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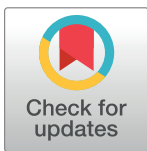
RESEARCH ARTICLE

Shipping amphorae and shipping sheep? Livestock mobility in the north-east Iberian peninsula during the Iron Age based on strontium isotopic analyses of sheep and goat tooth enamel

Silvia Valenzuela-Lamas^{1*}, Hector A. Orengo², Delphine Bosch³, Maura Pellegrini⁴, Paul Halstead⁵, Ariadna Nieto-Espinet¹, Angela Trentacoste⁴, Sergio Jiménez-Manchón⁶, Dani López-Reyes⁷, Rafel Jornet-Niella⁸

1 Consejo Superior de Investigaciones Científicas- Institutió Milà i Fontanals (CSIC-IMF), Barcelona, Spain, **2** McDonald Institute for Archaeological Research, University of Cambridge, Cambridge, United Kingdom, **3** Laboratoire Géosciences, CNRS- Université Montpellier, UMR-5243, Montpellier, France, **4** School of Archaeology, University of Oxford, Oxford, United Kingdom, **5** Department of Archaeology, University of Sheffield, Sheffield, United Kingdom, **6** Archéologie des Sociétés Méditerranéennes, UMR 5140, Labex ARCHIMEDE program IA- ANR-11-LABX-0032-01, Univ Paul-Valéry, CNRS, MCC, Montpellier, France, **7** Arqueovitis sccl, Avinyonet del Penedès, Spain, **8** Àrea de Prehistòria i Arqueologia, Universitat de Barcelona, Barcelona, Spain

* svalenzuela@imf.csic.es



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Data Availability Statement: All relevant data are within the paper. Information regarding the specimen numbers and names are detailed in Tables 1 and 2 under the tab 'Sample'. The precise geographic location of the present-day samples is detailed with the UTM coordinates in Table 1. Authors may be contacted for further details at svalenzuela@imf.csic.es.

Abstract

Animal mobility is a common strategy to overcome scarcity of food and the related overgrazing of pastures. It is also essential to reduce the inbreeding rate of animal populations, which is known to have a negative impact on fertility and productivity. The present paper shows the geographic range of sheep provisioning in different phases of occupation at the Iron Age site of Turó de la Font de la Canya (7th to 3rd centuries BC). Strontium isotope ratios from 34 archaeological sheep and goat enamel, two archaeological bones and 14 modern tree leaves are presented. The isotopic results suggest that sheep and goats consumed at the site were reared locally (within a few kilometres radius) during the whole period of occupation. The paper discusses the isotopic results in light of the socio-political structure of this period, as complex, strongly territorial societies developed during the Iron Age in the north-east Iberian Peninsula.

Introduction

The Bronze and the Iron Ages in Europe witnessed increased social differentiation and territoriality. This is reflected in the archaeological record in changing settlement pattern (from open-air sites on the plains to fortified sites on hills), the expansion and progressive complexity of fortifications, and the spread of warrior equipment and weapons in some tombs. These processes thus apparently involved a significant increase in warfare and, probably, in the

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maintenance of boundaries between territories [1–8]. In the north-east of the Iberian peninsula (present-day Catalonia), the spread of iron technology during the 8th-7th centuries BC coincided with the first evidence of rectangular stone buildings, urbanism and fortifications [4, 7, 9]. Iron Age animal husbandry, which did not change dramatically compared to the Late Bronze Age [10–11], was characterised by a remarkable predominance of sheep and goats and by the small size of domestic cattle, sheep/goats and pigs [10–16]. This changed only slightly in the 3rd century BC, when increased consumption of pigs and a slight increase in animal size are attested [10–14, 16], coinciding in time with the expansion of urban centres in the area [9, 17–19].

The site named Turó de la Font de la Canya (Barcelona, Spain) was an important point for cereal storage and trade with other cultures of the Mediterranean, as suggested by the presence of numerous subterranean 'silos' suitable for cereal storage, together with imports of Phoenician, Greek and other origins (Fig 1; [20–22]). The site is located on a small promontory (230 m a.s.l.), about 15 km from the present-day coastline and about 40 km south-west of Barcelona [22] (Fig 2). Its occupation spanned the 7th to 2nd centuries BC, that is, from the spread of iron metallurgy in the area to the period of the Roman conquest.

The analysis of strontium isotope ratios from tooth enamel is now a well-established method for exploring human and animal mobility [23–32]. The aim of this study is to characterise the geographical range of sheep provisioning for this important site through its period of occupation, and thus to assess its degree of connectivity regarding meat provisioning through the Iron Age. In other words, we wanted to know whether sheep were moving as much as other materials, such as pottery and other goods recovered from the site [22]. A previous study on seven sheep teeth from this site suggested that sheep were reared locally [33]. The present work significantly expands the number of sheep teeth analysed and covers different phases of occupation, allowing us to look for variations in the geographical range of meat provisioning through time; in this study, we also analysed a few goat teeth. In order to determine the baseline of strontium isotope variability, archaeological bones and modern leaves collected from trees growing on different geological units around the site were also analysed as a basis for comparison with archaeological results.

Strontium isotope analysis

Strontium substitutes for calcium and occurs as a trace element in biogenic tissues, including the hydroxyapatite of teeth and bones [23, 34–35]. The Sr isotopic ratio ($^{87}\text{Sr}/^{86}\text{Sr}$) varies in different geological formations according to the age and original rubidium (Rb) /strontium (Sr) ratio of the bedrock, leading to high radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in old or crustal rocks, and low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in young or mantle rocks [23, 36]. The $^{87}\text{Sr}/^{86}\text{Sr}$ isotope composition of plants reflects the strontium isotopic ratios of the underlying bedrock, as biologic processes involved during plant growth do not entail isotopic fractionation of strontium isotopes [37–38]. Other factors affecting strontium ratios in plants include a significant contribution of rainfall water [39] atmospheric pollution and the use of modern fertilizers [40–44].

