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Stable isotopes and human diet in central western Argentina

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ABSTRACT

Central western Argentina is the southern boundary of prehispanic maize in the archaeological record. This paper explores the stable isotope information from human bone ($\delta^{13}C$, from collagen and $\delta^{13}C$ from apatite) and tooth ($\delta^{13}C$ from enamel) samples in order to characterize the temporal and spatial trends of these isotopes and to understand them in terms of human diet. We analyzed 104 human individuals from the last 6000 years. Using the Kellner and Schoeninger (2007) model the results shows a high variation in human diet with few human individuals with a notably high significance of C_4 plants (probably maize) as an energy source and these samples have a chronology around *ca*. 1000 years BP. On the other hand a high variation in an individual's dietary life history is shown by differences between $\delta^{13}C$ collagen, apatite and enamel.

1. Introduction

In the last decade, research on American prehispanic farming related to the adoption and significance of domesticated plants in human diet, particularly maize, has revealed a more complex pattern than previously accepted (Staller et al., 2006). As was recently proposed by Schoeninger (2009), the adoption of maize agriculture was not a single phenomenon. This idea could be explored in different areas of the Americas to improve our understanding of the pattern of maize farming adoption and to discuss the hypothesis about diet change and the adoption of new resources. The central western area of Argentina provides the southernmost record of domesticated plants in prehispanic times (Bárcena, 1999; García, 1992; Gil, 2003; Gil et al., 2006, 2010; Lagiglia, 1999; Pearsall, 1992). For this reason it is a relevant region to explore the significance and the adoption of maize. Until recently it was assumed that in central western Argentina maize was a staple during a large part of the late Holocene, but recently this idea has been challenged and there is a need to explore more carefully this pattern (Gil et al., in press). A strong distinction has been proposed in central western Argentina between northern sedentary populations, that exploited corn and other domesticates, and southern more mobile populations that were hunter-gatherers. This produced an historic ethnic distinction of Huarpes in the north and Puelches in the south (Chiavazza, 2008; Durán, 2000; Michelli, 1979; Prieto, 1999), that could have started to separate around 2000 years BP (Lagiglia, 1977).

The antiquity of maize in central western Argentina is a controversial topic (Bárcena, 2001; García, 1992; Lagiglia, 2001). Bárcena et al. (1985; Bárcena, 2001) proposed an early entry of maize, *ca*. 4000 years BP, while other researchers accepted a later chronology for this domesticate, at *ca*. 2000 years BP (García, 1992; Lagiglia, 1980, 2001). Direct radiocarbon maize chronology agrees with the later proposition although the few *Zea mays* samples directly dated are recorded archaeologically in the southern part of this region (Gil, 2003). In general, the record of domesticates has been interpreted as a consequence of the settlement of farming societies (see details in Gil, 1997–1998), and generally proposed in its first phase as "incipient farming" (Lagiglia, 1980). Recently, alternative strategies to a hunter-gatherer/farming dichotomy have been proposed and temporal-spatial variations in corn incorporation and use are starting to be considered (Gil, 2003; Gil et al., 2006; Novellino et al., 2004). To improve our understanding of the spread of domesticated plants, it is necessary to look at different cases and explore how the domesticate was incorporated, and how its significance changed through time and space (Schoeninger, 2009). Furthermore, it has been proposed that domesticates were not a good choice in all cases, and during some times its role in human diet dropped (Coltrain and Leavitt, 2002; Falabella et al., 2007; Schoeninger, 2009). Also, there are reasons to propose a more complex pattern than hunting-gathering in the south and farming in the north of central western Argentina (Gil, 1997–1998). Direct

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radiocarbon dating and stable isotope analysis conducted on the same individuals present an excellent opportunity to explore the temporal and spatial variation in human diet and discuss the role of maize in the human diet (Cook and Schurr, 2009).

Gil et al. (2010) studied human dietary variation through time and space in central western Argentina conducting stable isotope analysis on late Holocene samples. Analyzing human bone collagen ($\delta^{13}C_{col}$ and $\delta^{15}N$) and bone apatite ($\delta^{13}C_{ap}$), Gil et al. (2010) did not reveal clear temporal nor spatial patterns. In the present paper, to extend the previous research and improve the temporal and spatial patterning, we add stable isotope analyses of teeth ($\delta^{13}C$). The stable isotope analysis from bone and teeth is used in this paper to explore the variation in the use of different resources. We present data on human archaeological samples from the last 6000 years recorded between 30° and 36° SL (Fig. 1). The human samples are from a museum collection with good provenance information and in general have archaeological contextual information too. In the paper we explore the relationship in the same individuals between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ ($\delta^{13}C_{col\text{-}ap}$) in bone and $\delta^{13}C_{col}$ in bone and $\delta^{13}C_{en}$ in teeth ($\delta^{13}C_{col\text{-}en}$) following the model presented by Kellner and Schoeninger (2007). With this approach we examine the trends proposed by Gil et al. (2010) on the role of maize and dietary variation. After that, the individual differences between $\delta^{13}C_{ap\text{-}en}$ are explored in spatial and temporal trends to consider variation in human life history.

2. Stable isotopes and human strategies

The inorganic and organic chemical constituents of bone provide a record of long-term dietary intake, and relate with aspects such as human mobility. The chemical composition of bone can be used to address prehistoric access to food. The study of paleodiet through stable isotope analysis proceeds from the experimental observation that the isotopic composition of animal tissues generally reflects their diet (Ambrose and Krigbaum, 2003; Schwarcz and Schoeninger, 1991). Such analyses utilize the variation in the ratios of the stable isotopes of carbon and nitrogen within ecosystems to measure the relative contribution of different resources to animals' diets (DeNiro and Epstein, 1978). As some foods, such as maize, have distinctive isotopic signatures, it is often possible to identify their consumers (Norr, 1995). The stable isotopes of carbon (^{13}C and ^{12}C) and nitrogen (^{15}N and ^{14}N) are expressed in parts per mil (‰) as δ values:

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

where $R = {}^{13}C/{}^{12}C$ for the measurement of carbon and $^{15}N/^{14}N$ for the measurement of nitrogen. The standards to which samples are compared are the limestone Vienna PeeDee Belemnite (VPDB) and atmospheric nitrogen (AIR) for carbon and nitrogen, respectively. As most materials including plant and animal tissues have less ^{13}C than

