



Who's been using my burial mound? Radiocarbon dating and isotopic tracing of human diet and mobility at the collective burial site, Le Tumulus des Sables, southwest France

Hannah F. James^{a,*}, Malte Willmes^{a,b}, Ceridwen A. Boel^{a,1}, Patrice Courtaud^c, Antoine Chancerel^d, Elsa Ciesielski^h, Jocelyne Desideriⁱ, Audrey Bridyⁱ, Rachel Wood^a, Ian Moffat^{a,e,f}, Stewart Fallon^a, Linda McMorrow^a, Richard A. Armstrong^a, Ian S. Williams^a, Leslie Kinsley^a, Maxime Aubert^{a,2}, Stephen Eggins^a, Catherine J. Frieman^j, Rainer Grün^{a,g}

^a Research School of Earth Sciences, The Australian National University, Acton 2601, ACT, Australia

^b Fish Department of Wildlife, Fish, and Conservation Biology, University of California Davis, Davis, CA, United States of America

^c PACEA - UMR 5199 CNRS - A3P, University of Bordeaux, 33615 Pessac, France

^d Musée National de Préhistoire, 24620 Les Eyzies-de-Tayac, France

^e Archaeology, College of Humanities, Arts and Social Sciences, Flinders University, Australia

^f McDonald Institute for Archaeological Research, University of Cambridge, United Kingdom

^g Australian Research Centre for Human Evolution, Griffith University, Nathan, QLD 4111, Australia

^h Archéologie des Sociétés Méditerranéennes, Université Paul Valéry, 34199 Montpellier, France

ⁱ Laboratoire d'archéologie préhistorique et anthropologie, Université de Genève, CH - 1211 Genève 4, Switzerland

^j School of Archaeology and Anthropology, The Australian National University, Acton 2601, ACT, Australia

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ABSTRACT

The burial mound of Le Tumulus des Sables, southwest France, contains archaeological artefacts spanning from the Neolithic to the Iron Age. Human remains have been found throughout the burial mound, however their highly fragmented state complicates the association between the burial mound structure and the archaeological material. Radiocarbon dating and isotopic analyses of human teeth have been used to investigate the chronology, diet and mobility of the occupants. Radiocarbon dating shows that the site was used for burials from the Neolithic to Iron Age, consistent with the range of archaeological artefacts recovered. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (from dentine collagen) suggest a predominately terrestrial diet for the population, unchanging through time. $^{87}\text{Sr}/^{86}\text{Sr}$ (on enamel and dentine) and $\delta^{18}\text{O}$ (on enamel) values are consistent with occupation of the surrounding region, with one individual having a $\delta^{18}\text{O}$ value consistent with a childhood spent elsewhere, in a colder climate region. These results showcase the complex reuse of this burial mound by a mostly local population over a period of about 2000 years.

1. Introduction

In 2006 school children accidentally uncovered buried human remains in a kindergarten playground in the town of Saint-Laurent-Médoc, Gironde, about 40 km north-west of Bordeaux, France (Fig. 1). The site, known as Le Tumulus des Sables, was excavated over the next four years (Chancerel and Courtaud, 2006; Courtaud et al., 2010), revealing the remains of multiple individuals and associated grave goods.

Archaeological material found throughout the site suggests that it was in use from the Neolithic to the Iron Age. Disarticulation and fragmentation of the human remains made it difficult to place individuals within the context of the site and to establish the connection between the remains and the archaeological material. Radiocarbon dating and isotopic analyses of human teeth have now enabled a better understanding of the chronology, diet and mobility of the occupants of this site.

* Corresponding author.

E-mail address: hannah.james@anu.edu.au (H.F. James).

¹ Now at University of New South Wales, School of Biological, Earth and Environmental Sciences, Palaeontology, Geobiology and Earth Archives Research Centre, Sydney, Australia.

² Now at Griffith University, Place, Evolution and Rock Art Heritage Unit (PERAHU), Gold Coast, Queensland 4222, Australia.

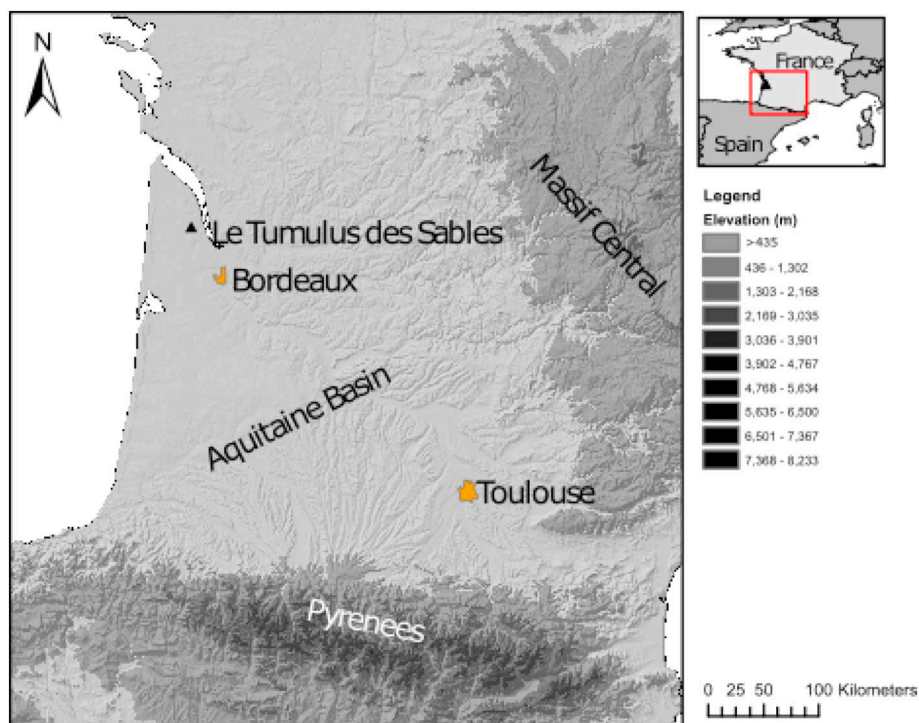


Fig. 1. Regional setting and location of the collective burial at Le Tumulus des Sables, southwest France. Elevation data taken from worldclim.org (Hijmans et al., 2005).

1.1. The site of Les Tumulus des Sables

The collective burial of Le Tumulus des Sables was contained within a roughly circular raised mound, 7×8 m in diameter and 0.5 m high at its peak (Fig. 2). Archaeological reconstructions suggest that this mound was a natural feature into which the burials may have been placed (Courtaud et al., 2010). The human remains found at the site were highly disarticulated and fragmented. No individual burials could be identified, but based on dentition, the remains represent at least 30 individuals (20 adults and 10 juveniles). The archaeological deposit associated with the burial area is irregular in shape and extends beyond the mound itself (Fig. 2).

The age of the burial mound has previously been estimated by radiocarbon dating of charcoal from the bottom and top of the mound, placing its use between 6092 and 5927 and 1397–1216 cal. BCE (Courtaud et al., 2010). Distinctive Bell Beaker pottery, arrow heads and bone buttons discovered within the burial area suggest repeated use of the site by people associated with the Bell Beaker Phenomenon (BBP) (Chancerel and Courtaud, 2006). In France the BBP is dated to between 2500 and 1800 BCE (Champion et al., 2009; Lemerrier, 2012). A radiocarbon date measured on a human bone from within the collective burial (Courtaud et al., 2009, 2010) yielded an age of 2487–2291 cal. BCE (Poz 23194), supporting a BBP association for that individual. Ceramic finds at the site, however, suggest activity extending from the Early Neolithic (~5500 BCE), through the Bell Beaker period, and into protohistoric and Iron Age periods (Chancerel and Courtaud, 2006; Courtaud et al., 2010). Radiocarbon dates also suggest that the mound was used over an extended period of time, with a date on a juvenile vertebra yielding an age of 3650–3375 cal. BCE (Erl 10575), indicating burial during the Middle Neolithic (Courtaud et al., 2010).

1.2. The Bell Beaker Phenomenon

Due to the presence of numerous and varied artefacts attributed to the BBP and the radiocarbon dated human bone belonging to this

phase, it has been presumed that the majority of burials at Le Tumulus des Sables belong to people of the BBP. The term Bell Beaker initially referred to a distinctive type of ceramic ware, but has since come to describe an artefact assemblage, a cultural complex, a group of people, and a time period (Benz and van Willigen, 1998; Desideri and Besse, 2010; Price et al., 1998; Vander Linden, 2006).

