



Caprine dental microwear reveals livestock management and exploitation of landscape during the Middle and Late Bronze Age of the Balearic Islands (ca. 1500–850 cal. BC)

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Abstract

In the last few decades, bioarchaeological studies have grown exponentially on the Balearic Islands. In general, animal husbandry based on domestic triad and a Mediterranean macchia landscape is well-attested during the prehistory of this archipelago. Despite providing meaningful data about dietary patterns and livestock practices, dental microwear analyses on animal teeth have not been previously applied to the research of the Balearic Islands. This study presents the results of dental microwear analyses from 107 caprine teeth from seven archaeological sites from the Balearics dated from the Middle and Late Bronze Age. The results suggest that sheep and goats were predominantly browsers, having a shrubby-predominant diet, with the exception of Cala Blanca caprines (Menorca) that were mixed feeders with a tendency towards a grazing diet. Dental microwear results also suggest that caprines from two archaeological sites located on the coast did not feed near to the settlements, thus suggesting livestock movement. The combination of these results with the archaeobotanical information available from some sites has allowed a better understanding about livestock management and its impact on the transformation of the prehistoric landscape of the Balearic Islands.

Keywords *Ovis aries* · *Capra hircus* · Tooth microwear · Bronze Age · Landscape · Balearic Islands

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Introduction

The Balearic Islands were the last large islands in the Mediterranean to be settled, as late as the 3rd millennium cal. BC (e.g. Ramis et al. 2002; Cherry and Leppard 2018). They are the most isolated archipelago in the Mediterranean basin. They are comprised of four main islands which join in two groups, or sub-archipelagoes, by proximity. Mallorca (3640 sq km) and Menorca (701 sq km), the largest ones separated by about 35 km, form the Gymnesic Islands. Ibiza (571 sq km) and Formentera (83 sq km), separated by a narrow channel of 7 km, are known as Pithyusic Islands. The minimum distance between both groups is about 80 km. The minimum distance from the mainland is nearly 200 km to the Gymnesics and 80 km to the Pithyusics. The Serra de Tramuntana, in north Mallorca, is the only important orographic system of the Balearics, with 10 peaks between 1000 and 1450 m above sea level.

The paleobotanical and paleoclimatic studies carried out on the Balearic Islands indicate a vegetation change around 3200–3000 BC in Mallorca and ca. 3650–2500 BC in Menorca, when mesophilic vegetation disappeared and

Mediterranean macchia expanded (Yll et al. 1999; Burjachs et al. 2017). This could be the result of early human activities associated with animal husbandry, agriculture and forest management, although it could also be related to climatic aspects such as reduced rainfalls and a higher seasonality (Burjachs et al. 2017; Servera-Vives et al. 2018; Picornell-Servera and Servera-Vives 2017; Yll et al. 1994, 1997). In this sense, paleoclimate studies in the Balearic Islands revealed an aridification process at the beginning of the Late Holocene (Frígola et al. 2007), which also favoured the expansion of thermomediterranean taxa (Servera-Vives et al. 2018).

The short Balearic prehistory starts with the arrival of the first human communities in an undetermined moment around the mid-3rd millennium cal. BC. This phase has been defined as a colonisation stage and a multicausal factor is proposed to explain this late colonisation (Ramis 2010; Cherry and Leppard 2018). The early archaeological record — like dwelling structures (Fernández-Miranda 1993), megaliths (Plantalamor 1976) and pottery styles (e.g. Coll and Ramis 2014) — shows clear similarities with that of the probable source regions, especially the Eastern Pyrenees and Languedoc. A similar interpretation derives from early metallurgy studies, with a metal composition of objects from Ibiza and Formentera being compatible with a Pyrenees or Languedoc origin (Sureda 2019), and tin alloys being present in Mallorca in the late 3rd millennium BC, before its spread into Iberia (Ramis 2014). Moreover, an aDNA analysis of a Mallorcan human remain dated to the 3rd millennium cal. BC shows an important Steppe ancestry, which has been linked with the arrival of this genetic ancestry to Iberia through the Pyrenees (Fernandes et al. 2020).

Around 1700/1600 cal. BC, the first clear evidence of the emergence of a local culture in the Balearic Islands is detected, with the spread of a kind of monumental house called *naveta* or *navetiform* (i.e. Lull et al. 1999; Salvà 2001; Guerrero et al. 2007; Calvo et al. 2011). It consists of an apsidal construction with a horseshoe-shaped layout, built using large dry blocks with inner filling. The complete length of the more monumental examples reaches about 20 m. Some of them are isolated, but usually they are grouped in villages. Although they are mostly situated in flat areas in the lowlands, some of these villages have been also identified in the mountains and in locations with rough relief. A common habitus between settlements all over the islands during the Middle and Late Bronze Age has been suggested based on the similarities of architecture, material culture and other social practices (Albero et al. 2011). Conversely, archaeobotanical studies indicate that every-day practices were managed independently at each household (Albero et al. 2011; Picornell-Servera and Servera-Vives 2017). This cultural period has received different names: Naviform, Dwelling naveta or Pretalaiotic.