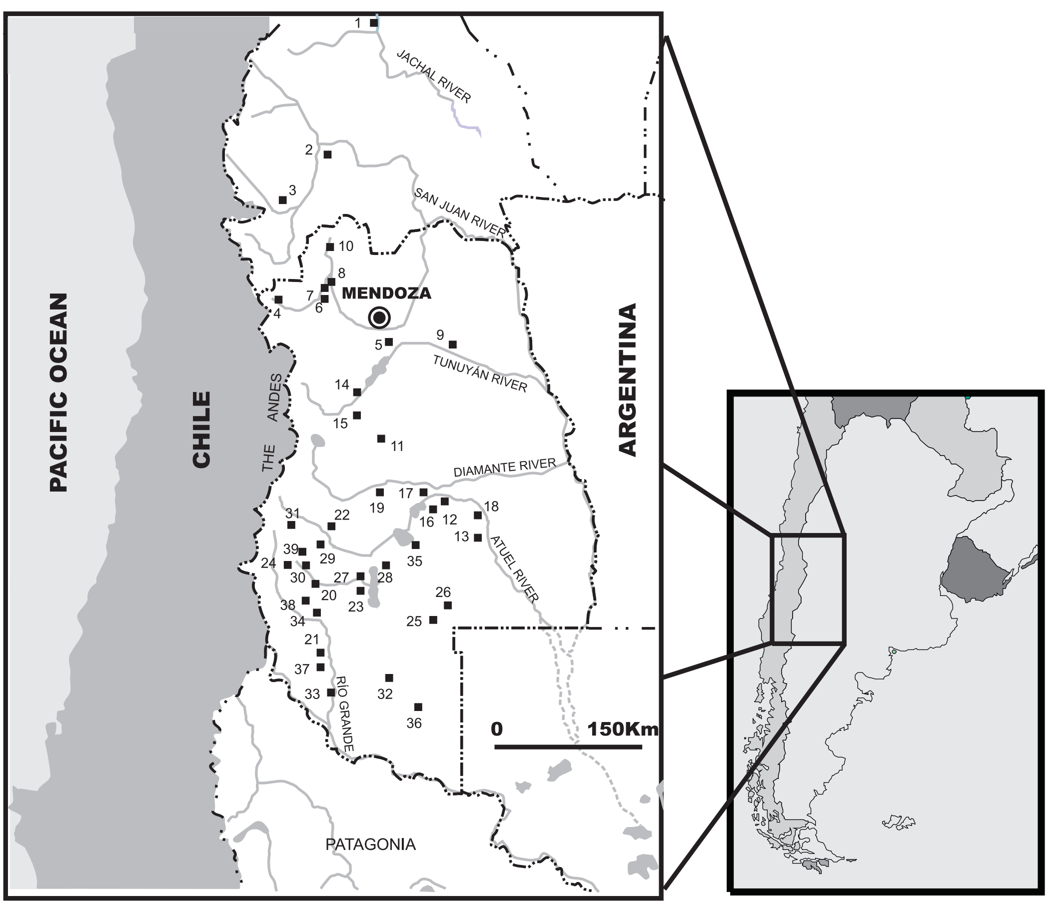

Fig. 1. Archaeological site mentioned in the text. References: 1-Angualasto; Punta del Barro; 2-Cerro Calvario; Calingasta; 3-Gruta 1 Los Morrillos; Morrillo Gruta 1; 4-Aconcagua; 5-Barrancas Yacimiento 1; 6-Potrero Las Colonias; 7-Uspallata; 8-Uspallata Túmulo I, II, III; 9-Alto Verde; 10-Agua de la Cueva; 11-Capiz Alto; 12-Rincón del Atuel; 13-La Olla; 14-Viluco; 15-San Carlos; 16-Cerro Negro; Gruta del Indio; 17-Cañada Seca; 18-Jaime Prats; 19-Médano Puesto Díaz; 20-Ea. Las Chacras; 21-Buta Mallín; 22-Tierras Blancas; 23-Llancanelo; Pozos del Carapacho; Llancanelo (W); Los Menucos; 24-Cañada de Las Vizcachas; Cerro Negro de Pincheira; 25-Cienaga de Borbarán; 26-RQ-1; 27-Cerro Trapal; 28-Norte de Llancanelo; 29-Ojo de Agua; 30-Cerro Mesa; 31-El Desecho; India Embarazada; 32-El Payén; 33-El Manzano; 34-Caverna de Las Brujas; 35-El Nihuil; Arbolito; 36-La Matancilla; 37-El Alambrado; 38-Mechenquil; Chenqueco; 39-El Chacay; El Chacay Puesto Adobe.

Table 1
Isotope ecology in central western Argentina.