The BBP was widely distributed (if somewhat patchily) across Europe, appearing at the transition from the Neolithic to the Bronze Age about 2500 BCE and persisting until about 1800 BCE. The BBP appears at different times in different areas, was established on very different older local substrates, and typically coexisted with and reflected locally specific material culture, technological traditions and practices (Desideri and Besse, 2010; Heyd, 2007; Vander Linden, 2007). The artefact assemblage of the BBP (almost always deriving largely or solely from the funerary sphere) unites this widespread phenomenon, while the funerary and domestic structures differ greatly (Price et al., 1998, 2004; Vander Linden, 2006). Funerary practices ranged from individual graves (predominantly in Eastern Europe, Britain and Scandinavia) to re-use of graves, collective tombs and mass inhumations (predominantly in Iberia and Western Europe) (Benz and van Willigen, 1998; Besse and Desideri, 2004; Desideri and Besse, 2010; Price et al., 1998, 2004; Vander Linden, 2007; Rojo-Guerra and Garrido-Pena, 2005).

The wide geographic distribution of the BBP has been interpreted in different ways, with models ranging from mass migration of a unique population, to long distance exchange of prestige goods, to the diffusion of the cultural components of the BBP (Shennan, 1976; Sherratt, 1987; Harrison, 1980; Vander Linden, 2007). The third millennium BCE was a period which saw increasing long-distance travel and communication, as evidenced by the widespread adoption of a variety of new materials, technologies and practices, only some of which became bound up in the Beaker sphere, such as ornaments of precious or rare materials like amber, variscite and gold, new artefact types, including flint daggers, and, of course, copper metallurgy (Frieman, 2012; Roberts and Frieman, 2012). Newly published genetic analyses support the idea that Beaker-using people were mobile, but did not form part of a single

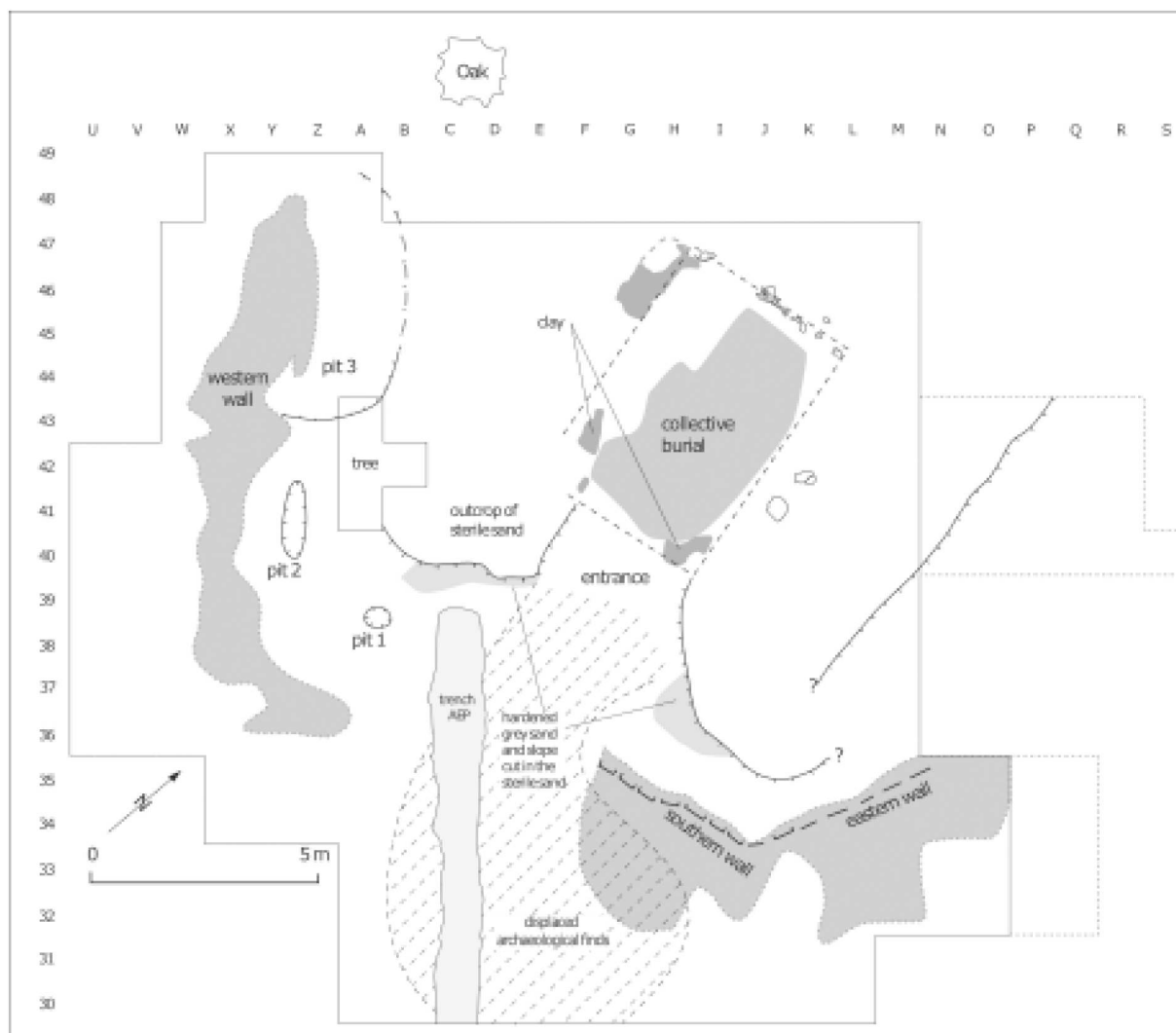


Fig. 2. The site of Le Tumulus des Sables, showing the collective burial and remains of the mound. Adapted from Courtaud et al. (2010).

migratory population (Olalde et al., 2018). The origin of the BBP is also debated. The earliest radiocarbon dates for BBP material suggest an Iberian Peninsula origin (Salanova, 2000, 2005; Lemercier, 2004; Cardoso, 2014; Müller and van Willigen, 2001), with later adoption phases in Atlantic, northern and central Europe (Czebreszuk, 2014; Desideri and Besse, 2010; Fokkens and Nicolis, 2012; Prieto Martínez and Salanova, 2009). One speculative proposal, based on ceramic typological evidence, is that the eponymous pottery, at least, might have its origins in North Africa (Turek, 2012).

Isotopic studies of mobility have been employed to understand the movement of BBP individuals in various parts of Europe, although no overarching model has yet been proposed. Direct evidence for mobility during the Bell Beaker period comes from studies of Bell Beaker sites in the United Kingdom, Germany, Hungary, Austria, Iberia and the Czech Republic (Grupe et al., 1997; Price et al., 2002, 2004; Parker Pearson et al., 2016; Fitzpatrick, 2011; Waterman et al., 2014). This research also supports the idea that, while some individuals were highly mobile—travelling great distances one or more times in their life—others were largely mobile within a confined local or regional range. Isotopic evidence possibly underestimates mobility as regions within Europe have overlapping isotopic values, and cyclical or seasonal mobility, such as one would find in pastoral economies like Chalcolithic Iberia, might be difficult to identify. Nevertheless, isotopic data from the BBP individuals excavated at Le Tumulus des Sables in south-western France

fill an important geographic gap and can offer new insights into the distribution and mobility patterns of the BBP in this particular corner of western Europe.

2. Isotopic analysis of human remains

Dental material is amenable to isotopic analysis as it is often preserved in archaeological sites and is relatively resistant to post-burial diagenesis. A combination of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) analysis on dentine collagen, strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) analysis on dentine and enamel and oxygen ($\delta^{18}\text{O}$) analyses on enamel provides information about both diet and mobility.

2.1. Reconstructing diet

The use of C ($\delta^{13}\text{C}$) and N ($\delta^{15}\text{N}$) isotopic compositions as tools for reconstructing palaeodiet has been discussed extensively elsewhere (Privat et al., 2002; Richards and Hedges, 1999; Richards, 2002; Schulting et al., 2008; Lee-Thorp, 2008; Sealy, 2001). In brief, the $\delta^{13}\text{C}$ of animal tissues is determined primarily by the photosynthetic pathway of the plants in the animal's food chain. It can be used to distinguish between plant types and between terrestrial and marine food sources (Schwarz and Schoeninger, 1991). Three pathways—C3, C4 and Crassulacean Acid Metabolism (CAM)—lead to mean $\delta^{13}\text{C}$

values of -26.5 , -12.5 and -19% , respectively (Deines, 1980). Most C4 plants (e.g. grasses and sedges) are found in dry or arid environments, so in temperate climatic regions, providing there are no introduced C4 plant species, $\delta^{13}\text{C}$ can be used to distinguish between diets from terrestrial or marine sources. The source of C in these two systems differs; atmospheric C (-7%) is the main source in terrestrial systems and dissolved carbonate (0%) is the main source in marine systems (Katzenberg, 2008). The incorporation of C into animal tissues is accompanied by isotopic fractionation, $\delta^{13}\text{C}$ being reduced relative to the food by $\sim 5\%$ in bone collagen, $\sim 10\%$ in tooth enamel in herbivores, and by an additional $\sim 1.5\%$ in the bone collagen of carnivores (Schoeninger and DeNiro, 1984). In human populations, an exclusively marine diet leads to a bone collagen $\delta^{13}\text{C}$ of $-12 \pm 1\%$, and an exclusively terrestrial C3 diet to a bone collagen $\delta^{13}\text{C}$ of $-20 \pm 1\%$ (Chisholm et al., 1982; Richards et al., 2006), mixed diets produce intermediate $\delta^{13}\text{C}$ values.

