
Volume 38 Number 4 April 2011 ISSN: 0305-4403
ELSEVIER
Published in association with the
Society for Archaeological Sciences
Journal of
Archaeological
SCIENCE

Journal of Archaeological Science 38 (2011) 884–895

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Paleonutritional and paleodietary survey on prehistoric humans from Las Cañadas del Teide (Tenerife, Canary Islands) based on chemical and histological analysis of bone

M. Arnay-de-la-Rosa [a], E. González-Reimers [b,*], Y. Yanes [c,d], C.S. Romanek [e], J.E. Noakes [f], L. Galindo-Martín [g]

[a] Dpto. de Prehistoria, Antropología e Historia Antigua, Universidad de La Laguna, Tenerife, Canary Islands, Spain
[b] Dpt. de Medicina Interna, Hospital Universitario de Canarias, La Laguna, Tenerife, Canary Islands 38320, Spain
[c] Laboratorio de Isótopos Estables, Estación Experimental de Zaidín (CSIC), Prof Albareda 1, 18008, Granada, Spain
[d] Huffington Department of Earth Sciences, Southern Methodist University (SMU), Dallas, TX 75275-0395, USA
[e] Department of Earth and Environmental Sciences, University of Kentucky, Lexington, KY 40506, USA
[f] Center for Applied Isotopes Studies, University of Georgia, Athens, GA 30602, USA
[g] Dpto. De Química Analítica, Universidad de La Laguna/Tenerife, Canary Islands, Spain

ARTICLE INFO

Article history:
Received 20 April 2010
Received in revised form
31 October 2010
Accepted 25 November 2010

Keywords:
Carbon hydrogen nitrogen stable isotopes
Paleodiet
Bone barium
Bone strontium
Osteoporosis
Las Cañadas del Teide
Tenerife
Canary islands

ABSTRACT

The aim of the present study is to perform a paleodietary and paleonutritional survey on 17 individuals buried in accordance with the prehispanic ritual in the central plateau of the island Tenerife, called Las Cañadas del Teide. We recorded hydrogen, nitrogen and carbon isotope compositions of human bone collagen, bone barium and strontium, and histomorphometrically assessed trabecular bone mass (TBM). Bone trace elements and TBM were compared with reference data derived from a modern sample consisting of 13 individuals. In addition, $\delta^{15}N$ and $\delta^{13}C$ values were determined in several modern indigenous plants, bone collagen of prehistoric domestic animals (goat and pig), and prehistoric wild animals (a giant lizard, *Gallotia goliath* and a giant rat, *Canaryomis bravoi*), which represent food sources potentially consumed by the prehistoric population of the Island. The carbon stable isotope composition of bone collagen ranged between −20.5 and −18.6‰ (VPDB), indicating a diet based on C_3 plants. Nitrogen isotope values ranged from 8.2 to 12.4‰ (AIR), suggesting a general meat-enriched diet, most likely domestic goats, of higher level consumers. Hydrogen isotope values ranged from −18 to +4‰, whereas log Ba/Sr was greater than −0.40 in the vast majority of cases. TBM showed a tendency to osteoporosis in 30% of the individuals analyzed. C-14 dating showed that two burial sites, including 5 individuals, belonged to the post-conquest era (after the 15th century), despite a fully "prehispanic" burial ritual, which lends credenceto the oral tradition that some of the prehispanic population fled to the highlands at the time of the Spanish conquest, and lived there during decades or even centuries. These individuals showed lower δD, $\delta^{13}C$ and $\delta^{15}N$, and higher log Ba/Sr values than those buried before the Spanish conquest, suggesting dietary differences between the two groups. Also, women showed a trend to a higher consumption of vegetables than men.

1. Introduction

Tenerife is located near the center of the Canary Archipelago, ~300 km off the Moroccan coast, NW Africa (Fig. 1). It is roughly triangular in shape and is the largest island (1917 km^2) of the Archipelago. The proximity of Tenerife to the Sahara desert; the northeast trade winds, and the existence of a central range of mountains, oriented ENE-WSW, result in a landscape with a humid northern slope and an arid southern slope, with clearly different environmental characteristics (i.e., temperature, humidity).

1.1. Las Cañadas: environmental conditions

The island has a central plateau, called Las Cañadas, at an altitude of 2200 m above sea level, with several large volcanoes in its center, culminating in the Teide peak (3718 m). Las Cañadas plateau has a peculiar climate and landscape (Fig. 2). Situated above the level of the northeastern trade winds, the sun shines in a cloudless sky more than 300 days a year; the very low humidity –frequently below

* Corresponding author.
E-mail address: egonrey@ull.es (E. González-Reimers).

0305-4403/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2010.11.018

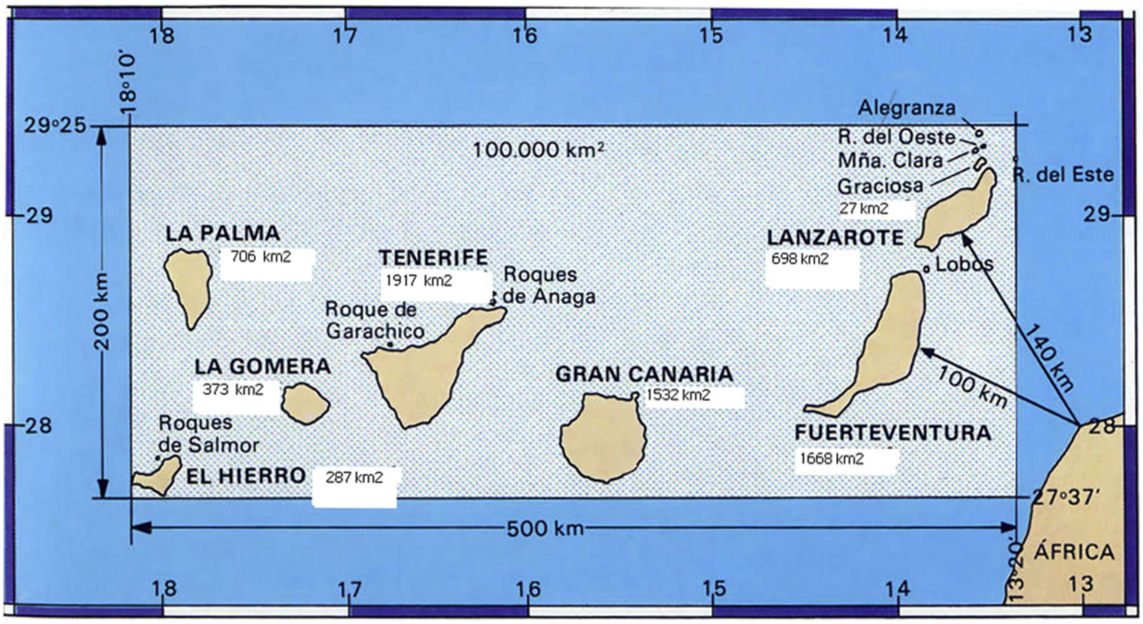

Fig. 1. Geographical location of the Canary Islands.

15%— favors a marked contrast between warm days and cold dry nights (soil temperatures frequently below −15° in winter, and sometimes below zero in summer). Sparse vegetation is maintained by irregular and torrential rainfall, and more frequently, snowfalls. Rainfall is a rare event at Teide, and snow, even after a single snowfall, may last for several months before melting. Some small streams exist.

1.2. Ethnographic and archaeological background

The Prehispanic population of North African origin (Maca-Meyer et al., 2004), locally known as "the Guanches", colonized the island in the middle of the first millennium BC. The aborigine people had a rudimentary agrarian life style with some shellfishing and coastal fishing, but the main daily activity was goat herding (Alberto-Barroso, 2004). In addition to goat products, pigs, *Gallotia goliath* (an extinct lizard of ∼1 m in length) and *Canaryomis bravoi* (an extinct giant rat) were consumed (Alberto-Barroso, 1998).

Knowledge is limited about the history of the population of the island during the 2000 years between the first arrival of the Guanches and the Spanish conquest. Based on etnohistorical and ethnographical grounds it has been hypothesized that the Guanches practiced seasonal herding in the highlands, moving to the central mountains from May to September, and abandoning the area by early fall. It is possible that those who occupied the highlands in summer lived in the high reaches of the southern slopes or in the

Fig. 2. Photograph of Las Cañadas, with several lava fields; burial places are indicated. The contrast between the forested northern slopes and the arid southern part of the Island is also observable.

forests below Las Cañadas during the coldest winter months, but it is also likely that the same people who lived in the coastal region during winter moved with their herds during summer to Las Cañadas. This last possibility, although not proven, is widely accepted (Diego Cuscoy, 1968), mainly based on some chroniclers' reports (Espinosa, 1980).

After the conquest, many Guanches probably fled to the central mountains and lived there perhaps during decades or even centuries (Espinosa, 1980; Aznar-Vallejo, 1988), maintaining their ancient lifestyle. In Las Cañadas there are important archaeological remains (Fig. 3), including several collective burial sites with partially mummified corpses (Arnay-de-la-Rosa and González-Reimers, 2006). Some chroniclers stated that dead were exclusively buried in the central mountains; nevertheless, the majority of the interments have not been found in these mountains, but in ravines lower down and near the coast. The dead were buried in volcanic caves, most of them of small dimensions, containing only a few partially or totally mummified corpses (a notable exception being El Salitre, in which several dozens corpses were found). These corpses were not interred, but deposited on layers of stone or plant material. Burial conditions were similar for all the individuals analyzed in this study, and the burial ritual does not differ from the ritual followed in many other burial caves of the island. In addition to burial caves, in the central mountains there are the remains of settlements, with many ceramic fragments, obsidian tools, and grinding stones.

