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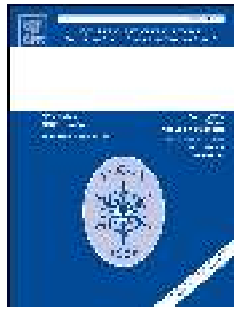

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Combining dental calculus with isotope analysis in the Alps: New evidence from the Roman and medieval cemeteries of Lamon, northern Italy

Elena Fiorin[a,*], Joanna Moore[b], Janet Montgomery[b], Marta Mariotti Lippi[c], Geoff Nowell[d], Paolo Forlin[b,e,*]

[a]DANTE - Diet and ANcient TEchnology Laboratory, Department of Odontostomatological and Maxillofacial Sciences, Sapienza University of Rome, Via Caserta 6, 00161 Rome, Italy
[b]Department of Archaeology, Durham University, South Road, DH1 3LE Durham, United Kingdom
[c]Department of Biology, University of Florence, Via La Pira 4, 50121 Florence, Italy
[d]Arthur Holmes Laboratory, Earth Sciences, Durham University DH1 3LE Durham, United Kingdom
[e]Alma Mater Studiorum - University of Bologna, DISCI, Dipartimento di Storia Culture Civiltà, Piazza S. Giovanni in Monte, 2, 40124, Bologna, Italy

* Corresponding authors.
E-mail addresses: elena.fiorin@uniroma1.it (E. Fiorin), paolo.forlin@unibo.it (P. Forlin).

Abstract

This study presents the results of complementary isotopic and dental calculus analyses of a number of individuals buried in two cemeteries of Roman and medieval chronology in Lamon, northern Italy. Eleven individuals from the Roman cemetery of San Donato and six from the medieval cemetery of San Pietro are presented and discussed. The results suggest a distinctive stability of the two populations, with most of the analysed individuals showing a local or regional origin. Carbon and nitrogen isotopes are indicative of a diet based on a mixed C_3/C_4 plant consumption and rich in animal proteins, with no significant difference between the Roman and the medieval populations. The consumption of C_4 plants, more resilient to the Alpine climate, is consistently documented both by isotopes and dental calculus. Dental calculus results permit the characterisation of the typology of the crop consumed, namely millet, barley/wheat and legumes and may also suggest differing cooking processes between the Roman and the medieval periods. Phytoliths, vascular elements, fungal spores and animal remains from dental calculus provide new insights into the diet of the analysed individuals but also, hypothetically, into possible medicinal treatments. The presence of

birds such as fowls and ducks in the medieval diet of some individuals from San Pietro has also emerged. Overall, the results of this study open a new window into the biographies of the individuals analysed, their diet, mobility, habits, and environment, thus stimulating further and more systematic investigation on the populations occupying an Alpine sector which is still poorly understood from an archaeological perspective.

Keywords: Dental calculus; Isotopes; Roman period; Middle Ages; Alps

1. Introduction

This study illustrates the results of a combined isotopic and dental calculus analysis of two populations from the municipality of Lamon in northern Italy. Excavations undertaken in this area from the 2000s onward have targeted a Roman necropolis located near the hamlet of San Donato di Lamon and the medieval parish church of San Pietro Apostolo. Despite the significance of these cemeterial sites, representing two of the largest funerary sites for the Italian eastern Alps, no in-depth analysis of the skeletal remains has been conducted. Questions around the mobility, diet, environment and health of such communities living in this Alpine area during the Roman and medieval periods remain unanswered. This paper presents the outcome of an integrated isotopic and dental calculus analysis conducted on a sample of the aforementioned populations, namely eleven individuals from the Roman necropolis of San Donato and six individuals from the medieval cemetery of the San Pietro parish church. Novel data is presented and discussed, showing how the application of combined isotopic and dental calculus methodologies is beneficial for the understanding of past mobility, diet, habits, health, as well as possible medicinal treatments. Information about dental calculus and principles of isotope analysis are included in Annex A.

1.1 The geographical setting and the sites under analysis

The municipality of Lamon (46° 2'50.55" N; 11°44'54.75" E; 610 m above sea level) lies along the southern flank of the Dolomites in northern Veneto (Figure 1). Its territory is delimited towards the north by Mount Coppolo (2069 m above sea level), a mountain relief of grey limestone; the narrow gorges of the streams Senaiga and Cismon, a tributary of the Brenta river, border the many sub-horizontal terraces and hillslopes characterising the Lamon plateau towards the south-west and east

(Tessari 1973). Prehistoric frequentation of this Alpine sector is attested at Riparo Villabruna, a rock shelter located along the Cismon gorge occupied during the late Upper Palaeolithic (Aimar et al., 1992), as well as on the terraces of Lamon, which produced abundant surface finds suggesting a widespread presence of permanent settlements during the Neolithic and Copper Age (Curto, 2017-18). Since ancient times, the area of Lamon belonged to a region which played a peculiar role connecting two of the most strategic valleys of the eastern Italian Alps: the Piave valley in the east and the Adige valley in the west. In the Roman period this role was marked by the presence of an E-W route connecting the Veneto plain to the Adige basin through Feltre (corresponding with the Roman town of *Feltria*), the Lamon and Tesino plateaus and eventually the upper Brenta valley. Such a route may be identified with the Roman road *Opitergium-Tridentum* attested by the 3rd century *Itinerarium Antonini* and running from Oderzo (Opitergium) in southern Veneto to Trento *(Tridentum)* in the Adige basin (Cavada, 2002; Ciurletti and Pisu, 2006; Pesavento Mattioli, 2003). From an administrative perspective, during the Roman period and the Middle Ages Lamon is framed within the territory of the *municipium* and then bishopric of Feltre. The bishop of this town formally recognised the village of Lamon as an autonomous community in AD 1177 (Conte, 1983; Forlin et al., 2020). Up to the 16th century AD, there is very little documentary evidence for such a geographical context, but recent archaeological investigations enabled a new window to be opened on the communities who settled in this area during the Roman and the medieval periods. In particular, this information is provided by two cemeteries excavated respectively at the place *Piasentot* of San Donato, a hamlet located over the Senaiga stream about 5 km NW of Lamon, and at the parish church of San Pietro installed on a hill located immediately to the south of the village.

1.2 The Roman necropolis of San Donato - Piasentot

The Roman cemetery at the locality of *Piasentot* (46° 3'38.38" N; 11°42'7.53" E; 760 m above sea level) was identified at the southern margin of a steep slope occupied by the settlement of San Donato in 2000, in a field where Roman burials have previously been discovered (*Carta Archeologica,* 1988, 82)(Figure 2A). The site is located not far from a historic path known locally as the *Via Pagana*, meaning the road of the *pagus* (this Latin term designating a rural settlement and its territory), very likely representing the local tract of the aforementioned Roman road *Opitergium-Tridentum*. The Roman cemetery of San Donato consists of around 120 inhumations dating between the 1st and 4th centuries AD (D'Incà and Rigoni, 2016; Casagrande, 2006) (Figure 2B). The individuals were buried in very small simple earthen pits, no wider than 1 - 1.5 meter in diameter. The limited dimensions of the burial pits reflect the anomalous position adopted by most of the bodies, which were positioned crouched or seated with their backs vertical against the pit edge and legs flexed, bent or sometimes straight (Figure 2C). Only a few burials, usually dating to a later chronology and occupying the northernmost portion of the cemetery, were deposed with a supine position. A gender-based differentiation in the grave goods' composition was observed. Male burials were usually furnished with knives, circular belt elements, and belt buckles; female burials typically produced brooches, characteristic B-shaped earrings and necklaces beads made of glass sometimes coated with golden foil. On the other hand, coins, brooches and rings were indistinctively found both in male and female burials (for an overview on the numismatic finds, see Callegher, 2020). Apart from a small number of new-born infants, only adult individuals were interred here (*unpublished report*) or at least in the sector of the cemetery investigated so far. Moreover, the remains of a young cow radiocarbon dated to the early Roman imperial era was identified at the very centre of the cemetery (Reggiani and Rizzi Zorzi, 2010). The animal was laid down with legs bent and the head carefully placed over a large pillow-stone, suggesting this was a ritual burial possibly associated to the 'sacralisation' of the funerary site.

1.3 The medieval cemetery of San Pietro

The second population considered comes from the excavation of the parish church of Lamon (46° 2'39.48" N; 11°44'48.88"E; 651 m above sea level). The church of San Pietro is located on the top area of a hill immediately to the south of the settlement and conforms to a 16th century building (Figure 3A). The southern slope of the relief was devoted to funerary use since ancient times, as testified by the discovery, during the 19th and early 20th centuries, of several inhumations producing Roman items and coins (Conte, 2003; *Carta Archeologica,* 1988, 82).

