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ORIGINAL PAPER

Dietary reconstruction of the Bronze Age necropolis of Cova des Pas (Minorca Island): evidence from $\delta^{13}C$ and $\delta^{15}N$ analyses

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Abstract

Current paleodietary studies about the Naviform and Talayotic groups that took place in Minorca (Balearic Islands) during the Late Bronze Age–Early Iron Age (ca.1600–850/800 BC) have suggested a mixed and variable diet, largely depending on terrestrial sources of vegetables and meat. This study explores the nutritional pattern of the individuals buried in the Cova des Pas site (Minorca Island, Spain), a cave used as a collective sepulcher and the most exceptional and major human assemblage found in the Balearic Islands during this period. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopic signatures were measured on extracted bone collagen from 49 individuals. Further, faunal remains from the Son Mercer de Baix site, the closest contemporaneous village to the collective sepulcher, were also analyzed to provide a baseline corpus of data to interpret human isotopic data. The results indicate a human diet based mainly on C_3 plants with an important consumption of animal protein. The $\delta^{15}N$ values of infants up to 4 years were high, indicating the enriched isotopic signature of breast milk, and weaning is assumed to occur around this age. Differences between sexes and the age subcategories were not statistically significant, assuming that the different groups of society had the same access to food. The data obtained in this isotopic study provides insight into the palaeodietary pattern of the human groups dated to the Late Bronze Age–Early Iron Age ages in the island of Minorca, contributing to the present debate on the emergence and development of complex societies on the Balearic archipelago.

Keywords Bronze Age · Balearic Islands · Stable isotopes · Human diet · Social complexity

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Introduction

Diet is one of the most important factors to understand ancient human populations, which is not only a means of survival but a cultural and social phenomenon as it reflects the socioeconomic dynamics involved in subsistence strategies and access to food consumption (Gumerman 1997). The necessity of archaeological research to better approach issues of economy and ideology in antiquity quickly led to the study of food, its origins, its production, and its consumption. The analysis of stable isotopes from bones offers a direct way to reconstitute an organism's diet and hence is a very optimal way to overcome the current limitations of traditional osteological approaches (Tykot 2004; Knudson & Stojanowski 2008).

During the Bronze Age (ca.1600–850/800 cal BC), the Balearics witnessed the emergence and development of complex societies, including the Naviform culture (documented in the whole archipelago) and, later during the Early Iron Age, the Talayotic culture (ca.1100–600 cal BC, exclusively in Majorca and Minorca) (see Lull et al. 1999; Guerrero Ayuso et al. 2002; Anglada et al. 2014; Depalmas 2014). The dietary pattern of these periods corresponds to a controversial issue. The traditional hypothesis that had been launched was that its subsistence strategy focused on animal husbandry (Cerdá, 1978; Roselló-Bordoy 1968), with plant cultivation remaining of minor significance. However, bioarchaeological studies dealing with zooarchaeological, archaeobotanical, and anthropological remains (Hernández-Gasch et al. 2002; Pérez-Jordà et al. 2018) pointed out a mixed farming and herding economy, without a systematical use of marine or freshwater food items in Majorca and Minorca. Contrarily, in the island of Formentera, C_4 plants such as millet and marine resources, including fish and mollusks, were apparently consumed by prehistoric human groups (Sureda et al. 2017a). First studies using the isotopic $\delta^{13}C$ and $\delta^{15}N$ measurements from human and animal bone samples measured for radiocarbon dates (^{14}C) suggested similar results (Van Strydonck et al. 2005). Palaeodietary studies using elemental analysis on human bones recovered from the necropolis of the Cova des Càrritx (1400–800 cal BC) in Minorca show that contribution on diet was proportional between vegetables and meat (Pérez-Pérez et al. 1999). Multi-element analysis on human and animal bones of the neighboring necropolis of S'Illot des Porros (ca. 1400–850 cal. BC) revealed a mixed diet with a high consumption of marine food, seeds, and cereals (Subirà & Malgosa 1992a). Dental microwear studies of a Talayotic population such as the Son Real (ca. 800–600 cal. BC) population (Majorca, Spain) found also a mixed diet, but depending on abrasive plant foods and a reduced amount of meat intake (Jarošová et al. 2006). Very interesting in those studies was that archeobiochemical data presented no nutritional difference between males and females in Cova des Càrritx (Pérez-Pérez et al. 1999) and S'Illot des Porros (Subirà & Malgosa 1992b), while an increased vegetal or cereal food intake by females in comparison to males is hypothesized in Son Real (Jarošová et al. 2006).

The Cova des Pas (CdP) is one of the most important prehistoric sites in Minorca and the Balearic archipelago (Fig. 1). During its excavation, a unique collection of burials was recovered. Although other massive contemporaneous burial deposits have been documented up today in this area (e.g., Son Olivaret, Cova des Càrritx), this deposit allows the major representation of complete individuals (Malgosa et al. 2011). The possibility to study each individual as a whole allowed performing a variety of different diet studies, such as dental or boning analysis, and comparing between them. Furthermore, all the paleoanthropological information available from previous studies (Fullola et al. 2008; Armentano et al. 2010; Van Strydonck et al. 2010; Malgosa et al. 2011; Cañas Cortés 2012; Simón et al. 2016) permits a better approach and comparative analysis of the samples of the site and witnesses its uniqueness.

CdP is a small burial cave located on the left side of the Trebalúger ravine, near the town of Ferreries in Minorca (Balearic Islands, Spain). It is a small cavity, approximately 6.5 m wide and 4.5 m long, situated in the wall of the ravine about 15 m above the ground (Fullola et al. 2008) (again see Fig. 1). It was used as a collective sepulcher during the Late Bronze Age (1100–800 BC) by the Talayotic culture of Minorca (Bergadà et al 2015). The cave was discovered by three speleologists, Pere Arnau, Pep Riera, and Monica Zubillaga during the spring of 2005. During the excavation works in 2005–2006, the site was completely dug up, and an important set of burials in the cave was recovered (Fullola et al. 2007; Armentano et al 2010).

The environmental conditions of the cave allowed an exceptional state of preservation of the skeletal remains (Armentano et al. 2010). Anthropological studies identify a total set of 66 different individuals (Fig. 2). The burial shows a picture of age (35 adults and 31 subadults) and sex structure (25 women, 26 men, and 15 more of unknown sex) highly representative of the population of the island more than 3000 years ago, associated with the Talayotic period (Armentano et al 2010; Simón et al. 2016). Health status was also reconstructed revealing an extensive record of diseases that include other pathologies, from congenital alterations to tumors, fractures, inflammatory alterations, or injuries due to activity (Malgosa et al. 2011). On the taphonomic level, the studies carried out have been able to recognize a complex treatment of the corpse (Cañas Cortés 2012) and the conditioned burial space itself. The great relevance of this burial chamber lies in the relative preservation of human organic tissues, compatible with muscles, brain, and lungs, for instance (Armentano et al. 2012; Prats-Muñoz et al 2013). At the genetic level, the results indicate the existence of important endogamy at the level of mitochondrial DNA, which could indicate a closed and isolated population (Simon et al., 2016).

Son Mercer de Baix (SMB) is an open-air settlement located on the edge of the Fideu ravine (Ferreries, Minorca Island). It is, possibly, one of the most emblematic naviform villages in the Balearic Islands, due to the state of conservation of its Naviform I, or "Cova des Moro" (Fig. 3). The village is composed of, at least, 4 naviform structures (boat-shaped houses with cyclopean walls) and 2 other rectangular rooms connected to them (rooms 1 and 2). It was initially excavated by Mª Lluïsa Serra Belabre in 1962 (Naviform II) and later in the 1980s by Cristina Rita and Lluís Plantalamor (Naviforms III, IV, and the connected rooms) (Plantalamor & Rita 1983; Rita 1982, 1987, Rita and Topp 1988). Finally, in 2001, conservation and consolidation actions were performed at Naviform I, including the excavation of some exterior areas. Most of those materials

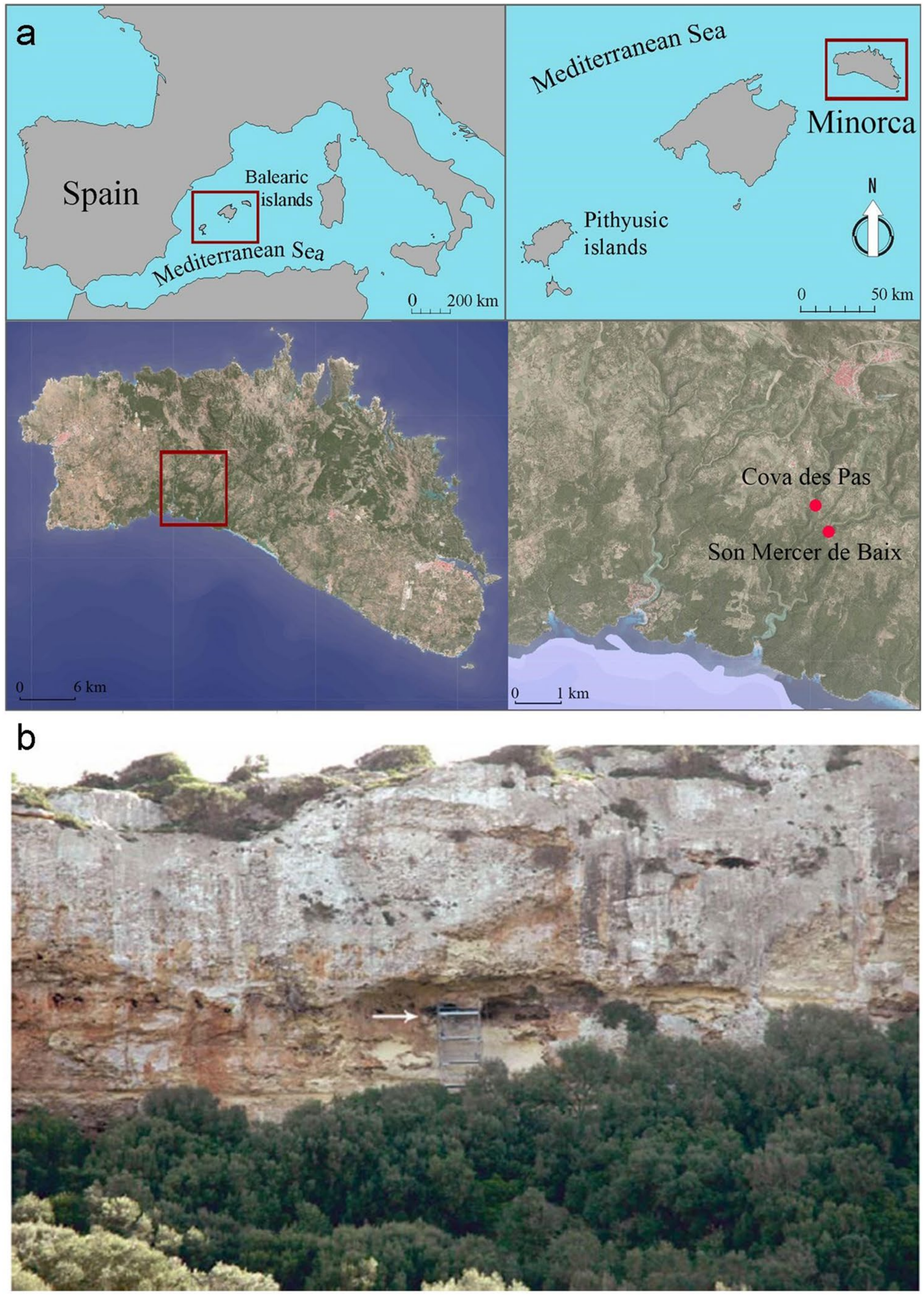


Fig. 1 **a** Map showing location of Cova des Pas (CdP) and Son Mercer de Baix (SMB) sites in the Minorca Island, Balearic Islands, and Mediterranean Sea. **b** The 15-m-high entrance (arrow) to the Cova des Pas (CdP) in the Trebalúger ravine in Minorca Island (Balearic Islands, Spain). Picture from Prats-Muñoz et al. (2012)

and archaeological contexts are still unpublished, although recently, some research related to their naviform structures or metallurgical remains have been started (Garcia Amengual 2006; Sureda 2022).

