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Territorial mobility and subsistence strategies during the Ebro Basin Late Neolithic-Chalcolithic: A multi-isotope approach from San Juan cave (Loarre, Spain)

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ABSTRACT

The use of isotopic analysis in human and animal remains from the Holocene has proved to be a very useful tool to explore the exploitation and adaptation of past populations to different environments. In this study we present isotopic analysis results of carbon, nitrogen and strontium from the Late Neolithic-Chalcolithic site of San Juan cave (Loarre, Spain). We analysed 33 humans, divided in adult and subadult groups, and 16 animals recovered from the same archaeological context. Stable isotope analysis of carbon and nitrogen has allowed to distinguish an homogeneous subsistence pattern during the Late Neolithic-Chalcolithic transition. The use of strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) in human dental enamel suggests 19% (4 out of 21) are non-local individuals, based on comparison with the local bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range calculated using microfauna teeth from the archaeological context, modern plants and snails. This new study gives information about Late Neolithic communities located in the north-east of the Iberian Peninsula, and it allows inference of the socio-economic structure, territorial mobility and individual provenance of humans.

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1. Introduction

Stable isotope measurements in human and animal remains has proved to be a very useful tool to explore the exploitation and environment adaptation of past populations (e.g. Makarewicz and

Sealy, 2015). Specifically, stable isotope ratio analysis of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) of bone collagen is a common method used to quantitatively approach protein dietary input from both prehistoric and historical populations (e.g. Salazar-García et al., 2016a). $\delta^{13}\text{C}$ values are suitable to discriminate between the consumption of terrestrial and aquatic resources (e.g. Carvalho and Petchey, 2013; Lillie et al., 2011; Schoeninger and DeNiro, 1984), as well as of plants with different photosynthetic pathways (i.e. C_3 and C_4) (e.g. Lee-Thorp, 2008; Van der Merwe, 1982). $\delta^{13}\text{C}$ values are lower in estuarine and brackish fish, giving rise to what has been defined as the “fish paradox” when interpreting human fish consumption in the past (Salazar-García et al., 2014a). $\delta^{15}\text{N}$ values

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are able to provide information about the trophic level a specific organism holds in the food chain of its environment (Bocherens and Drucker, 2003; Minagawa and Wada, 1986). $\delta^{15}\text{N}$ values are considered to increase generally between 3‰ and 5‰ with each trophic level up the foodweb (Bocherens and Drucker, 2003; Schwarcz and Schoeninger, 1991). Some researchers suggest this range could be wider (Hedges and Reynard, 2007), being estimated in ca. 6‰ combining short-scale studies from red blood cells with measured offsets in other studies (O'Connell et al., 2012). It is necessary to highlight that diet studies based on stable isotope analysis of bone collagen present two important traits to take into account: 1) collagen turnover is low during adulthood and therefore reflect an average diet of the last 10–20 years before the individual died (Hedges et al., 2007); and 2) collagen stable isotope ratios mainly reflect protein sources and this is the reason why plant food consumption could be masked by diets high in protein content (Ambrose and Norr, 1993). To complement isotopic dietary information from bone collagen, the study of trapped plant micro-remains (starches and phytoliths) inside dental calculus can be very useful to detect plant consumption (e.g. Power et al., 2014; Salazar-García et al., 2013a).

Strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) analyses of tooth enamel have the potential to provide insight on the use of a geological area by tracking territorial mobility of the individuals studied (Bentley, 2013; Copeland et al., 2011). $^{87}\text{Sr}/^{86}\text{Sr}$ ratios vary depending on the geology and bedrock age, and, because there is no isotopic fractionation due to their very small relative mass differences, they are incorporated directly into the foodweb (plants, animals, and eventually humans). Strontium is fixed during enamel mineralization and reflects the bioavailable strontium values from the region where an individual lived when enamel mineralization took place (Bentley, 2006; Ericson, 1985; Price et al., 2002). Enamel from second (M2) and third (M3) molars from the same human individuals are preferentially selected for this kind of analysis as they allow comparison of a childhood signature not influenced by breastfeeding and weaning (M2) with a signature from early adulthood (M3) (Hillson, 1996).

Although prehistoric dietary studies based on stable isotope ratio analysis have been increasing during the last decade in Spain (e.g. Arias, 2005; Fontanals-Coll et al., 2015; García-Guixé et al., 2006; Salazar-García et al., 2013b), territorial mobility studies based on strontium isotope analysis are still scarce in Iberia (Díaz-Zorita, 2014; Salazar-García, 2012a; Waterman et al., 2014). Most of the previous studies have focused on the “transition to agriculture”, leaving some gaps on other “transitions” between the Late Neolithic and the so-called Metal Ages in the Iberian Peninsula (López-Costas et al., 2015; McClure et al., 2011; Salazar-García, 2012b).

The aim of this paper is to bridge this gap by assessing, through a multi-isotope study of the Late Neolithic–Chalcolithic collective burial of San Juan cave in the Ebro Basin (Huesca, Spain), the socio-economical dynamics at the onset of metallurgy in northeast Iberia.

2. San Juan cave site and its archaeological context

Late Neolithic–Chalcolithic and early Bronze Age periods in Iberia are characterized by the presence of a high number of burials where people were usually buried together in shared spaces (Andrés, 1998). The use of both caves and rock shelters as burial sites is contemporary to the use of megalithic tombs during the Late Neolithic in northeastern Iberia (Fernández-Crespo, 2010). Overall, some authors suggest that the use of different types of burials was linked to different groups of people, or to people with different socio-economic status (Chapman, 1981; Hodder, 1984; Renfrew, 1976; Sherratt, 1990). In northeastern Iberia, there is still no solid

explanation for the differential use of the diverse types of burials (Andrés, 1998, 2005). However, some studies from the middle-high Ebro Valley reveal an overrepresentation of adult male individuals in Megalithic tombs, while subadults and female individuals are more abundant in cave burials (Fernández-Crespo and de-la-Rúa, 2015). Since at the site here studied there has been no sex or age selection when burying the remains, they are more representative of the whole past population of the region. San Juan cave is one of very few sites in the Ebro Basin for which the entire human burial population is available. Additionally, there are very few anthropological studies on the total sample of human remains recovered from the burial caves in the Ebro Basin, and to date there are no multi-isotopic studies carried out on these samples. Furthermore, the end of the Neolithic is still poorly understood in northeastern Iberia, where there are no clear limits between the Neolithic and Chalcolithic periods unlike what happens in the south when the Millares culture appears. In this context, the site of San Juan cave is of interest to fill in this gap.

San Juan cave is a burial site located between the Ebro Valley and the pre-Pyrenean mountain range, close to the town of Loarre, Huesca, Spain (X.697155; Y. 4688532, UTM30N, WGS84). It is a $2.5 \times 1.5 \times 1.5$ m. limestone cave situated in the western slope of Los Vallazos gorge, at 983.37 m.a.s.l. (metres above sea level) (Fig. 1). This site was excavated by M. Victoria Pastor and Diana Vicente in 2007 (Pastor and Vicente, 2009) in the framework of a rescue excavation of the Gobierno de Aragón. Material culture recovered as grave goods include stone and bone beads, *Cardium* and *Dentalia* seashells, two bone and wild board tusk pendants, flint tools, and some ceramic pot fragments. Also comingled with the human remains were several faunal remains (Pastor and Vicente, 2009). Since the collective burial has no clear archaeological stratigraphy, direct radiocarbon dates from several of the human remains show that the burial site was used mainly during the Late Neolithic–Chalcolithic, with only a single date pointing to the Bronze Age (Table 1, Fig. 2). The individuals were deposited individually and accumulatively over the surface of the cave. Most of the human remains were found comingled and disarticulated, with no anatomical connexions, suggesting that buried corpses were displaced to accommodate new ones (Pastor and Vicente, 2009).

3. Materials and methods

3.1. Study of faunal and human remains

Faunal taxonomic identification has been based on the works of Fernandez (2001), Pales and Lambert (1971), Rowley-Conwy et al. (2012), and Sanchís (2010), as well as on the zooarchaeological reference collection of the University of Zaragoza (UZ) and the Natural Science Museum of Zaragoza. In order to assess the skeletal representation of the assemblage from San Juan cave, we used the Number of Remains (NR), the Number of Identified Specimens (NISP) and the Minimum Number of Individuals (MNI), all of which have been calculated in accordance with Brain (1981) and Lyman (1994). Hillson (1992) and Morris (1978) were followed in order to determine age at death, dental replacement and degree of dental eruption. The degree of long bone epiphyses fusion was measured following Morris (1972). Different types of carnivore tooth marks have been differentiated (pits, punctures, grooves, furrowing, crenulated edges and impact points) according to the definitions of Binford (1981), Haynes (1980, 1983), and Sala (2012).