The archaeological investigation of the site identified early occupation of the hilltop area dating to the late Iron Age as well as the evidence for a possible fortification from the late Roman or early medieval period (Forlin, et al. 2020). Although the church is attested by archival records only since the 14th century AD, the presence of an earlier church has been indirectly supported by the recovery, at the very centre of the actual building, of two burials radiocarbon dated to late 7th – 9th centuries AD (SPT_47: AD 690-886; SPT_48: AD 661-777, both at 95.4% probability). These two burials produced the bodies of a female and a male individual (respectively SPT_47 and SPT_48) laid upon two parallel graves cut into the bedrock, partially lined with plaster and, in the case of the male burial, provided with a small structure functioning as a pillow stone (Figure 3B). The two burials were respectively accompanied by a temple ring of the so-called Köttlach culture, an archaeological culture originating in the eastern Alps between Italy, Austria, and Slovenia during the late Carolingian period (Possenti, *forthcoming*) and a fragmented bone comb. Based on the chronology of the inhumations and their location in relation with the earliest religious building, it is possible they represent the founders or patrons of the church. From the early medieval phase onward, the church attracted several burials in both the internal and external areas. Within the interior, the excavated areas intercepted the medieval burial of a subadult, found in front of the gothic door connecting the church and the bell tower, and a group of graves located underneath the early modern presbytery. Originally located outside the church, they were later surmounted by the 16th century building. One of these burials (SPT_49) produced a radiocarbon age dating to the 15th– early 16th centuries AD, thus representing one the latest inhumations deposed here before the enlargement of the church in the 16th century (AD 1416-1524 at 74.9% probability). In fact, the construction of the post medieval church resulted in the lowering of the medieval levels which erased much of the structural remains of the older church. In the external area, a group of late medieval burials radiocarbon dated to the 13th-14th centuries was excavated in the graveyard to the north of the church (burial SPT_25 has a radiocarbon date of AD 1220-1400 at 95.4% probability) (Figure 3C). Such burials were laid down without burial goods in earthen pits E-W oriented. In the early modern period (18th-19th centuries), this northern graveyard was surmounted by burials of adult individuals showing a different N-S direction compared to the earliest E-W orientation (see the right section on Figure 3C). These later burials testify the wide adoption of grave goods in the form of rosaries, medals, rings and coins. During the same phase, the external spaces located around the apse were exclusively reserved to the inhumation of infants or subadults, all deposited again with no grave goods. Overall, 60 burials were dug at this site.

2. Material and Methods

For this pilot study, isotopic analysis targeted seventeen individuals, six from the medieval skeletal collection of San Pietro (SPT_18, 20, 46, 47, 48, 49) and eleven from the Roman necropolis of San Donato (SDN_18, 20, 39, 60, 66, 67, 75, 97, 103, 107, 108) (Table 1). Dental calculus was sampled from the same group of individuals, with the exception of two Roman skeletons (SDN_103 and SDN_108) not included due to the insufficient amount of tartar. Ribs were sampled at the stores of the 'Soprintendenza Archeologia, Belle Arti e Paesaggio per l'Area Metropolitana di Venezia e le province di Belluno, Padova e Treviso (Italy)' whereas maxillae and mandibles were moved to the Department of Archaeology at Durham University (United Kingdom) where the sampling and the analyses of dental calculus and isotopes were conducted. Additional anthropological data such as sex, and age at death, were reported in Forlin et al. (2020) and other unpublished anthropological reports. The modern reference collection of plants stored at DANTE laboratory and previous published literature were employed for comparison (Carnelli et al., 2004; Madella et al., 2005; Dove and Agreda, 2007; Dove and Koch, 2011; Yang et al., 2012; Mariotti Lippi et al., 2015; Cristiani et al., 2018; Gismondi et al., 2019; (icpt) et al., 2019; Zeisler-Diehl et al., 2020). Appendix A includes detailed information about the methods employed by this study with reference to both dental calculus and isotope analysis.

3. Results

3.1 Dental calculus analysis

San Donato, Roman period

A summary of the micro-remains found in the San Donato dental calculus is presented in Table 2. From the nine individuals analysed more than 168 starch grains were observed. Based on their morphological feature, grains were divided into four different morphological types.

Type 1 was only detected in SDN_39 (N=114) (Table 2, Figure 4e, f, g). The grains have a 2D oval or reniform shape and 3D reniform shape, with elongated hilum and a deep longitudinal fissure. The extinction cross is bilaterally symmetrical. Lamellae are barely visible, but, when present, they can be seen near the border of the grains. The main axis ranges between 10 and 27 µm. Some of the grains were damaged or embedded in the calculus along with tissue fragments and micro-charcoals. They can be attributed to plants of the Fabaceae family.

Type 2 was found in the tartar of SDN_39, SDN_60, SDN_67, SDN_75, and SDN_107 (N= ca. 45) (Table 2, Figure 4a, b). These grains are irregularly polyhedral with a centric hilum and radial fissures; sometimes the hilum is open. The extinction cross is radially symmetrical. The grain size ranges between 15 and 24 µm. They can be identified with Panicoideae.

Type 3 is a lump of bimodal starch grains only found in SDN_66 (Table 2). The small grains have a 2D oval/circular shape and a 3D spherical/ovoidal shape, the large grains have a 2D oval/circular shape and a 3D lenticular shape. The hilum is centric, closed. The extinction cross is radially symmetrical. In the large grains, lamellae are concentric and distinct. The diameter/main axis ranges between 6 and 12 μm in the small grains, between 24 and 44 μm in the large grains. These features are characteristic of Triticeae.

Type 4 is represented by two grains observed in individual SDN_39. The grains are ovoid with a small 'tail' at the end. They have a centric hilum and a longitudinal fissure. The extinction cross is bilaterally symmetrical. The main axis measure around 17 μm. They can be attributed to plants of the Fagaceae family (cf. *Quercus*).

Other starch grains were not identified due to a lack of diagnostic features (i.e., the lump of small grains, as observed in the individual SDN_18). These types of grains may belong to several varieties of plants which are not possible to identify with certainty.

Phytoliths were observed in two individuals (SDN_18 and SDN_75). In SDN_18 several multi-cell phytoliths were embedded in flecks of calculus (Figure 4n, o, p). These elongate sinuate/lobate phytoliths could belong to the Poaceae family.

Isolated fibers, non-diagnostic vegetal tissue fragments as well as micro-charcoal residues were present in all the samples. In particular, the highest number of micro-charcoals were found in the adult female SDN_39 (Table 2).

Uncharred vascular elements were observed in five individuals (SDN_18, 20, 39, 75, 107) (Table 2). Tracheids with uniseriate bordered pits as occur in numerous Cupressaceae and Pinaceae were observed in SDN_75 and SDN_20. A wood fragment with a portion of cross-field pitting was found in the tartar of the adult female SDN_20. Cross-fields are the areas where the horizontal walls of the ray cells are in contact with the vertical walls of the tracheids. They present a structure of diagnostic value. In SDN_20, the pit apertures are one or two oblique, quite vertical ellipses, ascribable to the Cupressoid type (Figure 4m). Cupressoid cross-field pitting occurs in the members of the Cupressaceae family (for example *Cupressus* and *Juniperus*) but may also be present in few genera of Pinaceae and Taxaceae. Among the plants of the Northern Italian flora, it may be found in *Abies alba* and *Taxus baccata*, but *Taxus* may be ruled out because its tracheid walls show a spiral thickening that was not observed here (Greguss, 1955). Concerning *Abies,* cross-fields may display cupressoid, piceoid, and taxodioid pits.

Fungal spores, with different shapes and sizes, and fragments of hyphae occur in numerous individuals (Table 2, Figure 4p-v). Many of them (Figure 4r, 4t) recall morphologies observed in Glomeromycota, which are arbuscular mycorrhizal fungi (Walker et al., 2018). Roughly ovoid spores (Figure 4v), with a rather smooth wall surface, were also found, often attached to a fragment of the subtending hypha. They may be attributed to the Non-Pollen Palynomorph HdV 207 (Miola, 2012), also belonging to the Glomeromycota.

San Pietro, medieval period

Micro-remains found in the San Pietro dental calculus are summarised in Table 3.

Samples from six individuals belonging to the early and late medieval phases of the cemetery were analysed (Table 3). Starch grains detected within the tartar of individuals SPT_20, SPT_47 and SPT_48 were very small or damaged, with no diagnostic features (Figure 4d).

Isolated vascular elements were observed in three individuals. Pitted vessel fragments from sample SPT_47 and SPT_49 are common to numerous Angiosperms, whereas tracheids with uniseriate bordered pits (like those from Cupressaceae and Pinaceae) were found in SPT_48. Unfortunately, a detailed identification is not possible here. In the same sample, a bilobate phytolith diagnostic of leaves and stems of Panicoideae was found (Out and Madella, 2016). In addition, other phytoliths with a morphology like those of Poaceae and Cyperaceae were detected in the same individual (SPT_48). Additional evidence of Poaceae comes from SDN_18, whose dental calculus produced several long cells' silica skeletons with ∩ ornamentations (Madella et al., 2016; Out et al., 2016; Santiago-Marrero et al., 2021).

Among the animal remains, three barbules (elements of bird feathers) on samples SPT_18, SPT_47, and SPT_48 were observed. The morphology and the features of the barbule belonging to the young individual of grave SPT_18 is consistent with those of the Anatidae family (i.e., geese and ducks) (Figure 4i). The other two fragments found in SPT_48 (embedded in the calculus matrix, Figure 4l) and SPT_47 may be attributed to those of Galliformes (i.e. chickens). In the other two cases the fragments are too small to permit a clear identification. Fungal spores like those observed in the Roman samples, were observed only in SPT_48.

3.2 Stable Isotopes analysis

Carbon and nitrogen

The carbon and nitrogen isotope data are presented in Table 4. The San Donato bone samples had $\delta^{13}C$ values ranging between -17.0‰ and -15.1‰ (mean = -15.9 ± 0.6‰, 1 sd) and $\delta^{15}N$ values ranging between 7.3‰ and 8.9‰ (mean = 8.1 ± 0.5‰, 1 sd). The San Donato dentine had $\delta^{13}C$ values ranging from -19.1‰ to -15.3‰ (mean = -16.8 ± 1.1‰, 1 sd) and $\delta^{15}N$ values ranging between 7.1‰ and 10.3‰ (mean = 8.4 ± 0.8‰, 1 sd). The San Pietro bone samples had $\delta^{13}C$ values ranging between -18.8‰ and -12.6‰ (mean = -15.8 ± 2.1‰, 1 sd) and $\delta^{15}N$ values ranging between 6.9‰ and 9.4‰ (mean = 8.3 ± 1.1‰, 1 sd). The San Pietro dentine values were very similar, with the $\delta^{13}C$ values ranging from -19.5‰ to -13.4‰ (mean = -16.2 ± 2.1‰, 1 sd) and $\delta^{15}N$ values ranging between 8.2‰ and 9.8‰ (mean = 9.2 ± 0.6‰, 1 sd). Whilst most individuals show no significant difference in diet from early childhood to later life, one individual from San Donato (SDN_75) and three individuals from San Pietro (SPT_18, SPT_48 and SPT_49) demonstrate a significant change in diet of >3‰ in $\delta^{13}C$. The atomic ratios for all of the bone and dentine samples fall within the range (2.9 – 3.6) suggested by DeNiro (1985) as indicative of well-preserved collagen.

