FERNANDO MOLINA-GONZÁLEZ, FRANCISCO NOCETE-CALVO,
ANTONIO DELGADO-HUERTAS, JUAN ANTONIO CÁMARA-SERRANO,
RAFAEL M. MARTÍNEZ-SÁNCHEZ, SYLVIA JIMÉNEZ-BROBÉIL,
Mª. TERESA MIRANDA-LEÓN, JOSÉ ANTONIO RIQUELME-CANTAL,
LILIANA SPANEDDA, CRISTÓBAL PÉREZ-BAREAS, RAFAEL LIZCANO-PRESTEL,
JOSÉ MIGUEL NIETO-LIÑÁN, TRINIDAD NÁJERA-COLINO,
ARSENIO GRANADOS-TORRES AND FRANCISCO CARRIÓN-MÉNDEZ

DIET AND ENVIRONMENT IN SOUTH-EASTERN IBERIA DURING THE BRONZE AGE, BASED ON ISOTOPE ANALYSIS OF HUMAN REMAINS

Summary. *A large sample of human bones from a series of archaeological sites in the south-eastern Iberian Peninsula was selected for* $\delta^{13}C$ *and* $\delta^{15}N$ *stable isotope analysis. Except for some contrast samples, the remains date from the first half of the second millennium cal BC and are ascribed to the Argar Culture, which developed during the Bronze Age in south-eastern Iberia. Most authors have considered that this region reached a high degree of social hierarchical organization at this time, as demonstrated by the funerary record, both with regard to the grave goods and to the evidence of physical effort and diseases on the human remains. Results of the isotope analysis revealed the existence of differences among the settlements studied, as well as differences over time within every settlement and among the various individuals tested. Some variances can be assigned to social classes/status and others are linked to chronological factors. In particular, changes in* $\delta^{13}C$ *can be explained by the increasing aridity of the first half of the second millennium cal BC, although other causes can be put forward too.*

INTRODUCTION

Within European prehistory, one of the areas offering the strongest evidence of social asymmetries is south-eastern Iberia, especially in the second millennium, when the Argar culture developed (Chapman 2008; Lull *et al*. 2011, 2015; Cámara and Molina 2011; Risch and Meller

[Correction added on 22 March 2019, after first online publication: The surname for Sylvia Jiménnez Brobéil was incorrect previously and has been corrected in the current version.]

2015). Marked differences have been confirmed: based on settlement patterns, dimensions and contents of dwellings, unequal resource consumption in life and death (based on the analysis of containers, grave goods, or paleoanthropological indicators), the control of storage facilities or certain productive activities, such as the metallurgical and ceramic crafts. The El Argar Culture has been considered the first society in the Western Mediterranean to demonstrate the existence of classes: a state organization has been suggested (Lull *et al.* 2011). Family groups compete to maintain their social position in a context marked by emulation and warrior ideology (Cámara and Molina 2011). In this context, new indicators may better define social differences.

Several proposals for an internal division into periods have been advanced (Castro *et al.* 1996; Molina and Cámara 2004), based on the typology of materials, C-14 dating, and settlement restructuration: Early Bronze Age (2200–1900 cal BC), coming into being between the area of Lorca and the Vera Depression; Middle Bronze Age (1900–1600 cal BC), with an expansion of the Argar Culture towards the Granada High Plains and Upper Guadalquivir Valley; and Late Bronze Age (1600–1350 cal BC), characterized by a major crisis that transformed Argar society, while this was still expanding towards the area of Upper Vinalopó Valley in Alicante (Jover *et al.* 2014).

Most Argar settlements are located on steep hills, with the dwellings (generally with several rooms) and communicating streets arranged along artificial terracing of the hillsides. Some settlements were surrounded by a wall and some had a fortified 'acropolis' at their highest point (Molina and Cámara 2004; Lull *et al.* 2014, 2015). The nuclear area of Almeria-Murcia also contained small settlements on the plains, considered to be agricultural; dependent and specialized economic and political centers have been defined (Delgado-Raack *et al.* 2016).

The pottery shows a predominance of closed-containers, including pots and jars, but also more characteristic shapes, including calyxes and lenticular bowls, as well as carinated forms, with no decoration but often polished to a metallic shine. Metallurgy plays an outstanding role in social characterization, with weapons and abundant ornaments in copper, silver and gold, and with most of the tools made of arsenic copper and only rarely a true bronze (Lull *et al.* 2011).

The sites studied in this paper are in the current provinces of Granada and Jaén (Fig. 1). The first archaeological campaigns investigating Bronze Age sites of this area were sporadic and of little importance, made during the first half of the twentieth century. Campaigns of field research became more numerous from the 1960s onward, notably those performed by W. Schüle in the Cerro de la Virgen (Orce, Granada) (Schüle 1980) and by A. Arribas and F. Molina in the Cerro de la Encina, which continued in the subsequent decades (Arribas *et al.* 1974; Molina 1983).

In the 1970s, the study of Argar sites in Granada intensified, thanks to a research program of the Department of Prehistory and Archaeology of the University of Granada, notably with excavations at Cuesta del Negro (Purullena, Granada) in 1971 and 1972 (Molina and Pareja 1975; Molina 1983) and at Castellon Alto (Galera, Granada), between 1983 and 2002 (Molina *et al.* 1986; Cámara and Molina 2011). In Jaén province, the first systematic investigations took place at the end of the 1970s (Molina *et al.* 1978), including the Peñalosa Project (from 1985) (Contreras and Cámara 2002) and research in the La Loma region (Nocete *et al.* 2010).

This culture developed in a context of strong environmental stress, in which the impact of climatic change was enhanced by an intensification of human activity in especially sensitive areas, including farming, stock-breeding, and mining-metallurgy (Rodríguez *et al.* 1996; Fuentes *et al.* 2007).

The increase in aridity from 4000 cal BC has been verified in the south of the Iberian Peninsula (Carrión *et al.* 2007; Nachasova *et al.* 2007; Yanes *et al.* 2011), as in other areas of the Mediterranean (Cheddadi *et al.* 1997) and beyond (Wanner *et al.* 2015), although these conditions seem to have become more pronounced from 3100 cal BC (Magny and Hass 2004) and mainly from

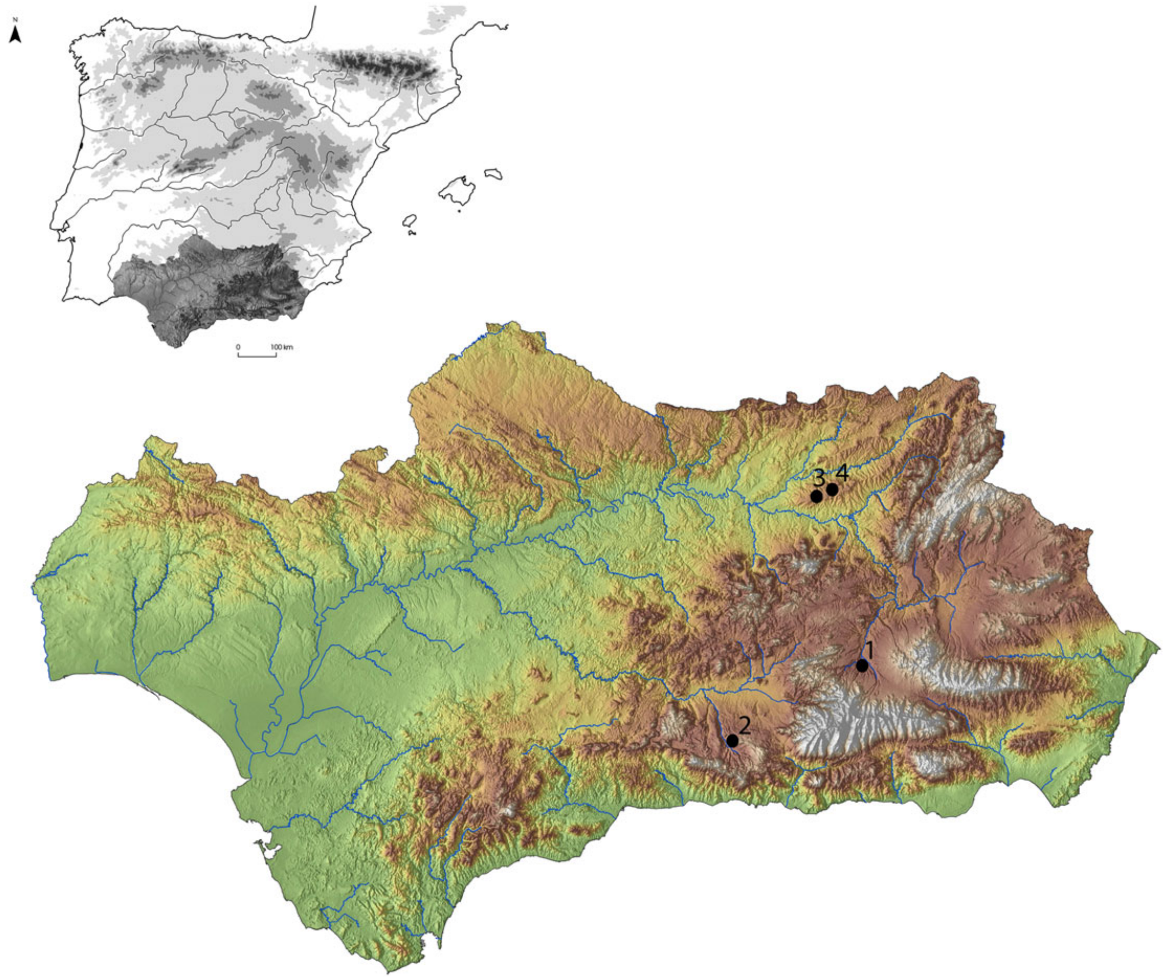

Figure 1
Localization of sites in the south of the Iberian Peninsula; 1, Navilla 1 dolmen; 2, Cuesta del Negro; 3, Baeza; 4, Úbeda.
[Colour figure can be viewed online at wileyonlinelibrary.com]