The total amount of human remains present at the site is 2148 bones and bone fragments according to a previous study (Gimeno, 2009). In that study, the Minimum Number of Individuals (MNI) was calculated to 47. No postcranial element is complete, so the MNI, sex and age diagnoses were based on cranial and mandibular

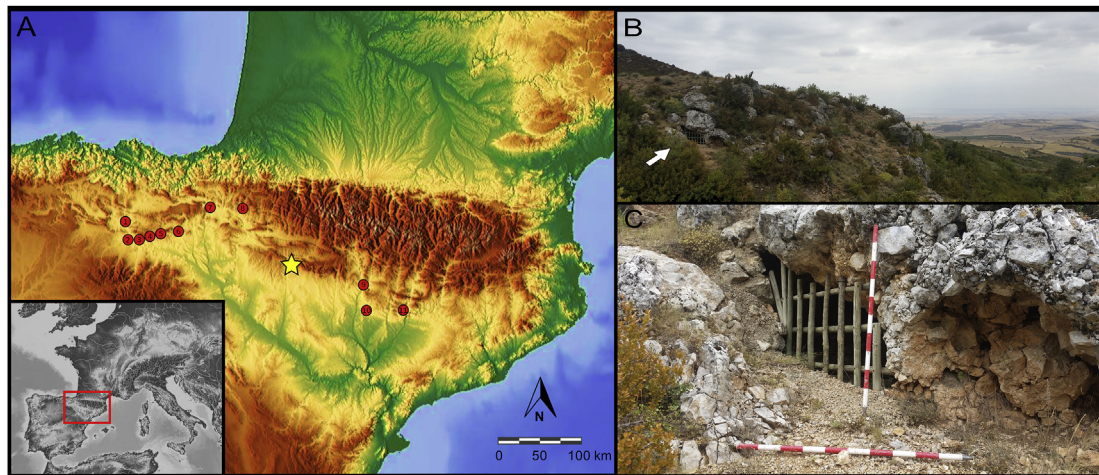


Fig. 1. Location map. A) Map of Sepulchral Late Neolithic–Chalcolithic caves in the Ebro Basin with anthropological studies and direct radiocarbon dates [1: Fuente Hoz (Basabe and Bennassar, 1983); 2: Las Yurdinas, 3: Peña Larga, 4 and 5: Los Husos I and II, 6: Peña Marañón (Fernández-Crespo, 2016); 7: Hombres Verdes (Fuste, 1982); 8: Zatoya (Lorenzo, 1989); 9: Peña de las Forcas (Lorenzo, 2014); 10: Los de los Moros de Alins del Monte (Rodanés et al., 2016); and 11: Forat de Conqueta (García-Guixé, 2011)]. The star shows the location of San Juan cave; B) Picture of San Juan cave and its surrounding landscape with the two different ecosystems: Pre-Pyrenean mountain range (left side of the picture), and Ebro Valley (right side of the picture) (The arrow indicates the entrance of San Juan cave); C) Detailed picture of San Juan cave.

Table 1

AMS radiocarbon dates of 6 individuals from San Juan cave calibrated with OxCal v4.2.3 and using the IntCal13 calibration curve (Bronk Ramsey, 2009; Reimer et al., 2013).

Lab code	Sample	^{14}C age	1 σ Cal BC	2 σ Cal BC	Cultural Period	Reference
GrA-38270	Vertebra	4620 \pm 30	3496–3359	3512–3348	Late Neolithic	Pastor and Vicente, 2009
GrA-38268	Crania	4120 \pm 30	2856–2624	2866–2579	Late Neolithic–Chalcolithic	Pastor and Vicente, 2009
GrA-3795	Rib	4110 \pm 30	2851–2586	2865–2575	Late Neolithic–Chalcolithic	Pastor and Vicente, 2009
D-AMS 09112	Mandible	4087 \pm 28	2835–2576	2858–2499	Late Neolithic–Chalcolithic	This paper
D-AMS 019113	Mandible	4053 \pm 35	2830–2492	2847–2474	Late Neolithic–Chalcolithic	This paper
GrA-38396	Humerus	3285 \pm 30	1611–1529	1629–1500	Bronze Age	Pastor and Vicente, 2009

elements, only using post-cranial elements to obtain information about pathologies and lifestyles (Gimeno, 2009).

In the present study only mandibles are considered and analysed, with the aim of avoiding stable isotope value duplicates from a same individual. Furthermore, in the context of a collective burial whose remains are all in secondary position, sampling mandibles allows to associate isotopic data obtained from bone and teeth of each individual. Although not as diagnostic as other elements,

mandibles might in some cases be able to provide information about sex and age. However, they should be checked with other skeletal elements that give higher accuracy in the sex and age determination (Brothwell, 1989; Buikstra and Ubelaker, 1994). The impossibility of associating mandibles with other skeletal elements of a same individual that are more useful for sex-determination at this site, has lead us to be cautious and avoid using sex-categories to discuss the isotopic data. Regarding age estimation, mandibles have

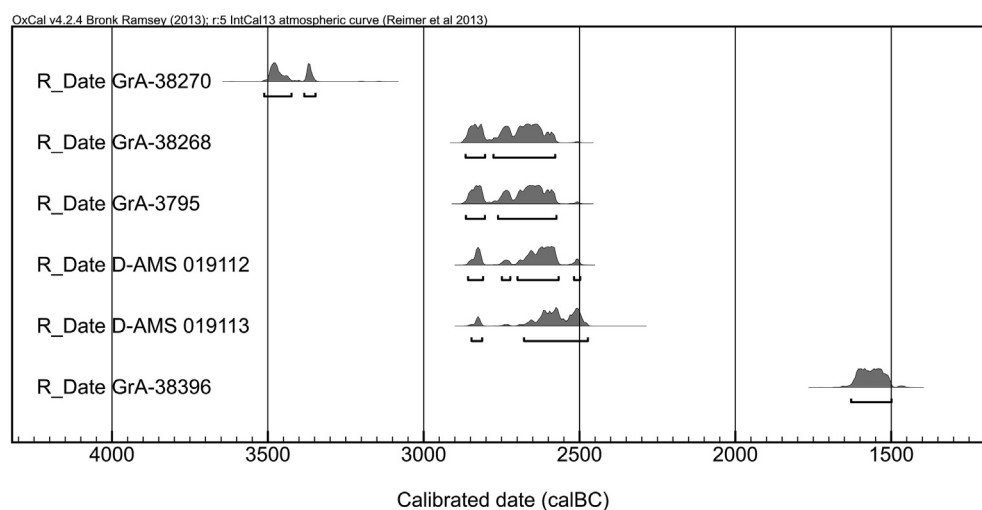


Fig. 2. AMS radiocarbon dates from San Juan cave. All dates have been calibrated with OxCal v4.2.3 and using the IntCal13 calibration curve (Bronk Ramsey, 2009; Reimer et al., 2013).

been divided into four age categories following [Buikstra and Ubelaker \(1994\)](#): infant (0–3 years), child (3–6 years), adolescent (12–20 years) and adult (>20 years). Subadult individual age was calculated using the eruption dental pattern ([Ubelaker, 1989](#)), and mandibles with totally developed permanent dentition have been classified as adults. Adult individual age was not considered, but molar wear patterns were nevertheless studied. Since molar wear patterns can be influenced by multiple factors and therefore not be reliable for estimating specific adult age ([El Aidi et al., 2011](#)), this study only correlates the degree of wear patterns itself to $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopic values (not inferred age from them). Following this, mandibles with preserved molars were divided according to wear scores from [Brothwell \(1989\)](#): low wear (from 2 to 3 wear scores), medium wear (from +3+ to +4), high wear (from 5 to +5) and very high wear (more than +5 in all molars).

3.2. Collagen extraction and CN analysis

Samples from 33 humans and 16 animals of 6 different species were taken from the archaeological burial for analysis ([Table 2](#)). Sample preparation and analysis were carried out in dedicated facilities of the Department of Archaeology at University of Cape Town (South Africa), as described below.

Prior to analysis, external contaminants were removed by manual abrasion using a Dremel 3500 drill with a diamond grinder bit attached. Collagen extraction for carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analysis was done following the [Longin \(1971\)](#) method with the addition of an ultrafiltration step ([Brown et al., 1988](#)) as described in the procedure in [Salazar-García et al. \(2014a\)](#). Approximately 300 mg of bone samples from each specimen were demineralized in 0.5 M HCl solution at 5 °C until fully demineralized (over the course of a week in all cases). When demineralization finished, samples were rinsed three times with deionized water until pH became neutral, before starting gelatinization at 70 °C for 48 h using a heater block (FMH instruments, South Africa). This was followed by filtering with a 9 ml EZEE-filter (Elkay, United Kingdom) to remove small (<8 µm) particles and ultrafiltering with 30 kDa ultrafilters (Amicon, Germany) using a centrifuge (Thermo Fisher Scientific Megafuge 16, USA) at 2500 rpm during variable times depending on the filtering speed of each sample. The solution was then frozen and lyophilized. Finally, ca. 0.5 mg of collagen was weighed into tin capsules in duplicate per sample, and loaded into the mass spectrometer.

The carbon and nitrogen isotope ratio measurements were performed using a Finnigan Delta plus XP continuous-flow isotope ratio mass spectrometer (Thermo Fisher Scientific, USA) after being combusted in an elemental analyser Flash EA 1112 interfaced with it (Thermo Fisher Scientific, USA). Stable carbon isotope ratios were expressed relative to the VPDB scale (Vienna PeeDee Belemnite), and stable nitrogen isotope ratios were measured relative to the AIR scale (atmospheric N₂), using the delta notation (δ) in parts per thousand (‰). Repeated analysis of internal and international standards (Valine, MG and Seal) determined an analytical error better than 0.1‰ (1 σ) for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. All analysis were carried out in duplicate.

3.3. Sample preparation for strontium isotope analysis

Thirty-two tooth samples from 21 humans were selected for strontium isotope analysis. Second and third molars were preferentially selected and sampled for each individual when possible. When not available, premolars or canines were chosen instead of second molars ([Table 2](#)). This sampling strategy ensured having two different windows to the individual's life: childhood (M2, P, C) and early adulthood (M3) ([Hillson, 1996](#)). Sample preparation and

analysis were done in dedicated facilities of the Departments of Archaeology and Geology of the University of Cape Town (South Africa), as described below.