$\delta^{15}\text{N}$ in biological tissues can be used to assess the trophic levels of the food consumed. ^{14}N is excreted by the body in preference to the heavier ^{15}N . Thus, an increase in trophic level within a given environment leads to an increase in $\delta^{15}\text{N}$ of 1.3 – 5.3% per trophic level (Schoeninger and DeNiro, 1984). The more abundant trophic levels found in marine environments lead to a larger fractionation of the N isotopes than in terrestrial environments, resulting in higher $\delta^{15}\text{N}$ values. Animals whose diets consist entirely of marine resources have a $\delta^{15}\text{N}$ on average 9% higher ($14.8 \pm 2.5\%$) than those with an entirely terrestrial diet ($5.9 \pm 2.2\%$), while those with a mixed diet have intermediate values (Schoeninger and DeNiro, 1984).

In the present study, the C and N isotopes were measured on tooth dentine collagen. Dentine collagen reflects the protein component of the diet (Ambrose and Norr, 1993; Fernandes et al., 2012) primarily while teeth are forming during childhood. Minimal dentine remodelling does occur in response to dental trauma in later life, so these values can be influenced in adulthood (Kuttler, 1959; Hillson, 1986).

2.2. Reconstructing mobility

Strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) and O ($\delta^{18}\text{O}$) are two independent isotopic systems that have been used together previously to investigate past mobility in Europe (Bentley and Knipper, 2005; Buckberry et al., 2014; Chenery et al., 2010; Eckardt et al., 2009; Edgar, 2007; Evans et al., 2006; Hemer et al., 2013, 2014; Lamb et al., 2014; Neil et al., 2017; White et al., 2007; Guede et al., 2017). The $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ of tooth enamel reflects the average isotopic composition of food and drinking water consumed during childhood, when the teeth are forming. By comparing the isotopic composition of a tooth with isotopic baseline maps it can be possible to identify mobility between different geological terranes and environments. A limitation of this method, however, is that geographically distant areas can have similar or overlapping isotopic compositions. Thus, skeletal remains that are 'local' in this context are those that are indistinguishable isotopically from the surrounding environment, although they might come from a distant area of similar isotopic composition. Characterisation using independent multiple isotopic systems minimises this ambiguity.

Humans and animals incorporate Sr from their diet into their dental and skeletal tissues (Beard and Johnson, 2000) where it substitutes for Ca and serves no metabolic function. The isotopic composition of bioavailable Sr depends on the age, composition and weathering regime of the local geology (Bentley, 2006; Capo et al., 1998; Slovak and Paytan, 2011). Consequently, the $^{87}\text{Sr}/^{86}\text{Sr}$ signature in archaeological human remains is primarily determined by the underlying geology, but it can be modified by additional sources of Sr from atmospheric deposition (precipitation, sea spray, dust) and, in a modern context, fertiliser use (Bentley, 2006; Evans et al., 2010; Frei and Frei, 2013; Maurer et al., 2012; Price et al., 2002; Slovak and Paytan, 2011; Voerkelius et al., 2010). In regions with exogenic surface deposits (loess, glacial deposits, peat), the $^{87}\text{Sr}/^{86}\text{Sr}$ of locally bioavailable Sr

can be decoupled from the underlying bedrock geology. These complexities hinder inferring the range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ from the bedrock geology, making it necessary to either measure or model the range for a specific area.

The $\delta^{18}\text{O}$ of skeletal and dental remains is related to the composition of body water, which in turn is influenced by diet, physiology and climate. Most of the water consumed by humans comes from drinking water, which in archaeological contexts is typically sourced locally. The $\delta^{18}\text{O}$ value of meteoric water is a function of climate. It changes with the source, temperature and quantity of precipitation, which creates a distinctive geographic profile often reflecting latitude and elevation (Bowen and Wilkinson, 2002; Dansgaard, 1964). The constant body temperature of mammals means that the $\delta^{18}\text{O}$ of tissue is not influenced by environmental temperature, changing with the tissue type and the composition of the water ingested (Longinelli, 1984; Luz et al., 1984).

3. Materials and methods

3.1. Human dental remains

Twenty-five teeth (18 permanent, 7 deciduous) from Le Tumulus des Sables were analysed for Sr isotopes (both enamel and dentine). Of these, fifteen (14 permanent, 1 deciduous) were analysed for $\delta^{18}\text{O}$ and eight (7 permanent, 1 deciduous) were radiocarbon dated in conjunction with C and N isotopic analyses. Teeth were selected for radiocarbon dating based on the amount of tooth available for analysis.

The left maxillary second molar (LM2) was chosen for the adult samples and the left deciduous maxillary second incisor (LdI2) for juveniles, thus ensuring that each tooth came from a different individual. The permanent teeth represent individuals who died at over 14 years of age, the deciduous teeth represent individuals younger than 8 years of age (Hillson, 1986).

Skeletal material is commonly affected by both the physical and chemical environment after deposition, potentially leading to contamination of the original isotopic composition. The degree of subsequent diagenetic overprinting can be different from sample to sample and depends on a large number of factors, including the duration of burial, the hydro-geochemical environment, and the type of dental material (e.g., Bentley, 2006; Slovak and Paytan, 2011). Tooth enamel (dense hydroxyapatite) is much more resistant than bone or dentine to post-burial diagenesis and is most likely to retain its original isotopic signatures. The samples for the present study were checked for diagenetic overprint using in situ mapping of uranium (U), thorium (Th) and Sr concentrations. U and Th are only present in teeth in trace amounts, so the presence of either in archaeological remains indicates a region overprinted with a diagenetic signal. Only samples that contained enamel areas likely to have preserved their original isotopic signatures were chosen for analysis (Boel, 2011; Grün et al., 2008).

3.2. Radiocarbon dating

The discoloured surface of the dentine was removed with a tungsten carbide drill and the sample either drilled or cut and crushed in a mortar and pestle. Collagen was extracted and purified using an ultrafiltration protocol similar to that described by Brock et al. (2010). Briefly, the powdered sample was demineralised (HCl, 0.5 M, 5 °C, overnight), washed in NaOH (0.1 M, room temperature, 30 min) and HCl (0.5 M, room temperature, 1 h), with thorough rinsing in MilliQ™ water between each treatment. Subsequently the sample was gelatinised (0.001 M HCl, 70 °C, 20 h), filtered ($\sim 90 \mu\text{m}$ Eze™ filter) and ultrafiltered (Vivaspin™ VS15 30 kDa MWCO ultrafilter). The freeze-dried collagen was combusted in an evacuated sealed quartz tube in the presence of CuO wire and Ag foil. The CO_2 generated was collected cryogenically and purified prior to reduction to graphite over an Fe catalyst in the presence of H for measurement in a NEC single stage accelerator mass spectrometer at the ANU (Fallon et al., 2010). A

background dependent on sample size, derived from repeat measurements of > 50 ka bone (from Latton, UK) and young bone (from the Batavia and Vergulde Draeck shipwrecks, Australia), was subtracted from each analysis following the method of Wood et al. (2010). Calibration was carried out in OxCal v4.2 (Bronk Ramsey, 2009) against IntCal13 (Reimer, 2013).

3.3. Carbon and nitrogen isotope analysis

A second aliquot for C and N stable isotope analysis was taken from the dentine collagen extracted for radiocarbon dating. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were measured in a Sercon 20–22 isotope ratio mass spectrometer coupled to an ANCA GSL elemental analyser operating in continuous flow mode. Samples were referenced to an in-house gelatin standard and corrected against USGS-40 and USGS-41. Instrument accuracy for C and N analysis is < 0.2‰.