2000 cal BC, although with oscillations throughout the third millennium cal BC (Magny *et al*. 2009; López *et al*. 2014). Human activities could also have played an important role, especially in forest decline (affecting *Quercus* and *Olea*) (Rodríguez 2018), which in turn can be also related to husbandry changes, for example with the lesser importance of swine as livestock in the second millennium cal BC (Cámara and Riquelme 2015).

BACKGROUND AND OBJECTIVES

The objective of this study was to appraise whether stable isotope analysis data let us test previous hypotheses on social hierarchical organization and environmental change in Bronze Age south-eastern Iberia. Given the extensive territory and timespan covered by the Argar Culture, it was necessary to study a large sample, representing different areas and chronological periods, as discussed in the next section.

The characterization of isotope signature ($\delta^{18}O$, $\delta^{13}C$) in mammal bones and teeth help to define climatic changes (Longinelli 1984; Delgado *et al.* 1997). The diet of animals and humans can be also determined from the isotope signature ($\delta^{15}N$, $\delta^{13}C$) of organic tissue remains or of collagen extracted from bones (De Niro and Esptein 1978; Ambrose and Noor 1993; Dorado *et al.* 2012). In humans, these values allow the calculation of the percentage of animal protein in their general diet (De Niro 1985), with the caveat that the consumption studied may or may not be representative of the typical intake during the whole of their lives.

Since the end of the 1970s, there has been a steady growth in the number of studies using stable isotopes to investigate human dietary patterns in the past (Katzenberg 2007; Herrscher and Le Bras-Goude 2010; Pearson *et al.* 2010; Lightfoot *et al.* 2011; Naumann *et al.* 2014; Schoeninger 2014; Makarewicz and Sealy 2015; Tsutaya and Yoneda 2015). In relation to archaeological remains, collagen isotope analysis from human bones has been widely used to identify consumption habits, because the isotopic signature of bone collagen reflects the source of proteins consumed throughout life. The carbon isotopic signature provides information on the type of primary production at the base of the food chain (e.g. C3 or C4 plants, seaweed, etc.), whereas the nitrogen isotopic signature yields data on the position of the consumed substance within the food chain and/or on the proportions deriving from vegetables and animals.

Most of isotope studies in Iberian Peninsula have been related to the Mesolithic-Neolithic transition (Lubell *et al.* 1994; García-Guixé *et al.* 2006; Hillier *et al.* 2008; Arias and Schulting 2010; McClure *et al.* 2011; Fernández-López *et al.* 2013; Salazar-García *et al.* 2014), although research has recently been extended to more recent chronological stages (Salazar-García 2009, 2011; Nájera *et al.* 2010; Díaz-Zorita *et al.* 2011; Molina *et al.* 2016; Esparza *et al.* 2017; Fontanals-Coll *et al.* 2015, 2016, 2017a; Salazar-García *et al.* 2016, 2017; Waterman *et al.* 2016; Díaz-Zorita 2017; Villalba-Mouco *et al.* 2017), searching for long term changes or differences in a paricular period, with some examples of intra-site analysis or the combination of methods.

Against this background, the objectives of the present study are to contribute data on the food consumption habits in different settlements of High Andalusia, and to evaluate possible temporal and spatial variations in diet and environment. A further objective is to investigate the relationship between diet and social status, an infrequently attempted approach in the archaeological application of isotope studies in prehistoric Europe (Le Bras-Goude *et al.* 2013; Pearson *et al.* 2013; Zvelebil and Pettitt 2013; Waterman *et al.* 2016), especially at such early dates as those visited in the present study. We also focus on regional and temporal changes in food consumption and differences by sex and age.

MATERIAL AND METHODS

Archaeological sites

This study is centered on the north-west of the Argar territory. The selection of sites for the study was based on two criteria: the availability of systematic records from extensive excavations and of funerary records with precise chronology; and the representation of a large and diverse territory inside the Argar Culture, from the Intrabetic Highlands (Granada) to the valley of Guadalquivir (Jaén). This process resulted in the selection of two sites in the Granada province and two in that of Jaén: Cuesta del Negro in the Guadix Highland (Granada), in an environment more favorable to stockbreeding; Navilla 1, a grave in the megalithic necropolis of Pantano de los Bermejales in south-western Granada Vega (Meadowlands), in an area with greater farming potential; and two large Argar settlements in the Upper Guadalquivir valley and beneath the cities of Baeza and Úbeda in Loma de Úbeda region (Jaén), a traditionally cereal-producing area (see supplementary materials).

Analytic methodology

The isotope analyses ($\delta^{15}N/\delta^{14}N$ and $\delta^{13}C/\delta^{12}C$) were conducted following the routine procedures of the Stable Isotope Biogeochemistry Laboratory of the *Instituto Andaluz de Ciencias de la Tierra*. In the first stage, collagen is extracted from the bone by a chemical procedure that ensures the removal of other organic compounds that might contaminate the sample. The baseline bone sample weighed between 20 and 300 mg (depending on its richness in collagen) and was ground to a size < 0.7 mm. The sample was decalcified by treatment with 0.5 M HCl at room temperature for 2-5 days, eliminating phosphates, fulvic acids, and other soluble acids. The sample was then filtered (5 μm) and the content of the filter was treated with 0.125 M NaOH for 20 hours. Next, the sample was neutralized by the addition of distilled water and was again filtered (5 μm) to remove humic acids and most lipids. The filter content was then treated with 0.001 M HCl for 17 hours at 100°C (in closed pyrex tubes), leaving the collagen in solution. Finally, the solution was centrifuged at 6300 rpm for 10 minutes, and the liquid containing the collagen in solution was lyophilized (Bocherens *et al.* 1997).

The collagen samples obtained were treated by a continuous flow system, using an elemental analyzer connected to the mass spectrometer. Sample combustion was obtained at 1020°C (with external oxygen supply), obtaining a mixture of carbon and nitrogen oxides that were then reduced at 650°C, obtaining a mixture of CO_2, N_2, and H_2O. The water was chemically removed (Chromosorb trap), and the CO_2 and N_2 were separated by a chromatographic column before their analysis by mass spectrometry. An Elemental Analyzer (Carlo Erba Modelo NA1500 NC series 2) was used for the combustion, reduction, water removal, and chromatographic separation processes. The N_2 and CO_2 obtained by the different procedures were introduced into a mass spectrometer (Delta Plus XL) for isotope analysis. The analytical error for the $\delta^{15}N$ and $\delta^{13}C$ determinations was < 0.1 ‰.

Because the abundance and absolute value of the isotopes of an element cannot be determined with sufficient accuracy for biogeochemical purposes, we used the relative differences in isotope ratios rather than absolute values, referencing the measurements to a sample of known composition. The measurement unit was 'δ', expressed as:

$$\delta = \left(R_m - R_p/R_p\right)*1000$$

where R_m and R_p are the isotope ratios for the sample and the reference pattern, respectively. Therefore, the isotope results are always expressed in relation to a universally accepted international reference pattern. Thus, the samples including carbon are referred to V-PDB (originally PDB, Pee Dee Belemnites), whereas the samples containing nitrogen are referred to the ratio in air (AIR). In the case of carbon, prefix V comes from 'Vienna', because after exhausting the reference standard PDB, we used international patterns prepared in the same city by the IAEA (International Atomic Energy Agency) and referred to this standard.

Statistical analyses

Means and standard deviations for every set of samples have been performed (see supplementary material) and different methods have been used to test the significance of the differences (ANOVA Test, Bonferroni Test, and Student T-Test).

RESULTS AND DISCUSSION

Introduction

Samples from 99 individuals were analyzed (see supplementary material): 36 from the Cuesta del Negro, 37 from the Cerro del Alcázar site, in the city of Baeza (henceforth named as Baeza) (five of them belonging to the Modern Age), 16 from the Eras del Alcázar site, in the city of Úbeda (henceforth named simply as Úbeda), and 10 from the tomb of Navilla 1.

