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RESEARCH

Livestock management at the Late Iron Age site of Baltarga (eastern Pyrenees): an integrated bio-geoarchaeological approach

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Abstract

Despite the important role of livestock farming amongst Iron Age communities living in mountain regions, there is little information about livestock management, and particularly stabling practises, breeding systems, and grazing/foddering patterns. The study of the ground floor of Building G in Tossal de Baltarga has provided valuable insights into these important issues and has given us a better understanding of the social and economic patterns involved in all these livestock activities. It revealed the existence of a stable from the Late Iron Age, thanks to unique in situ finds of the stabled animals, including four sheep, a goat, and a horse, in addition to a range of organic remains preserved by fire and penning deposits. It is the first documented to date in the northeastern Iberian Peninsula. Through an integrated bio-geoarchaeological approach, combining a range of analytic procedures, including osteology, dental microwear, stable isotopes, phytoliths, dung spherulite analyses, and thin-section micromorphology, for the first time, this study has provided new, high-resolution evidence of livestock management strategies. Specifically, the research shed light on animal penning and feeding practises, revealing variable herbivorous regimes between species, the practise of seasonal movements, and the possible use of fodder as the main dietary regime of the animals stabled there. At the same time, the Baltarga case-study illustrates an indoor production unit that could reveal possible private control of some domestic animals in the Pyrenean Late Iron Age.

Keywords Iron Age · Eastern Pyrenees · Archaeozoology · Dental microwear · Stable isotopes · Phytoliths · Dung spherulites · Micromorphology

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Introduction

In recent decades, it has been proven that mountains were important economic areas in which multi-purpose and diversified activities took place (e.g. Rendu 2003; Olesti and Mercadal 2009; Leveau and Palet 2010; Orengo et al. 2013; Olesti 2014; Gassiot et al. 2014, Palet Martinez et al. 2017, Oller et al. 2018a). Amongst these activities, livestock farming played a fundamental role by the *Cerretani*, the Iberian community mentioned by the ancient literary sources that occupied the Eastern Pyrenees from the 4th to the 1st c. BC. Strabo (3.4.11) indicates that they produced salted ham, *pernae*, although the available archaeozoological data indicate the economic preponderance of cattle (Colominas 2017). The research points to the exploitation of cattle for traction; sheep and goats for meat, milk, and wool; and pigs for tender meat (Colominas et al. 2020). The importance of livestock by this mountainous population is further supported by the presence of pastoral huts in the highlands, such as at Orri d'en Corbill

(Rendu 2003). Farming strategies were based on herding and cereal agriculture, mainly hulled barley and naked wheat production (Berrocal-Barberà 2021). These were complemented by legumes, including peas and beans, thus creating open spaces surrounding the sites, including crop fields, pastures, and the exploitation of the resources of the forest areas (Berrocal-Barberà 2021). Therefore, despite the importance of livestock practises, the available data focus on the livestock consumption and exploitation strategies of these communities. There is little information about livestock management and particularly the feeding practises, stabling methods, and breeding systems used in this mountain region at that time.

Recent excavations at the Ceretanian site of Tossal de Baltarga (Bellver de Cerdanya) have documented in situ burned faunal and vegetal remains in one of its buildings. Through an integrated bio-geoarchaeological approach, including a varied range of analytic procedures (osteology, dental microwear, isotopes, phytoliths, dung spherulite analyses, and thin-section micromorphology) from different disciplines (archaeozoology, archaeobotany, and geoarchaeology), these remains have provided extraordinary direct evidence on these topics. For the first time new, high-resolution evidence of the *Cerretani* community's livestock management strategies and foddering/grazing practises for herbivorous regimes, as well as the use of space at the site during the Late Iron Age in the eastern Pyrenees, have been obtained.

The Tossal de Baltarga site

The site of Tossal de Baltarga (Bellver de Cerdanya, Eastern Pyrenees) has been excavated from 2011 to 2021 (Morera et al. 2016; Morera 2017; Oller et al. 2018a-b; Oller et al. 2019). It is situated on the top of a hill (1,166 m.) that strategically blocks the Cerdanya valley, the main trans-Pyrenean road between the south of France (*Ruscino*) and the Segre/Ebro valley (*Ilerda*) (Fig. 1). From its southern slope, the site allows, control of the land route, and, from the northern slope, the crossing of the River Segre. We can determine the existence of a small settlement (a built area of about 0.2 ha) probably used as a lookout point for territorial control, in connection with other Iberian hillforts (*oppida*) deployed in the area (Oller et al. 2018a). The site presents three chronological phases: a barely known Late Bronze/Early Iron Age phase, a Late Iron Age/Iberian phase (4th–3rd century BC) and a Roman Republican phase (2nd–1st century BC). This paper focuses on the Late Iron Age Iberian period.

The site's location on the top of a calcareous hill, natural erosion, and recent agricultural work have contributed to the poor state of preservation of the Iberian remains. We have identified a set of scattered and partly unconnected structures that define several grouped buildings adapted to the slope. However, the settlement does not exhibit any real urbanism or a perimeter wall. The walls have local stone bases beneath rammed earth architecture. From these structures, we can currently identify four houses with relative precision: buildings A, D, F, and G (Fig. 2). Of particular interest are buildings D, F, and G, defined as storage structures that were violently destroyed by fire around the year 200 BC. This general destruction is dated from the analysis of the imported pottery (Catalan coast Rhode workshop), coins (Gallic drachma imitations, type ACIP 243 var, mid-3rd c. BC) and one C14 dating (Beta 458585, 2230 +/− 30 BP). The historical context of the Second Punic War is the most likely explanation for the violent destruction.

These living spaces probably alternated with others (stores and kilns) related to its main function: control of the routes crossing the Cerdanya plain. Its proximity to El Castellot de

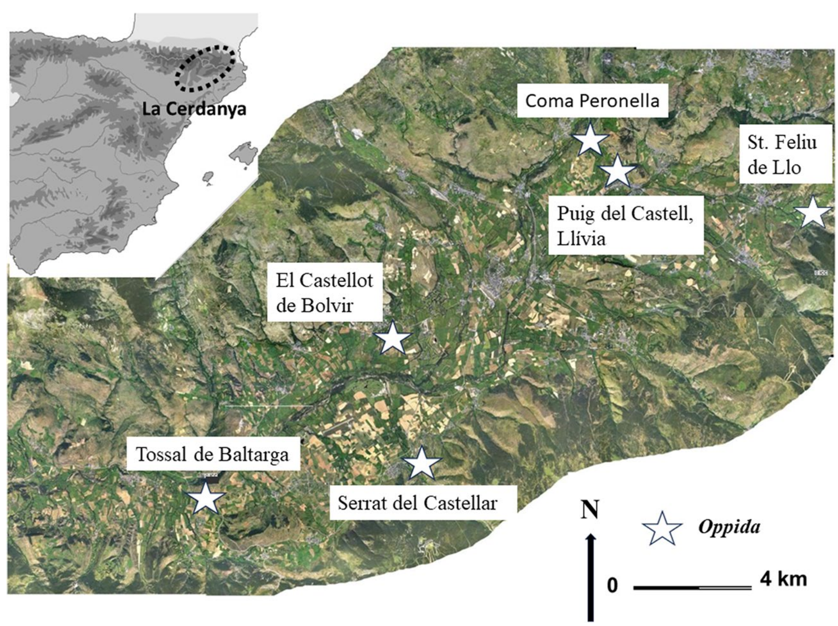

Fig. 1 Location of Tossal de Baltarga and other contemporary sites cited in the text. The inset shows the location of La Cerdanya plain in the Western Mediterranean

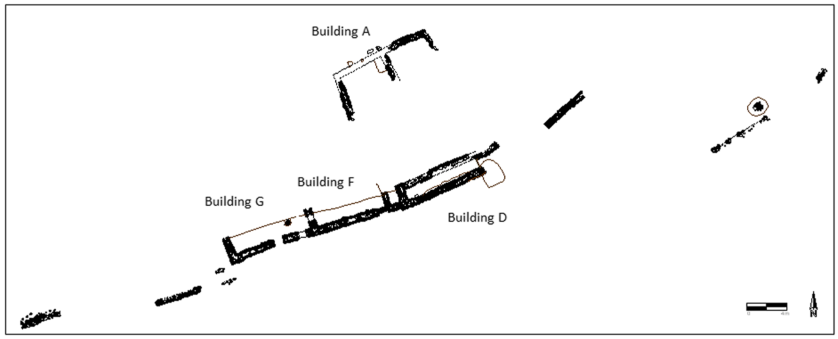

Fig. 2 Layout of the late Iron Age occupation of the Baltarga site

Bolvir, an *oppidum* located 7 km to the north-east, as well as the fact that the sites are visible from each other, allows us to consider Baltarga as a secondary settlement that depended on El Castellot. We cannot consider the site as an *oppidum* given that, as mentioned above, no perimeter wall or defensive structures have been documented. It was more likely to have been a singular settlement that combined territorial surveillance tasks with residential and working facilities linked to a single productive unit, with a certain social and economic relevance within the *Cerretani* context.