Latitude	Sample	Archaeological site	Sex	Age	Code	Chronology	Code	$\delta^{15}N$	$\delta^{13}C_{col}$	Code	$\delta^{13}C_{ap}$	Code	$\delta^{13}C_{en}$	Reference	Teeth
30	SJ10-ENT1	Angualasto	F	A	-	-	7386	9.9	-12.3	7159	-8.2	-	-	1, 5, 6	-
30	SJ4-ENT 2	Angualasto	-	A	BETA-134392	650 ± 40	7384	10.1	-13.8	7142	-10.3	-	-	1, 5, 6	-
30	SJ5-ENT2	Cerro Calvario	-	A	-	-	-	-	-	-	-	7143	-8.3	1, 5,6	C
30	SJ3-ENT3	Punta del Barro	-	A	BETA-161362	590 ± 40	7111	9.5	-13.3	7110	-9.8	7112	-9.0	1, 7	M
31	SJ2	Calingasta	M	A	-	-	7382	9.5	-13.8	7106	-10.1	7108	-6.3	1, 5, 6	PM
31	SJ7-ENT2	Gruta 1 Morrillos	?	A	GAK-4704	4070 ± 105	7152	10.8	-15.3	7151	-12.2	7150	-9.2	1, 8	PM
31	SJ6-ENT8	Gruta 1 Morrillos	F	A	GAK-4809	1280 ± 90	7385	8.1	-17.3	7380	-14.0	-	-	1, 7	-
31	SJ1-ENT 7	Morrillos Gruta 1 (F)	?	A	-	-	7381	9.7	-17.3	7104	-13.1	-	-	1, 7, 8	-
32	S/C	Aconcagua	F	-	GX-19991	370 ± 70	S/C	10.4	-10.8	-	-	-	-	2	-
32	S/C	Agua de la Cueva	-	I	S/C	2480 ± 50	UGA-8660	-	-14.6	-	-	-	-	-	-
32	MMy-1241	Barrancas yac. 1	F	17-20	-	-	8288	8.0	-10.8	8301	-5.0	8314	-12.0	-	2M
32	MMy-1263	Barrancas yac. 2	M	$\geq$ 45	AA-66560	2084 ± 40	8289	9.9	-18.0	8302	-13.6	8315	-11.5	-	3M
32	MMy-284	Potreros Las Colonias	F	30-45	AA-66564	568 ± 38	8296	10.0	-11.0	8309	-4.2	8320	-4.7	-	1M
32	MMy-1471	Alto Verde	-	-	AA-66563	1736 ± 49	8295	6.9	-15.9	8308	-10.0	8319	-9.2	-	1M
32	MMy-259	Uspallata	F	A	AA-66558	1922 ± 52	8290	9.9	-15.6	8303	-6.6	-	-	-	-
32	S/C	Uspallata	-	-	S/C	580 ± 90	AC-1050	9.8	-13.5	-	-	-	-	2	-
32	MMy-229	Uspallata Túmulo I		$\geq$ 50	AA-66568	977 ± 35	8294	9.7	-16.4	8307	-11.0	8318	-3.3	-	PM
32	MMy-239	Uspallata Túmulo II	F	$\geq$ 50	AA-66561	1269 ± 35	8291	9.6	-11.9	8304	-7.5	8316	-5.5	-	2M
32	MMy-243	Uspallata Túmulo II	F	38-53	AA-66565	1178 ± 41	8293	10.1	-12.1	8306	-6.5	8317	-7.6	-	3M
32	MMy-245	Uspallata Túmulo II	M	35-45	-	-	8292	9.8	-12.4	8305	-6.6	-	-	-	-
32	MMy-1097	Uspallata Túmulo III	-	-	AA-66566	671 ± 40	8297	7.8	-11.2	8310	-3.4	-	-	-	-
33	ENT-2	Capiz Alto	F	40-45	-	-	6226	11.7	-14.9	6227	-10.6	6228	-9.6	-	?
33	ind6	Capiz Alto	F	35-45	-	-	UGA-8661	-	-15.6	-	-	-	-	3	-
33	ind1	Capiz Alto	M	45-49	-	-	UGA-8662	-	-16.7	-	-	-	-	3	-
33	ind2	Capiz Alto	F	40-45	-	-	UGA-8663	-	-15.9	-	-	-	-	3	-
33	MMy-1221	San Carlos	F	40-49	AA-66567	142 ± 41	8298	8.4	-18.7	8311	-12.3	8321	-12.2	-	2M
33	MMy-1223	San Carlos	F	19-23	AA-66562	177 ± 34	8287	10.7	-17.9	8300	-10.2	8313	-11.7	-	2M
33	MMy-1197	Viluco	F	40-45	AA-66559	208 ± 38	8286	10.3	-17.2	8299	-12.9	8312	-13.7	-	1M
34	AF-2019	Cañada Seca	M	$\geq$ 50	-	-	7349	10.4	-14.5	7350	-10.1	7351	-8.8	-	M
34	AF-2018	Cañada Seca	M	30-35	-	-	7354	11.5	-14.3	7355	-9.8	7356	-9.0	-	2M
34	AF-2020	Cañada Seca	M	50-56	LP-1184	1790 ± 50	7358	11.3	-14.3	7359	-9.5	7357	-8.7	-	3M
34	AF-2017	Cañada Seca	-	A	-	-	AIE-7668	-	-14.9	-	-	-	-	4	-
34	CS-10001	Cañada Seca	M	30-45	LP-1374	1420 ± 60	6199	11.6	-15.7	6200	-9.0	-	-	-	-
34	MRM-20	El Perdido	-	-	AA-62937	2936 ± 60	8349	8.7	-16.9	8378	-11.5	-	-	-	-
34	AF-2000	Cerro Negro	M	27-34	AA-58279	580 ± 35	7619	9.0	-14.8	8191	-7.4	8192	-5.5	-	3M
34	AF-2021	Gruta del Indio	-	1.5	-	-	-	-	-	8189	-8.8	8190	-6.1	-	D
34	AF-13894	Gruta del Indio	-	I	-	-	7352	9.8	-15.0	7353	-10.1	-	-	-	-
34	GIRA-27	Gruta del Indio	-	A	-	-	6224	-	-	6225	-11.9	-	-	-	-
34	Gira-70	Gruta del Indio	-	A	AA-54670	2879 ± 37	6201	10.8	-14.0	6202	-9.8	-	-	-	-
34	AF-830	Gruta del Indio	-	-	AA-58280	3860 ± 60	-	-	-	8193	-12.0	-	-	-	-
34	GIRA-831	Gruta del Indio	-	-	AA-59588	3944 ± 46	7363	-	-	7364	-10.5	-	-	-	-
34	AF-828	Gruta del Indio	F	30-49	AA-58281	580 ± 40	7621	9.9	-13.7	8195	-7.6	-	-	-	-
34	JP-1155	Jaime Prats	F	20-26	-	-	6219	10.6	-16.8	6220	-10.2	6221	-8.6	-	-
34	JP/J4	Jaime Prats	-	-	AA-59590	1887 ± 42	7347	9.8	-17.4	7348	-13.5	7346	-13.5	-	M
34	JP-1352	Jaime Prats	-	A	AA-59589	1880 ± 49	7340	9.9	-16.3	7339	-10.6	7338	-11.2	-	3M
34	JP-1155	Jaime Prats	F	20-24	-	-	7344	10.9	-16.0	7345	-9.3	-	-	-	3M
34	JP-21	Jaime Prats	-	-	-	-	AIE-1396	-	-17.9	-	-	-	-	-	-
34	AF-008	La Olla	-	A	AA-58293	645 ± 42	7625	11.7	-17.6	-	-	-	-	-	-
34	AF-681	Médano Puesto Díaz	F	40-45	AA-59587	2865 ± 52	7360	8.7	-15.6	7361	-10.2	7362	-10.7	-	PM
34	AF-503	Rincón del Atuel	M	34-45	-	1760	6203	9.4	-13.8	6204	-7.9	6205	-9.9	-	-
34	AF-500	Rincón del Atuel	M	$\geq$ 50	-	-	7365	9.5	-15.2	-	-	-	-	-	-
34	AF-503	Rincón del Atuel	F	35-49	-	-	7366	9.2	-13.9	-	-	-	-	-	3M
34	AF-500	Rincón del Atuel	M	$\geq$ 50	LP-1370	1760 ± 70	6222	10.3	-13.5	6223	-8.1	-	-	-	-
35	MRM-24	A Negro de Pincheira	-	-	AA-62941	358 ± 45	8353	12.4	-18.2	8382	-15.8	-	-	-	-
35	AF-1083	Arbolito	F	35-50	AA-58284	97 ± 36	7624	9.6	-16.1	8199	-10.6	8196	-9.8	-	2M

(continued on next page)

Table 1 (*continued*).