Strontium and oxygen

The strontium and oxygen isotope data are presented in Table 5. The strontium isotope data for the San Donato individuals range from 0.708272 to 0.708609 (mean = 0.708439 ± 0.000115, 1 sd) and the San Pietro individuals range from 0.708432 to 0.709248 (mean = 0.708703 ± 0.000296, 1 sd). The San Pietro individuals exhibit a wider range in strontium isotope ratios than the San Donato individuals. Additionally, the San Pietro individuals also have significantly higher strontium isotope ratios than the San Donato individuals (t (17) = 2.66829, p = 0.008769). San Donato is situated on carboniferous limestones and marls, and although the underlying geology surrounding San Pietro also contains carboniferous limestone the local area predominantly consists of interglacial conglomerates (Forte et al., 2019). Therefore, the higher and more varied strontium isotope ratios observed in the San Pietro individuals are likely due to the more complex geology at the site.

The $\delta^{18}O_{VSMOW}$ values for the San Donato individuals range from 23.2‰ to 25.0‰ (mean = 24.0 ± 0.6‰, 1 sd) and the San Pietro individuals range from 23.6‰ to 24.8‰ (mean = 24.2 ± 0.5‰, 1 sd). There was no statistically significant difference in the $\delta^{18}O$ values measured at either site (t (17) = 0.82392, p = 0.211448). The wider range in $\delta^{18}O$ values seen in the San Donato individuals compared to the San Pietro individuals could be a function of the smaller sample size from San Pietro (n = 6).

Lead

The lead isotope data are presented in Table 6. The lead concentrations for the San Donato individuals range from 0.1 to 0.6 ppm with a median of 0.2 ppm, while the lead concentration for the San Pietro individuals range from 0.1 to 3.8 ppm with a median of 0.8 ppm. The San Pietro lead isotope ratios range between $^{206}Pb/^{204}Pb$ = 17.9854 to 18.5746, $^{207}Pb/^{204}Pb$ = 15.6128 to 15.6635, and $^{208}Pb/^{204}Pb$ = 37.9799 to 38.7026 and the San Donato lead isotope ratios range between

$^{206}Pb/^{204}Pb$ = 18.5423 to 18.8341, $^{207}Pb/^{204}Pb$ = 15.6561 to 15.6762, and $^{208}Pb/^{204}Pb$ = 38.8276 to 38.8276.

4. Discussion

The results summarised above entangle the mobility, diet and lifestyle of the two populations within this study. In addition, the cross-reference of the results from dental calculus analysis and isotope analyses proves to be beneficial in order to augment the resolution of the evidence identified, in particular in regard to the dietary habits of the analysed individuals.

4.1 Dental Calculus

Starch grains found in San Donato samples provide a direct insight into the plant foods consumed by this Roman community.

Evidence of starch grains belonging to plants of the Poaceae family were found in five individuals of both sexes belonging to the different phases of the necropolis (1st – 4th centuries AD). Based on the morphological features of the starch grains, it is possible to suppose that broomcorn millet (*Panicum miliaceum)* and/or foxtail millet (*Setaria italica)* were usually consumed at San Donato, as in other Italian sites (Rottoli and Castiglioni, 2011; Mariotti Lippi et al., 2017). As seen above, evidence of Poaceae was also found in SDN_18. In particular, phytoliths indicate the consumption of Panicoideae and other C_4 grasses inflorescence. Interestingly, with millet being a C_4 plant, this find appears consistent with the results of the isotopic analysis discussed below.

In terms of plant identification, broomcorn millet and foxtail millet seem to be more plausible than sorghum (*Sorghum vulgare*) which is only sporadically attested in archaeobotanical assemblages in northern and central Italy during the Roman period (Castiglioni and Rottoli, 2010). Moreover, sorghum as a crop seems to have been introduced to Italy in the second half of the first century AD (Bostock and Riley, 1855). Even in the early medieval period, sorghum is rarely attested, whereas evidence for broomcorn millet and foxtail millet is widespread (Moser, 2006; Castiglioni and Rottoli, 2010; Vanni et al., 2019).

Evidence of Triticeae consumption was found in only one adult male individual (SDN_66). Examples of these types of starch grains are attested by other studies suggesting the usual consumption of barley (*Hordeum vulgare*) or/and *Triticum* spp. (D'Agostino et al., 2019; Gismondi et al., 2020a; 2020b). Finally, starch grains belonging to the Fabaceae family were detected in one adult female

(SDN_39). In a review of the plant offerings from Roman cremations in northern Italy, Rottoli and Castiglioni (2011) report the presence of pulses such as lentil (*Lens culinaris*), fava bean (*Vicia faba* var. *minor*), and common vetch (*Vicia sativa*) particularly in two urban contexts not far from to the archaeological site under discussion here, namely Padua and Verona. The same authors also identified the presence of *S. italica*, *P. miliaceum*, and *Triticum aestivum* in those contexts. There are other indicators for pulses crops in the Alps nearby San Donato: at Mezzocorona (Trento), a Roman site in the Adige valley, carpological remains of fava bean, lentil, common vetch, and bitter vetch (*Vicia ervilia*) were found (Castiglioni and Rottoli, 1994). However, the authors of this study suggest that fava bean (*Vicia faba* var. *minor*) was exclusively used as a fodder for livestock.

Regarding the medieval site of San Pietro, apart from the presence of a bilobate phytolith possibly belonging to leaves and stems of Poaceae (perhaps Panicoideae), the few starch grains observed in the dental calculus of the individuals buried here are generally damaged or very small and lacking diagnostic features. This does not mean that cereals and pulses were rarely included in the diet but the paucity of remains might be fortuitous or perhaps the result of heavy cooking processes such as those adopted for the preparation of soups. In fact, when boiled in water starch grains gelatinize. Starch gelatinization is an irreversible hydrothermal process involving the breakdown of intermolecular bonds within starch granules, resulting in swelling that damages the granules original shape, i.e. the loss of their diagnostic features, and ultimately their preservation (Hoover, 2010; Wang and Copeland, 2013; Edwards et al., 2015).

The presence of barbules in three individuals (SD_18, 47 and 48) suggests the birds (domestic or wild) which were possibly consumed or processed by the medieval community buried at San Pietro. According to our finds, we suggest the presence of domestic fowl (*Gallus gallus*), geese (*Anser* spp.), and ducks (*Anas* sp.). These species are largely attested in northern Italy by both historical and zooarchaeological studies (for example Montanari, 1979; Baker, 2000). However, archaeologically, ducks were less documented than geese in early medieval Italy (Baker, 2000).

Minute fragments of charcoals occurred in all the analysed samples and can be indicative of food consumption, work activities that involve fire or environmental (domestic) pollution.

The vascular elements found in the dental calculus generally do not display sufficient characters for wood identification. However, in the calculus of the adult female SDN_20 from the Roman necropolis of San Donato, a wood fragment presented diagnostic features which are typical of the wood of Cupressaceae, even if they may also occur in *Abies*. Considering Cupressaceae the most probable source, Juniper (*Juniperus* spp.) is an evergreen conifer widely diffused in the Alpine area with the species *Juniperus communis* L. and *Juniperus sabina* L. By contrast, the Italian cypress (*Cupressus sempervirens* L.) does not grow in the Alps. Although it is impossible to rule out the importation of Cypress wood to the Lamon area, its presence is less likely that of *Juniper*.

In general, wood fragments preserved in dental calculus may have very different origins. In our case, we first suggest excluding that the find come from wood used as fuel or to smoke food since the fragment is uncharred.

Romans employed juniper wood for domestic supply but also as a natural aromatic for their resinous scent as well as medicinal plant (see for instance Bouchaud et al., 2018; Charles, 2012; Ziegler, 1932). As a medicine, juniper was used to treat abdominal and digestive disorders, as an anti-inflammatory, contraceptive, abortifacient, and uterine stimulant, both orally or applied externally (Riddle, 1991; Ernst, 2002). This aspect is particularly interesting in the fact that the remains of juniper wood were found in SDN_20, an adult female buried together with a newborn positioned between her bended legs. A postmortem fetal extrusion should be considered by further studies.

Fungal spores of Glomeromycota are attested in the individuals from the Roman community of San Donato. The presence of a noteworthy number of fungal spores and hyphae is not common in dental calculus and thus deserves an accurate consideration about the possible origin. The spores of Glomeromycota - often called chlamydospores - are responsible for the reproduction of these soil fungi which form the most common arbuscular mycorrhizas affecting the roots of about 80% of land plants (Moore et al., 2011). For this reason, these spores are frequently encountered in the soil, even if they are particularly susceptible to the damage caused by the necrotrophic parasites (Gams et al., 2004). The precise identification of isolated spores is difficult (Douds and Millner, 1999), making it challenging to attribute them to a species when found in an archaeological context. From a methodological standpoint, it is necessary to rule out the fungal remains as coming from the soil where individuals were buried or from contamination during subsequent storage and study. Based on the decontamination procedure adopted by the present study, we can exclude that the presence of those fungi is the result of a post-depositional intrusion. Moreover, the spores are not airborne and are not recorded in aerobiological monitoring and therefore we can also exclude that they come from air pollution in the laboratory. Hence, we suggest they were originally embedded by plaque formation as a result of the consumption of edible plant underground storage organs (such as leek, onion, carrot, turnip) or other poorly washed vegetables which still preserved traces of soils.