In the case of skeletal material, the $^{87}\text{Sr}/^{86}\text{Sr}$ isotope composition derives from the food and drink ingested by the animal [45–46]. The porosity of bones makes their strontium signature susceptible to diagenetic alteration, but the isotopic signature of tooth enamel bioapatite reflects the period of tooth formation with little subsequent change [47–48]. Therefore, strontium isotope ratios from tooth enamel indicate the type of geological formation from which food and water were sourced during the period of mineralization of the tooth analysed [23–38, 49].

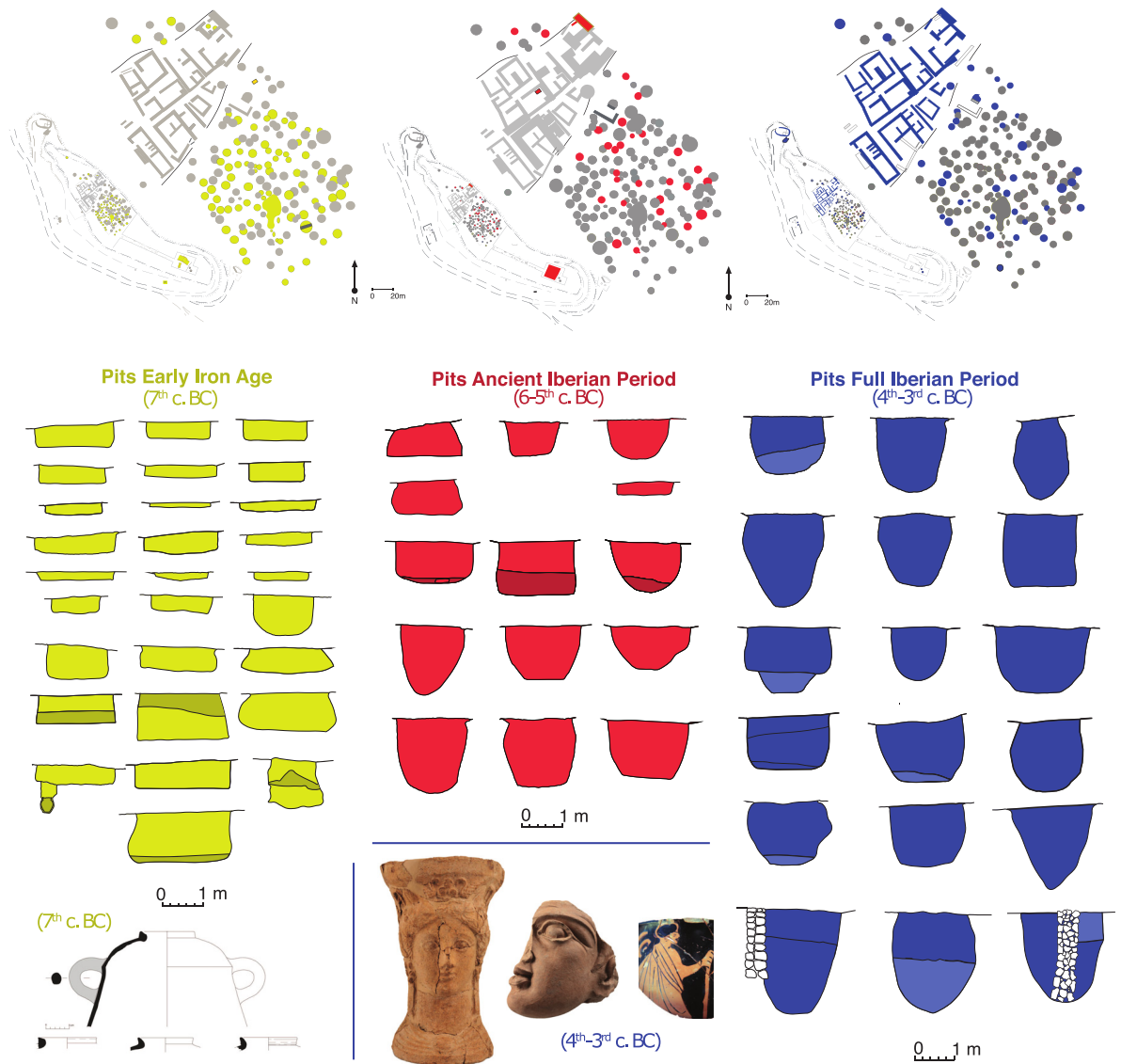


Fig 1. Plan of the site, sections of some silos, and examples of Mediterranean imports dated from the early Iron Age (7th century BC) and the Full Iberian Period (4th - 3rd centuries BC).

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Geology at the site

The site of Turó de la Font de la Canya is located on a coastal promontory on the south-west margin of the Catalan Coastal Range. From a geological perspective, this mountain range is characterised by fragmented outcrops of mainly Mesozoic and Tertiary sedimentary formations overlying infra-Silurian and Variscan batholith and other Palaeozoic metamorphic rocks [50]. The settlement is located on Miocene clays, sandstones and conglomerates and is surrounded by Plio-Pleistocene alluvia to the west and north, and by Cretaceous limestones to the east and south (Fig 2). In the vicinity of the site, within 10–15 km, other sedimentary (Triassic sandstones, dolomites, limestones and marls) and metamorphic (Cambro-Ordovician Micacitic slates) formations also outcrop. Further to the north-east, an extensive outcrop of Late Hercynian biotitic granodiorite is also present.