Latitude	Sample	Archaeological site	Sex	Age	Code	Chronology	Code	$\delta^{15}N$	$\delta^{13}C_{col}$	Code	$\delta^{13}C_{ap}$	Code	$\delta^{13}C_{en}$	Reference	Teeth
35	MRM-4	Cañada de las Vizcachas	F	25-35	AA-62922	573 ± 33	8334	7.4	-14.7	8363	-8.9	8388	-10.5	-	3M
35	MRM-22	El Chequenco	-	-	AA-62939	174 ± 48	8351	11.2	-17.9	8380	-14.3	-	-	-	-
35	AF-508	Cerro Mesa	M	38-49	-	-	6209	10.8	-17.9	6210	-12.2	6211	-11.3	-	3M
35	AF-510	Cerro Mesa	M	≥ 50	-	-	7331	10.9	-17.9	7330	-13.0	7329	-12.7	-	3M
35	AF-2077	Cerro Trapal	M	A	-	-	8358	13.2	-13.5	8383	-7.7	-	-	-	-
35	AF-2081	Cerro Trapal	M	J	AA-66572	2626 ± 61	8359	11.4	-16.5	8384	-12.8	-	-	-	-
35	MRM-12	Cienaga de Borbarán	M	45-50	AA-62921	274 ± 48	8333	13.2	-16.5	8362	-12.3	8387	-11.4	-	3M
35	MRM-13	Ea. Las Chacras	F	35-49	AA-62924	881 ± 33	8336	8.9	-17.4	8365	-12.5	8390	-13.3	-	3M
35	Ent 3	El Chacay	-	-	AA-59591	2321 ± 66	7342	7.9	-16.2	7343	-9.2	7341	-10.2	-	M
35	MRM-10	El Chacay-Pto. Adobe	M	20-34	AA-62923	1472 ± 34	8335	8.1	-17.7	8364	-13.6	8389	-10.8	-	3M
35	AF-2038	El Desecho	F	39-49	AA-54671	5502 ± 60	6217	6.4	-18.8	6218	-11.2	-	-	-	-
35	MRM-21	El Nihuil	-	-	AA-62938	274 ± 45	8350	12.3	-15.9	8379	-12.2	-	-	-	2M
35	AF-2036	India Embarazada	F	16-20	AA-54672	2576 ± 60	6206	9.7	-17.5	6207	-10.1	6208	-10.8	-	M
35	AF-2072	Las Ramadas	F	15-18		965 ± 35	7622	7.2	-13.7	8197	-7.6	8194	-6.2	-	3M
35	MRM-7	Llancanelo	F	20-23	AA-62927	855 ± 80	8339	8.3	-19.1	8368	-13.6	8393	-8.9	-	3M
35	MRM-6	Llancanelo	-	03-May	AA-62925	862 ± 33	8337	11.1	-18.2	8366	-15.9	8391	-11.8	-	1M
35	MRM-5	Llancanelo	F	20-25	AA-62919	850 ± 33	8331	8.8	-18.8	8360	-14.5	8385	-11.2	-	1M
35	MRM-25	Llancanelo	-	A	AA-62926	900 ± 36	8338	9.9	-18.5	8367	-14.1	8392	-13.4	-	M
35	MRM-17	Llancanelo	F	20-25	AA-62934	1008 ± 47	8346	11.5	-18.3	8375	-13.9	-	-	-	-
35	MRM-23	Llancanelo	-	J	AA-62940	896 ± 47	8352	10.1	-18.3	8381	-13.9	-	-	-	-
35	MRM-18	Llancanelo (W) Los Menucos	-	A	AA-62935	863 ± 47	8347	11.7	-17.3	8376	-12.8	-	-	-	-
35	MRM-1	Norte de Llancanelo	M	39-49	AA-62920	688 ± 36	8332	8.0	-19.4	8361	-14.2	8386	-12.3	-	1M
35	AF-2022	Ojo de Agua	M	15-18	LP-921	1280 ± 50	6194	10.5	-18.5	6195	-	6196	-11.9	-	3M
35	MRM-14	Pozos de Carapacho	-	A	AA-62928	797 ± 30	8340	11.3	-15.8	8369	-12.9	8394	-10.5	-	2M
35	MGA-1	RQ-1	-	-	-	-	6214	10.9	-14.2	6215	-8.9	2616	-8.7	-	3M
35	AF-2025	Tierras Blancas	F	30-48	LP-890	200	7333	9.5	-15.5	7334	-8.2	7332	-10.8	-	PM
36	AF-1082	Agua del Toro	F	35-49	LP-1368	210 ± 60	6212	12.9	-16.5	6213	-11.3	-	-	-	-
36	MRM-8	Ao Mechenquil	-	-	AA-62931	148 ± 31	8343	11.9	-20.9	8372	-14.3	-	-	-	-
36	MRM-16	Buta Mallín	-	-	AA-62933	2530 ± 36	8345	7.7	-17.2	8374	-13.1	-	-	-	-
36	12	Caverna de las Brujas	-	A	AA-58283	3847 ± 45	7623	11.4	-15.9	8198	-11.3	-	-	-	-
36	MRM-15	El Alambrado	-	-	AA-62932	1821 ± 35	8344	9.9	-17.1	8373	-13.2	8397	-9.0	-	2M
36	MRM-19	El Alambrado	-	-	AA-62936	282 ± 45	8348	10.0	-18.9	8377	-14.9	8398	-11.3	-	2M
36	AF-673	El Manzano	M	35-43	-	-	7335	10.2	-17.2	7336	-12.5	7337	-12.8	-	PM?
36	MRM-11	El Payén	-	A	AA-62929	443 ± 36	8341	12.6	-16.7	8370	-13.0	8395	-11.3	-	2M
36	MRM-9	Jagüel del Medio	-	-	AA-62930	3222 ± 46	8342	10.2	-15.2	8371	-10.5	8396	-9.8	-	1M
36	AF-505	La Matancilla	M	45-50	LP-1379	470 ± 50	6197	11.9	-16.0	6198	-10.1	-	-	-	

Sex: M: male; F. Female. Age: A: Adult; J: Juvenile; I: Infant. Teeth: M: molar: PM: premolar; 1M: Molar 1; 2M: Molar 2; 3M: Molar 3; D: deciduous; C: canine. Reference; 1: Gil et al. (2006); 2: Fernandez and Panarello (1999); 3: Durán and Novellino (2002); 4: Fernández and Panarello (1990); 5: Michelli, 1994, 6: Michelli, 2001; 7: Gambier 1977, 8: Gambier 1985.

Table 2
Stable isotope values ($\delta^{13}C$, $\delta^{15}N$) to central west Argentina. Animals value are from bone sample, except to samples USF-6173 (it is from molar).