Building G

The focus of this paper is the so-called building G (Fig. 2). It is the best-preserved building from this period measuring 7 × 2 m, it exhibits similar features to the neighbouring houses and was not affected by the subsequent Roman occupations. The door was placed in the middle of the southern wall. It had an upper floor, where we documented the presence of a loom, and a large collection of pottery vessels and jars, some of them for storing agricultural products (Morera 2017; Tàrraga 2020; Alliot 2022). In this paper, we focus on the lower floor and the finds made there.

To better understand the archaeological records examined in this paper, it is important to offer a brief overview of the excavated stratigraphy of building G, which, of course, was very much affected by the destruction process it was subjected to. Below the first superficial layers, several levels appeared within the building. These strata correspond to the remains of the upper floor. It is noteworthy that the stratigraphic sequence suggests that this upper storey was divided into two parts. First, on the western side of the room, a larger area where the finds can be linked to a pottery storage space, with the presence of 50 NMI of hand-made jars, cooking pots and vessels, and 17 NMI of wheel-thrown bowls and jars. However, on the eastern side, we identified a different stratigraphic sequence, with the finds of 19 *pondera* that suggest the presence of a loom in this part of the building. Most of the pottery from the upper floor was found mixed with carbonised beams and architectural remains in a large, burned layer on the western side of the building (SU 3224), whilst most of the *pondera* were recovered in different levels focusing on the eastern part (mainly SU 3181 and 3208). The presence of different layers with *pondera* can be related to the effects on this specific part of the building of the later construction of a wall of the edifice built there in the Republican period. Finally, we can also highlight other interesting finds from the upper floor; for instance, an iron *dolabra* and a small jar containing a naviform golden earring. Under the destruction level SU 3224, there began to appear elements related to the ground floor of the building, including several carbonised wooden beams from the ceiling of the room and the faunal remains that will be described below. Finally, a burned earthen floor covering the bedrock was documented (SU 3246). This was the last layer excavated in the building.

Interestingly, during the excavation, the remains of charred wood were documented in the open space of the building entrance. These could have come from a door that may have been closed at the time of the destruction by fire (Fig. 3). There is no indication of internal access to the upper floor. Behind the entrance, possibly hanging on the internal part of the door, an articulated iron horse brake was found. The Baltarga articulated horse brake belongs to type D2 (see Fig. 8 in Argente Oliver et al. 2000) It is typical of the Second Iron Age and was used for riding horses. Inside the building, there were just two identified structures. Close to the south-western wall, there was a posthole (20 cm in diameter), probably used as a support item. Its location allows it to be considered as a standing pole for tethering the domestic animals. On the opposite side, to the east of the entrance and leaning against the back wall, several stones were placed defining a flat surface that we interpret as the support for a manger (Fig. 3). In the layers belonging to the lower floor soil, there were very few handmade pottery sherds. However, we documented a large amount of organic material and animal bones that were analysed in the current study.

Materials and methods

The finds under study here come from the ground floor of building G. They are from below the last destruction level associated with the collapse of the upper floor and above the ground floor circulation level.

Fig. 3 From left to right: remains of charred wood linked to the door of building D, indicating that it was closed at the time of the fire; horse bit recovered in building G on the threshold of the entrance door; set of slabs located in the northeastern part of the room. Detail of two vertically wedged tiles stands out

Archaeozoological analyses

539 faunal remains were recovered on the building's occupation floor. The osteological analysis of these remains focused on the study of the taxonomic and body-part representation, age-at-death, withers height estimation, and pathologies, 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 on the pelvis) or taking measurements for comparison. Sheep and goat differentiation was carried out following Boessneck (1980), Payne (1985), and Prummel and Frisch (1986). Equid remains were studied following Peters (1998) and Armitage and Chapman (1979). Age at death was recorded on the basis of the fusion of long bones and the eruption and wear of mandibular teeth. For caprine, the tooth wear and age stages followed Payne (1973) and for equids Levine (1982). Sheep and horse wither height estimates followed Teichert (1975) and Kiesewalter (1888), respectively. In order to delve more deeply into the relationship between animals, livestock practises, and diet, we applied microwear and isotope analyses.

Dental microwear results from the tooth abrasion caused by organic and inorganic particles in the ingested food items vary according to the properties of food and related items (Dahlberg and Kinzey 1962; Fortelius and Solounias 2000). Therefore, this technique allows us to reconstitute an individual's diet during the last days or weeks before death by analysing the microwear on the tooth surface. Once the teeth had been selected, each occlusal surface was cleaned with acetone and then 96% alcohol. The surface was moulded using high-resolution silicone (vinylpolysiloxane), and casts were created using clear epoxy resin, following the protocol developed by Solounias and Semprebon (2002) and Semprebon et al. (2004). Casts were observed under incident light with a Zeiss Stemi 2000C stereomicroscope at 35× magnification at the Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA), using the refractive properties of the transparent cast to reveal microfeatures on the enamel. The microwear scars were quantified on the lower teeth in an area of 0.16 mm^2 using an ocular reticule. We used the classification of features defined by Solounias and Semprebon (2002) and Semprebon et al. (2004) as follows: pits (small and large), scratches (fine and coarse), and gouges. We also used a scratch width score that recorded the proportion of scratches on each specimen, from a predominance of fine scratches to a predominance of coarse scratches (SWS0, SWS1, SWS2). For a more detailed explanation of each feature, see Gallego et al. (2017).

Sequential isotopic analysis of sheep molar enamel provides life-history data on past animal populations (Balasse 2002). The $\delta^{18}O$ values in bioapatite, mainly derived from ingested water and plant consumption (Longinelli 1984; Luz et al. 1984), are related to meteoric water and temperature, which vary seasonally in temperature in temperate latitudes. At middle and high latitudes, higher $\delta^{18}O$ values occur during the warmest season, with lower $\delta^{18}O$ values during the coldest period (Gat 1980). On the other hand, the $\delta^{13}C$ values in bioapatite are related to the carbon isotopic composition of consumed plants (Lee-Thorp and van der Merwe 1987); the latter mainly varies according to the photosynthetic pathway (e.g., C_3 and C_4 plants), but also to the growing conditions (Bender 1971; Farquhar et al. 1989), amongst other factors. Here, $\delta^{18}O$ and $\delta^{13}C$ values were investigated in order to obtain information about livestock feeding habits, reproduction strategy, and vertical mobility patterns. Four lower molars (three second molars and one third molar; Table 1) from three sheep specimens were selected for sequential stable isotope analyses. Two isolated M_2 belong to two individuals (individual 2 and individual 5), whereas a pair of M_2 and M_3 still present in the mandible at the time of sampling belong to individual 4.

After cleaning the surface by abrasion with a tungsten drill bit, the enamel was sequentially drilled with a diamond bit; the positions of the samples from the enamel root junction (ERJ) were recorded. A total of 53 powdered samples (weighing between 3.1 and 8.9 mg) were drilled and chemically treated at the Biomolecular Laboratory of the Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA), following the protocol described in Balasse et al. (2002) and modified by Tornero et al. (2013). Samples were treated for 4 h in 0.1 M acetic acid (0.1 ml solution/mg of sample) to remove exogenous carbonates, rinsed in distilled water several times, and dried in an oven at 70 °C for 48 hours. Once treated, the samples were measured using a KIEL-III device coupled to a gas-ratio Finnigan MAT 252 IRMS at the Environmental Isotope Laboratory (Dept. of Geosciences) at the University of Arizona (USA), under the scientific supervision of Dr. David Dettman. Samples were reacted with dehydrated phosphoric acid in a vacuum at 70 °C. The accuracy and precision of the measurements were checked and calibrated using the international calcium carbonate standards (NBS-19 and NBS-18). Replicate measurements of the standards during analysis had errors of ±0.1‰ for $\delta^{18}O$ and ±0.08‰ for $\delta^{13}C$ (1σ). Results are expressed in δ notation and expressed per mil (‰), in agreement with the corrections from standard V-PDB (Vienna – Pee Dee Belemnite) for carbon and oxygen values.

Seasonality and reproduction patterns were investigated following Balasse et al. (2003, 2012) and Tornero et al. (2013). The $\delta^{18}O$ sequences were modelled using the equation described by Balasse et al. (2012) and based on a cosine function, in order to quantify the inter-individual variability in tooth size. The season of birth of building G's sheep is estimated by comparison with modern reference data sets including individuals from Blaise and Balasse (2011), Balasse et al. (2012), Balasse et al. (2017, 2020), and Tornero et al. (2018). Seasonal feeding habits are assessed through the analysis of $\delta^{13}C$ values along the tooth crown. Finally, annual vertical mobility is detected through the inverse relationship between $\delta^{18}O$ and $\delta^{13}C$ values, following original proposals described in Tornero et al. (2016, 2018).