Balearic Naviform villages are known to have a large occupation sequence that could last several centuries as the cases of Closos de Can Gaià (Majorca) (Servera 2005) or Cap de Barbaria II (Formentera) (Sureda et al. 2017b). SMB presents a first Bronze Age (Early Naviform) occupation phase (ca. 1600–1200/1100 cal BC), represented by the naviform buildings but also by several archaeological materials, including typical Naviform ceramic and metallic assemblages (globular bowls, truncated conical cups, quadrangular chisel, riveted knife, bronze bracelet, or various crucibles).

Furthermore, a specific Late Bronze Age/Early Iron Age (*ca.* 1200/1100–800 cal BC) occupation phase can be inferred in the site, re-using some of the old buildings (Naviforms II, III, IV, rooms 1 and 2) and generating new archaeological features and sedimentary deposits, especially

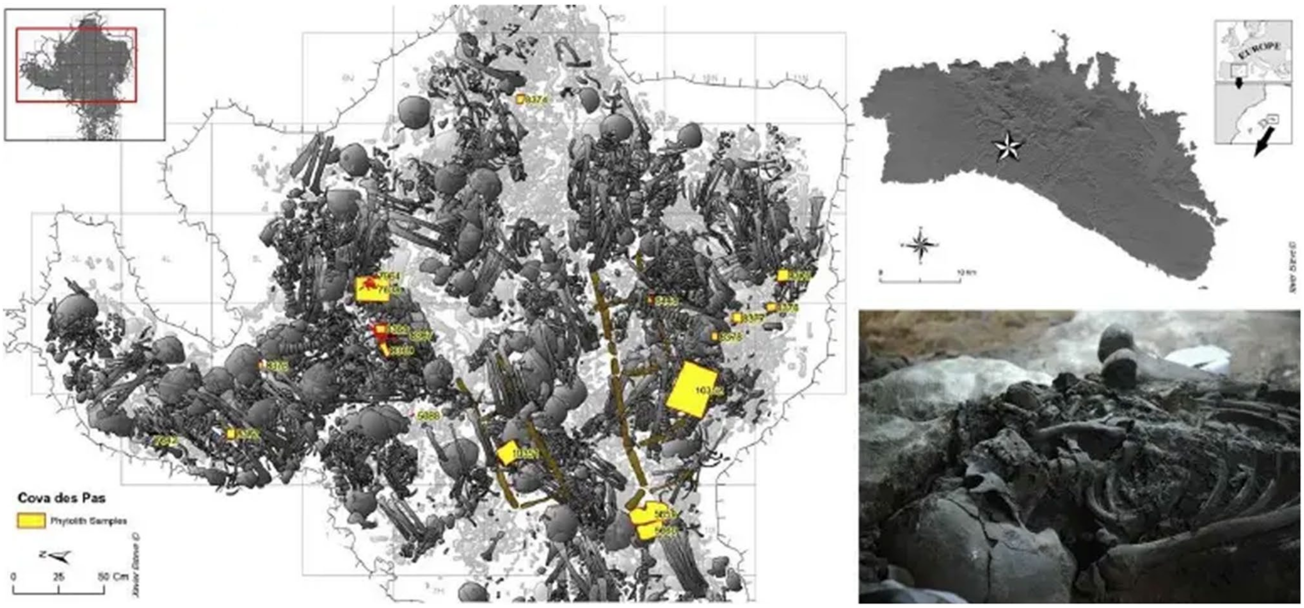


Fig. 2 The total set of individuals buried in Cova des Pas (CdP) (image re-drawn from Cabanes and Albert 2011)

represented by the presence ceramic sets of large barrels and large pots composed by globular shape and flat base, known to be "index fossils" for Balearic LBA (Guerrero, 2008). Besides, other Minorcan naviforms such as Cala Morell or Son Blanc have provided similar archaeological contexts with radiocarbon dates (ca. 1200–900 cal BC) associated with this set of materials (see SI Table 1).

The faunal remains that were found at SMB include *Ovis* sp., *Capra* sp., and a considerable number of *Sus* sp. No signs of agriculture were initially detected (Fernández Miranda, 1997), but this should be reconsidered as several grinding stones were recovered from the site, today hosted at the *Museu de Menorca* (Minorca, Balearic Islands; Spain). The SMB represents an appropriate context to be used as an isotopic referent for CdP cave. It is the closest contemporaneous site largely excavated in the area (less than 600 m distanced from the CdP and over 3 km from the sea), and it represents a domestic habitat co-existing with the CdP funerary cave.

The present research aims to study the dietary pattern of the prehistoric population buried in the CdP site, investigating the type of protein contribution to the diet and the degree of exploitation of marine resources for human consumption, as well as the potential differences in access to food resources among population groups (considering sex and age of sampled individuals). For this purpose, direct information will be obtained from the isotopic composition of the major number of individuals by measuring the isotopic signal of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) on the skeletal remains. At the same time, this study will investigate a corpus of faunal remains recovered from the SMB open-air site in order to interpret the isotopic data retrieved from the anthropological collection from CdP. Due to the absence of reliable chronological data from SMB, we also present here two new radiocarbon data to assure the chronological utility of CdP and SMB selected samples.

The results of all the previous studies carried out on this site, providing information on the population groups (i.e., age, sex, funeral rite, deposit, health status), render this study exceptional and allow much deeper project research. In addition, isotopic values of faunal remains were also analyzed to provide baseline values of the local trophic food chain and to explore whether domesticated animals had access to marine foods.

Stable isotopes and palaeodietary reconstruction

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratio analyses of the bone collagen are the method most used for the reconstruction of dietary protein patterns in archaeological populations (Schoeninger 1995; Katzenberg 2000).

Collagen isotopic values reflect the diet of the last 10 years, approximately, before the death of the organism being studied. This is because in every living organism, the bone tissue is continuously remodeled by the interaction of osteoblasts and osteoclasts, cells responsible for this process (Hedges et al. 2007). For the biochemical reconstitution of the human diet, carbon and nitrogen stable isotopes are the most used isotopic markers (Katzenberg 2000). The basic principle of these approaches is that "we are what we eat" (Kohn 1999); that is, the basic units that make up all body tissues of any animal, including bones, come from the foods

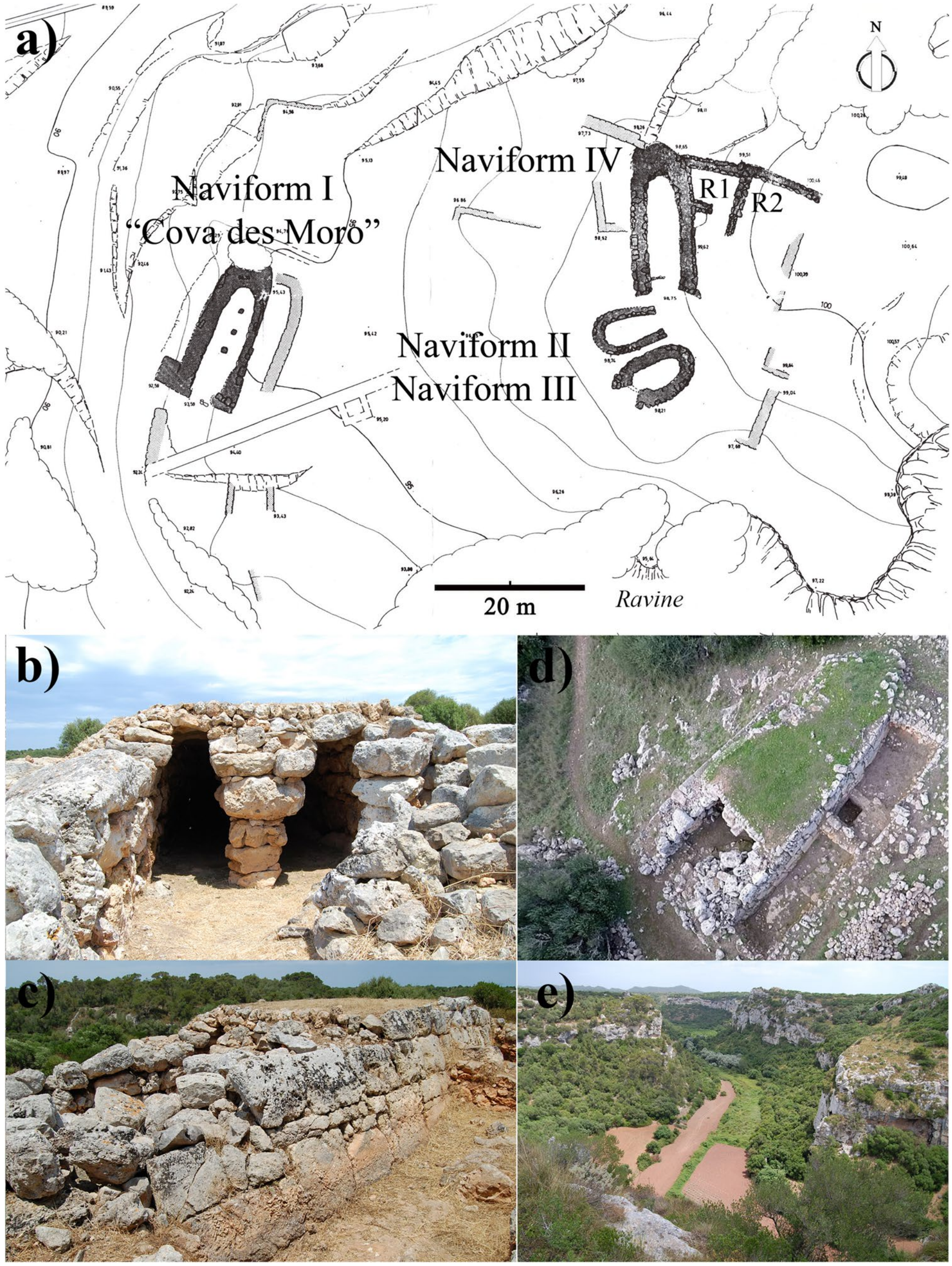


Fig. 3 Son Mercer de Baix and its landscape: **a** SMB naviforms and associated structures distribution (modified from Plantalamor and Rita 1983). **b**, **d**, and **e** Different views of the "Cova del Moro" Naviform in SMB. **c** General view of fhe Fideu's ravine where SMB is located