According to the T-test, differences between the Granada and Jaén sites are statistically significant in $\delta^{15}N$ (0,007) and $\delta^{13}C$ (0,095). Differences among the four sites can also seen according to the Anova Test (0,000 in $\delta^{15}N$ and 0,001 in $\delta^{13}C$), although the Bonferroni Test shows lesser differences between the two nearest sites (Baeza and Úbeda) and significant differences in $\delta^{13}C$ only can be found between Cuesta del Negro and Úbeda and between Úbeda and Baeza.

The mean $\delta^{13}C$ is -19.19‰, with a standard deviation (SD) of 0.50, whereas the mean $\delta^{15}N$ is ±9.12‰, with a higher SD of 1.33, reflecting a greater difference in nitrogen isotope values among the sites.

The mean $\delta^{13}C$ for Cuesta del Negro is -19.34‰ (SD of 0.26), i.e. at values very close to the mean for the whole sample. The mean $\delta^{15}N$ for Cuesta del Negro is ±10.00‰ (SD, 0.90), the highest value recorded among the studied sites; the samples for this site are closely grouped on the right side of the general graph (Fig. 2).

The samples from Úbeda show a substantially lower mean $\delta^{15}N$ value of ±9.18‰ (SD of 1.76). Differences have been also observed in the $\delta^{13}C$ values, which show a mean of -18.78‰ and SD of 0.53. In both cases, major differences in mean values have been observed between the samples from the second and third millennia cal BC, with mean $\delta^{15}N$ values of ±8.57‰ and ±10.54‰, respectively, and mean $\delta^{13}C$ values of -18.93‰ and -18.46‰, respectively. These results indicate a higher animal protein intake in the third as opposed to the second millennium cal BC. It is a tendency we cannot find in the other sites and difficult to explain, especially if we take into account the importance of pigs during the Copper Age in the Upper Guadalquivir valley (Cámara and Riquelme 2015). $\delta^{13}C$ values seem to indicate conditions of greater aridity, in contrast to the suggestions of other environmental studies (Rodríguez *et al.* 1996; Carrión *et al.* 2007; Rodríguez 2018). It is also possible that the $\delta^{13}C$ values could indicate fish or C4 plant consumption. However Stable Isotope results from different Mediterranean areas have shown a low-level of fish consumption, even in coastlands (Lightfoot *et al.* 2011; Waterman *et al.* 2017). Cultivated C4 plants are only attested in later periods (Laffranchi *et al.* 2016), although the consumption of native wild C4 plants in Iberia (Santana *et al.* 2010) cannot be excluded.

The samples from tombs of the second millennium cal BC at Baeza show a mean $\delta^{15}N$ of ±8.47‰, slightly lower than the value in Úbeda, but with a SD of 1.01, which can be due to a wider general heterogeneity rather than a markedly different result for a single sample. The mean $\delta^{13}C$ was

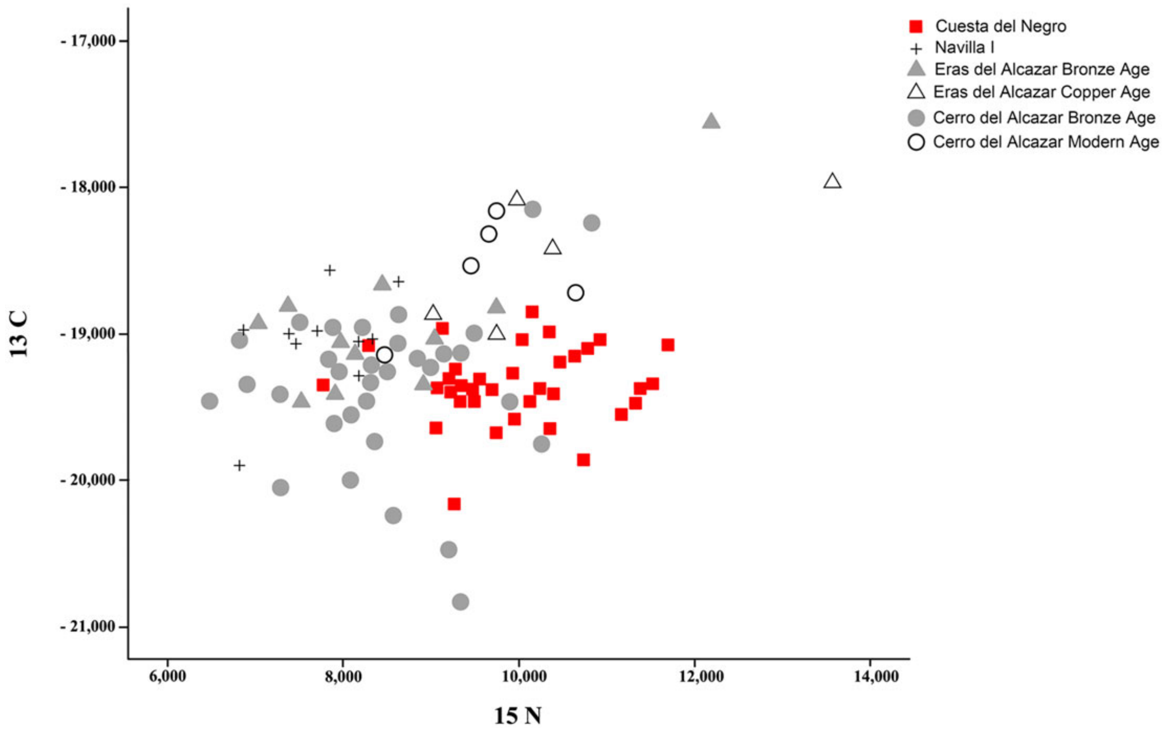

Figure 2
δ15N v. δ13C graph with all samples analyzed in this study. [Colour figure can be viewed online at wileyonlinelibrary.com]

-19.36‰ (SD 0.55), similar to the value found for Cuesta del Negro. The Modern Age samples (eighteenth century AD) from Baeza, studied for comparative purposes, reveal a radically different situation, with a mean $\delta^{15}N$ of ±9.60‰ and a mean $\delta^{13}C$ of -18.57‰; this $\delta^{13}C$ is only comparable with the values found for third millennium cal BC in Úbeda.

The samples from the Navilla dolmen show a mean $\delta^{15}N$ of ±7.74‰ and a mean $\delta^{13}C$ of -19.05‰, situating them on the left side of the graph (Fig. 2) and suggesting a lower consumption of animal proteins and a similar environment to that indicated by the carbon isotope values in Úbeda.

Cuesta del Negro

Chronology. Correlations among the available radiocarbon dates on human remains and the stratigraphy of Cuesta del Negro allow the analyzed samples to be related to the time dimension (Fig. 6). The mean value was ±9.51‰ in phase 1, ±9.69‰ in phase 2, and ±10.64‰ in phase 3. Temporal differences are significant for $\delta^{15}N$, according to the Anova Test (0,001) and Welch (0,002) and Brown-Forsythe (0,001), showing a continuous increase in $\delta^{15}N$ values over time (Table 1 in the supplementary information file). These results may be related to an increasing consumption of meat, due to the progressive importance of stockbreeding (cattle and horses) at the site; in addition other factors, such as social level (see below) (Lauk 1976; Molina and Cámara 2004), must be considered.

The mean $\delta^{13}C$ values at this site are highly homogeneous, although with a mild tendency (close to the analytical error) towards less negative mean values over time (-19.34‰ in phase 1,

-19.39‰ in phase 2, and -19.30‰ in phase 3), which may indicate a slight increase in humidity, taking into account the lack of evidence for C4 plants or fish consumption in those human communities. With respect to this fact, environmental changes should be borne in mind to explain the sample variability.

Sex. Concerning sex differences (Fig. 3), the highest $\delta^{15}N$ values belong to males, with two exceptions (P-12106 and P-45521), and the mean value was slightly higher in males (±10.10‰) versus females (±9.78‰), with a global mean of ±10.00‰. However, the relatively high SD values (1.07 for males, 0.89 for females) mean that this difference should be interpreted with caution: they are not statistically significant.

Age. Cuesta del Negro is the site where isotope differences according to age are the more significant (0,164 in $\delta^{15}N$ and 0,117 in $\delta^{13}C$ according to the Anova test). In comparison to adults, children always show higher $\delta^{15}N$ values (mean ±10.45‰, SD 0.60), while juveniles have lower nitrogen levels (mean ±9.01‰, SD 0.89). The decrease in $\delta^{15}N$ at different periods of childhood may be related to the dietary problems associated with weaning and the transition to an adult diet (Schurr 1998), although the small sample size should be taken into consideration too. At any rate, the infants with higher $\delta^{15}N$ values belong to the highest social levels (according to their grave goods) and show a relatively advanced age (Infant II), possibly because maternal milk had been replaced by animal milk, as its use in Mediterranean Iberia from the Neolithic would suggest (Martí *et al.* 2009). Caution should be exercised in interpreting these results, because almost all the infants studied belong to phase 3. A further consideration is that two of the five juveniles whose sex has been identified are female; therefore, their protein deficit could be related to pregnancy problems that may even have caused their deaths.