3.4. Strontium isotope analysis

After the tooth surface was cleaned, 0.2–0.5 mg of enamel and dentine were drilled out using a handheld 0.3 mm diamond blade drill. The tooth powder was then leached in 0.5 ml 1 M NH_4NO_3 to remove any residual contamination and digested in 1 ml ultrapure concentrated HNO_3 for 1 h. The samples were then evaporated to dryness, redissolved in 2 ml 2 M HNO_3 and the Sr extracted by ion exchange chromatography using micro columns with Eichrom Sr specific resin. A drop of dilute H_3PO_4 was added to each sample before loading onto Re filaments with a TaF₅ activator. Samples were analysed on the TRITON Plus thermal ionisation mass spectrometer (TIMS) at the Research School of Earth Sciences, ANU. Data were processed using a Rb correction, exponential mass bias correction ($^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$) and 2σ outlier rejection. Total procedural blanks were determined by isotope dilution using an ^{84}Sr enriched spike, measured on the TRITON Plus TIMS and were below 100 pg Sr. Long term measurements of the Sr carbonate standard SRM987 gave $^{87}\text{Sr}/^{86}\text{Sr} = 0.71023 \pm 0.00002$ (2σ , $n = 99$), which is within uncertainty of precise modern measurements (0.710250 ± 0.000003 ; Hans et al., 2013) and the original certified value of 0.71034 ± 0.00026 (Moore et al., 1982).

3.5. Oxygen isotope analysis

The selection of the human and rodent (*Arvicolinae* subfamily) teeth for O isotopic analysis was based on the amount of enamel available. A cross-section was cut from the enamel and cleaned manually using a dental drill fitted with a fine diamond-edged blade and tip. About 1.8 mg of finely powdered enamel was prepared for each sample, providing the ~60 μg of carbonate required for each analysis, the carbonate content of human tooth enamel being 3–6% by dry weight (LeGeros et al., 1996). The carbonate $\delta^{18}\text{O}$ was measured using an automated carbonate reaction (Kiel) device coupled to a Thermo MAT 253 in the Earth Environment Stable Isotope Laboratory, Research School of Earth Sciences, ANU. CO_2 was extracted from the powdered enamel by reaction with 105% H_3PO_4 at 90 °C. Carbonate standards NBS-19 ($\delta^{18}\text{O}_{\text{VPDB}} = -2.20$ ‰) and NBS-18 ($\delta^{18}\text{O}_{\text{VPDB}} = -23.2 \pm 0.1$ ‰) were also analysed, yielding mean values of -2.20 ± 0.03 ‰ (NBS-19, $n = 5$) and -22.82 ± 0.03 ‰ (NBS-18, $n = 2$). The $\delta^{18}\text{O}_{\text{Carbonate}}$ values were renormalised to VSMOW using: $\delta^{18}\text{O}_{\text{VSMOW}} = 1.03091 \times \delta^{18}\text{O}_{\text{VPDB}} + 30.91$ (Coplen et al., 1983; Brand et al., 2014). All oxygen data from the site are presented relative to VSMOW and as $\delta^{18}\text{O}_{\text{Carbonate}}$.

When using dental $\delta^{18}\text{O}_{\text{Carbonate}}$ to assess mobility, it has been common practice to convert tooth $\delta^{18}\text{O}_{\text{Carbonate}}$ to drinking water $\delta^{18}\text{O}_{\text{Water}}$ (Chenery et al., 2012; Daux et al., 2008). The multiple sources of uncertainty associated with this conversion, however, have led several researchers to suggest that, when assessing mobility, it is better to rely on direct comparisons to the $\delta^{18}\text{O}_{\text{Carbonate}}$ of skeletal material from

local fauna (e.g., rodents) (Laffoon et al., 2013; Pollard et al., 2011). Due to the limited amount of faunal material available to establish a site $\delta^{18}\text{O}$ baseline, we have chosen to convert human values to $\delta^{18}\text{O}_{\text{Water}}$ value and compare these to two faunal $\delta^{18}\text{O}_{\text{Water}}$ values and modern rainfall predictions. Interquartile range (IQR) is also used to identify individuals who fall outside 1.5 IQR as outliers to the site $\delta^{18}\text{O}$ value. This provides a conservative estimation of outliers or non-locals (Lightfoot and O'Connell, 2016). Human mobility can then be assessed relative to this site value and the regional variation in the $\delta^{18}\text{O}_{\text{Water}}$ of precipitation measured and modelled across Europe and Africa. The limited variation in $\delta^{18}\text{O}$ values seen in archaeological samples across Europe limits our ability to assess childhood residential areas (Lightfoot and O'Connell, 2016). Conversion of measured $\delta^{18}\text{O}_{\text{Carbonate}}$ values to a $\delta^{18}\text{O}_{\text{Water}}$ is by $\delta^{18}\text{O}_{\text{w}} = 1.590 \times \delta^{18}\text{O}_{\text{c}} - 48.634$ (Chenery et al., 2012).

3.6. Establishing isotopic baselines

To determine the range of $^{87}\text{Sr}/^{86}\text{Sr}$ in locally bioavailable Sr at Le Tumulus des Sables soil samples and associated faunal samples (11 *Microtus* sp. (vole) teeth) were collected from several sediment layers from within and around the burial (Table 2). Teeth from *Microtus* sp. were the most numerous within all areas of the site, and their small herbivorous foraging range provides a local site signature. The faunal teeth were crushed using a mortar and pestle and then subject to the same analytical procedure as the human teeth (described in Section 3.4).

The soil samples were pre-treated following the protocol DIN ISO 19730 (Din, 2009). Strontium was isolated from other elements by ion exchange chromatography using Eichrom Sr specific resin. Strontium isotope ratios were measured using a Thermo Finnigan Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) equipped with a quartz dual cyclonic spray chamber, PFA 100 μl nebuliser and standard Ni cones at the Environmental Geochemistry and Geochronology Laboratory at the Research School of Earth Sciences, ANU. Data reduction included a correction for isobaric interferences from Kr and Rb, an exponential mass bias correction ($^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$) and 2σ outlier rejection. Long term measurements of the SRM987 Sr carbonate standard on the Neptune gave an average $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.71023 ± 0.00001 ($n = 167$, 2σ).

Plant samples and soil leachates from the Isotopic Reconstruction of Human Migration (IRHUM) database (Willmes et al., 2014) were used to infer the regional range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ for the major geologic regions of southern France, including the Aquitaine Basin, the Pyrenees and Massif Central (BRGM, n.d). These types of samples were chosen because they provide a good estimate of the differences in bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$. A map of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ for all of France is included here (Fig. 5), but a detailed overview of our mapping procedures is published elsewhere (Willmes et al., 2018).

The faunal samples providing the baseline $\delta^{18}\text{O}_{\text{Carbonate}}$ for Le Tumulus des Sables were analysed using the same method as described above for human teeth. Conversion of measured vole $\delta^{18}\text{O}_{\text{Carbonate}}$ to a $\delta^{18}\text{O}_{\text{Water}}$ estimate was using $\delta^{18}\text{O}_{\text{rt}} = 1.36 (\pm 0.12) \delta^{18}\text{O}_{\text{mw}} + 32.22 (\pm 0.83)$, where rt is carbonate $\delta^{18}\text{O}$ in rodent tooth and mw is $\delta^{18}\text{O}$ meteoric water (VSMOW) (Peneycad et al., 2019). To provide an additional $\delta^{18}\text{O}$ baseline for the site, modern annual precipitation $\delta^{18}\text{O}$ was predicted from the Online Isotopes in Precipitation Calculator (OIPC) (Bowen, 2019; Bowen and Revenaugh, 2003; IAEA/WMO, 2015). To understand the trends in precipitation $\delta^{18}\text{O}_{\text{Water}}$ across Europe, a subset of the global dataset of gridded maps of the isotopic composition of meteoric waters (Bowen and Revenaugh, 2003; Bowen, 2015) was used to determine the range (Fig. 5). The data were processed in ESRI ArcGIS™ and statistical analysis was carried out using R (R Core Team, 2018).

To examine diet from $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, a comparison to potential food sources from the region is required. As no plant remains, and only rodent remains were uncovered at Le Tumulus des Sables, comparisons

Table 1

Details of ¹⁴C dating samples. The bone and charcoal dates are summarised in the excavation reports (Courtaud et al., 2009, 2010). For reliable stable isotope and radiocarbon analysis, % collagen yield should be > 1%, C:N ratio between 2.9 and 3.4 and %C > 30% (Van Klinken, 1999).