4.2 Isotopes

The crown dentine and enamel apatite $\delta^{13}C$ values from the San Donato and San Pietro individuals are presented in Figure 5 alongside the dietary regression lines adapted from Froehle et al., (2010). As both tissues form during the same period of life, the $\delta^{13}C$ values represent the whole diet between the ages of 4 to 8 years. The majority of the San Donato and San Pietro individuals plot slightly above the C_3 protein line. Their shift above and towards the right of this line suggests that their diets contained a significant proportion of C_4 or marine resources. However, two individuals, SDN_75 from San Donato and SPT_48 from San Pietro, plot tightly on the C_3 protein line to the left of the majority of individuals, suggesting a predominantly terrestrial C_3 diet with very little C_4 or marine input in their early childhood diets. Both these individuals show a shift towards higher $\delta^{13}C$ bone values indicating increased C_4 consumption in later life and bringing them inline with the rest of the population.

The $\delta^{13}C$ and $\delta^{15}N$ values from the San Donato and San Pietro bone samples are presented in Figure 6 alongside contemporaneous faunal data from San Donato. Published human $\delta^{13}C$ and $\delta^{15}N$ data from Roman and medieval sites from across northern Italy are also included for comparison. Studies into past diets in Italy have demonstrated that there is a general trend for increased C_4 consumption the further north a population is located (Tafuri et al., 2009; Iacumin et al., 2014; Milella et al., 2019), this trend can also be seen in the comparative data plotted in Figure 6. The San Donato and San Pietro individuals plot to the right of the majority of data from northern Italy, with high $\delta^{13}C$ and $\delta^{15}N$ values consistent with a mixed C_3/C_4 diet. These values are very similar to $\delta^{13}C$ and $\delta^{15}N$ values observed in Friuli-Venezia Giulia, which have also been interpreted as indicative of a mixed C_3/C_4 diet (Iacumin et al., 2014).

The cow and sheep bone fragments from San Donato have low $\delta^{13}C$ and $\delta^{15}N$ values indicating a diet entirely based on C_3 plants. The low $\delta^{13}C$ and $\delta^{15}N$ values seen in these animals compared to the humans indicates that the animals were not fed the C_4 plants being eaten by the local population but were most likely left to graze on the temperate C_3 grasses local to the region. Using the $\delta^{13}C$ and $\delta^{15}N$ values from these animals as a herbivore baseline for the region, it is clear that the San Donato and San Pietro individuals had diets rich in animal protein (eggs, milk, cheese, meat etc.) as they exhibit a mean ^{15}N enrichment of 5‰. This degree of trophic level shift has been seen in other Italian populations with diets containing high proportions of animal products (Craig et al., 2009). From this, it is evident that the C_4 component of the San Donato and San Pietro individuals' diet is not derived from animal protein, as they were exclusive C_3 feeders. It is likely that C_4 crops such as millet were an important component of these people's diets. Evidence for the consumption of these grains in northern Italy have been shown in populations dating back as early as the Bronze Age (Tafuri et al., 2009).

Although the majority of the San Donato and San Pietro individuals plot within 2 sd of the population means, there are two outliers from the San Pietro population (see Figure 6). Individual SPT_49 has a much lower $\delta^{13}C$ value than the rest of the population, indicating a predominantly terrestrial C_3 diet, which is to say a diet based on C_3 plants (wheat, barley etc) and animals grazing on or fed C_3 plants, with very little C_4 input. C_3 crops such as wheat were considered high quality foods, unlike C_4 crops such as millet and sorghum, which were only suitable for making soup or polenta, not bread (Iacumin et al., 2014). Therefore, with a diet dominated by C_3 resources it is possible that SPT_49 can be regarded as a high-status individual who had access to higher quality foods. However, the early childhood $\delta^{13}C$ value for SPT_49 is -13.4‰ indicating consumption of a high level of C_4 plants in childhood may therefore be indicative of acquired status in later life. Conversely, in later life individual SPT_18 had a higher $\delta^{13}C$ value of -12.6‰ indicating a predominantly terrestrial C_4 diet which contrasts sharply with their early childhood value of -17.0‰ when a mixed C_3/C_4 protein diet was consumed. It is possible that SPT_18 is an individual with limited access to higher status C_3 foods in their diet, possibly due to episodes of food scarcity.

The San Pietro and San Donato strontium isotope ratios are presented in Figure 7 alongside comparative data from Medieval (Milella et al., 2019) and Bronze Age (Cavazzuti et al., 2019) sites located across northern Italy. There is currently no published Roman data for northern Italy, however as strontium is predominantly derived from bedrock there is unlikely to be any changes to regional strontium isotope ratios over archaeological timescales. Therefore, data from any archaeological human samples recovered from northern Italy make useful comparators. The underlying predominantly limestone and glacial conglomerate geology at San Pietro and San Donato are expected to produce a bioavailable strontium isotope range of 0.7072 to 0.7096 (Emery et al., 2018). As can be seen in Figure 7, all of the San Pietro and San Donato individuals have strontium isotope ratios consistent with limestone and the local area. However, there is one outlier within the San Pietro group (SPT_46). This individual has a high strontium isotope ratio in comparison to the remainder of the population and plots close to the precipitation/seawater value. Sea-spray effect, whereby human or faunal strontium isotope ratios closely reflect seawater values, has been observed in populations up to 50 meters inland of coastal regions (Whipkey et al., 2000; Montgomery and Evans, 2006). There is no evidence to suggest that SPT_46 originated in a coastal region, as this individual has similar carbon, nitrogen and oxygen isotope ratios to the rest of the San Pietro population. However, precipitation is also derived from seawater, therefore areas with heavy rainfall can also produce strontium isotope ratios similar to seawater (Evans et al., 2010). It is possible that SPT_46 originated in a region prone to heavy rainfall or runoff, such as the uplands, which would have contributed to the local bioavailable strontium.

The low lead concentrations observed in the San Pietro, and particularly amongst the San Donato individuals suggests a childhood spent in regions with low environmental lead pollution and limited access to lead-containing products. The rural locations of these two villages, in the foothills of the Alps, may account for the low lead concentrations observed. A comparison of the San Donato and San Pietro individuals with data from Italian lead ore, slag, coins and artefacts (Butcher et al., 2014; Dolfini et al., 2020; Carroll et al., 2021) (OXALID) of known provenance demonstrates how this individuals group within the expected lead isotope field for Italy (see Figure 8). The San Pietro individuals show tighter clustering than the San Donato individuals, which may be due to the significantly higher lead concentrations seen in the San Pietro assemblage (Kruskal-Wallis: H = 5.5783, p = 0.01818). It is common for the lead isotope ratios of a population to become increasingly homogenous the higher their lead concentrations become. This phenomenon is termed 'cultural focusing' (Montgomery, 2002; Montgomery et al., 2005) and has been observed in archaeological populations across Europe (Montgomery et al., 2010; Shaw et al., 2016). Both populations plot closely with the Italian artefact and coin lead isotope data. Generally, post-prehistoric human lead isotope ratios are culturally focused, clustering together in a narrow range reflecting the lead ore sources used by a population (Montgomery, 2002; Montgomery et al., 2005; 2010). To some extent metals used in artefacts and coins are also culturally focused due to the reworking of ores and mixing of metals (Harl, 1996; Montgomery et al., 2010; Shaw et al., 2016). Therefore, it is expected that data from artefacts of known provenance would provide a more realistic representation of the expected human lead isotope compositions in populations engaging in anthropogenic lead use. The fact that the San Donato and San Pietro individuals plot closely with the Italian artefact datasets suggests that, although their lead concentrations are low, there may be some degree of anthropogenic contribution to their lead isotope compositions.

In relation to their lead isotope ratios, the San Donato and San Pietro individuals separate into two distinct groups, with the San Donato individuals exhibiting lower $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ values than the San Pietro individuals. The disparity in lead isotope ratios between the two populations could represent a temporal shift in the dominant lead ore source exploited in the region. Lower $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ values are consistent with the younger Alpine ore sources in northern and central Italy, while older, Variscan ore sources found in southern and Sardinian regions of Italy tend to produce higher $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ values (Muchez et al., 2005). The earlier, Roman population at San Donato may have relied upon predominantly local lead resources, with the later medieval population at San Pietro utilising more resources from further afield. Alternatively, it could also be that the very low lead levels (i.e. < 0.7 ppm) observed in the San Donato individuals are indicative of natural lead exposure from the rock and soil with only a small or no contribution from anthropogenic ore sources. Lead in marine carbonates such as limestone has low $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios and the San Donato individuals, particularly SND_60 and SND_108, have similar lead isotope ratios to prehistoric individuals from regions of chalk and limestone with no evidence for anthropogenic lead exposure (Montgomery et al. 2010).

Although all individuals are consistent with the expected range for Italy, there are three outliers within these populations. The two individuals from San Donato (SND_60 and SND_108) mentioned above and one individual from San Pietro (SPT_47) who has significantly higher $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ values than the rest of the San Pietro population (see Figure 8). Although these individuals plot within the Italian ore field, the lead level in SPT_47 is very low (i.e. 0.1 ppm) suggesting little exposure to anthropogenic ore sources. It is possible that this individual originates from another rural region of Italy or beyond. In particular, it is worth noting that this female individual, buried in a privileged grave within the earliest church of San Pietro, has produced a temple ring of the Köttlach culture characterizing the eastern Alpine area of Slovenia and Austria, which may suggest an allochthonous origin for this member of the medieval community at Lamon. San Pietro individual SPT_18 stands out due to their high lead concentration of 3.8 ppm, this value is over three times higher than the population mean. The significant difference in SPT_18's lead concentration suggests that they spent their childhood in a more polluted environment such as a nearby urban context like Trento, Feltre or Verona. Also the significant shift in diet between early childhood and later life described above may reflect a change in residential origins, e.g. from a city to a rural mountain region with more C4 foods.