Social differences. According to the grave goods found with the individuals (Cámara and Molina 2011), four social levels can be suggested, with the first two (levels 1 and 2) being related to the elite and associated with grave goods of precious metals, gold, and silver. $\delta^{15}N$ values are higher in those of higher social status (Fig. 4), but values are only truly significant if one considers social level 1 in relation to the others and also between social levels 3 and 4. The corresponding mean $\delta^{15}N$ values are ±10.78‰ for level 1, ±10.02‰ for level 2, ±10.22‰ for level 3 and ±9.40‰ (for level 4). The similar mean values for individuals in level 3 and level 2 reflect the possibility that males in level 3, who included a weapon as grave goods, possibly got some benefits because of their role as ‘warriors’. It suggests that only the most disadvantaged had no access to symbolic possessions and certain foods. This pattern is little changed if the infants are excluded from the analysis (±10.81‰, ±10.02‰, ±10.20‰, and ±9.38‰ as mean values) (Fig. 5).

Differences are also observed in relation to time, as previously suggested, but the relative samples for every phase and social category are too few in number to permit an evaluation of social differences in protein consumption in every phase (Fig. 6). The lack of lower-class individuals in the last phase could be related to burials being restricted to high class individuals in the Argaric last phases. However, no worsening in the general health conditions of the population has been observed, in contrast to previous reports on Argar communities from the Almería province (Lull *et al.* 2011). Animal protein consumption appears to have increased over time for all social classes in the

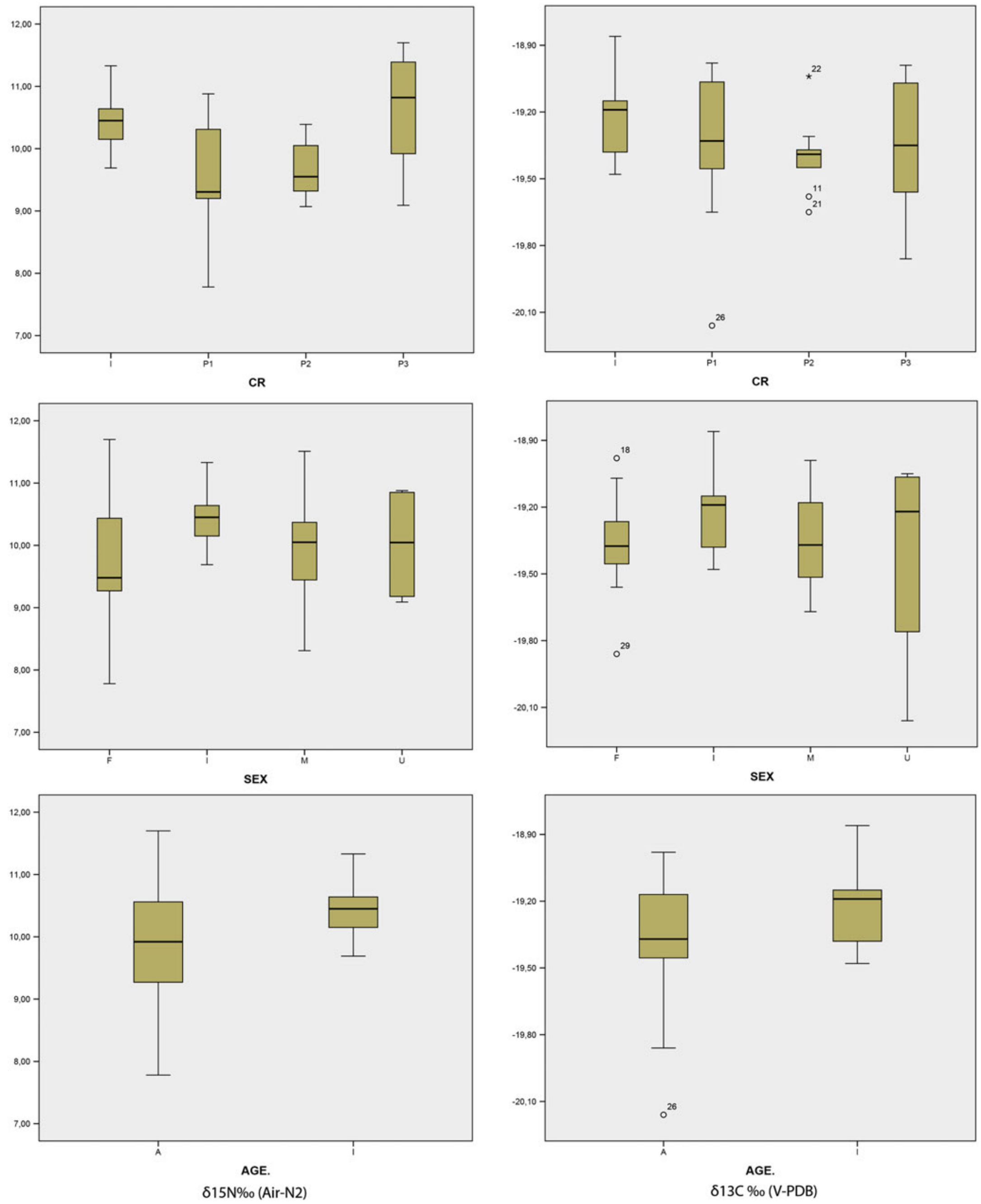

Figure 3
δ15N and δ13C Box Plots of Cuesta del Negro by chronology, sex and age (P1: phase 1, P2: phase 2, P3: phase 3: M: males, F: females; A: adults, I: infants; U: undefined). [Colour figure can be viewed online at wileyonlinelibrary.com]

settlement, while differences in access to gold and silver products and other social status symbols became very marked.

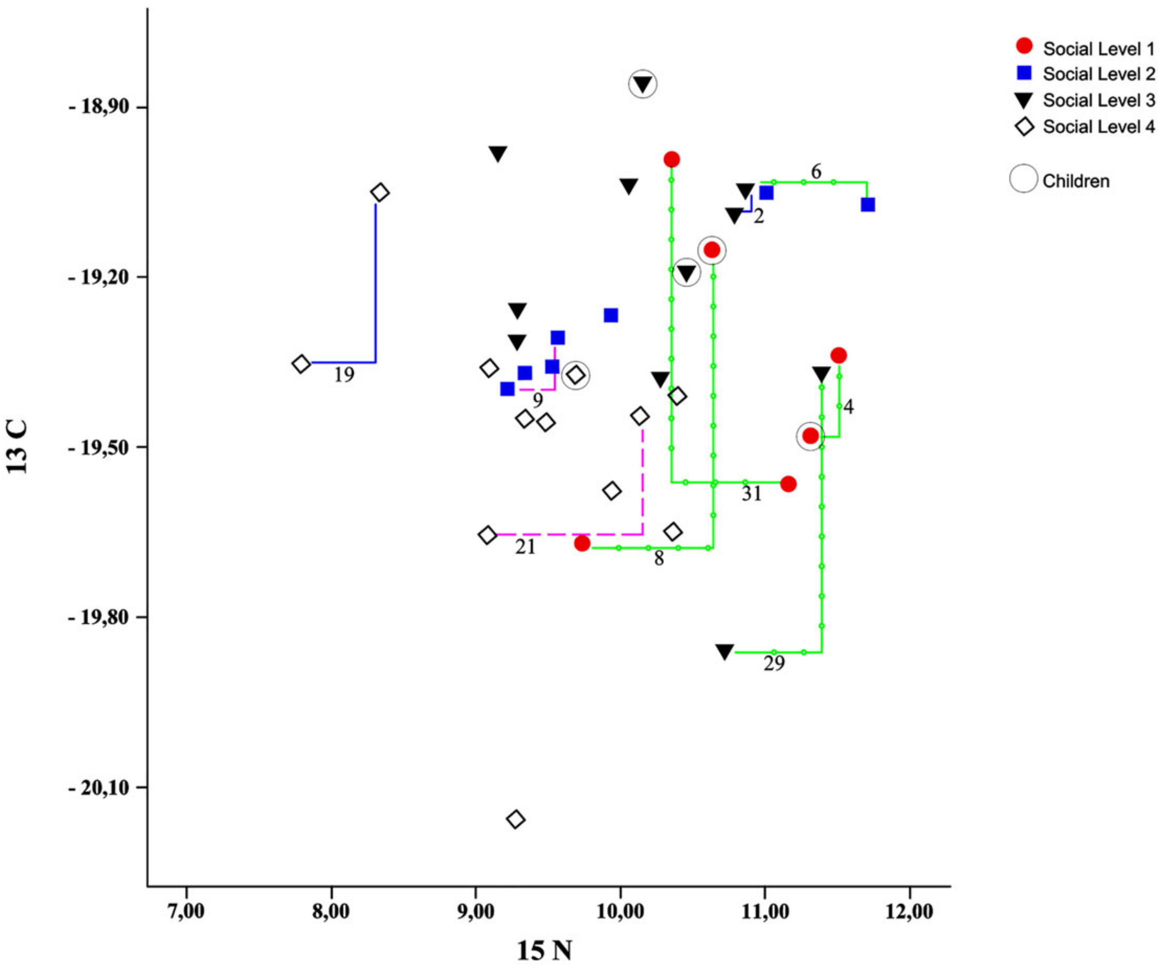

Figure 4
$\delta^{15}N$ v. $\delta^{13}C$ graphs of Cuesta del Negro by social level (lines link double tombs). [Colour figure can be viewed online at wileyonlinelibrary.com]

In the double tombs, there is a greater homogeneity in nitrogen values between the individuals, whereas the carbon values are almost always higher (except for tomb 21) in the male, which may also be related to factors associated with lipid metabolism (diet and mobility). Potential problems regarding the contemporaneity or not of the different burials in double tombs (Lull *et al*. 2013, 2016) should be considered, although most of the examples cited here show very similar dates for each of the bodies.