The high number of *navetiform* villages suggests a substantial increase of the population and the adoption of a more sedentary economic system at this time (c. 1700/1600 cal. BC). From fewer than ten open-air settlements known in Mallorca in the late 3rd millennium cal. BC, and none in Menorca, there is a shift to about 180 *navetiform* villages inventoried in the former island (Pons 1999) and 80 in the latter (López Pons 2001). Funerary evidence supports this interpretation, considering the large funerary *nawetes* in Menorca and rock cut tombs grouped in necropolis in Mallorca (e.g. Coll 1993; Lull et al. 1999). All these structures are characterised by an emphasis on monumentality that corresponds closely with increasingly sedentary behaviour.

By the end of the 2nd millennium cal. BC, there was gradual collapse of the society of the *navetiform* villages in Mallorca and Menorca. They were abandoned (Ramis and Salas 2014), in parallel with a very deep transformation which lead to the beginning of the Talaiotic culture. This culture is characterised by the emergence of the public tower-like monuments called *talaiots*, and new villages arised surrounding these monumental buildings.

A mixed economy is recorded in Mallorca, Menorca and Formentera in the Bronze Age, with well-established cereal agriculture (López-Dóriga et al. 2015; López et al. 2013; Berrocal 2016, 2018; Valenzuela-Suau et al. 2017; Pérez-Jordà et al. 2018). These agropastoral activities have also been evidenced in paleobotanical studies from lagoon sequences in Menorca, Mallorca and Eivissa, as suggested by noticeable values of cereal and apophytic taxa (Burjachs et al. 2017; Servera-Vives et al. 2018). The livestock economy of this society was based on the exploitation of domesticated mammals (sheep, goats, cattle and pigs), with a residual presence of wild resources (Ramis 2006; Hernández-Gasch et al. 2011; Valenzuela-Suau 2020). In addition, mortality profiles show a preference for meat consumption compared to secondary products (Ramis 2006; Hernández-Gasch et al. 2011; Valenzuela-Suau and Valenzuela-Lamas 2013; Valenzuela-Suau et al. 2018). In the early faunal assemblages, those dated to the late 3rd-early 2nd millennium cal. BC, there is a very high proportion of domestic caprines among the livestock species (about 90% or higher in abundance). In the Mid Bronze sites, an important cattle increase is recorded, with percentages between about 20 and 40% of the identified specimens (Ramis 2018). This more balanced distribution of the different domestic mammals, and specially the significant cattle increase in the Mid Bronze Age, also point to a more sedentary pattern with a more intense exploitation of the surrounding landscape of the villages.

One way to evaluate this assumed scenario, that of an increasing intensity of landscape exploitation during the Mid and Late Bronze Age, is the study of livestock nourishment. Isotopic analyses on herbivorous bones show

Table 1 Basic information of the samples analysed on this study

| Archaeological site | Bitopic situation | Samples chronology | No. of analysed specimens | No. of specimens with conserved microwear |
|-------------------------|---|----------------------|---------------------------|---|
| S'Hospitalet Vell | Settlement near the coast | ca.1600–850 cal. BC | 17 | 6 |
| Els Closos de Ca'n Gaià | Settlement near the coast | ca.1600–850 cal. BC | 8 | 6 |
| Sa Ferradura | Coastal head without habitat structures | ca.1100–900 cal. BC | 15 | 8 |
| S'Illot des Porros | Islet without habitat structures | ca.1400–850 cal. BC | 25 | 8 |
| Cova del Camp del Bisbe | Sacred natural cave in centre Mallorca | ca.1300–1000 cal. BC | 14 | 7 |
| Cala Morell | Settlement on a coastal head | ca.1400–1200 cal. BC | 10 | 4 |
| Cala Blanca | Bronze Age house on the beach | ca.1750–1200 cal. BC | 18 | 17 |
| Total | | | 107 | 56 |

differences between their diet but they conclude that this could be related to the consumption of different types of vegetation and other factors such as salinity or humidity (Van Strydonck et al. 2005). Other data from faecal analyses showed a lack of gramineous plants in sheep diet during the Early Bronze Age (Valenzuela et al. 2010). Finally, the identification of forage plants through carpological record on a Mallorca Middle and Late Bronze Age site could be related with animal diet (Berrocal 2016, 2018; Valenzuela-Suau et al. 2017). The aim of this work is to characterise sheep and goat diets during the Middle and Late Bronze Age on the Balearic Islands, in order to analyse the relationship between livestock feeding and landscape exploitation. In this sense, we intend to examine what they ate, if there are similarities or differences between sites (is this related with the site functionality or location?), and if animals were fed with cultivated plants or rather they browsed around the landscape. In conclusion, the objective is to understand the role of livestock practices on the formation and exploitation of the landscape.

To achieve this goal, dental microwear analyses have been performed on six different archaeological sites from Mallorca and Menorca (as explained later in the “Materials and methods” section). Microwear analyses have been traditionally performed on wild and extinct species (Solounias and Semprebon 2002) but they have been also applied to domestic mammals showing their great contribution to the discussion of livestock management (e.g. Mainland 1997, 2003; Mainland and Halstead 2005; Henton et al. 2014; Rivals et al. 2011; Rieau 2012; Jiménez-Manchón et al. 2018). On the Balearic Islands, prior microwear studies focused on extinct animals and human remains (Hautier et al. 2009; Winkler et al. 2013a, 2013b; Jarosova et al. 2006). For these reasons, we wanted to cover as many biotopes as possible and different site functionalities, in order to obtain a comprehensive view of what livestock management was like, and how these populations exploited their landscape. This study focuses on the major Balearic Islands, Mallorca and

Menorca (Gimnesic Islands), where most of the evidence of this cultural period comes from, while it is still quite limited in the Pithyusics.

