Isotopic evidence for the reconstruction of diet and mobility during village formation in the Early Middle Ages: Las Gobas (Burgos, northern Spain)

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Abstract

Strontium, carbon and nitrogen isotopes of human bone and tooth remains have been used to reconstruct residential mobility and diet of early medieval populations at Las Gobas from the 6th to 11th centuries. Most non-local individuals correspond to the 10th-11th centuries and were mostly women and infants. This residential mobility coincided with the formation of Laño village and the abandonment of artificial cave settlement. Carbon and nitrogen isotope ratios of bone collagen indicate an omnivorous homogenous diet based on terrestrial plant resources, with few animal-derived proteins from livestock. Millet consumption was restricted to an earlier period of time (7th-9th centuries), and in later periods (10th-11th centuries) mainly C_3 plants such as wheat and barley were consumed. In general, there were no dietary differences between individuals according to sex or age. Sex-related dietary differences have only been observed in the 10th-11th centuries, when females consumed a more vegetarian diet and less animal protein. The higher $\delta^{15}N$ values in infants reflect the weaning effect, while the differences in $\delta^{15}N$ values between young adult men and young adult women can be explained as a physiological factor related to pregnancy or different origins. In a comparison with contemporaneous medieval populations in the northern Iberian Peninsula, both $\delta^{13}C$ and $\delta^{15}N$ values suggest similar foodstuff resources and diet among Christian and Muslim populations.

Keywords: palaeodietary patterns, human migration, rock-hewn dwelling, Middle Age, northern Iberian Peninsula

Introduction

A profound transformation affecting territorial organization occurred after the collapse of the Roman Empire. In the Cantabrian region of north Spain, the post-Roman landscape showed a high degree of territorial fragmentation with a lack of villages or rural structures. In this historical context, small and dispersed farmsteads and a few rock-hewn dwellings dated in the 6th and 7th centuries have been identified. In the course of the 8th century, a profound transformation of the Cantabrian region landscape started with the creation and gradual expansion of a network of villages (Quirós Castillo, 2009; 2011). In the 9th century, the former peasant settlement densification occurred with the creation of true village networks. Unlike in other regions, churches in the Cantabrian region never played a significant role in the formation of village networks. Early medieval churches were constructed once the villages were created and the construction of a church implied new ways of social organization and the exploitation of the territory.

The Las Gobas site consists of cave settlement and adjoining farmsteads. The use of artificial caves has been subject to the most varied interpretations. Traditional historiography has explained such occupations as a phenomenon related to different variables of Christian asceticism (e.g. Gonzalez Blanco 1993; Monreal 1997; Castellanos 1998; Espinosa 2006). Alternatively, they have been interpreted as farming communities that later moved to new settlements as they founded medieval villages (Quirós Castillo 2006; Azkarate and Solaun 2008). The cave settlement occurred over 300 years between the 6th and 9th centuries. In the late 9th century, a gradual abandonment of the settlement occurs and the community was relocated to a new settlement site in the valley (now Laño village) but the liturgical and burial function continued until the 12th century (Azkarate and Solaun 2015). New archaeological data together with biogeochemical analyses of human remains enables the observation of peasant landscape transformation from the collapse of the Roman Empire to the formation of medieval villages.

To reconstruct the lifestyle of the early medieval peasants, carbon and nitrogen stable isotopes provide insights into dietary habits whereas strontium isotope provides information about residential movements (Alt et al., 2014; Lopez-Costas and Müldner, 2015; Hemer et al., 2017; Salazar-Garcia et al., 2016). Diet, and its change over time, can shed light on the social and economic structure and such aspects as sex, age and wealth within the communities. The aim of this work is to determine the dynamics and articulation of early medieval peasant society in the Cantabrian region through strontium, carbon and nitrogen isotope studies of human remains from Las Gobas.

Isotope background

Most dietary reconstruction in recent decades is based on carbon and nitrogen isotope values in human skeletal tissues. The principle of the method is based on the chemical signature of skeletal tissues reflecting the isotope signature of food consumed. The carbon isotope values ($\delta^{13}C$) in human bone and tooth enamel depend on the types of plants consumed directly and via animal species incorporated into human diet (Ambrose and Katzenberg 2000). Early medieval dietary resources in the Cantabrian region of north Spain consisted of C_3 plants combined with C_4 plants. Cereals like millet and sorghum corresponding to C_4 plants group were present in Europe in the Middle Ages but the archaeobotanical data from Cantabrian sites show that millet was the only C_4 plant in the diet (Quirós Castillo, 2016). The $\delta^{13}C$ of modern of C_3 plants ranges between -20 and -35 ‰ and between -9 ‰ and -14 ‰ for C_4 plants (Katzenberg 2000). When the carbon isotopes of foods are incorporated into human bone collagen a shift of approximately 5 ‰ occurs (Ambrose and Norr 1993). Thus, measuring $\delta^{13}C$ of bone collagen makes it possible to obtain the proportion of C_3 and C_4 resources consumed (Schoeninger and DeNiro 1984; Schwarcz and Schoeninger 1991; Richards 2000).

In contrast, nitrogen isotope values ($\delta^{15}N$) provide a measure of animal protein consumption compared to plant source proteins although calculating the percentage corresponding to each protein source is difficult (Bocherens and Drucker 2003; Hedges and Reynard 2007). Between trophic levels, the fractionation of nitrogen isotope leads to an enrichment in $\delta^{15}N$ values of 2-5‰ (an average of 3‰) from diet to body tissues, although recent studies estimate an offset of about 6‰ (Bocherens and Drucker 2003; Hedges and Reynard 2007; O'Connell et al. 2012). Individuals consuming mainly vegetarian diet have $\delta^{15}N$ values ranging from 3 ‰ to 9 ‰, while individuals consuming meat of terrestrial herbivores will have $\delta^{15}N$ values ranging from 9 ‰ to 12 ‰ (DeNiro and Epstein, 1981; Hedges and Reynard 2007). Meat protein (20-25%) dominates the $\delta^{15}N$ values of bone collagen over plants (10%) in individuals with an omnivorous diet. Cantabrian region medieval peasant communities practiced an economic structure of self-subsistence based on a reduction of risk of the production patterns of agriculture and livestock, and $\delta^{15}N$ values will reflect the protein sources (Quirós Castillo 2013a; Quirós Castillo 2016).

The territorial reorganization in the Early Middle Age, during the formation of villages, involved the restructuring of peasant society and hence residential mobility of individuals. Strontium isotope signature potentially enables the identification of local and non-local individuals, although it is crucial to define the local $^{87}Sr/^{86}Sr$ baseline (Bentley et al. 2004; Price et al. 2002, Tütken et al. 2011). Strontium is incorporated in bone apatite and dental enamel by the intake of food and water so individuals consuming local food and inhabiting a specific geological region will have an isotope signature reflecting the area (Ericson 1989; Bentley 2006; Price et al. 2002). Local freshwater, soil, bedrock and archaeofauna can usually be used to define the local bioavailable strontium isotope composition (Montgomery et al. 2006; Voerkelius et al. 2010; Frei and Price 2012).

Materials and Methods

Las Gobas is an excellent site for an investigation into rural landscape transformation in the Cantabrian region during the Early Middle Age until the creation of village networks. Las Gobas is located in the gorge of the Barrundia and Ayuda streams in Laño (Burgos, north of Spain). The rock-hewn dwellings on the western bank correspond to Las Gobas site whereas the artificial caves on the eastern bank form the Santorcaria site (Fig. 1). The whole complex is formed by 29 caves and is considered one of the best examples of rock-hewn dwellings in the north of the Iberian Peninsula (Azkarate 1988). In particular, Las

Gobas consists of 13 artificial caves of different geometries and uses. Radiocarbon analyses date the site between the 6th and 11th centuries (Table 1) and the history and evolution of the site shows two main phases according to the use of the space, Phase I from the 7th to 9th centuries and Phase II from the 10th to 11th centuries (Azkarate and Solaun 2008, 2015). Phase I comprised the first rock-hewn church (Las Gobas 6) and several single-room dwellings, with a large wooden building and a graveyard with 15 graves on the terraced hillside (Fig. 2). The wooden building was later rebuilt in stone together with other archaeological evidences suggesting power and wealth (Wickham 2008; Bianchi 2012). In Phase II the second rock-hewn church (Las Gobas 4) and three huge silos were dug. These silos implied an increase in storage capacity due to the development of new farmland favoring the gradual abandonment of the settlement in favor of a new emplacement and the foundation of the present Laño village. At the same time, the graveyard was reorganized with the development of a new level of burials. Finally, the settlement was definitively abandoned although worship in the churches continued.