Navilla 1

As reported above, the human remains of La Navilla 1 have been only studied for comparison purposes. The mean $\delta^{15}N$ value was ±7.74‰, even lower than findings from the settlements in the Jaén province (±8.25‰ in Baeza and ±8.57‰ in Úbeda), indicating a diet based on agricultural products and contrasting with the mean value of ±10.00‰ found in Cuesta del Negro. In contrast, the $\delta^{13}C$ values are similar to those found in Cuesta del Negro.

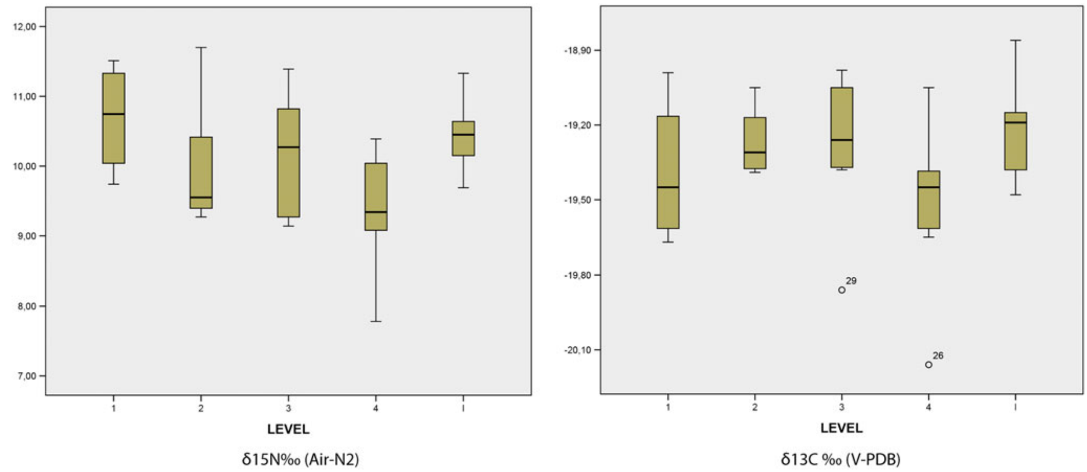

Figure 5
Cuesta del Negro. $\delta^{15}N$ and $\delta^{13}C$ Box Plots by social level separating infants (I). [Colour figure can be viewed online at wileyonlinelibrary.com]

Baeza

Areas/chronology. The most outstanding result in the sample from the Baeza prehistoric tombs is the difference in $\delta^{13}C$ values between the two excavated areas (East and West sectors), which is probably related to climatic differences existing in the times of their utilization (Fig. 7, top). Although we only have one dating for the Eastern sector (I16488), yet if the hypothesis of chronological difference is correct, these variances in mean values (-19.04‰ for the Eastern sector and -19.50‰ for the Western sector) would confirm the tendency towards greater aridity at later times in the Middle Bronze Age, taking into account the absence of data about fish or C4 plant consumption in late prehistoric Iberia. Stratigraphical studies of the Western sector show that conditions became drier between phases 8 and 9-10 (-19.63‰ and -19.28‰), according to the associated analysed deceased, if, as we think, climate is the main operative factor behind the $\delta^{13}C$ values.

In fact, this is the only site where differences in $\delta^{13}C$ are statistically significant (9,162 according the T test), as this site yielded some samples with very low $\delta^{13}C$ values.

For comparative purposes, we have analyzed individuals of the Modern Age (eighteenth century AD), obtaining isotope values that differed from the second millennium cal BC samples in both $\delta^{13}C$ and $\delta^{15}N$. Their higher $\delta^{15}N$ values are attributable to a higher animal protein consumption, while a similar tendency is observed in $\delta^{13}C$, which may be related to more arid conditions or even to a slight ^{13}C enrichment, due to the increase in the trophic level that sometimes affects carbon.

Sex. Results obtained for the Bronze Age human remains indicate a higher consumption of animal proteins by female individuals ($\delta^{15}N$ ±8.54‰ for females and ±8.33‰ for males) (Fig. 7, below).

Age. There is no difference in mean protein consumption between infants and non-infants (±8.48‰ in both cases), although there is a higher variability among the children (SD of 1.45 *versus* 0.67), which reflects a marked difference between individuals who died in their first infancy and those

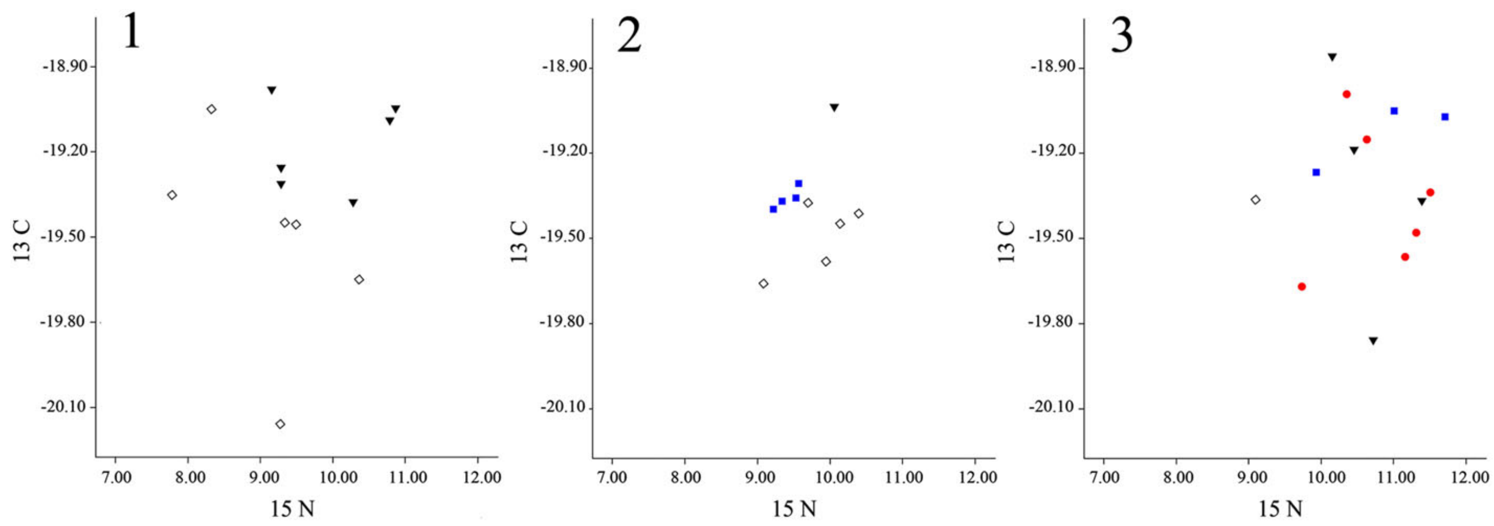

Figure 6
$\delta^{15}N$ vs. $\delta^{13}C$ graphs of the Cuesta del Negro for chronological phases P1, P2, and P3 by social level. [Colour figure can be viewed online at wileyonlinelibrary.com]