Materials and methods

Materials

The selected samples for this study correspond to domestic caprines because they are the most frequent taxon in the Bronze Age of the Balearic islands (e.g. Ramis 2006; Hernández-Gasch et al. 2011; Ramis and Anglada 2012; Valenzuela-Suau and Valenzuela-Lamas 2013; Valenzuela-Suau et al. 2018; Valenzuela-Suau 2020). Despite the difficulties in distinguishing between sheep and goats, priority was given to identify sheep jaws. Regarding the archaeological sites, assemblages available from this period are scarce, a fact that conditioned the selection. Among the available sets, those for which there was a good registration system and with a clear chronology were selected.

As summarised in Table 1, one hundred seven samples from seven archaeological sites — five from Mallorca and two from Menorca — could be analysed. The poor conservation of the majority of the assemblages did not allow us to analyse the microwear and, in the case of Es Coll de Cala Morell, the number of teeth is really low and the information will be taken prudently in the discussion. Even that, the low number of teeth with conserved microwear prevents making subdivisions in terms of phases or structures. For this reason, we have grouped them into a generic set.

Methods

Tooth microwear analysis can be described as a traceological study because it is based on the observation of diverse marks present on the occlusal surface of ungulates' teeth. In this study, the second and third lower molars of caprines

have been preferably selected and we observed the protocenid of each tooth. When sample size was too small, we also included the upper molars and analysed the paracone. The occlusal surface of the teeth was cleaned to remove dust and potential remains of consolidants using acetone and then 96% ethanol. The next step was to create a reproduction of the microwear of the tooth. In this case, the surface of the tooth was coated with a high-resolution dental silicone (*Provil Novo Light CD2 regular*) and then the mould was created with the application of *Turboflex Putty Soft*. To produce the positive, the moulds were filled with transparent epoxy resin (*Epoxy 1060/1585*).

Different parameters were analysed on the positive replicas of the teeth with a stereomicroscope at 35 \times . For that purpose, we followed the method established by Solounias and Semprebon (2002), which is based on the quantification of microwear features (gouges, large pits, cross scratches). For each tooth, we quantified the number of pits and scratches on two subsamples of 0.16 mm² and we computed the mean. Scratches are elongated features that were quantified for each subsample. In addition, their thickness (SWS) and orientation were also observed and recorded in a qualitative way. Pits are circular or sub-circular depressions that were also counted on each subsample. Their size was also taken into account by recording the presence or absence of large pits on the surface.

All these qualitative and quantitative variables were used to characterise paleodiet in our samples based on three main dietary groups of ungulates: browsers, grazers and mixed feeders. The first respond to a diet based on the consumption of herbaceous plants. This type of diet is characteristic of ruminants and their teeth have few scratches (lower than 17 per counting area) and more pits. Grazers' microwear show a higher average of seventeen scratches and less pits, and their diet is based on the ingestion of gramineous plants which are very abrasive due to their high content of phytoliths. The mixed feeders have a more diversified and opportunistic diet as a combination of the previous two. The data were plotted on a scatter diagram using the R code created by Rivals (2019). The data on fossil species were compared to a dataset based a large number of extant species with known diets and, in some cases, the interpretation of the results was complemented with other works such as Mainland (2003).

The integration of all the variables analysed allows for a more accurate approximation and identification of the diet. In addition to the numbers of pits and scratches, the qualitative variables (gouges, large pits and scratch width score) make it possible to characterise the consumption of twigs, small branches or that animals fed close to the ground on short vegetation. Finally, it is important to note that dental microwear has a high turnover and features are replaced in few days or weeks (Grine 1986). The microwear observed reflects the diet of the last days of life of an individual and,

consequently, the vegetation consumed in the surroundings of the archaeological site where they were killed. In summary, through the average number of pits and scratches combined with other dietary indicators, it is possible to work on the details of which kind of plants they ate, what part of it (i.e. leaves or branches) and even, if the land was over-exploited.

Results

S'Hospitalet Vell (SH)

This archaeological site is located on the southern part of Manacor (Mallorca), 2 km from the coast (Fig. 1). Located on a coastal flat, the land is not deep enough and it is not optimum for agriculture (Munar and Salas 2005). During the Bronze Age, its functionality was a stable settlement (Pons 1999; Ramis and Salas 2014) and continued to be occupied during the Iron Age with new typology of constructions (Riera and Rosselló-Bordoy 1995; Ramis and Salas 2011). Archaeological evidence suggests that during the Middle and Late Bronze Age, the household constructions were in use ca. 1500 cal. BC. They were abandoned at different times between 1450 and 900 cal. BC (Ramis and Salas 2014) (view Supplementary Table 1). The samples from this site come from a household building with two different chambers called navetiforms 3 and 4.

The results show a poor quality of preservation of the microwear pattern on the enamel surfaces. Only 6 from 20 specimens conserved the microwear pattern, and the presence of dissolution marks due to the activity of plant roots on the enamel was registered on some teeth. Focusing on the results, the average number of pits and scratches indicates that, generally, caprines from S'Hospitalet Vell were browsers with an herbaceous based-diet (Fig. 1). Furthermore, the high number of large pits (LP = 83%) and gouges (100%) suggests that they consumed plants near to the ground and ingested some amounts of soil mineral particles (Tables 2 and 3; Fig. 3).