5. Conclusion

Isotopic and dental calculus analysis allowed better understanding of the diet, mobility and lifestyle of two archaeological populations from Lamon, Italy. The results suggest a limited mobility of the two groups, with the vast majority of the individuals analysed showing a local or regional origin. Only a few individuals may be incomers both at San Pietro and San Donato, and the isotopic lead analysis has improved the resolution of the mobility among the members of such communities. In particular, the female individual SPT_47 buried in a privileged grave at San Pietro, may come from a close, possibly eastern area of the Alpine Arc, as furthermore suggested by the Köttlach temple ring found in her grave.

Isotopes are indicative of a diet based on a mixed C_3/C_4 plants consumption and rich in animal proteins, with no significant difference between the Roman and the medieval populations. The consumption of C_4 plants, more resilient to the Alpine climate, are consistently documented both by isotopes and dental calculus. Moreover, dental calculus results permit to better characterise the typology of the crop consumed, namely millet, barley/wheat and legumes. Phytoliths, vascular elements, fungal spores, and animal remains were also found embedded in the dental calculus. In particular, the fungal spores found on some Roman individuals from San Donato might provide evidence for the consumption of plant underground storage organs and, in general, poorly washed vegetables. The remains of uncharred conifer wood, very likely juniper, in the dental calculus of a young female buried with a newborn in the Roman cemetery of San Donato proved to be of particular interest. Even though its provenance from wooden tools is likely, we stress the possibility this find may be evidence for the use of juniper for medicinal purposes given the particular characteristics of the burial context. Among the results relating to the diet of the medieval individuals buried at San Pietro, the consumption of birds such as fowls and ducks emerge as an additional find. From a methodological perspective, we believe that this study stresses the benefits coming from a complementary and comparative application of both isotopes and dental calculus analysis on the same skeletal assemblage. If the isotopic study is essential in the understanding of the mobility of the communities here under scrutiny, when it comes to the diet the combination of dental calculus with this methodology has demonstrated to be very effective in augmenting the resolution of the results. Overall, it is thanks to these conjunct methods that the outcomes of this study open a new window into the biographies of the individuals here analysed, their diet, mobility, habits, and environment, thus stimulating further and more systematic investigation on the ancient populations occupying an Alpine sector which remains poorly understood from an archaeological perspective.

Author contributions

Conceptualization: **EF, PF**; Data curation: **EF, JOM, JAM, MML, PF**; Formal analysis: **EF, JOM, JAM, GN**; Funding acquisition: **PF**; Investigation: **EF, JOM, JAM, MML, PF**; Methodology: **EF, JOM, JAM, GN, PF**; Project administration: **EF, PF**; Roles/Writing - original draft: **EF, JOM, JAM, MML, GN, PF**; Writing - review & editing: **EF, JOM, JAM, MML, PF.**

Data availability

Data presented in this manuscript is available on request.

Declaration of competing interest

The authors declare no conflicts of interest.

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Figure captions (color should be used for all the figures)

Figure 1. Map showing the location of the funerary sites of Lamon here presented (SDN = San Donato; SPT = San Pietro). Red dotted lines show historic routes crossing the area during the Roman and medieval periods (Map by Paolo Forlin).

Figure 2. The location of the Roman cemetery of San Donato (red circle) (A). The cemetery under excavation in 2003 (B). The Roman burial SDN_75 which shows the typical crouched position adopted by the bodies at San Donato (C) (Photos by Paolo Forlin [A] and Davide Pacitti [B, C]; Photos B and C, © Archaeological Superintendence of Veneto).

Figure 3. The parish church of San Pietro, Lamon (A). The early medieval burials SPT_47 (right) and SPT_48 (left) (B). Late medieval burials excavated outside the church in the northern portion of the cemetery (C). SPT_20 (above) and SPT_18 (below) are visible (Photos by Paolo Forlin; Photos B and C, © Archaeological Superintendence of Veneto).

Figure 4. Scale bars are 20 μm apart from a couple of them which are specified in the caption. (**a**, **b**) Type 2 starch grains from SDN_39 and SDN_75 possibly belonging to Panicoideae; (**c**) Starch grains of *Panicum miliaceum* from experimental reference; (**d**) Damaged starch grain from SPT_48; (**e, f, g**) Type 1 starch grains from SDN_39 possibly belonging to Fabaceae; (**h**) Starch grains of *Vicia faba* from experimental reference; (**i**) Fragment of barbule from SPT_18 (scale bar 50 μm); (**l**) Fragment of barbule embedded in dental calculus from SPT_48; (**m**) Fragment of wood from SDN_20 possibly belonging to Cupressaceae; (**n**) Single elongated lobate phytolith from SDN_18; (**o**) Several multi cell phytoliths embedded in the calculus of SDN_18 (scale bar 50 μm); (**p**) Multi cell phytoliths, fungal spores and hyphae embedded in dental calculus of SDN_18; (**q**, **r**, **s, t, u, v**) Fungal spores and hyphae possibly attributed to Glomeromycota observed in several individuals of SDN (Photos by Elena Fiorin).

Figure 5. Crown dentine collagen and tooth enamel apatite δ^{13}C values from the San Donato (*n* = 11) and San Pietro (*n* = 6) individuals. (Regressions lines from Froehle et al., (2010), adapted by Jay, M.)

Figure 6. Comparison of the δ^{13}C and δ^{15}N values for the San Pietro and San Donato individuals. Comparative data from Friuli-Venezia Giulia, NE Italy (Iacumin et al., 2014), Eppon Altenburg, Montan Pinzon and Terfan (Paladin et al., 2020) and Bologna (Milella et al., 2019).

Figure 7. San Donato and San Pietro strontium and oxygen isotope data alongside regional comparative data (Cavazzuti et al., 2019; Milella et al., 2019). The shaded grey box represents the local strontium and oxygen isotope ranges for the Lamon region as defined by Emery et al., (2018) and Giustini et al., (2016). The analytical error for strontium isotope ratio analysis is within the symbol size.

Figure 8. Comparative data from OXALID (Italian Pb ore), Butcher and Pointing, 2014 (Italian coins), Dolfini et al., 2020 (Italian artefacts), Italian Roman slag (Carroll et al., 2021) and Montgomery et al., 2010 (Italian humans). The analytical error is within the symbol size.

Table captions

Table 1. Table showing the burials sampled for dental calculus analysis, sex, estimated age, tooth and the position of the calculus as well as its weight obtained before (WBC) and after (WBA) the manual cleaning.

Legend: WBC: weight before cleaning, WAC: weight after cleaning, - = the calculus' fleck was too small to be weight. The weigh is expressed in mg.

Table 2. Description of the micro-remains found within the calculus of the individuals of San Donato.

Legend: PHYT= phytoliths, T/F= tissues and fibers, CHARC= charcoal, VE= vascular elements, the symbol '>' is used when micro-remains cannot easily be counted (i.e., when embedded in dental calculus), GSM= group of small grains.

Table 3. Description of the micro-remains found within the calculus of the individuals of San Pietro.

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Table 4. Results and quality control parameters of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) analysis.

Table 5. Results of the strontium oxygen (carbonate) isotope analysis with calculated V-SMOW values.

Table 6. Results of the lead isotope analysis.

SAN DONATO (ROMAN)						
GRAVE	SEX	AGE	TOOTH	POSITION	WBC	WAC
SDN_18	M	21-29?	URC	BUCCAL	6.35	4.82
			LLI1	BUCCAL	4.44	3.16
			LLI1	LINGUAL	1.30	-
SDN_20	F	25-35?	ULI1	BUCCAL	48.75	30.1
			URM2	LINGUAL	1.90	-
SDN_39	F	Adult	LRPM2	BUCCAL	3.99	2.30
			LRM1	BUCCAL	2.78	1.49
SDN_60	M	25-35?	ULM3	BUCCAL	8.29	4.79
			LLM1	BUCCAL	12.15	9.32
			ULC	BUCCAL	0.89	-
SDN_66	M	21-29?	LLI2	BUCCAL	3.23	2.25
			LLI1	MESIAL	1.56	-
SDN_67	M	21-29?	ULC	BUCCAL	4.48	2.73
			LLPM2	LINGUAL	2.83	1.99
SDN_75	F	25-35?	LRI1	BUCCAL	3.11	1.80
			ULMR3	BUCCAL	1.40	-
			ULI2	BUCCAL	1.53	1.05
SDN_97	M	35-45?	LLI1	BUCCAL/MESIAL	6.12	4.10
SDN_107	F	25-35?	LLI2	DISTAL	4.40	2.74
			LRI1	LINGUAL	11.34	3.26
			LRM2	LINGUAL	8.51	4.29
SAN PIETRO (MEDIEVAL)						
GRAVE	SEX	AGE	TOOTH	POSITION	WBC	WAC
SPT_18	I	10-13	URPM1	BUCCAL	1.33	0.95
			URM1	BUCCAL	2.09	-
SPT_20	I	9-11	LLM1	DISTAL	1.19	0.91
			LRM1	DISTAL	0.45	-
SPT_46	I	25-35	ULPM2	MESIAL	0.7	-
			ULM1	LINGUAL	1.13	0.82
			URI2	MESIAL	11.7	9
SPT_47	F	≥35/40	LRI1	MESIAL	12.97	11.26
			LRI1	LINGUAL	4.33	3.66
			ULM2	DISTAL	1.56	0.77
			ULPM2	DISTAL	3.18	1.70
SPT_48	M	25-35	LLI2	LINGUAL	21.65	19.23
			LRI2	BUCCAL	15.07	11.7

			LRM1	LINGUAL/DISTAL	4.85	2.97
			LRC	BUCCAL/MESIAL	20.14	16.1
SPT_49	F	35-45	LLPM2	DISTAL	2.12	1.88
			LRI1	DISTAL	1.48	1.25
			LRI1	BUCCAL/MESIAL	6.96	5.36