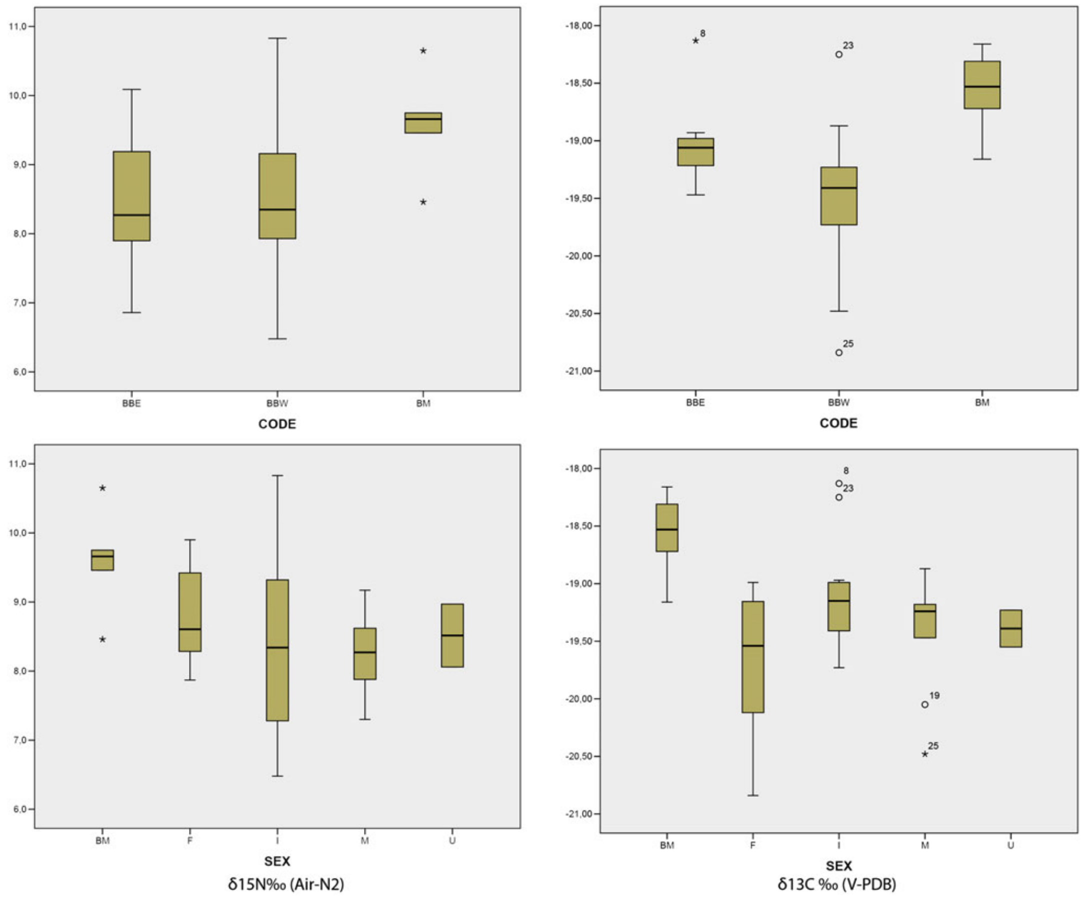

Figure 7
δ^{15}N and δ^{13}C Box Plots for Baeza by zone (top) and sex (below) (BBE: Bronze Age Eastern area, BBW: Bronze Age Western Area, BM: Modern Age; M: males, F: females; A: adults, I: infants; U: undefined). [Colour figure can be viewed online at wileyonlinelibrary.com]

who died after weaning (Fig. 8, top). Among the infants, the fall in δ^{15}N takes place at around the fourth year of life. We emphasize that the lowest values at the site were found for the 8-9–year-old in tomb 15, the 6-year-old in tomb 5, the 10-year-old in tomb 10, and the 4-year-old in tomb 30. The low values of the infant under 2 years of age in tomb 16 are even more surprising.

There are also major differences among non-infant individuals, with mean values of ±8.15‰ for adults and ±8.62‰ for mature individuals. The latter value is more difficult to explain, although as the majority belonged to social level 2, access to protein consumption throughout their life (and perhaps lesser physical effort) would have favored their survival. Differences for age groups are also significant in δ^{13}C (0,038 according to the Anova test).

Social differences. Tomb 9 was excluded from this analysis because of the anomalous values recovered, which may be related to the preservative substance applied to the bones. Hence, no tomb included in our study sample can be considered as level 1 according to the grave goods, except infant tomb 24. Although the sample is very heterogenous, differences in mean δ^{15}N levels have been

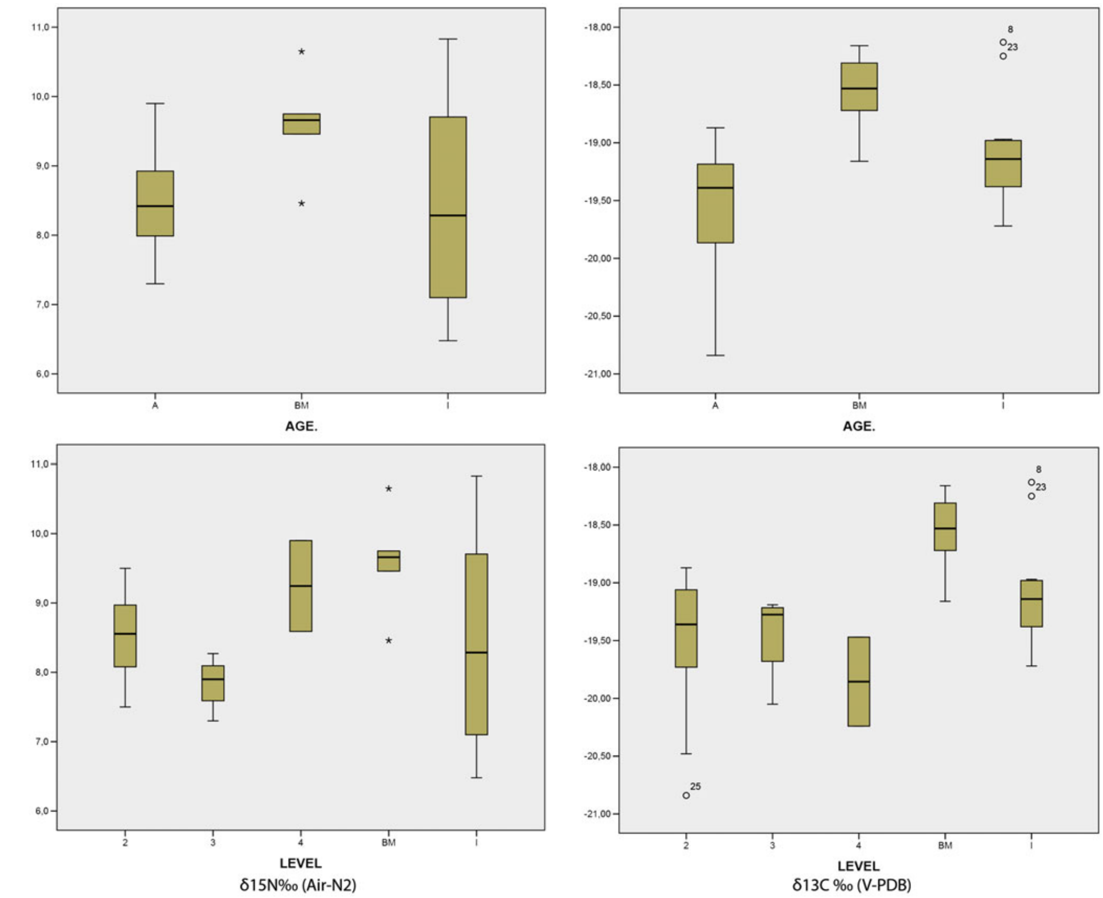

Figure 8
δ^{15}N and δ^{13}C Box Plots for Baeza by age (top) and social level (below) (BM: Modern Age; A: adults, I: infants, U: undefined). [Colour figure can be viewed online at wileyonlinelibrary.com]

observed between tombs with level 2 and 3 goods (±8.53‰, SD of 0.8 *versus* ±7.58‰, SD of 0.6, respectively); the exclusion of infant individuals from the analysis did not affect these results (±8.55‰, SD of 0.58 *versus* ±7.84‰, SD of 0.40 respectively). Social level 4 was almost completely comprized of young infants with no grave goods, but relatively high nitrogen levels (Fig. 8, below).

Úbeda

The Úbeda record because of its relatively small sample does not allow us to study the statistical signification. It is the only site with tombs from the third and second millennia cal BC.

Chronology. The trends in δ^{13}C values are contrary to the expected increase in aridity, as can be seen by comparing the mean values in δ^{13}C for the first half of third millennium cal BC (-18.47‰) and those of the first half of the second millennium BC (-18.93) (Fig. 9, top).