Closos de Ca'n Gaià (CG)

This is a navetiform Bronze Age village located at 700 m from the coast of Felanitx (Mallorca) (e.g. Calvo and Salvà 1999; Javaloyas et al. 2007). It has different houses and work areas grouped in an open space, without walls, with a long-time occupation (ca. 1000 years) (Javaloyas et al. 2007; Javaloyas et al. 2013). The analysed caprine teeth come from two structures (ca. 1500–850 ca. BC): a household (navetiform 1) and a structure placed on the work area without a clear functionality (IIA) (view Supplementary Table 1).

Fig. 1 Balearic Islands map showing the location of archaeological sites analysed in this paper

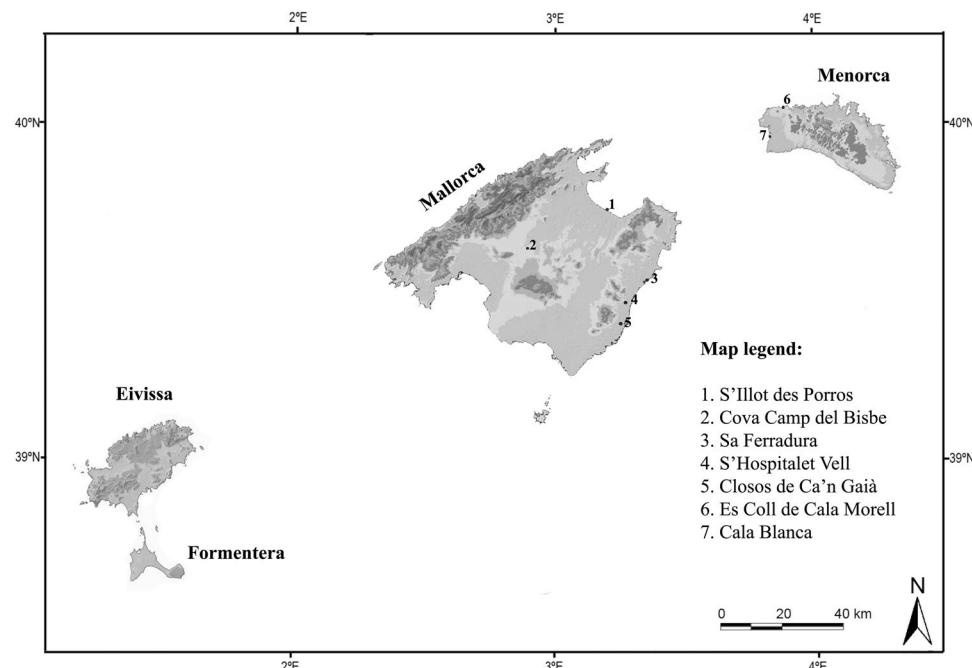


Table 2 Summary of the dental microwear data. *N*, number of specimens; *NP*, average number of pits; *SEM*, standard error of the mean; *NS*, average number of scratches; *%LP*, percentage of individuals with large pits; *SWS*, scratch width score; *%XS*, percentage of indi-

viduals with cross scratches; *%G*, percentage individuals with gouges. *SH*, S'Hospitalet Vell; *CG*, Closos de Ca'n Gaià; *SF*, Sa Ferradura; *IP*, S'Illot des Porros; *CCB*, Cova del Camp del Bisbe; *CM*, Cala Morell; *CBL*, Cala Blanca

| | <i>N</i> | <i>NP</i> | <i>SEM</i> | <i>NS</i> | <i>SEM</i> | <i>%LP</i> | <i>SWS</i> | <i>%XS</i> | <i>%G</i> |
|------------|----------|-----------|------------|-----------|------------|------------|------------|------------|-----------|
| SH | 6 | 36.2 | 4.8 | 13.4 | 1.5 | 83.3 | 1 | 16.6 | 1 |
| CG | 6 | 34.8 | 2.5 | 15.8 | 0.7 | 66.6 | 1 | 0 | 1 |
| SF | 8 | 35.6 | 3.5 | 16.3 | 0.6 | 100 | 1.25 | 0 | 75 |
| IP | 8 | 29.4 | 2.2 | 12.6 | 1.1 | 87.5 | 0.75 | 12.5 | 75 |
| CCB | 7 | 34.7 | 1.7 | 13.9 | 1 | 85.7 | 1.14 | 0 | 71.4 |
| CM | 4 | 51.9 | 6.9 | 14.4 | 0.6 | 100 | 0.75 | 0 | 75 |
| CBL | 17 | 22.5 | 1.7 | 19.1 | 0.7 | 47.05 | 0.88 | 29.41 | 11.76 |

Table 3 Summary of caprine diet in each archaeological site related with dental microwear results

| Sites | Dietary group | Specific diet |
|-------------------------|-------------------------------|---|
| S'Hospitalet Vell | Browser | Herbaceous plants |
| Closos de Ca'n Gaià | Browser | Herbaceous plants and leaves from shrubs |
| Sa Ferradura | Browse-dominated mixed feeder | Plants near to the ground; soil particles |
| S'Illot des Porros | Browser | Herbaceous plants and leaves from shrubs |
| Cova del Camp del Bisbe | Browse-dominated mixed feeder | More shrubs leaves than grass |
| Es Coll de Cala Morell | Browser | Herbaceous plants |
| Cala Blanca | Grass-dominated mixed feeder | Gramineous plants |

The number of analysed teeth from this site is not large ($N=8$) but the majority of teeth preserved microwear ($N=6$). The presence of a low average of scratches, an intermediate number of pits large pits (66.6%) and an average of 1 SWS and gouges (100%) suggests that caprines had a

browser diet pattern based on herbaceous and leaf intake from an open scrubland and herbal landscape (Table 1; Figs. 3 and 4) (Valenzuela-Suau et al. submitted). The data also suggests that leaves had dirt or maybe the intake of minerals for the proximity of plants to the ground.