GRAVE	TOOTH	VEGETAL					ANIMAL/OTHERS
		STARCH GRAINS	PHYT	T/F	CHARC	VE	
SDN_18	LLI1, URC	GSM	>20	26	4	2	fungi
SDN_20	ULI1, URM2	-	-	1	1	2	-
SDN_39	LRPM2, LRM1	127	-	14	75	1	fungi
SDN_60	ULM3, LLM1, ULC	5	-	11	7	-	fungi
SDN_66	LLI2	1 + GSM	-	7	2	-	fungi
SDN_67	ULC, LLPM2	6	-	15	2	-	fungi
SDN_75	LRI1, ULMR3, ULI2	26	1	11	1	7	-
SDN_97	LLI1	-	-	5	3	-	fungi
SDN_107	LLI2, LRI1. LRM2	3	-	19	6	3	fungi

GRAVE	TOOTH	VEGETAL					ANIMAL/OTHERS
		STARCH GRAINS	PHYT	T/F	CHARC	VE	
SPT_18	URPM1, URM1	1	1	11	16	-	1 barbule
SPT_20	LLM1, LRM1	2 + GSM	-	30	3	1	-
SPT_46	ULPM2, ULM1, URI2	-	-	9	3	-	-
SPT_47	LRI1, ULM2, ULPM2	2 + GSM	-	70	7	1	1 barbule
SPT_48	LRC, LRM1, LRI2, LLI2	3 + GSM	13	122	47	15	1 barbule, fungi
SPT_49	LLPM2, LRI1	-	2	16	11	-	-

Sample	Crown dentine					Bone				
	$\delta^{13}C$ PDB ‰	$\delta^{15}N$ AIR ‰	%C	%N	C:N	$\delta^{13}C$ PDB ‰	$\delta^{15}N$ AIR ‰	%C	%N	C:N
SPT_18	-17.03	9.50	42.01	15.51	3.2	-12.55	9.36	44.07	15.30	3.4
SPT_20	-16.22	9.03	42.55	15.66	3.2	-16.10	6.93	43.20	15.07	3.3
SPT_46	-16.28	9.25	42.58	15.55	3.2	-16.43	7.84	44.38	16.07	3.2
SPT_47	-14.60	9.26	41.92	15.38	3.2	-14.92	9.27	41.15	14.46	3.3
SPT_48	-19.48	8.21	41.85	15.36	3.2	-16.00	9.25	43.80	15.67	3.3
SPT_49	-13.38	9.78	42.45	15.52	3.2	-18.82	7.16	44.23	15.80	3.3
Mean	-16.17	9.17	-	-	-	-15.80	8.30	-	-	-
1 SD	2.09	0.54	-	-	-	2.05	1.13	-	-	-
SDN_18	-17.16	8.08	41.15	15.06	3.2	-16.75	8.18	36.90	12.77	3.4
SDN_20	-16.44	8.92	41.88	15.34	3.2	-16.02	8.51	39.69	13.65	3.4
SDN_39	-17.26	8.85	41.78	15.23	3.2	-15.94	8.85	41.91	14.77	3.3
SDN_60	-17.08	8.38	41.85	15.34	3.2	-17.01	8.24	36.37	12.69	3.3
SDN_66	-15.47	8.06	42.19	15.34	3.2	-15.44	7.48	30.33	10.62	3.3
SDN_67	-17.42	7.89	41.82	15.29	3.2	-15.75	8.01	34.40	11.73	3.4
SDN_75	-19.11	7.05	41.69	15.35	3.2	-15.11	7.30	42.72	15.28	3.3
SDN_97	-17.30	7.94	41.74	15.21	3.2	-15.78	7.45	41.46	14.57	3.3
SDN_103	-16.45	10.31	41.49	15.18	3.2	-15.67	8.33	41.11	14.90	3.2
SDN_107	-15.55	8.15	41.77	15.33	3.2	-16.17	8.32	41.76	14.63	3.3
SDN_108	-15.30	8.26	41.69	15.28	3.2	-15.21	8.19	39.78	14.19	3.3
Mean	-16.78	8.35	-	-	-	-15.90	8.08	-	-	-
1 SD	1.11	0.82	-	-	-	0.59	0.48	-	-	-
Sheep	-	-	-	-	-	-21.33	2.33	42.79	15.38	3.2
Cow	-	-	-	-	-	-21.54	3.70	43.10	15.18	3.3

Sample	Sr ppm	$^{87}Sr/^{86}Sr$	2SE	$\delta^{13}C_{(carb)}$ V-PDB ‰	$\delta^{18}O_{(carb)}$ V-PDB ‰	$\delta^{18}O_{(carb)}$ V-SMOW ‰	$\delta^{18}O_{(phos)}$ V-SMOW ‰	$\delta^{18}O_{(dw)}$ V-SMOW ‰
SPT_18	96	0.708779	0.000008	-8.7	-7.0	23.7	14.8	-9.6
SPT_20	61	0.708432	0.000008	-9.8	-6.1	24.6	15.7	-8.8
SPT_46	61	0.709248	0.000008	-8.4	-7.1	23.6	14.7	-9.7
SPT_47	67	0.708471	0.000008	-7.1	-6.0	24.8	15.9	-8.6
SPT_48	95	0.708610	0.000009	-12.4	-6.5	24.3	15.4	-9.1
SPT_49	114	0.708678	0.000007	-6.3	-6.4	24.4	15.5	-9.0
Mean	82	0.708703	-	-8.8	-6.5	24.2	15.3	-9.1
1 SD	22	0.000296	-	2.2	0.5	0.5	0.5	0.5
SDN_18	72	0.708531	0.000007	-9.2	-6.3	24.4	15.5	-8.9
SDN_20	48	0.708507	0.000007	-9.0	-6.7	24.0	15.1	-9.3
SDN_39	72	0.708430	0.000007	-9.2	-6.3	24.5	15.6	-8.9
SDN_60	58	0.708550	0.000007	-9.3	-7.4	23.3	14.4	-10.0
SDN_66	70	0.708516	0.000008	-7.5	-7.5	23.2	14.2	-10.1
SDN_67	69	0.708392	0.000007	-9.3	-5.7	25.0	16.2	-8.3
SDN_75	119	0.708317	0.000008	-11.6	-7.2	23.5	14.6	-9.8
SDN_97	59	0.708426	0.000008	-9.3	-6.5	24.2	15.3	-9.1
SDN_103	43	0.708272	0.000006	-9.8	-6.3	24.4	15.5	-8.9
SDN_107	62	0.708274	0.000005	-6.9	-7.0	23.7	14.8	-9.6
SDN_108	50	0.708609	0.000007	-7.5	-7.0	23.7	14.7	-9.7
Mean	66	0.708439	-	-9.0	-6.7	24.0	15.1	-9.3

1 SD	20	0.000115	-	1.3	0.6	0.6	0.6	0.6

Sample	Pb ppm	$^{206}Pb/^{204}Pb$	2SE	$^{207}Pb/^{204}Pb$	2SE	$^{208}Pb/^{204}Pb$	2SE	$^{207}Pb/^{206}Pb$	2SE	$^{208}Pb/^{206}Pb$	2SE
SPT_18	3.8	18.51132	0.00047	15.65965	0.00053	38.65724	0.00153	0.845962	0.000009	2.088314	0.000039
SPT_20	0.6	18.44139	0.00066	15.66030	0.00074	38.56098	0.00240	0.849195	0.000013	2.091000	0.000069
SPT_46	1.1	18.44893	0.00042	15.65780	0.00049	38.58975	0.00158	0.84871	0.00001	2.09169	0.00005
SPT_47	0.1	17.98544	0.00125	15.61279	0.00130	37.97991	0.00344	0.86810	0.00002	2.11171	0.00009
SPT_48	0.8	18.44172	0.00057	15.66011	0.00063	38.59867	0.00179	0.84917	0.00001	2.09305	0.00005
SPT_49	0.7	18.57464	0.00069	15.66350	0.00073	38.70259	0.00203	0.84327	0.00001	2.08364	0.00004
MEAN	1.18	18.40058	-	15.65236	-	38.51486	-	0.85073	-	2.09323	-
SD	1.32	0.21005	-	0.01947	-	0.26699	-	0.00882	-	0.00966	-
SDN_18	0.5	18.61899	0.00049	15.66683	0.00057	38.78309	0.00183	0.84144	0.00001	2.08299	0.00006
SDN_20	0.1	18.68272	0.00163	15.65783	0.00130	38.67574	0.00376	0.83809	0.00002	2.07019	0.00008
SDN_39	0.1	18.60291	0.00142	15.65791	0.00166	38.65222	0.00503	0.84169	0.00003	2.07780	0.00013
SDN_60	0.2	18.83417	0.00060	15.67620	0.00062	38.73280	0.00186	0.83233	0.00001	2.05653	0.00005
SDN_66	0.2	18.64890	0.00071	15.66284	0.00073	38.72046	0.00217	0.83988	0.00001	2.07631	0.00005
SDN_67	0.1	18.54227	0.00104	15.65606	0.00101	38.61131	0.00288	0.84434	0.00001	2.08231	0.00006
SDN_75	0.4	18.65039	0.00081	15.67119	0.00083	38.82759	0.00245	0.84027	0.00001	2.08186	0.00004
SDN_97	0.1	18.67420	0.00108	15.66847	0.00099	38.71646	0.00301	0.83906	0.00001	2.07332	0.00006
SDN_103	0.3	18.68763	0.00049	15.66897	0.00050	38.74712	0.00144	0.838468	0.000010	2.073403	0.000035
SDN_107	0.2	18.70413	0.00063	15.66686	0.00055	38.73046	0.00160	0.837609	0.000010	2.070676	0.000036
SDN_108	0.6	18.82835	0.00040	15.66881	0.00043	38.79042	0.00120	0.832177	0.000006	2.060198	0.000032
MEAN	0.25	18.67951	-	15.66563	-	38.72615	-	0.83867	-	2.07324	-
1 SD	0.18	0.08771	-	0.00628	-	0.06284	-	0.00370	-	0.00864	-


