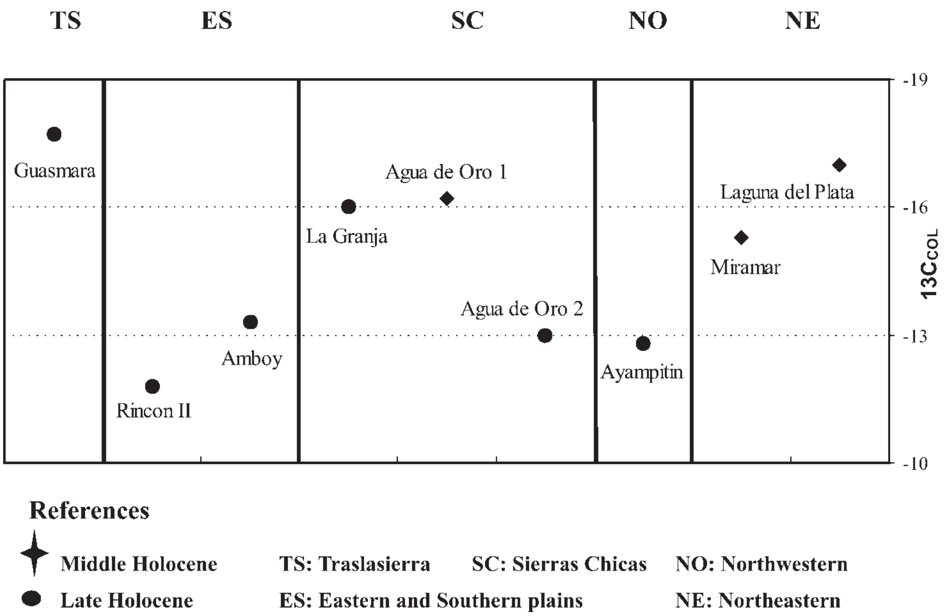

Figure 5. Temporal and spatial variation.

Spatial variation

Based on geographical-ecological criteria, the region of study was divided into five subregions: (1) Northeastern (NE), including Laguna del Plata and Miramar sites, and the wetlands surrounding Mar Chiquita lagoon; (2) Sierras Chicas (SC), including Agua de Oro and La Granja sites; (3) Northwestern (NO), including Ayampitín site; (4) Eastern and Southern plains (ES), including Amboy and Rincón II sites; and (5) Traslasierra (TS), including the Guasmara site (Figure 6). Values for $\delta^{13}C$ are presented in Figure 6 and values for $\delta^{15}N$ are presented in Figure 7. The mean values for $\delta^{13}C_{COL}$ do not show differences between NE and SC in the early sites (−16.2‰ and −16.2‰ $\delta^{13}C_{COL}$, respectively), suggesting similar hunter-gatherer diets. The interpretation is not so clear in the case of agricultural sites, which present values similar to each other (−12.9‰ *vs*. −12.6‰ $\delta^{13}C_{COL}$), and to those obtained for SC. These results suggest the incorporation of new resources into the diet in comparison with the hunter-gatherers of the same region. On the other hand, the TS sample is placed far from the other agricultural sites, presenting the highest negative value for $\delta^{13}C_{COL}$, which might reflect the absence of cultigens in the diet or, at least, their low incidence in the total diet.

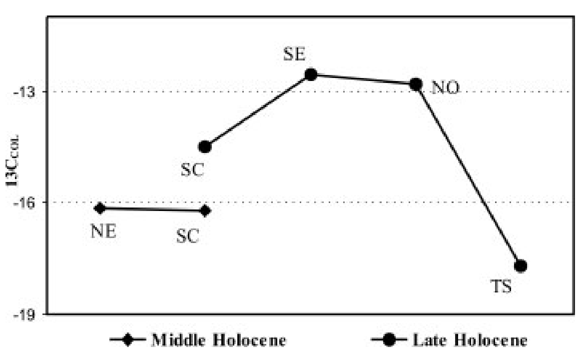

Figure 6. Spatial variation.

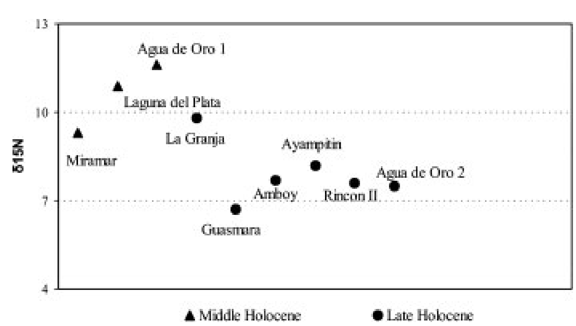

Figure 7. Temporal variation.

DOI: 10.1002/oa

In Figure 7 we present an analysis of the temporal variation in $\delta^{15}N$. The $\delta^{15}N$ values are higher in the hunter-gatherer sites, indicating greater consumption of animal protein. The Guasmara and La Granja sites, like in the $\delta^{13}C_{COL}$ analysis, take an intermediate position, reinforcing the idea of a transition.