Prior to analysis, enamel surfaces were cleaned by abrasion, rinsed and ultrasonicated for 20 min in MilliQ water. Diamond drill bits were cleaned with ethanol and ultrasonicated in MilliQ water between samples to avoid cross-contamination ([Budd et al., 2000](#)). After this, ca. 20 mg of cleaned enamel sample was digested with 2 mL of distilled 65% HNO₃ in a closed Teflon beaker placed on a hotplate at 140 °C for an hour. Digested samples were then dried and redissolved in 1.5 ml of 2 M distilled HNO₃. These redissolved samples were centrifuged at 4000 rpm for 20 min, and the resulting supernatant was collected for strontium separation chemistry. A separate fraction for each sample was used to calculate the Sr concentration; ^{88}Sr intensity (V) regression equation was built with the SRM987 standard from the NIST (National Institute of Standards and Technology, Gaithersburg, MD, USA).

Strontium was isolated with 200 µl of Eichrom Sr.Spec resin loaded in 2 ml Bio-Spin Disposable Chromatography *Bio-Rad* Columns following the method of [Pin et al. \(1994\)](#). The separated strontium fraction for each sample was dried down, dissolved in 2 ml 0.2% distilled HNO₃ and diluted to 200 ppb Sr concentrations for isotope analysis. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were measured using a NuPlasma HR multicollector inductively-coupled-plasma mass spectrometer (MC-ICP-MS). Sample analyses were referenced to bracketing analyses of SRM987, using a $^{87}\text{Sr}/^{86}\text{Sr}$ reference value of 0.710255 from the NIST. All strontium isotope data are corrected for isobaric rubidium interference at 87 amu using the measured signal for ^{85}Rb and the natural $^{85}\text{Rb}/^{87}\text{Rb}$ ratio. Instrumental mass fractionation was corrected using the measured $^{86}\text{Sr}/^{88}\text{Sr}$ ratio and the exponential law, and a true $^{86}\text{Sr}/^{88}\text{Sr}$ value of 0.1194. Results for repeat analyses of an in-house carbonate standard processed and measured with the batches of samples in this study ($^{87}\text{Sr}/^{86}\text{Sr} = 0.708936$; 2 sigma 0.000041; n = 33) are in agreement with long-term results for this in-house standard ($^{87}\text{Sr}/^{86}\text{Sr}$; 0.708915; 2 sigma 0.000047; n = 125).

To discern possible non-local individuals, the $^{87}\text{Sr}/^{86}\text{Sr}$ bioavailable range from the site and region were estimated by preparing and analysing microfauna teeth, modern snails and plants from two sampling areas, following [Bentley et al. \(2004\)](#) and [Price et al. \(2001\)](#). Except for the site, for which 5 microfauna teeth were also analysed, from every sampling area only 5 plants and 5 snail shells were sampled and analysed. The same Sr extraction and purification procedure previously described was used on the microfauna teeth and modern snail shells ([Price et al., 2002](#)). The sample preparation used for modern plants was similar to that described in [Copeland et al. \(2016\)](#). No strontium concentrations were measured in modern samples.

4. Results

4.1. Anthropological study on mandibles

The minimum number of individuals (MNI) was calculated to 33 based on the number of mandibles and mandible fragments, as in the previous carried out anthropological study ([Gimeno, 2009](#)). A number of 24 belonged to adults (73%), 2 belonged to adolescents (6%), and 7 belonged to children (21%). In 19 adult mandibles it was possible to measure the wear pattern based on criteria from [Brothwell \(1989\)](#). Most of the mandibles from inside this group, 58%, belonged to individuals that showed a medium molar wear pattern (from +3 to +4). They are followed by 26% that showed a low wear pattern (from 2 to 3), and by 16% that showed a high molar wear pattern (from 5 to +5). None of the mandibles showed a molar wear pattern higher than +5 score. In 5 adult mandibles it

Table 2

San Juan cave S-UCT code, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, species, biological age group, collagen control indicators (yield, %C, %N, C:N elemental), $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, Sr concentration (ppm) and sampled bone and tooth, [l.w: low wear (from 2 to 3 score); m.w: medium wear (from +3 to +4 score); h.w: high wear (from 5 to +5 score); scores according with Brothwell (1989); C: canine; P1: premolar 1; P2: premolar 2; M2: second molar; and M3: third molar].

S-UCT code	Species	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	Age	Molar wear pattern	Collagen yield (%)	C (%)	N (%)	C: N (Elemental)	Sampled bone (sample code)	Sampled tooth	$^{87}\text{Sr}/^{86}\text{Sr}$	Sr conc. (ppm)
18472	Human	-18.9	10.9	Child	–	7.2	42.1	15.2	3.2	Mandible (M1)	–	–	–
18480	Human	-19.4	10.3	Child	–	4.6	42.8	15.3	3.3	Mandible (M9)	–	–	–
18492	Human	-19.5	10.6	Child	–	2.2	39.9	13.8	3.4	Mandible (M28a)	–	–	–
18493	Human	-19.4	10.1	Child	–	2.1	42.1	14.5	3.4	Mandible (M28b)	P2	0.708520	110.3
18499	Human	-18.4	9.1	Child	–	4.4	43.4	15.7	3.2	Mandible (M40)	–	–	–
18500	Human	-19.5	11.6	Child	–	6.7	44.1	15.9	3.2	Mandible (M41)	–	–	–
18477	Human	-19.2	10.4	Child	–	5.8	42.9	15.4	3.2	Mandible (M6)	M2	0.708569	127.6
18474	Human	-19.3	10.8	Adolescent	–	2.3	41.5	14.4	3.4	Mandible (M3)	M2	0.708383	119.2
18488	Human	-19.4	10.8	Adolescent	–	2.4	40.9	14.1	3.4	Mandible (M19)	M2	0.708495	121.3
18475	Human	-19.3	10.4	Adult	l.w.	2.2	35.9	12.3	3.4	Mandible (M4)	M2	0.708375	222.4
18484	Human	-19.3	10.1	Adult	l.w.	7.8	43.6	15.7	3.2	Mandible (M13)	M2	0.707750	338.0
											M3	0.707838	285.9
18485	Human	-19.1	10.4	Adult	l.w.	4.9	40.8	14.2	3.4	Mandible (M14)	M2	0.708076	222.2
											M3	0.708424	226.3
18495	Human	-19.4	10.4	Adult	l.w.	5.1	43.6	15.8	3.2	Mandible (M32)	–	–	–
18502	Human	-19.2	9.9	Adult	l.w.	6.5	43.2	15.6	3.2	Mandible (C1)	M2	0.708351	133.0
											M3	0.708361	128.1
18473	Human	-19.7	9.7	Adult	m.w.	2.2	39.9	13.6	3.4	Mandible (M2)	P2	0.708095	168.4
18478	Human	-19.2	10.6	Adult	m.w.	4.8	43.5	15.4	3.3	Mandible (M7)	M2	0.708095	323.2
											M3	0.708278	316.2
18479	Human	-19.5	9.9	Adult	m.w.	1.6	39.9	14.1	3.3	Mandible (M8)	M2	0.708331	77.87
18483	Human	-19.3	11.0	Adult	m.w.	1.4	43.3	14.8	3.4	Mandible (M12)	M2	0.708412	85.99
											M3	0.708313	75.41
18487	Human	-19.1	10.0	Adult	m.w.	2.8	41.0	14.6	3.3	Mandible (M17)	M2	0.708424	141.2
											M3	0.708345	147.5
18494	Human	-19.6	10.4	Adult	m.w.	2.7	42.3	14.9	3.3	Mandible (M30)	M2	0.710787	80.16
18496	Human	-19.3	9.8	Adult	m.w.	5.7	43.1	15.5	3.3	Mandible (M33)	–	–	–
18501	Human	-19.6	10.5	Adult	m.w.	3.2	42.3	15.0	3.3	Mandible (M42)	P1	0.710415	79.99
18503	Human	-19.4	9.2	Adult	m.w.	2.7	39.3	14.1	3.2	Mandible (C3)	M2	0.708484	211.2
											M3	0.708430	225.5
18504	Human	-19.2	10.2	Adult	m.w.	4.1	39.4	13.8	3.3	Mandible (C7)	M2	0.711710	76.44
											M3	0.711142	75.36
18505	Human	-18.7	11.2	Adult	m.w.	2.2	39.5	13.7	3.4	Mandible (C13)	M2	0.708392	175.9
											M3	0.708384	150.6
18476	Human	-19.0	10.9	Adult	h.w.	3.5	39.4	10.9	3.3	Mandible (M5)	M2	0.708316	103.7
											M3	0.708756	143.5
18482	Human	-19.2	11.0	Adult	h.w.	2.4	42.2	11.0	3.3	Mandible (M11)	P1	0.708465	150.1
18491	Human	-19.7	9.6	Adult	h.w.	2.5	41.4	9.6	3.4	Mandible (M24)	M2	0.708196	170.5
											M3	0.708145	201.9
18486	Human	-19.4	10.6	Adult	–	5.3	43.6	10.6	3.3	Mandible (M15)	–	–	–
18489	Human	-19.2	10.9	Adult	–	1.1	38.7	10.9	3.4	Mandible (M20)	–	–	–
18490	Human	-19.9	9.4	Adult	–	2.8	43.1	9.4	3.3	Mandible (M23)	–	–	–
18481	Human	-19.4	10.2	Adult	–	4.6	42.6	10.2	3.3	Mandible (M10)	–	–	–
18498	Human	-19.5	10.2	Adult	–	3.7	42.3	10.2	3.3	Mandible (M39)	–	–	–
18506	<i>Ovis aries</i>	-20.0	4.9	Adult	–	7.0	43.9	15.7	3.3	Metapodial	–	–	–
18509	<i>Ovis aries</i>	-18.5	8.7	Adult	–	6.0	44.0	15.8	3.2	Tibia	–	–	–
18510	<i>Ovis aries</i>	-19.1	6.2	Adult	–	2.1	41.3	14.7	3.3	Metapodial	–	–	–
18507	<i>Ovis aries</i>	-20.2	6.6	Subadult	–	3.3	40.4	14.3	3.3	Metapodial	–	–	–
18508	<i>Ovis aries</i>	-20.0	6.8	Subadult	–	7.6	41.0	14.8	3.2	Metapodial	–	–	–
18520	<i>Ovis aries</i>	-19.5	6.9	Subadult	–	5.9	43.2	15.6	3.2	Radius	–	–	–
18511	<i>Oryctolagus cuniculus</i>	-21.4	3.7	Adult	–	3.4	42.2	14.9	3.3	Humerus	–	–	–
18512	<i>Oryctolagus cuniculus</i>	-21.7	5.1	Adult	–	4.7	41.6	14.9	3.3	Femur	–	–	–
18513	<i>Oryctolagus cuniculus</i>	-21.5	3.6	Adult	–	6.2	44.3	16.0	3.2	Femur	–	–	–
18514	<i>Oryctolagus cuniculus</i>	-21.3	5.0	Adult	–	5.7	43.8	15.9	3.2	Ulna	–	–	–
18515	<i>Oryctolagus cuniculus</i>	-22.1	4.6	Subadult	–	4.1	41.9	14.6	3.3	Femur	–	–	–
18516	<i>Oryctolagus cuniculus</i>	-20.3	7.6	Subadult	–	4.6	42.1	15.0	3.3	Femur	–	–	–
18517	<i>Sus domesticus</i>	-19.8	10.5	Subadult	–	5.4	43.5	15.7	3.2	Mandible	–	–	–
18521	<i>Meles meles</i>	-16.8	5.3	Adult	–	4.4	42.4	15.1	3.3	Femur	–	–	–
18522	<i>Vulpes vulpes</i>	-18.9	7.9	Adult	–	5.4	42.8	15.3	3.3	Skull	–	–	–
18523	<i>Felis silvestris</i>	-19.1	6.7	Adult	–	8.8	42.7	15.5	3.2	Skull	–	–	–
18524	<i>Meles meles</i>	-18.7	11.4	Adult	–	3.7	42.9	15.4	3.2	Skull	–	–	–

was not possible to assess the molar wear pattern due to post-mortem or ante-mortem molar loss. In 2 cases, the ante-mortem molar loss was associated to degenerative traits, suggesting an older age inside the adult group. No sexual identification has been attempted, as no human remains were found in primary position to test if the mandibular dimorphic traits are in agreement with sexual dimorphism of the innominate bone or other more diagnostic skeletal elements (Buikstra and Ubelaker, 1994). Distribution of biological age and wear molar pattern of the sample analysed is included in Table 2 and Fig. 3.

4.2. Zooarchaeological and environmental reconstructions

More than a hundred faunal remains are present at the San Juan cave burial. Of these, 79 have been taxonomically identified, and 36 have been classified as indeterminate (Table 3). Overall, the MNE (Minimum Number of Skeletal Elements) is 74. The most frequently represented elements are metapodials (12), ribs (10), vertebrae (10), pelvis (8), and teeth (7). The long bones show an analogous representation, comprising in order of decreasing frequency tibiae (9), femora (8), humeri (6), and radiuses (4). Complete or fragmented crania are less represented (5), as well as mandibles (1). Most of the taxonomically assigned remains belong to *Oryctolagus cuniculus* (European rabbit, $n = 59$), followed by *Ovis aries* (sheep, $n = 10$), *Felis silvestris* (wildcat, $n = 5$), *Vulpes vulpes* (red fox, $n = 4$), *Meles meles* (European badger, $n = 3$), *Sus domesticus* (pig, $n = 3$) and *Lepus granatensis* (Iberian hare, $n = 2$) (Table 3, Fig. 4). As far as the elements classified by size are concerned, all these elements belong to the small-sized category (20–100 kg). Furthermore, microfaunal remains from *Bufo bufo*, *Arvicola sapidus*, *Talpa europaea* and *Serpentes* indet. have also been recovered. Regarding the number of individuals, *Oryctolagus cuniculus* (MNI = 4) is the predominant taxon in the assemblage, representing 36% of the total. The species *Ovis aries* is the next most abundant taxa (MNI = 2, one juvenile and one adult), representing 18% of all. The remaining taxa are represented by only one individual (Fig. 4).

Carnivore marks are abundant in the assemblage. They appear in 29 remains, representing 33.7% of the sample. All the herbivores except *Sus domesticus* show alterations produced by carnivores. The Iberian hare is the mammal with the highest percentage of modified remains (100%), although only two elements have been recovered from this taxon. The herbivore with the next highest percentage of modified remains by carnivores is *Oryctolagus cuniculus*, with 40% from a sample of 59 remains. The sheep present 37.5% of its remains with carnivore marks from a total of 8. The main types of carnivore tooth marks found are pits, scores, punctures, crenulated edges and scooping outs. Considering all the taxa as a whole, the most modified elements are the tibiae (88%),

followed by the pelvis (62%) and the humeri (50%). The other elements show less modification, with a percentage equal to or less than 25%. Pits and scores are the most abundant tooth marks, present in a total of 15 and 12 skeletal remains respectively. Furrowing has been confirmed in six remains. Furthermore, the breakage caused by carnivores is recorded by the presence of crenulated edges (Number of Remains = 6) and scooping outs (Number of Remains = 2), and eight remains have been found showing evidence of digestion. However, no remains show evidence of anthropic cut marks. Despite the cave being a burial, there seems to be no anthropogenic influence in the origin of the faunal assemblage, suggesting the cave was possibly used at some point as a carnivore den in which red fox or wild cat accumulated herbivore remains.

This assemblage, although scarce, is useful to make environmental inferences from the past, as the herbivores present at San Juan cave are associated with various types of landscapes. The leporids (*Oryctolagus cuniculus* and *Lepus granatensis*) indicate open environments (Gálvez-Bravo, 2011; Purroy, 2011). On the other hand, *Sus domesticus* and *Ovis aries* prefer a broad range of habitats (Rowley-Conwy et al., 2012). The carnivores of San Juan cave (*Meles meles*, *Felis silvestris* and *Vulpes vulpes*) are opportunistic carnivores that populate wooded habitats ranging from Mediterranean to high mountainous areas (Palomo, 2007). Taking all this into account, the purported landscape at the time of the burials would be similar to what we currently find in the area around the cave, the mouth of which opens at a ravine with rocky walls, but close to the open environment suitable for leporids of the Hoya de Huesca.

4.3. Carbon and nitrogen stable isotope ratios

Bone samples from 33 humans and 16 animals were analysed from San Juan cave. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results are presented in Table 2 and plotted in Fig. 5. All the samples from San Juan cave yielded enough collagen at the >30 kDa fraction for analysis in duplicate. Their %C, %N and C:N elemental ratio values indicate a good collagen quality (Ambrose, 1993; Van Klinken, 1999).

Herbivore $\delta^{13}\text{C}$ values range between -22.1‰ and -18.5‰ with a mean value of $-20.5 \pm 1.1 [1\sigma]\text{‰}$. These $\delta^{13}\text{C}$ values are consistent with typical values for a terrestrial C_3 European ecosystem (De Niro and Epstein, 1978; Schwarcz and Schoenniger, 1991). The high deviation is caused by ^{13}C -depleted rabbit $\delta^{13}\text{C}$ values. Herbivore $\delta^{15}\text{N}$ values are between 3.6‰ and 8.7‰, with a mean value of $5.8 \pm 1.6 [1\sigma]\text{‰}$, defining the trophic baseline of the ecosystem foodweb. The highest values belong to adult ovicaprids, which also show the biggest dispersion of $\delta^{15}\text{N}$ values, followed by subadult rabbit values, showing their possible nursing effect (Fogel et al., 1989). Carnivore $\delta^{13}\text{C}$ values range between -19.1‰ and -16.8‰ , with a

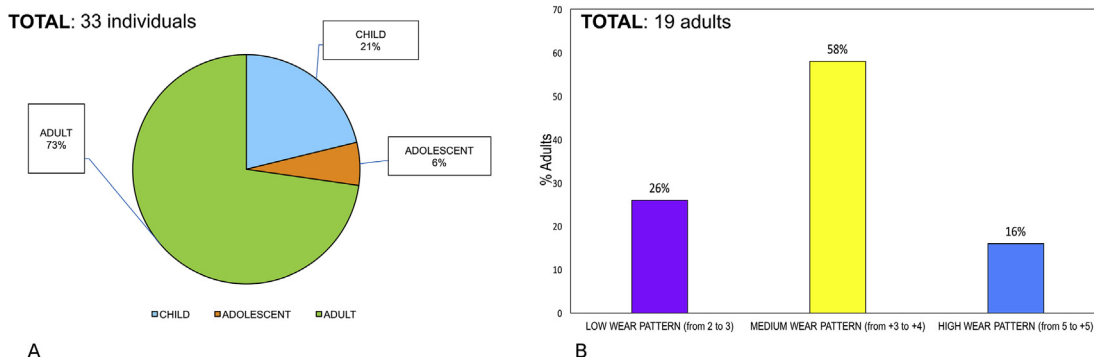


Fig. 3. A) Distribution of biological age; and B) molar wear pattern groups of the samples analysed (see text for details).

Table 3

NR (Number of Remains), NISP (Number of Identified Specimens), MNE (Minimum Number of Elements) by taxa and size categories from San Juan cave faunal assemblage [dP4: third milk molar; m2: second lower molar; P4: fourth upper premolar; P3: third upper premolar; M1: first upper molar].

Sample code	Element	Taxa	NR	NISP	NME	NMI
NIG 11678	Vertebrae	<i>Oryctolagus cuniculus</i>	7	7	7	2
NIG 11678	Metacarpals/Metatarsals	<i>Oryctolagus cuniculus</i>	9	9	9	1
NIG 11678	Scapula	<i>Oryctolagus cuniculus</i>	2	2	2	2
NIG 11678	Pelvis	<i>Oryctolagus cuniculus</i>	8	8	7	4
NIG 11678	Tibia	<i>Oryctolagus cuniculus</i>	8	8	7	4
NIG 11678	Humerus	<i>Oryctolagus cuniculus</i>	6	6	6	3
NIG 11678	Femur	<i>Oryctolagus cuniculus</i>	7	7	7	4
NIG 11678	Radius	<i>Oryctolagus cuniculus</i>	3	3	3	2
NIG 11678	Ribs	<i>Oryctolagus cuniculus</i>	9	9	9	1
NIG 11678	Tibia	<i>Lepus granatensis</i>	1	1	1	1
NIG 11678	Femur	<i>Lepus granatensis</i>	1	1	1	1
NIG 11678	Long bone	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Radius	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Metatarsus	<i>Ovis aries</i>	2	2	2	1
NIG 11678	Metacarpus	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Scaphocuboide	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Lumbar vertebra	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Ribs	<i>Ovis aries</i>	1	1	1	1
NIG 11678	dP4	<i>Ovis aries</i>	2	2	1	1
NIG 11678	m2	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Tibia	<i>Ovis aries</i>	1	1	1	1
NIG 11678	Mandible	<i>Sus domesticus</i>	1	1	1	1
NIG 11678	M1	<i>Sus domesticus</i>	2	2	1	1
NIG 11678	Skull fragment	<i>Felis silvestris</i>	1	1	1	1
NIG 11678	Maxilar P4 and P3	<i>Felis silvestris</i>	1	1	1	1
NIG 11678	Incisive	<i>Felis silvestris</i>	1	1	1	1
NIG 11678	Skull fragment	<i>Felis silvestris</i>	1	1	1	1
NIG 11678	Pelvis	<i>Felis silvestris ?</i>	1	1	1	1
NIG 11678	Atlas	<i>Meles meles</i>	1	1	1	1
NIG 11678	Skull	<i>Meles meles</i>	1	1	1	1
NIG 11678	M1	<i>Meles meles</i>	1	1	1	1
NIG 11678	Cervical vertebra	<i>Vulpes vulpes</i>	1	1	1	1
NIG 11678	Maxilar P4 and M1	<i>Vulpes vulpes</i>	1	1	1	1
NIG 11678	Skull fragment	<i>Vulpes vulpes ?</i>	2	2	1	1
NIG 11678	Skull fragment	Indet.	1			
NIG 11678	Indeterminate	Mammals	12			
Total			101	88	83	10

mean value of -18.4 ± 1.1 [1σ] ‰. Three of four $\delta^{13}\text{C}$ values (-19.1‰ , -18.9‰ and -18.7‰) are consistent with typical values for a terrestrial C_3 european ecosystem (De Niro and Epstein, 1978; Schwarcz and Schoeninger, 1991), while a *Meles meles*, shows an unusual higher value (-16.8‰). This could be explained if it comes from a foreign ecosystem or if it consumes small mammals, reptiles or carrion from big mammals (Martín et al., 1995). Carnivore $\delta^{15}\text{N}$ values are between 5.3‰ and 11.5‰ , with a mean value of 7.9 ± 2.7 [1σ] ‰, positioning this group in a higher trophic level than the

herbivores. The highest $\delta^{15}\text{N}$ data belongs also to *Meles meles*. There is only one $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ value from a subadult omnivore, *Sus domesticus* ($\delta^{13}\text{C} = -19.8\text{‰}$; $\delta^{15}\text{N} = 10.5\text{‰}$), which is placed above carnivores, possibly caused by a nursing effect (Fogel et al., 1989; Fuller et al., 2006) and/or by feeding on anthropic wastes (Müldner and Richards, 2005).

The human $\delta^{13}\text{C}$ values range between -19.9‰ and -18.4‰ , with a mean value of -19.3 ± 0.3 [1σ] ‰. Human $\delta^{15}\text{N}$ values go between 9.1‰ and 11.6‰ , with a mean value of 10.3 ± 0.6 [1σ] ‰.

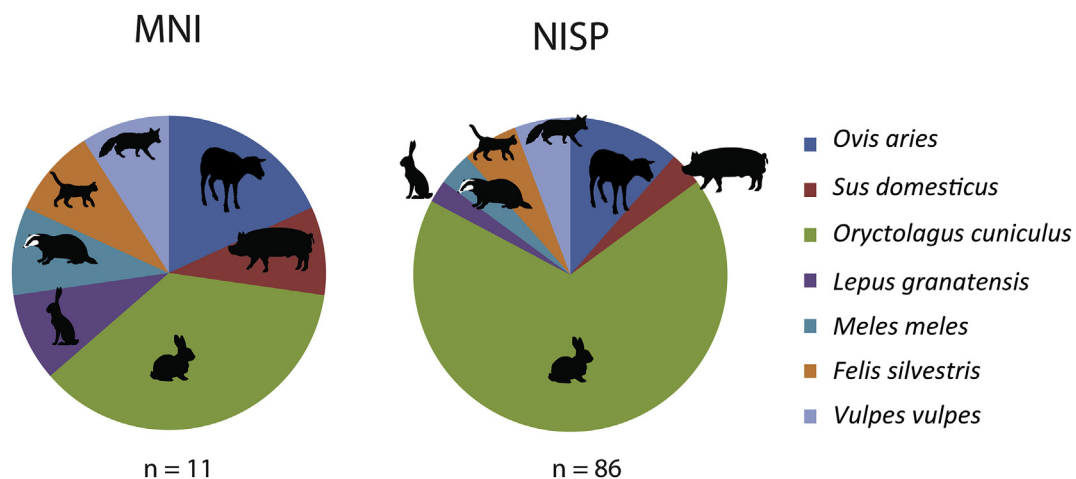


Fig. 4. % MNI (Minimum Number of Individuals) and % NISP (Number of Identified Specimens) of the faunal assemblage from San Juan cave.

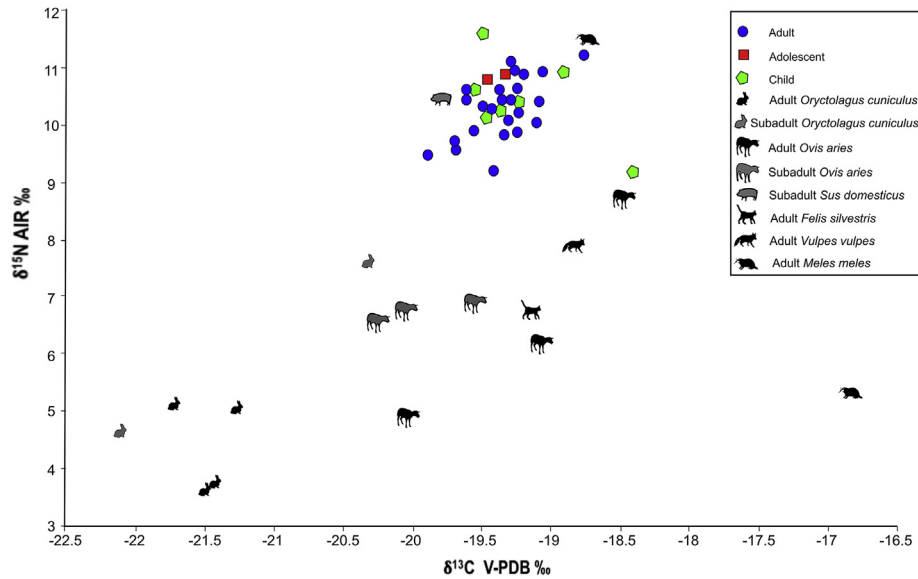


Fig. 5. Scatter plot of human and animal bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from San Juan cave.

These values show that human dietary protein was mainly coming from C_3 terrestrial resources, with no evidence of regular aquatic resource consumption, and that humans are at a higher trophic level than contemporary adult herbivores ($\delta^{15}\text{N}$ 5.3‰ higher than the mean) and even carnivores ($\delta^{15}\text{N}$ 2.4‰ higher than the mean).

A non-parametric statistical test (Mann-Whitney) reveals that isotopic values do not differ between age groups (adult and subadult, $\delta^{13}\text{C}$: $p = 0.744$; $\delta^{15}\text{N}$: $p = 0.292$), and children (3–12 years), not showing breastfeeding or weaning influence amongst the latter (Fuller et al., 2006). A non-parametric statistical test (Kruskal-Wallis) was applied to test if there were different $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values among the different groups of molar wear patterns observed. No significant differences can be seen nor in $\delta^{13}\text{C}$ ($p = 0.777$) or in $\delta^{15}\text{N}$ ($p = 0.832$) values among the different molar wear pattern groups (Fig. 6).

4.4. $^{87}\text{Sr}/^{86}\text{Sr}$ results

4.4.1. Bioavailable strontium from modern samples

The results of plants and snails analysed to determine bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ are presented in Table 4. Different geological

zones sampled around San Juan cave are shown in Fig. 7. Strontium isotope ratios in the proximity of San Juan cave, (Cretaceous-Miocene) show a range between 0.709984–0.708291 for plants and 0.708943–0.708243 for snails. Paleogene deposits show a similar bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values with a range between 0.708306–0.708249 for plants and 0.708188–0.707986 for snails (Fig. 8). The range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values from the geological area where San Juan cave is located was higher than that for the bioavailable range from the Paleogene deposits. This is probably due to San Juan cave being situated in a transition Cretaceous-Miocene geological area.

The range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values for plants was larger than for snails. The range in this group is likely caused by the different kinds of plants sampled, herbaceous, bushes and trees, which take water from different depths within the ground. The small range for $^{87}\text{Sr}/^{86}\text{Sr}$ values from snails reflects the extremely limited movement over the landscape.

4.4.2. Strontium in archaeological material

$^{87}\text{Sr}/^{86}\text{Sr}$ enamel ratios from small vertebrates, small-medium sized mammals and humans were analysed. They include 32

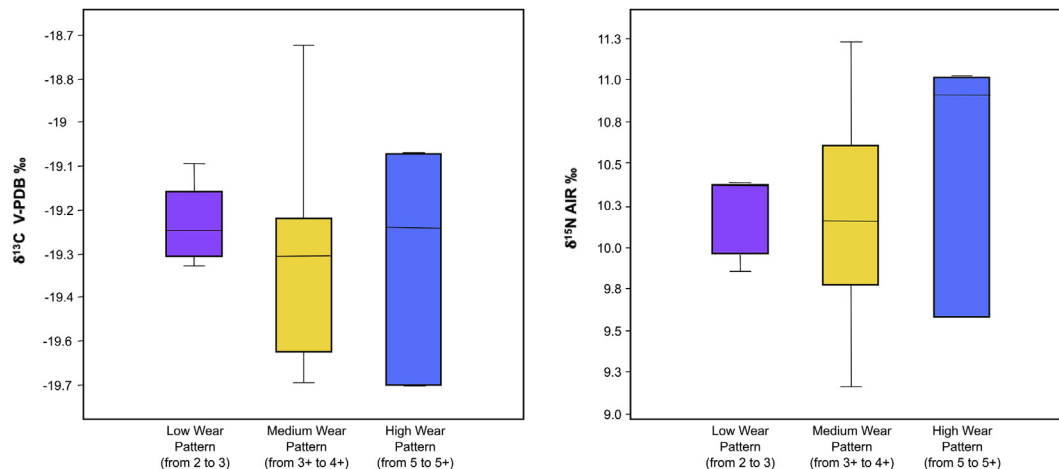
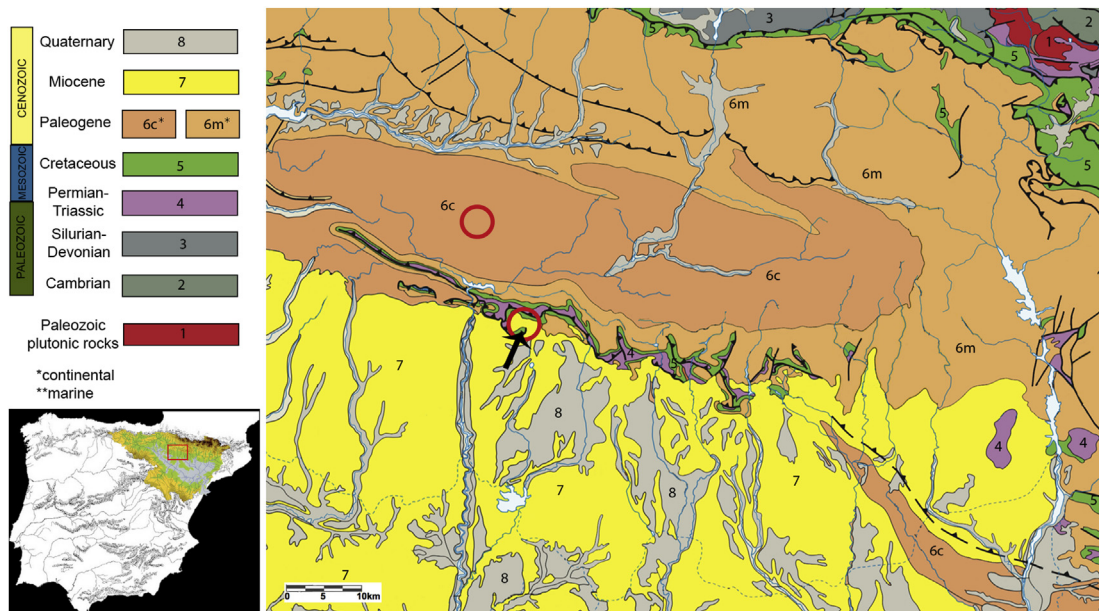


Fig. 6. Box plot of bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of different wear pattern measured in adults from San Juan cave according to Brothwell (1989). Boxes represent the median value and 1st and 3rd quartiles, whiskers are 1.5 times the interquartile range.

Table 4 $^{87}\text{Sr}/^{86}\text{Sr}$ and Sr concentration (ppm) of bioavailable samples: sample type or genus/specie, S-UCT code and corresponding geologic area.

Sample type/Genus/Specie	Origin	S-UCT Code	Geological zone	$^{87}\text{Sr}/^{86}\text{Sr}$	Sr conc. [ppm]
Snail (<i>Helix</i> sp.)	modern	18277	Cretaceous-Miocene	0.708943	–
Snail (<i>Helix</i> sp.)	modern	18278	Cretaceous-Miocene	0.708275	–
Snail (<i>Helix</i> sp.)	modern	18279	Cretaceous-Miocene	0.708729	–
Snail (<i>Helix</i> sp.)	modern	18280	Cretaceous-Miocene	0.708266	–
Snail (<i>Helix</i> sp.)	modern	18281	Cretaceous-Miocene	0.708243	–
Herbaceous	modern	18113	Cretaceous-Miocene	0.709984	–
Bush (<i>Buxus sempervirens</i>)	modern	18114	Cretaceous-Miocene	0.708322	–
Tree (<i>Quercus ilex</i>)	modern	18115	Cretaceous-Miocene	0.708915	–
Bush (<i>Juniperus</i> sp.)	modern	18116	Cretaceous-Miocene	0.708291	–
Bush (<i>Rubus ulmifolius</i>)	modern	18117	Cretaceous-Miocene	0.708378	–
Tooth (<i>Oryctolagus</i> sp.)	archaeological	18419	Cretaceous-Miocene	0.708490	167.1
Tooth (<i>Oryctolagus</i> sp.)	archaeological	18420	Cretaceous-Miocene	0.709047	140.0
Tooth (<i>Oryctolagus</i> sp.)	archaeological	18423	Cretaceous-Miocene	0.708710	177.0
Tooth (<i>Bufo</i> sp.)	archaeological	18421	Cretaceous-Miocene	0.708885	129.7
Tooth (<i>Talpa</i> sp.)	archaeological	18422	Cretaceous-Miocene	0.708506	167.1
Snail (<i>Helix</i> sp.)	modern	18307	Continental Paleogene	0.707986	–
Snail (<i>Helix</i> sp.)	modern	18308	Continental Paleogene	0.708031	–
Snail (<i>Helix</i> sp.)	modern	18309	Continental Paleogene	0.708096	–
Snail (<i>Helix</i> sp.)	modern	18310	Continental Paleogene	0.708004	–
Snail (<i>Helix</i> sp.)	modern	18311	Continental Paleogene	0.708189	–
Herbaceous	modern	18143	Continental Paleogene	0.708306	–
Bush (<i>Pistacia lentiscus</i>)	modern	18144	Continental Paleogene	0.708249	–
Tree (<i>Pinus</i> sp.)	modern	18145	Continental Paleogene	0.708283	–
Bush (<i>Juniperus</i> sp.)	modern	18146	Continental Paleogene	0.708270	–
Bush (<i>Buxus sempervirens</i>)	modern	18147	Continental Paleogene	0.708060	–

**Fig. 7.** Simplified geological map of the area of the Ebro Basin discussed in the text. The tip of the arrow indicates the location of San Juan cave and the circles show the sampling areas for bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range.

samples from 21 human individuals, 3 samples from rabbit (*Oryctolagus cuniculus*), and 2 samples from mole (*Talpa europaea*) and toad (*Bufo Bufo*). $^{87}\text{Sr}/^{86}\text{Sr}$ and Sr concentration (ppm) results from San Juan cave human enamel are presented in Table 2, and small vertebrate enamel results are presented in Table 4. A plot with enamel and bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ values from San Juan cave is shown in Fig. 8.

There are only four individuals (M42: 0.710415 -second molar-; M30: 0.710787-second molar-; C7: 0.711710 -second molar- and 0.711142 -third molar-; M13: 0.707750 -second molar- and 0.707838 -third molar-) whose $^{87}\text{Sr}/^{86}\text{Sr}$ values are outside of the local bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range, and not within the Paleogene

bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range showed in the present study. The M13 individual shows a $^{87}\text{Sr}/^{86}\text{Sr}$ value lower than the bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range of the two zones (surroundings of the caves with Cretaceous-Miocene transition and Paleogene deposits), and M42, M30 and C7 individuals have a higher value than the bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ range from both. The high $^{87}\text{Sr}/^{86}\text{Sr}$ values from both the second and third molars of individuals C7 and M13 suggest that these individuals spent their childhood and early adulthood in the same place, where both molars mineralized (Hillson, 1996). There was no great difference between inter-tooth analysis from same individuals, being the highest variation of 0.0006 (C7 individual; M2-M3) and 0.0001 the lowest (C1 individual; M2-M3).

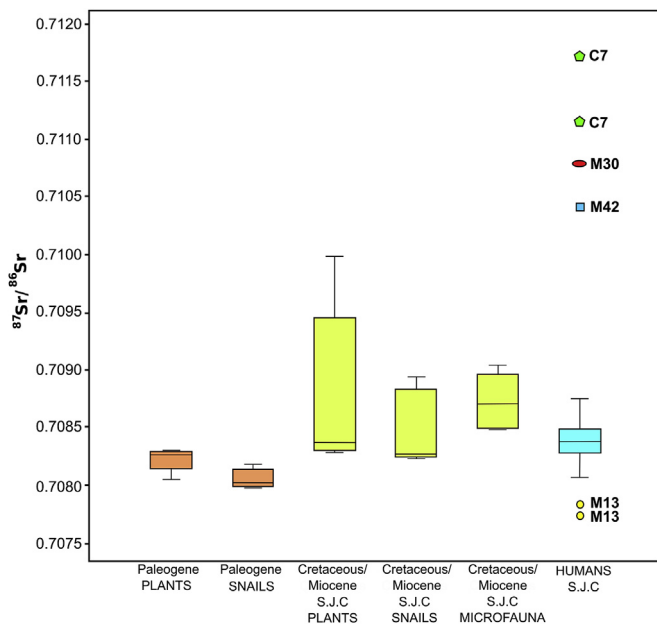


Fig. 8. Box plot of $^{87}\text{Sr}/^{86}\text{Sr}$ range for bioavailable samples from different geologic areas, modern plant and modern snails, microfauna teeth taken from the archaeological burial context and human teeth. Boxes represent the median value and 1st and 3rd quartiles, whiskers are 1.5 times the interquartile range. The outlier values are shown [S.J.C: San Juan cave].

Differences between individuals are higher than inter-tooth analyses done in same individuals (Fig. 9). Two bone samples of these four non-local individuals were sent to DirectAMS laboratories in Seattle (Washington) to be dated by Radiocarbon with AMS. These new radiocarbon dates refer to M30 (4087 ± 28 BP) and M42 (4053 ± 35 BP) (Table 1, Fig. 2).

5. Discussion

San Juan cave is a typical collective burial site from the Late Neolithic-Chalcolithic period situated on the Ebro Basin (Rodanés

et al., 2016). The radiocarbon record for San Juan cave shows the use of the cavity during all the Late Neolithic-Chalcolithic period and, sporadically, also during the Bronze Age (Table 1, Fig. 2). The high number of radiocarbon dates from the Late Neolithic-Chalcolithic period suggests a greater sepulchral use during this phase. This recurrent use of the cavity is also proved by the kind of grave goods found inside the cave, which show high concentrations of material attributed to the Late Neolithic-Chalcolithic period (Pastor and Vicente, 2009). These grave goods have parallels with other sepulchral sites located in the high Ebro Valley, for example those from the sites of San Juan Ante Portam Latinam (Etxeberria et al., 1999) and Cueva de Abauntz (Utrilla et al., 2015).

It is possible that when the cave began to have a less intensive use, carnivores visited the cave more regularly and accumulated their preys in it. This could explain the high percentage of faunal remains with carnivore marks. A few herbivore remains do not have carnivore modifications, so it is not possible to rule out the intentional accumulation by humans. Faunal and human remains are commingled with each other because of human bone reacommodations, making this impossible to distinguish between casual or intentional accumulation by humans. Apart from that, all faunal remains seem to be in the same archaeological context.

The domestic faunal remains recovered from San Juan cave show overall high $\delta^{15}\text{N}$ values, which could be associated to it being a warm ecosystem where organic nitrogen is taken by plants more efficiently (Amundson et al., 2003; Handley et al., 1999). This idea would be supported by environmental studies done in Estanya Lake, in the Pre-Pyrenean range, which portray a warmer climatic phase in the Recent Holocene (4200–2000 cal. BP) for the region (González-Sampériz et al., 2017). However, in this case the high $\delta^{15}\text{N}$ values can't be explained by warmer conditions alone, because most of wild faunal remains (rabbits and carnivores) do not show increased $\delta^{15}\text{N}$ values similar to the ones observed amongst contemporary domestic animals. Only one subadult rabbit shows a higher value ($\delta^{15}\text{N} = 7.6\text{‰}$) that could be due to a nursing effect (Fogel et al., 1989). Carnivores present in the sample (*Felis silvestris*, *Vulpes vulpes* and *Meles meles*) do not show elevated $\delta^{15}\text{N}$ values compared with domestic herbivores (only 1.1‰ higher). Only one *Meles meles* presents an elevated $\delta^{15}\text{N}$ value that might be caused by carrion feeding (Martín et al., 1995). In the case of the carnivores,

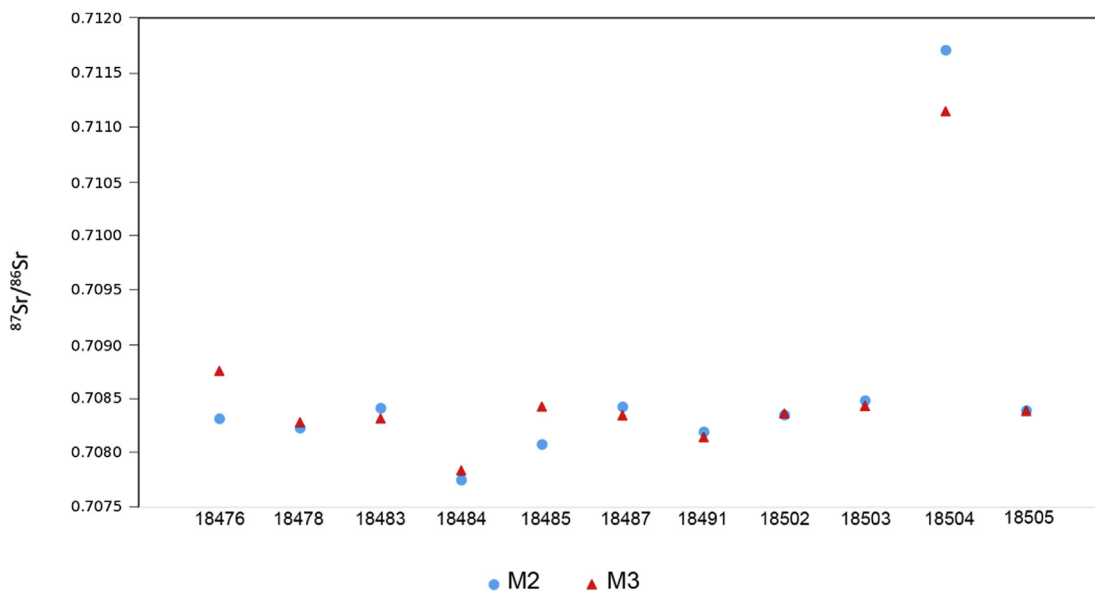


Fig. 9. Plot of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of human enamel inter-tooth samples from same individuals. The legend shows the molar piece: second molar (M2: completed mineralization during childhood) and third molar (M3: completed mineralization during early adulthood). Horizontal axis refers to the S-UCT code.

the low $\delta^{15}\text{N}$ values could be explained by a sporadic domestic herbivore intake and a more usual wild herbivore intake that would have lower $\delta^{15}\text{N}$ values (e.g. rabbits). On the other hand, higher $\delta^{15}\text{N}$ values from domesticated herbivores could be explained by the use of composted fodder (Bogaard et al., 2007), as suggested by some authors for these chronologies in near-by regions (Salazar-García, 2012b). We should anyway consider the possibility that all human and faunal remains might not be strictly contemporaneous, as not all of them have been directly radiocarbon dated (Fig. 5).

The huge variability observed in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values from domestic adult ovicaprids could be explained by the presence of different sheep flocks (Martín et al., 2015) and also transhumance livestock activities, which are suggested by other isotopic studies in the recent Holocene of the Iberian Peninsula (Valenzuela-Lamas et al., 2016). Sequential $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotopic analysis done in ovicaprid teeth (Torner et al., 2016) are necessary to discriminate if the differences in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ ovicaprid values are due to transhumance activities or not. It is also possible that these range of values are due to livestock coming from different origins, perhaps through trading, or that all remains are after all not strictly contemporaneous.

The human isotope values from San Juan cave indicate a quite homogeneous protein diet based on C_3 terrestrial resources, and consistent with domestic herbivores being consumed preferentially. Differences between herbivore and human $\delta^{15}\text{N}$ values ($\delta^{15}\text{N}$ enrichment of 2.4‰) suggest a moderate animal protein intake assuming 3–5‰ as typical $\delta^{15}\text{N}$ collagen enrichment (Bocherens and Drucker, 2003). A mixed diet with a moderate animal intake combined with a plant food intake could be in agreement with the $\delta^{15}\text{N}$ values. Nevertheless, there are some limitations that are necessary to take into account. The most important limitation is the exclusive use of San Juan cave as a burial site. If the burial was shared by different communities, there is a risk that the $\delta^{15}\text{N}$ values from the few available faunal remains do not represent all available faunal resources at the time. Indeed, as this is something very difficult to prove at a burial site, it is necessary to calculate a common $\delta^{15}\text{N}$ baseline for all human individuals. Besides, the animal sample is very small and the $\delta^{15}\text{N}$ values for wild medium- and large-sized herbivores are unknown, being difficult to prove their consumption (much less to try to quantify it). There is, however, no isotopic evidence of the consumption of C_4 resources. Additionally, a regular feeding of marine or freshwater resources has not been observed, something supported by the lack of ictiofaunal remains recovered at the cave and surrounding sites (Fig. 5). Furthermore, all marine malacofaunal materials recovered at the site are perforated and suggested to be used as decorative beads and pendants (Pastor and Vicente, 2009). This is all consistent with the presence of exchange networks but not with the consumption of these resources.

The limited anthropological capacity of the human sample has not allowed making sex diagnoses, so possible differences between sexes cannot be tested as in other isotopic studies from the Neolithic period in the Western Mediterranean (Le Bras-Goude et al., 2009; Fontanals-Coll et al., 2015). However, no differences between adults and subadults have been observed. Only one of the five infants has high $\delta^{15}\text{N}$ values (1.3‰ higher than the mean adult value), probably as a result of the last moments of breastfeeding, at the transition to weaning (Fogel et al., 1989; Fuller et al., 2006). The remaining infants have similar values to adults, with one of them presenting the lowest $\delta^{15}\text{N}$ value of the whole population. This could be growth-related physiological processes, a signal of change in the diet, or both of them (Beaumont et al., 2013; Reynard and Tuross, 2015). Furthermore, and alternatively to specific ages amongst the adult individuals, dental wear from adult specimens analysed was checked against the isotopic values. No differences in

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were observed among individuals with different molar wear pattern (Fig. 6). It is possible that macro-wear tooth and protein consumption are here not correlated, making it necessary to use dental microwear to test this relationship as done in previous studies (Salazar-García et al., 2016a). Macrowear pattern could be associated with age in this case (Brothwell, 1989), but it is not possible to associate it to a discriminatory agent regarding protein consumption.

This homogeneous C_3 terrestrial based dietary subsistence pattern is representative of the Late Neolithic-Chalcolithic and the beginning of the Bronze Age. While no other previous isotopic studies have been carried out before for the Late Neolithic-Chalcolithic or Bronze Age in the Ebro Basin, there is data available from other surrounding Iberian regions for this chronology: La Pijotilla and Valencina-Castilleja in the south (Díaz-Zorita, 2014); Cova Moura, Paimogo I and Feteiras II in the west (Waterman et al., 2015); Cova do Santo in the north-west (López-Costas et al., 2015); and Cova de la Pastora, Avenc dels dos Forats (McClure et al., 2011), La Vital (Salazar-García, 2012b), Cova dels Diablets (Salazar-García, 2014b) and Coveta del Frare (García-Borja et al., 2013) in the east of the Iberian Peninsula. When plotting all human carbon and nitrogen isotope values available for the surrounding regions, we can see that there is not a large difference among the five areas and San Juan cave in the Ebro Basin (north-east) (Fig. 10). San Juan cave only presents slight differences in their $\delta^{13}\text{C}$ values regarding north and north-west plotted sites. It also shows some differences in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values with two southern sites. In both cases, standard deviations calculated for these groups are not overlapping, although the slight differences with the southern sites could be due to the low number of individuals analysed in that area ($n = 8$). Therefore, an homogeneous C_3 terrestrial diet with no clear marine input was the common feeding pattern during the Late Neolithic-Chalcolithic Period among the different regions of Iberia.

$^{87}\text{Sr}/^{86}\text{Sr}$ data show that only 4 of 21 individuals (19% of the total studied population) come from further afield than the surroundings of San Juan cave: M13, M42, M30 and C7 (Fig. 8). Non-local individuals found in a sepulchral cave could have different meanings. They could be actual migrants that travelled at some point during their life to settle at a community living close to San Juan

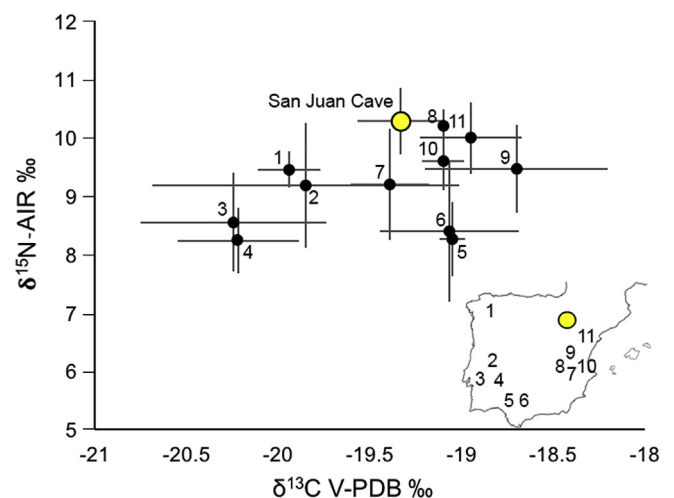


Fig. 10. Plot of bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of different Late Neolithic-Chalcolithic and Bronze sites from Iberian Peninsula [1: Cova do Santo (López-Costas et al., 2015); 2,3,4: Cova Moura, Paimogo I and Feteiras II (Waterman et al., 2015); 5, 6: Valencina-Castilleja and La Orden-Seminario (Díaz-Zorita, 2014); 7, 8, 9, 10, 11: La Vital (Salazar-García, 2012b), Coveta del Frare (García-Borja et al., 2013), Cova de la Pastora, Avenc dels dos Forats (McClure et al., 2011), Cova dels Diablets (Salazar-García, 2014b)]. The position of the numbers is approximate.

cave, where they were eventually buried. Or, alternatively, could mean that the site was used as a shared funerary space by communities living in a wider area encompassing different major geological regions other than the one from the immediate burial surrounding. In order to better assess these two possibilities, distances should be considered. If a non-local individual shows values compatible with those from nearby geological areas, we can't rule out the possibility that the individual is no real migrant but instead was transported to the cave from its "local" community once dead. However, if the non-local values correspond to geological domains situated further away, it is less plausible that the corpse was brought into the cave from far away distances, and we are possibly talking in this case of a real migrant.

Individual M13 shows $^{87}\text{Sr}/^{86}\text{Sr}$ values lower than those from San Juan cave surroundings (Cretaceous-Miocene) and nearby Paleogene deposits. If it is considered that lower $^{87}\text{Sr}/^{86}\text{Sr}$ values come from more recent geologic deposits (Bentley, 2006), it is possible to speculate that individual M13 came from the flattest area of the Ebro Valley, which is dominated exclusively by Miocene-Quaternary deposits. Furthermore, since both second and third molar values are similar and lower than the local range, it is quite possible that this individual arrived only after the mineralization of the third molar occurred during early adulthood (Hillson, 1996). As Miocene-Quaternary deposits exist close to the cave in a southern direction, individual M13 could well be either a migrant or an example of corpse transportation from a local community. Furthermore, as this study has confirmed that Paleogene deposits show similar $^{87}\text{Sr}/^{86}\text{Sr}$ values to those from San Juan cave immediate surroundings (Cretaceous-Miocene), and knowing that a huge part of the Ebro Valley is dominated by this type of deposits, it is difficult to know if migrants coming from this latter type of geology could be also masked among the sample population (i.e. even if non-locals, they would have same values as local people).

Individuals C7, M30 and M42 show higher $^{87}\text{Sr}/^{86}\text{Sr}$ values than the bioavailable Sr range from San Juan cave surroundings (Cretaceous-Miocene) and nearby Paleogene deposits. C7 also shows similar values for second and third molars, suggesting as well a movement after his early adulthood (Hillson, 1996). Noteworthy is that $^{87}\text{Sr}/^{86}\text{Sr}$ values from these non-local individuals (M42, M30 and C7) are consistent with published bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ data from the southwest of the Iberian Peninsula (Waterman et al., 2014), as well as from Lower Triassic deposits of northern Iberia (Villalba-Mouco et al., 2017). Because of proximity, it is likely that these individuals arrived from other regions with abundant Lower Triassic formations: the Iberian System in the south of San Juan cave or the Navarre Pyrenees in the north (visible on the geological map from Instituto Geológico y Minero, Ministerio de Ciencia e Innovación, Gobierno de España; (<http://www.igme.es/>)). In this two cases the Lower Triassic deposits with considerable surface area are more than 100 km away from San Juan cave, and it is therefore likely that these three individuals (M30, M42 and C7) are actual migrants coming from afar. As a result, and further supported by the fact that all this far away region is full of cavities potentially available for burying the dead, the corpse-transportation hypothesis is in the case of individuals M30, M42 and C7 case less plausible than in the case of individual M13.

Only two of the non-local individuals have been directly radiocarbon dated: M30 (4087 ± 28 BP) and M42 (4053 ± 35 BP). That both of these dates correspond to the later stages of the Late Neolithic-Chalcolithic suggest that the purported higher mobility pattern would have started only at the end of the Late Neolithic-Chalcolithic period (Fig. 2). This proposed higher mobility scenario could be also common amongst other communities of the Ebro Basin with same cultural attribution. It could also be that San Juan cave started to be used overall more during this stage, and therefore

have more probability of detecting the non-locals by randomly sampling for dating. As a result of this uncertainty, it is necessary to perform more intensive radiocarbon studies in collective burials of the region as done elsewhere in Iberia (e.g. Salazar-García et al., 2016b). A more detailed study encompassing a wider variety of geological sampling areas for better portraying the bioavailable strontium map of Iberia would also help in profiling better provenance and territorial mobility of these past farming communities.

6. Conclusions

This study represents the first multi-isotope analysis of dietary and mobility strategies from the Ebro Basin Late Neolithic-Chalcolithic period. The isotopic dietary study shows a mixed diet based on C_3 terrestrial resources, with domestic herbivores as probably the main protein source. The individuals buried in San Juan cave did not consume marine or freshwater resources, at least enough as to have it reflected on the bone collagen signature. No differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are observed between adults and subadults, nor between different molar wear patterns. Only four individuals are potentially detectable non-locals, as their $^{87}\text{Sr}/^{86}\text{Sr}$ values are different from those of the immediate geological surrounding of the cave and the region. This mobility pattern seems to have happened at the end of the cave's use as burial site, during the end of the Late Neolithic-Chalcolithic period, as shown by the radiocarbon dates of these individuals. The $^{87}\text{Sr}/^{86}\text{Sr}$ bioavailable values that exist today for the Iberian Peninsula suggest different origins for these non-local individuals: one from Miocene-Quaternary deposits, and three from Lower Triassic geologic regions. The flattest part of the Ebro Valley is dominated by a Miocene-Quaternary geology, but the closest Lower Triassic geologies to San Juan cave are in the Navarre Pyrenees to the north or at the Iberian System to the south. Both of them are located more than 100 km away from the place of burial, suggesting a migration movement of at least these three individuals.

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