they have ingested during their lifetime. Several experimental studies have shown that as an organism processes the amino acids, it has consumed to create the protein it needs, and a difference in the carbon isotope ratio between the dietary protein and collagen is created by ~ 4 to 5‰ from bulk diet to collagen consumer (Ayliffe et al 2004; Ambrose & Norr 1993; Schoeninger & DeNiro 1984) and ~ 1‰ from collagen diet to collagen consumer in a mono-isotopic diet (Bocherens & Drucker 2003). However, the nitrogen isotopic fractionation increases by ~ 3–5‰ for each trophic level (Minagawa & Wada 1984).

Stable carbon isotope values are able to distinguish the presence of plants with different photosynthetic pathways (i.e., C_3 and C_4 plants) in human diet since the ranges of their $\delta^{13}C$ values do not overlap each other (Deines 1980; Van der Merwe & Vogel 1978): C_3 plants from temperate and cold areas with values of about – 26.5‰ such as wheat, and C_4 plants from tropical, dry, or semi-dry regions with values around – 13 ± 2 ‰ such as millet (Vogel et al. 1978; Winter 1981; Kohn 2010). Moreover, carbon isotopes can also detect a diet based on terrestrial or marine foods with values approximately at – 20‰ and – 12 ± 1‰, respectively (Schwarcz & Schoeninger 1991; Richards & Hedges 1999). Something similar occurs with the stable nitrogen isotopes. The $\delta^{15}N$ composition of human bone can determine the trophic level position on the food chain, with the values

Table 1 List of human specimens sampled for collagen analysis

Human sample	Bone	Sex	Age (years)	$\delta^{13}C$	%C	$\delta^{15}N$	%*N*	C:N
1	Rib	Female	25–35	− 19.5	36.2	9.7	13.0	3.3
6*	Rib	Female	6 ± 1	− 22.2	8.7	9.4	2.3	4.3
2–5	Phalange	Male	30–40	− 19.5	37.0	9.6	13.0	3.3
3	Phalange	Female	30–40	− 19.6	39.1	10.1	13.9	3.3
4	Rib	Male	15–16	− 19.8	30.3	8.7	10.9	3.3
8	Rib	Male	45–50	− 19.5	36.0	9.3	12.9	3.2
9	Rib	Female	12 ± 1	− 19.9	41.0	10.1	14.4	3.3
11	Rib	Male	45–55	− 19.6	36.6	9.0	13.2	3.2
13	Rib	Male	43–55	− 19.8	42.4	10.2	15.3	3.2
16–17	Rib	Male	16–17	− 19.8	39.3	8.4	14.3	3.2
18	Rib	Female	50–60	− 19.6	40.1	9.4	14.6	3.2
20	Rib	Male	Indet	− 19.4	35.4	9.3	12.9	3.2
23	Rib	Male	35–38	− 19.6	39.7	9.4	14.5	3.2
24	Rib	Male	12–13	− 20.1	28.1	8.3	10.2	3.2
25	Rib	Indet	9–10	− 19.4	36.1	9.2	13.9	3.0
26*	Rib	Female	13 ± 1	− 26.2	1.0	-1.5	0.2	6.2
27	Rib	Indet	10 ± 1	− 19.2	36.5	9.7	12.5	3.4
29	Rib	Male	21–24	− 19.7	34.0	8.4	12.3	3.2
30	Rib	Female	35–45	− 20.0	36.0	9.4	13.2	3.2
31	Rib	Female	20–22	− 19.5	37.5	10.0	13.5	3.2
32	Rib	Male	30–34	− 19.4	31.9	8.5	11.8	3.2
33*	Cranium	Female	24–29	− 21.8	11.8	8.4	4.0	3.4
34*	Rib	Female	30–40	− 22.8	11.7	6.9	4.2	3.3
36	Phalange	Indet	Indet	− 20.1	39.6	10.0	13.8	3.3
37	Rib	Indet	2 ± 8 months	− 19.2	38.5	9.8	12.8	3.5
38	Rib	Indet	1–5	− 19.6	40.9	10.0	14.7	3.2
39	Rib	Indet	3	− 19.4	32.4	12.4	11.3	3.3
41	Rib	Female	35–45	− 20.5	38.1	9.0	13.3	3.3
43	Rib	Male	21–23	− 19.5	35.4	10.0	12.9	3.2
44	Rib	Female	45–60	− 19.6	26.8	8.7	9.5	3.3
47	Rib	Male	40–45	− 19.7	37.9	9.5	13.5	3.3
48	Rib	Indet	7 ± 1	− 19.3	37.8	8.7	13.5	3.3
49	Rib	Indet	3–4	− 18.9	38.4	12.0	14.0	3.2
50*	Rib	Male	40–50	− 26.4	1.8	2.2	0.3	6.6
51	Rib	Female	45–55	− 19.4	40.1	8.9	14.7	3.2
55*	Rib	Female	2	− 19.4	1.1	-1.9	0.2	5.1
57	Rib	Indet	8 ± 1	− 20.0	31.3	9.1	11.5	3.2
58*	Fibula	Female	Indet	− 28.1	2.0	2.7	0.9	2.5
59	Rib	Female	40–50	− 20.0	30.6	9.2	11.2	3.2
60	Rib	Indet	8 ± 1	− 19.6	38.1	9.8	13.4	3.3
61	Rib	Male	45–60	− 19.8	29.3	8.8	10.7	3.2
62	Rib	Male	30–45	− 20.4	21.8	8.3	7.8	3.3
63	Rib	Male	Indet	− 20.0	30.7	8.8	11.1	3.2
64*	Cranium	Indet	22–24	− 19.4	6.9	6.8	1.6	5.1
65	Rib	Indet	1.5–2	− 19.8	39.3	11.4	15.1	3.0
66*	Rib	Indet	4–5	− 22.5	2.3	7.8	0.7	4.0
68	Rib	Indet	22–24	− 20.3	28.3	9.0	10.4	3.2
69	Rib	Female	12 ± 1	− 19.4	41.4	8.6	15.2	3.2
70	Phalange	Indet	3 ± 1	− 19.8	37.4	9.3	13.3	3.3

Type of bone, sex and age of sampled specimens, collagen carbon (%C) and nitrogen (%*N*) contents, collagen carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope compositions, and collagen carbon:nitrogen atomic ratio (C:N). The samples that were excluded from further discussion due to their poor collagen preservation are presented with an asterisk increasing by 3–5‰ with each ascending step of the food chain (Bocherens & Drucker 2003; O'Connell et al. 2012). The local baseline background of the trophic food chain (faunal and floral remains) is required to build a more reliable interpretation of the nitrogen isotope values in the human diet (O'Connell et al. 2012). In the same time, carbon and nitrogen isotopic values in human and animal tissues could also reflect environmental factors affecting the soil–plant system at the base of the food chain, such as temperature, precipitation, aridity, salinity, soil composition, or manuring, as well as physiologic and metabolic factors (Szpak 2014; Reitsema 2013).

Materials and methods

Sample preparation

Cova des Pas (CdP)

A total of 49 human specimens were measured by stable isotope analysis. The rest of the samples recovered from the site did not proceed to analysis due to the lack of enough yields during the extraction procedure. Samples were selected considering previous paleoanthropological data from Armentano et al. (2010), Malgosa et al. (2011), and Simón et al. (2016) among others. For each specimen, age and sex were provided from previous studies (Armentano et al. 2010; Simón et al. 2016) (Table 1). The sampling procedure was carried out by careful selection of rib bone fragments for almost all individuals, except in five cases (samples 2–5, 3, 33, 36, 58, 64, and 70) where rib bones were not available and then skull bone or phalanx or fibula was selected, depending on the bone available for each specimen. Ribs have a relatively fast cortical turnover rate, depicting an individual's diet from a more recent period prior to death (Cox & Sealy 1997; Fahy et al. 2017).

Son Mercer de Baix (SMB)

Faunal samples for isotopic analyses belonged from rooms 1 (level III) and 2 (sector 1, Capa 1) and UE 1008. These archaeological contexts are stratigraphically linked to the Late Bronze Age/Early Iron Age (*ca.* 1200/1100–800 cal BC) occupation of the site. Before selection, faunal samples were identified and classified following zooarchaeological criteria. The osteological analysis focused on the study of the taxonomic and body part representation, age-at-death, and potential pathologies observed in order to obtain as much information as possible about these animals when they were alive. Sex information was not possible to record due to the high fragmentation of the bones that prevented observing possible diagnostic traits (such as in the pelvis) or taking measurements for comparison. *Ovis* sp. and *Capra* sp. samples were classified following osteological criteria in Boessneck (1980), Payne (1985), and Prummel and Frisch (1986). The faunal set is compound of 33 samples (Table 2) and comprised samples of Caprinae (*Capra hircus*/*Ovis aries*) ($n=11$), *Bos Taurus* ($n=5$), *Capra hircus* ($n=6$), *Ovis aries* ($n=7$), and *Sus domesticus* ($n=4$). Further, two faunal samples recovered from room 1 in SMB were selected for radiocarbon dating and measured at the CNA-CSIC research center (Spain). The first of these (SMB03) corresponded to an upper *Ovis* sp./*Capra* sp. molar, while the second (SMB06) was a second phalanx of *Sus* sp.

Bone collagen extraction

Sample preparation and collagen extractions were performed at the biomolecular laboratory at the Catalan Institute of Human Palaeoecology and Social Evolution (IPHES) held in Tarragona, Spain. The protocol has been developed in an innovative way in IPHES for remains of different chronology and relative preservation of the organic fraction, from the remains of the Middle Pleistocene (Ramírez-Pedraza et al. 2019), Upper Pleistocene (González-Guarda et al. 2018) to the Holocene times (Jordana et al. 2019). This protocol allows working with very small samples of bones while ensuring optimal extraction of fractions of collagen fibers, including those samples that by a diagenetic or fossilization process preserve very little quantity. A small bone fragment of each specimen was mechanically cleaned using a Dremmel rotating tool equipped with a circular diamond-coated blade to remove all visible contaminants. Briefly, the bone collagen was purified according to the acid–base-acid protocol proposed by Longin (1971) and modified by Bocherens et al. (1991). Bone shards (ca. 300 to 350 mg) were soaked in 0.5 M HCl for demineralization, in NaOH (0.125 M) to remove contaminants, rinsed with distilled water several times, and gelatinized with 0.01 M HCl at 100 °C for 17 h (pH 2). Once filtered after the gelatinization process and frozen, samples were freeze-dried at the Institute of Chemical Research in Catalonia (ICIQ). Gelatin-collagen samples weighing about 300 µg were analyzed using a Thermo Flash 1112 elemental analyzer (EA) coupled to a Thermo Delta V Advantage isotope ratio mass spectrometer (IRMS) with a Conflo III interface, at the Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona (Barcelona, Spain). The international standard laboratory IAEA 600 (caffeine) was used as a control. Analytical precision was checked using the international standard laboratory IAEA 600 (caffeine), and the average analytical error was <0.15‰ (1σ) calculated for each isotopic measurement, $\delta^{13}C$ and $\delta^{15}N$ separately. The standard utilized for $\delta^{13}C$ was Vienna PeeDee Belemnite (V-PDB), and the standard used for $\delta^{15}N$ was air N_2 (AIR). The isotope ratios are expressed

Table 2 List of faunal specimens sampled for collagen analysis

Sample	Bone	Species identification	Age (years)	δ^{13}C	%C	δ^{15}N	%*N*	C:N
32.2	Metacarpal	*Capra hircus/Ovis aries*	Sub-adult	− 20.3	33.1	8.8	11.6	3.3
42.1	Radium	*Capra hircus/Ovis aries*	Sub-adult	− 21.7	38.1	8.7	13.1	3.4
42.2	Humer	*Capra hircus/Ovis aries*	Sub-adult	− 20.7	39.9	6.6	14.0	3.3
42.3	Metacarpal	*Capra hircus/Ovis aries*	Sub-adult	− 20.8	36.9	7.0	13.1	3.3
42.4	Metatarsal	*Capra hircus/Ovis aries*	Sub-adult	− 20.8	31.6	9.6	11.2	3.3
42.5	Calcaneus	*Capra hircus/Ovis aries*	Sub-adult	-21.8	40.6	8.6	13.8	3.4
42.6	Metacarpal	*Capra hircus/Ovis aries*	Sub-adult	− 21.2	29.7	8,0	10,5	3,3
42.7	Metacarpal	*Capra hircus/Ovis aries*	Sub-adult	− 21.2	29.8	9.0	10.9	3.3
02.1	Femur	*Capra hircus/Ovis aries*	Sub-adult	− 21.5	31.4	7.3	10.9	3.4
39.1	Metatarsal	*Capra hircus/Ovis aries*	Sub-adult	− 19.7	40.3	7.0	13.8	3.4
43.4	First phalange	*Capra hircus/Ovis aries*	Sub-adult	− 20.9	35.5	6.3	12.2	3.4
01.1	Metapodial	*Bos taurus*	Sub-adult	− 20.7	31.6	7.1	11.7	3.2
41.1	Mandible	*Bos taurus*	Sub-adult	− 21.4	37.2	6.9	13.3	3.3
41.2	Scapulae	*Bos taurus*	Sub-adult	− 20.9	37.7	6.3	13.4	3.3
41.4	First phalange	*Bos taurus*	Adult	− 21.1	36.8	5.9	13.2	3.3
41.5	Ulnae	*Bos taurus*	Adult	− 21.6	36.0	5.7	12.9	3.3
37.1	Mandible	*Capra hircus*	Sub-adult	− 19.1	37.2	5.4	13.1	3.3
43.1	Humer	*Capra hircus*	Adult	− 19.4	39.4	6.5	13.6	3.4
43.7	Talus	*Capra hircus*	Adult	− 20.0	31.2	5.3	10.7	3.4
43.8	Scapulae	*Capra hircus*	Adult	− 19.7	31.1	6.2	11.4	3.2
39.2	Talus	*Capra hircus*	Adult	− 19.8	31.4	7.3	10.9	3.4
43.6	Femur	*Capra hircus*	Adult	− 19.2	41.7	6.7	14.6	3.3
32.1	Metacarpal	*Ovis aries*	Adult	− 20.5	32.2	6.2	11.9	3.2
32.3	First phalange	*Ovis aries*	Adult	− 20.7	42.1	6.0	14.6	3.4
39.5	Ulnae	*Ovis aries*	Adult	− 20.7	30.1	6.6	10.2	3.4
39.3	Radium	*Ovis aries*	Adult	− 21.0	36.9	6.6	12.7	3.4
39.4	Radium	*Ovis aries*	Adult	− 20.7	32.3	6.5	11.6	3.3
43.2	Humer	*Ovis aries*	Adult	− 21.0	36.5	6.5	13.0	3.3
43.5	Scapulae	*Ovis aries*	Sub-adult	− 20.3	40.4	7.0	14.0	3.4
44.1	Ulnae	*Sus domesticus*	Sub-adult	− 20.1	33.6	7.4	12.8	3.1
44.2	Metapodial	*Sus domesticus*	Adult	− 20.2	32.1	6.4	11.5	3.3
44.3	Lateral metapod	*Sus domesticus*	Sub-adult	− 19.6	38.6	7.5	13.5	3.3
44.5	Second phalange	*Sus domesticus*	Sub-adult	− 20.7	33.3	6.0	11.8	3.3

Type of bone, species identification, age of sampled specimens, collagen carbon (%C) and nitrogen (%N) contents, collagen carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope compositions, and collagen carbon:nitrogen atomic ratio (C:N) (Pr = probably)

for carbon as δ^{13}C vs. Vienna Pee Dee Belemnite (V-PDB) and for nitrogen as δ^{15}N vs. atmospheric nitrogen (AIR): δ χ¼ ($R_{sample}/R_{standard}{}^{-1}$) × 1000‰, where χ stands for ^{13}C or ^{15} N and *R* stands for $^{13}C/^{12}C$ or ^{15} N/^{14} N. The reliability of the isotopic signatures of the collagen extracts was addressed using several criteria (yield of extraction ≥ 10 mg·g^{-1}, percentages of C ≥ 30% and N ≥ 10%, and the atomic C/N ratio 2.9 < C/N > 3.6).

When evaluating the differences in the stable isotope results between samples, statistical significance was tested using the *T* test and the ANOVA and MANCOVA tests, setting the significance p value < 0.05. Nonparametric tests were used when the data did not follow a normal distribution. As for the age, the samples were grouped as two different subcategories, one including the individuals over 13 years old and the other those with age under 13 years old.

Selection of radiocarbon dates from Son Mercer de Baix

Two faunal samples from Son Mercer de Baix were selected for radiocarbon dating. These samples proceed from room 1 and level 4, collected during the 1978 excavation campaign. It is expected that these samples correspond to the oldest archaeological context documented in this area.

Results

Radiocarbon dates from Son Mercer de Baix

From the results of both dates, it can be proposed that room I of SMB was in use, at least, between 1643 and 1412 cal BC (Table 3). In the same way, it is interesting to note that the construction of rooms I and II as well as that of the Naviform IV, to which they have adhered, would necessarily be prior to 1504 cal BC and its abandonment, necessarily posterior to 1514 cal BC. Also, these dates define a *terminus post quem* for all the selected fauna remains which are necessarily younger than those levels.

Collagen preservation

The results of the stable isotopes and collagen quality indicators are reported in Tables 1 and 2. In the faunal samples, yields were ranging from 25 to 159 mg/g. In the human samples, all the selected bones yielded collagen which was ranging from 6 to 169 mg/g. Five samples 5 (24, 44, 61, 62, and 68) show slightly low C or N% values lower than these limits but showed C:N ratios ranging within the internationally accepted limits and were considered for discussion. However, nine samples (6, 26, 33, 34, 50, 55, 58, 64, and 66) presented both C and N contents, and C:N ratios out of the accepted limits were discarded for final interpretation. Excluding these nine samples, the mean carbon and nitrogen contents (%C and %N) of the bone collagen extracts were 35.7 ± 4.64% and 12.8 ± 1.68%, respectively. The mean atomic C:N ratio of samples used for interpretation is 3.2 ± 0.09. These results are indicative of collagen suitable for isotopic analysis supporting markers of good collagen preservation (DeNiro 1985; Ambrose 1990).

Table 3 Results of radiocarbon dating of samples of Son Mercer de Baix

ID	ID lab	BP	CAL 2σ	$d^{13}C$	C:N
SMB03	CNA4965	3300±30	1643–1504	– 16.42	3.2
SMB06	CNA4966	3190±30	1514–1412	– 18.16	3.2

The results were calibrated with OxCal 4.4 software (Bronk Ramsey 2009) and curve IntCal20 (Reimer et al. 2020)

Faunal isotope results

The faunal stable isotope data are provided in Table 2. The mean of carbon and nitrogen faunal isotope values are – 20.6 ± 0.72‰ and 6.9 ± 1.05‰, respectively. The mean results per species are the following: *Capra sp.* $\delta^{13}C$ = – 19.5 ± 0.36‰ and $\delta^{15}N$ = 6.23 ± 0.77‰, *Ovis* sp. $\delta^{13}C$ = – 20.7 ± 0.25‰ and $\delta^{15}N$ = 6.5 ± 0.32‰, Caprinae $\delta^{13}C$ = – 21 ± 0.62‰ and $\delta^{15}N$ = 7.9 ± 1.11‰, *Bos* sp. $\delta^{13}C$ = – 21.1 ± 0.37‰ and $\delta^{15}N$ 6.4 ± 0.61‰, and *Sus* sp. $\delta^{13}C$ = – 20.1 ± 0.45‰ and $\delta^{15}N$ = 6.8 ± 0.74‰. There were statistically significant differences between faunal and human isotopic values for both isotopic signals ($\delta^{13}C$: ANOVA test: $F = 49.2$; $p < 0.001$; $\delta^{15}N$: Kruskal–Wallis: $x^2 = 44$, $p < 0.001$). *Capra* sp. seem to differ significantly from other animal categories in $\delta^{13}C$ isotopic values (ANOVA test: $F = 28.8$; $p < 0.001$), while no differences in $\delta^{15}N$ values were observed (Kruskal–Wallis: $x^2 = 20.3$; $p = 0.09$). Some juvenile Caprinae (samples 32.2, 42.1, 42.4, 42.5, 42.6, 42.7) showed significant differences in both $\delta^{13}C$ and $\delta^{15}N$ isotopic values in relation to the adult animal samples (ANOVA test: $\delta^{13}C$: $F = 5.67$; $p = 0.02$; $\delta^{15}N$: $F = 76.0$; $p < 0.001$).

Human isotope results

Results from the isotope analysis of bone collagen from human specimens are presented in Table 4. The mean of carbon and nitrogen isotope values are – 19.7 ± 0.34‰ and 9.5 ± 0.91‰, respectively. The carbon isotope results range from – 20.5 to – 18.9‰, while those of nitrogen isotope range from 8.3 to 12.4‰.

The $\delta^{13}C$ and $\delta^{15}N$ data for adult sample are plotted in Fig. 4. 95CIs and mean values are presented in Fig. 5, where sexes do not show statistically significant differences. Considering both isotopic signals separately, as well as, jointly, there were not significant differences between sexes in both cases ($\delta^{13}C$: *T* test: 0.228; $p = 0.822$; $\delta^{15}N$: *T* test: 1.306; $p = 0.205$; and MANCOVA test: Wilks' Lambda = 0.903, $p = 0.342$).

The $\delta^{13}C$ and $\delta^{15}N$ data for all samples between different age categories are plotted in Fig. 6. The differences between the three subcategories (16 to 25 years old, 25 to 45 years old, and over 45 years old) for the individuals

Table 4 Statistical summary of the $\delta^{13}C$ and $\delta^{15}N$ data according to sex of the adult sampled specimens

	Males				Females				All adults			
	N	Mean	SD	Min/Max	*N*	Mean	SD	Min/Max	*N*	Mean	SD	Min/Max
$\delta^{13}C$(‰)	15	– 19.7	0.26	– 20.4/– 19.4	9	– 19.7	0.35	– 20.5/– 19.4	26	– 19.8	0.31	– 20.5/– 19.4
$\delta^{15}N$(‰)	15	9.1	0.6	8.3/10.2	9	9.4	0.5	8.7/10.1	26	9.2	0.57	8.3/10.2

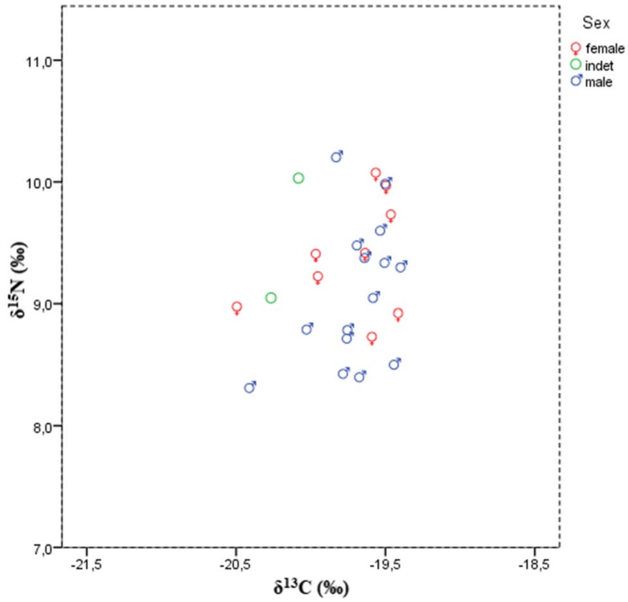


Fig. 4 Scatter plot of δ^{13}C and δ^{15}N of adult human samples from CdP between sexes. Blue symbols represent the male samples and red symbols the female samples, while green circles the samples with indeterminate sex

over 13 years old were not statistically significant in both δ^{13}C and δ^{15}N (δ^{13}C: Kruskal–Wallis: $x^2 = 0.25$; $p = 0.880$; δ^{15}N: ANOVA test: $F = 0.195$; $p = 0.825$) (Fig. 7).

The δ^{15}N results show that three out of six specimens (39, 49, and 65), classified in the age category under 4 years old, present high values (12.4‰, 12‰, and 11.4‰, respectively). This observation is shown in Fig. 8, where δ^{15}N values are distributed only for individuals under 13 years old. In this case, the graph shows that young specimens under 4 years old have high δ^{15}N signatures and that this value is decreasing on sampled specimens between 0 and 13 years old.

Discussion

The local faunal baseline

The isotopic analysis of faunal samples offers a more reliable interpretation of the human isotopic values. In this study, considering the mean and ranging δ^{13}C values (-20.6 ± 0.72‰; max -19.1, min -21.8‰) of all faunal samples, it can be demonstrating a livestock diet based on C_3 plants. However, it is noteworthy the enrichment of the carbon isotope values of *Capra* sp. (samples 37.1, 43.1, 43.7, 43.8, 39.2, 43.6). This could be explained by the broad range of variation in C_3 plants, since this plant group includes most of the species known, nearly all trees, herbs, and cold climate grasses. Further, C_3 plants can also vary due to a wide range of environmental effects like radiation, water availability, soil nutrients, temperature, or salinity, among others (O'Leary, 1995; Farquhar et al. 1989; Tieszen and Boutton 1989; Ehleringer and Monson 1993; Heaton, 1999), and plants adapted to dry environments tend to show greater water use efficiency (hence, higher δ^{13}C).

δ^{15}N values in faunal adult samples provided a mean value of 6.5 ± 0.60‰ and maximum and minimum values of 7.5‰ and 5.3‰, respectively. However, it is interesting the fact that juvenile Caprinae (samples 32.2, 42.1, 42.4, 42.5, 42.6, 42.7) show high values (max. value 9.6‰). Considering their low δ^{13}C value (from -20.3 to -21.8), the values of these specimens could be explained by the breastfeeding effect. Moreover, some subadult animal specimens (samples 2.1, 39.1, 1.1, 41.1, 43.5, 44.1, and 44.3) show slightly enriched δ^{15}N values (7.1‰, 7‰, 7.1‰, 6.9‰, 7.1‰, 7‰, 7.4‰, and 7.5‰, respectively) in relation to the adult samples. These values could indicate the weaning effect and the introduction to the adult diet. However, their difference is not statistically significant and strong enough to make a powerful conclusion (Kruskal–Wallis: $x^2 = 3.51$; $p = 0.06$).

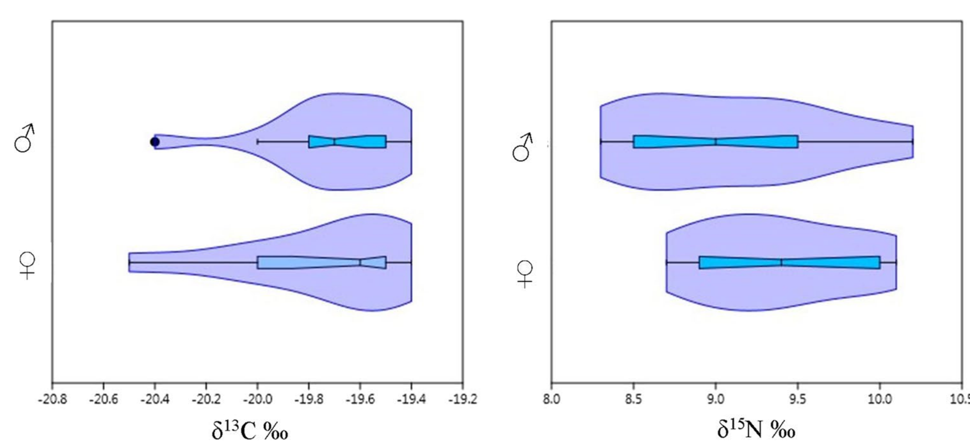


Fig. 5 Mean and 95CIs of δ^{13}C (left) and δ^{15}N (right) by sex of human samples from CdP (δ^{13}C: *T* test: 0.228; $p = 0.822$; $\delta.^{15}$ N: *T* test: 1.306; $p = 0.205$)

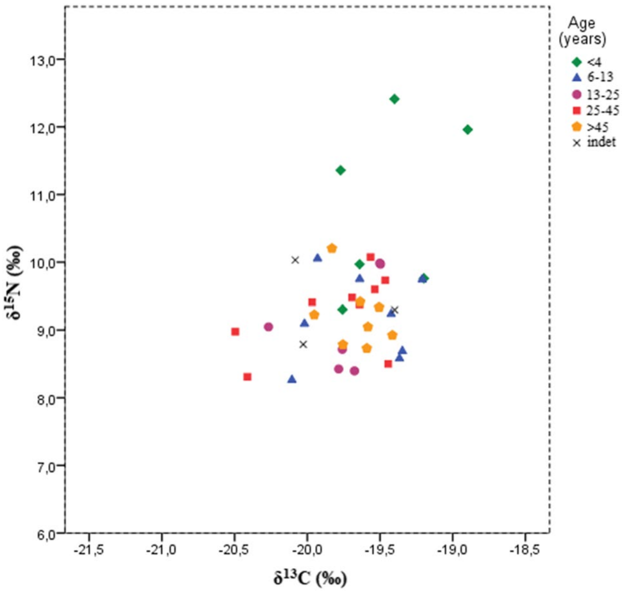


Fig. 6 Scatter plot of δ^{13}C and δ^{15}N of all human samples from CdP between different age categories

Human dietary reconstruction

The isotopic results of the human samples from the CdP site indicate a main diet based on terrestrial resources. Considering data from faunal remains, the mean δ^{13}C value of the bone collagen in adult samples (– 19.7‰ ± 0.31‰) fits well with a consumption mainly based on C_3 plants compounds in their diet, while the mean δ^{15}N value (9.2‰ ± 0.57‰) will suggest a significant contribution of animal protein in the human diet (e.g., Lanting and van der Plicht 1996a, b).

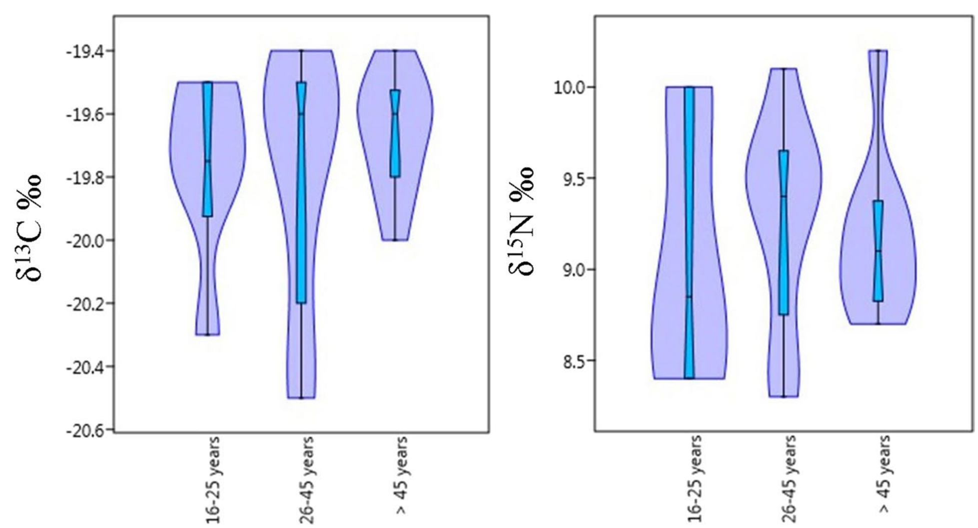
Interestingly, some of the δ^{13}C results obtained from bone adult samples, like in the case of samples 20, 25, 27, 32, 37, 39, 48, 51, and 69, representing the 34% of the samples tested, show slightly enriched values (≥ – 19.4‰).

These values in the case of the samples 32, 48, 51, and 69 (– 19.4‰, 19.3‰, 19.4‰, and – 19.4‰ respectively), accompanied by low δ^{15}N values (8.5‰, 8.7‰, 8.9‰, and 8.6‰ respectively) not expected in marine ecosystems, could suggest a minor proportion of C_4 plants in the diet of those specimens, although current uncertainties on bulk collagen isotope must be taken into account. Because C_4 plants are naturally scarce or absent in Minorca Island today and in the past (Mateu, 1993; Pyankov et al 2010), a simple explanation will suggest consumption of domestic C_4 plants on the diet of Talayotic individuals buried in the CdP site. Millet is the early C_4 plant introduced in the Iberian Peninsula, but its introduction on the human diet during the Middle and Late Bronze Age is still an open debate (see López-Costas et al. 2015, for instance), and its introduction in the Balearic Islands is only suggested for the Naviform period in Formentera (Sureda et al. 2017a), while its presence in the other islands is still unknown.

Alternatively, some of these enriched δ^{13}C values (e.g., sample 27; – 19.2‰) could be the consequence of another carbon source diet. Indeed, these adult specimens like 3, 8, 18, and 25 show also higher δ^{15}N values in collagen (≥ 10‰), potentially revealing the influence of marine food products on their diet.

At this point, it must be stressed that previous δ^{13}C and δ^{15}N analyses (Van Strydonck et al. 2005) clearly indicated that the diet in the Balearic Islands during the prehistory was not predominantly based on marine resources. This lack of a clear evidence of consumption of marine foods has also observed in other studies from Majorca (Davis 2002; Garcia et al. 2004) and the Mediterranean region in general (Craig et al. 2006), all of them during prehistoric times, although that does not mean that human groups did not consume a small amount of it, undetectable by current bulk collagen isotope analysis.

Fig. 7 Mean and 95CIs of δ^{13}C (left) and δ^{15}N (right) by age subcategories for the human individuals over 13 years old. δ^{13}C: Kruskal–Wallis: $x^2 = 0.25$; $p = 0.880$; $\delta.^{15}$ N: ANOVA test: $F = 0.195$; $p = 0.825$



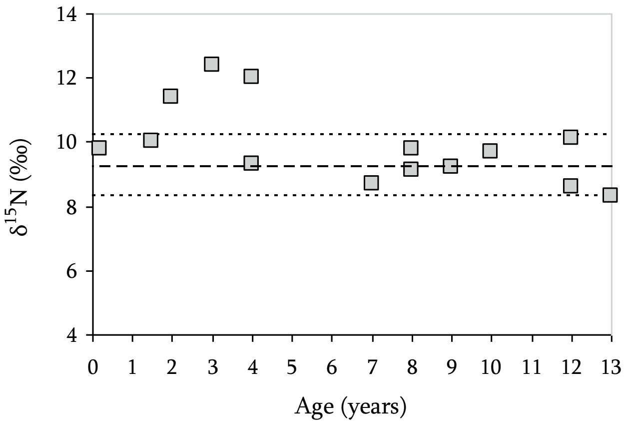


Fig. 8 Plot of δ^{15}N values measured on human samples from CdP against age of samples aged less than 13 years old. Dotted lines show maximum, mean, and minimum δ^{15}N values measured on adult individuals from CdP

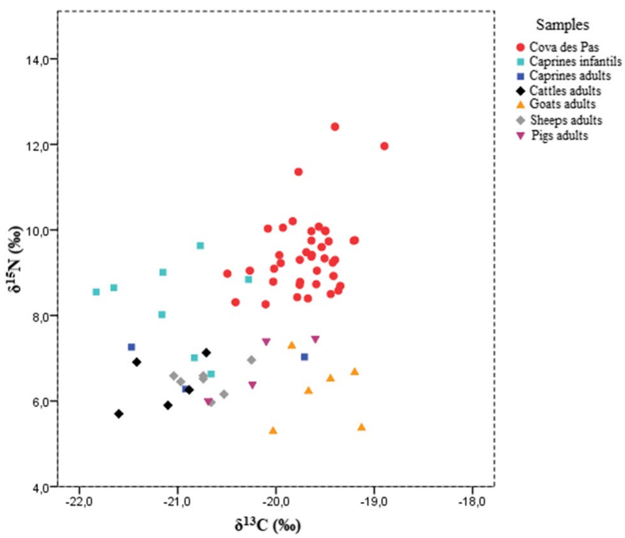


Fig. 9 Scatter plot of δ^{13}C and $\delta.^{15}$ N of human samples from CdP (1100–800 BC) and faunal samples from Son Mercer de Baix of Minorca Island (1400–1000 BC)

Comparing the adult samples of the CdP with other contemporaneous samples (1100–800 BC) (Fig. 9) from Minorca and Majorca Islands (Fig. 10), it can be observed that the samples from the CdP share, basically, the same mixed diet of animal products and vegetables as the other contemporaneous sites (Van Strydonck et al. 2005) (data about samples used is provided in Table C1 of SI).

However, considering both isotopic signals jointly, differences between the different sites were statistically significant (MANCOVA test: Lambda de Wilks = 0.331, $p < 0.001$). When evaluating the values of δ^{13}C and δ^{15}N separately, it seems that these differences are statistically significant for both δ^{13}C and δ^{15}N values (ANOVA test: δ^{13}C: $F = 4.57$; $p < 0.001$; δ^{15}N: $F = 3.34$; $p = 0.002$), where CdP samples tend to show higher δ^{15}N but lower δ^{13}C values than the majority of the other sites. It is interesting the fact that CdP shows considerably lower values than those obtained in the two human samples from the close Ses Arenes site from Minorca (Fig. 10). Unfortunately, although the number of sites is important to elaborate this comparison, the limited number of samples per site and the quality of the information provided for each sample (i.e., unknown data about sex and age of specimens sampled) make it difficult to reach more deep interpretations.

The age information about the samples of Son Blanc and Binipati Nou is unknown (Van Strydonck et al. 2005), but taking into account that they show the same high δ^{15}N values as the infant samples of CdP, and it can be assumed that they share the same range of age. Otherwise, it could indicate the consumption of an unknown terrestrial dietary item or a diet containing juvenile animals not fully weaned and thus N-enriched (Jay & Richards 2006).

Other socioeconomic glints of light

Differences on diet between males and females are not statistically significant, the fact that does not allow concluding for variation between sexes in the access to food. The scatter plot in Fig. 4 confirms that males and females up to date measured share close values in both δ^{13}C and δ^{15}N results. These results agree with those of previous studies in different sites of Minorca such as the Cova des Càrritx (Pérez-Pérez et al. 1999) or the Binipati, Es Tudons, and southern Rafal Rubí (Van Strydonck et al. 2002).

This can be explained by the general trend that the Naviform and Talayotic societies—both in Majorca and Minorca Islands—consisted of egalitarian communities (e.g., Gasull et al. 1984; Lull et al. 1999) with no sign point the existence of a hierarchical society or constituted by units of population differentiated within a settlement by its social function or its economic resources (Fernández-Miranda 1991).

However, Anglada et al. (2014) proposed that some of the human communities that inhabited Minorca between the late 2nd and early 1st millennium cal BC were immersed in an incipient process of increasing complexity and maybe social inequality, suggesting that a kind of an elite group was connected to the control of storage and redistribution of agricultural products. This seems not to relate to the population of the CdP, since differences in the access to food do not appear to exist either between sexes or the different age categories. Paleodemographic and taphonomical studies of the CdP indicating the same life expectancy and burial treatment between sexes (Armentano et al. 2010; 2012) confirm this social equality.

The nitrogen isotopic signal of the infant samples #37 (2 years ± 8 months old), #38 (1.5 years old), #39 (3 years

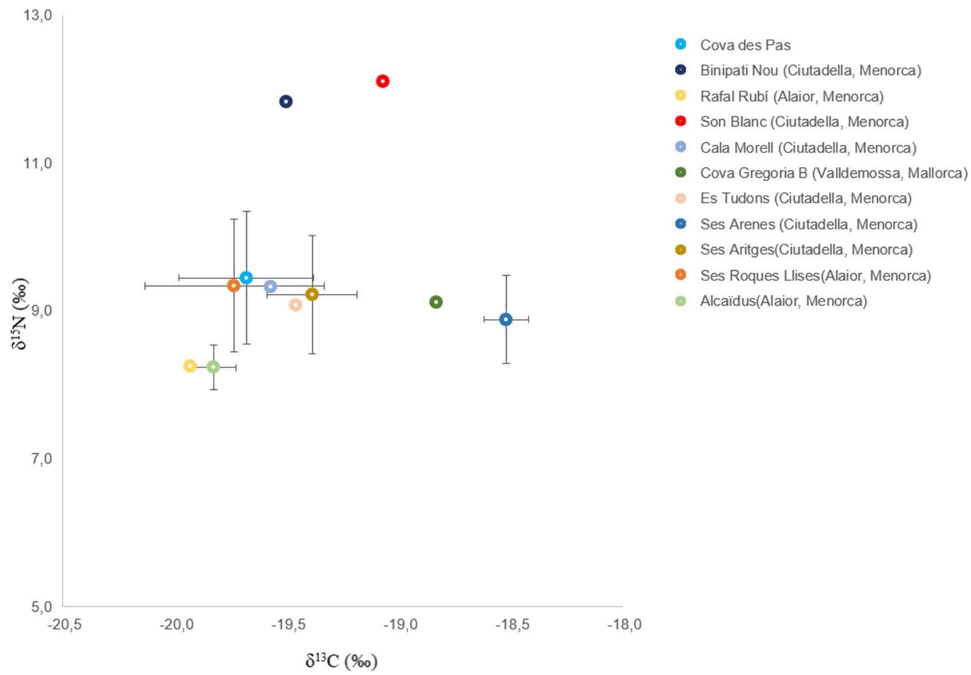


Fig. 10 Scatter plot of the mean values of $\delta^{13}C$ and $\delta^{15}N$ of different sites of Minorca and Majorca Islands during Late Bronze Age and Early Iron Age periods (1100–800 BC) (Van Strydonck et al. 2005). The analysis was performed between 11 different sites (Table 1 of Supplementary Information) and comprised samples from Cova des Pas ($n=40$), Binipati Nou ($n=1$), Rafal Rubí ($n=6$), Son Blanc ($n=1$), Cala Morell ($n=1$), Cova Gregoria B ($n=1$), Es Tudons ($n=1$), Ses Arenes ($n=2$), Ses Aritges ($n=5$), Ses Roques Llises ($n=4$), and Alcaïdus ($n=2$). The appropriate bars for standard deviation have also been included

old), #49 (3–4 years old), and #65 (1,5–2 years old), 9.8‰, 10‰, 12.4‰, 12‰, and 11.4‰, respectively, was highly indicating the enriched isotopic signature of breast milk (see again Fig. 8). Fogel et al. (1989), attempting to evaluate nursing and weaning, demonstrated that infants feeding on mothers' milk exhibit enrichment $\delta^{15}N$ values and a decrease to levels similar to those of mothers shortly after breastfeeding stopped. Taking into account that samples #25 (9–10 years old), #48 (7 ± 1 years old), and #57 (8 ± 1 years old) do not follow the same pattern as #37, #38, #39, #49, and #65, and it can be assumed that breastfeeding was occurring until around the age of 4 years, at least. A major number of samples are required to investigate this point to exclude other reasons for these values, such as potentially ill or malnourished infants whose isotope values could have been influenced by metabolic processes or not enough isotopic information from infants under and above the age of 4 years old. However, these data could add some light on the duration of the breastfeeding period and weaning process of the prehistoric population of the Cova des Pas.

Conclusions

The foregoing analysis uses the stable isotope of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in order to make inferences about the diet pattern of the individuals buried in CdP site. The isotopic data from human samples show a human diet based largely on C_3 plants with an important contribution of meat revealing a mixed diet of plants and animals. The $\delta^{15}N$ values of infants up to 4 years were high, indicating the enriched isotopic signature of breast milk, while it is hypothesized that weaning occurred around this age in this population. Differences between males and females were not statistically significant, assuming that both men and women had the same access to food. The same pattern seems to occur between the age subcategories. The paleodietary data obtained here is important in broadening the debate on the emergence and development of complex societies in the Balearic archipelago, providing direct information about the way how these societies managed diet habits and how insularity conditions affected the way they were socially organized.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-022-01707-y.

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Data Availability The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Declarations

Competing interests The authors declare no competing interests.

References

Ambrose SH (1990) Preparation and characterization of bone and tooth collagen for isotopic analysis. J Archaeol Sci 17(4):431–451

Ambrose SH, Norr L (1993) Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Prehistoric human bone (pp. 1–37). Springer, Berlin, Heidelberg

Amengual EG (2006) El proceso constructivo de un edificio de la edad del bronce en Menorca. El caso de Son Mercer de Baix (Ferreries, Menorca). Mayurqa 31:113–136

Anglada M, Ferrer A, Plantalamor L, Ramis D, Van Strydonck M, De Mulder G (2014) Chronological framework for the early Talayotic period in Menorca: the settlement of Cornia Nou. Radiocarbon 56(2):411–424

Armentano NA, Jordana XJ, Malgosa AM (2010) Aproximación paleodemográfica de una población protohistórica de las Baleares. El yacimiento de la Cova des Pas (Ferreries, Menorca). Revista de Demografía Histórica, Vol. XXVIII, Issue 1:91–108

Armentano, N, Prats-Muñoz, G, Galtés, I, Malgosa, A (2012) Reconstrucción tafonómica de la Cova des Pas (Ferreries, Menorca). In Biodiversidad Humana y evolución. Actas of XVII Congreso de la SEAF, Barcelona, 2 al 4 Septiembre 2011, 180–185

Armentano Oller NA, Esteve XE, Nociarová D, Malgosa AM (2012) Taphonomical study of the anthropological remains from Cova Des Pas (Minorca). Quatern Int 275:112–119

Ayliffe LK et al (2004) Turnover of carbon isotopes in tail hair and breath CO2 of horses fed an isotopically varied diet. Oecologia 139(1):11–22

Bergadà M et al (2015) On the presence of gypsum in the archaeological burial site of Cova des Pas (Menorca, western Mediterranean). J Archaeol Sci 53:472–481

Bocherens H, Drucker D (2003) Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. Int J Osteoarchaeol 13(1–2):46–53

Bocherens H et al (1991) Isotopic Biogeochemistry (δ13C, δ15N) of fossil vertebrate collagen: implications for the study of fossil food web including Neandertal man. J Hum Evol 20(6):481–492

Boessneck, J (1980) Diferencias osteológicas entre las ovejas (Ovis aries Linné) y cabras (Capra hircus Linné). Ciencia en arqueología, 338–366

Bronk Ramsey C (2009) Dealing with outliers and offsetsin radiocarbon dating. Radiocarbon 51(3)

Cabanes D, Albert RM (2011) Microarchaeology of a collective burial: Cova des Pas (Minorca). J Archaeol Sci 38(5):1119–1126

Cañas Cortés R (2012) Biological aspects of funeral ritual of the Cova des Pas (Talaiotic Culture, Minorca). Màster de Biologia Humana. Universitat Autònoma de Barcelona, Bellaterra, p 2012

Cerdá, D (1978) Economía antigua de Mallorca. Historia de Mallorca II. Vicente Colom Rosselló, Palma de Mallorca, 1–32

Cox G, Sealy J (1997) Investigating identity and life histories: isotopic analysis and historical documentation of slave skeletons found on the Cape Town foreshore, South Africa. Int J Hist Archaeol 1(3):207–224

Craig OE et al (2006) Palaeodietary records of coastal Mediterranean populations. Journal of Mediterranean Studies 16(1):63–77

Davis MHLA (2002) Putting meat on the bone: an investigation into palaeodiet in the Balearic Islands using carbon and nitrogen stable isotope analysis. BAR International Series 1095:198–216

Deines, P (1980) The isotopic composition of reduced organic carbon. Handbook of environmental isotope geochemistry, 1, 329–406, Springer Science & Business Media, Baskaran, M. (Ed.). 2011

DeNiro MJ (1985) Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317(6040):806–809

Depalmas A (2014) New data from fortified coastal settlement of Cap de Forma, Mahon, Menorca (Balearic Islands). Radiocarbon 56(2):425–437

Ehleringer, JR, Monson, RK (1993) Evolutionary and ecological aspects of photosynthetic pathway variation. Annu Rev Ecol Syst, 411–439

Fahy GE et al (2017) Bone deep: variation in stable isotope ratios and histomorphometric measurements of bone remodelling within adult humans. J Archaeol Sci 87:10–16

Farquhar GD, Ehleringer JR, Hubick KT (1989) Carbon isotope discrimination and photosynthesis. Annu Rev Plant Physiol Plant Mol Biol 40(1):503–537

Fernández PA, Hachero JSG, Stika HP (2003) Los hipogeos de S'Alblegall (Ferreries) y la agricultura cerealística a mediados del II milenio cal ANE en Menorca. Trab Prehist 60(2):117–130

Fernández Miranda, M (1997) Aspects of Talayotic Culture. Encounters and Transformations. The Archaeology of Iberia in Transtion. Sheffield, 59–68

Fernández-Miranda M (1991) La transición hacia la cultura talayótica en Menorca. Trab Prehist 48:37–50

Fogel ML, Tuross N, Owsley DW (1989) Nitrogen isotope tracers of human lactation in modern and archaeological populations. Carnegie Institution of Washington Yearbook 88:111–117

Fullola JM, Petit MÀ, Guerrero V, Calvo M, Malgosa A (2007) Los hallazgos de la cueva de Es Pas de Ferrerías. Revista de Menorca 90(I):171–174

Fullola JM et al (2008) La Cova des Pas (Ferreries, Menorca): un jaciment cabdal en la prehistòria de les Balears. Unicum 7:10–16

Garcia E, Subirà ME, Richards MP (2004) Régime et société d'après l'analyse des isotopes stables : l'exemple de la population de «Can Reinés» (Mallorca, Espagne, 600 ap. JC). Antropo 7:171–176

Gasull, P, Lull, V, Sanahuja, ME (1984) Son Fornés, la Fase Talayótica: ensayo de reconstrucción socioeconómica de una comunidad prehistórica de la isla de Mallorca (Vol. 1). Oxford, England: BAR International Series, 209

González-Guarda E et al (2018) Multiproxy evidence for leaf-browsing and closed habitats in extinct proboscideans (Mammalia, Proboscidea) from Central Chile. Proc Natl Acad Sci 115(37):9258–9263

Guerrero Ayuso V, Calvo Trias M, Salvà Simonet B (2002) La cultura talayótica. Una sociedad de la Edad del Hierro en la periferia de la colonización fenicia. Complutum 13:221–258

Guerrero VM (2008) El Bronce Final en las Baleares. Intercambios en la antesala de la colonización fenicia del archipiélago. En S. Celestino, N. Rafel, y X. L. Armada (eds.): Contacto cultural entre el Mediterráneo y el Atlántico (siglos XII-VIII ane). La precolonización a debate. Madrid: Consejo Superior de Investigaciones Científicas, Escuela Española de Historia y Arqueología en Roma; 183–217

Gumerman G (1997) Food and complex societies. J Archaeol Method Theory 4(2):105–139

Hedges RE, Clement JG, Thomas CDL, O'Connell TC (2007) Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. American Journal of Physical Anthropology: the Official Publication of the American Association of Physical Anthropologists 133(2):808–816

Hernández-Gasch J, Nadal J, Malgosa A, Alesán A, Juan J (2002) Economic strategies and limited resources in the Balearic insular ecosystem: the myth of an indigenous animal farming society in the First Millennium BC. BAR International Series 1095:275–291

Heaton THE (1999) Spatial, species, and temporal variations in the 13C/12C ratios of C3 plants: implicationsfor palaeodiet studies. J Archaeol Sci 26:637–649

Jarošová I, Perez-Perez A, Dočkalová M, Drozdova E, Turbon D (2006) Buccal dental microwear as a dietary indicator in the Iron Age human population from Son Real. Spain Anthropologie 44(2):139–150

Jay M, Richards MP (2006) Diet in the Iron Age cemetery population at Wetwang Slack, East Yorkshire, UK: carbon and nitrogen stable isotope evidence. J Archaeol Sci 33(5):653–662

Jordana X, Malgosa A, Casté B, Tornero C (2019) Lost in transition: the dietary shifts from Late Antiquity to the Early Middle Ages in the North Eastern Iberian Peninsula. Archaeol Anthropol Sci 11:751–763

Katzenberg MA (2000) Stable isotope analysis a tool for studying past diet, demography, and life history. In M Anne Katzenberg and Shelley R Saunders Edited Biological anthropology of the human skeleton. John Wiley and Sons Inc, Hoboken, New Jersey, pp 305–327

Knudson KJ, Stojanowski CM (2008) New directions in bioarchaeology: recent contributions to the study of human social identities. J Archaeol Res 16(4):397–432

Kohn MJ (1999) You are what you eat. Science 283(5400):335–336

Kohn MJ (2010) Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo) ecology and (paleo) climate. Proc Natl Acad Sci 107(46):19691–19695

Lanting, J N, Van der Plicht J (1996) Wat hebben Floris V, skelet Swifterbant S2 en visotters gemeen?. Palaeohistoria, 491–519

Lanting JN, Van der Plicht J (1996) Wat hebben Floris V, skelet Swifterbant S2 en visotters gemeen? Palaeohistoria 37(38):491–519

Longin R (1971) New method of collagen extraction for radiocarbon dating. Nature 230(5291):241

López-Costas O, Müldner G, Cortizas AM (2015) Diet and lifestyle in Bronze Age Northwest Spain: the collective burial of Cova do Santo. J Archaeol Sci 55:209–218

Lull, V, Micó, R, Rihuete, C, Risch, R (1999) La Cova des Càrritx y la Cova des Mussol. Ideología y sociedad en la prehistoria de Menorca. Consell Insular de Menorca, Ajuntament de Ciutadella, Fundació Rubio, Barcelona.

Malgosa A (2011) La Paleopatología bajo diversos prismas: A propósito de la Cova des Pas. In: González-Martín A et al (eds) Paleopatología: ciencia multidisciplinar. Universidad Autónoma de Madrid, Madrid, pp 25–44

Mateu AI (1993) Micro-ecology and some related aspects of C4plants living in Europe. Photosynthetica 29: 583–594

Minagawa M, Wada E (1984) Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between $\delta^{15}N$ and animal age. Geochim Cosmochim Acta 48(5):1135–1140

O'Connell TC et al (2012) The diet-body offset in human nitrogen isotopic values: a controlled dietary study. Am J Phys Anthropol 149(3):426–434

O'Leary, MH, (1995) Environmental effects on carbon isotope fractionation in terrestrial plants. In: Wada, E., Yoneyamat, T., Minigawa, M., Ando, T., Fry, B.D. (Eds.), Stable Isotopes in the Biosphere. Kyoto. Kyoto University Press, pp.78-91

Payne S (1985) Morphological distinctions between the mandibular teeth of young sheep, Ovis, and goats. Capra Journal of Archaeological Science 12(2):139–147

Pérez-Jordà G, Peña-Chocarro L, Picornell-Gelabert L, Marco YC (2018) Agriculture between the third and first millennium BC in the Balearic Islands: The archaeobotanical data. Veg Hist Archaeobotany 27(1):253–265

Pérez-Pérez A, Fernández E & Turbón D (1999). Análisis de oligoelementos sobre restos humanos de la Cova des Càrritx. In: Llul V, Micó R, Rihuete C, Risch R (Eds.) Ideología y sociedad en la prehistoria de Menorca: La Coves des Càrritx y la Cova des Mussol. Barcelona. pp: 557- 566. Barcelona: Consell Insular de Menorca

Plantalamor, L, Rita, C (1983) Formas de población durante el segundo y primer milenio BC en Menorca: Son Mercer de Baix, transición entre la Cultura Pretalayótica y Talayótica. In: The Deyà Conference of Prehistory – BAR Internacional Series, 229, Vol. III. Oxford: 797-826

Prats-Muñoz G et al (2012) A paleoneurohistological study of 3,000-year-old mummified brain tissue from the Mediterranean Bronze Age. Pathobiology 79(5):239–246

Prats-Muñoz G, Galtés I, Armentano N, Cases S, Fernández PL, Malgosa A (2013) Human soft tissue preservation in the Cova des Pas site (Minorca, Bronze Age). J Archaeol Sci 40:4701–4710

Prummel W, Frisch HJ (1986) A guide for the distinction of species, sex and body side in bones of sheep and goat. J Archaeol Sci 13(6):567–577

Pyankov VI, Ziegler H, Akhani H, Deigele C, Luettge U (2010) European plants with C4 photosynthesis: geographical and taxonomic distribution and relations to climate parameters. Bot J Linn Soc 163(3):283–304

Ramírez-Pedraza I et al (2019) Microwear and isotopic analyses on cave bear remains from Toll Cave reveal both short-term and long-term dietary habits. Sci Rep 9(1):5716

Reitsema LJ (2013) Beyond diet reconstruction: stable isotope applications to human physiology, health, and nutrition. Am J Hum Biol 25(4):445–456

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, Bronk-Ramsey C, Butzin M, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg AG, Hughen KA,Kromer B, Manning SW, Muscheler R, Palmer JG, Pearson C, van derPlicht J, Reimer RW, Richards DA, Scott EM, Southon JR, Turney CS M, Wacker L, Adolphi F, Büntgen U, Capano M, Fahrni SM,Fogtmann-Schulz A, Friedrich R, Köhler P, Kudsk S, Miyake F, OlsenJ, Reinig F, Sakamoto M, Sookdeo A, Talamo S (2020) The IntCal20Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon 62:725–757

Richards MP, Hedges RE (1999) Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. J Archaeol Sci 26(6):717–722
Rita, MC, Topp, C (1988) The evolution of the Minorcan pretalayotic culture as evidenced by the sites of Morellet and Son Mercer de Baix. In Proceedings of the Prehistoric Society (Vol. 54, pp. 241–247). Cambridge University Press
Rita, MC (1982) Constatación de la manufactura del bronce en el yacimiento arqueológico de "Son Mercer de Baix" (Menorca). in: AA.VV. Estudis de Prehistòria, d'Història de Mayurka i d'Història de Mallorca dedicats a Guillem Rosselló Bordoy. Mallorca: 43–49
Rita, MC (1987) Evolución de la cultura pretalayótica menorquina a través de los yacimientos de Morelllet i Son Mercer de Baix. In: Atti del 2 Convegno di Studi "Un millennio di relazioni fra la Sardegna e i Paesi del mediterraneo. Selargius-Cagliari: 547–556
Roselló-Bordoy G (1968) Aspectos económicos de la cultura talayótica mallorquina. SAGVNTVM. Papeles Del Laboratorio De Arqueología De Valencia 5:23–30
Schoeninger MJ (1995) Stable isotope studies in human evolution. Evolutionary Anthropology: Issues, News, and Reviews 4(3):83–98
Schoeninger MJ, DeNiro MJ (1984) Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim Cosmochim Acta 48(4):625–639
Schwarcz HP, Schoeninger MJ (1991) Stable isotope analyses in human nutritional ecology. Am J Phys Anthropol 34(S13):283–321
Simón M, Armentano N, Afonso C, Malgosa A (2016) La Menorca talayótica desde el punto de vista genético: la necrópolis de la Cova des Pas. Trab Prehist 73(2):335–351
Subirà ME, Malgosa A (1992a) Multi-element analysis for dietary reconstruction at a Balearic Iron Age site. Int J Osteoarchaeol 2(3):199–204
Subirà ME, Malgosa A (1992) Trace element contents in the bone as an age and sex indicator A case of the necropolis of "S'Illot des Porros" (Spain). Int J Anthropol 7(2):65–70
Sureda P et al (2017a) Surviving on the isle of Formentera (Balearic Islands): adaptation of economic behaviour by Bronze Age first settlers to an extreme insular environment. J Archaeol Sci Rep 12:860–875
Sureda P, Camarós E, Cueto M, Teira LC, Álvarez-Fernández E, López-Dóriga I (2017) El poblado naviforme de Cap de Barbaria II (Formentera, Islas Baleares). Nuevos datos sobre su cronología y secuencia de ocupación. Trabajos de Prehistoria 74(2):319–334
Sureda, P. (2022) Producción y circulación de metal en Menorca (Islas Baleares) durante el periodo Naviforme (ca. 1.600-850 cal ANE): los talleres de Son Mercer de Baix (Ferreries) y Cala Blanca (Ciutadella) y algunos lingotes inéditos. Trabajos de Prehistoria 79, Núm. 2, julio-diciembre.
Szpak P (2014) Complexities of nitrogen isotope biogeochemistry in plant-soil systems: implications for the study of ancient agricultural and animal management practices. Front Plant Sci 5:288
Tieszen LL, Boutton TW (1989) Applications of stable isotopic ratios in terrestrialecosystems. In: Rundel PW, Ehleringer JR, Nagy KA (eds) Stable Isotopes inEcological Research, vol 68. the Series Ecological Studies. Springer Verlag, New York, pp 167–195
Tykot, R H (2004) Stable isotopes and diet: you are what you eat. Physics methods in archaeometry. IOS press, pp. 433–444
Van der Merwe NJ, Vogel JC (1978) 13C content of human collagen as a measure of prehistoric diet in woodland North America. Nature 276(5690):815–816
Van Klinken GJ (1999) Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J Archaeol Sci 26(6):687–695
Van Strydonck M, Boudini M, Ervynck A (2002) Stable isotopes (13C and 15N) and diet: animal and human bone collagen from prehistoric sites on Mallorca, Menorca and Formentera (Balearic Islands, Spain). BAR International Series 1095:189–197
Van Strydonck M, Boudin M, Ervynck A, Orvay J, Borms H (2005) Spatial and temporal variation of dietary habits during the prehistory of the Balearic Islands as reflected by 14C, d15N and d13C analyses on human and animal bones. Mayurqa 30(2):523–542
Van Strydonck M, Boudin M, Ayuso VMG, Calvo M, Fullola JM, Petit MÀ (2010) The necessity of sample quality assessment in 14C AMS dating: The case of Cova des Pas (Menorca–Spain). Nucl Instrum Methods Phys Res, Sect B 268(7–8):990–994
Vogel JC, Fuls A, Ellis RP (1978) The geographical distribution of Kranz grasses. S Afr J Sci 74:209–215
Winter K (1981) C4 plants of high biomass in arid regions of Asia-occurrence of C4 photosynthesis in Chenopodiaceae and Polygonaceae from the Middle East and USSR. Oecologia 48(1):100–106