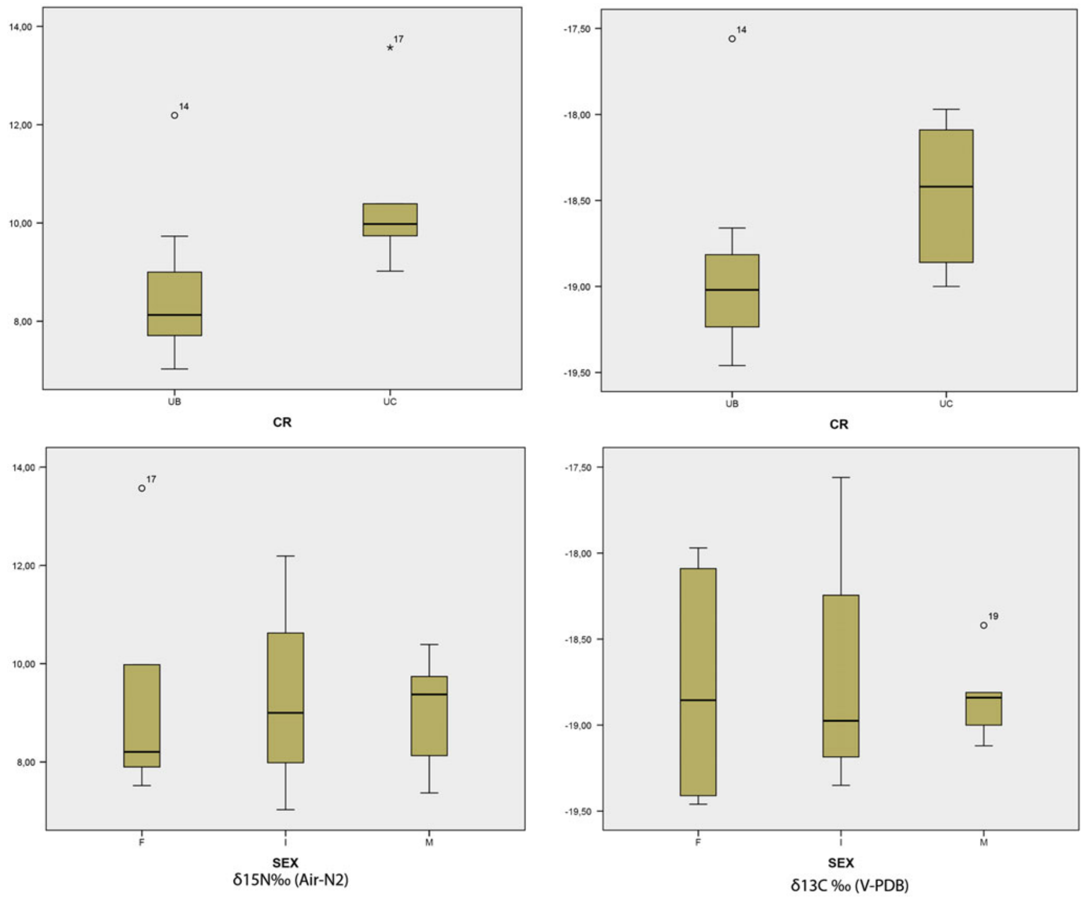

Figure 9
δ^{15}N and δ^{13}C Box Plots of Úbeda by chronology (top) and sex (below) (UB: Bronze Age, UC: Copper Age; M: males, F: females; I: infants). [Colour figure can be viewed online at wileyonlinelibrary.com]

Given the difficulties in proving the consumption of fish or C4 plants in the area during this period (Arias 2007; Lightfoot *et al*. 2011; Laffranchi *et al*. 2016; Waterman *et al*. 2017), changes in δ^{13}C may be attributable to the absence of funerary records for the second half of the third millennium cal BC; previous reports assert a definite constancy of rain in the central centuries of that millennium (Nachasova *et al*. 2007; Yanes *et al*. 2011) and can also demonstrate a drier period at the end of the fourth millennium cal BC (Magny and Haas 2004). Only one individual of the second millennium cal BC (the child in tomb 14) shows high δ^{13}C values, possibly indicative of a more arid environment. This situation may be also due either to a greater development of farming and the use of irrigation, as is proposed for certain leguminous plants and even for cereals (Mora *et al*. 2016), or from changes in the approach to stockbreeding, the source of animal protein, now featuring transhumance to the nearby mountain areas.

If the results for infants are excluded, thereby eliminating the influence of breastfeeding, the δ^{15}N values indicate a higher meat (or protein) consumption in the third millennium (mean of ±10.54‰) than in the second millennium cal BC (mean of ±8.1‰). This could suggest a higher proportion of agricultural products (including legumes) in the diet during the Bronze Age. Meat consumption in the third millennium can be supposed to be even higher, if we think that the $\delta^{15}N$ values do not reflect the meat of swine (Pearson *et al.* 2010; Fontanals-Coll *et al.,* 2017b). Swine-meat seems to have played a significant role in the diet, given the importance of pigs in the Upper Guadalquivir Copper Age (Cámara and Riquelme 2015).

The records for individuals from the third millennium show a direct relationship between increased $\delta^{15}N$ and increased $\delta^{13}C$ (N/C correlation coefficient of 0.715), whereas the records for the second millennium cal BC show that an increase in $\delta^{15}N$ is not necessarily associated with a rise in $\delta^{13}C$ (N/C correlation coefficient of 0.444). This suggests an increased intake of cereals in the second millennium cal BC and, in some samples with intermediate $\delta^{15}N$ values, a greater consumption of legumes. Social standing would also influence the access to animal proteins and may account for these differences (see below).

Age. In comparison to the $\delta^{15}N$ mean value of ±8.15‰ in the adults, the value in the infants is ±9.3‰, and only the child in tomb 3, who was considerably beyond weaning age, shows exceptionally low values (Fig. 10, top).

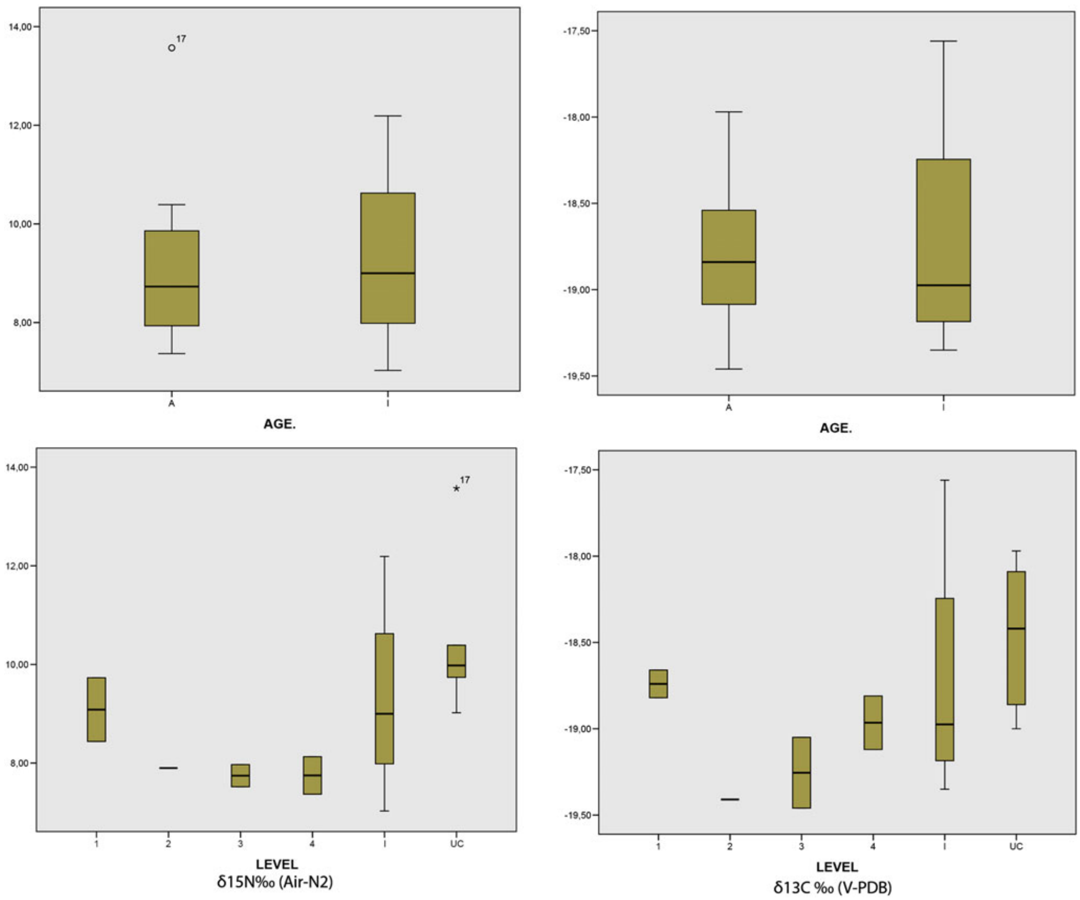

Figure 10
$\delta^{15}N$ and $\delta^{13}C$ Box Plots of Úbeda by age (top) and social level (below) (UC: Copper Age; A: adults, I: infants). [Colour figure can be viewed online at wileyonlinelibrary.com]

Sex. The $\delta^{15}N$ values for adults of the second millennium cal BC indicate nutritional differences between women (mean of ±7.96‰) and men (mean of ±8.41‰), reflecting the general trend observed in the studied sites. Nevertheless, the lowest $\delta^{15}N$ value is for a man (in tomb 9) (±7.37) and the highest are for a woman (in double tomb 13) (±8.44‰), and for the man in the same tomb (±9.73‰), and also the child in tomb 14 from the same house and probably the same family unit (Fig. 9, below).

Social differences. The records for the first half of the third millennium cal BC suggest a socially restricted burial system, with a notable absence of infant tombs and grave goods, except for some animal products. The $\delta^{15}N$ and $\delta^{13}C$ values indicate a balanced diet and an absence of gender differences (Fig. 10, below). This coincides with other available anthropological data, which show no significant nutritional deficits and no differences in muscle development between the sexes.