Carbon and nitrogen isotopes analyses were performed for 40 human bone collagen samples corresponding to all inhumed individuals and for 15 archaeological fauna bone samples (Tables 2, 3). In addition, enamel from twenty-six teeth was analyzed for strontium isotope composition (Table 2). To define strontium isotope baseline, 13 tooth enamel samples from archaeological fauna and two freshwater samples were analyzed (Table 3). The archaeological fauna analyzed correspond to 4 sheep/goats, 3 cows, 2 pigs, 2 horses and 2 red deer.

Human remains correspond to 19 males, 12 females, 7 infants and 3 of indeterminate sex (Table 2). The anthropological analysis was performed by Herrasti and Etxeberria (2014). Sex determination was carried out according to the classical patterns of dimorphism and age was defined by the most reliable markers: changes in auricular surface and pubic symphysis, epiphyseal closure, cranial sutures and dental eruption (Ferembach et al., 1980; White et al., 1991). Individuals were categorized by age into infants (aged younger than 7), young adults (aged 16–27), adults (aged 27–35), mature adults (aged 35–50) and senile (aged older than 60). Within this classification, the absence of individuals aged from 7 to 12 years old is noteworthy and all the individuals were younger than 50 years old, except for one man of over 60 years of age.

For stable isotope analyses, bone collagen was extracted following the Bocherens et al. (1991) procedure at the University of the Basque Country (UPV/EHU). Long bones, when possible, or rib bones were pulverized and 300 mg of bone powder was demineralised in 1 M HCl for 20 min at room temperature until the sample dissolved. To remove humic acid, the samples were rinsed with distilled water and treated with 0.125 M NaOH. After having been rinsed again with distilled water, the resulting insoluble fraction was gelatinized in HCl solution at pH 3 for 17 h at 90 ºC. Then, samples were filtered using a MCE membrane filter (5µm) before being freeze-dried and finally, lyophilized using a FreeZone Plus 12 Liter Lyophilizer. Lyophilized collagens (0.900-1.100 mg) were enclosed in tin capsule for isotopic analysis. Carbon and nitrogen isotopes analyses were performed using a continuous-flow isotope ratio mass spectrometer (EA-IRMS) at Iso-Analytical (Cheshire, UK).

To confirm instrument accuracy, internal standards of multiple samples of bovine liver NBS-1577B standard and ammonium sulphate IA-R045 standard were used. Isotopic values are reported as δ values in per mil (‰) relative to international defined standards for carbon (VPDB: Vienna Pee Dee Belemnite) and nitrogen (AIR: Ambient Inhalable Reservoir). The instrumental precision for $\delta^{13}C$ was ± 0.06‰ or better and for $\delta^{15}N$ was between ± 0.06‰ to ± 0.08‰, determined by replicated analyses of internal standards.

Tooth enamel was used to determine strontium isotope composition. The samples were washed by ultrasonic bath to remove impurities and further cleaned by mechanical abrasion to remove the outer surface to avoid potential contamination. A fraction of dental enamel was collected mechanically with a diamond-coated trepanation drill (MF-perfect, W & H Dentalwork, Bürmoos, Austria). The direction of the sampling was always perpendicular to the growth axis of the tooth. Enamel samples (~10 mg) were dissolved in 7 mL Savillex® vials (Minnetonka, MN, USA) with 1.5 mL of 2N HNO_3 (analytical grade purified by sub-boiling distillation).

Water samples were collected in the Barrundia stream from the banks of the river. Prior to analysis, water samples were filtered to remove suspended materials. Then approximately 10–15 mL was evaporated to dryness in acid-cleaned Teflon beakers and added to 1.5 mL of 2N HNO_3 (analytical grade purified by sub-boiling distillation).

The solutions were loaded into cation exchange columns filled with Sr.spec® (ElChroM industries, Dariel, IL, USA), a strontium selective resin. The resin was used once to elute the sample and then discarded. Strontium procedural blanks were less than 100 pg and hence provided a negligible contribution. The purified strontium was loaded onto a single Re filament using TaF activator following the method proposed by Birck (1986). The isotope ratios were determined by Thermal Ionization Mass spectrometry (TIMS) using a ThermoFinnigan MAT 262 multi-collector mass spectrometer at the Advanced Research Facilities (SGIker) of the University of the Basque Country (UPV/EHU). Multiple samples of strontium of reference material NBS 987 were run to confirm instrument accuracy. External batch reproducibility was ± 0.00002 (absolute 2σ) based on 232 measurements. Replicate analyses of the NBS 987 during runs was 0.710268 ± 12 (2σ, n = 7).

Statistical tests were performed using SPSS for windows version 20. Differences between sample groups were analyzed by applying the two-tailed Mann-Whitney U test. This test was selected over the t-test because of small sample sizes, import differences in sample size between groups and some heterogeneity between variances. The null hypothesis states that there is no difference between the ranks of two samples. A probability level of 5% was considered significant to reject the null hypothesis.

Results

Carbon and Nitrogen isotopes

The human and fauna analytical results are listed in Table 2. The collagen quality and diagenesis effect were verified according to C/N atomic ratios. Collagen yielding a C/N of 2.9-3.6 was considered acceptable for stable isotope analyses and radiocarbon dating (DeNiro 1985; Ambrose 1990; Schwarcz and Schoeninger 1991). The C and N in collagen samples are higher than +36.7 %wt and +12.0 %wt respectively, with a C/N atomic ratio between 3.2-3.6, indicative of well-preserved collagen.

The δ^{13}C ratios for Las Gobas individuals (n=40) range between -20.1 and -17.2‰ (mean -19.0‰ ±0.58, 1σ) and δ^{15}N values range from +7.7 to +11.7‰ (mean 8.9‰ ±0.9, 1σ). Unlike the δ^{13}C values, the δ^{15}N values display significant variations. Nitrogen isotope ratios of most individuals are lower than +10.0‰ (n=33) while five infants have δ^{15}N higher than +10.0‰ ($p<0.001$). Carbon and nitrogen isotope values of archaeological fauna reveal two compositional groups. The first fauna group consisting of two cows, one horse and one red deer is largely depleted in δ^{13}C (n=4) (mean -21.8‰ ±0.3, 1σ) and δ^{15}N (mean +2.3‰ ±0.3, 1σ) while the second group formed mainly by pigs, sheep/goats and one cow and one red deer (n=11) are less depleted in δ^{13}C (mean -20.7‰ ±0.3, 1σ) and enriched in δ^{15}N (mean +5.0‰ ±0.8, 1σ). The shift between the first group of fauna and humans are on average about $\Delta\delta^{15}$N 6.5‰, $\Delta\delta^{13}$C 2.8‰, while the shift between the second group of fauna and human is lower ($\Delta\delta^{15}$N 4‰, and $\Delta\delta^{13}$C 1.7‰, on average) (Fig. 3).

Nitrogen and carbon isotope composition of adult individuals does not shown statistical differences by sex or age. However, significant differences in δ^{13}C values were observed between settlement phases (p=0.04). Within Phase I, the δ^{13}C values are clustered into two groups; one group with δ^{15}N mean values of +9.1‰±0.6 (1σ, n=6) and δ^{13}C mean values of -18.2‰±0.1 (1σ), and the other with δ^{15}N mean values of +8.5‰ ±0.4 (1σ, n=7) and δ^{13}C mean values of -19.2‰ ±0.2 (1σ). In Phase II, only when considering young adult individuals, females have significantly lower mean values in δ^{13}C (-19.4±0.4, 1σ, n=4) than males (-18.8±0.4, 1σ, n=4) (p=0.04).