Macrobotanical analyses: wood charcoal, seeds, and fruits

Forty charcoal remains were analysed from three different stratigraphic units (SU 3182, 3224, and 3246). In each SU, the maximum number of available samples was analysed: SU 3182 (n = 5), SU 3224 (n = 25), and SU 3246 (n = 10). The wood taxa were identified by analysing the three anatomical wooden sections (transversal, radial longitudinal, and tangential longitudinal) of each analysed fragment. The samples were prepared manually by fracturing each piece of charcoal. The samples were examined with an Olympus BX51 optical microscope with bright field reflected light and compared with reference samples of modern wood. The keys for their identification are described by Schweingruber (1990) in an atlas of European species.

The seed and fruit finds come from a single soil sample corresponding to building G and associated with the main floor (SU3246). The volume of the sample was 20 litres, processed by the bucket flotation method using 2- and 0.35-mm mesh sizes; the residue from the 0.35-mm mesh was washed again using the wash-over method. The 2-mm fraction was completely sorted with the naked eye, whilst the 0.35-mm fraction was first sampled with the grid method technique (Vander Veen and Fieller 1982) and then sorted with an Olympus SX10 stereoscopic lens. The atlases used to identify the remains were the Jacomet et al. (2006) cereal guide and The Seed Atlas of the Netherlands (Cappers, Bekker and Jans 2012). The criteria proposed by Jones (1990) and Hillman et al. (1996) at a 1992 London workshop were followed to count cereal remains, whilst legumes and wild plant seeds were counted following the criteria proposed by R. Buxó (1997).

Micromorphological analysis

Micromorphology analysis was conducted on four thin sections prepared from two undisturbed block sediments (samples BTB-3 and BTB-4) comprising SU 3224, attributed to the collapse of the upper floor and the walls, and SU 3246 related to the use of the space. Sample BTB-3 was collected from the western part of the northern profile, whilst sample BTB-4 was cut from the eastern profile in order to compare the results and ascertain whether there were any differences or spatial variations (Fig. 4).

Following oven-drying at *ca.* 40 °C, the sediment blocks were consolidated by impregnating them with a polystyrene resin and dried for several weeks. Next, 30-μm thin sections measuring 78 × 53 mm were produced. Microscopic analysis was carried out using a petrographic microscope (×25 to ×400 magnifications) under plane-polarised light (PPL), crossed polarised light (XPL), and oblique incident

Table 1 Number of scratches (Ms), pits (Pm), small pits (Spm), large pits (Lpm), gouges (Gm), cross scratches (XSm), fine scratches (FSm), and coarse scratches (CSm) from Baltarga site individuals

Ind.	Sm	Pm	Spm	Lpm	Gm	XSm	FSm	CSm
Ind. 2	11	21	18	3	0	0	11	0
Ind. 3	12	15	11	2	2	0	10	2
Ind. 4	9	18	14	4	0	0	9	0
Ind. 5	10	18	15	2	1	0	9	1

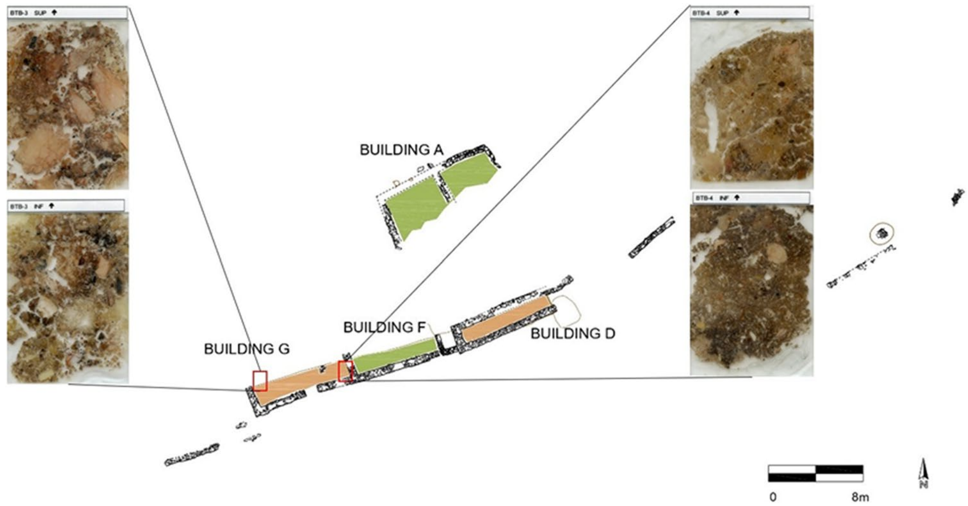

Fig. 4 Location of the micromorphological samples from building G

light (OIL). The descriptions followed published guidelines (Bullock et al. 1985; Courty et al. 1989; Stoops 2003; Stoops et al. 2010). The archaeological deposits were classified and defined by microstructure and porosity, groundmass, organic, and inorganic components, as well as pedofeatures.

Phytoliths and dung spherulite analyses

Five sediment samples were selected for integrated phytolith and dung spherulite analyses. The samples corresponded to two stratigraphic units described in the field as the collapse of the roof, the walls (SU 3224), and the occupational floor (SU 3246). All the samples examined were obtained from the sub-sampling of two undisturbed sediment blocks for micromorphological analyses (samples BTB-3 and BTB-4). This sampling approach allows a direct comparison between opal phytolith and calcitic dung microfossil records and micromorphological observations (Portillo and Matthews 2020, and references therein).

Phytolith analyses followed the methods of Katz et al. (2010). A weighed aliquot of *ca*. 40 mg of dried sediment was treated with 50 µl of a volume solution of 6N HCl and 450 µl 2.4 g/ml sodium polytungstate solution [$Na_6(H_2W_{12}O_{40})$]. Microscope slides were mounted with 50 µl of material. A minimum of 200 phytoliths with consistent morphologies were examined at 200× and 400× using an Olympus BX43 optical microscope. Morphological identification was based on modern plant reference collections and standard literature (Twiss et al. 1969; Brown 1984; Rosen 1992; Twiss 1992; Mulholland and Rapp 1992; Albert and Weiner 2001; Piperno 2006; Tsartsidou et al. 2007; Albert et al. 2008, 2016; Portillo et al. 2014). Where appropriate, the terms used follow the International Code for Phytolith Nomenclature–ICPN 2.0 (Neumann et al. 2019).

The methods used for calcitic dung spherulite analyses were similar to those developed by Canti (1999, 2003). Samples of *ca*. 1 mg of dried sediment were mounted on microscope slides using Entellan New (Merck). Dung spherulites were counted at 400× magnification under the optical microscope with cross-polarised light (XPL). Phytolith and dung spherulite samples were compared to modern ethnoarchaeological dung reference records that followed a similar quantitative approach (Tsartsidou et al. 2008; Portillo et al. 2012, 2014, 2017, 2019, 2020, 2021; Portillo and Matthews 2020). Both analyses were conducted at the Laboratory of Archaeobotany, Autonomous University of Barcelona.

Results

Archaeozoological analyses

539 faunal remains were analysed from the building's occupation floor (stratigraphic units 3248, 3249, 3250, 3270, 3271, and 3277). These faunal remains belonged to the skeletons of 6 individuals (Fig. 5), poorly preserved due to the fire and the subsequent collapse of the building.

Osteological data

- Individual 1 (SU 3248): 77 bone fragments were recovered from this specimen. Taxonomic identification showed they belonged to a sheep (*Ovis aries*). It was possible to recover the trunk, the right upper forelimb, and both hind limbs (Fig. 5). The study of bone fusion shows that this specimen was between 3.5 and 4.5 years old when it died. It was not possible to estimate the withers height of this specimen due to the high degree of fragmentation and thermoalteration (with a black and white colouration) of the bones.
- Individual 2 (SU 3249): 102 bones belong to this specimen, which corresponds to a sheep (*Ovis aries*). Body-

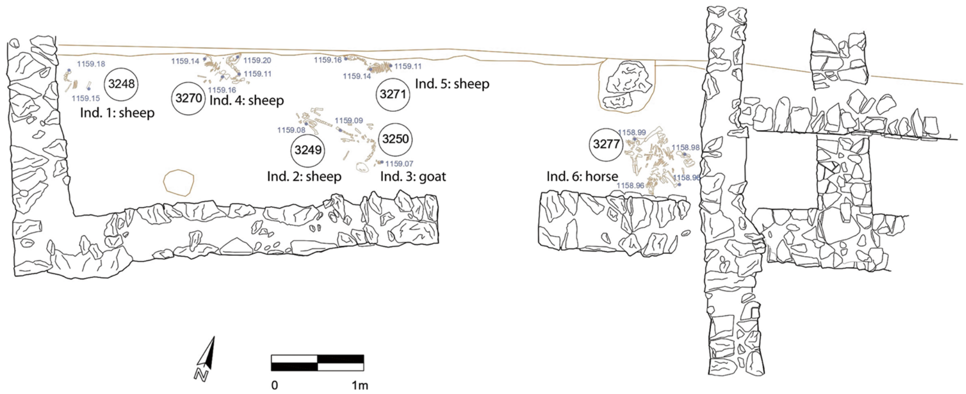

Fig. 5 Layout of building G at the Baltarga site with the location of the different animal skeletons

part representation shows the presence of the entire skeleton (Fig. 5), except for some elements (left scapula, left metacarpal, and some ribs, vertebras, and phalanges) due to taphonomic and recovery issues. Tooth wear and long bone fusion analyses show that this specimen was about 3 years old when it died. There is an exostosis in the proximal diaphysis of the right metatarsal produced by a tear in the bone (Campillo 1993-1994). This pathology shows that this animal survived a broken leg, probably thanks to human care. Withers height estimation of this specimen is 61.92 cm.

– Individual 3 (SU 3250): 49 bones were recovered from this specimen. It was a goat (*Capra hircus*) estimated to be between 12 and 20 months old. Body-part reconstruction shows a similar representation to individual 2, with the presence of almost the entire skeleton except for the left scapula, the left femur, and some ribs, vertebras, and phalanges, due to taphonomic and recovery issues. It was not possible to estimate the wither height of this individual due to the continued growth of its bones.
– Individual 4 (SU 3270): 93 bone fragments belong to this specimen. The taxonomic identification showed they were from a sheep (*Ovis aries*). It was possible to recover the head, some elements of the forelimbs, most of the trunk, and a fragment of pelvis and femur (Fig. 5). Tooth wear and long bone fusion analyses show that this specimen was between 3 and 4 years old when it died. Its wither height estimation is 61.54 cm.
– Individual 5 (SU 3271): 53 elements were recovered from this individual, which corresponds to a sheep (*Ovis aries*). Tooth wear and long bone fusion show that it was about 2 years old when it died (21–24 months). Body-part reconstruction shows a similar representation to individual 4, with the presence of the head, the right forelimb, most of the trunk, and the left humerus (Fig. 5). It was not possible to estimate the wither height of this individual because its bones were still growing.
– Individual 6 (SU 3277): 165 bone fragments were recovered from this specimen. The taxonomic identification showed that they belonged to a horse (*Equus caballus*). The entire skeleton was recovered (Fig. 5), except some bones from the right and left forelimbs, the feet of the left hind limb, and the trunk (some ribs and vertebras). Based on the study of bone fusion, it is estimated that it was over 4 years old at the time of death. Through the osteometric study of the right hind limb, we know that it had a wither height of 125 cm and was robust, with a similar morphology to a present-day Mongol horse or a Konik pony. These breeds have traditionally been used as riding animals (Arbogast et al. 2002).

Dental microwear data

Only four specimens: individual 2 (3-year-old sheep), individual 3 (12–20-month-old goat), individual 4 (3–4-year-old sheep), and individual 5 (21–24-month-old sheep) were suitable for microwear analysis. The molars of individual 1 (3.5–4.5-year-old sheep) and individual 6 (more than 4-year-old horse) were totally altered by the fire and any reading was impossible.

Sheep and goat from Baltarga exhibit enamel surface with microwear characterised by a low number of pits (Mean = 18) and scratches (Mean = 10.5) (Fig. 6). The scratches have a range of between 9 and 12 and the pits between 15 and 21. The pits are more numerous than the scratches on all sheep specimens, but not on the subadult goat specimen, where the number of scratches and pits is more similar. Despite these differences, the diets of these 4 specimens were very similar.

In order to learn more about the type of vegetables these individuals ate during the days before their deaths, we compared the microwear pattern observed on their teeth with the microwear pattern of modern sheep teeth with known diets (Gallego-Valle et al. 2020). In this paper, Gallego-Valle et al. (2020) presented a reference collection through a controlled food trial to study sheep feeding management systems. They investigated the microwear pattern of four different types of vegetation potentially used by agropastoral societies (alfalfa, ray grass, forage, and barley) administered following different

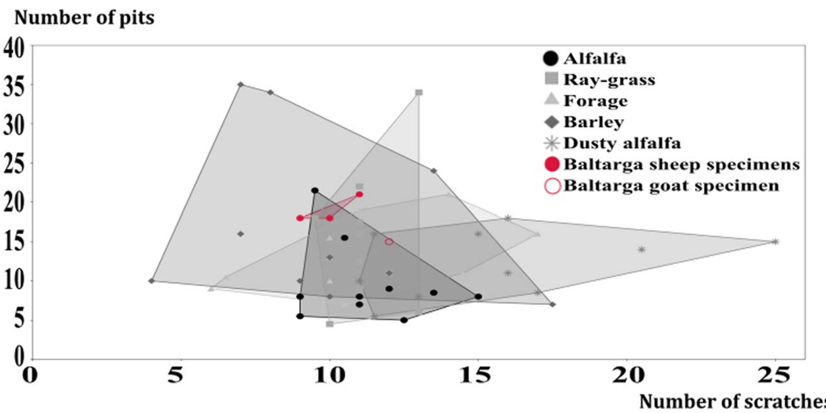

Fig. 6 Bivariate plot of scratches versus pits from Baltarga site individuals and from a controlled food trial experiment on sheep (Gallego-Valle et al. 2020)

processing techniques (wet, dried, and fresh). The comparison of our data with this reference collection showed interesting results (Fig. 6). If the number of scratches and pits is considered, our four specimens clearly differ from the individuals that were fed with the dusty alfalfa diet—composed of sand mixed with the alfalfa to simulate a pasture on an over-grazed meadow—which tend to have more scratches. Although the archaeological specimens fall into the range of the forage group—which simulates free grazing in pastures and forages—they differ from it in that the latter has a higher variability of scratches and pits. The wide diversity in the number of pits and scratches that characterises the barley diet—composed of a mixture of dry barley seeds and straw to simulate a diet mainly based on cereal hay (straw and grains)—also differs from the homogeneity documented in the four Baltarga specimens. Therefore, the most similar diets based on the number of pits and scratches are gramineae (ray grass) and a fabaceae (alfalfa) silage that also tend towards homogeneity in the number of scratches and pits.

These comparisons are strengthened if feature trait data are also considered. Fine scratches (FS) predominate in all four individuals, and large pits (LP) are less numerous than small pits (SP). In addition, the absence or near absence of cross scratches (XS), coarse scratches (CS), and gouges (G) in sheep specimens is noteworthy (Table 1). The goat specimen has the highest values in number of scratches, gouges, and coarse scratches. The presence/absence and quantity of these different features also match their presence/absence and quantity on ensilaged gramineae and fabaceae diets. Gallego et al. propose that these two wet ensilaged diets are defined by a moderate count of scratches and pits, where most scratches are fine and pits are small, with a low computation of large pits and a near absence of gouges and coarse scratches (Table 5 in Gallego-Valle et al. 2020).

Stable isotope data

The results of the intra-tooth sequences of $\delta^{18}O$ and $\delta^{13}C$ values are summarised in Table 2. The mean $\delta^{18}O$ value from all samples was −1.9 ± 1.6‰, ranging from 0.9‰ to −4.6‰; mean $\delta^{13}C$ value from all samples was −11.4 ± 0.7‰, ranging from 9.4‰ to −12.5‰.

In all sheep specimens, except individual 4's second molar, oxygen sequences show high intra-tooth variation, with a sinusoidal pattern and clear maximum and minimum events that reflect the seasonal cycle; the highest values were recorded during summer, whilst the lowest ones were during winter. Instead, carbon sequences show low intra-tooth variation along the crown, with the exception of individual 4, which shows an increase in carbon values towards the end of the second molar sequence (Fig. 7). The third molar of the same individual shows a sinusoidal pattern with minimum and maximum events in the oxygen sequence and a decrease in values over the carbon sequence.

Birth season was assessed from $\delta^{18}O$ sequential series observed in the second molars investigated by identifying the position of the maximum $\delta^{18}O$ values in the tooth crown and by comparison with modern reference data. All three M_2s were modelled, and the results are shown in Table 3 and Fig. 8 in a circular graph, to visually reflect the cyclical

Table 2 Isotopic results ($\delta^{18}O$ and $\delta^{13}O$ values) in bioapatite samples from building G sheep lower second (M_2) and third (M_3) molars

			$\delta^{18}O_{V\text{-}PDB‰}$				$\delta^{13}C_{V\text{-}PDB‰}$			
Individuals	Tooth	*N*	Mean	Range	Max.	Min.	Mean	Range	Max.	Min.
Individual 2	M_2	16	−2.3	4.1	0.5	−4.6	−11.3	1.3	−10.8	−12.1
Individual 5	M_2	13	−2.5	4.4	−0.1	−4.5	−12.1	1.0	−11.5	−12.5
Individual 4	M_2	10	−0.6	2.2	0.9	−3.0	−11.3	2.5	−9.4	−12.0
Individual 4	M_3	14	−2.1	5.2	0.0	−5.3	−11.0	1.9	−9.8	−11.7

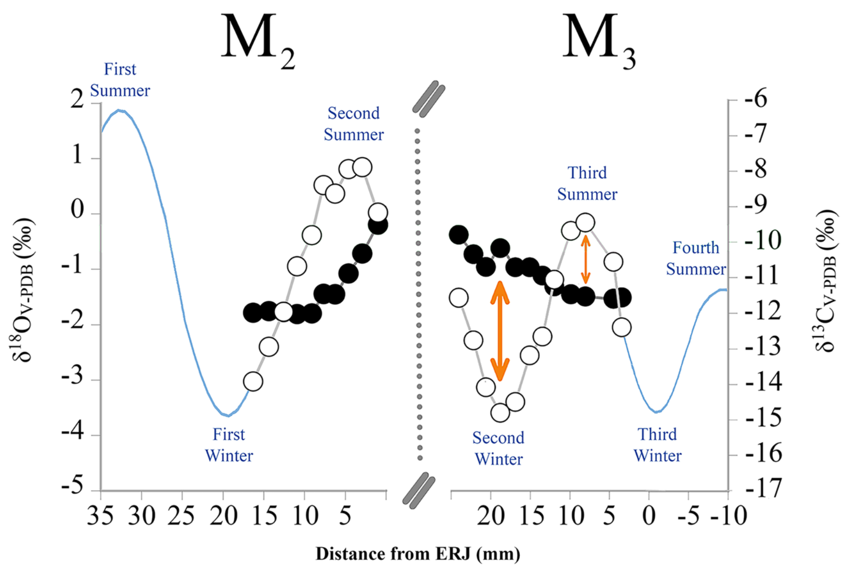

Fig. 7 Sequential analysis of oxygen ($\delta^{18}O_{V\text{-}PDB}$, white circles) and carbon ($\delta^{13}C_{V\text{-}PDB}$, black circles) isotope composition in individual 4's (*Ovis aries*) lower second (M_2) and third (M_3) molars from building G. Represented in blue is the reconstruction of the expected trend of the oxygen value sequence, which, combined with the results, reproduces the first four years of the individual's life

nature of seasonality (Balasse et al. 2020). The results suggest that the sheep from building G were born from late winter to mid-spring, within a limited time frame between them (Messana et al. 2023).

The $\delta^{13}C$ values measured on sheep molars suggest a diet widely based on C_3 plants throughout the year. Individual 2 and individual 5 show a very narrow amplitude during all the sequences, suggesting no changes or very small ones in consumed plant resources during the first year of life. On the other hand, individual 4 shows an increase in amplitude towards the final part of the sequence of the M_2, which can be followed in the M_3 sequence. Crown formation of M_2 in sheep begins between the first and second month and is completed at 12 months. M_3, on the other hand, is formed from the tenth month onwards and completes around 22 months (Milhaud and Nézit 1991; Hillson 2005; Zazzo et al. 2010). The information obtained from the two molars combined thus makes it possible to reconstruct the first two years of an individual's life. Therefore, the variation in the two combined sequences reflects changes in the isotopic composition of individual 4's diet during its second year of life; these changes may derive from an altitudinal movement from the second year of life. Further data in favour of this hypothesis can be found in the inverse relationship between the end of $\delta^{18}O$ and $\delta^{13}C$ sequences of M_2 and between part of $\delta^{18}O$ and $\delta^{13}C$ of M_3 sequences.

Macrobotanical remains

Three different taxa were identified amongst the 40 analysed charcoal samples: *Pinus sylvestris/nigra* (Scots pine or black pine), *Abies alba* (silver fir), and Rosaceae/Maloideae. Scots pine or black pine is the main taxon and represents 80% of the total samples analysed. The other taxa were 12.5% (silver fir) and 7.5% (Rosaceae/Maloideae). Some important differences can be seen amongst the SU, although the total numbers are also very different. SU 3182 is exclusively represented by silver fir and, at the same time, is the only SU where this species is represented. SU 3224 is the more numerous and exclusively represented by Scots or black pine. SU 3246 is mainly dominated by Scots or black pine, although there are also some fragments of Rosaceae/Maloideae (Table 4).

Although the data is limited, four different cereal species were identified: hulled barley (*Hordeum vulgare*), naked wheat (*Triticum aestivum/durum/turgidum*), millet (*Panicum miliaceum*), and einkorn (*T. monococcum*) (Table 5). They are

Table 3 Results from the calculation of the best fit (least squares method) for combined variation of *X* (period), *A* (amplitude), x_0 (delay), and *M* (mean). The Pearson's correlation coefficient (*R*) is also indicated

	Individual 4	Individual 5	Individual 2				
n (model)	10	12	14	**Mean**	**Δ**	**Max**	**Min**
X (mm)	27.13	25.63	26.45	26.40	0.751		
A (%)	2	2.2	2.5	2.23	0.252		
x_0 (mm)	4.58	7.12	2.00	4.57	2.560		
M (%)	−1.2	−2.3	−2.2	−1.90	0.608		
Coeff. Pearson	0.994	0.995	0.992	0.99	0.002		
x_0/X	0.17	0.28	0.08	0.18	0.100	0.28	0.08

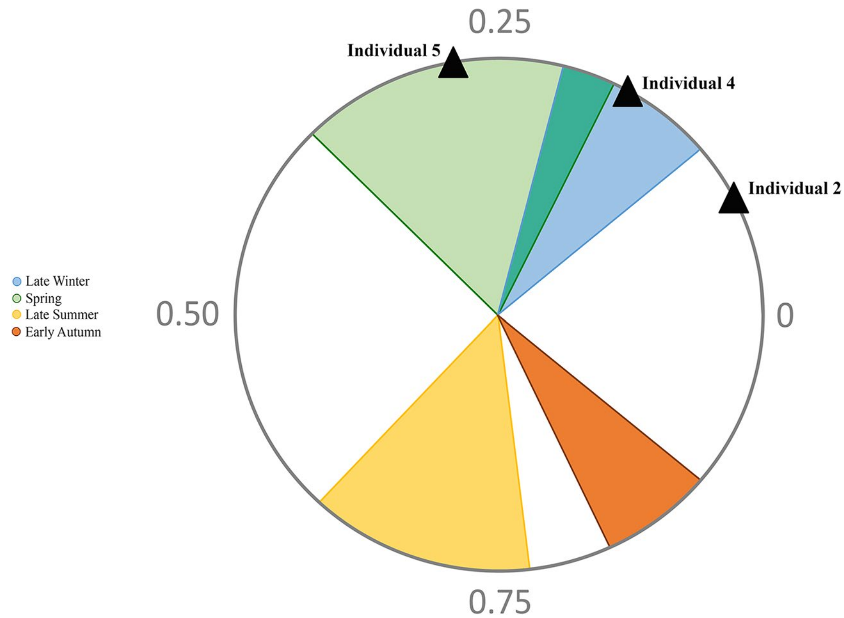

Fig. 8 Distribution of sheep births (black triangles) at building G (Tossal de Baltarga), as reflected by the position of the maximum $\delta^{18}O$ value in M_2 tooth crown (x_0) normalised to the period of the cycle (X). The birth season is compared with modern reference populations with known dates of birth

staple crops and basic products in the human diet, although it should not be ruled out that some of them (such as barley) could also have been used to feed livestock. Regarding legumes, one genus—vetch/pea (*Vicia/Lathyrus*)—was identified, which would have been part of the human diet, although it could also have been used to feed livestock, as in the case of some cereal species. The highest number of macrobotanical remains corresponded to wild plants, including weeds, ruderals, and a shrub. White goosefoot (*Chenopodium album*) and bedstraw (*Galium* sp.) were the largest group of seed remains, both weeds commonly present in cultivated (cereal) fields and/or anthropised lands, along with wild buckwheat (*Fallopia convolvulus*). These probably arrived at the settlement mixed with cereals. Single remains/seeds of ground cherry (*Physalis alkekengi*), hawthorn (*Crataegus* sp.), sedge (*Carex* sp.), and the Fabaceae family were also found. It is necessary to emphasise that ground cherry and hawthorn are plants with some economic value (edible plants).

Micromorphological observations

The microstratigraphic analysis allowed us to delve into the characterisation of the penning floor (SU 3246) and the collapse deposit (SU 3224). The micromorphological analysis

Table 4 Wood charcoal taxa from Baltarga

	SU 3182	SU 3224	SU 3246	Total
Pinus sylvestris/nigra		25	7	**32**
Abies alba	5			**5**
Rosaceae/Maloideae			3	**3**
Total	**5**	**25**	**10**	**40**

Values in bold indicate total numbers

revealed spatial differences depending on the location of the samples. This is because SU 3246 is poorly preserved in BTB-3, e.g., the western area of the stable, compared to the eastern portion of the building where sample BTB-4 was obtained. Accordingly, micromorphological observations on this layer were mostly based on sample BTB-4, which points to an organic-rich deposit built-up of decayed and partially burnt animal dung and some randomly oriented subangular gravel. It has a spongy/massive microstructure with a 10% porosity and a porphyric c/f-related distribution. The main component is herbivore dung, evidenced by the amorphous yellowish-brown phosphatic groundmass under PPL containing disarticulated phytoliths, humified plant tissues, and ubiquitous calcitic faecal spherulites (Brochier et al. 1992; Canti 1997; Shahack-Gross 2011; Brönnimann et al. 2017) (Fig. 9a–c), according to the osteological results outlined above. Moreover, reddish dark-brown reworked faecal inclusions also appear, probably burnt (Brönnimann et al. 2017). Additionally, occasional fragments of bones and charred plant remains are found randomly distributed, including a charred seed suspected to be a cereal grain. Nevertheless, the major concentrations of these materials occur in the upper part of the deposit, where most of the bones are found burnt at *ca.* 500 °C following Villagran et al. (2017) and crushed, and charcoal fragments are bigger (Fig. 9d). It is also in the upper part where the colours of the pen deposit become pale yellowish to greyish at the microscopic level in PPL, probably as a direct consequence of the fire, evidenced by the presence of ashes, blackened phytoliths, and darkened spherulites, suggesting burning temperatures of between 500 and 700 °C (Canti and Nicosia 2018).

Higher in the sequence, SU 3224 shows a collapse deposit formed by red silty clay and medium-to-coarse angular gravels.

Table 5 List of seeds and fruit remains collected from Baltarga, with numbers of seeds unless otherwise stated

Taxa	Common name	SU 3246	SU 3224	SU 3192	SU 3182
Avena sp.	Oat		1		
Cerealia		19	13		6
Hordeum vulgare	Hulled barley	1	2		
Panicum miliaceum	Millet	2			
Triticum a/d/t	Naked wheat	1	1		
Triticum dicoccum, spikelet base	Emmer		1		
Triticum monococcum	Einkorn	1			
Triticum sp.			1		
Vicia sativa	Vetch		1		
Vicia/Lathyrus	Vetch/peavine (generic)	1	1		
Cultivated plants:		**25**	**21**		**6**
Carex sp.	Sedge (generic)	1			
Chenopodium album	Goosefoot	41	5	1	
Crataegus sp.	Hawthorn (generic)	1			
Fabaceae		1			
Fallopia convolvulus	Buckwheat	1			
Galium sp.	Bedstraw (generic)	76			
Physalis alkekengi	Bladder cherry	1			
Poaceae			2	2	
Wild plants:		**122**	**7**	**3**	
Undetermined remains		40	21		
Total remains:		**187**	**49**	**3**	**6**

Values in bold indicate total numbers

The reddened colour is a direct consequence of fire, also evidenced by the fractured gravel, the split minerals, and the iron impregnations on them. The lack of internal stratification and chaotic orientation of the coarse components, along with the 25–35% porosity containing packing voids and vughs, points to a single and sudden deposition event. Regarding the

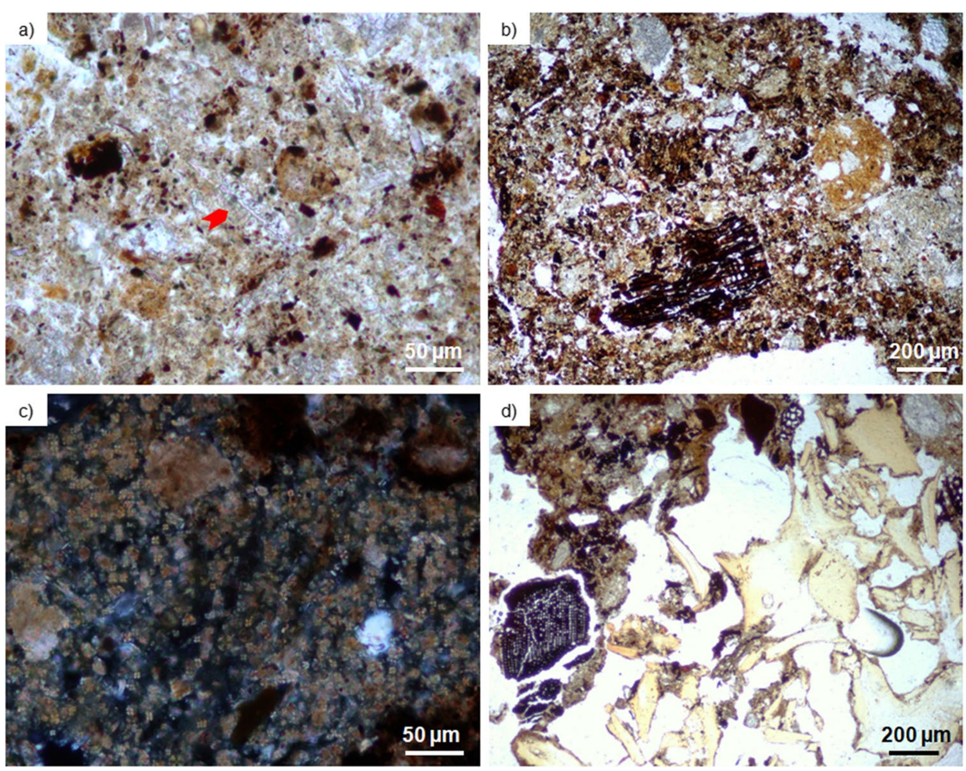

Fig. 9 Microphotographs of some of the most characteristic microscopic features of SU 3246, all from sample BTB-4. **a** Disarticulated phytoliths embedded in a phosphatic groundmass of decayed corprogenic material. Note the presence of a dendritic elongate phytoliths in the middle of the picture (arrow), PPL; **b** humified organic materials and plant tissues, PPL; **c** high concentrations of calcitic faecal spherulites, XPL; **d** accumulation of charred plant remains and crushed bones on top of SU 3246 as a consequence of the building collapse, PPL

components, it is worth noting the increased presence of minerogenic elements compared to the pen deposit characterised by limestone fragments, siltstones, and burnt clay aggregates deriving from the collapse of the construction materials. In that case, mainly charcoal remains represent organic components that probably belonged to the roof or supporting structure.

Generally, both units appear occasionally altered by root activity distinguished by partially degraded cellulose tissue, often showing ferruginous coatings and the presence of rounded voids displaying thin planar voids and sometimes compacted edges. Soil mesofauna is also documented, as shown by the appearance of channels, probably attracted by the high organic content.

Phytolith and dung spherulite assemblages

Phytoliths were abundant in most of the samples throughout the depositional sequence (from *ca*. 0.02 to 2.15 million phytoliths per gram of sediment, Table 6). The richest assemblages by far were recorded in samples from block BTB-4, located in the eastern portion of the building (more than 1.3 m phytoliths/g of sediment). Interestingly, phytolith concentrations overlap spatially with rich-dung spherulite abundances (up to 6.7 m spherulites/g of sediment in sample 3246-s3, block BTB-4, Table 6), which are consistent with the micromorphological observations pointing to well-preserved faecal deposits. Furthermore, the presence of multicellular or anatomically interconnected phytoliths in most of the samples (up to 10.9% in sample 3224-s2, block BTB-4, Fig. 10a), in addition to the low proportion of unidentifiable weathered morphologies displaying etching and pitting on their surfaces (below 8.5%, Table 6), is indicative of the generally good state of preservation of these microfossil records (e.g., Cabanes et al. 2011; Portillo et al. 2020). Most of the phytolith assemblages derive from monocotyledonous plants, particularly from grasses of the Pooideae subfamily according to the dominant short cell morphologies (around 85% of all the counted phytoliths, Fig. 10a). In addition to short cells (mainly rondels, polylobates, and saddles), characteristic morphotypes from grass leaves and culms, including bulliforms, acute bulbosus (trichomes), and psilate (smooth) elongates, were common in the phytolith assemblages (Fig. 10b). Diagnostic morphotypes from the inflorescences of grasses, such as single-celled or multicellular dendritics, occurred in greater amounts in certain samples, rather than being ubiquitous in all assemblages. This is particularly the case of the aforementioned multicellular-rich phytolith records (sample 3224-s2 from block BTB-4, *ca*. 30% of all the counted grass phytoliths). Of particular note is the presence of short cell morphologies belonging to the Panicoideae subfamily, including both bilobates and crosses in all samples from block BTB-4 (Fig. 10c). This is consistent with the poorly preserved macro-botanical records dominated by wild grasses, but also by finds of undetermined Cerealia fragments and weeds, in addition to hulled barley (*Hordeum vulgare*), free-threshing wheat (*Triticum aestivum/durum/turgidum*), einkorn (*T. monococcum*), and millet (*Panicum miliaceum*).