The results obtained for the Miramar site deserve additional comments. As can be observed in Figures 2, 5 and 7, Miramar always occupies an intermediate position between the hunter-gatherers and agricultural sites, sometimes even closer to the latter, in spite of being the oldest of all the sites studied (4525 ± 20 BP). There are at least three related factors that could contribute to such a pattern: diet composition, differences in regional resource exploitation, and palaeoenvironmental variation.

Based on ^{14}C dating of the bottom of the Mar Chiquita Lagoon and from oxygen stable isotope studies it was possible to determine that around 4220 years BP there was a major retraction of the lagoon, down to more than 6 m below the mean height, one of the lowest levels known so far (Piovano, 2005). This negative water balance would be the result of aridity and water deficit, and certainly had an influence on the quality and quantity of food resources, probably reducing the availability of animals. It is necessary to consider the possibility of changes in the cycle of nitrogen due to water deficits, plus the possibility of lacustrine adaptation: the exploitation of aquatic and riverside resources, like fish and birds, now abundant in the region.

Discussion and conclusions

The isotopic values obtained for all the samples fall within the range expected for mixed diets, with consumption of C_3, C_4 and CAM plants. However, when these results are analysed within a temporal frame, we can observe different $\delta^{13}C_{COL}$ and $\delta^{15}N$ values for the initial and final stages of the Late Holocene. The early samples present lower mean values that suggest a mixed diet, although with a tendency towards a greater consumption of C_3 plants.

On the other hand, the mean values obtained for the later samples remain within the range expected for mixed diets, with the possible incorporation of C_4 plants. Nevertheless, if we take into account that populations with variable agricultural dependency present mean $\delta^{13}C_{COL}$ values of *ca*. −8‰ (Hard *et al*., 1996), we can conclude that the results obtained for the populations settled in the Central Mountains of Argentina would reflect the relative incidence of maize in their diet. Similar results have been reported for the central-western region of Argentina (Novellino *et al*., 2004).

Previous studies in this region (Laguens, 1999) have suggested that agriculture covered at least 50% of subsistence, with the other 50% divided into 30% for gathering and 20% for hunting (Laguens, 1999; Laguens *et al*., 2007). The combination of hunting, gathering and productive strategies implies a complete knowledge of the available resources and their regional variations. These results imply that the differences observed between the hunter-gatherer sites could be associated with a possible emphasis on animal resources, while samples from agricultural sites can be interpreted as more omnivorous, with greater emphasis on vegetal resources. The isotopic results would confirm the mixed character of the resources, a fact that we have suggested before based on indirect evidence and projections of similar anthropological cases (Laguens, 1999).

Regarding the timing of agriculture adoption, we interpret that two sites (La Granja and Guasmara) could represent a transitional stage through adoption of maize agriculture –between 1280–920 BP – as we stated in our model, with a diet based principally on high consumption of faunal and C_3 vegetal species.

If we consider spatial variation and regional differences in diets, the $\delta^{13}C_{COL}$ results suggest slight regional differences in diet for later periods. The values observed for these samples are similar in two of the analysed subregions (NE and SC), with similar variations among other subregions, with the exception of the result found for the sample of TS, which is closer to those obtained in the samples corresponding to the Middle Holocene. Although preliminary, these results suggest that the adoption of agriculture was not only complementary to hunter-gatherer strategies, but also that adoption of cultigens was regionally different, having a much

DOI: 10.1002/oa

smaller incidence in some regions (for example, TS) that in others (SE, NE). It is necessary to study this subject in depth through the analysis of a larger number of human samples and the available resources in order to evaluate their isotopic variability.

These results are remarkable since it is the first approach to palaeodietary studies based on isotopic evidence for this region. Most interestingly, our findings coincide with the evidence obtained from the archaeological record, and provide new elements to suggest that the incorporation of maize agriculture would have arisen as a complement to the preceding and effective economic strategies such as hunting and harvesting, all of them organised around an optimal exploitation of the different resources offered by each particular environment, with the purpose of obtaining a constant annual supply.

Acknowledgements

This study was funded by FONCyT (Fondo para la investigación científica y tecnológica, Agencia Nacional de Promoción Científica y Tecnológica) grant PICT 2003 15187. Isotopic determinations were carried out at KCCAMS/UCI. Special thanks go to the Museo de Antropología (F.F. y H., UNC) and other museums in the Córdoba province for providing us access to the specimens analysed here: Museo Histórico "Dalmacio Velez Sarsfield" (Amboy), Casa de la Cultura de Marull (Marull), Museo de la región de Ansenuza "Aníbal Montes" (Miramar), Museo "Capitan Juan de Zeballos" (Valle Hermoso) and Museo Arqueológico Provincial "Aníbal Montes" (Rio Segundo). We are also most grateful to Marcela Macias and Maria Soledad Salega who kindly revised an earlier version of this article, and to Paola Sebal for helping with the map. This manuscript was greatly improved by comments from editors and one anonymous reviewer.

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DOI: 10.1002/oa