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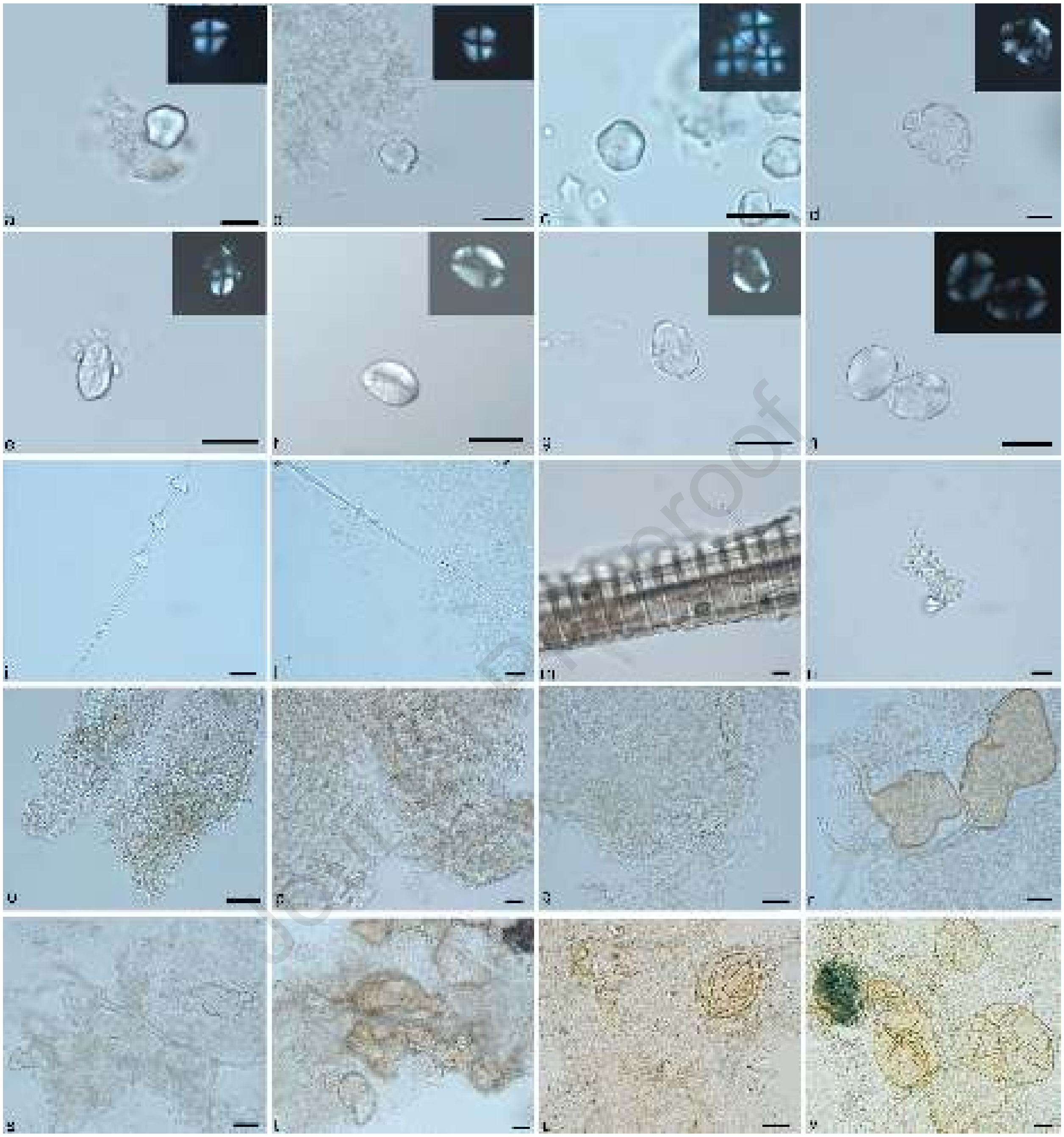