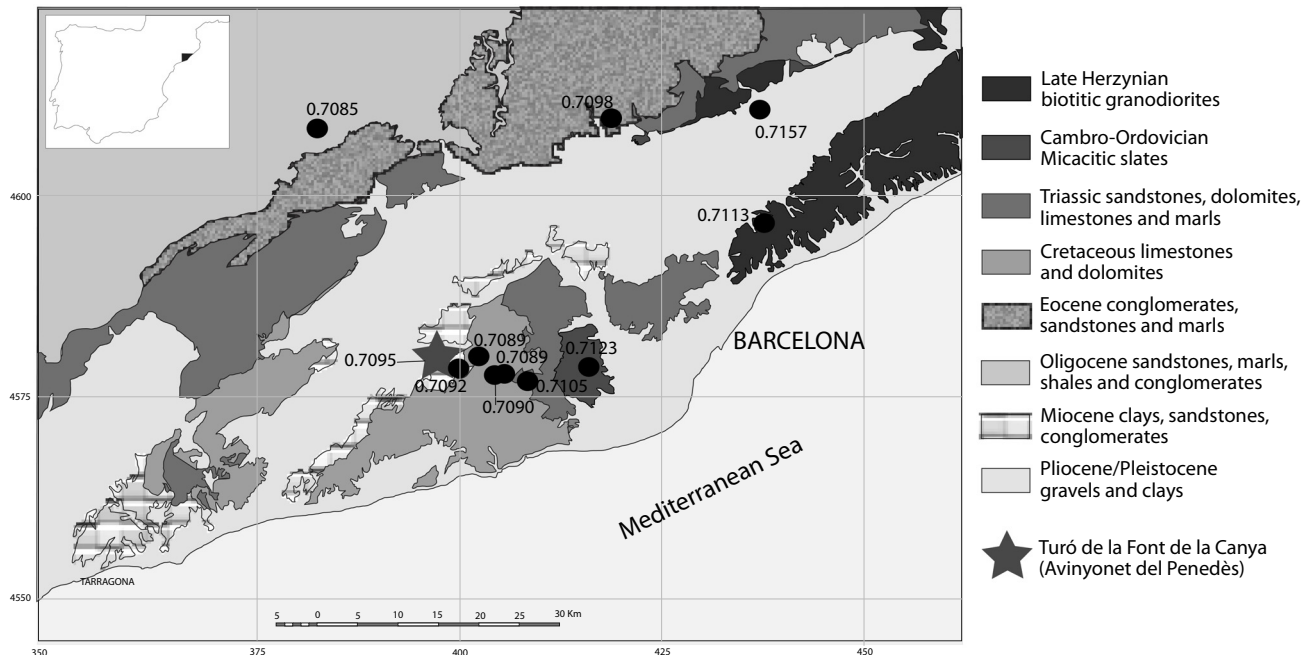


Fig 2. Location of the site (star) and the sampling locations of modern tree leaves and archaeological bones used to assess the bioavailable strontium of the different geological formations surrounding the site. The site is on a Miocene plateau surrounded by Pliocene and Pleistocene sediments.

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Materials and methods

The analysed archaeological material totals 30 sheep and four goat teeth (including seven sheep teeth previously reported [33]) from different levels of occupation and silos filled with domestic debris. Sheep and goat identification followed usual criteria [51–53]. The selected teeth correspond to second and third molars dated from different phases of occupation of the site: nine teeth dated from the early Iron Age (7th century BC), nine from the Middle Iron Age (6th -5th centuries BC), and 16 from the Late Iron Age (4th -3rd centuries BC). Despite the higher inter-individual variation in the enamel mineralization of the third molar in comparison to the second [54–55], as well as the possible averaging of isotope ratios [56], third molars were selected because they were easily identifiable even when isolated. In all cases, only fully erupted teeth (i.e. in wear) from different individuals were chosen for analysis.

The enamel samples were prepared for strontium isotope analysis following standard practices described in previous studies [24, 33, 57]. The tooth enamel surface was first mechanically abraded to remove all dentine and cementum to a depth of 100 µm using a tungsten carbide dental burr. A transversal slice of enamel about 2mm wide was cut above the enamel root junction (ERJ) from the protoconid of each tooth using a diamond cutter disc coupled to a dentist’s drill. On ten teeth, two more transversal slices of enamel about 2mm wide were cut at the middle and top of the tooth crown (about 9mm and 15mm from the enamel root junction) to analyse potential strontium variations during the period of enamel mineralisation. Although some variation may occur between breeds, mineralisation of sheep third molars starts about 9–12 months, and finishes about 22–34 months [58–59]. Consequently, sequential sampling allows us to observe whether animals moved between different geological layers during enamel mineralisation [49, 56, 60–61]. These ten teeth were added to the seven teeth published in our previous study [33] thus totalling 17 teeth sequentially sampled (minimum 5 teeth per

chronological period). The resulting samples were transferred to a clean (class 100, laminar flow hood) working area in the Laboratoire de Géosciences (Montpellier, France) for further preparation. This involved ultrasonic cleaning to remove adhering material and immersion in 60°C water for an hour for further cleaning. After each cleaning phase the sample was rinsed three times on MilliQ high purity de-ionized water. A final cleaning step, in 5% acetic acid for half an hour in an ultrasonic bath, followed by rinsing three or four times with pure water, was also performed in order to be sure that potential remaining diagenetic effects were removed. Once cleaned and dried in a laminar flow hood, the samples were weighed in pre-cleaned Teflon beakers. The samples were then dissolved in Teflon distilled nitric acid (8 M HNO₃). Strontium was collected using standard resin columns (Eichrom Sr-Spec resin) and then loaded onto single rhenium filaments with a TaCl₅ activator. Total chemistry blanks were less than 20pg and thus negligible for this study. The strontium isotope composition was determined with a solid-source thermal-ionization mass spectrometer at the Labogis of Nîmes University (Thermo Finnigan TRITON TI). Repeated measurements of the international standard for ⁸⁷Sr/⁸⁶Sr NBS 987 gave a mean value of 0.710251 ± 0.000018 for static analysis (2 s, n = 9).

In order to assess the variability of bio-available strontium ratios in the vicinity of the site and surrounding geological areas, 14 modern leaves from oak, pine and strawberry trees growing on different geological formations were also analysed (see [Table 1](#) for details, specimen name and precise location). Six of them originated from forests protected as a natural reserve (Natural Park of Garraf, Sant Llorenç del Munt i l'Obac, Montseny, and Montnegre-Corredor), and eight from trees growing on non-cultivated fields far (>100m) from human activities and rivers or streams. The field permits were granted by Diputació de Barcelona. Each sampling location was recorded using a hand-held GPS device. The preparation protocol was adapted from the one described in [40]. Samples of modern leaves were crushed in a Retsch 200ZM grinder, and then weighed in pre-cleaned pressure vessels in a clean laboratory environment. They were dissolved in Teflon distilled nitric acid (8 M HNO₃) overnight at room temperature. Further acid and a trace of H₂O₂ were added, before the samples were processed in a microwave oven at 175°C for 20 minutes. The samples obtained were then dried overnight on a hotplate prior to a secondary oxidation stage which repeated the whole process. The samples were converted to chloride in a solution of 6 M HCl, then dried and taken up again in 2N HNO₃ prior to strontium separation using standard resin columns (Eichrom Sr-Spec resin).

Despite every effort was made to collect reliable samples from the Pleistocene sediments of the Vallès-Penedès valley, it proved difficult due to the high degree of anthropic impact on the landscape—buildings, agriculture—. We therefore took two bone samples from two archaeological sites located on Pliocene and Pleistocene sediments further away to the West ([Table 1](#)) as bone tissue absorbs the strontium signature of the burying environment [47–48]. The bone sample preparation followed the same protocol described above for enamel samples.

Results

Modern samples

[Table 1](#) and [Fig 3](#) (left) show the strontium ⁸⁷Sr/⁸⁶Sr isotopic ratios obtained from the 14 modern leaf samples and two archaeological bones sourced from different geological formations neighbouring the site. The results indicate that the strontium signature of the site is around 0.7095, and that the potential strontium variation in the surroundings of the site ranges between 0.7089 and 0.7123. The neighbour Jurassic and Cretaceous bedrock of the Garraf mountain displays a range between 0.7089 and 0.7090. Further to the north, the Triassic dolomites gave a signal of 0.7105, and further to the north-east, the Palaeozoic granodiorites and micacitic slates of the littoral mountains display strontium ratios between 0.7113 and 0.7123.

Table 1. Strontium isotopic ratios (⁸⁷Sr/⁸⁶Sr) obtained on modern tree leaves and sheep bones from different geologic formations. Coordinates ETRS89 UTM31N.

| Sample | W | N | Era | Period | Epoch | Bedrock | Species | ⁸⁷ Sr/ ⁸⁶ Sr | Error (2s) | Geological layer |
|--------|-----------|------------|-----------|-----------------------|---------------------------------|---|-----------------|------------------------------------|------------|------------------|
| VI-11 | 329415.2 | 4603851.5 | Cenozoic | Quaternary | Pleistocene | Gravels with lutite matrix and sandy banks | Sheep bone | 0.708589 | ±0.000004 | Qvpu |
| GAR-5 | 401093.85 | 4578084.81 | Cenozoic | Neogene | Late Miocene | Calcarenites | Evergreen oak | 0.709226 | ±0.000007 | NMe |
| TFC 50 | 397472 | 4580693 | Cenozoic | Neogene | Middle Miocene | Clays, sandstones and conglomerates | Evergreen oak | 0.709508 | | Nmag |
| TFC 51 | 397472 | 4580693 | Cenozoic | Neogene | Middle Miocene | Clays, sandstones and conglomerates | Oak | 0.709528 | | Nmag |
| VG-020 | 449065.3 | 4616603.9 | Cenozoic | Neogene | Miocene | Lenticular levels of conglomerates with arcsic sandy matrix | Evergreen oak | 0.715757 | ±0.000003 | NMcga |
| VG-002 | 331435.8 | 4635310.3 | Cenozoic | Paleogene | Oligocene | Conglomerates | Oak | 0.709304 | ±0.000005 | Pogm1 |
| VI-98 | 291167.6 | 4611828.6 | Cenozoic | Paleogene | Oligocene | Shales and sandstones | Sheep bone | 0.709606 | ±0.000006 | POmgc4 |
| VG-001 | 324446.7 | 4630001.3 | Cenozoic | Paleogene | Eocene-Oligocene | Gray marls | Pine | 0.708506 | ±0.000007 | PEOx |
| VG-025 | 380229.6 | 4606831.3 | Cenozoic | Paleogene | Eocene-Oligocene | Marls, limestones and sandstones | Pine | 0.708541 | ±0.000005 | PEOmg |
| VG-022 | 421143.4 | 4610785.2 | Cenozoic | Paleogene | Eocene | Heterometric conglomerates | Evergreen oak | 0.709820 | ±0.000003 | PEcg |
| GAR-6 | 401454.53 | 4578621.58 | Mesozoic | Cretaceous | Late Cretaceous | Calcareous and dolomitic | Pine | 0.708977 | ±0.000012 | CVBcd |
| GAR-3 | 405910.83 | 4576288.54 | Mesozoic | Jurassic-Cretaceous | Upper Jurassic-Lower Cretaceous | Calcareous and dolomitic | Evergreen oak | 0.709063 | ±0.000008 | Jd |
| GAR-4 | 405910.83 | 4576288.53 | Mesozoic | Jurassic-Cretaceous | Upper Jurassic-Lower Cretaceous | Calcareous and dolomitic | Evergreen oak | 0.708923 | ±0.000007 | Jd |
| GAR-1 | 409109.00 | 4575181.04 | Mesozoic | Triassic | Middle—Late Triassic | Calcareous and dolomitic | Evergreen oak | 0.710552 | ±0.000092 | Tm2 |
| VG-024 | 443688.4 | 4602000.2 | Paleozoic | Carboniferous-Permian | Carboniferous-Permian | Granodiorites and alkaline granites | Strawberry tree | 0.711321 | ±0.000005 | Ggd |
| GAR-7 | 416507.47 | 4579214.7 | Paleozoic | Cambro-Ordovician | Cambro-Ordovician | Micacitic slates | Evergreen oak | 0.712337 | ±0.000006 | ÇOrp |

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In the Vallès, the sample collected on Miocene sediments close to Palaeozoic sediments of the Montseny gave a ⁸⁷Sr/⁸⁶Sr value of 0.7157, and the sample from the Eocene conglomerates in the West a ⁸⁷Sr/⁸⁶Sr ratio of 0.7098. The Eocene- Oligocene marls and the Pleistocene sediments of the Catalan Central Depression had values around 0.7085 and, further to the West (130 Km distant from Turó de la Font de la Canya) the Oligocene bedrock displayed values comprised between 0.7093 and 0.7095. All these strontium ratios are consistent with other measurements from similar geological formations in the Iberian Peninsula and elsewhere [29–30, 32, 38].

Archaeological samples

Table 2 and Fig 3 show the results of the 34 archaeological sheep and goat teeth from Turó de la Font de la Canya. The vast majority of strontium ⁸⁷Sr/⁸⁶Sr isotopic ratios (n = 27), including those for all four goats, range between 0.7091 and 0.7096, compatible with the values attested on the Miocene sediments where the site is located. Six teeth (one of 7th century BC, two of 6th–5th centuries BC, and three of 4th–3rd centuries BC) have values in the range 0.7086–0.7090, which could correspond to Cretaceous sediments from the neighbouring Garraf mountains (circa 4km away). Only one tooth dated to the 7th century BC has a value of 0.7102 (sample

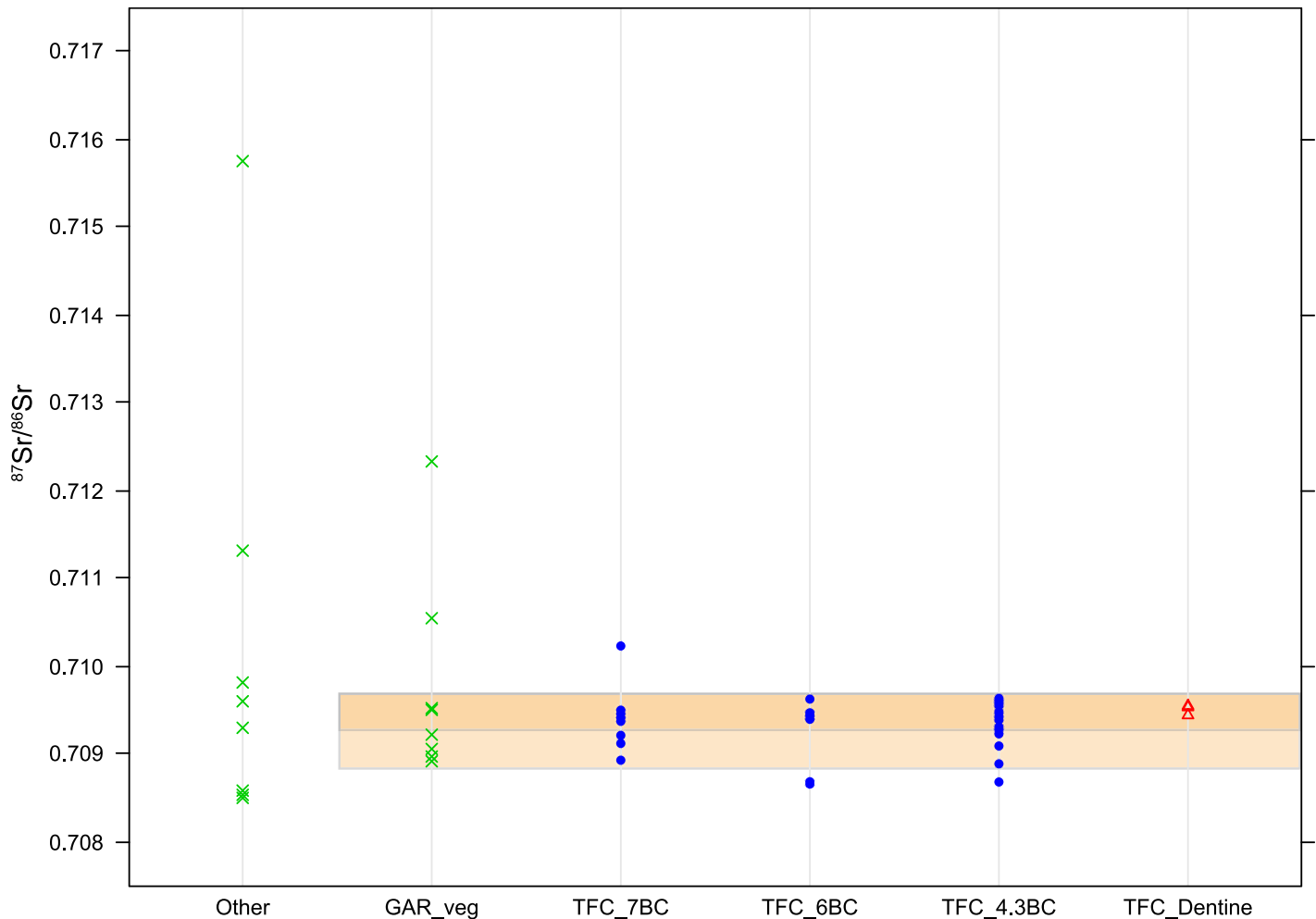


Fig 3. Strontium isotopic ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) obtained from 14 modern tree leaves and two archaeological bones (green crosses), 34 archaeological sheep enamel from Turó de la Font de la Canya (blue dots) and three archaeological sheep dentine from Turó de la Font de la Canya (red triangles). The dark orange band indicates the strontium isotopic range of the Miocene bedrock where the site is located, and the light orange band indicates the range of the Jurassic and Cretaceous sediments neighbour to the site. ‘GAR’ vegetal samples refer to the samples collected on the Garraf mountain area (sample codes starting with GAR on Table 1), ‘Other’ refer to all the other areas (see Table 1 for sample details).

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37–1, SU 1549), which could be compatible with the Triassic limestone and dolomites present further away in the Garraf (circa 10km from the site).

The 17 teeth for which sequential sampling was done display low variability along the tooth crown (Table 3, Fig 4). Again, most teeth have strontium ratios compatible with the local Miocene geology all along the tooth enamel. This indicates that most animals grazed in the vicinity of the site all the year round, and thus suggests that herding was mainly done locally. Only three teeth (717—6th century BC, SU1087A, 4th century BC and SU1090B, 3rd century BC) have notable differences along the tooth height (over 0.000200 between the maximum and the minimum $^{87}\text{Sr}/^{86}\text{Sr}$ value, see Table 3 for details). Two of those animals grazed on an area with strontium values compatible with the Cretaceous sediments from the neighbouring Garraf mountains (teeth 717 and SU1087A), thus reinforcing the idea that some animals arrived to the site from other locations. In this respect, no seasonal pattern of mobility is evidenced between the Garraf mountains and the Plio-Pleistocene valley, but some teeth have similar degrees of variation along the tooth crown. This is the case of teeth 32 and 33 (7th century BC)

Table 2. Strontium isotopic ratios (⁸⁷Sr/⁸⁶Sr) obtained from archaeological sheep and goats enamel. Sample located at the base of each tooth, about 1mm above the enamel root junction. In the table, 's/g' refers to specimens identified as 'sheep/goat'.

| Sample code | SU | Tooth | Species | Chrono | Wear stage (Payne 1987) | ⁸⁷ Sr/ ⁸⁶ Sr | Error (±2sigma) | Reference |
|-------------|---------|--------|---------|------------|-------------------------|------------------------------------|-----------------|-----------------------------|
| 25-1 | SU 1233 | m2 inf | sheep | 7th BC | 9A | 0.709378 | 0.000004 | This study |
| 30-1 | SU 1549 | m3 inf | goat | 7th BC | 10G | 0.709418 | 0.000004 | This study |
| 32-1 | SU 1549 | m3 inf | sheep | 7th BC | 11G | 0.709218 | 0.000004 | This study |
| 33-1 | SU 1549 | m2 inf | sheep | 7th BC | 9A | 0.708935 | 0.000003 | This study |
| 34-1 | SU 1549 | m3 inf | goat | 7th BC | 11G | 0.709379 | 0.000004 | This study |
| 37-1 | SU 1549 | m3 inf | sheep | 7th BC | 11G | 0.710236 | 0.000005 | This study |
| 38-1 | SU 1549 | m3 inf | sheep | 7th BC | 5A | 0.709126 | 0.000008 | This study |
| 41-1 | SU 1649 | m2 inf | sheep | 7th BC | 5A | 0.709505 | 0.000004 | This study |
| 59-1 | SU 1670 | m2 inf | sheep | 7th BC | 10A | 0.709464 | 0.000004 | This study |
| 137-1 | SU 1710 | m2 inf | sheep | 6th BC | 9A | 0.709631 | 0.000004 | This study |
| 139-1 | SU 1710 | m3 inf | sheep | 6th BC | 6G | 0.709402 | 0.000004 | This study |
| 47-1 | SU 1616 | m3 inf | sheep | 6th BC | 11G | 0.709452 | 0.000008 | This study |
| 712-1 | SU 1710 | m3 inf | sheep | 6th BC | 9G | 0.709441 | 0.000015 | This study |
| 714-1 | SU 1710 | m3 inf | sheep | 6th BC | 11G | 0.709475 | 0.000004 | This study |
| 716-1 | SU 1710 | m3 inf | goat | 6th BC | 6G | 0.709401 | 0.000005 | This study |
| 717-1 | SU 1710 | m3 inf | sheep | 6th BC | 11G | 0.708664 | 0.000005 | This study |
| 718-1 | SU 1710 | m3 inf | sheep | 6th BC | 11G | 0.708690 | 0.000003 | This study |
| 719-1 | SU 1710 | m3 inf | goat | 6th BC | 5G | 0.709445 | 0.000008 | This study |
| 53-1 | SU 1696 | m2 sup | s/g | 4th-3rd BC | 9A | 0.709097 | 0.000004 | This study |
| 54-1 | SU 1696 | m3 sup | s/g | 4th-3rd BC | 9A | 0.709486 | 0.000003 | This study |
| 13-1 | SU 1615 | m2 sup | s/g | 4th BC | 9A | 0.709569 | 0.000005 | This study |
| 15-1 | SU 1615 | m3 sup | s/g | 4th BC | 4A | 0.709309 | 0.000003 | This study |
| 17-1 | SU 1646 | m3 inf | sheep | 4th BC | 9G | 0.709394 | 0.000006 | This study |
| 58-1 | SU 1660 | m3 inf | sheep | 4th BC | 9G | 0.708687 | 0.000004 | This study |
| SU1022 | SU 1022 | m3 inf | sheep | 4th BC | 2A | 0.709557 | | Valenzuela-Lamas et al 2016 |
| SU1030 | SU 1030 | m3 inf | sheep | 4th BC | 10G | 0.709430 | | Valenzuela-Lamas et al 2016 |
| SU1081 | SU 1081 | m3 inf | sheep | 4th BC | 6G | 0.709235 | | Valenzuela-Lamas et al 2016 |
| SU1087A | SU 1087 | m3 inf | sheep | 4th BC | 5G | 0.708894 | | Valenzuela-Lamas et al 2016 |
| SU1087B | SU 1087 | m3 inf | sheep | 4th BC | 6G | 0.709471 | | Valenzuela-Lamas et al 2016 |
| 1-1 | SU 1090 | m2 inf | sheep | 3rd BC | 7A | 0.709622 | 0.000004 | This study |
| 2-1 | SU 1090 | m2 inf | sheep | 3rd BC | 4A | 0.709287 | 0.000005 | This study |
| 44-1 | SU 1769 | m2 sup | s/g | 3rd BC | 5A | 0.709638 | 0.000004 | This study |
| SU1090A | SU 1090 | m3 inf | sheep | 3rd BC | 4A | 0.709592 | | Valenzuela-Lamas et al 2016 |
| SU1090B | SU 1090 | m3 inf | sheep | 3rd BC | 11G | 0.709314 | | Valenzuela-Lamas et al 2016 |

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as well as SU1087A and SU1090B (3rd century BC, see Fig 4). This suggests that some animals may have moved around in a similar way, although this was not the case for most animals.

Discussion

The ⁸⁷Sr/⁸⁶Sr data of the modern vegetation and archaeological bone reflect the diversity of the geological settings in the Catalan central coast and central depression. The samples originated from the main geological areas around Turó de la Font de la Canya and provide a first overview of the strontium isotopic ranges from the vicinity of the site to 130 Km away to the West. The sampling of the Pleistocene sediments of the Vallès-Penedès valley proved challenging due to the high degree of human impact in this area, which prevented us to collect reliable samples. The strontium results from the large majority of the archaeological samples (27 out of

Table 3. Strontium isotopic ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) obtained from 17 archaeological sheep and goats enamel. Samples located at the base, middle and top of enamel. Teeth codes are the same as in Table 2.

| Sample code | Top | Middle | Base | Chronology | Max | Min | Difference |
|-------------|----------|----------|----------|------------|----------|----------|------------|
| 25 | 0.709390 | 0.709392 | 0.709378 | 7th BC | 0.709392 | 0.709378 | 0.000014 |
| 30 | 0.709434 | 0.709386 | 0.709418 | 7th BC | 0.709434 | 0.709386 | 0.000048 |
| 32 | 0.709153 | 0.709139 | 0.709218 | 7th BC | 0.709218 | 0.709139 | 0.000079 |
| 33 | 0.708826 | 0.708864 | 0.708935 | 7th BC | 0.708935 | 0.708826 | 0.000108 |
| 34 | 0.709430 | 0.709460 | 0.709379 | 7th BC | 0.709460 | 0.709379 | 0.000081 |
| 714 | 0.709475 | 0.709387 | 0.709259 | 6th BC | 0.709475 | 0.709259 | 0.000215 |
| 716 | 0.709401 | 0.709303 | 0.709331 | 6th BC | 0.709401 | 0.709303 | 0.000099 |
| 717 | 0.708664 | 0.708297 | 0.708323 | 6th BC | 0.708664 | 0.708297 | 0.000367 |
| 712 | 0.709441 | 0.709414 | 0.709398 | 6th BC | 0.709441 | 0.709398 | 0.000044 |
| 719 | 0.709445 | 0.709450 | 0.709410 | 6th BC | 0.709450 | 0.709410 | 0.000040 |
| SU1022 | 0.709557 | 0.709537 | 0.709387 | 4th BC | 0.709557 | 0.709387 | 0.000170 |
| SU1030 | 0.709430 | 0.709432 | 0.709391 | 4th BC | 0.709432 | 0.709391 | 0.000041 |
| SU1081 | 0.709235 | 0.709274 | 0.709269 | 4th BC | 0.709274 | 0.709235 | 0.000039 |
| SU1087A | 0.708894 | 0.708804 | 0.709006 | 4th BC | 0.709006 | 0.708804 | 0.000202 |
| SU1087B | 0.709471 | 0.709375 | 0.709412 | 4th BC | 0.709471 | 0.709375 | 0.000096 |
| SU1090A | 0.709592 | 0.709614 | 0.709566 | 3rd BC | 0.709614 | 0.709566 | 0.000048 |
| SU1090B | 0.709314 | 0.709193 | 0.709394 | 3rd BC | 0.709394 | 0.709193 | 0.000201 |

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34 considering the bottom slice, and 53 out of 64 considering all the samples) are compatible with the geology immediately surrounding the archaeological site. This is consistent with sheep and goats being reared locally in the different phases of occupation, most likely on the Miocene sediments and Pleistocene gravels and clays of the Penedès Valley. Nevertheless, the use of other areas of this valley (the Vallès) cannot be excluded, as the Vallès-Penedès forms a corridor of Plio-Pleistocene alluvial sediments surrounded by older geological formations (see text above and Fig 2, also [50]). The presence of various stone pastoral enclosures in the

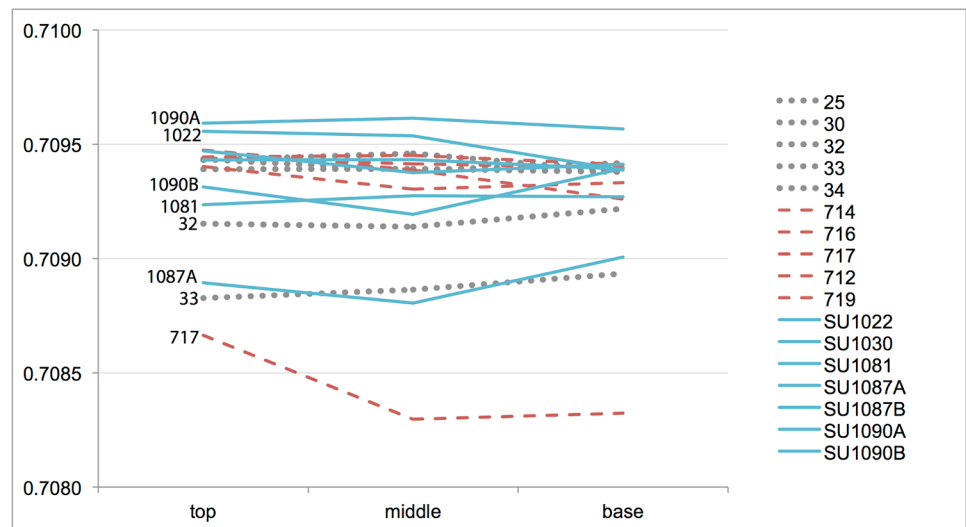


Fig 4. Strontium isotopic ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) of the 17 teeth sequentially sampled (top, middle and bottom of tooth enamel). Grey dots refer to teeth dated from the 7th century BC, red dashed-lines to teeth from 6th century BC and blue lines to teeth dated from the 4th and 3rd centuries BC.

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neighbouring Garraf mountains indicates that livestock was present in this coastal mountain area during the first millennium BC [62–65]. Interestingly, the strontium results obtained so far at Turó de la Font de la Canya suggest that this human community did not pasture its sheep and goats on the Garraf or other neighbouring mountains on a regular basis. Only six teeth out of the 34 analysed have a strontium signature compatible with that of the Cretaceous limestones of the Garraf, despite their proximity (*circa* 4 km as the crow flies). Overall, the limited variability of strontium ratios points towards local rearing of caprines rather than long-distance trade of animals.

The homogeneity of the strontium results contrast with the diversity of imports recovered from the site, which include Cruz del Negro pottery from the Straits of Gibraltar, *Tanit* figurines of Punic origin, a clay mask from the central or eastern Mediterranean, and numerous Campanian A ceramics from Italy in the levels dated from the 4th and 3rd centuries BC among others [20–22]. While the possibility cannot be excluded that the sheep and goats analysed originated from other areas with similar geology, the homogeneity of tooth values in a fairly large sample argues against this. It seems, therefore, that sheep and goats were mainly bred locally, and only ‘prestige’ goods (e.g. Phoenician wine, Greek pottery) arrived from distant sources.

Overall, material cultural data suggest that Turó de la Font de la Canya had an active role in the Mediterranean trade. Conversely, the results from strontium isotopic analysis on sheep and goats suggest that animal were reared locally, and so probably on a small-scale basis, and that caprines slaughtered at the site were mainly reared in the Penedès valley and perhaps also the neighbouring Vallès. This local breeding of livestock may reflect (and be a consequence of) the local socio-political context. The significant change in settlement pattern in the Late Bronze and Iron Ages—from open-air sites located on the plains to fortified settlements located on hills—is thought to reflect increased warfare and territoriality [1, 5, 7, 66], while weapons in some tombs and severed heads at several sites suggest the existence of a military elite at this time [18–19]. Perhaps, even if long-distance maritime trade flourished during the Iron Age across the Mediterranean, long-distance *terrestrial* movements of livestock were difficult in the north-east Iberian Peninsula at this time.

Conclusions

This study has established baseline strontium isotopic ratio ($^{87}\text{Sr}/^{86}\text{Sr}$) values for the vicinity of the Iron Age site of Turó de la Font de la Canya (Barcelona, Spain) and surrounding geological areas, based on analysis of modern leaves from trees growing on different geological substrates around the site and two archaeological bone samples. Modern leaves provided a consistent and fairly narrow range of local strontium ratio values. This new baseline has been central for the interpretation of the strontium isotopic ratios measured in 34 archaeological sheep and goat tooth enamel samples dated from the 7th to 3rd centuries BC, to explore the geographical range of meat provisioning at Iron Age Turó de la Font de la Canya. Seventeen of these samples were sequentially analysed to observe variations along the tooth crown. The investigated archaeological samples indicate limited variability of strontium values throughout the occupation of the site, and 27 of the 34 samples are compatible with the local geology ($^{87}\text{Sr}/^{86}\text{Sr}$ range: 0.7091–0.7096), while seven samples may be derived from bedrocks as close as 5 km from the site ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.7086–0.7090), and one more ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.7102) is compatible with slightly more distant (about 15 km from the site) geological areas. The sequential sampling suggests that most animals were reared locally all the year round, thus supporting the idea of small scale herding rather than long-distance sourcing. Interestingly, some animals display similar patterns of variation along the tooth crown, thus suggesting that some movement of livestock

existed. Overall, the archaeological results suggest that sheep and goats slaughtered at the site were mainly reared in the local area, most notably the Miocene clays and Plio-Pleistocene alluvial sediments of the plain. This contrasts with the role of the site as central point for cereal storage (see Fig 2) as well as the diversity of imports recovered at the site, which suggests that only 'prestige' goods (e.g. Phoenician wine, Greek pottery)—rather than animals—were brought to this storage-rich site. It further suggests that crop rather than livestock surpluses financed participation in supra-regional exchange.

The low diversity of strontium ratios of sheep and goats at Turó de la Font de la Canya implies herding over a limited geographical range that may partly have been dictated to the difficulty of long-distance terrestrial movements in the Iron Age, as a result of the emergence of the small, strongly defended territories suggested by the settlement pattern, architecture and finds of weapons. Alternatively, the limited geographical scale of herding may primarily reflect the rearing of livestock in only modest numbers. Further zooarchaeological studies, both macroscopic and isotopic, may clarify which of these rival explanations is more plausible.

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Author Contributions

Conceptualization: Silvia Valenzuela-Lamas, Hector A. Orengo.

Data curation: Silvia Valenzuela-Lamas.

Funding acquisition: Silvia Valenzuela-Lamas, Hector A. Orengo.

Investigation: Silvia Valenzuela-Lamas, Hector A. Orengo, Dani López-Reyes.

Methodology: Delphine Bosch.

Project administration: Silvia Valenzuela-Lamas, Hector A. Orengo.

Resources: Silvia Valenzuela-Lamas, Ariadna Nieto-Espinet, Dani López-Reyes.

Supervision: Hector A. Orengo, Delphine Bosch, Paul Halstead, Dani López-Reyes.

Validation: Delphine Bosch, Maura Pellegrini, Paul Halstead, Dani López-Reyes.

Visualization: Ariadna Nieto-Espinet.

Writing – original draft: Silvia Valenzuela-Lamas, Hector A. Orengo, Delphine Bosch, Maura Pellegrini, Paul Halstead, Dani López-Reyes.

Writing – review & editing: Silvia Valenzuela-Lamas, Hector A. Orengo, Delphine Bosch, Maura Pellegrini, Paul Halstead, Ariadna Nieto-Espinet, Angela Trentacoste, Sergio Jiménez-Manchón, Dani López-Reyes, Rafel Jornet-Niella.

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