Code lab	Taxa	Lat	Area	Procedence	$\delta^{15}N$	$\delta^{13}C_{col}$	$\delta^{13}C_{ap}$
USF-5912/6178	*Chaetophractus villosus*	36	PIEDMONT	Alero Puesto Carrasco (arch)	5.6	−17.7	−11.1
USF-5908/6174	*Cholephaga melanoptera*	35	HIGHLAND	EL Indígeno (arch)	4.1	−22.0	−11.5
USF-5911/6177	*Lagidium viscacia*	36	PIEDMONT	Alero Puesto Carrasco (arch)	3.7	−19.3	−9.1
USF-5905/6170	*Lama guanicoe*	35	HIGHLAND	Arroyo El Desecho-10 (arch)	4.3	−19.1	−10.7
USF-5906/6171	*Lama guanicoe*	35	LOWLANDS	Agua de los Caballos-1 (arch)	5.0	−14.7	−6.8
USF-5907/6172	*Lama guanicoe*	36	PIEDMONT	Cueva de Luna (arch)	4.6	−19.4	−11.1
USF-6173	*Lama guanicoe*	53	HIGHLAND	El Indígeno (arch)	–	–	−9.1
USF-8354	*Lama guanicoe*	36	PIEDMONT	La Gotera (arch)	6.2	−18.7	–
USF-8355	*Lama guanicoe*	35	HIGHLAND	Arroyo Malo-3 (arch)	4.8	−18.8	–
USF-8356	*Lama guanicoe*	35	PIEDMONT	Ojo de Agua (arch)	6.6	−18.7	–
USF-8357	*Lama guanicoe*	35	PIEDMONT	El Sosneado-3 (arch)	6.1	−18.9	–
USF-5913/6179	*Lama guanicoe*	35	HIGHLAND	Arroyo El Desecho-10 (arch)	4.3	−18.8	−8.9
USF-8864	*Lama guanicoe*	36	LOWLANDS	La Payunia-La Corredera (arch)	6.3	−19.3	–
USF-8865	*Lama guanicoe*	35	LOWLANDS	Agua de Los Caballos-1 (arch)	7.6	−18.5	–
USF-8866	*Lama guanicoe*	36	PIEDMONT	Gruta El Manzano (arch)	7.6	−17.6	–
USF-8859	*Lama* sp.	32	HIGHLAND	Potrerillos- Casa 1 (arch)	4.9	−18.7	–
USF-8862	*Lama* sp.	32	HIGHLAND	La Manga, Casa de Piedra (arch)	4.4	−19.7	–
USF-8863	*Lama* sp.	32	HIGHLAND	Agua de La Cueva (arch)	6.4	−17.5	–
USF-7368	*Lama* sp.	30	LOWLANDS	Angualasto (arch)	9.0	−14.2	–
USF-7370	*Lama* sp.	31	HIGHLAND	Morrillos (arch)	5.6	−18.1	–
s/d	*Lama* sp.	39	PIEDMONT	Neuquén (arch)	–	−19.8	–
s/d	*Lama* sp.	39	PIEDMONT	Neuquén (arch)	–	−19.7	–
USF- 8860	*Pterocnemia pennata*	32	HIGHLAND	Agua de La Cueva (arch)	7.6	−18.6	–
USF-5914/6180	*Pterocnemia pennata*	36	PIEDMONT	Alero Puesto Carrasco (arch)	4.9	−21.0	−11.5
USF-5910/6176	*Pterocnemia pennata*	36	PIEDMONT	Alero Puesto Carrasco (arch)	4.6	−20.6	−12.1
USF-5909/6175	*Rhea americana*	36	PIEDMONT	Malargue (modern)	5.7	−20.0	−11.8
USF-7369	*Rhea* sp.	30	LOWLANDS	Angualasto (arch)	6.7	−18.3	–
s/d	*Araucaria araucana*	39	PIEDMONT	Neuquén (arch)	–	−23.6	–
USF-6187	*Cassia arnottiana*	35	HIGHLAND	Arroyo Malo (modern)	1.6	−25.4	–
USF-6185	*Chenopodium* sp.		LOWLANDS	–	6.9	−27.6	–
USF-6192	*Condalia microphylla*	34	LOWLANDS	Cuadro Benegas (moden)	–	−25.3	–
USF-6183	*Cucurbita maxima*	34	LOWLANDS	Gruta del Indio (arch)	13.1	−23.2	–
USF-7375	*Curcurbita maxima*	31	LOWLANDS	Iglesia (arch)	6.0	−26.7	–
USF-7376	*Curcurbita maxima*	31	LOWLANDS	Calingasta (arch)	7.0	−24.3	–
USF-7379	*Curcurbita maxima*	31	LOWLANDS	Iglesia (arch)	9.8	−24.2	–
USF-6190	*Geoffroea decorticans*	34	LOWLANDS	Rincón del Atuel (modern)	–	−20.8	–
USF-6189	*Geoffroea decorticans*	35	LOWLANDS	Agua de Los Caballos-1 (arch)	14.0	−20.2	–
USF-6184	*Lagenaria* sp.		LOWLANDS	–	10.4	−25.4	–
USF-6188	*Phaseolus vulgaris* Var. oblo	34	LOWLANDS	Gruta del Indio (arch)	5.5	−24.0	
USF-7371	*Phragmite australis*	31	LOWLANDS	Iglesia (arch)	4.2	−23.6	–
R-V-8	*Phragmite australis*	31	LOWLANDS	Iglesia (arch)	9.5	−22.4	–
USF-6186	*Prosopis* sp.	34	LOWLANDS	Rincón del Atuel (modern)	–	−23.9	–
USF-7377	*Prosopis* sp.	31	LOWLANDS	Calingasta (arch)	2.1	−21.0	–
USF-6191	*Prosopis* sp.	35	LOWLANDS	Agua de Los Caballos-1 (arch)	11.6	−24.9	–
USF-6193	*Schinus polygamus*	35	HIGHLAND	Arroyo Malo (modern)	1.6	−24.4	–
s/d	Starchy tuber	39	PIEDMONT	Neuquén (arch)	–	−24.6	–
USF-7372	*Zea mays*	31	LOWLANDS	Iglesia (arch)	9.6	−9.7	–
USF-7373	*Zea mays*	31	LOWLANDS	Calingasta (arch)	10.2	−9.1	–
USF-7374	*Zea mays*	31	LOWLANDS	Iglesia (arch)	9.5	−10.3	–
USF-6181	*Zea mays*	35	LOWLANDS	Cueva Zanjón del Buitre (arch)	3.4	−9.7	–
USF-6182	*Zea mays*	34	LOWLANDS	Gruta del Indio (arch)	3.9	−9.6	–

VPDB, $\delta^{13}C$ values are typically negative. The overwhelming majority of plants utilize the Calvin Cycle (C_3) and have tissues with an average $\delta^{13}C$ value of −26.5‰. The $\delta^{13}C$ values of plants relying upon the Hatch-Slack pathway (C_4), mainly tropical grasses, millet, and sugarcane, are much higher, averaging −12.5‰. Plants utilizing a third pathway, Crassulacean acid metabolism (CAM), have $\delta^{13}C$ values ranging from −27 to −12‰. Controlled feeding studies of laboratory animals reveal that the carbon isotope signature of animal proteins, such as collagen in bone and keratin in hair and nails, predominantly reflects the protein component of diet, as essential amino acids are preferentially routed from diet to be incorporated into body tissue (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). $\delta^{13}C$ values of the collagen of large herbivores are enriched (more positive) by about 5‰ relative to their dietary average. The collagen of carnivores, in turn, reflects the isotopic signature of the animal protein in their diets, ultimately derived from the plants eaten by primary consumers. The isotopic signature of omnivore collagen represents the contribution of both plant and animal protein to diet.