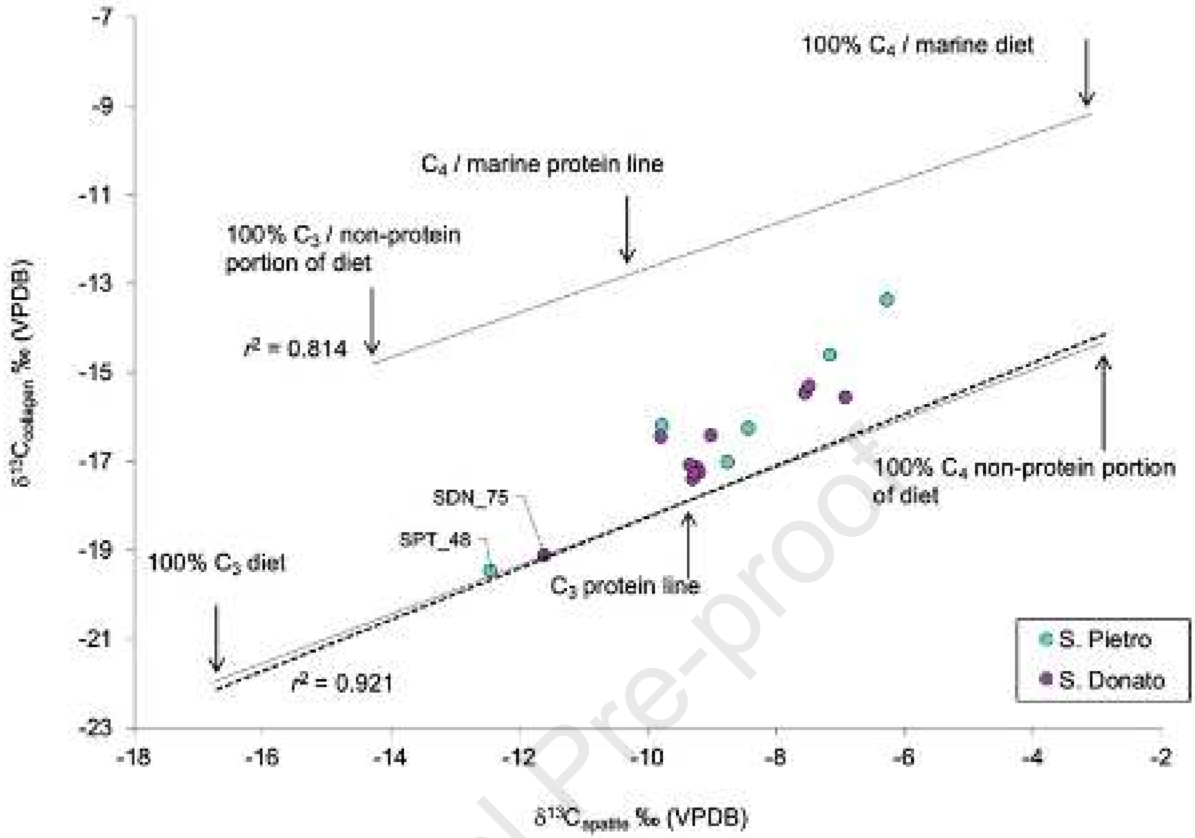

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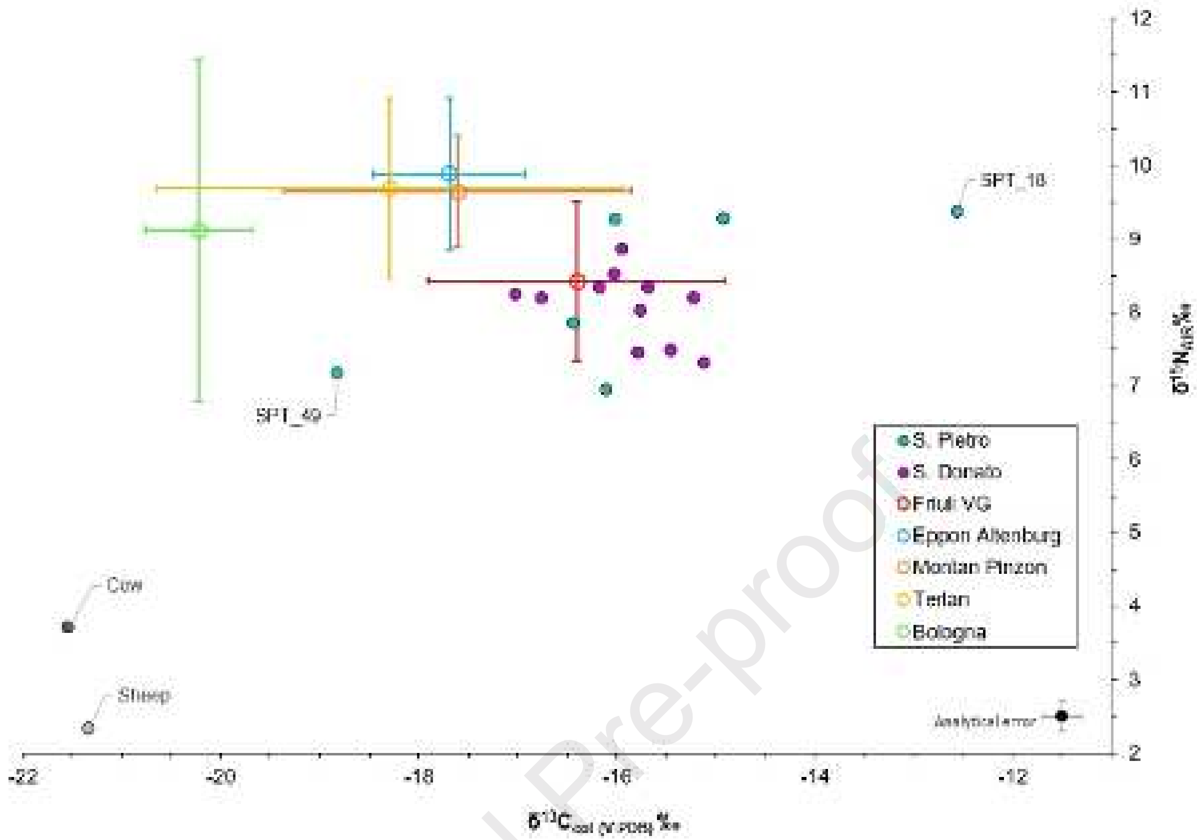
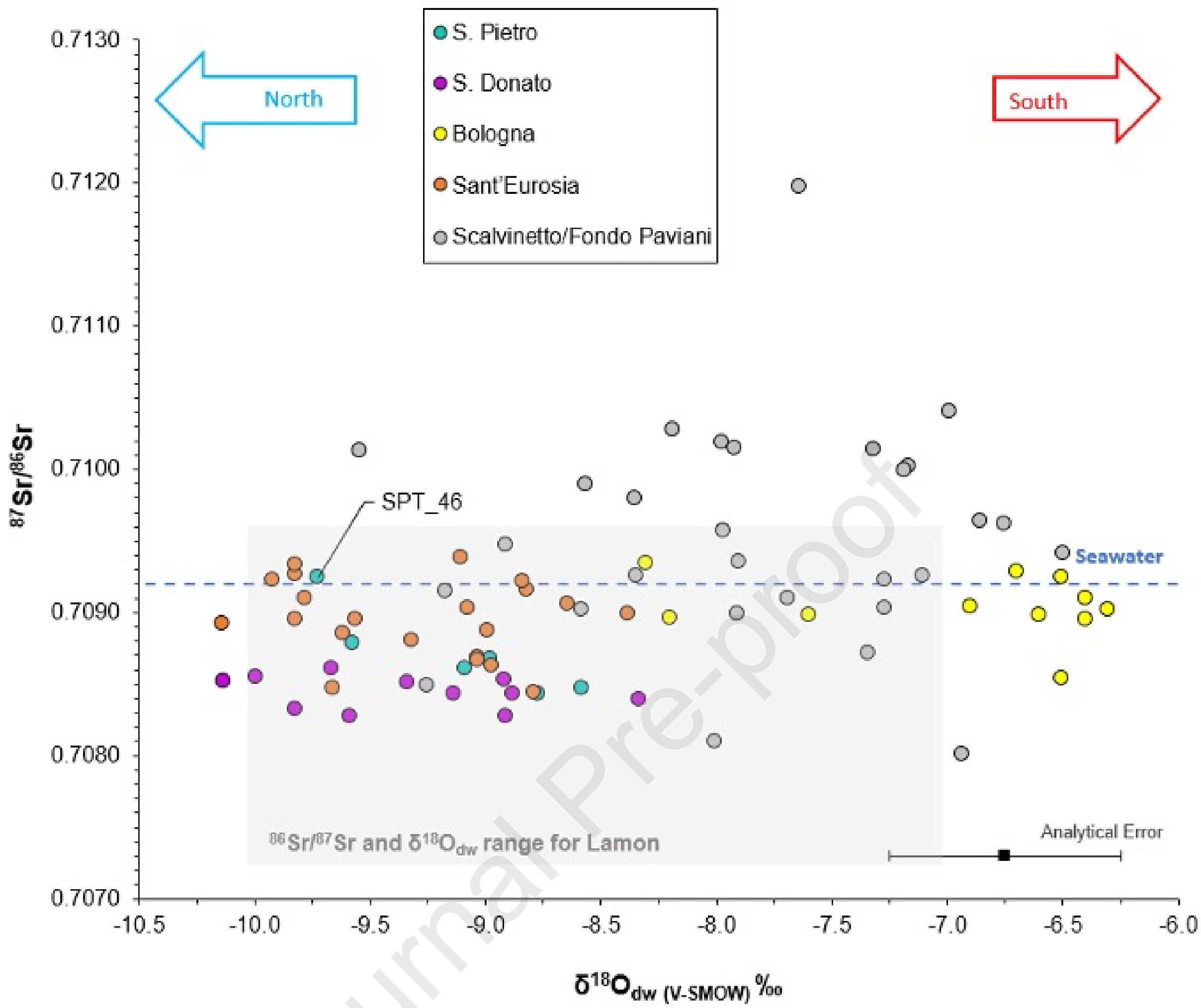
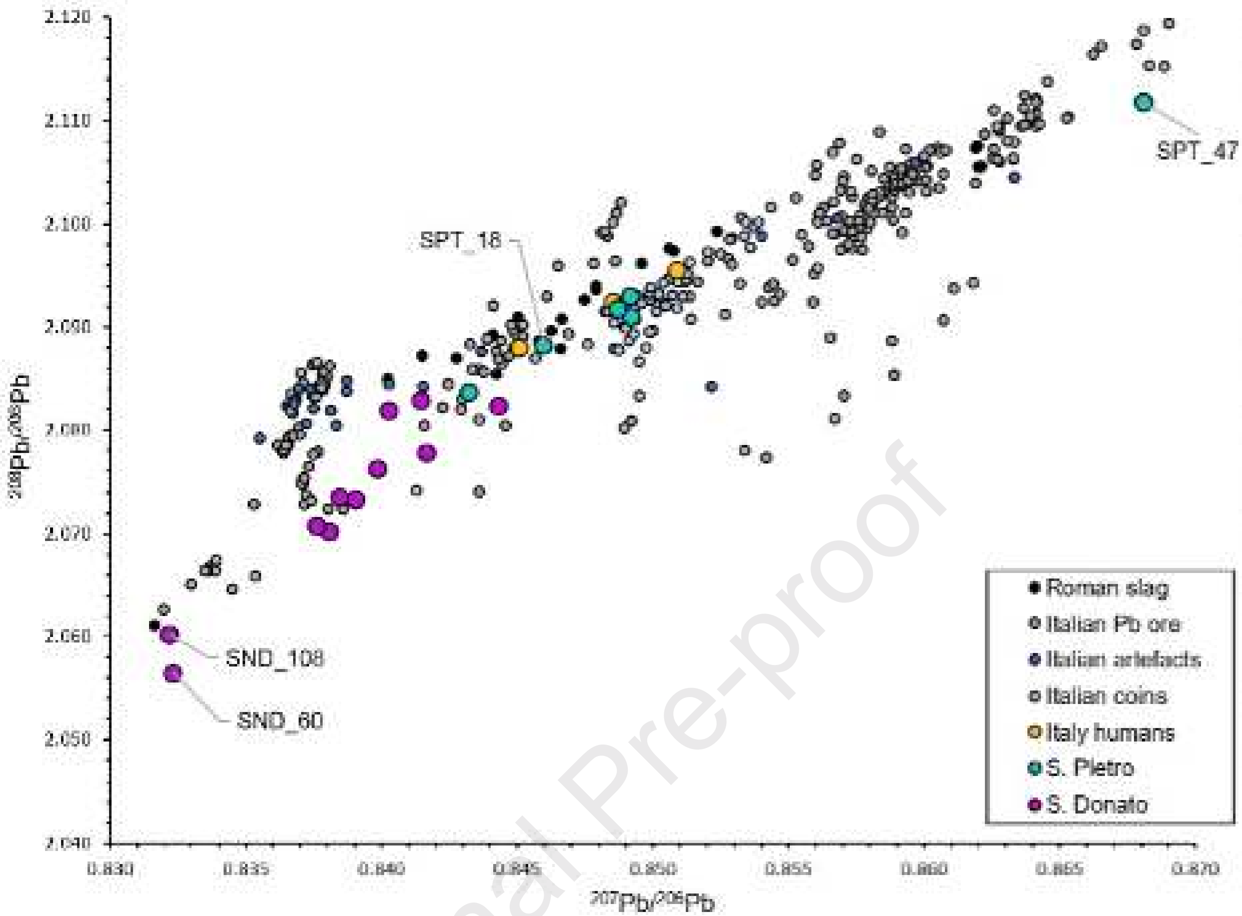
δ13Ccollagen ‰ (VPDB)
δ13Capatite ‰ (VPDB)
100% C4 / marine diet
C4 / marine protein line
100% C3 / non-protein portion of diet
r2 = 0.814
100% C4 non-protein portion of diet
SDN_75
SPT_48
100% C3 diet
C3 protein line
r2 = 0.921
S. Pietro
S. Donato


SPT_18
SPT_49
Cow
Sheep
S. Pietro
S. Donato
Friuli VG
Eppan Altenburg
Montan Pinzon
Terlan
Bologna
Analytical error
-22
-20
-18
-16
-14
-12
2
3
4
5
6
7
8
9
10
11
12
$\delta^{13}C_{col}$ (V-PDB) ‰
$\delta^{15}N_{AIR}$ ‰


S. Pietro
S. Donato
Bologna
Sant'Eurosia
Scalvinetto/Fondo Paviani
North
South
SPT_46
Seawater
86Sr/87Sr and δ18Odw range for Lamon
Analytical Error
87Sr/86Sr
0.7130
0.7120
0.7110
0.7100
0.7090
0.7080
0.7070
-10.5
-10.0
-9.5
-9.0
-8.5
-8.0
-7.5
-7.0
-6.5
-6.0
δ18Odw (V-SMOW) ‰


2.120
2.110
2.100
2.090
2.080
2.070
2.060
2.050
2.040
0.830
0.835
0.840
0.845
0.850
0.855
0.860
0.865
0.870
$^{208}Pb/^{206}Pb$
$^{207}Pb/^{206}Pb$
SPT_47
SPT_18
SND_108
SND_60
Roman slag
Italian Pb ore
Italian artefacts
Italian coins
Italy humans
S. Pietro
S. Donato

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: