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Research Article

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Tracing Mobility Patterns of Buried Species of the Late Iron Age Funerary Staggered Turriform of Son Ferrer (Calvià, Spain)

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Abstract: This is the first mobility $^{87}Sr/^{86}Sr$ analysis in human remains made on the Balearic Islands. Eight human individuals buried at the same Late Iron Age funerary chamber of Son Ferrer site (Calvià, Mallorca) have been sampled for strontium and oxygen isotopic analysis ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$). The study includes strontium and oxygen isotopic analysis of domestic mammals buried in the same Funerary Area (FA1) together with present-day vegetation and archaeological bone to assess the strontium isotopic ratios ($^{87}Sr/^{86}Sr$) around the site. All the results are compatible with the $^{87}Sr/^{86}Sr$ documented in Mallorca and, more specifically, with the surrounding bedrocks from the site. Humans, caprines, and dogs provided similar results and no significant differences are found between the species. The only exception is a caprine which shows seasonal movement through the period of enamel mineralisation. The isotopic information agrees with the previous studies, which proposed that Son Ferrer site was a symbolic place for the surrounding territory where people from the nearby villages were buried.

Keywords: human mobility, livestock mobility, strontium isotopes, oxygen isotopes, Balearic Islands

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1 Introduction

The Balearic Islands are located on a privileged position on the Western part of the Mediterranean Sea, where different commercial routes crossed on throughout History. The Late Iron Age (LIA) of the Balearic Islands (c. 550–123 BCE) is best known for the presence in Ibiza of the Phoenicians with the colony of *Ebusus*. However, during this time period, a division between the islands occurred. During the second part of the eighth century BCE, the influence of Phoenicians in the Ibiza island started (Ramon, 2008) and at sixth century BCE, *Ebusus* has already become an important commercial centre of redistribution (e.g. Gómez Bellard, 1995). In the case of Mallorca and Menorca – later known as Gymnesic islands – the local culture continued evolving (Calvo & Guerrero, 2004, 2011). During this time period, local population started many socio-economic changes (see below) but it has been demonstrated that they started before the foundation of the colony of *Ebusus.* In fact, a resistant phenomenon occurred (García-Rosselló, 2010) and a new social organisation is perceivable through the diversity of funerary practices such as human burials on zoomorphic coffins or differentiated infantile necropolis (e.g. Calvo & Guerrero, 2011; Calvo et al., 2020; Garcias & Gloaguen, 2003; Guerrero, 1979; Rosselló & Guerrero, 1983). The archaeological record shows a demographic growth together with new strategies of social cohesion, surplus accumulation, and control with the arrival of social hierarchisation (Calvo, 2009; Castro, Escoriza, & Sanahuja, 2003; Lull, Mico, Risch, & Rihuete, 1999; Palomar, 2005). However, the study of the skill practices shows a high fragmentation in knowledge transmission (García-Rosselló, 2010; Perelló, 2017). For this reason, it has been proposed that a process of social dismemberment together with an increase in social hierarchisation occurred (García-Rosselló, 2010, p. 1567).

First, during the Early Iron Age (EIA, c. 800/700–550 cal. BCE), the concept of landscape changed. While, during the Bronze Age, there was an "open" concept of the territory, in the Iron Age, many control and visual strategies occurred (Calvo, 2009; Galmés & Calvo, 2022). During the LIA (ca. 550–123 cal. BCE), territorial location points disappeared as well as some *talayots* – public tower-like monuments – were abandoned or re-used while new villages appeared as explained before (Calvo, 2009; Galmés & Calvo, 2022). This new panorama is well-studied in the peninsula of Calvià (Mallorca) where domestic and production settlements mainly concentrate surrounding the Puig de Sa Morisca. Indeed, since this site is located near the coast, it centralised the overseas trade (Hernández-Gasch & Quintana, 2013; Quintana, 2000) (Figure 1). One of the sites located in the network visibility and control area of Puig de Sa Morisca is the necropolis of the staggered turriform of Son Ferrer, which for its location, monumentality, and long-term use has been interpreted to be a symbolic place for local population (Calvo, Fornés, García-Rosselló, Iglesias, & Juncosa, 2005). This site is also located at c. 3 km from the LIA settlements of Ses Penyes Rotges and Turó de Ses Abelles. Hence, it has been hypothesised that maybe people from these places could be buried within the necropolis (García-Rosselló, 2010, p. 1473).

The staggered turriform of Son Ferrer (Figures 1 and 2) is an archaeological site located on the west coast of the island of Mallorca in Calvià (Spain). This archaeological site is a long-term used place where different constructions and remodelling events occurred from the Early Bronze Age (EBA, c. 1800–1500 cal. BCE) to the LIA (c. 550–123 cal. BCE) (Calvo et al., 2005; Calvo, García-Rosselló, Albero, & Javaloyas, 2015a; Calvo, García-Rosselló, Iglesias, & Juncosa, 2006; Calvo, García-Rosselló, Javaloyas, Albero, & Van Stryndonck, 2014; García-Rosselló, Calvo, Javaloyas, & Albero, 2015). During the first phase of use (EBA), Son Ferrer was an hypogeum probably from the Can Vairet necropolis (Calvo et al., 2006). It is known that this hypogeum has a collective burial functionality, but likely due to the later constructions and uses of the site, no materials from this phase were found. During the Late Bronze Age (LBA, c. 1300–850 cal. BCE), a possible ritual context has been discovered above the artificial cave – the EBA hypogeum – with the construction of a cyclopean staggered turriform. This context was partially destroyed by the alteration of the structure of the staggered turriform and, thus, no material culture was documented. Some animal bones and pollen were found and, despite the lack of more information, ritual purposes were interpreted for this context (Calvo, Garcia-Rosselló, Albero, & Javaloyas, 2015b; García-Rosselló et al., 2015). The LIA context provided the major information about the site. In the beginning of the EIA (c. 900/800 cal. BCE), the staggered turriform was built on top of the hypogeum. This kind of monumental constructions are typical from the Balearic Iron Age and, despite their several functions, they represented important visible places (Calvo et al., 2005; Galmés, 2015, 2016, Galmés & Calvo, 2022).

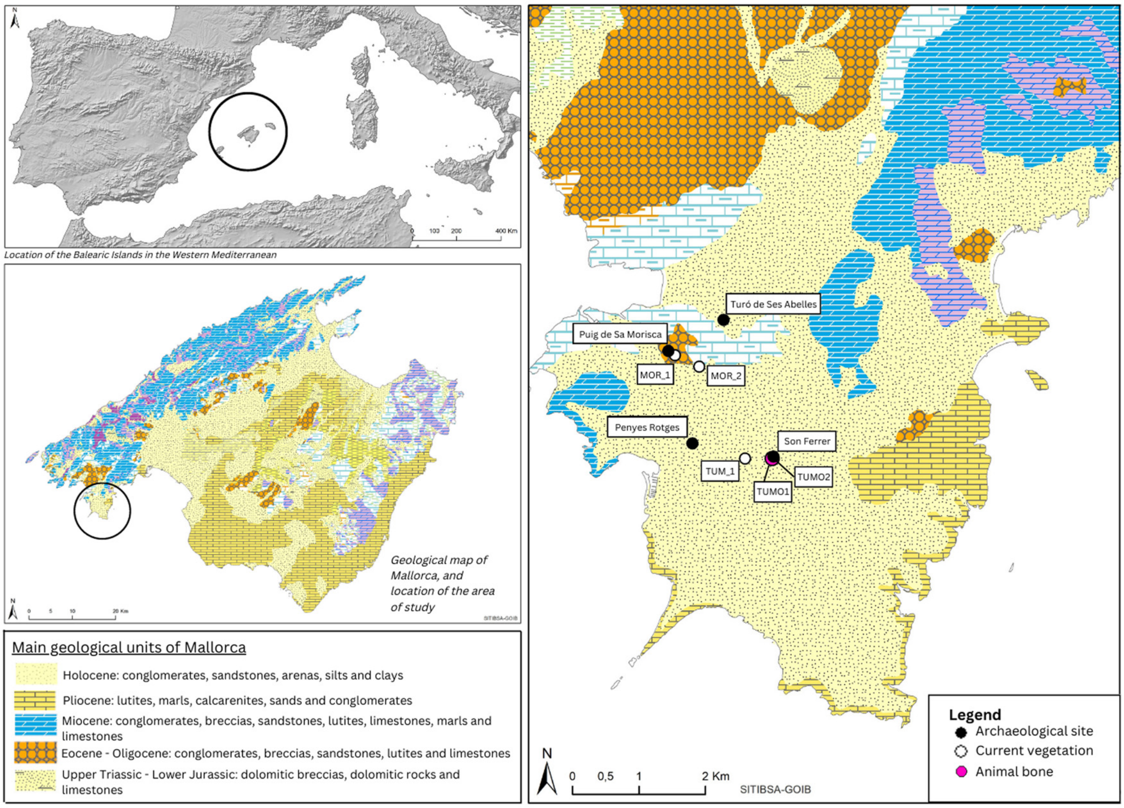

Figure 1: Main geological units of Mallorca island with sites cited in the text and location of sampling sites indicated by white and pink circles (created by Alejandra Galmés).

During the LIA (c. 550–123 cal. BCE), Son Ferrer was remodelled and the necropolis use was well-documented with collective burials, offerings, and feastings (Calvo et al., 2005; García-Rosselló et al., 2015). The presence of exogenous pottery – i.e. Greco-Italic and phoenician – suggests that people buried in this place had an active exchange network with overseas (Calvo, Garcia-Rosselló, Albero, & Javaloyas, 2015b; García-Rosselló, 2010). The collective burial included both adults and infants and was located inside the EBA cave. All the individuals received similar funerary treatment except for the perinatal individuals that were buried inside pottery and sandstone containers (Alesan & Malgosa, 2005; Alesan, 2007). This differential practice with infant burials has been documented in other LIA sites of the island. After two centuries of use, the cave was sealed (354–245 cal. BCE) and funerary practices were focused on the access corridor, where perinatal and also some adolescent/adult inhumations took place. In parallel, votive activities involving plants and faunal remains were also discovered on this corridor, where a combustion structure was also documented. Recorded plants were used to create an olfactory and visual ambience during ceremonies (Picornell-Gelabert et al., 2018). Domestic species dominate in the faunal remains from LIA contexts, with a majority of caprines and a low number of cattle, pig, and dog bones – infantile and adults – as a part of the feasting or offering activities (Picornell-Gelabert et al., 2018).

Zooarchaeological analysis was based on a total of 4,125 remains of different chronologies from Son Ferrer (carried out by one of us – JN – and available at Picornell-Gelabert et al., 2018). Regarding the Funerary Context I, where samples from this study originated, the faunal assemblage was composed of 1,537 number of individual specimens (NISP). The domestic triad (caprines, bovines, and suids) and dogs predominate and wild species were also identified (e.g. rabbits, birds, and fishes) (Nadal, unpublished report). The presence of marine and bird faunal remains testifies that these societies exploited their surrounding territory and animals who lived at almost 2.5 km (the distance of the necropolis from the coast). Focusing on domestic mammal remains not interpreted as intrusive (such as rabbits), 172 NISP were identified and they were all recovered