The diet of the population buried in Las Cañadas is largely unknown. Assuming that these people were mainly goatherds, it is

Fig. 3. Archaeological remains from Las Cañadas, including: A) a dwelling area; B) the burial cave of La Angostura; C) the partially mummified corpse of the child of Cascajo; D) ceramic vessel; E) grinding stone.

likely that they lived from goat products, such as milk and meat. However, many grinding stones have also been found, supporting the view that certain kinds of cereal (possibly barley or seeds from *Arrhenaterum calderae* (an endemic type of oat-grass) were also consumed. Regarding other sources of food, including wild animal species, the giant lizard *G. goliath* was probably consumed (there are only some anecdotical findings of bone remains of this extinct animal in Las Cañadas), and less probably the giant rat (*C. bravoi)*. However, to our knowledge, no remains of this animal have been found in Las Cañadas, and it is said that it only lived below an altitude of 1000 m (Alberto-Barroso, 1998). Thus, knowledge about the diet of those who lived (and died) in Las Cañadas is scarce. In addition, the possible different patterns of occupation of the highlands throughout the centuries, especially considering the differences between people buried before and after the Spanish conquest, add confusion to any paleodietary inference. The frequent occurrence of grinding stones points to the importance of cereals in the diet. Also, analysis of the intestinal content of a partially mummified corpse revealed remains of *Hordeum* sp. (barley) and *Triticum* sp. (wheat) (Arnay de la Rosa et al., 2008). In some dwellings a few bones of goats have been found, suggesting some consumption of meat. These highlands, far away from the sea, are scarce in archaeological remains derived from marine products. This suggests that the marine component of the highlander diet was very low or even absent.

However, besides the information derived from archaeological remains, there are very few studies on the dietary pattern of the inhabitants of the highlands of Tenerife. Bone trace element determinations (González–Reimers and Arnay-de-la-Rosa, 1992) support the hypothesis of a plant-based diet, although bone strontium content was lower than that observed among people buried in lowlands (perhaps indicating a higher consumption of marine products by the latter, although bone barium was not determined). It is therefore important to investigate the diet of the highland people and compare it with that of the lowland inhabitants and understand how these groups interacted.

1.3. Paleodietary and paleonutritional research

The determination of stable isotopes in bone collagen constitutes a more precise approach in paleodietary reconstruction. Indeed, since 1978, the stable isotope composition of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in well-preserved collagen from prehistoric bones have been widely used to estimate dietary patterns of ancient human groups (DeNiro and Epstein, 1978, 1981; Ambrose et al., 2003; Valentin et al., 2006; Thompson et al., 2008; Quinn et al., 2008). Collagen is the material of choice for dietary analyses because it comprises approximately 20% of bone weight and is remarkably resistant to post-mortem degradation (Ambrose, 1990). Therefore, determination of carbon and nitrogen stable isotopes in bone collagen, both alone or combined with analysis of isotopes of other elements, such as hydrogen (Reynard and Hedges, 2008) or sulphur (Privat et al., 2007), may accurately elucidate the dietary pattern of ancient population groups. Indeed, hydrogen isotope (δD) may aid in paleodietary reconstruction, since it is subjected to a wider range of isotope fractionation than δ^{13}C or δ^{15}N.

The stable isotope composition of human bone collagen can thus provide direct information about the average integrated protein content of the diet of an adult human over 5–10 years (Schwarcz and Schoeninger, 1991), including: (1) the consumption of C_3 or C_4 plants, (2) terrestrial animal products, and (3) marine products. The isotopic fractionation between diet and human bone collagen has been estimated as about $+1‰$ for δ^{13}C, $+3–4‰$ for δ^{15}N (DeNiro and Epstein, 1978, 1981; Ambrose and DeNiro, 1986, 1989) and 27‰ for δD (Birchall et al., 2005; Reynard and Hedges, 2008). Based on chroniclers' reports, plants consumed by the highland Guanches include C3 cereals (barley, wheat, and, perhaps, some locally-growing cereals). There are no archaeological or archaeobotanic data which support the hypothesis that these people consumed C4 plants.

Complementary information may be obtained from trace elements. Barium content is very low in the marine environment, but high in vegetables, as is strontium, which is also relatively abundant in marine food. Although diagenesis may hinder the interpretation of the results, and despite criticism (Fabig and Herrmann, 2002), the barium to strontium ratio still allows a differentiating between marine and terrestrial diet (Burton and Price, 1990). Indeed, solubility of barium salts in the marine environment is extremely low, so the relation of barium to strontium is very low if marine resources are consumed. It has been proposed that values of log Ba/Sr below -1.40 may indicate consumption of a diet based on marine products, whereas values over -0.40 suggest consumption of a terrestrial diet (Burton and Price, 1990). In addition, since the mammalian intestine discriminates strontium absorption with respect to calcium, bone strontium content decreases along with the food chain, so a pure vegetarian diet should lead to higher bone Sr values than a mixed or carnivorous diet.

Bone mass data may inform us about the presence of osteoporosis. An unusually high prevalence of osteoporosis in a given, non-selected, population may indicate deranged nutritional status (González-Reimers et al., 2004), since bone mass depends on an equilibrium between bone synthesis and bone resorption, which may be disrupted in situations of starvation or poor protein intake. In this regard, it is important to note that stable isotopes may also be altered in starvation (Williams et al., 2007). Normally, the organism tends to excrete greater amounts of light isotopes than heavy ones, so reduced (exogenous) protein intake should theoretically lead to an enrichment in δ^{15}N. This may explain the inverse relationship between body mass index and δ^{15}N described by Mekota et al. (2006) in hair samples of patients suffering from anorexia nervosa, and the inverse relation between nitrogen balance and δ^{15}N values (Fuller et al., 2004). Since starvation may lead to reduced bone mass (Bourrin et al., 2000a,b), it is of interest to discern if there is a relation between bone mass and δ^{15}N values.

The main objective of the present study was to perform a paleodietary research, based on bone trace elements and collagen stable isotopes, and an estimation of nutritional status, based on histomorphometrical analysis of bones, on well-preserved skeletal remains of aborigine individuals buried in Las Cañadas del Teide, as a paleodietary and paleonutritional survey on people living (either permanently or not) in an arid highland with quite extreme conditions. We also wished to ascertain whether the Spanish conquest led to changes in dietary pattern among those who conserved their "prehispanic" style of life in the central mountains.

2. Material and methods

2.1. Sample

2.1.1. Human remains

Bone samples of 17 prehispanic individuals were included in this study. In two cases (CAP-4 and CAP-135), collagen C/N ratios were out of the range which allows an accurate interpretation of the isotope values, and in a further case (MB-2), only trace elements and bone mass were determined (Tables 1 and 2). The samples analyzed belong to individuals from different burial sites from Las Cañadas: four individuals from El Portillo, five from Angostura, two from Montaña Blanca, one from Cascajo, two from Cañada del Capricho and three from El Salitre (Table 1; Fig. 2). The burial sites of El Portillo, Cascajo and Cañada del Capricho are intact ones, which were excavated by members of the Departament of

Table 1
Nitrogen and carbon stable isotopes of bone collagen from prehistoric humans from Tenerife, Canary Islands.

Sample ID	Locality	Altitude (m a.s.l.)	Bone type	Sex	Age	δ^{15}N‰ (AIR)	δ^{13}C‰ (VPDB)	%N	%C	C/N	Collagen %	Antiq. (BP)
B 82	Portillo	2081	Axis	Female	Old adult	8.5	−20.5	15.6	42.0	3.1	13.0	410 ± 40
C 34	Portillo	2081	1st rib	Female	Young adult	8.2	−20.4	15.5	41.2	3.1	14.1	354 ± 56
A34	Portillo	2081	Left coxal	Male	Adult	9.3	−19.7	11.7	30.0	3.0	2.6	
D17	Portillo	2081	Coxal	Male	Old adult	9.6	−20.0	9.0	24.6	3.2	1.3	
CA77-8[a]	Cascajo	1641	Tibia	Male	Infant	10.7	−20.2	6.3	17.8	3.3	1.1	200 ± 40
SAL2	Salitre	2239	Tibia	Female	Adult	9.3	−19.4	10.7	28.0	3.0	2.6	
SAL3	Salitre	2239	Tibia	Female	Adult	9.8	−20.3	14.8	36.6	2.9	7.1	830 ± 59
ANG1	Angostura	2193	Tibia	Male	Adult	11.7	−18.8	13.5	34.7	3.0	4.9	
ANG2	Angostura	2193	Tibia	Male	Adult	11.7	−20.0	12.5	33.7	3.1	4.5	
ANG3	Angostura	2193	Tibia	Male	Adult	9.7	−19.0	13.5	34.5	3.0	5.7	
ANG4	Angostura	2193	Tibia	Male	Adult	11.7	−18.7	12.8	33.0	3.0	3.7	
ANG5	Angostura	2193	Tibia	Male	Adult	12.4	−19.3	12.4	32.1	3.0	2.7	594 ± 38
Ind. 6	Montaña Blanca	2423	Tibia	Male	Adult	12.2	−19.5	10.7	29.5	3.2	1.8	550 ± 40
SAL1	Salitre	2239	Tibia	Male	Adult	10.0	−19.5	6.1	16.7	3.2	1.4	

[a] Not subjected to bone histomorphometrical analysis.

Prehistory, University of La Laguna. They contained only a few corpses (4 in the cave of El Portillo, 2 in Cañada del Capricho, and 1 in Cascajo). The burial site of Montaña Blanca contained two corpses, and was already not intact before archaeologists were able to study it; Angostura was also a collective burial site, located in a volcanic cave, but partially pillaged, whereas El Salitre was a huge collective burial site, excavated several decades ago (Álvarez-Delgado, 1947), with many corpses, most of which have been lost. The type of bone analyzed was mostly tibiae, but also pelvic bones, ribs and axis were selected (Table 1).

Radiocarbon (C-14) dating of bone samples yielded antiquity values shown in Table 1. Two sites (El Portillo, confirmed by two different laboratories: Center for Applied Isotopes Studies, University of Georgia, and Beta Analytic, Miami, Florida) and Cascajo (only one dating), despite their fully "prehispanic" characteristics, belong to the post-conquest times (Spanish conquest took place at the end of the 15th century). The Portillo site was excavated about 30 years ago. As with other "prehispanic" burial sites, it consisted of a small volcanic cave, at the base of a lava flow, in which four corpses were deposited on a layer of trunks of the local broom (*Spartocytissus supranubius*). Corpses were deposited in supine position, in a similar fashion to other fully prehispanic interments. The interment of Cascajo was also in a small cave; the corpse was partially mummified, in supine position. The inferior part of the body was less well preserved, because some bones had rolled down to the lowest part of the cave.

Age at death was estimated by inspection of the pubic symphysis. Sex was estimated by inspection of the pelvic bones (Ubelaker, 1989). This was possible in all the cases (13 males and 4 females).

2.1.2. Potential food sources

In addition to human bones, the nitrogen and carbon stable isotope composition of food sources potentially consumed by the aborigines were analyzed, including two modern local plants (barley, wheat), as well as the collagen extracted from prehistoric animal bones, specifically one pig, one giant lizard, one *C. bravoi* (an extinct giant rat), and also three goats (Table 3). In addition we also include some data relative to marine products previously reported (Arnay-de-la-Rosa et al., 2010; Tieszen et al., 1993). Although marine food was surely not available to people who lived permanently in Las Cañadas or nearby, it could be consumed by goatherds who only remained there during summer, or spent some days in coastal regions and some days in the highlands (Table 4).

Unfortunately, there were no samples of prehistoric plants available for isotopic analysis. However, it is known that aborigines cultivated and consumed cereals (i.e., wheat and barley) and probably, some local endemic plants, such as the seeds of *A.*

Table 2
Hydrogen stable isotopes of bone collagen, bone trace elements, and trabecular bone mass (TBM)from prehistoric humans from Tenerife, Canary Islands.

Sample ID	Locality	Altitude (m a.s.l.)	Bone type	Sex	Age	TBM (%)	Sr (mg/kg)	Ba (mg/kg)	logBa/Sr	Δ D
B 82	Portillo	2081	Iliac	Female	Old adult	16.65	77.63	45.28	−0.23	−18
C 34	Portillo	2081	Iliac	Female	Young adult	20.86	57.26	56.50	−0.01	−16
A34	Portillo	2081	Iliac	Male	Adult	26.37	69.94	22.53	−0.49	−18
D17	Portillo	2081	Iliac	Male	Old adult	22.21	82.72	82.70	0.00	−15
CA77-8	Cascajo	1641	Tibia	Male	Infant		263.81	28.00	−0.97	−18
SAL2	Salitre	2239	Tibia	Female	Adult	25.46	409.47	18.73	−1.34	−2
SAL3	Salitre	2239	Tibia	Female	Adult	15.04	364.74	20.37	−1.25	
ANG1[a]	Angostura	2193	Tibia	Male	Adult		443.45	22.68	−1.29	4
ANG2[a]	Angostura	2193	Tibia	Male	Adult		85.05	28.92	−0.47	−17
ANG3[a]	Angostura	2193	Tibia	Male	Adult		125.63	38.34	−0.52	−8
ANG4	Angostura	2193	Tibia	Male	Adult	14.00	56.89	31.27	−0.26	−8
ANG5	Angostura	2193	Tibia	Male	Adult	23.29	163.31	22.72	−0.86	−4
Ind. 6	Montaña Blanca	2423	Tibia	Male	Adult	18.80	54.77	22.52	−0.39	1
SAL1	Salitre	2239	Tibia	Male	Adult	9.78	48.40	26.00	−0.27	
CAP135	Capricho	2200	Iliac	Male	Adult	16.58	62.33	47.24	−0.12	
MB-2	Montaña Blanca	2423	Iliac	Male	Adult	23.46	62.78	54.17	−0.06	
CAP 4	Capricho	2200	Iliac	Male	Adult	14.86	29.96	7.57	−0.60	

[a] Lack of trabecular bone mass precluded TBM determination.

Table 3
Stable isotope values of the potential food sources analyzed.

Species	Delta 15 N (‰)	Delta 13 C (‰)	N (%)	C (%)	C/N	Collagen yield
Plants						
Spartocytissus supranubius (broom) (wood)	−1.3	−22.8	1.2	54.7	45.8	
Pinus canariensis (leaves) (pine)	−2	−25.4	0.8	52.3	66.5	
Adenocarpus viscosus (leaves of this leguminous plant)	0	−23.8	3.4	62.5	18.1	
Arrhenaterum calderae (seeds of this cereal)	1.3	−23.8	1.1	44.7	39.8	
Triticum aestivum wheat (seed)	4.9	−23.3	2.2	45.5	20.9[a]	
Wheat (Modern)	2.0	−23.4				
Hordeum vulgare barley (seed)	3.4	−25.0	3.4	51.3	15.0[a]	
(Fruit)of *Phoenix canariensis* (palm)	5.4	−26	0.6	41.4	74.9	
Ficus carica (leaves) (Fig tree)	8.7	−27.1	2.0	44.7	46.7	
Animals (prehistoric bone remains)						
Gallotia goliath (giant lizard)	10.9	−20.5	11.5	29.9	3.0	2.6
Canaryomis bravoi (giant rat)	9.6	−16.5	12.7	35.2	3.2	5
Pig *(Sus Scofra)*	5.9	−12.5	6.4	18.1	3.3	1.3
Ovicaprid	4.8	−20.1	14.2	36.8	3.0	11.3
Ovicaprid	7.1	−20.8	12.9	34.2	3.1	5.9
Ovicaprid	8.2	−18.3	11.3	30.7	3.2	1.9

[a] Tieszen et al., 1993.

calderae (a local cereal) and of *Pinus canariensis* (pine), and perhaps, the fruits (dates)of *Phoenix canariensis* (palm tree) and *Ficus carica*. (fig tree). These two last species are not present in Las Cañadas, but some trees may grow at altitudes of 1200–1300 m, and their fruits could be, perhaps, consumed by these people. Consequently, modern samples of vegetables that may have been consumed by the Guanches in the past have been analyzed for their stable isotopes. All these data are shown in Table 3.

Table 4
Carbon and nitrogen isotopes in some species potentially consumed by prehispanic inhabitants of the Canary Islands (although hardly by those who permanently lived in Las Cañadas).

Species	Tissue	Δ15 N	Δ 13 C
Osilinus attratus[a]	Body tissue	6.7	−18.4
Osilinus attratus[a]	Shell organic matter	7.0	−16.5
Osilinus attratus[a]	Body tissue	7.9	−18.4
Patella piperata[a](modern)	Shell organic matter	3.3	−14.5
Patella sp[a]	Body tissue	5.1	−14.1 [d]
Thais haemastoma[a]	Body tissue	7.8	−15.0 [d]
Patella piperata[a] (modern)	Shell organic matter	4.4	−13.1
Grapsus grapsus (crab)	Body tissue	8.7	−15.3 [d]
Sea urchin	Body tissue	9.5	−16.6[d]
Hogfish[b]	Bone collagen	12.1	−15.0 [d]
Mycteroperca rubra[b] (Prehistoric)	Bone collagen	11.4 ± 0.23[c]	−11.1 ± 0.6[c d]
Sparisoma cretensis[b] (Prehistoric)	Bone collagen	8.3 ± 0.10[c]	−13.1 ± 0.32[c d]
Phoenix canariensis (modern palm tree)	Fruit	9.0	−27.5
Pteridium aquilinum (fern) (modern)	Rhyzoma	5.4	−25.5

[a] = Gastropods.
[b] = Fish.
[c] = standard error.
[d] Tieszen et al., 1993.

2.2. Methods

2.2.1. Stable isotope analysis

2.2.1.1. Bone collagen extraction. Bone samples were first physically cleaned with a brush and sonicated in distilled water, and then dried at room-temperature. The collagen extraction procedure used was established by Ambrose (1990) and Bocherens et al. (1991). Pieces of bone were ground by hand in an agate mortar and pestled to a grain size less than 0.7 mm. About 200 mg of bone powder was weighed into a 2 ml Eppendorf centrifuge tube, and 1 M HCl was added to dissolve the mineral phase. The mixture was agitated for 20 min in an ultrasonicator to ensure even dispersal of the bone powder through the acid. Samples were then centrifuged at 6300 r.p.m. for approximately 5 min and the supernatant was poured off. The pellet was rinsed with distilled water and centrifuged three times. The remaining solid was plunged into 0.1 M NaOH for 20 h at room-temperature to remove organic contaminants such as humic acids and the majority of lipids. Samples were again rinsed with distilled water three times by repeated centrifugations. The residue was then placed into 0.01 M HCl (pH = 2) in closed tubes, at 57 °C for 17 h, to solubilize the collagen. After centrifugation of the samples, the supernatant (containing solubilized collagen) was freeze-dried overnight. Yield collagen was expressed as the mass of freeze-dried collagen relative to the original dry weight of bone.

2.2.1.2. Plant sample preparation. Plant tissues were first cleaned with distilled water by sonication and then oven-dried at 40–50 °C overnight. Additionally, cereal grains (barley and wheat) were lipid-extracted using 2:1 Chloroform: Methanol mixture for 20 h prior isotope analysis. Dry plant tissues were then ground and homogenized.

2.2.1.3. Stable isotope analyses. About 1 mg of freeze-dried bone collagen and ∼5 mg of plant powder were weighed into a pre-cleaned tin capsule, crimped and analyzed on a Carlo Erba Elemental Analyzer (NC 2500), where combustion (oxidation and then reduction) of the sample occurred. The CO_2 and N_2 produced after combustion were analyzed using a Thermo Finnigan Delta Plus XL isotope ratio mass spectrometer. The δ values are defined as:

$$\delta^{13}\mathrm{C}\ \text{or}\ \delta^{15}\mathrm{N}\ \text{or}\ \delta\mathrm{D} = \left[\left(R_{\text{sample}}/R_{\text{standard}}\right) - 1\right] \times 1000(\text{in ‰ units})$$

Standards used: Vienna-Pee Dee Belemnite (VPDB) for carbon, air for nitrogen, and Vienna-Standard Mean Ocean Water (VSMOW) for hydrogen.

The content of carbon and nitrogen in modern bone collagen is about 40–47% and 12–15%, respectively, so well-preserved bone collagen should display a carbon/nitrogen molar ratio, based on the content (in %) of these elements in the sample, between 2.9 and 3.6 (DeNiro, 1987). Therefore, in paleodietary studies of prehistoric humans it is fundamental to check the quality of the bone collagen prior to the interpretation of the isotope results. Well-preserved prehistoric material (fossil) should yield carbon content above 13% and nitrogen amount above 5% (Ambrose, 1990). Yield collagen percentage, expressed as the amount of freeze-dried collagen relative to the dry weight of bone, should be above 1% (Ambrose, 1990). These conditions were achieved for all but the two samples mentioned before, which were therefore excluded from stable isotope analysis. In the other samples, both in humans and prehistoric animals bone samples, C/N ratios were within the appropriate range for pristine material (Table 1). In addition, the yield collagen of all the samples was generally above 1% and the content of nitrogen was above 5% (usually > 10%) for the majority of the samples (Tables 2 and 3). Because of these factors, all the samples, with the exceptions mentioned before, were considered to display a general good state of preservation, and were consequently appropriate for paleodietary analysis.

2.2.1.3.1. Nitrogen and carbon stable isotope analysis in bone collagen. About 1 mg of bone collagen and ~5 mg of ground plant tissue and of soil organic matter powder was weighed into a pre-cleaned tin capsule, crimped and combusted in a Carlo Erba Elemental Analyzer (NC 2500). The CO_2 produced after combustion was analyzed using the CF-IRMS. Multiple in-house standards ($n = 20$) were analyzed as a check on the analytical precision of the analysis, which was better than $\pm 0.1‰$ (1 standard deviation).

The carbon isotope composition of modern food sources were corrected for the Suess effect (i.e., isotopic depletion of surface carbon reservoirs due to the burning of fossil fuels) by adding 1.6‰ to measured food values (Marino and McElroy, 1991; Ambrose et al., 1997). The following assumptions regarding metabolic fractionations and the Suess effect employed in this study are:

(1) $\delta^{13}C_{\text{prehistoric tissues}} = \delta^{13}C_{\text{modern tissues}} + 1.6‰$,
(2) $\delta^{13}C_{\text{diet}} = \delta^{13}C_{\text{human collagen}} - 1‰$ and
(3) $\delta^{15}N_{\text{diet}} = \delta^{15}N_{\text{collagen}} - 3‰$.

2.2.1.3.2. Hydrogen stable isotope analysis in bone collagen. About 0.8 mg of bone collagen was weighed into a pre-cleaned silver capsule, crimped and analyzed in the High Temperature Conversion/Elemental Analyzer (TC/EA) connected to the IRMS. The H_2 produced after pyrolysis was analyzed using the CF-IRMS. Multiple in-house standards ($n = 16$) were analyzed as a check on the analytical precision of the analysis, which was better than $\pm 1‰$ (1σ standard deviation).

2.2.2. Trace elements determination

Bone samples of the inner cortical region of pelvis (when available) or tibiae were extracted for trace element analysis. They were dehydrated in a furnace at 100 °C during 4–7 days, and then dissolved in 65% HNO_3 and 10% H_2O_2, in order to digest organic material. The digestion solutions were quantitatively transferred to volumetric flasks and diluted up to 10 ml with ultrapure water (Milli-Q OM-140 deionization system).

Prior to the analysis of each element we prepared a blank with ultrapure deionised water (Milli-Q system) and different solutions, at known concentrations, using certified standards of 1000 mg/kg for each of the elements analyzed, which were further diluted. These solutions were used for the calibration of the apparatus.

Bone barium was measured using a Spectra A 220-Z atomic absorption spectrophotometer equipped with a Zeeman effect, a Varian GTA 110Z graphite furnace with pyrolized tubes provided with an Ĺvov platform, and a microcomputer-controlled AS-40 auto sampling system. Detection limits for barium were 0.04 μg/kg.

Strontium and calcium concentrations were determined with the aid of a Varian Spectra AA spectrophotometer by flame atomic absorption spectrophotometry. Detection limit for Sr is 0.042 mg/kg. Samples destined for calcium analyses were further diluted (1:1000). Detection limit for calcium is 0.017 mg/kg.

Bone Ba, Sr and Ca were compared to a modern sample of cadavers from previously healthy individuals that died of traumatic injuries and who ate a mixed diet.

2.2.2.1. Control for diagenesis. We performed two kinds of analysis in order to assess the importance of diagenesis.

1. We took several random SEM microphotographs of bone samples from just beneath the place from which bone samples for trace element analysis were extracted (Figs. 4 and 5). As seen, some small particles were observed adhered to the surface of the trabeculae. These particles were analyzed with dispersive X-ray microanalysis, and composition was invariably consistent with complex silicates from lava-derived soil particles, but not calcium, strontium or barium salts. In addition, the fine trabecular structure is sufficiently preserved to allow an accurate estimation of trabecular bone mass.
2. We determined trace elements in the ground around the skeletal remains, finding significantly lower strontium and barium contents than in the skeletons (Table 5).

2.2.3. Bone histomorphometry

Transiliac crest bone specimens were processed for undecalcified bone sample analysis. Briefly, samples were embedded in methylmetacrylate, stored for 24 h at 4 °C and later polymerised at 32–34 °C for 3–4 days. Embedded samples were then cut in 9–12 μm thick slices with a Reichert-Jung microtome and stained with toluidin blue. Trabecular bone mass (TBM) was determined using an image analyser equipped with the program "Image Measure 4.4a", at 40×. Results are presented as % of total area. Prehispanic data were compared with those of our modern control group (González–Reimers and Arnay-de-la-Rosa, 1992).

2.2.4. Statistics

We compared the results with those derived from a control group by means of Student's t test, and also between men and women. We previously performed a Kolmogorov–Smirnov test in order to assess parametric distribution of the variables analyzed. Mann–Whitney's *U*-test was used for variables with a non-parametric distribution. Statistical analysis was performed with SPSS (Statistical package for Social Sciences).

3. Results

3.1. Stable isotopes

3.1.1. Nitrogen, hydrogen, and carbon stable isotopes in food sources

Results regarding isotope compositions of animals and plants are shown in Tables 3 and 4. Results for wild plants which could have been consumed by the prehispanic population, such as *A. calderae*, and those of wheat, barley, and pine (*P. canariensis*)

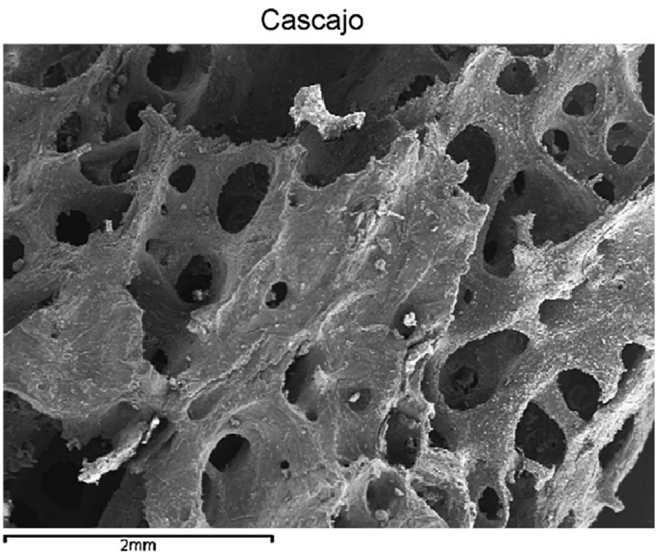

Fig. 4. Bone sample from Cascajo.

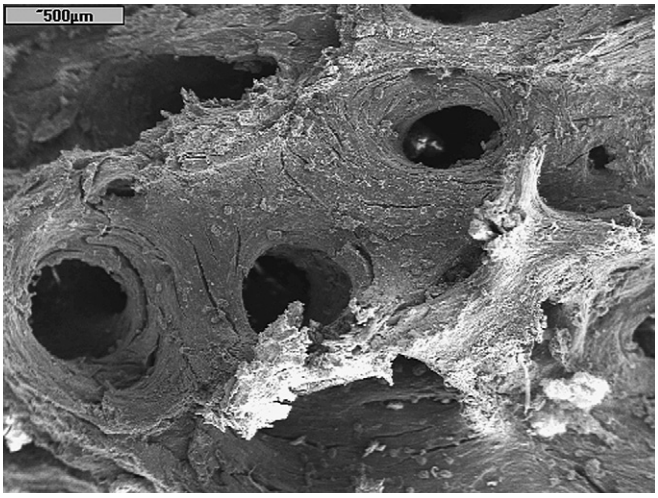

Fig. 5. Bone sample from Montaña Blanca.

seeds, range around −25‰, values observed in C3 plants (Farquhar et al., 1982). The collagen carbon and nitrogen isotope values of the lizard bones, which show $\delta^{13}C$ values of about −20‰, and $\delta^{15}N$ values around 11‰, fit well with a consumption of C_3 plants (and probably insects), and those of *C. bravoi* , with consumption of a mixed diet.

3.1.2. Nitrogen, hydrogen, and carbon stable isotopes in human samples

Crude data obtained from each of the individuals analyzed are shown in Tables 1 and 2. On pooling the data, nitrogen stable isotopes ranged from 8.2 to 12.4‰, and $\delta^{13}C$ values range from −18.6 to −20.5‰. In the cases in which δD was also determined, values ranged from −18 to +4‰ (Tables 1 and 2). All these data indicate dietary differences between the individuals analyzed. Indeed, although the differences were not statistically significant when compared with a population of Tenerife's lowland (Arnay-de-la-Rosa et al., in press), there was a tendency to higher $\delta^{15}N$ and $\delta^{13}C$, but lower δD values. Interestingly, significant differences were observed between men and women regarding $\delta^{13}C$ ($T = 2.6$, $p = 0.025$) and $\delta^{15}N$ ($T = 3.57$, $p = 0.005$), but not regarding δD (Table 6).

As reflected in Table 1, radiocarbon dating was performed at 5 of the 6 burial sites. It is interesting that significant differences were observed in δD, $\delta^{13}C$ and $\delta^{15}N$ between individuals buried before the Spanish conquest and after the Spanish conquest (assuming that all the individuals buried in the same cave belong to the same period, i.e, before the conquest or after the conquest). Individuals buried before the conquest showed higher $\delta^{13}C$, $\delta^{15}N$ and δD than those buried after the Spanish conquest (Table 7).

Since two of the 4 women included in this study were buried after the Spanish conquest, and $\delta^{15}N$ and $\delta^{13}C$ differed between those buried before and after the Spanish conquest, sex differences might act as a confounding factor. Therefore, multivariate analysis was performed. This showed that, regarding $\delta^{13}C$, sex was the only

Table 5
Barium and strontium in soil samples of the burial caves.

Archaeological site	Barium (mcg/g)	Strontium (mcg/g)
Capricho	50.45	4156.63
Cascajo	193.57	1948.73
Angostura	392.60	1716.31
Portillo	15704.55	2151.52
Salitre	898.95	3378.30

Table 6
Differences of TBM, trace elements and isotopes between men and women.

	Men	Women	
Trabecular bone mass	18.82 ± 5.43	19.50 ± 4.670	$T = 0.22$; NS
Bone strontium	107.10 ± 111.89 66.36 (55.30–115.49)	227.28 ± 185.64 238.87 (62.35–398.29)	$Z = 1.09$; NS
Bone barium	33.88 ± 19.74 27.46 (22.57–45.02)	35.22 ± 18.68 32.83 (19.14–53.70)	$Z = 0.24$; NS
Log Ba/Sr	−0.44 ± 0.36 −0.43(−0.58 to −0.16)	−0.71 ± 0.69 −0.74 (−1.32 to −0.06)	$Z = 0.36$; NS
Calcium	213216 ± 40288	204311 ± 42588	$T = 0.37$; NS
Delta C13	−19.39 ± 0.48	−20.15 ± 0.51	$T = 2.60$; $p = 0.025$
Delta N15	10.92 ± 1.24	8.95 ± 0.73	$T = 3.57$; $p = 0.005$
Delta D	−8.13 ± 8.20–8.0 (−16.5 to −0.25)	−12.00 ± 8.72–16.00 (−18.00 to −2.00)	$Z = 0.72$; NS

independent factor ($p = 0.04$), but regarding $\delta^{15}N$, burial period was the main parameter responsible for the differences observed ($p = 0.01$).

Since diet consumed by children might differ from that consumed by adults, data derived from the remains of the boy from Cascajo were not included in the global statistical analysis. However, analyses yield a $\delta^{13}C$ value of −20.15‰ and also a very low δD value (−18‰, in the lower range of the individuals buried after the conquest), but higher $\delta^{15}N$ values.

3.2. Bone mass

In Table 2 we show data relative to bone trace elements and bone mass. As shown, significant differences were observed between prehispanic individuals and modern controls regarding TBM (Table 8). If, based only on our results, we established the range of normal TBM (mean ± 1.96 × SD = standard deviation) we would obtain an exceedingly wide range for normality (from 14% to 35%). However, pooling together data from other series (Thomsen et al., 2002; Mohsen, 2006), a more realistic low boundary for normal TBM would be 16–17%. In our study there was one individual whose TBM was clearly in the osteopenic range, and three more individuals with borderline TBM values between the lower limit of the normality and osteopenia (Table 2). All these 4 individuals belonged to the group of those died before the Spanish conquest. However,

Table 7
Differences of TBM, trace elements, and isotopes between individuals buried before the 15th century and after the 15th century.

	After 15th century	Before 15th century	
Trabecular bone mass	21.52 ± 4.01	17.92 ± 5.22	$T = 1.22$; NS
Bone strontium	71. 89 ± 11.08 73.78 (60.4–81.45)	158.90 ± 154. 14 73.92 (55.3–314.4)	$Z = 0.24$; NS
Bone barium	51.75 ± 25.01 51.16 (28.35–76.15)	28.38 ± 12.88 24.36 (20.98 −36.57)	$Z = 1.70$ NS
Log Ba/Sr	−0.18 ± 0.23 −0.12 (−0.43 to −0.02)	−0.62 ± 0.46 −0.52 (−1.15 to −0.26)	$Z = 1.94$; $p = 0.052$
Calcium	227025 ± 38901	205644 ± 40025	$T = 0.93$; NS
Delta C13	−20.15 ± 0.37	−19.39 ± 0.53	$T = 2.60$; $p = 0.016$
Delta N15	8.90 ± 0.66	10.94 ± 1.22	$T = 3.11$; $p = 0.01$
Delta D	−16.75 ± 1.50–17.0 (−18.0–15.25)	−4.86 ± 6.94–4.00 (−8.00 to +1)	$Z = 2.28$; $p = 0.024$

Table 8
Differences in TBM and Trace elements between the prehistoric sample and the modern controls.

	Cañadas	Control	
Trabecular bone mass	19.03 ± 5.02	24.30 ± 5.17	$T = 2.64$; $p = 0.014$
Bone strontium	137.15 ± 137.70 73.8 (57.0–153.9)	121.48 ± 41.62 122.9 (81.8–162)	$Z = 1.28$; NS
Bone barium	34.22 ± 18.86 27.5 (22.5–46.8)	9.60 ± 12.43 3.7 (2.4–10.7)	$Z = 3.48$; $p < 0.001$
Log Ba/Sr	−0.51 ± 0.45 −0.43 (−0.79 to −0.15)	−1.26 ± 0.46 −1.35(−1.66 to −0.88)	$Z = 3.17$; $p = 0.001$
Bone calcium	210 989 ± 39609	232 645 ± 37995	$T = 1.46$; NS

classifying all of them as osteoporotic, the association between osteoporosis and burial after or before the Spanish conquest was not statistically significant ($\chi 2 = 1.12$, $p > 0.5$) No differences were observed between men and women regarding bone mass (Table 6), or between individuals buried before the Spanish conquest and after the Spanish conquest (Table 7). There was no relation between TBM and the barium to strontium ratio (log Ba/Sr), and also, no relation between TBM and δD, δ^{13}C or δ^{15}N values.

3.3. *Bone trace elements*

Log Ba/Sr ranges from 0.00 to −1.34; statistically significant differences were observed between prehispanic individuals and modern controls regarding log of bone Ba/Sr ratios (Table 8). No differences were observed between men and women regarding trace elements (Table 6), or between individuals buried in prehispanic times or after the Spanish conquest. (Table 7), although there was a tendency to higher log Ba/Sr ratios among those buried after the Spanish conquest. The half of the individuals analyzed (50%) showed log Ba/Sr ratios over −0.40 (indicative of a diet based on terrestrial products), and a further 20%, log Ba/Sr values close to the boundary of −0.40. Only in four cases (from La Angostura and Salitre, two burials with C-14 dating far before the Spanish conquest), bone log Ba/Sr values point to the consumption of a mixed (marine + terrestrial) diet. In all the cases, bone Ba and Sr were, by far, higher than soil content of these elements (Table 4).

Significant, direct relationships were observed between δ^{13}Cand δ^{15}N ($\rho = 0.54$, $p = 0.045$; Fig. 6) and between δD and δ^{13}C($\rho = 0.73$, $p < 0.01$; Fig. 7

In summary, individuals buried before the Spanish conquest showed no significant differences in bone mass compared with those buried after the conquest, suggesting that nutritional status was similar in both groups, so the Spanish conquest did not exert an impact on nutritional status among those who fled to Las Cañadas. However, individuals buried before the conquest showed higher δ^{13}C, δ^{15}N, and δD values than those buried after it, suggesting a higher plant consumption after the conquest. Moreover, values of log Ba/Sr are high, around −0.40 or higher, which confirms the virtual absence of marine products in the diet, although some individuals buried during the times before the conquest showed values of log Ba/Sr which suggest consumption of a mixed diet.

4. Discussion

4.1. *Dietary information derived from isotope analysis*

As said before, assuming that the Guanches who were buried in Las Cañadas were mainly goatherds, it is likely that they lived from goat products, such as milk and derivatives, and meat, although the finding of many grinding stones in archaeological sites also support the consumption of a certain kind of cereal (barley? Seeds from

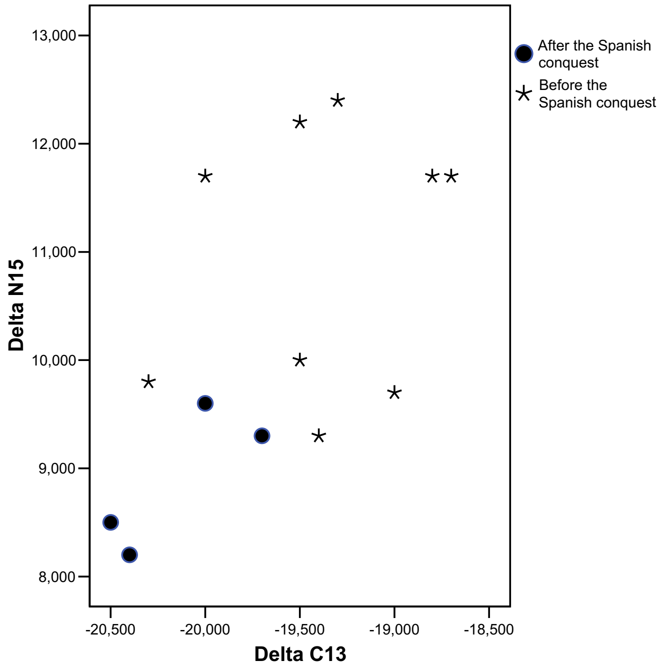

Fig. 6. Carbon and nitrogen stable isotopes of the analyzed human bone collagen.

A. calderae?). Our results support the hypothesis that these individuals ate a mixed diet, with a relatively high δ^{15}N values. There are no archaeobotanic evidences regarding consumption of C4 plants, and the results of this study also agree with this statement: the carbon stable isotope composition of C_4 plants ranges from −14 to −9‰ and averages −12‰, while C_3 plants display a range of δ^{13}C values from −35 to −20‰, with a typical mean value of −27‰ (Farquhar et al., 1982, 1989). Indeed, δ^{13}C values obtained for wild and domestic plant species included in this study (*A. calderae*, wheat, barley, and pine (*P. canariensis*) seeds) range around −25‰. The range of δ^{13}C values for bone collagen in the population analyzedin this study was from −20.5 to −18.7‰. Therefore, assuming

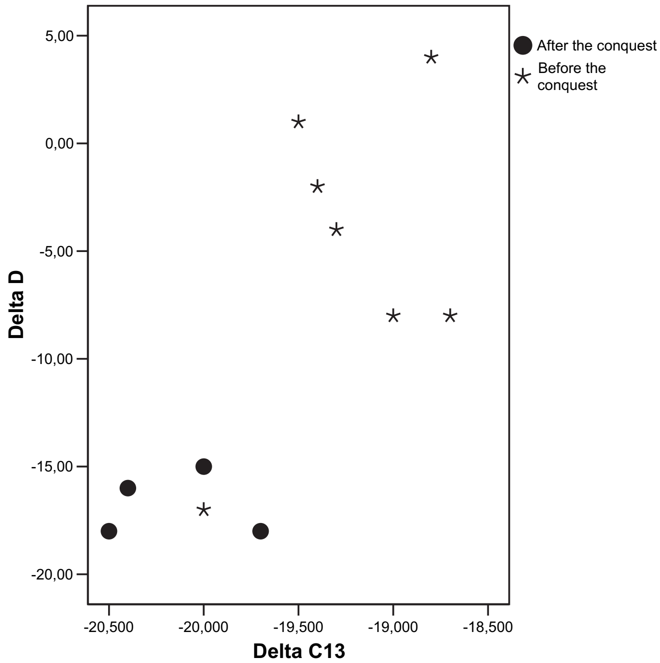

Fig. 7. Carbon and hydrogen stable isotopes of the analyzed human bone collagen.

that $\delta^{13}C$ value of bone collagen is about 5‰ greater than the diet (DeNiro, 1985), it is likely that prehistoric humans from Las Cañadas consumed primarily C_3 plant types.

The $\delta^{15}N$ values in plants display a wide range in our study (Table 2). Leguminous plants display $\delta^{15}N$ values of nearly 0‰, whereas non-leguminous plants show slightly higher $\delta^{15}N$ values (Katzenberg, 2000). Successively higher trophic levels lead to enrichment in the heavier nitrogen isotope (Schoeninger et al., 1983; Hedges et al., 2007). Herbivores show values 3‰ higher than their plant-based diet, and carnivores also show 3‰ higher isotopic values than their herbivore-based diet (DeNiro, 1985). In the present study we have observed $\delta^{15}N$ values higher than others reported for inhabitants of Tenerife's lowland (Arnay-de-la-Rosa et al., 2010). The significantly higher $\delta^{15}N$ values of bone collagen of humans from Las Cañadas support the hypothesis that consumption of non-leguminous plants and/or meat was greater by individuals from the highlands compared to those form the lowlands. The nitrogen isotope values of the analyzed native plants which could be consumed by the inhabitants of the highlands are not consistent with the human collagen results, except for the endemic palm tree fruit (dates of *P. canariensis*) and *F. carica* fruits, which do not grow in this altitude, but may have been collected sporadically, since some trees of these species reach an altitude of 1200 m. The $\delta^{15}N$ value of goat collagen (8.2‰), however, could fit with that of prehistoric humans, suggesting a contribution of goat meat (or, probably, milk). The $\delta^{15}N$ value of the giant extinct lizard, *G. goliath*, also allows us to hypothesize that it too may have contributed to the food items consumed by these individuals.

The quantitative contribution of potentially consumed food sources were computed using the *IsoSource 1.3.1* software (http://www.epa.gov/wed/pages/models/StableIsotopes/isotopes.htm) using a model proposed by Phillips and Gregg (2003), which computes the range of feasible source contributions to a mixed diet when there are too many sources to allow a unique solution through isotopic signatures. All possible combinations of each source contribution (0–100%) are examined in small increments with a small tolerance. Using Isosource program, introducing data on potential food sources allowed an interpretation of the diet consumed by some of the individuals (lizard ≈46–50%, goat 48–50%), but the amount of vegetal species consumed was exceedingly low (≈2%), suggesting that perhaps other food sources, not analyzed in the study, could have contributed. Nevertheless, it is important to consider another factor which may explain these results: climate of Las Cañadas is very arid, with very low humidity values, even in winter (for instance, 8% humidity on 25th February 2010, or 18.6% on 31st December 2009; www.iac.es/telescopes/tiempo/weather.html). In these conditions, evaporation of sweat is increased, and some degree of dehydratation (relative to people living in a humid environment) may ensue. It is well known that dehydratation leads to an increase in blood urea, which diffuses into tissues, ant that nitrogen which evaporates or becomes eliminated is enriched in the lightest isotope. So, it is possible that values of $\delta^{15}N$ are somewhat higher partly because of this mechanism; this does not apply to the animals samples analyzed, since they do not belong to archaeological sites from Las Cañadas. Dwelling areas in Las Cañadas have not been systematically excavated, and very few goat bones have been recovered and the bones of giant lizards have only been found occasionally. In any case, in this study, both goat and lizard bones were dug out in prehispanic coastal sites, belonging to animals probably not subjected to such arid conditions.

4.2. Differences between individuals buried before and after the Spanish conquest

It is interesting to point out the differences among individuals buried before or after the Spanish conquest. In this study, C-14 analysis by two laboratories allowed accurate dating of the skeletal remains belonging to two individuals from a burial site which contained 4 corpses. The analysis showed that some of the "Guanche" population still occupied the highlands after the Spanish conquest, continued with their lifestyle, and buried their dead in caves as in former times. They probably remained there for many decades, perhaps even two or three centuries, as may be deduced from chronicles written at the end of the 16th century (nearly 100 years after the conquest), in which there is a warning for potential travelers to the highlands that this was a dangerous place inhabited by "wild people" (Aznar-Vallejo, 1988), and the references to the "alzados" (rebels who did not accept the Spanish rule and fled to the mountains). The fate of the Guanches who remained in the conquered Canary Islands is quite well documented. Those who survived became rapidly integrated in the new society, many as slaves (although slavery was theoretically forbidden by the Spanish kings), others as free people, some workers as labourers on the properties of the new owners, and most, as goatherds. Chronicles and writings of the 16th century emphasize the worth of the aborigines in herding work, arguing that they were those who best knew the countryside. These herders probably served as contacts with the "alzados", about whom the knowledge is imprecise. Indeed, during the 16th and 17th century, the central mountains were considered as remote areas, to which any trip was considered dangerous, with vague references to ghosts, witchesand "savages", which may even have been fostered by the "Guanches" in order to preserve their freedom.

Importantly, this study detected differences in dietary indicators between individuals buried before the Spanish conquest and after it. In those buried after the Spanish conquest, $\delta^{15}N$ values were lower, $\delta^{13}C$ and δD values were also lower, and there was a tendency to higher bone barium values. In a previous study, transforming the information provided by $\delta^{13}C$ and $\delta^{15}N$ values in proportions of meat, vegetables, and marine products by means of Isosource program (Arnay-de-la-Rosa et al., 2010), we showed that high δD values were associated with animal protein consumption. In support of this view, this study found a close correlation between δD and $\delta^{13}C$ values, and also a nearly significant relationship between δD and $\delta^{15}N$. Individuals buried after the Spanish conquest showed the lowest δD values, supporting the hypothesis that they consumed a more vegetable-based diet than their ancestors.

The Spanish conquest led to disruption of the subsistence activities of the prehispanic people who fled to the mountains. Productive land now belonged to the new Spanish owners, so those who fled were forced to depend more heavily on wild plants and animals instead of agricultural products. In addition, they also had to preserve the few herds still left to them, and this entailed reduced culling and less consumption of goat's meat. Forced to consume wild plants, some giant lizards, and less meat, the differences in isotope values between the Guanches buried before and after the Spanish conquest are not surprising. In contrast, the Guanches buried in Las Cañadas before the Spanish conquest had probably spent most of their lives near the coast, or at medium altitudes, moving to the mountains with their herds in summer, so they probably had more accessibility to food sources and consumed a more varied diet.

Interestingly, all 4 individuals buried at El Portillo showed the lowest δD values, together with one prehispanic individual from Angostura (Ang-2, Table 1), and the boy buried at Cascajo. Although an child's diet may differ from that of an adult, a preliminary result of C-14 analysis of a bone sample of this boy yielded an antiquity of only 200 ± 40 years BP (i.e, he died between 1710 and 1790). This is a very recent C-14 dating for a partially mummified individual buried in a small cave near a fully "prehispanic" dwelling, excavated in 1977 by one of the authors (M.A–R), although it is important to note that antiquity of one individual of El Portillo was 354 ± 56 years (see Table 1), not so distant from that of Cascajo.

Despite the possible more restricted access to food, and greater plant consumption, the bone mass of individuals buried after the Spanish conquest was similar to that of those buried before. A high prevalence of osteoporosis in a non-selected population group may be interpreted as secondary to malnutrition (Bourrin et al., 2000a, 2000b).Normal TBM values may span from approximately 15–16% to 25–26%, although wider ranges have been reported in some populational studies (Thomsen et al., 2002; Mohsen, 2006). In our study, TBM values were significantly lower than those of the modern control group. As stated before, some prehispanic individuals were indeed osteoporotic, but no significant association was found between suffering osteoporosis and being buried after or before the Spanish conquest. ($\chi 2 = 1.12$, $p > 0.5$). There was no relation between TBM and any of the isotopes analyzed or the barium to strontium ratio (log Ba/Sr), and also, no relationship between TBM and δ^{13}C or δ^{15}N values. In addition, δD, δ^{13}C and δ^{15}N values did not differ between individuals with low TBM or normal TBM, so there is no argument to support the hypothesis that changes in stable isotopes may be due to malnutrition, at least in this study. Also, data derived from this study do not support the hypothesis that perhaps those who survived in the central mountains were undernourished. Chroniclers reported that the Guanches who survived and maintained their ancient style of life were helped by Guanches who lived under the Spanish rule in medium altitude areas of the island (about 700–1000 m altitude; Betancor Quintana, 2002). Perhaps this might explain the relative preserved nutritional status of these people, although this is speculative, due to the small number of individuals belonging to the post-conquest period.

Post mortem changes and bone-soil ion exchange hinders the interpretation of bone trace elements as paleodietary indicators, but barium to strontium ratio still allows a differentiation between marine and terrestrial diet (Burton and Price, 1990). Since marine environment is poor in barium, but not in strontium, it is said that log Ba/Sr values below −1.40 indicate a diet based on consumption of marine resources, and a value of −0.40 or higher, a diet based on terrestrial products (Burton and Price, 1990). Most of the values obtained in the present study are higher than −0.40; only three cases show values around −1.25, all of them belonging to individuals of prehispanic burials (who could have lived in coastal areas and only sporadically moved to the highlands). As commented earlier, it is likely that prehispanic goatherds who moved to the central mountains did so for relatively short periods. Chroniclers underscore that the high mountains were only seasonally occupied; it is also possible that goatherds moved to medium altitudes, or even to the coast, every few days. In any case, these habits could have suffered changes during the many centuries of prehispanic occupation of the island. The remains of marine food products are very rare in Las Cañadas dwellings; the isotope composition of *Patella* and other gastropods (Table 4) is not consistent with human collagen isotopes, and as said, it is very unlikely that the inhabitants of Las Cañadas consumed marine food.

The sample is too small to allow a firm inference on gender differences regarding dietary indicators. However, despite the short number of cases, men showed higher δ^{15}N and δ^{13}C than women, as shown in Table 6. These results point to higher consumption of animal protein by men than by women, which has also been reported for other parts of the island and for other islands of the Archipelago (Arnay-de-la-Rosa et al., 2010). However, it should not be forgotten that pregnancy has been also associated to a decrease in δ^{15}N values (Fuller et al., 2004).

5. Conclusions

In the present study we have analyzed the stable isotope composition of bone collagen extracted from 17 well-preserved prehistoric humans buried in arid highlands (Las Cañadas del Teide) of Tenerife, Canary Islands. The stable isotope composition was also analyzed for prehistoric animals and potentially consumed modern plants.

As a whole, the carbon and nitrogen isotope composition of human bone collagen of the population buried in Las Cañadas suggest consumption of a diet rich in terrestrial meat, especially goat and perhaps lizard, and also C_3 plants. Isotope composition of the samples belonging to the population buried in Las Cañadas show some differences (although non significant) with that buried near the coast, with higher δ^{15}N and slightly higher δ^{13}C values (Arnay-de-la-Rosa et al., 2010), which suggest consumption of higher proportion of meat by the former.

For the first time we have documented that prehispanic forms of life persisted, in Las Cañadas, far beyond the Spanish conquest, affecting 5 individuals (a collective burial containing 4 corpses, and one mummified child). Interestingly, these individuals showed differences in their carbon, nitrogen, and hydrogen isotope composition when compared with those buried before the Spanish conquest, suggesting lower consumption of meat but more plants. These results may be explained by the disruption of the subsistence activities of those who fled to the mountains and were forced to depend more heavily on wild plants and animals instead of agricultural products, and to preserve the few herds still left to them, leading to less consumption of goat's meat. Also, differences in the logBa/Sr ratios suggest that they consumed a terrestrial diet, in contrast with those buried before the Spanish conquest, who should have consumed a mixed diet.

References

Álvarez Delgado, J., 1947. La necrópolis de la cueva del Salitre en Montaña Rajada (Las Cañadas del Teide). Excavaciones Arqueológicas en Tenerife (Canarias). Plan nacional 1944-1945. Informes Y Memorias 14, 48–59.

Alberto-Barroso, V., 1998. Los otros animales. Consumo de Gallotia Goliath y Canaryomis bravoi en la prehistoria de Tenerife. El Museo Canario 53, 59–83.

Alberto-Barroso, V., 2004. De carne y hueso. La ganadería en época prehispánica. El Pajar. Cuadernos de Etnografía Canaria 18, 4–8.

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17, 143–145.

Ambrose, S.H., DeNiro, M.J., 1986. The isotopic ecology of East served collagen suitable for reliable stable isotopic measure- African mammals. Oecologia 69, 395–406.

Ambrose, S.H., DeNiro, M.J., 1989. Climate and habitat reconstruction using stable carbon and nitrogen isotope ratios of collagen in prehistoric herbivore teeth from Kenya. Quaternay Res. 31, 407–422.

Ambrose, S.H., Butler, B.M., Hanson, D.B., Hunter-Anderson, R.L., Krueger, H.W., 1997. Stable isotopic analysis of human diet in the Marianas Archipelago. Western Pacific. Am. J. Phys. Anthropol. 104, 343–361.

Ambrose, S.H., Buikstra, J., Krueger, H.W., 2003. Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. J. Anthropol. Archaeol 22, 217–226.

Arnay-de-la-Rosa, M., González-Reimers, E., 2006. El poblamiento prehistórico del Parque Nacional del Teide. In: Carracedo, J.C. (Ed.), Los volcanes del Parque Nacional del Teide. Organismos Autónomo Parques Nacionales. Ministerio de Medio Ambiente, Madrid, pp. 314–341.

Arnay-de-la-Rosa, M., Gijón-Botella, H., Afonso-Vargas, J., Valladares-Parrilla, F., González-Reimers, E., 2008. Trichuris Eggs in Ancient Samples. 16th Congress of the European Anthropological Association. University of Southern Denmark, Odense. pp.170.

Arnay-de-la-Rosa, M., González-Reimers, E., Yanes, Y., Velasco-Vázquez, J., Romanek, C.S., Noakes, J.E., 2010. Paleodietary analysis of the Prehistoric population of the Canary Islands inferred from Stable Isotopes (carbon, nitrogen and hydrogen) in Bone Collagen. J. Archaeol. Sci. J. Archaeol. Sci. 37, 1490–1501.

Aznar-Vallejo, E., 1988. El capítulo de Canarias en el Islario de André Thevet. VI Coloquio de Historia Canario-Americana. Cabildo Insular de Gran Canaria. Las Palmas de Gran Canaria, 829–862. T II.

Betancor Quintana, G., 2002. Los canarios en la formación de la moderna sociedad tinerfeña –. Integración y aculturación de los indígenas de Gran Canaria 1596–1525. Ediciones del Cabildo de Gran Canaria. Las Palmas de Gran Canaria.

Birchall, J., ÓConnell, T., Heaton, T.H.E., Hedges, R.E.M., 2005. Hydrogen isotope ratios in animal body protein reflect trophic level. J. Anim. Ecol. 74, 877–881.

Bocherens, H., Fizet, M., Mariotti, A., Lange-Badre, B., Vandermeersch, B., Borel, J.P., Bellon, G., 1991. Isotopic biogeochemistry (13C, 15N) of fossil vertebrate collagen: implications for the study of fossil food web including Neandertal Man. J. Hum. Evol. 20, 481–492.

Bourrin, S., Amman, P., Bonjour, J.P., Rizzoli, R., 2000a. Dietary protein restriction lowers plasma insulin-like growth factor 1 (IGF-1), impairs cortical bone formation, and induces osteoblastic resistance to IGF-1 in adult female rats. Endocrinology 141, 3149–3155.
Bourrin, S., Toromanoff, A., Amman, P., Bonjour, J.P., Rizzoli, R., 2000b. Dietary protein deficiency induces osteoporosis in aged male rats. J. Bone Miner. Res. 15, 1555–1563.
Burton, J.H., Price, T.D., 1990. The ratio of barium to strontium as a paleodietary indicator of consumption of marine resources. J. Archaeol. Sci. 17, 547–557.
DeNiro, M.J., 1985. Post-mortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317, 806–809.
DeNiro, M.J., 1987. Stable isotopy and archaeology. Am. Sci. 75, 182–191.
DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochim. Cosmochim, Acta 42, 495–506.
DeNiro, M.J., Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochim. Cosmochi, Acta 45, 341–351.
Diego Cuscoy, L., 1968. Los Guanches. Vida y cultura del primitivo habitante de Tenerife. Publicaciones del Museo Arqueológico de Tenerife, Santa Cruz de Tenerife.
Espinosa A.de, 1594 (1980).Historia de Nuestra Señora de Candelaria. (Del origen y Milagros de la Santa Imagen de Nuestra Señora de Candelaria, que apareció en la isla de Tenerife, con la descripción de esta Isla). Goya ed. Santa Cruz de Tenerife.
Fabig, A., Herrmann, B., 2002. Trace elements in buried human bones: intrapopulation variability of Sr/ca and Ba/Ca ratios –diet or diagenesis? Naturwissenschaften 89, 115–119.
Farquhar, G.D., O'Leary, M.H., Berry, J.A., 1982. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Austr. J. Plant Physiol. 9, 121–137.
Farquhar, G.D., Ehleringer, J.R., Hubick, K.T., 1989. Carbon isotope discrimination and photosynthesis. Ann. Rev. Plant Physiol. Plant Mol. Biol. 40, 503–537.
Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., ÓConnell, T.C., Hedges, R.E., 2004. Nitrogen balance and delta 15N: why you're not what you eat during pregnancy. Rapid Commun. Mass Spectrom. 18, 2889–2896.
González-Reimers, E., Mas-Pascual, A., Arnay-de-la-Rosa, M., Velasco-Vázquez, J., Santolaria- Fernández, F., Machado-Calvo, M., 2004. Non-invasive estimation of bone mass in ancient vertebrae. Am. J. Phys. Anthropol. 125, 121–131.
González–Reimers, E., Arnay-de-la-Rosa, M., 1992. Ancient skeletal remains of the Canary Islands: bone histology and chemical analysis. Ant. Anz 50, 201–215.
Hedges, R.E., Reynard, L.M., 2007. Nitrogen isotopes and the trophic levels of humans in archaeology. J. Archaeol. Sci. 34, 1240–1251.
Katzenberg, M.A., 2000. Stable isotope analysis: a tool for studying past diet, demography, and life history. In: Katzenberg, M.A., Saunders, R.E. (Eds.), Biological Anthropology of the Human Skeleton. Wiley-Liss, New York, pp. 305–327.
Maca-Meyer, N., Arnay, M., Rando, J.C., Flores, C., González, A.M., Cabrera, V.M., Larruga, J.M., 2004. Ancient mtDNA analysis and the origin of the Guanches. Eur. J. Hum. Gen. 12, 155–162.
Marino, B.D., McElroy, M.B., 1991. Isotopic composition of atmospheric CO_2 inferred from the carbon in C_4 plant cellulose. Nature 349, 127–131.
Mekota, A.M., Grupe, G., Ufer, S., Cuntz, U., 2006. Serial analysis of stable nitrogen and carbon isotopes in hair: monitoring starvation and recovery phases of patients suffering from anorexia nervosa. Rapid Commun. Mass Spectrom. 18, 2889–2896.
Mohsen, S.S., 2006. Comparison of cancellous bone histomorphometry between young men and women. Pakistani J. Biol. Sci. 9, 1338–1341.
Phillips, D.L., Gregg, J.W., 2003. Source partitioning using stable isotopes: coping with too many sources. Oecologia 136, 261–269.
Privat, K.L., ÓConnell, T.C., Hedges, R.E.M., 2007. The distinction between freshwater- and terrestrial-based diets: methodological concerns and archaeological applications of sulphur stable isotope analysis. J. Archaeol. Sci. 34, 1197–1204.
Quinn, R.L., Tucker, B.D., Krigbaum, J., 2008. Diet and mobility in Middle Archaic Florida: stable isotopic and faunal evidence from the Harris Creek archaeological site (8Vo24), TickIsland. J. Archaeol. Sci. 35, 2346–2356.
Reynard, L.M., Hedges, R.E.M., 2008. Stable hydrogen isotopes of bone collagen in paleodietary and paleoenvironmental reconstruction. J. Archaeol. Sci. 35, 1934–1942.
Schoeninger, M.J., DeNiro, M.J., Tauber, H., 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220, 1381–1383.
Schwarcz, H.P., Schoeninger, M.J., 1991. Stable isotope analyses in human nutritional ecology. Yearbook Phys. Anthropol. 34, 283–321.
Thompson, A.H., Chaix, L., Richards, M.P., 2008. Stable isotopes and diet at ancient Kerma, Upper Nubia (Sudan). J. Archaeol. Sci. 35, 376–387.
Thomsen, J.S., Ebbesen, E.N., Mosekilde, L.I., 2002. Static histomorphometry of human iliac crest and vertebral trabecular bone: a comparative study. Bone 30, 267–274.
Tieszen, L.L., Matzner, S., Buseman, S.K., 1993. Dietary reconstruction based on stable isotopes (^{13}C and ^{15}N) of the Guanche of PreHispanic Tenerife, Canary islands. In: Proceedings of the 1st World Congress on Mummies Studies. Santa Cruz de Tenerife, Museo Arqueológico y Etnográfico de Tenerife-Organismo Autónomo de Museos y Centros, Santa Cruz, Tenerife, Canary Islands, pp. 41–57.
Ubelaker, D.H., 1989. Human Skeletal Remains. Taraxacum, Washington.
Valentin, F., Bocherens, H., Gratuze, B., Sand, C., 2006. Dietary patterns during the late prehistoric/historic period in Cikobia island (Fiji): insights from stable isotopes and dental pathologies. J. Archaeol. Sci. 33, 1396–1410.
Williams, C.T., Buck, C.L., Sears, J., Kitayski, A.S., 2007. Effects of nutritional restriction on nitrogen and carbon stable isotopes in growing seabirds. Oecologia 153, 11–18.