Strontium isotope

The results of strontium isotope values of human and archaeological fauna dental enamels and local waters are shown in Table 2. Local freshwater composition ranges between 0.70784 and 0.70789 and, archaeological fauna composition varies between 0.70769 and 0.71153. Additionally Las Gobas bedrock lithology strontium values were taken into consideration, where ^{87}Sr/^{86}Sr composition varies between 0.70796 and 0.70813 (Baceta et al. 2013). The human dental enamel ^{87}Sr/^{86}Sr values range between 0.70787 and 0.70890.

Discussion

Residential Mobility

Archaeofauna, local freshwater and bedrock composition were considered to establish the local strontium isotope signature at Las Gobas. The lithology is quite homogeneous and is formed by carbonate sedimentary rocks; mainly dolostones and limestones. Since the bedrock in the area surrounding Las Gobas is uniform, strontium isotope composition of both bedrock and local freshwater can be used to establish the local strontium baseline. Archaeological fauna associated with the site also reflect the average bioavailable strontium isotope composition. However, one horse, one cow and one sheep/goat deviate significantly from local bedrock and freshwater isotope values, suggesting trade and transhumance of livestock. Considering the uncertainty of livestock to establish the isotope baseline, not only freshwater and bedrock but also contemporaneous wildlife (red deer) was considered (grey area in Fig. 4). Thus, the local baseline, at two standard deviations, exhibited a range between 0.7075 and 0.07084. Hence, most individuals of Las Gobas site were of local origin and eight are non-local although two females plot close to the upper limit of the local range (Fig. 4).

Regarding the settlement phases, most individuals in the 7th-9th centuries were of local origin except two males (LG-28 and LG-33), whereas during the 10th-11th centuries, the number of non-local individuals increased and most were females. During the Early Middle Ages, few people regularly moved because it was simply too difficult and too dangerous. However, at the time of the formation of villages, the mobility of individuals increased probably from nearby areas. Las Gobas illustrates this restructuring of peasant society where males moved to achieve better economic opportunities and possibility to improve their status and females would move by patrilocal marriages (Bittel 2002).

Dietary patterns

For firm conclusions about human diet, the local baseline must be established. Since $\delta^{13}C$ and $\delta^{15}N$ values of Las Gobas archaeofauna plot in two compositional groups, it is difficult to set the local isotope baseline. The variation of $\delta^{13}C$ and $\delta^{15}N$ in the domestic animals might be caused by varying baseline isotopic signatures due to differences in herding or feeding practices or by browsing or grazing in different habitats with different isotopic baselines (Oelze et al. 2011). The different patterns observed among domestic animal species (sheep/goat vs. cows and horses) suggest dissimilar kinds of pasture between grazers and browsers. Additionally, the strontium isotope results of fauna reveal local and non-local livestock and therefore habitats with a different isotope baseline. Therefore the cluster formed by pig and sheep/goat with similar isotope composition has been used to establish the local baseline, according to the $^{87}Sr/^{86}Sr$ signature.

The analyzed fauna correspond to two different periods, like the human remains. Faunal $\delta^{13}C$ and $\delta^{15}N$ values do not display statistically significant differences between the two periods, so the farming structure was not modified despite the relocation of the settlement to the village. The $\delta^{13}C$ and $\delta^{15}N$ data from Las Gobas inhabitants indicate mainly the consumption of terrestrial plant and animal-derived food. Staple food was based on cereals, mainly C_3 plants like wheat, barley and legumes ($\delta^{13}C$ mean -19.0‰ ±0.58, 1σ); as the archaeobotanical evidence confirms. However, archaeobotanical evidence also shows the presence of millet (C_4 plants) (Azkarate and Solaun 2015). Consequently, in addition to consumption of C_3 cereals and legumes, C_4 cereals like millet were also consumed directly or through fauna intake. $\delta^{15}N$ values indicate that the diet was omnivorous and meat was also consumed. However, most samples fall below the human-fauna offset for nitrogen of 6‰ indicating a diet with a low animal protein intake (O'Connell et al. 2012). Between human and faunal remains, two different shifts can be related to different use of animals. In the Middle Ages, zooarchaeological studies show that some domestic animals (cows and horses) were used for farm work and animals were sacrificed in their old age and generally were excluded from the primary production of meat (Woolgar et al. 2006). Zooarchaeological studies at

Las Gobas show the predominance of ovicaprine livestock, slaughtered as both young and adult animals. They were complemented by adult cattle and young pigs, hence providing evidence of a mixed livestock strategy oriented towards meat consumption and the production of secondary products (milk and wool). Also worth mentioning is the important presence of wild animals, especially deer, while rabbit was also recorded and even bear (Castaños Ugarte and Castaños de la Fuente 2014). The comparison of human values with archaeological fauna at Las Gobas indicates that the dietary spacing is as expected for trophic level enrichment (Bocherens and Drucker 2003). This can be indicated that Las Gobas inhabitants consumed pork and sheep/goat as their main source of proteins. Whether taking the potential dietary spacing for δ^{15}N being 6‰ (O'Connell et al. 2012), the consumption of beef and horse meat cannot be ruled out as an additional dietary source.

When considering the isotopic composition by sex of Las Gobas individuals, no significant difference in δ^{13}C and δ^{15}N exist. Same cases of peasant settlement studies in Iberian Peninsula showed differences between males and females, whereas in other cases no differences were seen between sexes. This heterogeneous behavior can be related to local dynamics (Mundee 2010). Assuming a consumption of typical C$_3$ plants foods with similar values in the literature (δ^{13}C = -26‰, Schoeninger and DeNiro 1984) and the δ^{13}C value of consumer's collagen is approximately 5‰ higher than that of their diet (Ambrose and Norr 1993), the individuals consuming only C$_3$ plants have δ^{13}C values of about -20‰ (Chisholm et al. 1982; Schoeninger et al. 1983). In the absence of marine food, which can also cause an increase in δ^{13}C, stable carbon isotope analyses of bone collagen can be used to determine the contribution of C$_3$ vs C$_4$ plants to the diet. Most individuals at Las Gobas fall into the region expected for C$_3$ resource dependence, indicating that the main diet was based on such staples as wheat and barley. However six individuals, five males and one female (LG-3, LG-28, LG-36, LG-38, LG- 39, LG-41), shift slightly away from the mean composition with δ^{13}C values of ca -18.2‰, indicating a relatively major consumption of C$_4$ resources such as millet, which might have been consumed directly or indirectly through consumed fauna.

Statistical comparison by age revealed no significant difference among young adults (18–27 years), adults (27–35 years) and mature adult (35–50 years) when calculated for each sex separately and both sexes combined. The lack of significant variation in the carbon and nitrogen isotope composition indicates the absence of dietary changes among adults, even those who are elderly. Five infant individuals (younger than 3 years of age) have more positive mean values of δ^{15}N +10.9 ± 0.7‰ (1σ) compared to adults. The enrichment in nitrogen isotopic signal can be explained by breastfeeding (Schurr and Powell 2005). Breastfeeding results in higher nitrogen isotope values in the infant's tissue compared to mothers due to the trophic level effect (Fuller et al. 2005; Schwarcz and Schoeninger 2011). However two infants have the lowest δ^{15}N values (<8‰) as found in post-weaned infants that died aged between 3-6 years. The lower δ^{15}N values could be attributed to a major solid food ingest in the diet (Richards et al. 2002). Lower δ^{15}N values in immature individuals (<8‰) are also attributed to nitrogen imbalance during periods of intense growth (De Luca et al. 2012).