Sample name	Lab code	Sample material	±	Collagen yield [%]	C:N	%C	¹⁴ C age [BP]	±	¹⁴ C age [cal BCE, 95.4%range]	
A01 - SLMEM263	SANU 39010	Dentine	1	2.8	3.2	46.7	3570	25	2017	1784
A02 - SLMEM900	SANU 38939	Dentine	1	9.1	3.2	46.2	3950	25	2566	2347
A03 - SLMEM454	SANU 38938	Dentine	1	7.6	3.2	46.0	2980	25	1277	1121
A04 - SLMEM466	SANU 39009	Dentine	1	6.9	3.2	45.0	4800	30	3650	3522
A06 - SLMEM282	SANU 39005	Dentine	1	5.9	3.2	46.0	4030	25	2620	2475
A08 - SLMEM432	SANU 39006	Dentine	1	9.3	3.2	45.3	4045	25	2831	2480
A12 - SLMEM1007	SANU 39007	Dentine	1	5.9	3.2	45.5	3850	25	2458	2207
J02 - SLMEM66	SANU 38901	Dentine	1	6.0	3.2	46.3	3815	25	2345	2146
Bone SLMEM07	Poz 23194	Bone					3915	35	2487	2291
Bone St. Laurent 02/07-1	Erl 10575	Bone					4755	35	3648	3374
Charcoal Lyon-6217	SacA 16631	Charcoal					3040	30	1397	1216
Charcoal Lyon-6216	SacA 16630	Charcoal					7160	40	6092	5927

were made to the values from the Late Neolithic site of Champ-Durand (3300–3100 cal. BCE), about 140 km north of this site (Schulting and Hamilton, 2012), along with other reported values for Neolithic human diets in France (Pollard, 1993; Schoeninger et al., 1983; Goude and Fontugne, 2016).

4. Results and discussion

4.1. Chronology of the site

The new radiocarbon results from the eight teeth, in combination with the two human bone and two charcoal dates from previous studies,

illustrate the complex chronology of Le Tumulus des Sables (Table 1, Fig. 3). The charcoal dates from the top and bottom of the burial are 1395–1215 cal. BCE and 6090–5925 cal. BCE, respectively, bracketing the teeth and bone ages from the site. It is likely, however, that the charcoal dates are not directly related to the funerary use of the site, as charcoal is readily redistributed when sediments are disturbed.

The dates of one bone and six of the teeth fall within the range of the Bell Beaker period in France: 2500–1800 BCE (Champion et al., 2009; Lemerrier, 2012). One tooth (A4-SLMEM466) and the juvenile vertebra are significantly older, 3650–3520 cal. BCE and 3650–3375 cal. BCE, respectively. One tooth (A3-SLMEM454) is much younger, 1275–1120 cal. BC, close to the age of the charcoal sample from the top

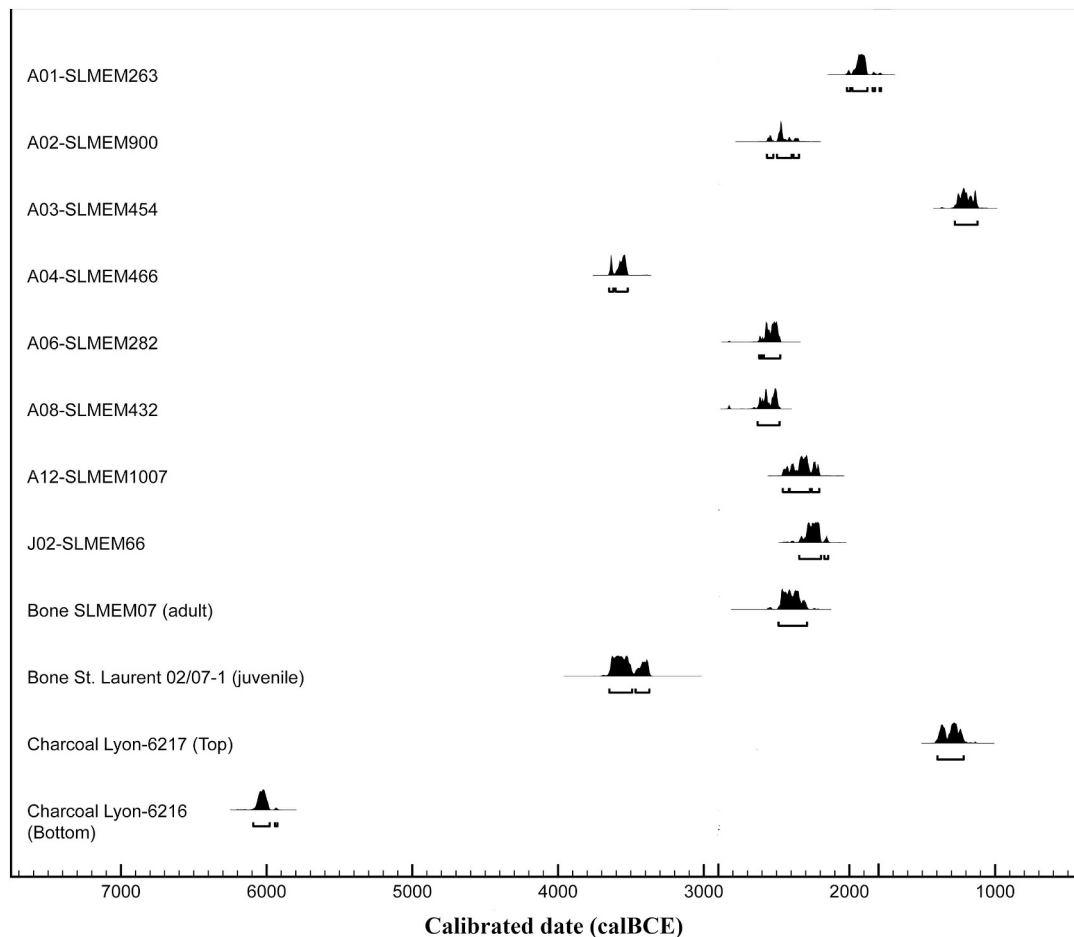


Fig. 3. Radiocarbon results from the eight teeth analysed in this study, as well as the two bone and two charcoal dates previously obtained from this site (Courtaud et al., 2010).

Table 2Bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ at Le Tumulus des Sables determined by soil leachates and faunal samples (*Microtus*. sp. teeth).

Grid reference	Location	Soil $^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\text{se}$	Faunal $^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\text{se}$
H43	Within the burial	0.70893	0.00001	0.70827	0.00003
I43	Within the burial	0.70973	0.00002	0.70909	0.00002
H42	Within the burial	0.70963	0.00002		
H45	Within the burial	0.70910	0.00004		
J44	Within the burial	0.70883	0.00002	0.70808	0.00005
G40	Within the burial	0.70879	0.00002	0.70906	0.00017
G44	Within the burial	0.70876	0.00002	0.70904	0.00015
E30	Outside the burial	0.70949	0.00004	0.71016	0.00006
E34	Outside the burial	0.70920	0.00002	0.70906	0.00009
H36	Outside the burial	0.70991	0.00002	0.70961	0.00003
H38	Outside the burial	0.70887	0.00001	0.70827	0.00008
$^{87}\text{Sr}/^{86}\text{Sr}$ range in the burial		0.7088–0.7097		0.7081–0.7091	
$^{87}\text{Sr}/^{86}\text{Sr}$ range adjacent to the burial		0.7089–0.7099		0.7083–0.7102	
Local $^{87}\text{Sr}/^{86}\text{Sr}$ range combined		0.7081–0.7102			

of the burial. These dates show that Le Tumulus des Sables is a highly complex site that was used across multiple time periods. The chamber formerly on the mound was probably constructed for collective burial rites during the Middle Neolithic (4th millennium BCE); and the site was later reused for further funerary activities during the Bell Beaker Period (late 3rd millennium BCE) and Final Bronze Age (last quarter of the 2nd millennium BCE). The discovery of many broken and dislocated bones outside the burial chamber, close to its entrance (Fig. 2), suggests either a partial emptying of the burial before its use by the Bell Beaker people, disturbance of the whole site at a later date, or complex rites which included the deposition of remains both within and outside the chamber.

The large number of artefacts associated with the BBP found at the site, and the fact that six of the eight individuals randomly selected for the present study are from the BBP period, suggests that most of the individuals at this site were buried there during the middle and later 3rd millennium BCE, probably in connection with Bell Beaker funerary rites.

4.2. Diet

The eight analysed individuals had $\delta^{13}\text{C}$ values between -19.6 and -20.6‰ and $\delta^{15}\text{N}$ values between 9.4 and 11.4‰ (Table 3). The dietary range data (roe deer, ovicaprid, and pig remains) from the comparison site, Champ-Durand, are between -21.3 and -20.1‰ for $\delta^{13}\text{C}$ and between 4 and 6.4‰ for $\delta^{15}\text{N}$. Human remains ($n = 13$) from Champ-Durand range between -20.9 and -19.3‰ for $\delta^{13}\text{C}$ and between 8.3 and 11.2‰ for $\delta^{15}\text{N}$, and are interpreted as representing a terrestrial diet (Schulting and Hamilton, 2012). These narrow ranges of values at the site and their similarities to other European Neolithic sites including Champ Durand, suggests that despite the very different ages of the individuals all consumed a predominantly terrestrial diet (Fig. 4). It appears that over the 2.4 ka period of use at Le Tumulus des Sables the diet of the individuals buried here included little sea food, despite the close proximity of the Gironde Estuary and the Atlantic Ocean. This predominantly terrestrial diet has also been observed at Bell Beaker sites in the United Kingdom (Parker Pearson, 2016), and suggests that mobility of the individuals buried at the site may have been on a regional scale, or from inland regions.