It is accepted that bone collagen has a slow turnover rate (Ambrose, 1993), so that the isotope results obtained would represent the average diet over at least the last 5–7 years of life. A similar turnover time applies to bone apatite as well. It became clear from studies of animals raised on controlled diets that bone collagen is produced basically from dietary protein, whereas bone apatite is a product of the whole diet, with the difference between diet and bone apatite estimated at around 9.5‰ (Ambrose and Norr, 1993), while larger spacing of about 12‰ are suggested for humans (Schwarcz, 2006). More research needs to be done to address this spacing (Tykot et al., 2009). Taking into consideration the actual state of research, it could be proposed, at least for omnivores, that animal food would make a much greater contribution to bone collagen, at least when meat/fish are more than a minimal part of the overall diet. Non-essential amino acids may be produced from consumed carbohydrates and lipids, as well as proteins, so that overall collagen values may be strongly influenced for agriculturalists highly dependent on plant products. Differences between individuals in the proportion of maize versus C_3 plants in the diet would be more apparent in apatite than in collagen (Harrison and Katzenberg, 2003). For pure C_3 feeders the collagen value expected is around −21.5‰, and the apatite value expected around −14.5‰. For pure C_4 feeders, the collagen value expected is around −7.5‰, and the apatite value expected is around −0.5‰, as in the case of maize. Intermediate values are expected for mixed diets (Tykot, 2006).

On the other hand, $\delta^{15}N$ indicates differences caused by trophic level effects, especially in marine/continental ecosystems (Pate, 1997). Recent studies have shown the effects of climate and environment on both plant and animal $\delta^{15}N$ values and trophic level increases in both terrestrial and marine ecosystems (Ambrose, 2000; Ambrose and De Niro, 1986; Hedge and Reynard, 2006). In any case the construction of regional isotopic ecology (see below) is a necessary foundation to understand stable isotope data for humans and their meaning in terms of diet.

3. Materials and methods

Well-established procedures for extracting bone collagen, and bone and tooth enamel apatite were performed in the Laboratory for Archaeological Science at the University of South Florida (Gil et al., 2009; Tykot, 2004). A few samples considered in this paper were informed by other researchers and they do not necessarily follow this methodology (see details in Table 1). In Table 1 the stable isotope information from the human sample ($n = 104$) is detailed. It includes $\delta^{13}C_{co}$ ($n = 101$) and $\delta^{15}N$ ($n = 88$) from bone collagen, $\delta^{13}C_{ap}$ ($n = 77$) from bone apatite and $\delta^{13}C_{en}$ ($n = 49$) from teeth enamel. Table 1 also includes the chronology of the samples, mostly obtained with AMS radiocarbon dating ($n = 81$), and information about sex and age of the individuals. For this analysis the samples were grouped in geographic units: north (30°–33° SL; Fig. 1) and south (34°–36° SL; Fig. 1). The samples were also grouped in temporal units. We used 1000 years-long temporal units, except for the most recent samples where the last 300 were discriminated. This was done in order to consider probable changes after Spanish contact.

4. Environment and isotope ecology in central western Argentina

The area is located between 30° and 36° S, and can be subdivided into three environments: the western mountain area, the central plains (which are the driest biome with a mean annual precipitation below 250 mm), and the southeastern volcanic plateau of La Payunia, characterized by a mean annual precipitation ranging between 200 and 400 mm (Capitanelli, 1972; Abraham and Rodríguez Martínez, 2000). The mountain area includes two vegetation provinces: the Altoandina Province, between 2200 and 4500 m, and the Puneña Province, developed from the north to approximately 32° S (Cabrera, 1971; Roig et al., 2000). The Central plains belong to the "*Monte*" phytographic province, presenting xerophytic vegetation (i.e. *Larrea* sp.) and an arboreal stratum dominated by *Prosopis flexuosa* (Roig et al., 2000). Cabrera (1971) defined La Payunia as a particular district of the Patagonian phytographic province. The animal food sources can be divided in two main provinces: the "*Fauna de Montaña*" and the "*Fauna de Llanura*" (Roig, 1972). The first is characterized by the presence of camelids (*Lama guanicoe* and *Vicugna vicugna*), carnivores such as the gray fox (*Dusicion griseus*) and puma (*Felis concolor*), small rodents, and several birds. The "*Fauna de Llanura*" is more diverse, including the previously mentioned species plus other small mammals and big flightless birds like *Pterocnemia pennata* and *Rhea americana*. The region is settled over the South American Arid Diagonal and within the inversion zone of precipitation regimes (Bruniard, 1982). The study area is located in a temperate zone, a Mediterranean and continental region with an arid to semiarid climate with average annual precipitations of around 250 mm. It is exposed to the action of the Atlantic anticyclone (piedmont, depressions and oriental plains) and the Pacific Ocean anticyclone (west mountains). From the morpho-climatic aspects, these regions are highly contrasting due to their relief, dominant masses of maritime air and the yearly season the precipitations take place in. Based on stable isotope information ($\delta^{13}C$, $\delta^{15}N$) from archaeological and modern resources from the region a model of isotope ecology is presented basically in order to produce expectations about corn consumption and its role as energy and protein sources for humans (Table 2).

The central western isotope ecology shows a clear differentiation of corn, with more enriched values of $\delta^{13}C$ values in comparison to other resources, both wild and domesticate (Table 2). The *Zea mays* samples show high variation in $\delta^{15}N$ (see details in Gil et al., 2010) that could be associated with mature practice in the north of the area (where the high $\delta^{15}N$ values are present), but this needs to be checked. The camelids show variation in both $\delta^{13}C$ and $\delta^{15}N$ but basically with depleted values in $\delta^{13}C$ (Barberena et al., 2009). There are two camelids with different trends because they are more enriched. The first one is USF-7368 recorded in the north area; the second sample is USF-5906/6171 (Table 2). These values are outliers and we cannot explain it satisfactorily so far. In the second camelid sample (USF-5906/6171) the $\delta^{18}O$ is unexpected too and it can be explained by a different geographic origin of this individual (see Gil et al., 2010). Fernandez and Panarello (1999) show a similar value for a northwest Argentina *Lama glama* sample which is also an outlier.

The other animal resources (*Chaethophractus villosus*, *Chloephaga melanoptera*, *Lagidium viscacia*, *Pterocnemia pennata*, *Rhea americana*) are basically depleted and clearly different in isotope values from maize. Those plants other than maize (wild: *Cassia arnottiana*, *Araucaria araucana*, *Chenopodium* sp., *Condalia microphylla*, *Geoffroea decorticans*, *Phragmite australis*, *Prosopis* sp., *Schinus polygamus*; domesticated: *Cucurbita maxima*, *Lagenaria* sp.) are also depleted in $\delta^{13}C$ but highly variable intra and inter taxa (Table 2).