Fig. 2 Some of the analysed sites: (a) Es Coll de Cala Morell (Pons et al. 2017); (b) S'Illet des Porros (Hernández-Gasch 2006); (c) Sa Ferradura (Anglada et al. 2013); (d) Cova del Camp del Bisbe (Valenzuela-Suau et al. 2017). The analysed sites have different functionalities

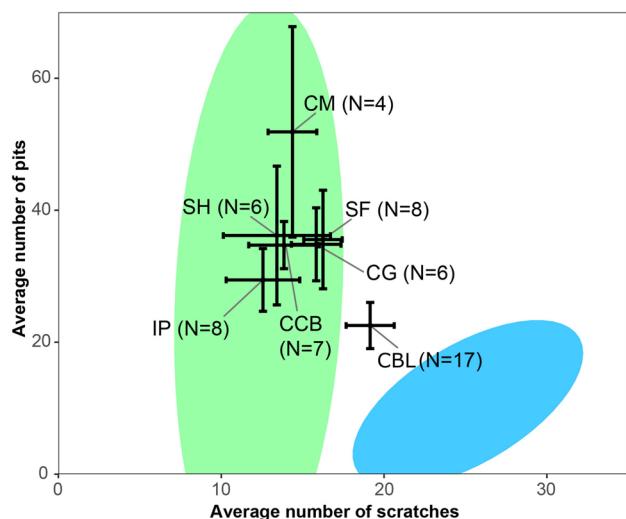


Fig. 3 Bivariate graph with the average number of pits and scratches of analysed caprine teeth. SH, S'Hospitalet Vell; CG, Closos de Ca'n Gaià; SF, Sa Ferradura; IP, S'Illet des Porros; CCB, Cova del Camp del Bisbe; CM, Cala Morell; CBL, Cala Blanca

Sa Ferradura (SF)

Located on the north of Porto Cristo (Manacor, Mallorca), this fortified archaeological site is constructed on a coastal head and accessed along an isthmus (Anglada et al. 2013)

(Figs. 1 and 2). It has a large number of hearths but no stable household structures, and radiocarbon dating indicates that its occupation occurred between ca. 1100 and 900 cal. BC (Anglada et al. 2017) (view Supplementary Table 1). Regarding its functionality, similar sites had been related with maritime activities just as other islets and other coastal sites occupied during this chronology (Guerrero 2006; Guerrero et al. 2007; Calvo et al. 2011). However, the monumental defensive wall facing inland, the absence of households, and a typical archaeological record originated by domestic activities, has led the researchers who excavated the site to interpret it as a temporary refuge for some population to protect from other neighbours (Anglada et al. 2017, 2019).

From this site, fifteen teeth were selected and eight conserved the dental microwear. As shown on the bivariate graph, caprines from Sa Ferradura were predominantly browsers with a mixed feeder tendency (Fig. 1). The presence of large pits (100%), gouges (75%) and an average of 1.25 on the scratch thickness (the highest on this study), as previously observed at S'Hospitalet Vell, suggests that caprines fed on plants near to the ground and may have ingested soil particles (Tables 2 and 3; Figs. 3 and 4).

S'Illet des Porros (IP)

This archaeological site is located on an islet on the Alcúdia Bay (Santa Margalida, Mallorca) and at 2 km from a Bronze