Table 3Summary of isotopic data for the individuals from Le Tumulus des Sables. $\delta^{18}\text{O}$ values relative to VSMOW.

Sample ID	Tooth type	$^{87}\text{Sr}/^{86}\text{Sr}$		$\delta^{18}\text{O}_{\text{carbonate}}$		$\delta^{18}\text{O}_{\text{water}}$ (‰)	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	Local?	
		Enamel	$\pm 2\text{se}$	Dentine	$\pm 2\text{se}$					Enamel (‰)
A01 - SLMEM263	Permanent	0.71051	2	0.70967	3	28.95	-2.6	-20.2	10.5	Yes
A02 - SLMEM900	Permanent	0.70988	18	0.70995	4	28.13	-3.9	-19.8	11.4	Yes
A03 - SLMEM454	Permanent	0.71039	3	0.70994	7	28.20	-3.8	-20.2	10.5	Yes
A04 - SLMEM466	Permanent	0.70951	3	0.71058	4			-19.6	10.5	Yes
A05 - SLMEM308	Permanent	0.70939	1	0.70918	2	28.50	-3.3			Yes
A06 - SLMEM282	Permanent	0.71141	1	0.71014	3			-19.7	10.8	
A07 - SLMEM1157	Permanent	0.71000	2	0.70960	4	28.74	-2.9			Yes
A08 - SLMEM432	Permanent	0.70938	8	0.70936	3	28.88	-2.7	-19.6	9.4	Yes
A09 - SLMEM112	Permanent	0.71169	1	0.71003	2					
A10 - SLMEM813	Permanent	0.71046	4			28.58	-3.2			Yes
A11 - SLMEM861	Permanent	0.70989	4	0.70988	2					Yes
A12 - SLMEM1007	Permanent	0.71331	7	0.71187	26	28.74	-2.9	-20.3	9.7	
A13 - SLMEM1094	Permanent	0.71069	9	0.70922	1	27.88	-4.3			Yes
A14 - SLMEM1289	Permanent	0.70963	4	0.71023	2	28.95	-2.6			Yes
A15 - SLMEM491	Permanent	0.70951	3	0.70953	7	28.46	-3.4			Yes
A16 - SLMEM298	Permanent	0.70962	3	0.70972	16	28.77	-2.9			Yes
A17 - SLMEM509	Permanent	0.70950	2	0.70934	3	27.60	-4.7			Yes
A18 - SLMEM5	Permanent	0.71028	18	0.70958	3	26.03	-7.2			No
J02 - SLMEM66	Deciduous	0.71027	11	0.71005	43			-20.6	9.9	Yes
J03 - SLMEM1251	Deciduous	0.70962	2	0.70904	16	29.40	-1.9			Yes
J04 - SLMEM119	Deciduous	0.71019	4	0.70986	6					Yes
J05 - SLMEM102	Deciduous	0.71024	1	0.71014	4					Yes
J06 - SLMEM1192	Deciduous	0.71113	14	0.70929	13					
J07 - SLMEM86	Deciduous	0.71001	13	0.70999	4					Yes
J08 - SLMEM276	Deciduous	0.71106	25	0.71030	18					

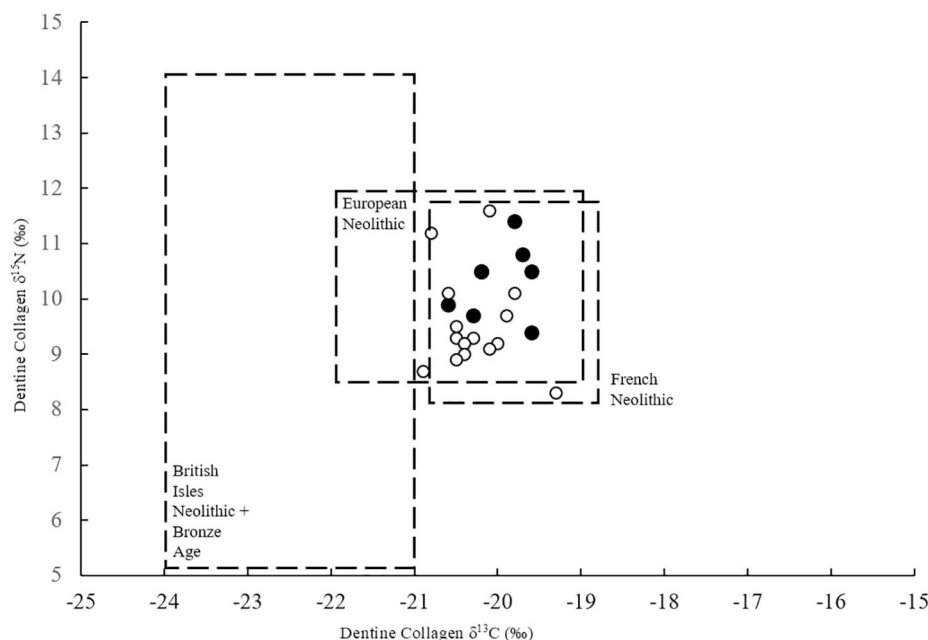


Fig. 4. Carbon and nitrogen isotope results for eight individuals in this study (filled circles) compared with approximate dietary groups from previous studies. Carbon and nitrogen isotope results for 13 individuals from the site of Champ Durand represented by open circles (Schulting and Hamilton, 2012). Dashed boxes represent dietary ranges for the British Isles and European Neolithic (from Pollard, 1993; Schoeninger et al., 1983), and the French Neolithic (13 sites from Goude and Fontugne, 2016 and references therein).

4.3. Human mobility

4.3.1. $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ baseline data

Le Tumulus des Sables is situated within the Aquitaine Basin on the Médoc peninsula, a flat, low lying region between the Atlantic coast and the Gironde Estuary, dominated by unconsolidated Quaternary and Neogene sediments. The site lies within Pliocene sand, clay and gravel, with a band of Holocene sands, clays, pebbles and gravel along the shorelines to the north and east. The range of $^{87}\text{Sr}/^{86}\text{Sr}$ in bioavailable Sr at Le Tumulus des Sables is 0.7081–0.7102, as determined from soil leachates (0.7088–0.7099) and faunal samples (0.7081–0.7102). This range is large for a single site and probably reflects the variety of sand- and clay-rich sediments within the site and the mixing caused by reuse of the site. The local range in the $^{87}\text{Sr}/^{86}\text{Sr}$ of bioavailable Sr at Le Tumulus des Sables is distinct from the isotopic compositions of volcanic, igneous and metamorphic rocks in the mountain ranges of the Massif Central and Pyrenees but overlaps with those of carbonaceous and clastic sedimentary units of the Aquitaine Basin (Willmes et al., 2014, 2018).

Faunal samples (*Arvicolinae* tooth enamel) recovered from inside the burial mound at Le Tumulus des Sables show similar $\delta^{18}\text{O}_{\text{Carbonate}}$ values (29.19 and 29.25‰, average 29.22‰), leading to an average converted $\delta^{18}\text{O}_{\text{Water}} = -2.21 \pm 0.58\text{‰}$. The site of Le Tumulus des Sables (45.152206 N, -0.821772E , elevation 10 m) has a predicted modern annual $\delta^{18}\text{O}_{\text{Water}} = -5.9 \pm 0.2\text{‰}$ (Bowen, 2019; Bowen and Revenaugh, 2003; IAEA/WMO, 2015). These values suggest a large local $\delta^{18}\text{O}_{\text{Water}}$ range, and a conservative approach to identifying non-locals from this data will be used. The annual average $\delta^{18}\text{O}_{\text{Water}}$ of precipitation exhibits a distinct geographic profile across Western Europe and Northern Africa (Fig. 5). The $\delta^{18}\text{O}_{\text{Water}}$ is highest in Africa, closest to the equator, becoming progressively lower with increasing latitude northwards into Spain and southwest France. In addition, there is a superimposed trend to more negative $\delta^{18}\text{O}_{\text{Water}}$ across Europe from southwest to northeast, and lower $\delta^{18}\text{O}_{\text{Water}}$ values are also found in areas of higher elevation, such as the Pyrenees and the Alps. The seasonal change in $\delta^{18}\text{O}$ of modern rainwater samples for the same location in France is $\sim 3\text{‰}$ (IAEA GNIP database), which potentially introduces variation within a static population. How $\delta^{18}\text{O}_{\text{Water}}$ has changed through time is not well understood, but both the magnitude and geographic distribution of $\delta^{18}\text{O}_{\text{Water}}$ may have been significantly different ~ 4 ka ago.