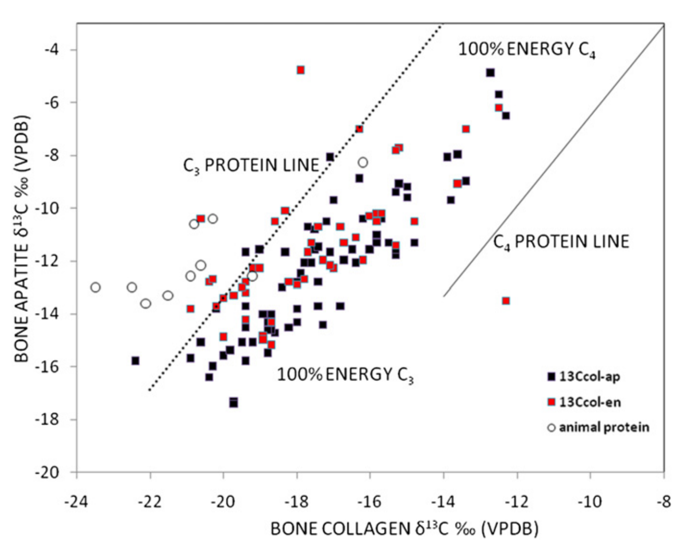

Fig. 2. $\delta^{13}C_{ap}$ plotted against $\delta^{13}C_{col}$ from archaeological human bone and teeth and animal bone samples from central western Argentina. Line references included as proposed by Kellner and Schoeninger (2007) model.

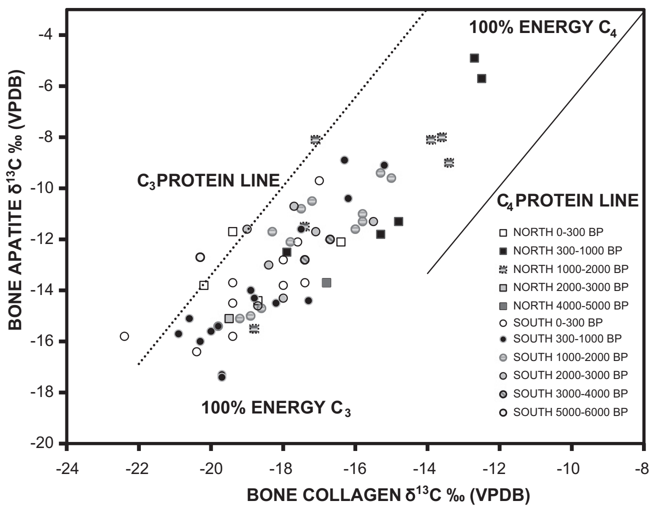

Fig. 3. $\delta^{13}C_{ap}$ plotted against $\delta^{13}C_{col}$ for human samples from central western Argentina, in spatial and temporal units (see details in text). Line references as proposed by Kellner and Schoeninger (2007).

5. Human stable isotope trends

We explore here the application of the Kellner and Schoeninger (2007) model. Kellner and Schoeninger (2007) combined all the experimental data plotted as $\delta^{13}C_{col}$ vs. $\delta^{13}C_{ap}$, and showed that the positions of individuals on the plot revealed both the main dietary sources of energy and protein. The data fall along two parallel regression lines with individuals that ate only C_3 protein falling about 6‰ to the left (more negative) of those individuals eating only C_4 protein (Kellner and Schoeninger, 2007; Schoeninger, 2009); those eating only C_3 energy plotted at the lower end of the graph, while those eating only C_4 energy plotted at the top. Those individuals with mixed sources of energy are plotted midway along their respective regression lines (Fig. 2). The model is used here as another way to try to comprehend the trends in central western Argentina stable isotope information. In the present paper the relationship is shown not only between $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ but also between $\delta^{13}C_{col}$ and $\delta^{13}C_{en}$.

5.1. $\delta^{13}C_{col\text{-}ap}$ difference

Fig. 2 shows the relationship of $\delta^{13}C_{col\text{-}ap}$ based on the Kellner and Schoeninger (2007) model. It shows a clear and strong mix of protein and energy sources, but a stronger domain of the C_3 protein source. Few human samples, less than 10, show significant C_4 energy source levels and none show significant C_4 protein. The other group shows a medium level of C_4 energy and a mixed but C_3 predominant protein source. To explore the meaning of these trends this information is considered in terms of the spatial and temporal units as previously defined (Fig. 3). Fig. 3 shows a general mixed energy-protein source, with emphasis on C_3. The only case with mostly C_4 energy was recorded in the north. But not all individuals in the north during this time have high C_4 energy, which indicates a general diversity observed in human diet in the region. In Fig. 3 the temporal pattern shows that samples from the north, and between 1000 and 300 years BP have the highest level of C_4 energy, specifically 3 individuals. Others with high but clearly less significant values in C_4 energy are in the north too, dating between 2000 and 1000 years BP. Unexpected is the pattern in the post-contact Spanish period (here 300-0 years BP; historic time). In this sense, and contrary to the southeastern United States (Hutchinson, 2004), in central western Argentina the C_4 energy-protein significance (maize?) drops after contact with the Spanish (Gil et al., 2009, 2010).

Taking into consideration the stable isotope ecology for this region (Table 2) it could be proposed that maize is the more significant C_4 energy resource, and in general the animal protein has mostly a C_3 signal. Problems arise about what resource(s) is responsible for part of the C_4 protein and generate the mixed pattern. Two preliminary possibilities could be proposed. The first one is that it is reflecting the corn protein intake in low protein animal ecosystems. Another possibility to explain these values is the exploitation of animal resources that are not seriously considered at the moment. The first explanation could be expected in places with low animal biomass or under a high human intensification pattern. For the second explanation, for example, only in the last years has zooarchaeological research informed us about fish and small animal exploitation in the region (García Llorca and Cahiza, 2007; Chiavazza, 2008; Corbat et al., 2009). This zooarchaeological research suggests that fish and small animals could be more significant in lowland (probably oriental plains) rather than in

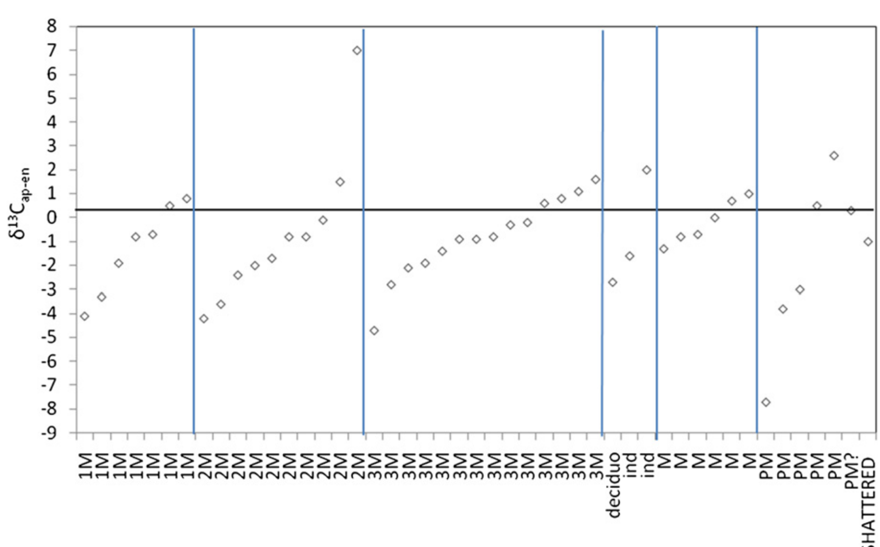

Fig. 4. Individual differences in $\delta^{13}C_{ap\text{-}en}$ plotted by type of teeth (see details in text). 1M: First molar; 2M: Second Molar; 3M: Third Molar.