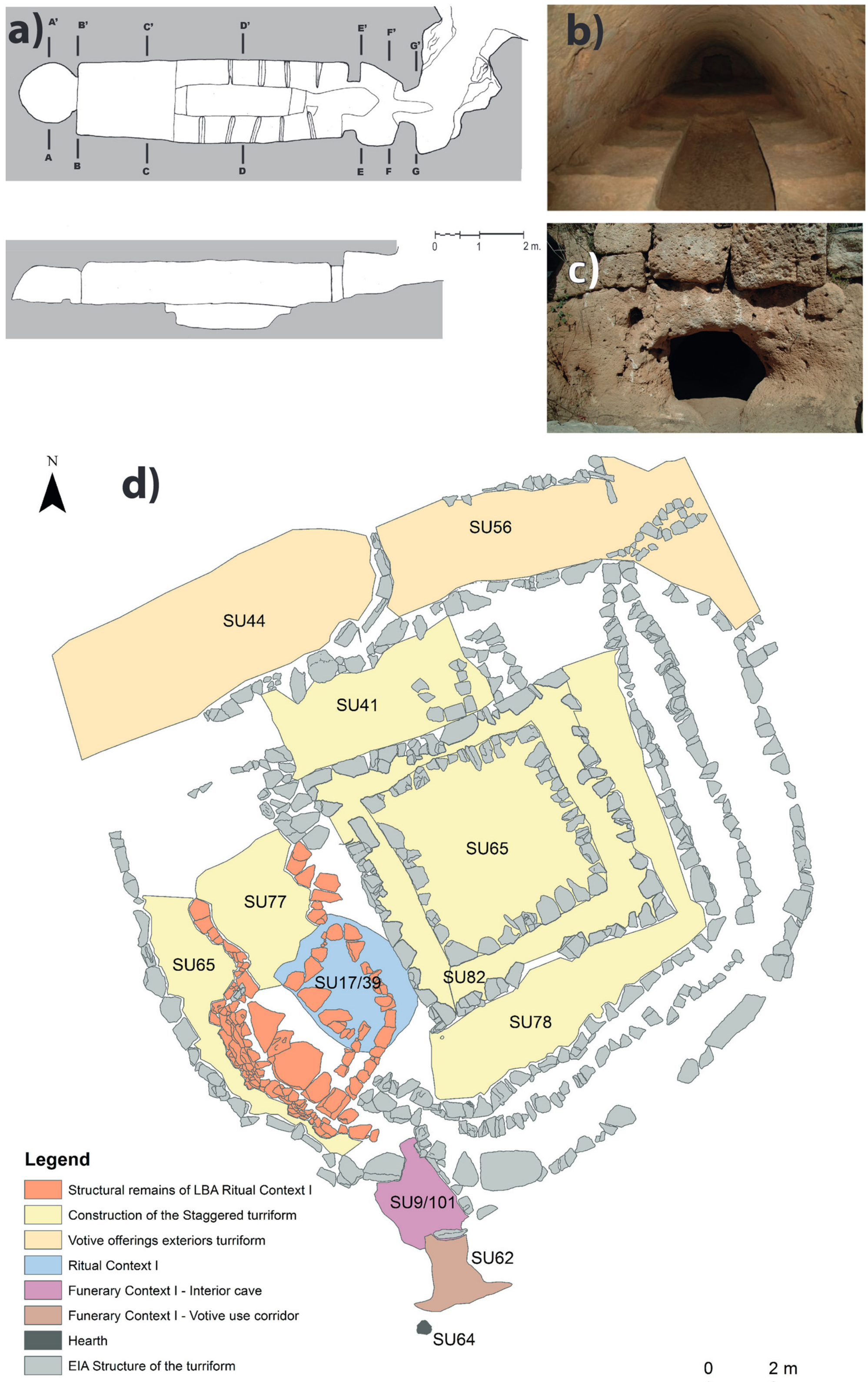

Figure 2: Son Ferrer site stratigraphy and constructions: (a), (b) and (c) Calvo et al. (2006); (d) modified at Picornell-Gelabert et al. (2018) from Calvo et al. (2005).

from SU 9 and 101. Caprines were the majority of identified taxa (66.8%, minimum number of individuals [MNI] = 7), followed by dogs (30.2%, MNI = 3), pigs (2.3%, MNI = 1), and cattle (0.5%, MNI = 1) (Picornell-Gelabert et al., 2018). Although the number of bones was scarce, the lack of some anatomical parts of sheep and goats – the most represented taxa – was documented, thus allowing to propose that selected parts of these animals were buried. However, dog remains show a better representation of different parts of the body, thus suggesting that this species was an offering and not a part of ceremonial feasting consumption (Picornell-Gelabert et al., 2018). The presence of these animals on the Funerary Context I could be the result of feasting ceremonies, animal offerings, or both purposes. Nonetheless, the transport and burial of these animals to Son Ferrer along with the human remains clearly showed that they were ceremony consumed (Picornell-Gelabert et al., 2018).

The initial hypothesis of this research is that humans who were buried within this necropolis would be mainly "locals" as they could have lived on the nearby villages from ca. 2–3 km of distance (i.e. Turó de Ses Abelles, Ses Penyes Rotges, or at Puig de Sa Morisca). On the Balearic Islands, different studies have proposed that collective burials were composed by family members from a nearby village also during the LBA (e.g. see Guerrero, Calvo, & Gornés, 2006). However, as it has been explained previously, this site was identified as a symbolic place for different villages, one of them being the Puig de Sa Morisca, which operated as central control place of the territory and their resources and also overseas (e.g. Calvo, 2009). Additionally, during this period, new ideas and know-how practices were identified thus showing that people arrived or moved abroad and also testifying human mobility (Calvo, Garcia-Rosselló, Albero, & Javaloyas, 2015b; García-Rosselló & Calvo, 2021). In this sense, the use of islets as exchange points with the punic-ebusitanes – from fourth century BCE, such as Na Guardis or Na Galera both in Mallorca coast – played an important role in the interaction between cultures (e.g. Guerrero, 1980, 1984, 2004). For these reasons, humans and animals buried in this place are expected to be mainly "locals" but in this time period the presence of foreigners and broader catchment areas have to be considered.

In order to deepen this discussion, different direct analyses were developed on Son Ferrer. In parallel, strontium isotopes ($^{87}Sr/^{86}Sr$) are a useful tool as these analyses can fill the gap between the place of birth (addressed by future aDNA analyses) and place of death (the necropolis). Indeed, each tooth formed during different periods in life and different ages from the same individual was compared (Section 2). In this study, one tooth from the same individual selected to perform aDNA analysis have been examined.

$^{87}Sr/^{86}Sr$ analyses have traditionally been used for understanding human mobility. However, in the case of the Balearic Islands, no human remains have been analysed before and, until this study, strontium isotope studies ($^{87}Sr/^{86}Sr$) focused on caprine teeth from Bronze Age sites while few Iron Age contexts are also starting to be analysed (Valenzuela-Suau, Valenzuela-Lamas, & Hernández-Gasch, 2022a; Valenzuela-Suau et al., 2022b, in press; Valenzuela-Suau, 2020; Valenzuela-Suau, Valenzuela-Lamas, Ramis, & Bosch, 2021). In this study, not only humans have been examined for the first time on the archipelago but also animals that were involved in their funerary practices are included. A sequential analysis was also performed on two cattle and two caprines combining strontium and oxygen isotopes ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) in order to assess or discard seasonal mobility. The main goal of this research is that, for the first time, human mobility and livestock management will be discussed together based on a direct analysis. This information will contribute to understand how LIA human populations from Mallorca perceived and exploited their territory.

2 Materials and Methods

As explained in Section 1, the staggered turriform of Son Ferrer is a complex site with different occupations and functionalities. First, the structure was built upon a Bronze Age hypogeum (first used between c. 1800–1450 cal. BCE) and, later, it worked as a collective funerary space during the LIA – also called Postalaiotic period – (550–123 BCE). The hypogeum and its access corridor composed the main inhumation area where at least 79 individuals (MNI) were buried (Alesan, 2007; Salvador Gómez-Grandoli, in progress).

Materials have been selected following different criteria. In all cases – humans and animals – tooth enamel was selected as it is the least porous part of the body and it is less affected due to diagenetic alterations (e.g. Budd, Montgomery, Barreiro, & Thomas, 2000; Madgwick, Mulville, & Evans, 2012; Nelson, DeNiro, Schoeninger, De Paolo, & Hare, 1986; Price, Burton, & Bentley, 2002). First, all human remains came from the Funerary Area 1 (FA1) and also dogs were just found on this area (Alesan, 2007; Picornell-Gelabert et al., 2018). Moreover, caprines and cattle were best represented in the FA1 compared with FA2 and FA3 (Picornell-Gelabert et al., 2018). For these reasons, this study is focused on the LIA phase of the staggered turriform (c. 550–123 BCE) and all the analysed species came from the same burial context (FA1).