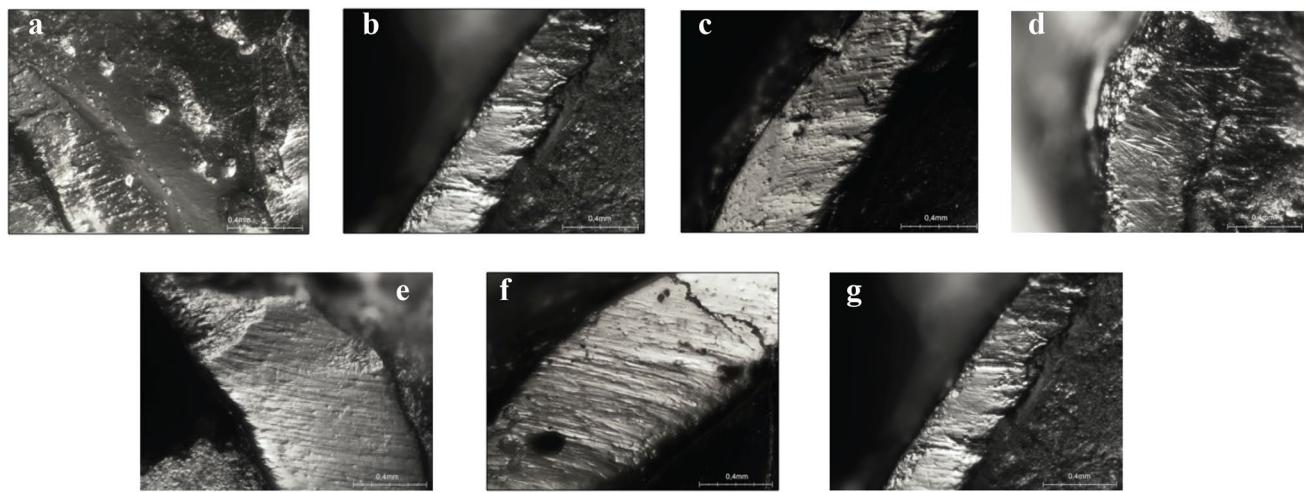


Fig. 4 Detailed pictures of dental microwear from the analysed sites: (a) Closos de Ca'n Gaìà; (b) S'Hospitalet Vell; (c) Cova del Camp del Bisbe; (d) S'Illet des Porros; (e) Sa Ferradura; (f) Cala Blanca; (g) Es Coll de Cala Morell. Photo scale: 0.4 mm

Age settlement (Es Figueral de Son Real) (Figs. 1 and 2). The bad preservation of the Bronze Age structures made it difficult to understand its functionality during this time period (Hernández et al. 1998). However, well-preserved stratigraphic units were found and its chronology indicates that the islet was used between ca. 1400 and 850 cal. BC (Hernández-Gasch and Sanmartí 2021) (view Supplementary Table 1). During the Second Iron Age, a funerary place was built on this islet. Its functionality during the Middle and Late Bronze Age has been related with the exploitation of maritime resources (Guerrero 2006; Guerrero et al. 2007; Calvo 2011).

From this site, twenty-five dental specimens were selected but only eight preserved the microwear pattern. The results indicate that caprines recovered from this site were browsers and they consumed herbaceous plants and leaves (Fig. 1). The presence of large pits (LP = 87.5%), gouges (75%) and a majority of fine scratches (SWS = 0.75) reveals that these animals ate leaves from shrubs (Tables 2 and 3; Figs. 3 and 4).

Cova del Camp del Bisbe (CCB)

Unlike the other sites, this is a natural cave located on the centre of Mallorca (Sencelles) (Figs. 1 and 2). During the Second Iron Age, this cave was used as a necropolis. Unfortunately, human bones from Bronze Age levels did not preserve collagen and could not be dated. Nevertheless, a funerary functionality cannot be excluded because of the presence of objects registered in other funerary contexts from the Bronze Age of the Balearic Islands such as a high quantity of "V" section buttons (i.e. Lull et al. 1999). In any case, it was a sacred place where people consumed and offered a high quantity of food and other objects ca. 1300–1100 cal.

BC (Palomar and Valenzuela-Suau 2020; Valenzuela-Suau 2020) (view Supplementary Table 1).

Although fourteen teeth were selected from different caprines,¹ only seven preserved dental microwear. As it is shown in Figure 1, sheep and goat from this site were browsers with a mixed feeder tendency. Moreover, the presence of large pits (LP = 85%), gouges (G = 71%) and a scratch thickness higher than 1 (SWS = 1.14) is indicating that they ate more shrub leaves than grass (Tables 2 and 3; Figs. 3 and 4).

Es Coll de Cala Morell (CM)

This Bronze Age settlement is located on the northwest part of the island of Menorca, on the top of a rock promontory at 35 m above sea level (Figs. 1 and 2). The settlement is formed by thirteen navetiforms and other structures, including two cisterns (Anglada et al. 2019). Its occupation is dated to ca. 1600–1200 cal. BC cal. (Anglada et al. 2017) (view Supplementary Table 1). The archaeological evidence shows that it is a permanent and long-term settlement. But the location of the site on very arid cliffs, directly exposed to the north winds, and the monumental wall closing the access from inland suggest a defensive preoccupation because of the existence of some kind of social instabilities in the region (Anglada et al. 2010, 2019).

Although samples could be collected from two households, only a total of ten teeth were available following the selection criteria. In addition, dental microwear was only

¹ In this case, almost all samples come from entire jaws from the same side being a greater guarantee of belonging to different individuals.

Table 4 Tukey's method results from the average number of pits and scratches. The *p*-values in bold indicate significant differences

| Pits | SF | CG | SH | CCB | CM | IP | CBL |
|------------------|-----------|-----------|-----------|------------|---------------|---------------|---------------|
| SF | - | 1 | 1 | 1 | 0.0234 | 0.8645 | 0.1224 |
| CG | 0.2129 | - | 1 | 1 | 0.0155 | 0.9208 | 0.1678 |
| SH | 0.1764 | 0.3893 | - | 0.9999 | 0.0325 | 0.8048 | 0.0928 |
| CCB | 0.2477 | 0.03476 | 0.4241 | - | 0.0145 | 0.9283 | 0.1763 |
| CM | 4.763 | 4.976 | 4.587 | 5.011 | - | 0.0006 | 0.0001 |
| IP | 1.788 | 1.576 | 1.965 | 1.541 | 6.552 | - | 0.7851 |
| CBL | 3.806 | 3.593 | 3.982 | 3.558 | 8.569 | 2.017 | - |
| Scratches | | | | | | | |
| SF | SF | CG | SH | CCB | CM | IP | CBL |
| SF | - | 1 | 0.5313 | 0.7134 | 0.8851 | 0.2252 | 0.5047 |
| CG | 0.3818 | - | 0.704 | 0.8575 | 0.9631 | 0.358 | 0.3427 |
| SH | 2.596 | 2.214 | - | 1 | 0.9959 | 0.9978 | 0.009 |
| CCB | 2.193 | 1.811 | 0.4036 | - | 0.9999 | 0.9795 | 0.020 |
| CM | 1.718 | 1.336 | 0.8781 | 0.4745 | - | 0.9004 | 0.0479 |
| IP | 3.379 | 2.997 | 0.7827 | 1.186 | 1.661 | - | 0.0018 |
| CBL | 2.655 | 3.036 | 5.251 | 4.847 | 4.373 | 6.034 | - |