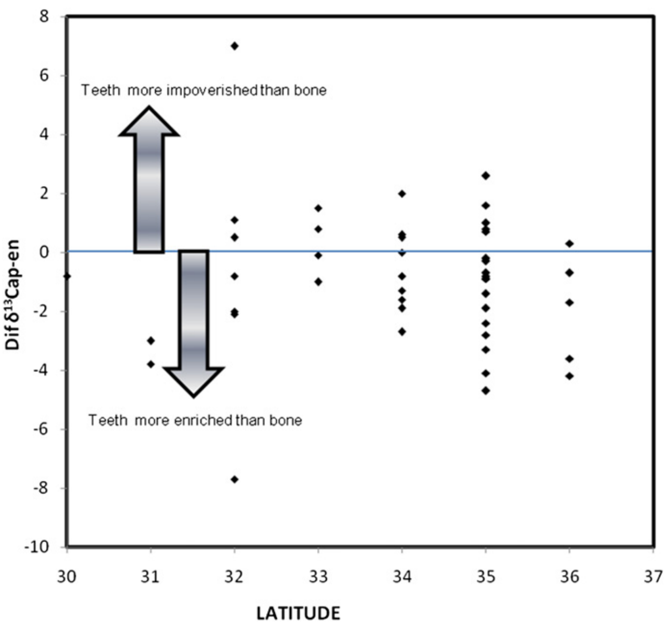

Fig. 5. Individual differences in $\delta^{13}C_{ap\text{-}en}$ plotted by temporal units (see details in text).

highland (mostly Cordillera) regions (Neme and Gil, 2009) but we need to advance in the stable isotopic ecology in these taxa and in these regions. The possibility that some animal resources partially eating C_4 is possible but in that case we would expect a human diet high in C_4 energy and that is not the case.

5.2. $\delta^{13}C_{ap\text{-}en}$ difference

Using the differences between bone apatite and tooth enamel it is possible to evaluate, at the level of individuals, change in the life history of their diet. It is a way to explore changes in diet and mobility in the human population. The bone apatite $\delta^{13}C$ value informs us about the average value taken in the last 7–10 years of life, but the tooth $\delta^{13}C$ value provides the average value of the isotope diet when it was formed. In our samples many of the teeth are third molars (M3), forming mainly during ages 8–15 (Hillson, 1996; White and Folkens, 2000). The others teeth analyzed are M2 (2.5–8 years), M1 (0.0–3.5 years) and PM (1–8.5 years).

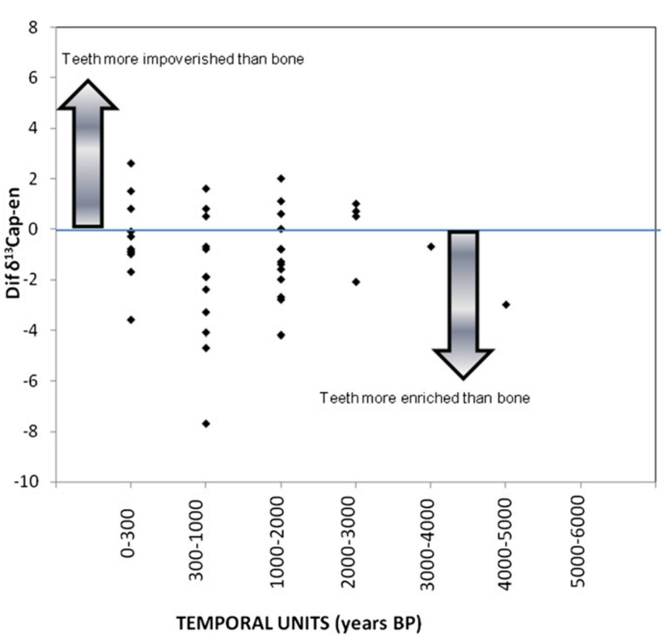

Fig. 6. Individual differences in $\delta^{13}C_{ap\text{-}en}$ plotted by temporal units (see details in text).

The $\delta^{13}C_{ap\text{-}en}$ shows variation in diet between the ages of the individuals (Fig. 4). The $\delta^{13}C_{ap\text{-}en}$ difference has an average value of -0.9 ($n = 47$) with a standard deviation of 2.3 (max = 7, min = -7.7). It indicates significant variation in the individual diets through their life history. Fig. 5 shows significant differences between $\delta^{13}C$ from apatite and enamel ($\delta^{13}C_{ap\text{-}en}$) in terms of spatial distribution of samples. In general the diet was more enriched when at a younger age than in the last time of the individual's life. It is significant to remark that the maximum and minimum values in the $\delta^{13}C_{ap\text{-}en}$ are in the north (32 SL; Fig. 5). The temporal trends do vary, but a clear trend through time is not observed (Fig. 6). The biggest difference, more depleted, is around 1000 years BP and probably the more enriched is around this date, but a radiocarbon date for this individual is not available. In general the differences of $\delta^{13}C_{ap\text{-}en}$ show significant variation in the individuals' diets.

6. Stable isotope variation and human diet in central western Argentina

The stable isotope $\delta^{13}C$ information shows that C_4 resources initially were not very significant in central western Argentina human diet. When C_4 resources were significant as an energy source it was highly variable between contemporary individuals. Mostly in the northern part and in the last 1000 years C_4 resources became significant as an energy source. In general the $\delta^{13}C$ and $\delta^{15}N$ values show a highly variable dietary pattern in a population with a highly heterogeneous diet. The difference between $\delta^{13}C$ enamel and bone apatite shows significant change in individuals' life history with strong variation in an individual's diet during his life. In this sense a classical farming boundary in central western Argentina needs to be reconsidered as a limit between clearly different subsistence modes. This boundary could be useful as a first approach and a way to differentiate stylistic variation in spatial distribution but dietary subsistence shows a more dynamic reality. The diet in any way was not monotonic. Probably the stylistic distinction does not necessarily imply "stability" neither in the human population nor in their diet.

7. Final remarks

Central western Argentina is the southern record of prehispanic cultigens, and a clear limit between hunter-gatherers and farmers had been proposed for the last 2000 years BP. The result of stable isotope analyses on human bone and teeth show a dynamic diet between these records. Based on a model by Kellner and Schoeninger (2007) the C_4 resources were not clearly dominant and only a few individuals from the northern part and in the last 1000 years clearly consumed these resources (probably maize) in significant quantity. But the individual differences between $\delta^{13}C_{ap\text{-}en}$ show a high variability in the individual diets in their life history; in other words, that could be interpreted as a non stable diet. Variation in time, space and among individuals was probably the norm, and corn was never uniformly used as a staple in this region.

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