In contrast, differences in health, in the incidence of infant nutritional deficiency after weaning, in the effects of physical exertion and in muscle development are visible between individuals buried beneath the houses in the second millennium cal BC, further reflected to differences in grave goods.

Tomb 13 and its two bodies offer a revealing reading of the main contradiction of the society, i.e. class versus gender. As already noted, the man and woman had the highest $\delta^{15}N$ values among the adults studied and further possessed the only silver grave goods in the excavated area (ring, bangle, copper knife with silver rivets). These values are within the range observed in the third millennium cal BC, evidencing the presence of protein in their diet, in contrast to the protein deficiency of most of the population of the second millennium. This suggests that impoverishment was not generalized but obeyed criteria based on social exclusion. The fact that the lowest $\delta^{15}N$ value of the series is observed in the man in tomb 9 is of interest, because he also showed the most severe nutritional deficiencies in childhood and the hardest and most prolonged physical activity (lesions and arthrosis).

FINAL CONCLUSIONS

1. The methodology used proved appropriate for evaluating environmental changes, differences among environments, and variations in animal protein consumption as a function of the time-period and also the sex, age, and social situation of the individuals under study. Other possible factors exist.
2. This study increases the regional stable isotope database for the late prehistory in the Iberian Peninsula, adding 99 individuals (in addition to the 81 included in Waterman *et al*. 2016), as well a new dataset of AMS datings for Bronze Age Baeza and Úbeda (see supplementary material). The geographical representation, contextualization, and dating range of the sample offer contrasting avenues for historical interpretation. Nevertheless, the sample size for some sites and categories is still too low to achieve a higher level of statistical significance.
3. The $\delta^{13}C$ values observed reveal temporal variations at each site that in general indicate an increased aridity in the second millennium cal BC. However, the values found for Chalcolithic burials at Úbeda (first half of the third millennium cal BC) suggest that there

was also a marked reduction in humidity between the late fourth millennium and the early third millennium cal BC. A pair of climatic events could explain this situation (5.2 ka cal BP event and 4.2 ka cal BP one) (Magny and Haas 2004; Magny et *al*. 2009), but the Cuesta del Negro site shows a strong variability even after the second event, as previously suggested (Magny et *al*. 2009; López *et al*. 2014). The values for Cuesta del Negro also show a slightly more humid environment in comparison to the other sites.

4. Our research approach allows the discrimination of regional models and the comparison of their relative economic specializations. $\delta^{15}N$ values differed between Cuesta del Negro and the other settlements studied. The proportion of animal protein in the adults' diet was much greater in this site than in adult individuals retrieved from Úbeda and Baeza in the Upper Guadalquivir valley or in those buried in the Navilla dolmen in the Granada Vega, areas in which farming activity would have been more important.
5. Although the consumption of animal protein in Úbeda decreased between the third and second millennia cal BC, the radiocarbon dates and stratigraphic position of the individuals in Cuesta del Negro reveal a much more complex situation, showing an increase in $\delta^{15}N$ levels throughout the Bronze Age in the second millennium cal BC. In the first case, the sequence documents the development of an agricultural society specialized in the management of cereals and leguminous plants with complementary stockbreeding (Nocete *et al*. 2010). In the second case, stockbreeding had much greater importance (Molina 1983).
6. These patterns hide a strong variability, especially in the second millennium cal BC (Bronze Age), to which most of the samples belong. At all sites, $\delta^{15}N$ levels were higher in infants than in adults, although there are also differences in both age groups that are generally related to the age of the children (higher $\delta^{15}N$ levels in breastfeeding infants) and to the social category of the adults, measured on their grave goods and signs of physical activity or disease. However, as clearly observed in Cuesta del Negro, social status is also associated with the $\delta^{15}N$ levels in infant individuals, something also supported by the high values of the individuals in tomb 24 in Baeza and possibly of the individual in tomb 14 in Úbeda, who, although lacking grave goods, may have been part of the same family unit as the individuals in tomb 13, given their proximity in date and physical positioning. Differences according to social status, as defined previously according to the grave goods, can be also seen if we consider all the sites as a single entity. Differences are significant between level 1 and the others in $\delta^{15}N$, with statistical values of 0,007 (including children) and 0,033 (without children) according to the T test. These results support the hypothesis about Argar communities being class societies (Lull *et al*. 2011).
7. The process of social hierarchical organization must have been very slow, and differences among individuals can be more easily distinguished in its advanced phases. In fact, statistical differences in consumption based on stable isotope analysis have been also observed in Chalcolithic Portuguese graves (Waterman *et al*. 2016), showing that collective burial is also a way of masking social differences.
8. At most of the sites, there was a greater mean consumption of animal proteins by the males than the females during the second millennium cal BC, although the differences are not statistically significant. However a higher protein consumption by females over males can be found in many of the double tombs, showing that gender differences play a secondary role to those of class and status.

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(FM-G, JAC-S, RMM-S, LS, TN-C, FC-M) Departamento de Prehistoria y Arqueología, Facultad de Filosofía y Letras
Universidad de Granada, Campus Universitario Cartuja s/n
18071, Granada
SPAIN
(Corresponding author) E-mail: rmmartinez@ugr.es

(FN-C) Departamento Historia I (Prehistoria)
Universidad de Huelva
Edificio Marie Curie, Campus del Carmen s/n, 21007, Huelva
SPAIN

(AD-H, AG-T) Instituto Andaluz de Ciencias de la Tierra (CSIC-Universidad de Granada)
Avenida de las Palmeras 4, 18100, Armilla, Granada
SPAIN

(SJ-B) Laboratorio de Antropología, Facultad de Medicina
Universidad de Granada
Parque Tecnológico de Ciencias de la Salud, 18071, Granada
SPAIN

(MTM-L) Departamento de Estadística e Investigación Operativa, Facultad de Medicina
Universidad de Granada
Parque Tecnológico de Ciencias de la Salud, 18071, Granada
SPAIN

(JAR-C) Departamento de Geografía y Ciencias del Territorio, Facultad de Filosofía y Letras
Universidad de Córdoba
Plaza Cardenal Salazar, 3, 14071, Córdoba
SPAIN

(CP-B) Archaeologist
C/Cuesta de San Gil, 22, 23440 Baeza
Jaén
SPAIN

(RL-P) Área de Urbanismo. Ayuntamiento de Úbeda. Pza. Vázquez de Molina, s/n.
23400, Úbeda, Jaén
SPAIN

(JMN-L) Departamento de Geología
Universidad de Huelva
Campus del Carmen s/n, 21007, Huelva
SPAIN

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Fig. 1. General view of *Cuesta del Negro* site.
Fig. 2. Tomb n° 27 of Cuesta del Negro site.
Fig. 3. *Navilla 1* dolmen.
Fig. 4. General view of Baeza town, with the archaeological area of Cerro del Alcázar.
Fig. 5. Tomb n° 9 of Baeza.
Fig. 6. View of the town of Úbeda with the archaeological area of Eras del Alcázar (depopulated zone).

Fig. 7. View of the excavated area in Úbeda.
Fig. 8. Tomb n° 3 of the Eras del Alcázar zone (Úbeda).
Table 1: Radiocarbon dates on human bones from Cuesta del Negro (Cámara and Molina 2011), calibrated according to the IntCal13 curve (Reimer *et al*. 2013).
Table 2. Radiocarbon dates on human bones in La Navilla 1 grave (Cámara and Molina 2015), calibrated according to the IntCal13 curve (Reimer *et al*. 2013).
Table 3. Available radiocarbon dates from carbon samples for the prehistoric stages of Baeza, calibrated according to the IntCal13 curve (Reimer *et al*. 2013).
Table 4. Available radiocarbon dates for the prehistoric phases of Úbeda (Nocete et *al*. 2010, except for Ua42635 and Ua42636, both published here for the first time), calibrated according to the IntCal13 curve (Reimer *et al*. 2013).
Table 5: Summary tables for means and standard deviations. (KEY: M: males, F: females; A: adults, I: infants; U: undefined; P1, Cuesta del Negro Phase 1; P2, Cuesta del Negro Phase 2; P3, Cuesta del Negro Phase 3; BBE, Baeza Bronze Age Eastern Area; BBW Baeza Bronze Age Western Area; BM, Baeza Modern Age; UB, Úbeda Bronze Age; UC, Úbeda Copper Age).
Table 6. Samples included in the study (KEY: P1, Cuesta del Negro Phase 1; P2, Cuesta del Negro Phase 2; P3, Cuesta del Negro Phase 3; UB, Úbeda Bronze Age; UC, Úbeda Copper Age; BBE, Baeza Bronze Age Eastern Area; BBW Baeza Bronze Age Western Area; BM, Baeza Modern Age; NB, La Navilla 1 Bronze Age). C:N Ratio is within 3.1-3.3 in all cases.