4.3.2. $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ in the human remains

The $^{87}\text{Sr}/^{86}\text{Sr}$ of enamel and dentine from the 25 individuals ranges between 0.70904–0.71331 and 0.70904–0.71187, respectively (Table 3). Nine individuals have significant differences in $^{87}\text{Sr}/^{86}\text{Sr}$ (> 0.00050) between dentine and enamel, with the ratio always lower in dentine (Fig. 6). Enamel and primary dentine reflect the same time in an individual's life, and consequently should have similar $^{87}\text{Sr}/^{86}\text{Sr}$, but dentine is more susceptible to diagenetic alteration that can shift its isotopic composition towards the local range. An additional influence is that in response to dental trauma, secondary and tertiary dentine is laid down which may shift the isotopic composition of the bulk dentine measurement towards signature from later in life (Kuttler, 1959; Hillson, 1986). These inconsistencies between dentine and enamel compositions show that, at this site, dentine has not preserved its original $^{87}\text{Sr}/^{86}\text{Sr}$, leaving enamel $^{87}\text{Sr}/^{86}\text{Sr}$ as the more reliable tracer of mobility.

Enamel $\delta^{18}\text{O}_{\text{Carbonate}}$ values from the 15 analysed individuals range from 26.03 to 29.40‰ (a range of 3.37‰), $\delta^{18}\text{O}_{\text{Water}}$ ranges from -1.9 to -7.2‰ (Table 3). Most individuals ($n = 14$) are in the range 27.60 to 29.40‰ ($\delta^{18}\text{O}_{\text{Water}} = -1.9$ to -4.7‰), and fall within 1.5 IQR for the population (Fig. 7). This large group partially overlaps with the faunal $\delta^{18}\text{O}$ baseline for the site ($\delta^{18}\text{O}_{\text{Water}} = -2.21 \pm 0.58\text{‰}$), and the remainder of the individuals show values moving towards the modern annual precipitation value ($\delta^{18}\text{O}_{\text{Water}} = -5.9 \pm 0.2\text{‰}$). One individual (adult A18 – SLMEM5) has a lower $\delta^{18}\text{O}_{\text{Carbonate}}$ value (26.03‰), and its converted $\delta^{18}\text{O}_{\text{Water}}$ of -7.2‰ places it outside the conservative local range for the site. The IQR identifies them as an outlier from the site's population (Fig. 7). The juvenile individual (J3 – SLMEM1251), represented by a deciduous tooth, has the highest $\delta^{18}\text{O}_{\text{Carbonate}}$ (29.40‰). Deciduous teeth commonly are influenced by breastfeeding, leading to them having a higher average $\delta^{18}\text{O}_{\text{Carbonate}}$ than permanent dentition (Wright and Schwarcz, 1998; Wright, 2013). The population variation of 3.37‰ is in line with the range of $\delta^{18}\text{O}$ variation seen in other European archaeological sites (Lightfoot and O'Connell, 2016).

4.3.3. Human mobility

K-means cluster analysis applied to the Sr and O isotopic compositions of tooth enamel from the 15 individuals identifies one large group and two distinct individuals (Fig. 8). Interpretation of movement patterns for these groups is hindered by the wide range of isotopic

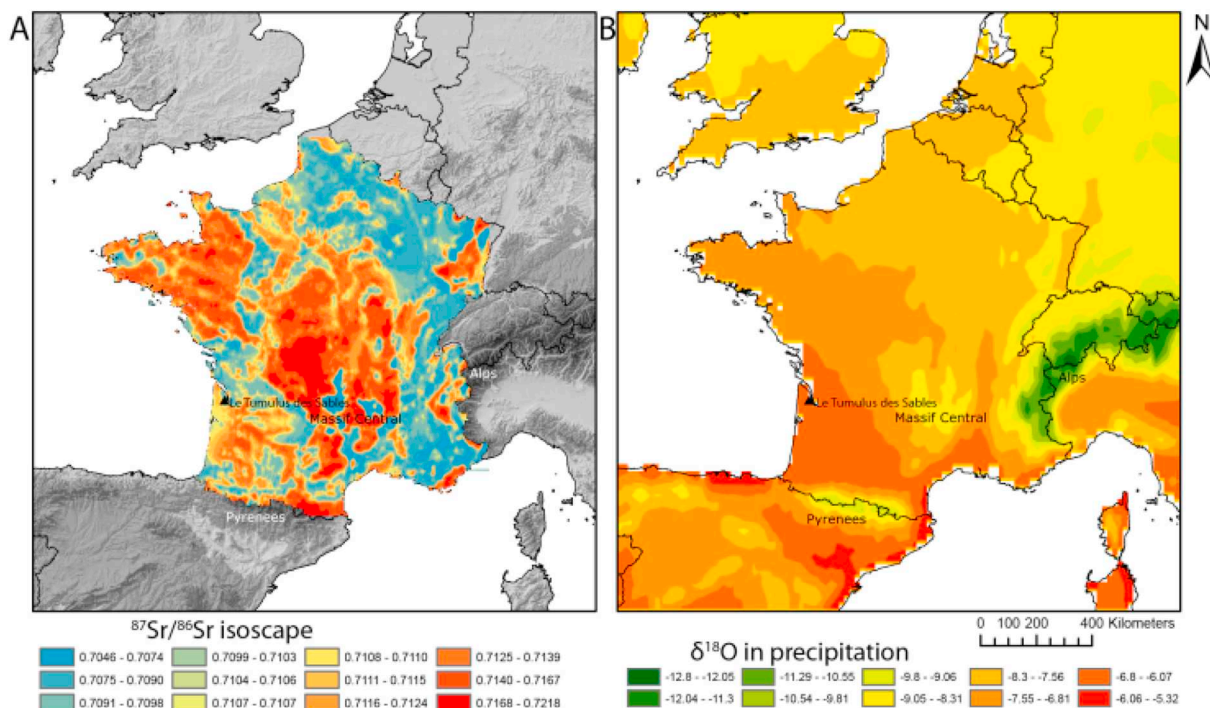


Fig. 5. A: Bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ isoscape for France (Willmes et al., 2018) B: Average annual $\delta^{18}\text{O}_{\text{water}}$ of precipitation in western Europe. Data from waterisotopes.org (Bowen and Revenaugh, 2003; Bowen, 2015).

compositions in the bioavailable Sr within the burial site and the immediately surrounding Aquitaine Basin related to the complex mosaic of unconsolidated Quaternary sediments in the Gironde Estuary. In combination, however, the isotopic data nevertheless indicate possible childhood residence areas of these individuals.

Individuals in the large group ($n = 13$) have isotopic compositions ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.70938–0.71069, $\delta^{18}\text{O}$: 27.60–29.40‰) consistent with the range of Sr isotope values at the burial site. One individual (A12) has a

$\delta^{18}\text{O}_{\text{carbonate}}$ that overlaps with the large group (28.74‰), but more radiogenic Sr isotope ratio ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.71331). Large areas of the Aquitaine Basin have $^{87}\text{Sr}/^{86}\text{Sr}$ consistent with this distinct individual, the closest being ~50 km south of the burial site. Hence the large group contains individuals who probably spent their childhood in the area of Le Tumulus des Sables or immediately north of the site, while individual A12 might have spent their childhood elsewhere in the Aquitaine Basin (< 50 km away from Le Tumulus des Sables). The

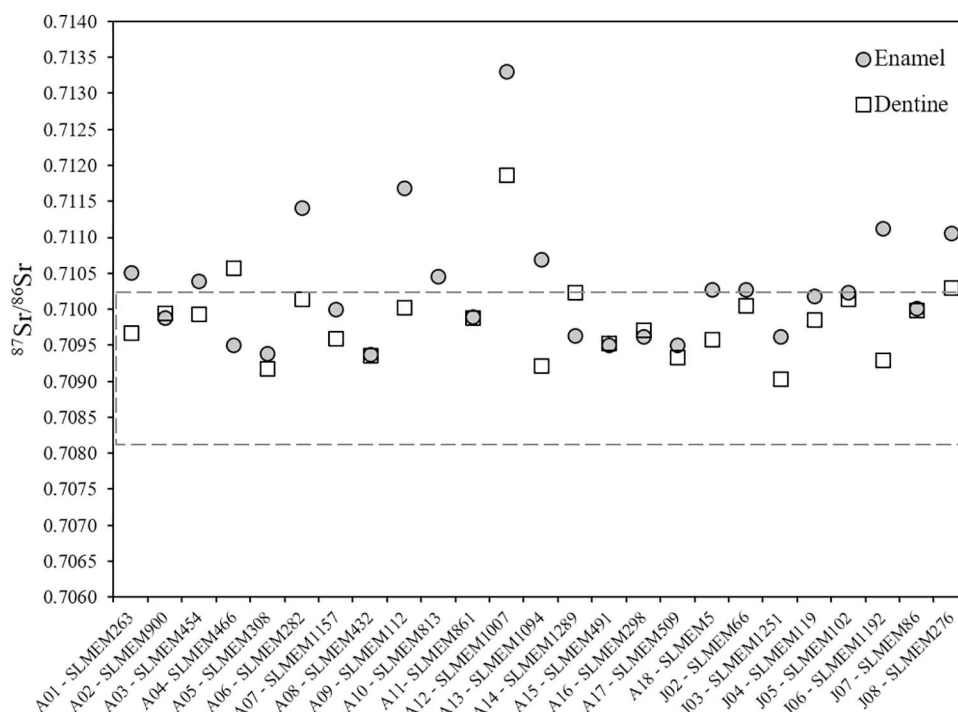


Fig. 6. $^{87}\text{Sr}/^{86}\text{Sr}$ in human tooth enamel and dentine. Samples beginning with A are permanent teeth, and J are deciduous teeth.