Discussion

Spatial organisation and penning

The findings reported above provide a snapshot of the stable just before its destruction by fire. The architectural characteristics of the building and spatial distribution, along with the in situ finds of animal skeletons, and the penning deposits and both macrobotanical and plant and faecal microfossil records, indicate the existence of three differential spaces.

First, right at the entrance, an empty central space of *ca*.1'5 × 2 m could have been represented the existence of some type of enclosure on both sides with very few remains that included the horse bite. This would have had the only entrance door to this lower floor, oriented towards the south. This is consistent with the orientation of the site, stepped in terraces following the natural slope, and the protection it would have offered against the cold north winds, as well as better insulation, as ancient agronomists recommended. In fact, when Roman agronomists describe sheep penning, they point to a rectangular space, longer than wider, with a lower roof, and open to the south, similar to this case-study (Col. 3.1.2).

Furthermore, within the eastern portion of the building, just to the right of the door, is where the isolated remains of a horse were located. Also, to the east, in contact with the rear wall cut out of the rock, the area cut out with the set of slabs could represent some type of enclosure or, more hypothetically, the base of an installation for the horse fodder. Interestingly, the phytolith records point to a concentration of panicoid grasses (probably millet) within the eastern portion of the penning floor that overlaps spatially with the in situ articulated horse skeleton remains that may relate either to foddering, or even bedding, according to the micromorphological observations outlined above. It should be noted that this space of *ca*. 2 × 2 m intended for the horse was a little lower, than that intended for the rest of the animals, and that its remains do not go beyond the stony feature and therefore could mark the base of an interior fence.

Lastly, the western portion of the building, of around 3.5 × 2 m, is where the rest of the animals were found, including four sheep and a goat, which appear to share the same space. The goat was found nearest the entrance door, almost in contact with individual 2. The location of these animals does not go beyond a straight line close to the western axis of the door, which may suggest some type of feature delimiting the space intended for animals. Of particular note is the presence of a posthole near the northwestern corner of this

Table 6 Location, description of samples, and main quantitative phytolith and dung spherulite results obtained from building G, with correspondence to micromorphological block samples (coded as BTB)

SU/sample n.	Block sample n.	Phytoliths 1 g of sediment (million)	Monocotyledonous (%)	Dicotyledonous leaves (%)	Dicotyledonous wood/bark (%)	Phytoliths weathering (%)	Multicelled phytoliths (%)	Spherulites 1 g of sediment (million)	Description
3224-s1	BTB-3	0.02	83.3	0	16.7	0	0	0	Stony ashy red silty-clay deposit with charcoal fragments
3246-s1	BTB-3	0.72	89.2	1.5	1	8.3	1	0.40	Dark-brown compacted deposit, *in situ* faunal remains, herbivorous penning
3224-s2	BTB-4	2.15	86.5	5.9	3.4	4.2	10.9	1.30	Stony ashy red silty-clay deposit with charcoal fragments
3246-s2	BTB-4	1.35	89.4	6.7	2.7	1.3	4.8	1.80	Dark-brown compacted dung, *in situ* faunal remains, herbivorous penning
3246-s3	BTB-4	1.32	89.2	4.9	3.1	2.7	4.4	6.70	Dark-brown compacted dung, *in situ* faunal remains, herbivorous penning

area, possibly for a fastening element linked to a hypothetical structure associated with this part of the stable. It is noteworthy that the sparse quantity of animal dung microscopically detected in this area compared to the eastern portion of the building could hypothetically suggest it was used for maintenance activities such as bedding replacement (Milek 2012).

Despite the simplicity, however, it seems clear that the stable was organised in a planned way, with the physical separation of the horse from the sheep and goat, and an entry space free of animals. The evidence of the stable's end due to a fire, the closed door, and the fact that the animals remained within their respective sectors without crossing a central space or attempting to exit suggest the existence of internal separations that would have prevented the animals from reaching the door. They would probably have been made of wood and therefore have not been preserved archaeologically. Their presence might have been difficult to distinguish during the excavations along with the mixed building materials from the upper floor. The anthracological study indicates that these wooden partitions or the door itself could have been built with Scots or black pine and/or silver fir. Scots or black pine and silver fir, due to their straight morphology, were traditionally exploited for architecture or construction, as well as for cabinetmaking. The use of the different species of the Rosacea/Maloideae genus is usually related to the consumption of their fruits, although their wood is also appreciated for cabinetmaking.

Overall, the spatial distribution of the different animal carcasses recovered from the floor of building G and the evidence of some arrangements in its interior indicate that different animal species shared the stable, each, however, in its own space. This suggests that the animals documented in the interior of the building were those species regularly stabled there, which served as a barn equipped with all the necessary accessories. Therefore, these finds demonstrate that caprines and a horse shared this space on a regular basis.

This is a very interesting point, as the central areas of the Iron Age sites in the north-eastern Iberian Peninsula have been interpreted as communal spaces in which the livestock was sheltered (Mata et al. 2005). These finds demonstrate that there were also indoor penning spaces, revealing animal management and livestock penning within buildings at the site. It could be argued that the colder weather in the Pyrenean area would have favoured the shelter of the animals in the stable, although the isotope analyses suggest that the destruction of the site probably occurred during the summer, at a time when the use of indoor penning spaces could suggest the private management of these animals.

Livestock exploitation

The osteological analysis of the animal carcasses recovered from the floor of building G allowed the documentation of

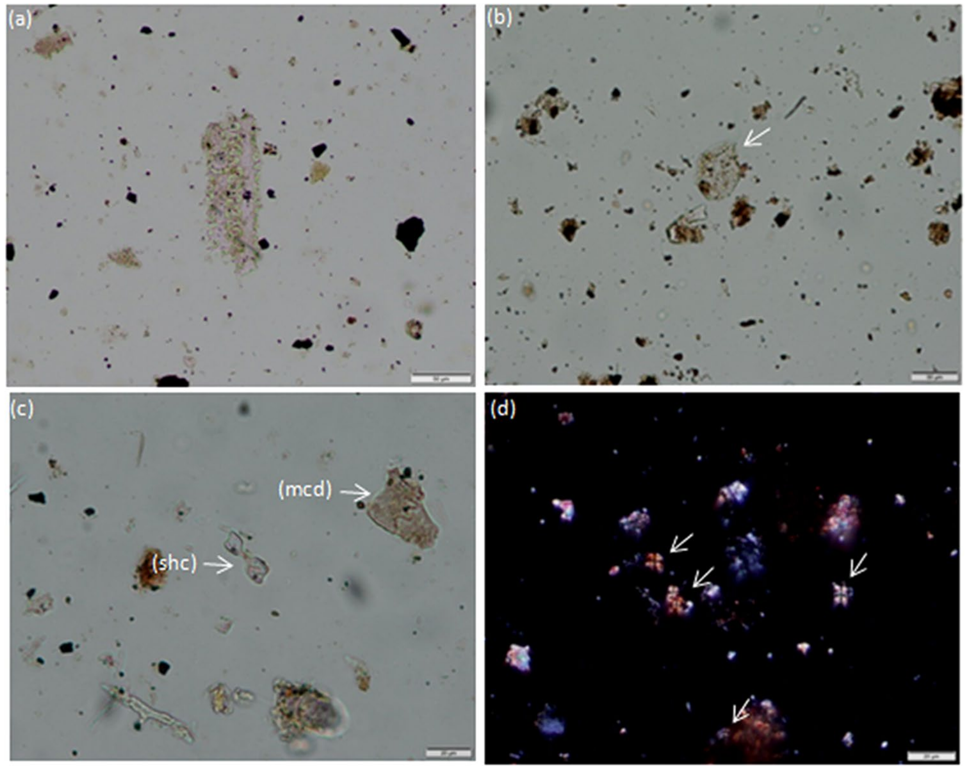

Fig. 10 Photomicrographs of phytoliths and other calcitic microfossils identified in the samples (200× or 400×); **a** multicellular dendritics with short cell rondels from Pooideae grasses (sample 3224-s2); **b** bulliform from grass leaves (3246-s3); **c** short cell bilobate from Panicoideae grasses (shc) and multicellular dendritics (mcd) (3224-s2); **d** dung spherulites (3246-s3)

four sheep, one goat, and one horse. All were subadults or adults at the time of death. This suggests that the value of other products obtained from them during their lifetime was greater than that of their meat. In this respect, mortality profiles show that the sheep from this stable were kept alive primarily for exploiting their wool and possibly also their milk. Indeed, they were between two and four years old at the time of death and exceeded their optimal weight for meat production (Oueslati 2006). Furthermore, it is possible that some of them were also exploited as breeding animals, not forgetting the use of their dung for manuring the soil or as fuel. The exploitation of the goat specimen, which was 12–20 months old and at its optimal weight at the time of death, is more challenging to determine. Indeed, it is uncertain whether it would have been slaughtered shortly thereafter, indicating an exploitation of this animal for meat, or if the inhabitants of Baltarga wanted to keep the goat alive until it was older for milk production and/or as a breeding animal. These mortality profiles differ somewhat from those documented at the neighbouring site of El Castellot de Bolvir (Fig. 1). Archaeozoological studies at this site show a predominance of sheep slaughtered before maturity (between 6 and 12 months) with a lower proportion of sheep slaughtered after the age of 12 months. In contrast, goats were predominantly slaughtered at adult ages (between 48 and 72 months), although we document some slaughtered prior to those ages (Colominas 2017). Therefore, the available information suggests different caprine exploitation patterns in these two settlements (the only two Iron Age sites in the area with archaeozoological data). However, more data from Baltarga are needed to properly establish livestock production at the site in this period, as the information presented here is only from building G. Sheep births in Tossal de Baltarga occurred from late winter to spring, in agreement with the natural lambing season in high and mid-temperate latitudes (Hafez 1952; Jewell and Grubb 1974; Santiago-Moreno et al. 2000; Gootwine 2011; Gómez-Brunet et al. 2012). None of the three individuals isotopically analysed shows out-of-season lambing. Therefore, no anthropogenic modifications in order to extend or shift the expected breeding season were detected. Furthermore, lambing occurred over a quite short period. The small number of samples does not allow absolute conclusions to be drawn, but it would appear that people from Tossal de Baltarga were not interested in obtaining milk all year round (Gómez-Brunet et al. 2012) and did not need two different birth seasons in order to increase herd size. On the other hand, concentrating births in a relatively narrow time frame could have resulted from anthropogenic intervention aimed at synchronising births in the same period.

In relation to the horse, through the osteological analysis, we know that it was 4 years old when it died. Once horses reach this age, they are usually considered adults and they can start to be ridden (Arbogast et al. 2002). The presence of a horse bit in the same room could indicate that it was already trained for this activity. We must point out in this regard that the osteometric study shows that it was small and robust, with a similar morphology to a present-day traditional riding breed.

Therefore, when the fire started, the barn of building G housed mature animals, in which the inhabitants of Baltarga would have invested time and care in order to exploit them for several productions. This investment in care is also reflected in the recovery of the broken leg of individual 2 (3-year-old sheep).

Livestock diet

The nature of the livestock diet varies according to a range of factors including ecological and seasonal variability in food sources, sex/age-based dietary requirements, selection of feed by animals, or management practises. The combination of the techniques performed here shows that, effectively, different feeding practises were used in Baltarga.

Dental microwear results show that specimens 2 (3-year-old sheep), 3 (12–20-month-old goat), 4 (3–4-year-old sheep), and 5 (21–24-month-old sheep) had a very similar diet the last days before dying, and that it was very little abrasive. The comparison of these data with the microwear pattern of modern sheep with known diets (Gallego-Valle et al. 2020) allows us to suggest that the microwear pattern documented in the Baltarga individuals reflects a soft diet, probably composed mainly of wet ensilaged leafy-fodder. As a homogeneous fodder, it produced a low variation (in quantity of traces and diversity of typology) between the individuals. The slight difference of the goat specimen, however, with a few more scratches and fewer pits than the sheep specimens, must be considered, suggesting that perhaps this specimen ingested some abrasive particles from the ground (such as grit or sand), mixed with the fodder or that it was nourished in a free forage regime. In this respect, recent studies demonstrate that grit is one of the main abrasive agents, considering the dental microwear on the tooth enamel surface (Lawrence 2019; Mainland 2003; Sanson et al. 2007; Teaford et al. 2021, amongst others). However, the data from Baltarga is still limited and the available records on livestock diets from other contemporary sites in the region are completely absent.

Interestingly, the phytolith records from the western part of the stabling floor deposits, which overlapped with an articulated sheep skeleton, are indicative of plant composition linked to variable herbivorous diet regimes. These include herbaceous plants, mainly Pooideae grasses and weeds. These findings are consistent with the macrobotanical assemblages, which are composed mainly of wild plants and cereals, such as barley and wheat, although to a lesser extent.

In contrast, phytolith results indicate a different vegetal component in the dung deposits from the eastern part of the penning floor. These deposits are dominated by Panicoid grasses, including millets (*Panicum miliaceum*), according to the macrobotanical records of charred seeds, which correspond to the horse location. This pattern is probably related to differential dietary regimes between the horse and the caprines throughout the penning lifetime.

Furthermore, isotopic results show that the feeding habits of the sheep during the first year of life were based on C_3 plants with little variability in their isotopic composition. It is probable that the herd fed in the same location during this period, exploiting the local resources. This pattern, however, seems to have changed after the second year of life. The variation observed in the two combined sequences reflects changes in the isotopic composition of individual 4's diet during its second year. The inverse relationship between the maximum and minimum peak events of $\delta^{13}C$ and $\delta^{18}O$ values documented in individual 4 is interpreted as evidence of a seasonal altitudinal movement across pastures with different vegetation (Tornero et al. 2016; Tejedor-Rodríguez et al. 2021). These data testify that individual 4, after its second summer and during its second year of life, joined the practise of vertical mobility and descended to a lowland location. Looking at the oxygen and carbon isotope curves in the third molar, after the second winter, there is a new decrease in carbon values at the same time as an increase in oxygen values. This indicates a new change in altitude for individual 4 and a return to the same place of origin, within an annual vertical movement. In the other two sheep analysed (individuals 2 and 5), the same dynamics can be intuited at the end of the M_2 sequence, in the last formed part of the crown. However, the absence of M_3 makes it impossible to verify the presence of the same pattern and continuity of the trend. Therefore, through the inverse relationship between the two isotope sequences, we have documented changes in the seasonal feeding habits after the second year of life that would imply a vertical mobility. This mobility must not have reached the coastal planes, but rather the middle lands or perhaps neighbouring areas such as the Ausetani or Lacetani regions, where the contacts with local communities would have been frequent, as the ancient ethnonym *Ausocerretani* indicates (Avienus, *OM*, 549-552, Olesti et al. in press).

Conclusions

The current study of the ground floor of building G in Tossal de Baltarga has revealed the existence of a Late Iron Age stable, the first so far documented in the northeastern Iberian Peninsula. The excavation has revealed in situ finds of stabled animals, including four sheep, a goat, and a horse, along with a range of organic remains preserved by fire. An integrated biogeoarchaeological approach has provided unique information on its internal distribution and the conditioning of the spaces according to the different animals, as well as on livestock management and feeding practises. The stable had a planned distribution, with a physical separation between the horse and the caprines. The penning deposits, examined through thin-section micromorphology and integrated macrobotanical, plant, and faecal microfossil records at high-resolution, support the hypothesis that animals displaying differential dietary regimes shared this indoor space. Dental microwear evidence indicates that caprines consumed a soft diet, probably mainly composed of wet ensilaged leafy-fodder. Furthermore, isotope signatures indicate changes in the seasonal feeding habits after the second year of life in one individual that imply a vertical mobility. In short, this case-study highlights the diversity of livestock management practises in a Late Iron Age production unit, in turn implying a complex social and economic organisation of the community living in Baltarga, in order to carry out the activities documented here. It also suggests the possibility of a private management and exploitation of at least part of the livestock, the domain of an important part of the local resources, in a hierarchical pattern typical of aristocratic groups. The destruction by fire of this stable with the animals inside, contemporary to the general violent destruction of the settlement at the end of the 3rd century BC or the beginning of the 2nd century BC, possibly coincides with the phenomena linked to the Second Punic War and the beginning of the Roman conquest (Oller et al. 2018a, b). This destruction has made it possible to reconstruct the internal organisation of a highly complex production unit (building G) at a very specific moment, with the coexistence of several animal species kept in the same space, to better understand Late Iron Age livestock practises in the eastern Pyrenees. New questions have now been opened up and further research is needed to properly interpret this livestock management.

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Data availability All data generated or analysed during this study are included in this published article.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Informed consent was obtained from all subjects involved in the study.

Competing interests The authors declare no competing interests.

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