Analysed samples reflect the time mineralisation of the dental crown. Its position on each tooth will show an earlier or later stage of mineralisation, where lowest samples – near roots – are the latest formed, while the highest are the earliest. The position of teeth from the sequential analysis is shown in Table 3, where the distance from the enamel root junction (ERJ) are shown. In case of humans, teeth from this study show mobility patterns in a range of ca. 7 months to 8 years old (AlQahtani, Hector, & Liversidge, 2010). Dog samples reflect the time mineralisation from *in utero* to ca. 1 year old (Hillson, 1996). In case of caprines, crown mineralisation from the analysed tooth show a range from prior to birth to ca. 1.5 years old (Witzel, Kierdorf, Frölich, & Kierdorf, 2018). Finally, cattle samples reflect mobility patterns from prior to birth to 24 months (Brown, Christofferson, Massler, & Weiss, 1960).

The human bones selected for this study came from SU 9 in FA1 (MNI = 18) where 8 mandibles of both adults and adolescent individuals were documented. From these individuals, each adult (>20 years old) or adolescent (13–20 years old) mandible with available teeth were selected to assure the evaluation of the same individuals in both aDNA and strontium isotopic analysis ($^{87}Sr/^{86}Sr$). Therefore, it was possible to analyse 8 individuals to determine the mobility patterns and the geographic origin of this population. Morphological age and sex estimation of chosen individuals was carried out by one of us (PS). Genetic sex assessment will be performed in the future in order to confirm the current results. In Table 1, all samples are listed along with the followed methodology for age and sex determination. Regarding strontium isotopic analysis ($^{86}Sr/^{87}Sr$), just adult individuals were considered and the sampling was based on a vertical enamel extraction to assess the average of strontium isotopic signal ($^{87}Sr/^{86}Sr$) during the time of tooth mineralisation. Isotopic analysis will show only the age of teeth mineralisation (e.g. the second molar mineralise between 7 and 8 years of age (AlQahtani et al., 2010)) and will not reflect the estimated age at death of each individual (Table 1).

A total of five caprines and three cattle have been analysed for strontium isotopes ($^{87}Sr/^{86}Sr$, Tables 2 and 3). Following the criteria of sampling adult teeth with closed root junction from the same side – to avoid sampling the same individual – $^{87}Sr/^{86}Sr$ sequential analysis was only possible in two caprines (sample codes 25595 and 28672; Table 2). From these two differentiated individuals, a third upper molar was selected, and a sequential study has been done combining oxygen and strontium analysis ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) and comparing different moments of the life of these animals (from ca. 12–18 months, Witzel et al., 2018). Moreover, the other three caprines have been

Table 1: Basic information of human samples with morphological age and sex estimation

Sample code	Teeth	Laterality	Sex estimation (Buikstra & Ubelaker, 1994; Ferembach, Schwidetzky, & Stloukal, 1980)	Age of death estimation in years (Lovejoy, 1985)
31525-31536	First premolar	Left	Male	18–22
7989*	First premolar	Right	Male	18–22
28967-31534	First low molar	Right	Female	30–35
31233	First low molar	Left	Male	35–40
31521-31330-31517	First low molar	Left	Male	35–40
31524-26793	Canine	Right	Male	40–45
31529-31614-27705	Second low molar	Left	Female	40–55
31519	Second low molar	Left	Male	45–55

*Age and sex assessment of this individual was also made by morphology of left *Os coxae* (Buikstra & Ubelaker, 1994) and its epiphyseal fusion pattern (Cunningham, Scheuer, & Black, 2016).

Table 2: List of animal remains that have been selected for this study

Sample code	SU	Species	Teeth	Laterality	Wear stage (Gardeisen, 1997; Payne, 1973)
28672	9	Caprine	Third upper molar	Left	48–60
25595	9	Caprine	Third upper molar	Left	48–60
36662	9	Caprine	Third upper molar	Right	72–84
30425	9	Caprine	Incisive	Left	—
28039	9	Caprine	Third upper molar	Left	48–60
25893	9	*Bos taurus*	Third low molar	Left	48–96
22994	9	*Bos taurus*	Second low molar	Right	27–48
27367	9	*Bos taurus*	Third low molar	Right	48–96
20332	9	*Canis familiaris*	First low molar	Left	5–24
18296	9	*Canis familiaris*	First low molar	Left	5–24
21206	9	*Canis familiaris*	First low molar	Left	5–24

Table 3: List of results from all analysed samples from Son Ferrer site (Calvià, Spain)

Species	Sample code	Teeth	Laterality	$^{87}Sr/^{86}Sr$	Uncertainty (2σ)	$\delta^{18}O$	ERJ
Human	31233	First low molar	Left	0.708361	0.000033		
Human	28967-31534	First low molar	Right	0.708891	0.000013		
Human	31524-26793	Canine	Right	0.708943	0.000013		
Human	31521-31330-31517	First low molar	Left	0.709022	0.000025		
Human	31519	Second low molar	Left	0.708929	0.000013		
Human	31525-31536	First premolar	Left	0.708497	0.000013		
Human	31529-31614-27705	Second low molar	Left	0.709444	0.000013		
Human	7989	First premolar	Right	0.708721	0.000013		
Caprine	36662	Third upper molar	Right	0.709074	0.000013		
Caprine	30425	Incisive	Left	0.708807	0.000032		
Caprine	28039	Third upper molar	Left	0.708864	0.000022		
Caprine	28672.1	Third upper molar	Left	0.708756	0.000029	−2.63	3.5
Caprine	28672.2	Third upper molar	Left	0.70933	0.000029	−2.62	5.3
Caprine	28672.3	Third upper molar	Left	0.709826	0.000029	−4.35	7.5
Caprine	28672.4	Third upper molar	Left	0.710081	0.000029	−2	10
Caprine	28672.5	Third upper molar	Left	0.710162	0.000029	−1.65	12.2
Caprine	25595.1	Third upper molar	Left	0.708984	0.000029	−1.15	2.9
Caprine	25595.2	Third upper molar	Left	0.708946	0.000029	−1.64	4.6
Caprine	25595.3	Third upper molar	Left	0.708921	0.000029	−2.77	7.4
Bos taurus	27367	Third low molar	Right	0.708576	0.000013		
Bos taurus	25893.1	Third low molar	Left	0.708338	0.000029	−3.83	4.6
Bos taurus	25893.2	Third low molar	Left	0.708301	0.000029	−3.4	7.9
Bos taurus	25893.3	Third low molar	Left	0.708327	0.000029	−3.29	11.7
Bos taurus	25893.4	Third low molar	Left	0.708292	0.000029	−3.21	14.4
Bos taurus	25893.5	Third low molar	Left	0.70834	0.000029	−3.24	17.1
Bos taurus	22994.1	Second low molar	Right	0.70842	0.000029	−3	4.8
Bos taurus	22994.2	Second low molar	Right	0.708295	0.000029	−2.22	8.1
Bos taurus	22994.3	Second low molar	Right	0.708366	0.000029	−2.64	11.4
Bos taurus	22994.4	Second low molar	Right	0.708313	0.000029	−2.27	14.3
Bos taurus	22994.5	Second low molar	Right	0.708414	0.000029		
Canis familiaris	20332	First low molar	Left	0.708831	0.000029		
Canis familiaris	18296	First low molar	Left	0.708913	0.000029		
Canis familiaris	21206	First low molar	Left	0.708735	0.000029		
Animal bone	TUMO1	—	—	0.70891	0.000016		
Animal bone	TUMO2	—	—	0.70901	0.000016		
Pistacia lentiscus	TUM_1	—	—	0.709138	0.000018		
Olea europaea	MOR_1	—	—	0.708552	0.000018		
Olea europaea	MOR_2	—	—	0.708713	0.000018		

ERJ = enamel root junction; Subsamples from sequential analysis are specified by .1, .2, .3, .4 and .5 at the end.

analysed with just one sample per individual (one incisor and two upper molars) (sample codes 3662, 30425, and 28039) in order to provide more information about the catchment area of this taxon (Table 2).

A similar situation happened with cattle, with just few adult dental remains documented. From this species, three samples from three individuals based on dental wear stage were analysed. A third lower molar from the left mandible and a right second low molar probably come from different cattle according to wear stage but it cannot be ruled out that they came from the same individual. The same situation happened with the other third low molar from the right side with a different wear stage (Table 2). From cattle, two teeth could be sequentially sampled – thus combining $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ – while from the other one, just one sample could be analysed due to preservation conditions. Finally, three dogs' first lower molars from the left part were sampled, two of them were still in the jaw.

A total of five samples were used as a baseline to assess the $^{87}Sr/^{86}Sr$ variability around the site. First, two archaeological animal bones from the same FA1 and SU 9 were analysed (sample codes TUMO1 and TUMO2). Second, present-day vegetation from a broader geographic zone, composed of two different bedrocks, was analysed in order to assess a wider "local" radius (Table 3 and Figure 1). It is important to note that this part of the island has been over-constructed and nowadays the staggered turriform is located inside a residential area and surrounded by golf camps and constructed areas (Vives, 2011). For these reasons, sampling strategy has been designed combining different distant points together with less-contaminated options: (1) the local baseline of the site (Holocene bedrock) has been characterised through archaeological bones sampling (TUMO1 and TUMO2); (2) in addition, one sample of current vegetation located nearby the site has been analysed (c. 500 m) (TUM1); (3) two vegetation samples from different parts of a natural zone (c. 2.5 and 3 km) were also analysed. These last samples are also interesting as they are located near the village of Puig de Sa Morisca (Eocene-Oligocene bedrock), where humans and also animals could have lived (Figure 1). Finally, baseline samples are discussed with other 35 published strontium data from Mallorca, Menorca, and Formentera islands from previous studies (Valenzuela-Suau et al., 2021; 2022a,b, in press).

3 Methods

All the selected teeth were fully erupted (with closed roots) and mineralised and mainly from the same laterality in each species (Tables 2 and 3). Human samples came from complete adolescent and adult mandibles and this selection criteria were not necessary to be followed as they were, for sure, different individuals.

Human enamel was mechanically cleaned with a rotary motor process extraction to remove the dirt and the tartar. Human enamel was collected by the rotary motor and no slices were done. Although it was intended to sample lower and third molars in all species, there were not enough samples available. For this reason, in some cases, upper molars and one incisor have also been included and age estimation was used to assure that they were not the same individuals as other samples. A total of eight humans, five caprines, three cattle, and three dogs have been sampled (number of enamels analysed samples = 33).

Animal enamel was first cleaned like in human teeth but in this case, a slice of ca. 2 mm above the enamel root was cut and, for sequential analysis, slices every 2 mm were sampled (Table 3). Dentine from these slices was later removed with the rotary motor. Strontium and oxygen isotopes were measured from the same enamel slice. Present-day vegetation samples were collected from the less possible altered locations (see explanations above) and kept in paper envelopes before cleaning and further processing in the lab.

Samples for strontium isotope analyses ($^{87}Sr/^{86}Sr$) were further processed at the *Laboratori d'Isòtops Radiogènics i Ambientals* at *Universitat de Barcelona* under the supervision of one of us (LP). Samples were first dissolved in double distilled nitric acid and purified by standard chromatographic techniques (Triskem Sr-spec) to separate Sr from sample matrix and interfering elements such as Rb. Following sample purification, Sr isotope ratios were determined by multicollector inductively coupled mass spectrometry (MC-ICPMS) on a Nu Plasma 3 MC-ICPMS at the *Centres Científics i Tecnològics* (CCiT-UB). In all cases, Sr/Rb > 1,000 ensuring proper chemical purification during chromatography. For the determination of the $^{87}Sr/^{86}Sr$ isotope ratios, the contribution of ^{87}Rb to the ^{87}Sr signal was corrected from the measurement of the ^{85}Rb signal, assuming a ratio of $^{87}Sr/^{85}Sr$ 0.38562. $^{87}Sr/^{86}Sr$ ratios were normalised for instrumental mass bias to $^{86}Sr/^{88}Sr$ = 0.1194. Instrumental drift was corrected by sample-standard bracketing using NBS 987 = 0.710249 as the primary standard with matching standard and sample Sr concentrations. During the session, external analytical reproducibility was ± 0.000018 (2σ, $n = 19$). Samples for oxygen and carbon isotopes were crushed in an agate mortar at IMF-CSIC and carried out at the Stable Isotope Biogeochemistry Laboratory of the Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR, Granada) under the supervision of one of us (AD). Oxygen isotopic samples were analysed at the Stable Isotope Biogeochemistry Laboratory of the Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR, Granada). Carbon dioxide was evolved from the carbonate present in the tooth enamel using 100% phosphoric acid in a thermostatic bath at 50°C for 12 h (McCrea, 1950). Isotopic ratios were measured with a Delta XP mass spectrometer (Isotope Ratio Mass Spectrometer). The experimental error for carbonates ($\delta^{18}O$) was ± 0.05‰, using Carrara and EEZ-1 as internal standards that were previously compared to NBS-18 and NBS-19.

4 Results

Based on the results of this study (Table 3), the expected ratio from Son Ferrer "local" $^{86}Sr/^{87}Sr$ ratio bedrock (TUMO1, TUMO2, and TUM_1) would be between 0.7089 and 0.7091 $^{86}Sr/^{87}Sr$. Previous studies from the same geology of the Balearic Islands provided similar values ($^{86}Sr/^{87}Sr$ = 0.709131–0.709193) (Valenzuela-Suau et al., 2021, in press). Samples from Puig de Sa Morisca (MOR_1 and 2) show a lower $^{86}Sr/^{87}Sr$ ratio of 0.7085–0.7087. Other samples from the same bedrock provided $^{86}Sr/^{87}Sr$ ratios of 0.7083 and 0.7089 (Valenzuela-Suau et al., 2021, in press).

Figure 3 displays the strontium isotopic ratios obtained in the samples close to the ERJ in each of the individuals analysed. The eight human samples provided a $^{86}Sr/^{87}Sr$ ratio between 0.7083 and 0.7094 (Table 3, Figure 3). Three estimated males provided the lowest values – 0.7083 and 0.7087 – on teeth mineralised at different ages (first low molar and first premolar, Table 1). Four individuals – three males and one female – have slightly more radiogenic ratios ($^{86}Sr/^{87}Sr$ = 0.7088–0.7089) but still lower than the $^{86}Sr/^{87}Sr$ ratio measured at Son Ferrer (0.7089–0.7091). The most radiogenic $^{86}Sr/^{87}Sr$ isotopic ratio – 0.7094 – is provided by a second lower molar from an estimated woman individual. The three dog (*Canis familiaris*) samples provided similar $^{86}Sr/^{87}Sr$ ratios (0.7087–0.7089) between them and also to the local baseline of the turriform and Puig de Sa Morisca site (0.7085–0.7091). They are also similar to the majority of human strontium results. *Bos taurus*

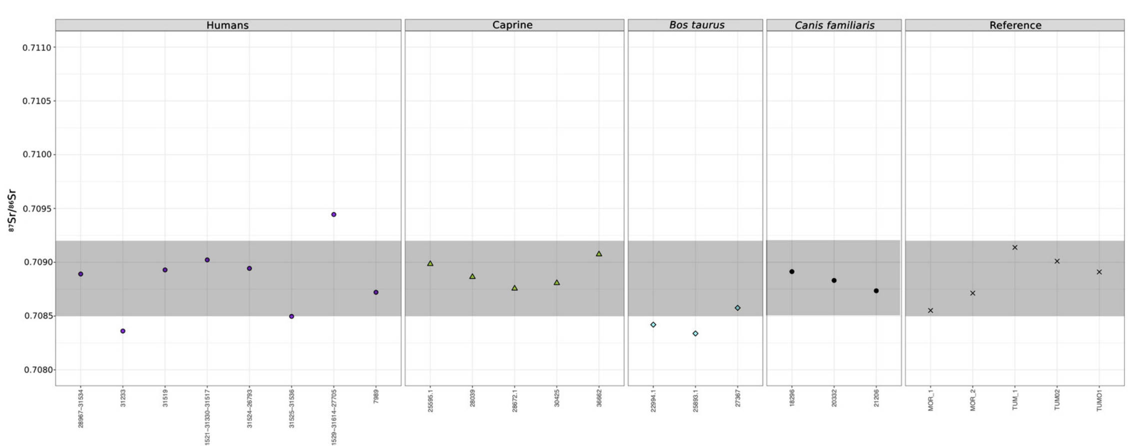

Figure 3: Strontium isotopic ratios from archaeological samples from Son Ferrer. In this figure, just one sample per individual is shown. Based on the analysed samples from this study, the expected baseline from Son Ferrer is c. 0.7089–0.7091 $^{86}Sr/^{87}Sr$, and the nearby Iron Age village of Morisca is 0.7085–0.7087 $^{86}Sr/^{87}Sr$. Given the vicinity of both sites (2.5 km), both bedrocks are considered as the local range, shaded in grey (0.7085–0.7091 $^{86}Sr/^{87}Sr$).

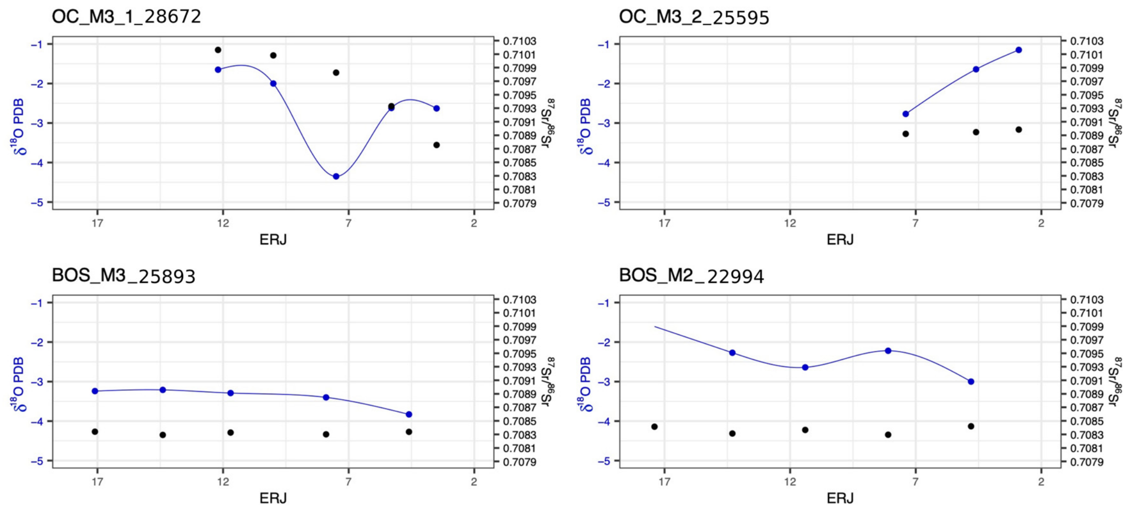

Figure 4: Sequential analysis results from cattle and caprines from Son Ferrer.

provided the lowest ^{86}Sr/^{87}Sr ratios of this study and were similar to the three teeth analysed (0.7082–0.7085) (Table 3, Figures 3 and 4). Finally, caprine samples show more diverse ^{86}Sr/^{87}Sr isotopic ratios (0.7087–0.7101).

Figure 4 presents the sequential results from two cattle and two caprines. Both cattle provided ^{86}Sr/^{87}Sr values below 0.7085 for all cases. This is different from the expected local range of Son Ferrer site (0.7089–0.7091). Baseline samples from Morisca bedrock are also slightly higher (0.7085–0.7087). Intra-tooth variation is very limited along the tooth crown (0.000048 and 0.000125) and between them, thus suggesting that no geographic movement during the time of tooth mineralisation occurred. Conversely, caprines showed different results. Three sequential samples from caprine 25595 provided almost the same strontium ratio as documented in the local baseline (^{86}Sr/^{87}Sr = 0.7089 in all cases). The other caprine, despite being also a third upper molar, provided different strontium ratios in all subsamples (^{86}Sr/^{87}Sr from 0.7087 to 0.7101). Intra-tooth variability of this caprine is 0.001325, thus being consistent with animal mobility (Bishop, Garvie-Lok, Haagsma, MacKinnon, & Karapanou, 2020).

Oxygen results (δ^{18}O) show two different patterns between individuals. Caprine provide differences compatible with a seasonal temperature variation (e.g. Blaise & Balasse, 2011; Valenzuela-Lamas et al., 2016), and in the case of OC_M3_1, the combination between oxygen and strontium isotopes point out to a seasonal movement. The other caprine, with just three subsamples, do not show strontium mobility but oxygen results are also compatible with some changes related to water seasonal temperatures variation. Regarding cattle oxygen and strontium results, there is not much variation intra-teeth, especially on M3.

5 Discussion

During the LIA, an important colonial expansion of Cartago in the Central and Western Mediterranean occurred. Regarding the Balearic Islands, this situation supposed a demographic increase and an urban development of Ebusus together with an increase in trade exchanges (Guerrero, 1997). The occupation of islets near the coast of Mallorca island – such as Na Guardis – by the Punic-ebusitanes and the arrival of imported products suggest that the Gymnesic Islands were also under control or even territorially occupied (e.g. Camps & Vallespir, 1974; Guerrero, 1985, 1986). This interpretation has been reviewed during the last decades and, even the existence of inequalities between these two entities, no territorial occupation or colonisation, seems to have happened in Mallorca and Menorca – the Gymnesic islands – (Hernández-Gasch & Quintana, 2013; García-Rosselló, 2010).

There are some examples of fluid contacts between these communities such as the presence of exogenous materials in the Gymnesic islands or the fact that slingers become mercenaries during the Punic Wars.

Conversely, indigenous people avoid to incorporate some products and techniques such as coins or gold. Moreover, islets were just seasonal used for exchanges and indigenous populations must have an important role with the redistribution of products from these islets to the interior of Mallorca and Menorca (Guerrero, 1997; Hernández-Gasch & Quintana, 2013; Perelló, 2017; Ramón, 2017). For these reasons, a process of acculturation has been ruled out (García-Rosselló, 2010; García-Rosselló & Calvo, 2021; Hernández-Gasch & Quintana, 2013).

What it seems clear is that the presence of Punic-ebusitanes in Ibiza island impacted the Postalaiotic society that was already immersed in a difficult social context. During the LIA, an increment of social hierarchisation occurred together with a demographic growth and consequent problems with land distribution within indigenous communities (Calvo, 2009; Castro et al., 2003; Guerrero, 1980, 1997; Lull et al., 1999; Palomar, 2005). This socioeconomic situation might be a significant factor to enlist as mercenaries and the consequences of wars impacted the indigenous society as many young men were not present for land work (Guerrero, 1980).

The staggered turriform of Son Ferrer is located on an elevated area of the Peninsula of Calvià, that is one of the nearest parts of Mallorca from Ibiza island and the commercial contacts with Ebusus are documented from the sixth century BCE (García-Rosselló & Calvo, 2013; Quintana & Guerrero, 2004). In Puig de sa Morisca, higher quantities of imported materials from fourth to fifth centuries BCE were found in comparison with other parts of the island (García-Rosselló & Calvo, 2013). The staggered turriform of Son Ferrer is also visually connected with Puig de Sa Morisca site and was a satellite structure of this village (Figure 1) (Calvo et al., 2005). Results from this study show that all the analysed samples provided ^{86}Sr/^{87}Sr ratios compatible with the availability of the bioavailable ^{86}Sr/^{87}Sr of the Balearic Islands, which is between 0.70832 and 0.71047 (Valenzuela-Suau et al., 2021, in press). Although the Balearic baseline samples are still limited (N = 40 in total with this study), no highly radiogenic bedrocks were found on the islands and the presence of outliers from highly radiogenic areas (e.g. Corsica, Sardinia, or the northern coast of Catalonia) could be assessed. The staggered turriform of Son Ferrer is located on a Quaternary bedrock formed by conglomerates, sandstones, arenas, silts, and clays (Figure 1). The nearby geologies correspond to Jurassic-Triassic, Paleogene, and Neogene geologies (for more information see Figure 1).

The expected strontium isotopic range (^{86}Sr/^{87}Sr) of Son Ferrer site and its bedrock has been estimated to be 0.7089–0.7091 in this study, which is coherent with other data from similar bedrocks in Mallorca (Valenzuela-Suau et al., 2021, in press). This site is located on a hill formed by an older bedrock (120 m a.s.l.) c. 2 km distant from Son Ferrer (Figure 1). This bedrock showed (^{86}Sr/^{87}Sr) ratios of 0.7085 and 0.7087. Other samples from the Eocene-Oligocene bedrock in Mallorca provided ratios between 0.7083 and 0.7089 (Valenzuela-Suau et al., 2021, in press). The proximity of both bedrocks (less than 3 km) makes us to consider all of them as a "local" (^{86}Sr/^{87}Sr = 0.7085–0.7091).

Son Ferrer is located close to the actual coast-line (c. 2 km), and a possible sea spray effect might have occurred. This would provide an isotopic ratio between the local and the sea water (^{86}Sr/^{87}Sr = 0.7092) (Frei & Price, 2012). While some samples could be affected, strontium results of this study have shown a majority of lower strontium isotopic ratios. Consequently, sea spray seems to not have altered the results. Interestingly, Morisca samples have less radiogenic strontium isotopic ratios and are located on a higher terrain and closer to the sea compared to Son Ferrer.

Son Ferrer site is close to other geologies that could potentially be the catchment areas both for humans and animals (Figure 1). Based on the Balearic Islands available baseline data, Upper Triassic-Lower Jurassic dolomitic breccias, dolomitic rocks, and limestones are expected to provide a ^{86}Sr/^{87}Sr ratio of 0.7091–0.7094. Only one baseline from Upper Triassic-Lower Jurassic bedrock in Mallorca provided the most radiogenic strontium isotopic ratio documented in the island, notably higher compared to the others (^{86}Sr/^{87}Sr = 0.70101) (Valenzuela-Suau et al., 2021, in press). Conversely, the strontium analysis in the island of Menorca – with older geologies– provided more ^{87}Sr/^{86}Sr ratios higher than 0.7010 (Valenzuela-Suau et al., 2021, in press). In previous studies (Valenzuela-Suau et al., 2021, in press), we considered this high isotopic ratio from Mallorca with caution and thought that it may be related to present-day contamination. However, in this study, caprine (28672 sample code) provided two strontium isotopic ratios similar to this one, and Son Ferrer site is close to this Upper Triassic-Lower Jurassic bedrock. Consequently, it is the second time that this ratio is documented on the island. Future studies with further baseline samples will help to clarify this issue.

Another close bedrock is the Pliocene lutites, marls, calcarenites, sands, and conglomerates that provided $^{87}Sr/^{86}Sr$ ratios between 0.7089 and 0.7092. This is also compatible with the local baseline of Son Ferrer. Also, in the surroundings of the site (2.5 km), Puig de Sa Morisca is located on Eocene-Oligocene conglomerates, breccias, sandstones, lutites, and limestones, and baseline samples provided $^{87}Sr/^{86}Sr$ ratios comprised between 0.7083 and 0.7089. These lower strontium signals are similar to those provided by cattle and some humans. Interestingly, this bedrock is located on higher terrains that could be used for pastures. *Bos taurus* is the only animal species of this study that showed an $^{87}Sr/^{86}Sr$ ratio below 0.7084. Seasonal movements are not discovered in the sequential analysis so they may have grazed on the area around Puig de Sa Morisca village all the year round. The low strontium results from these cattle (also shown by the sequential analysis) allow us to propose that these animals fed in a different place than caprines and dogs. It is important to note that this species needs a higher quantity and quality of grass to be fed than caprines and they could be fed/stabled in another place in the nearby mountains (e.g. Puig de Sa Morisca site). Indeed, the sequential analysis of two teeth provided exactly the same results and, as they came both from left and right side, it is possible that they belong to the same individual. Even so, they are not the same teeth and different times of mineralisation are shown. So, even in the case that they were from the same individual, this animal always pastured on the same geology or fed the same grass which provides different strontium results than the expected local signal from the staggered turriform of Son Ferrer.

Humans are the most represented taxa in this study and some variability between individuals has been documented ($^{87}Sr/^{86}Sr$ = 0.7083–0.7094) (Figure 3). All human results are compatible with the local baseline and the surroundings areas of the turriform of Son Ferrer. The Kruskal–Wallis test suggests that there are no significant differences in the mean strontium isotopic ratios of humans, dogs, caprines, and cattle and the baseline around the site (df = 4; p-value = 0.1952). No domestic activity has been found at the funerary turriform of Son Ferrer. However, based on the Balearic Iron Age pattern, the provenance of this population was thought to be close (from sites as Ses Penyes Rotges, Turó de Ses Abelles, or Puig de Sa Morisca). Even being mainly "locals" in terms of geological bedrock, there are differences of 0.001 between individuals, thus suggesting that people originated from different places located in the surroundings of the turriform during their childhood. Future ancient DNA analysis will clarify the origin of these people and will also confirm sex determination. Strontium results also suggest that no people from overseas were buried. The two outliers – a woman and a man – are also compatible with the surrounding areas located at c. 3 km distance from the site. Moreover, strontium results of these two individuals were also consistent with caprine and cattle results from the sequential analysis.

Caprine strontium results are generally compatible with the local strontium isotopic ratios which is also the same as the majority of humans and dogs, and no significant differences were found between species (Figure 3, Table A1). The sequential analysis of one individual (OC_M3_1) suggests that this animal fed on different geologies during the time of mineralisation of the third molar (Figure 4). Oxygen analysis of the same teeth also showed seasonal variation in water, while the other teeth do not. This suggests that OC_M3_1 pastured on different landscapes during the year contrasting with the other two. However, more data are necessary to confirm this hypothesis.

When considering the strontium results from different species from the Son Ferrer site, it can be noted that the majority of humans, caprines, and also dogs can be considered as locals. The data are compatible with a local human community and with the context of exchanges, contacts, and unequal relationship with *Ebusus*, it seems clear that people buried on the staggered turriform of Son Ferrer grew up in the island of Mallorca, therefore possibly reflecting indigenous people. The same situation can be inferred with the animals, in which strontium ranges ($^{87}Sr/^{86}Sr$) are also compatible with the baseline of Mallorca. In this necropolis, people from the nearby territory were buried together with their domestic animals.

Finally, the results corroborate the initial hypothesis of previous archaeological studies on this region, which proposed that Son Ferrer site was the necropolis of the surrounding villages (García-Rosselló, 2010, p. 1473). This information supports the idea of a regional landscape exploitation during the LIA that was controlled by some central villages in a process of social and economic hierarchisation. Considering that the territory of the Peninsula of Calvià is limited (with a maximum of c. 145 km^2), a problem of lack of lands and other consequences such as animal endogamy might have occurred.

6 Conclusion

Son Ferrer LIA necropolis is the perfect "closed" context with well-delimited chronology where people from different generations from probably the same group (in terms of village or family) were buried. Moreover, typical livestock from domestic places were also present in this funerary area as part of the feastings and/or offerings. This was a great context to pose a mobility and aDNA analysis. To fill the gap between the place of origin (aDNA) and place of burial (the site), strontium isotopic analyses were conducted in humans, caprines, dogs, and cattle. Moreover, a sequential analysis was developed on two caprines and two cattle to assess possible seasonal movements.

All analysed samples showed strontium ratios compatible with the island of Mallorca. Humans, dogs, and caprines provided similar strontium results, thus suggesting that these species fed locally. However, some human and caprine individuals are distributed outside the estimated $^{87}Sr/^{86}Sr$ range of the site, but they are compatible with the surrounding geologies located at minimum c. 3 km from the necropolis. In addition, cattle showed the lowest strontium results and no seasonal mobility was found. It is possible that these animals were feeding in a different place. The results are compatible with the nearby mountain ranges (e.g. at Puig de Sa Morisca village). Another explanation is that these animals were stabled and fed with fodder cultivated far from the site, but this seems less plausible. One of the caprines sequentially sampled showed seasonal mobility and it records some of the highest strontium results of Mallorca, that is also compatible with the nearby variability of bioavailable $^{87}Sr/^{86}Sr$.

It is interesting that cattle, an animal well-known as a community consumption species (Halstead, 1992), has shown the most different strontium results in the study of the necropolis. The fact that these animals were brought to the site as an offering from people from elsewhere to a place with a regional symbolism is suggestive and has been identified in other places (Madgwick et al., 2019). Unfortunately, the scarcity of samples restricts the interpretation and future studies will confirm or discard this interpretation. The fact that humans show some outliers or the presence of a caprine with seasonal mobility show that Son Ferrer buried individuals were mainly locals but some mobility occurred. Other archaeological data point to the same direction with the presence of foreign pottery or fishes and seashells (Calvo, Garcia-Rosselló, Albero, & Javaloyas, 2015b; García-Rosselló, 2010; Picornell-Gelabert et al., 2018). Additionally, Son Ferrer site is an important monumental place for the surrounding areas with a long-term use (Calvo et al., 2005, 2015a; García-Rosselló et al., 2015) and the strontium results are also compatible with these geologies. The discussion is limited by the low number of remains but this information opens new questions and possible future studies about pastoral practices. Further studies from LIA domestic places and regions are needed to compare the data. Moreover, expanding the sequential analyses will elucidate if seasonal movements of livestock occurred during the LIA in the Balearics.

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Appendix

Table A1: Kruskal Wallis-chi square results (lower left part) and the p-values (upper right part). In bold, *p*-values significant differences are indicated

Species	**Humans**	**Caprines**	***Bos taurus***	***Canis familiaris***	**Reference**
Humans	—	0.1167	**0.00128**	0.6831	0.8836
Caprines	2,461	—	**7.11×10^{-5}**	0.07337	0.1926
Bos taurus	10.37	15.78	—	**0.0102**	**0.002681**
Canis familiaris	0.1667	3 206	6.6	—	0.8815
Reference	0.02143	1 697	9.013	0.02222	—