When addressing questions of temporal variations in diet, the isotope data of infants were excluded to avoid the nursing effect. Variations in δ^{15}N and ^{87}Sr/^{86}Sr between time periods are not significant. On the contrary, $\delta^{13}C$ mean values in the 7th-9th centuries are significantly enriched ($p=0.042$) compared with the 10th-11th century samples (Fig. 5). Besides, within the 7th-9th centuries, two sets of individuals were observed and one of them shift towards a slightly less negative mean value of $\delta^{13}C$ corresponding to millet consumers. Such variation does not reflect a large change of diet in the broad population but it can indicate two groups with different diets. The absence of precise dating of 7th-9th century individuals with apparently different diets does not allow us to establish whether these groups correspond to different times or if both groups coexisted throughout the whole time. The hypothesis of two populations from different times who change diet is more probable than two groups coexisting with a different diet.

The dissimilar distribution of sex by periods of time complicates population comparisons. During the 7th-9th centuries, most individuals were males and only three of the ten were females. In the 10th-11th centuries within a group of 26 individuals, infants (n=6) and females (n=9) were more numerous; and men were less abundant (n=8), excluding the three individuals of indeterminate sex. However, age and sex distribution provides details about differences in life expectancy between males and females. Only one female reached a mature age, corresponding to 7% of females, whereas nine men reached a mature age (43% of men). This difference in life expectancy is common in medieval ages (Acsádi and Nemeskéri 1970; Šlaus 2000; Šlaus et al. 2002). Higher female mortality was related to pregnancy and childbirth (Högberg et al. 1987; Šlaus 2000; Joyce 2001; Tocheri et al. 2005). It should be noted that most individuals were young adults, particularly females, so most females died before 30 year of age (4/5).

When comparing only the 10th-11th century young adults by sex, females have significantly lower mean values in $\delta^{13}C$ and $\delta^{15}N$ than males (Fig. 6). This difference can be attributed to differences in diet. Thus, lower isotope values in females indicate a more vegetarian diet and relatively less meat consumption than the average males. Different diets may result from sexual division of labor, characteristic of the medieval period. However, considering the number of females that died at fertile ages, the most likely hypothesis seems to be a physiological factor related to pregnancy rather than to different diet. This hypothesis is strongly supported by studies performed by Fuller et al. (2004) who found $\delta^{15}N$ depletion of 1‰ in hair of modern pregnant females. However, another option to describe the $\delta^{15}N$ depletion in females could be the different origins of the individuals of both sexes.

Diet compared with other settlements in Iberian Peninsula

The isotope data from Las Gobas were compared to other contemporaneous archaeological sites in order to better integrate the evidence of diet patterns with historical written sources or other archaeological proxies. Table 4 summarizes archaeological sites taken into consideration: San Martín de Dulantzi (6th-11th centuries), Zornoztegi (7th-14th centuries), Aistra (7th-9th centuries), Zaballa (10th-15th centuries), Treviño (12th-14th) and Tauste (8th-10th centuries) (Quirós Castillo 2013b, 2013a; Guede et al. 2017, Sirignano et al. 2014). Tauste is located around 160 km away (Aragon, NE Iberian Peninsula,) and represents a Muslim population while the other sites were Christian. Since Zaballa, Zornoztegi, Aistra and Treviño sites are geographically close to Las Gobas (between 10 km and 50 km away), they are considered regional sites. Since local isotope baseline varies according to climatic conditions, only the nearby sites with archaeofauna were included for comparison. All the Christian sites correspond to the same climate region with temperate oceanic climate (Cfb type) according to the Koeppen-Geiger classification system, while the Muslim site is located in a semi-arid climate (Bsk type) (Peel et al. 2007).

Muslim population at Tauste exhibits enrichment in $\delta^{15}N$ with respect to Christian populations, which at first sight seems to suggest dietary differences between both groups of population probably linked to the differing culture and faith. Guede et al. (2017) used modern fauna from Tauste to calculate the carbon and nitrogen offset in the mean $\delta^{13}C$ and $\delta^{15}N$ values. Muslim individuals have a human-fauna offset of c. 1‰ in $\delta^{13}C$ and 4.5‰ in $\delta^{15}N$, indicating slightly higher nitrogen offset value than one trophic level, suggesting also consumption of freshwater fish.

The nearby Christian communities have mean human-fauna offsets ranging between 0.1‰ and 2.7‰ for carbon and between 2.9‰ and 5.2‰ for nitrogen (Table 4). The human-fauna mean offset for carbon higher than 2‰ suggests consumption of some C_4 plants (millet) or low trophic level marine proteins. The lack of correlation between $\delta^{15}N$ and $\delta^{13}C$, the location of the sites far from the coastline and the archaeozoological data discard marine resources, whereas archaeobotanical data point to some millet consumption. Treviño and Las Gobas show the highest mean offset for nitrogen, suggesting higher animal protein intake. Treviño shows a mean offset of 5.2‰ for nitrogen, near to a trophic level increase, suggesting regular access to animal protein intake. In fact, archaeological data indicate that the Treviño population consisted of a social structure formed mainly by an elite that regularly consumed animal proteins (Quiros Castillo 2013a). On the contrary, Las Gobas was a peasant community and the proximity to a river could explain the mean offset for nitrogen, also near to one trophic level, by the consumption of some freshwater fish.

In summary, most of the medieval samples fall below a $\Delta\delta^{15}N$ of 6‰, indicating that the diet was based on low animal protein, except for the individuals at Treviño. It might be expected that Muslim and Christian individuals had dietary differences according to religious laws. Muslims were forbidden to consume pork and any meat not prepared in the halal way (Insoll 1999; Zaouali 2007). Christians were prohibited from consuming meat during fast days and Lent, which accounts for a total of 150 days per year (Tomas 2009), and in some religious orders, meat was entirely forbidden due to their own fasting practices (Sesma 1977; Grumett and Muers 2010). However, the isotopic evidence at the sites does not support dietary differences due to these religious requirements.

Conclusions

Archaeological data indicate two periods of occupation at Las Gobas in the course of five centuries from the territorial reorganization in the Early Middle Age until the formation of villages. Since the number of individuals at the site in these centuries was not large, the interpretations should be taken with caution. Isotope composition gives insight into different socio-economic aspects of the rural medieval population. In earlier times, small communities were established in the vicinity of some rock-hewn dwellings and later they moved to a new medieval village. Although the village had been founded, liturgical and graveyard functions of the artificial caves continued centuries after leaving the site. The formation of the village involved mobility of individuals and in Las Gobas they were mainly females who would move because of patrilocal marriages. Stable isotope data indicated a steady omnivore diet consisting mainly of C_3 plants, such as wheat and barley, and low animal protein intake from livestock, mainly pigs and sheep/goats. However, in the 7th-9th centuries a set of individuals differs, with $\delta^{13}C$ values ca -18.2‰, indicating a relatively major consumption of C_4 resources such as millet that could have been eaten directly, or indirectly through consumed fauna.

In general, no significant sex-based variation in diet existed, nor is there any evidence of age-based variation in diet among the adults. In contrast, isotopic data reflect dietary differences between adults and infants due to the nursing effect. Dietary differences only existed between the young adult individuals in the 10th-11th centuries because of sexual division of labor, characteristic of the medieval period. In a comparison of contemporaneous Medieval populations in the northern Iberian Peninsula, both $\delta^{13}C$ and $\delta^{15}N$ values do not suggest evident dietary differences between Muslim and Christian populations.

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Figure caption

Figure 1. Geographical location of Las Gobas archaeological site, illustrating the artificial cave complex in the gorge of Barrundia and Ayuda streams and the location of Laño village.

Figure 2. Aerial view of the site of Las Gobas with the location of the rock-hewn caves and a building, and the graveyard remains in the terraced hillside.

Figure 3. Strontium isotope ratios of human remains, archaeological fauna, freshwater and bedrock (Baceta et al. 2012) at Las Gobas.

Figure 4. Human bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values in comparison with the fauna isotope data from Las Gobas.

Figure 5. Boxplot of $\delta^{13}C$ values from Las Gobas individuals for different periods.

Figure 6. Boxplot of $\delta^{13}C$ and $\delta^{15}N$ values of 10th-11th century young adult individuals.

Table 1. List of the directly dated samples from Las Gobas (Laño, Burgos), with result of AMS dating and chronological range. The results were calibrated at 2 sigma based on the Intcal13 atmospheric data (Reimer et al., 2013) and calculated with the 'Calib Rev 7.0.4' software (Stuiver et al. 2017).

Table 2. Strontium, carbon and nitrogen isotope results for humans bone and tooth from Las Gobas (Burgos).

Table 3. Strontium, carbon and nitrogen isotope results for fauna and freshwater samples from Las Gobas (Burgos).

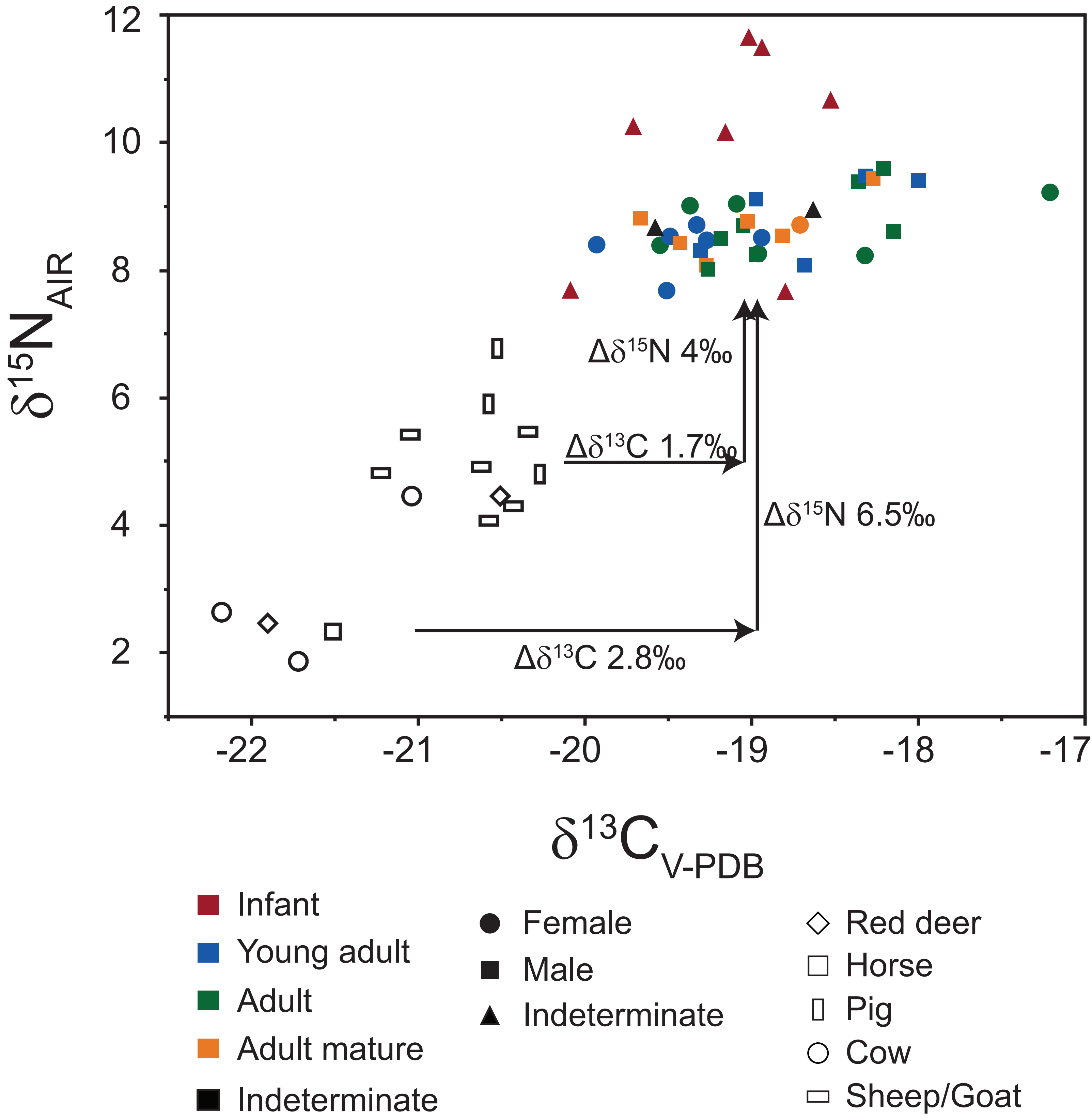
Table 4. $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) mean values of human and fauna from contemporaneous medieval Iberian archaeological sites and the offset ($\Delta\delta^{13}C$, $\Delta\delta^{15}N$) between human and fauna.


Las Gobas-6
Las Gobas-5
Las Gobas-4

Figure 1

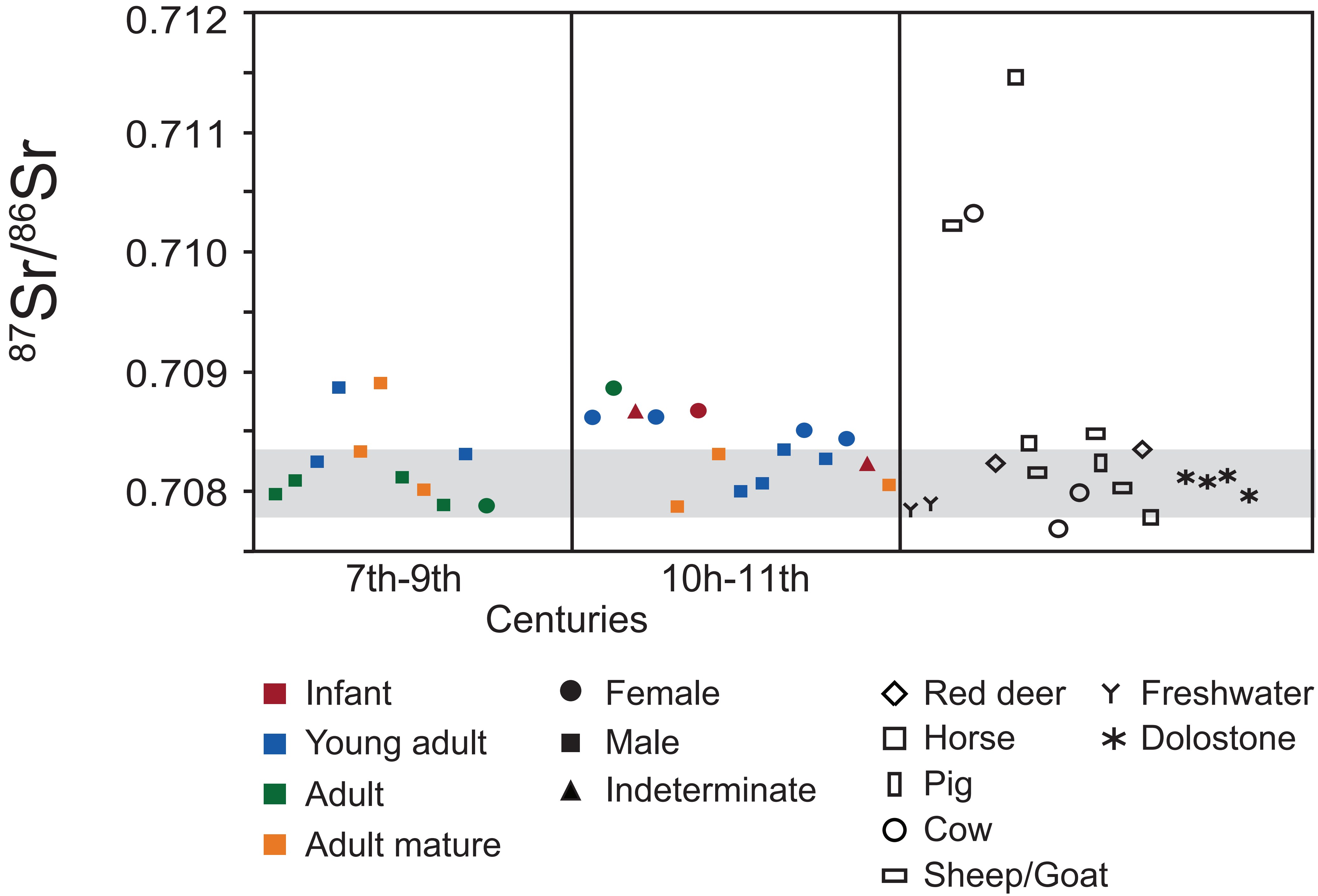

Álava
Las Gobas
Burgos
N
ARGOTE
URARTE
PARIZIA
FUIDIO
ALBAINA
Las Gobas
Santorcaria
FAIDO
Sarracho
S Julián
LAÑO
Nª Sra de la Peña
Rupestrian church
Dwelling cave
1000
0
1000 m

Figure 3



$\delta^{15}N_{AIR}$
12
10
8
6
4
2
-22
-21
-20
-19
-18
-17
$\delta^{13}C_{V-PDB}$
$\Delta\delta^{15}$N 4‰
$\Delta\delta^{13}$C 1.7‰
$\Delta\delta^{15}$N 6.5‰
$\Delta\delta^{13}$C 2.8‰
Infant
Young adult
Adult
Adult mature
Indeterminate
Female
Male
Indeterminate
Red deer
Horse
Pig
Cow
Sheep/Goat

Figure 4



$^{87}Sr/^{86}Sr$
0.712
0.711
0.710
0.709
0.708
7th-9th
10h-11th
Centuries
Infant
Young adult
Adult
Adult mature
Female
Male
Indeterminate
Red deer
Horse
Pig
Cow
Sheep/Goat
Freshwater
Dolostone

Figure 5

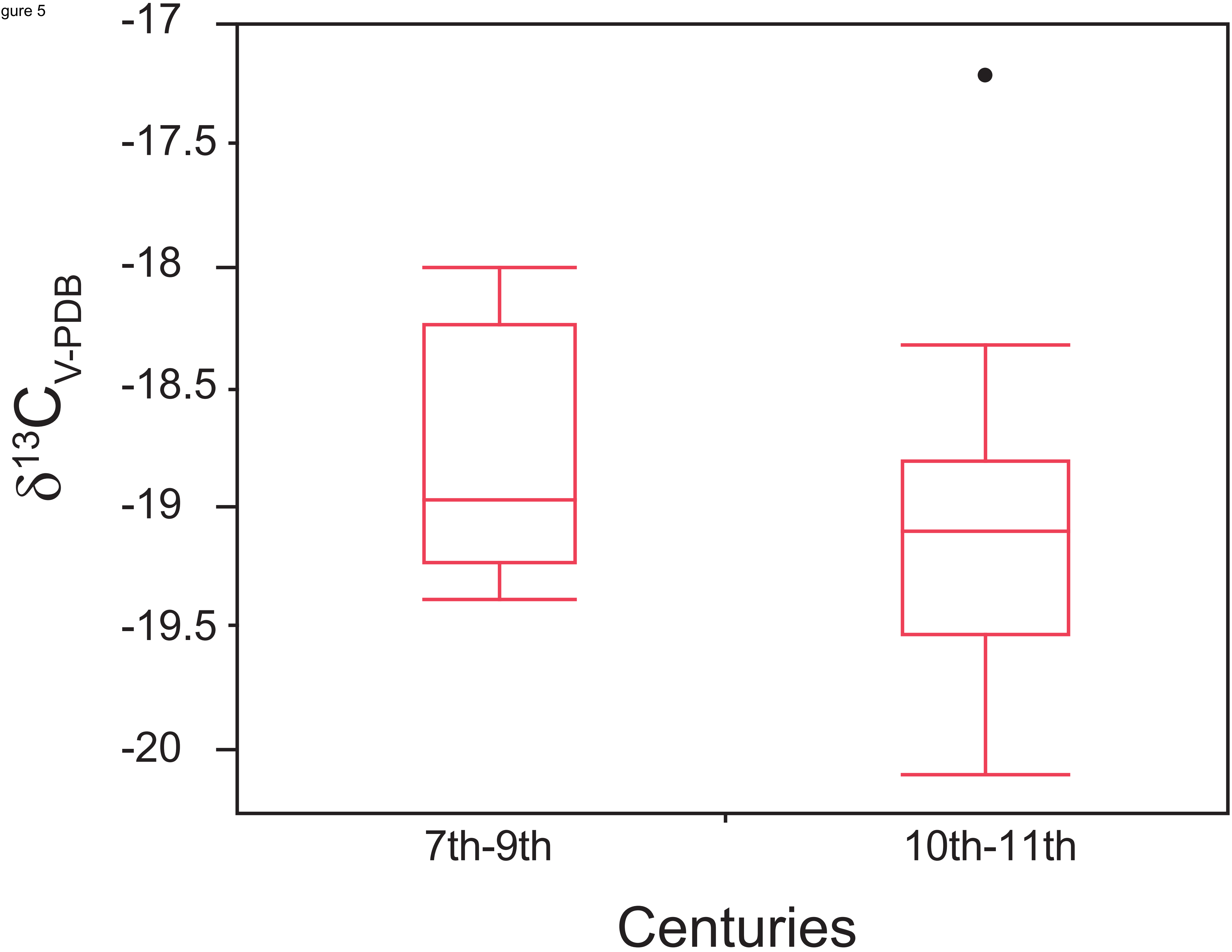
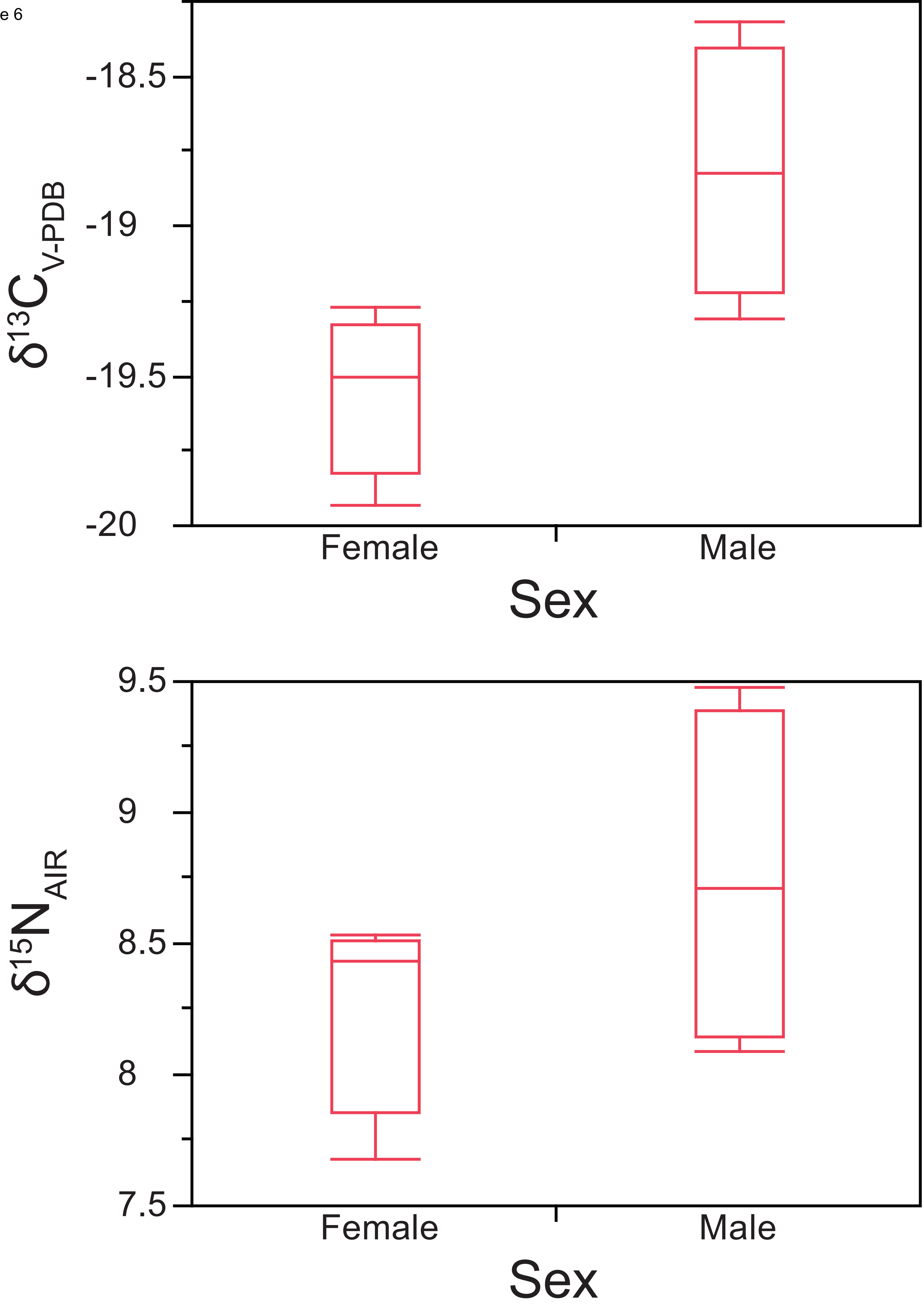

-17
-17.5
-18
-18.5
-19
-19.5
-20
$\delta^{13}C_{V\text{-}PDB}$
7th-9th
10th-11th
Centuries

Figure 6



-18.5
-19
-19.5
-20
$\delta^{13}C_{V\text{-}PDB}$
Female
Male
Sex
9.5
9
8.5
8
7.5
$\delta^{15}N_{AIR}$
Female
Male
Sex

Table 1. List of the directly dated samples from Las Gobas site (Laño, Burgos), with result of AMS dating and chronological range. The results were calibrated at 2 sigma based on the Intcal13 atmospheric data (Reimer et al., 2013) and calculated with the 'Calib Rev 7.1' software (Stuiver et al. 2017).

Lab Code	Sample	Material	C:N	BP ages	Calibrated date 2σ range (cal. a AD)	%	Calibrated date (cal. a AD) mean probability
Ua-47414	ENT 07	Bone	3.3	1002±31	981-1051	75	1025
Ua-43972	UE 231	Bonel		1134±30	857-986	88	920
Ua-47415	ENT 42	Bone	3.5	1149±31	799-972	91	892
Ua-43969	ENT 37	Bone	3.4	1204±30	764-894	91	822
Ua-43975	UE 328	Bone		1348±30	640-712	92	667
Ua-43971	UE 227	Bone		1356±30	622-695	94	663
Ua-43974	UE 305	Bone		1370±30	610-687	100	656
Ua-43970	UE 102	Bone		1393±33	597-675	100	644
Ua-46155	ENT 26	Bone		1400±30	599-668	100	641
Ua-43973	UE 245	Bone		1467±30	549-645	100	598
Ua-43976	UE 357	Bone		1525±31	505-603	63	540

Table 2

Table 2. Strontium, carbon and nitrogen isotope results for humans bone and tooth from Las Gobas (Burgos).

Sample	Tooth	Bones	Centuries	Sex	Age group	^{87}Sr/^{86}Sr ± 1s(last digit)	δ^{15}N‰	δ^{13}C‰	C/N	%C	%N
LG-1	Max M3 Rigth	costal fragment	7th-9th	Male	Adult	0.707976 ± 6	8.6	-18.15	3.3	43.4	15.6
LG-28	Max I2 Left	costal fragment	7th-9th	Male	Adult	0.708090 ± 5	8.71	-19.05	3.3	42.8	15.1
LG-4		rib	7th-9th	Indet	Infant I		7.68	-18.8	3.3	39.6	13.7
LG-8		costal fragment	7th-9th	Female	Adult		8.26	-18.96	3.3	41.9	14.9
LG-22		costal fragment	7th-9th	Male	Adult		8.5	-19.18	3.4	40.4	13.9
LG-26	Max M2Right	metatarsal	7th-9th	Male	Young adult	0.708248 ± 6					
LG-28		metatarsal	7th-9th	Male	Young adult	0.708863 ± 4	9.59	-18.21	3.4	43.2	15.1
LG-31		costal fragment	7th-9th	Female	Adult		8.23	-18.32	3.4	39.7	13.7
LG-32	Max PM2 Right	costal fragment	7th-9th	Male	Adult mature	0.708368 ± 5	8.78	-19.03	3.4	43.1	14.9
LG-33	Max M2 Left	costal fragment	7th-9th	Male	Adult mature	0.708901 ± 6	8.08	-19.27	3.4	42.4	14.7
LG-34	Max	rib	7th-9th	Male	Adult	0.708113 ± 5	8.02	-19.26	3.3	43.1	15.1
LG-36	PM1	costal fragment	7th-9th	Male	Adult mature	0.708012 ± 4	9.43	-18.27	3.3	44.1	15.4
LG-37	Max M2 Left	phalanx	7th-9th	Male	Adult	0.707889 ± 4	9.38	-18.36	3.4	42.9	14.7
LG-38	Max PM2 Left	costal fragment	7th-9th	Male	Young adult	0.708312 ± 5	9.41	-18	3.3	41.3	14.7
LG-47	Max PM1 Right	phalanx	7th-9th	Female	Adult	0.707881 ± 4	9.01	-19.37	3.4	43.4	15.1
LG-2	Max M2 Left	costal fragment	10th-11th	Female	Young adult	0.708619 ± 5	8.4	-19.93	3.3	41.7	14.7
LG-103	Max PM Left	3 metatarsal	10th-11th	Female	Adult	0.708863 ± 5	9.22	-17.21	3.3	42.3	14.9
LG-7		vertebra	10th-11th	Female	Adult mature		8.71	-18.71	3.3	41.6	15.2
LG-7 ENT		costal fragment	10th-11th	Indet	Indet		8.95	-18.63	3.3	43.4	15.4
LG-9	Mand M1 Right	costal fragment	10th-11th	Indet	Infant I	0.708667 ± 4	7.7	-20.09	3.3	42.1	14.8
LG-10		costal fragment	10th-11th	Female	Adult		9.04	-19.09	3.3	41.9	14.8
LG-11		costal fragment	10th-11th	Male	Adult		8.24	-18.97	3.3	41.8	14.7
LG-13		diaphyseal radius	10th-11th	Indet	Infant I		10.66	-18.53	3.3	42.5	14.5
LG-14		costal fragment	10th-11th	Indet	Infant I		10.16	-19.16	3.3	41.6	14.7
LG-12		costal fragment	10th-11th	Indet	Infant I		11.5	-18.94	3.3	43.3	15.4
LG-17	Mand M2 Right	rib	10th-11th	Female	Young adult	0.708622 ± 5	8.51	-18.94	3.3	43.4	15.5
LG-23		costal fragment	10th-11th	Female	Adult		8.39	-19.55	3.3	41.2	14.6
LG-24		diaphyseal ulna	10th-11th	Indet	Infant I		11.66	-19.02	3.3	44.0	15.6
LG-27		costal fragment	10th-11th	Indet	Indet		8.68	-19.58	3.4	43.1	15.0
LG-29	Mand PM1 Right	costal fragment	10th-11th	Male	Adult mature	0.707871 ± 5	8.55	-18.82	3.3	43.3	15.4
LG-30	Max M3 Left	rib	10th-11th	Female	young adult	0.708675 ± 5	8.53	-19.49	3.4	40.9	14.2
LG-35	Max M2 Left	ulna	10th-11th	Male	Adult mature	0.708317 ± 5	8.43	-19.43	3.6	37.5	11.9
LG-39	Max M2 Left	sacrum	10th-11th	Male	Young adult	0.708009 ± 5	9.12	-18.97	3.5	38.0	12.7
LG-40	MaxPM2 Right	costal fragment	10th-11th	Male	Young adult	0.708063 ± 5	8.09	-18.68	3.3	41.3	14.7
LG-41	Mand PM2 Right	costal fragment	10th-11th	Male	Young adult	0.708349± 6	9.48	-18.32	3.2	43.5	15.7
LG-42	Max M2 Right	costal fragment	10th-11th	Female	Young adult	0.708482 ± 5	8.47	-19.27	3.4	41.4	14.4

LG-43	Max M2 Right	calcaneus	10th-11th	Male	Young adult	0.708274 ± 4	8.31	-19.31	3.3	43.3	15.3
LG-44	Max M2 Right	rib	10th-11th	Female	Young adult	0.708412 ± 6	7.68	-19.51	3.2	42.3	15.3
LG-45	Mand M2 Left	costal fragment	10th-11th	Indet	Infant I	0.708234 ± 6	10.26	-19.71	3.5	41.6	14.4
LG-46	Max M2 Left	rib	10th-11th	Male	Adult mature	0.708056 ± 5	8.81	-19.67	3.5	36.7	12.2
LG-3		femoral shaft	10th-11th	Indet	Indet		8.71	-19.33	3.4	40,1	15.2

Tooth column (location and type) abbreviations: Max., maxillary; Mand., mandibular; M1., molar 1; M2., molar 2; M3., molar 3; PM1., premolar 1; PM2., premolar 2; I2., incisor 2. Sex column abbreviation: Indet., indeterminate.

Table 3

Table 3. Strontium, carbon and nitrogen isotope results for fauna and freshwater samples from as Gobas (Burgos).

Sample	Species	Period	Centuries	Material	Tooth type	^{87}Sr/^{86}Sr ± 1□ (last digit)	δ^{15}N‰	δ^{13}C‰	C/N	%C	%N
LG-163.12	sheep/goat	1	7th	Tooth	Mand M1-2	0.710219 ± 7					
LG-198.12	cow	2	10th	Tooth	Max M1-2	0.710323 ± 6					
LG-198.38	red deer	2	10th	Tooth	Max M1-2	0.708229 ± 7					
LG-199.92	horse	1	9th-10th	Tooth	Mand P2	0.711527 ± 12					
LG-249.1	sheep/goat	2	10th-11th	Tooth	Max M1-2	0.708163 ± 7					
LG-265.1	cow	1	8th	Tooth	Mand M3	0.707689 ± 6					
LG-301.1	cow	1	7th	Tooth	Mand M?	0.707990 ± 8					
LG-301.4	pig	1	7th	Tooth	Mand M?	0.708183 ± 7					
LG-340.1	sheep/goat	1	8th-9th	Tooth		0.708035± 8					
LG-199.92	horse	1	9th-10th	Tooth		0.708585 ± 6					
LG-163.12	sheep/goat	1	7th	Tooth	Mand M1-2	0.708600 ± 5					
LG-328.6	red deer	1	7th	Tooth	Max M1-2	0.708347 ± 8					
LG-102.9	horse	2	10th-11th	Tooth	Mand M3	0.707984 ± 6					
LG-Agua	water					0.707842 ± 8					
Rio Ayuda	water					0.707894 ± 8					
LG-160.228	sheep/goat	1	9th-10th	Bone	Vertebra		4.11	-20.57	3.3	41.5	13.2
LG-160.281	horse	1	9th-10th	Bone	Metacarpal		2.36	-21.5	3.3	41.8	13.8
LG-198.18	Cow	2	10th	Bone	Humerus		1.87	-21.72	3.3	40.8	15.2
LG-198.27	sheep/goat	2	10th	Bone	Axis		4.31	-20.43	3.3	39.9	14.6
LG-198.35	pig	2	10th	Bone	Calcaneus		4.8	-20.27	3.3	37.9	14.2
LG-198.40	red deer	2	10th	Bone	Scapula		4.45	-20.51	3.2	42.9	14.7
LG-227.17	red deer	1	7th	Bone	Vertebra		2.46	-21.9	3.3	41.3	13.9
LG-227.79	pig	1	7th	Bone	Scapula		6.78	-20.53	3.3	41.3	15.2
LG-227.188	sheep/goat	1	7th	Bone	Scapula		4.91	-20.62	3.3	41.5	15.8
LG-245.84	sheep/goat	1	6th-7th	Bone	Pelvis		4.8	-21.27	3.3	40.7	15.3
LG-265.3	cow	1	8th	Bone	Rib		4.46	-21.04	3.3	39.7	15.3
LG-265.16	sheep/goat	1	8th	Bone	Humerus		5.41	-21.06	3.3	41.5	13.2
LG-312.2	cow	1	8th	Bone	Vertebra		2.64	-22.18	3.2	42.5	14.5
LG-312.7	sheep/goat	1	8th	Bone	Mandibular		5.47	-20.34	3.3	39.8	14.7
LG-312.15	pig	1	8th	Bone	Vertebra		5.9	-20.58	3.3	41.2	15.3

Max., maxillary; Mand., mandibular; M1-2., molar 1-2; M3., molar 3; P2., premolar 2

Table 4

Table 4. δ^{13}C (‰) and δ^{15}N (‰) mean values of human and fauna from contemporaneous medieval Iberian archaeological sites and the offset ($\Delta\delta^{13}$C, $\Delta\delta^{15}$N) between human and fauna.

Site	**δ^{13}C (‰)**				**δ^{15}N (‰)**				**Reference**
Human	**Mean**	**Std Dev**	**Max**	**Min**	**Mean**	**Std Dev**	**Max**	**Min**	
Las Gobas (7th-11th)	-18.9	0.6	-17.2	-19.9	8.7	0.5	9.6	7.7	This work
Las Gobas (7th-9th)	-18.7	0.5	-18.0	-19.4	8.8	0.6	9.6	8.0	This work
Las Gobas (10th-11th)	-19.1	0.6	-17.2	-19.9	8.6	0.4	9.5	7.7	This work
Aistra (8th-9th)	-19.0	1.0	-16.7	-22	7.9	1.0	12.1	6.8	Quiros. 2013a
Treviño (12th-14th)	-19.6	0.7	-18.7	-22	9.6	1.2	12.0	7.5	Quiros. 2013a
Dulantzi (6th-11th)	-19.8	1.4			9.2	1.2			Quiros. 2013b
Zaballa (10th-15th)	-19.8	0.7	-18.8	-21.3	9.0	0.8	10.4	7.6	Quiros. 2013a
Zornoztegi (12th-14th)	-18.1	1.1	-16.7	-9.91	8.3	0.6	9.2	7.5	Quiros. 2013a
Tauste (8th-10th)	-17.7	1.3	-14.2	-18.9	15	1.4	16.6	9.3	Guede et al 2017
Fauna									
Aistra (8th-9th)	-21.7	0.3	-21.8	4.0	4.0	1.0	4.7	2.3	Quiros. 2013a
Treviño (12th-14th)	-20.6	1.1	-21.3	4.5	4.5	2.1	5.9	5.9	Quiros. 2013a
Dulantzi (6th-11th)	-20.8	0.7	-21.7	6.1	6.1	1.5	9.8	9.8	Quiros. 2013b
Zaballa (10th-15th)	-19.9	1.0	-20.6	6.1	6.1	1.8	7.5	7.5	Quiros. 2013a
Zornoztegi (12th-14th)	-20.2	2.2	-22.8	5.3	5.3	1.6	7.4	7.4	Quiros. 2013a
Tauste (8th-10th)	-20.6		-23.0	10.7	10.7		14.5	14.5	Guede et al 2017
Fauna-human	**$\Delta\delta^{13}$C**				**$\Delta\delta^{15}$N**				
Aistra (8th-9th)	2.7				3.9				
Treviño (12th-14th)	1.0				5.2				
Dulantzi (6th-11th)	1.0				3.1				
Zaballa (10th-15th)	0.1				2.9				
Zornoztegi (12th-14th)	2.1				3.0				
Tauste (8th-10th)	2.9				4.3				