preserved on four teeth, which makes it the smallest sample of the entire study. As a consequence, the results presented below should be treated with caution. On the bivariate graph (Fig. 3), it can be seen that, despite the fact that caprine from Es Coll de Cala Morell is included in the browsers group, they show the most distant average number of pits compared to other sites (NP= 51.8). However, the scratches are mainly fine (SWS = 0.75) (Tables 2 and 3; Figs. 2 and 4). The results indicate that sheep and goats would be incorporating soil or the consumed leaves had dust. In other words, the high average number of pits can be a consequence of browsing in a dry environment in which leaves accumulate dust due to scarce rainfall.

Cala Blanca (CBL)

The navetiform of Cala Blanca is located on the west coast of Ciutadella (Menorca) (Fig. 1) and, at least nowadays, is an isolated structure nearby the beach. The radiocarbon dating indicates a chronology ca. 1700–1200 cal. BC (Plantalamor and Van Strydonck 1997) (view Supplementary Table 1). Regarding its functionality, the faunal study concludes that there are remains of a domestic area (Ramis and Anglada 2012). However, other researchers emphasise other aspects (such as its location or orientation) and also propose its relation with an exchange network and navigation (Guerrero et al. 2007; Calvo et al. 2011).

All the analysed samples preserved the dental microwear and the results show that caprines from this site have the highest values for the numbers of scratches (above 17 scratches per counting area). They fall close to the grazer group — as they ate gramineous plants — with mixed feeder tendency (i.e. grass-dominated mixed feeders) (Figs. 1 and 4). Large pits are present on 47.05% of the samples,

cross scratches on the 29.41% and scratch thickness is 0.88 (Tables 2 and 3; Fig. 3).

Discussion

Inter-site comparisons

The dental microwear results from the Bronze Age sites on the Balearic Islands show that caprines were predominantly leaf browsers. Cala Blanca is the most distant regarding to the others, with a grass-dominated mixed feeding diet (Fig. 3). Fig. 1 shows that S'Hospitalet Vell and Cova del Camp del Bisbe have a similar microwear patterns. Therefore, despite the fact that the sites are in different biotopes on Mallorca and have different functionalities, sheep and goat from these two sites had a similar pasture and diet.

Sheep and goats from Es Coll de Cala Morell have the highest number of pits from all the samples (Fig. 3). Despite the low number of teeth analysed ($N = 4$), the results show significant differences between the majority of sites related to the average of pits (Table 4). This site is located on a rocky promontory, a place where the wind blows hard and with a dry climate as archaeobotanical data attest (Pons et al. 2017; Servera-Vives and Currás 2017b; Servera-Vives and Picornell-Servera 2019). These environmental factors could be quite similar during the Bronze Age, and the high number of pits may be the result of caprines that were browsing on the same site or its surroundings. This is supported by the strontium isotopic analyses conducted on the same caprine teeth, which suggests that animals were grazing on the promontory and fields nearby (Valenzuela-Suau et al. 2021). In this sense, these animals were probably ingesting dirty vegetation, where the leaves were coated with dust or

grit as well as the consumption of lower plants with the incorporation of soil mineral particles.

Of all analysed sites, Cala Blanca results indicate a different diet compared to the others, as shown by the average number of scratches, with the exception of Sa Ferradura site, where sheep and goats had a mixed feeder tendency (Table 4).

The microwear results from this study are coherent with the vegetation data available from some of the analysed sites. It is likely that caprines grazed on the immediate landscape registered at S'Hospitalet Vell, Closos de Ca'n Gaià, Es Coll de Cala Morell and Sa Ferradura, where a predominance of olive tree and shrub is attested, with a small percentage of gramineous plants at the Sa Ferradura site. This local grazing is also supported by the strontium isotopic data obtained from the same caprine teeth (Valenzuela-Suau et al. 2021). Therefore, microwear data reinforce the idea of a landscape where olive trees and shrubs predominated, and a feeding regime where caprines grazed on the vegetation available in the nearby areas of the settlements.

The palynological data from Sa Ferradura show noticeable values of nitrophilous and ruderal taxa (e.g. *Plantago*, *Asphodelus*). Nevertheless, the lack of coprophilous fungi suggested the existence of agropastoral activities nearby the site but reduced on-site presence of livestock (Servera-Vives and Currás 2017a; Picornell-Servera and Servera-Vives 2019). This is consistent with the idea of a seasonal exploitation of this site (Anglada et al. 2017). Based on the fact that dental microwear changes in a few days, we propose that caprine could be transported the days before being killed. In any case, it seems clear that they were not stabled all year round at Sa Ferradura which, again, has been documented based on strontium isotopic data (Valenzuela-Suau et al. 2021).