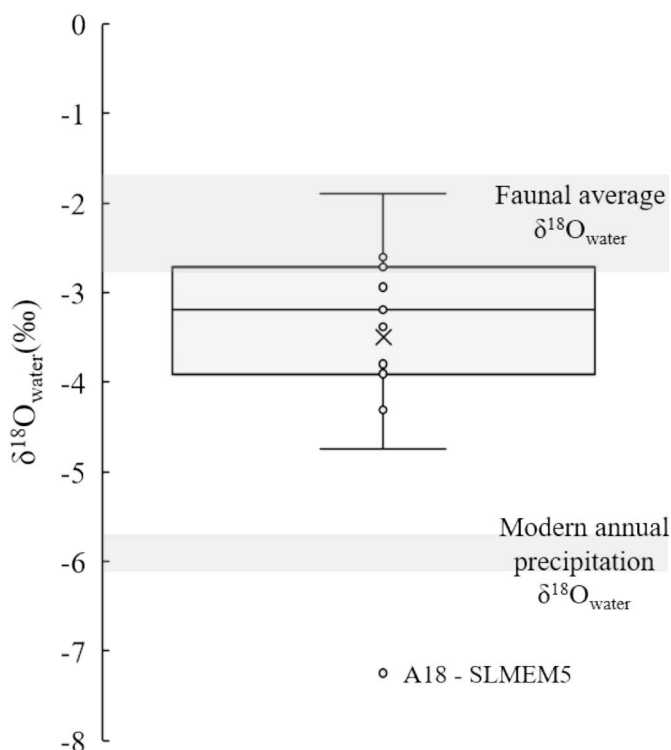


Fig. 7. Box and whisker plot of the $\delta^{18}\text{O}_{\text{carbonate}}$ in human tooth enamel. The upper and lower quartile are represented by the top and bottom of the box, the median in the black line through the box, and the interquartile range (IQR) is calculated by subtracting the upper quartile from the lower. The whiskers are 1.5IQR from the upper or lower quartile.

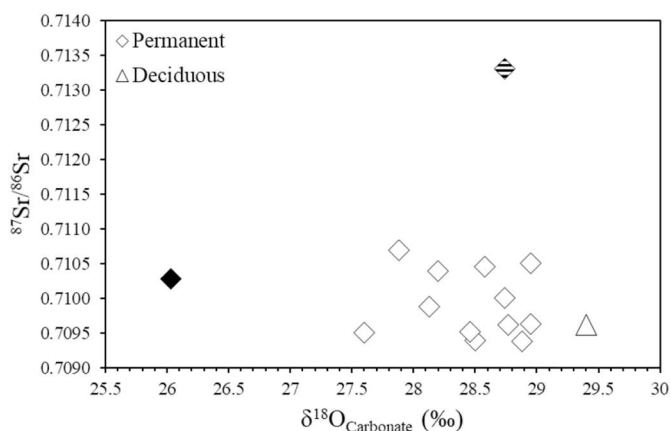


Fig. 8. Strontium and oxygen isotope values of tooth enamel from the individuals buried at Le Tumulus des Sables. Individuals in the large group = unfilled symbols, Individual A18 = filled symbol, Individual A12 = striped symbol. Diamonds represent permanent teeth, while the triangle represents a deciduous tooth. Groups determined by K-means cluster analysis using R (R Core Team, 2018).

second distinct individual (A18) has a Sr composition ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.71028) that overlaps those of the individuals in the large group, but a distinctly lower and outlying $\delta^{18}\text{O}_{\text{Carbonate}}$ (26.03‰). This $\delta^{18}\text{O}_{\text{water}}$ is well below the range for the Aquitaine Basin (Fig. 5) and is $\sim 3\text{‰}$ lower than the site faunal value, implying a childhood spent in a region with a colder climate or further inland, potentially the high-altitude areas such as the Pyrenees, the Alps, or the Massif Central, further inland to Germany or north to Britain (Fig. 5) (Bentley and Knipper, 2005; Pellegrini et al., 2016). $^{87}\text{Sr}/^{86}\text{Sr}$ values of the Massif Central do not match this individual (A18) (Fig. 5), $^{87}\text{Sr}/^{86}\text{Sr}$ values along the south western coast

of Britain match the enamel measurement of this individual (Evans et al., 2010), but limited $^{87}\text{Sr}/^{86}\text{Sr}$ data for Germany, the Pyrenees, and the Alps hinders a more thorough investigation of the childhood residence area.

No systematic differences were found between the isotopic compositions of adults and juveniles. Individuals in the large group can be considered locals to Le Tumulus des Sables and individual (A12) came from close by, so over 90% of the individuals (sampled for both O and Sr) buried at the site spent their childhood locally. The remaining individual (A18) can be classified as a non-local.

The rest of the individuals analysed for $^{87}\text{Sr}/^{86}\text{Sr}$ but not $\delta^{18}\text{O}$ ($n = 10$) have compositions either consistent with the individuals in the large group ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.70951–0.71027, $n = 6$) or slightly more radiogenic ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.71106–0.71169, $n = 4$), consistent with individual A12. This suggests that these individuals are locals to the site or the wider Aquitaine Basin. The lack of $\delta^{18}\text{O}_{\text{Carbonate}}$ data for these individuals, and any Sr or O isotopic data for the remainder of the teeth from Le Tumulus des Sables, hampers a more complete understanding of the geographic origins of the people buried at the site.

Eight of the teeth collected were of sufficient size and quality for ^{14}C dating (Fig. 3), with six of those falling within the Bell Beaker period. Assuming that most of the individuals buried at Le Tumulus des Sables are from the BBP, the mobility detected at the site is much lower than the $\sim 62\%$ of mobile individuals detected by Price et al. (2004) from Sr isotope analysis of Bell Beaker sites in Germany, Austria, the Czech Republic and Hungary. Our results are in agreement with the local mobility patterns seen in BBP sites in Britain (Parker Pearson et al., 2016). Considering the large range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}_{\text{Water}}$ around Le Tumulus des Sables and the lack of data on how the local $\delta^{18}\text{O}_{\text{water}}$ values have changed during and after the occupation period, it is possible that the percentage of migrants has been underestimated, or that some of the undated burials at this site do not relate to the BBP.

5. Conclusions

The results of this study of the chronology, diet, and mobility of individuals from the collective burial Le Tumulus des Sables lead to the following conclusions:

- (1) The site was used for burials over a much longer period than previously thought. Initially classified as an early Bell Beaker site, the radiocarbon chronology and artefacts associated with the burials instead document its use over a period of ~ 2.5 ka. Given the tendency for BBP funerary activities to be emplaced within collective tombs of preceding cultures and considering the relatively large quantity of Bell Baker material exhumed (especially ceramic finds), it is likely that most of the human remains found at this site represent the deceased of the BBP.
- (2) The remains of eight individuals analysed to determine diet had a narrow range of isotopic compositions ($\delta^{13}\text{C} = -19.6$ to -20.6‰ , $\delta^{15}\text{N} = 9.4$ to 11.4‰). This suggests, in combination with the radiocarbon dates, that the diet of the inhabitants remained terrestrial throughout the lifetime of the site, despite its close proximity to the Gironde Estuary and the Atlantic Ocean, and suggests limited regional mobility. A similar result has been found at other Neolithic sites in France and BBP sites in the United Kingdom.
- (3) The geographic differences in bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ and precipitation $\delta^{18}\text{O}_{\text{Water}}$ within southern France make it possible to infer the regions in which the individuals spent their childhood, although the large range of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}_{\text{Water}}$ near Le Tumulus des Sables and in the surrounding Aquitaine Basin makes it difficult to distinguish locals from short-distance migrants. Far-travelled migrants can be readily identified, especially when data from the independent Sr and O isotopic systems are used in combination.

(4) Human mobility data from Le Tumulus des Sables shows limited mobility of the individuals buried there, instead suggesting that the majority of individuals came from the local region, with only one individual identified as a non-local.

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