At Cova del Camp del Bisbe, the carpological data documented the presence of forage plants (Berrocal 2016, 2018; Valenzuela-Suau et al. 2017). In contrast, this is not reflected in the dental microwear results. On the one hand, forage plants could be addressed to other animals such as cattle and, on the other hand, it could be related with the season when animals were killed, as it could be intended to feed them in times of scarcity (e.g. summer). Nonetheless, the lack of evidence of the consumption of gramineous plants based on dental microwear, in a site where cereal agriculture is well attested (Berrocal 2016, 2018; Valenzuela-Suau et al. 2017), suggests that caprines were not allowed to feed on the crops.

The results from S'Illet des Porros and Cala Blanca show that sheep and goat diets were different between both sites during prehistory. At the Mallorcan site, caprines had a shrub vegetation diet, also based on the consumption of leaves and herbaceous plants. In contrast, samples from Cala Blanca show a mixed diet based on a wide range of vegetation, also including grass (Fig. 3). However, these

two archaeological sites have a low number of pits indicating that caprines did not incorporate sedimentary particles while they were feeding. This is interesting data if we take into account that these sites are nowadays located on the coastline and, in the case of the islet, it is in a bay formed by a fossil dune. For this reason, the microwear data suggest that caprines did not feed around the sites the days before being killed, but they could be transported after death or in a short time before being killed. This is also coherent with the strontium isotopic results obtained at these sites, which indicate a higher diversity in the provenance of the caprines analysed (Valenzuela-Suau et al. 2021).

Finally, following this discussion about sheep feeding nearby the coast, there is no information on this study allowing us to relate the results with the intake of seaweed (Mainland 2000). On the one hand, the incidence of the sea salt on the tooth enamel is unclear and, on the other hand, other studies proved that the identification of seaweed-eating through dental microwear is based on the sand attached on it. In this case, a high number of pits and large pits would be expected in contrast to the results from these two sites.

Paleoenvironmental data

As detailed above, microwear studies also provide environmental and climatic data (see “Methods” section) and there are some aspects that are needed to take into consideration in most general terms. As explained in the “Introduction” section, it is proposed that the later colonisation of the Balearic Islands was related, among other motivations, with climate and vegetation conditions that were not favourable for agricultural neolithic populations (Cherry and Leppard 2018). Indeed, during the first phase of establishment on the Balearic Islands, livestock was composed by ca. 90% of caprines, highest than in other Mediterranean parts such as south of France, Iberia or Sardinia and it has been related with the “relatively low water requirements of ovicaprids and the capacity (especially of goats) to tolerate woody, scrubby morphologies in sclerophylls that have become increasingly prevalent in the Mediterranean in the course of the later Holocene (Rogosic et al. 2006)” (Cherry and Leppard 2018).

However, during the Mid and Late Bronze Age, there is an increase of cattle presence on the livestock and a cerealistic agriculture is also attested (Berrocal 2016, 2018; Valenzuela-Suau et al. 2017; Pérez-Jordà et al. 2018) and an increase of cattle livestock size is also documented. In this sense, the extension of Mediterranean macchia and scrubby vegetation observed by archaeobotanical and palaeoenvironmental studies is also registered on microwear results. In this study, a scrubby-predominant diet is attested, with leaves and twig consumption, and a significant incidence of dirt and grit on the leaves in some cases. These data are consistent

with other paleoenvironmental studies (Picornell-Servera and Servera-Vives 2017; Servera-Vives and Currás 2017a, 2017b; Carrión et al. 2021). At this point, it is necessary to add that no other dental microwear studies have been done for western Mediterranean Bronze Age sites but it will be interesting to compare this data in the future.

Specifically, the landscape registered at Sa Ferradura, Es Coll de Cala Morell and S'Hospitalet Vell shows an environment dominated by shrubs, characterised by olive trees, and with the presence of gramineous plants on Sa Ferradura and Closos de Ca'n Gaià sites. At this time period, cereal agriculture is well attested in the Balearics, and forage plants are also attested at Cova del Camp del Bisbe (Berrocal 2016, 2018; Valenzuela-Suau et al. 2017; Pérez-Jordà et al. 2018). Consequently, dental microwear data reinforce the idea of a Balearic Bronze Age landscape where caprines would be eating the available plants, almost on the days before being killed. These livestock practices most probably contributed to the formation of an anthropised mosaic landscape (Picornell-Servera and Servera-Vives 2017; Servera-Vives et al. 2018).

Conclusions

This study analysed 107 sheep and goat teeth from six archaeological sites located on different biotopes from Mallorca and Menorca (Balearic Islands, Spain). The results were compared with archaeobotanical data available. Dental microwear suggests that the majority of caprines from Gimnesic islands during the Middle and Late Bronze Age had a preferably shrubby diet that was part of the most widespread landscape. In addition, the presence of mixed feeders along with the browsers indicates that caprines would be feeding on the vegetation available in the surroundings of the sites. This is also supported by strontium isotopic analyses on the same teeth analysed for microwear (Valenzuela-Suau et al. 2021).

The absence of indicators of seaweed consumption, as well as the low presence of sedimentary particles on sheep teeth, suggests that these animals would not feed on the coastal line. Finally, the results support the incidence of livestock practices on the formation of the mosaic landscape registered on the Balearic Islands during Prehistory. Microwear studies are yet under-utilised in the archaeological research of the Balearic Islands and it is also the first microwear study of the western Mediterranean Bronze Age. The fact of it being a non-destructive method and its simple application make it a great ally for future studies.

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Declarations

Conflict of interest The authors declare no competing interests.

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