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Understanding the post-Archaic population of Satricum, Italy: A bioarchaeological approach

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ABSTRACT

This paper contributes to the current debate regarding the ethno-cultural identity and origins of the post-Archaic (5th to 4th centuries BCE) population of the town of Satricum by introducing bioarchaeologial data including strontium isotope ratios, strontium concentrations, δ^{13}C and δ^{18}O values of tooth enamel, as well as dental morphological traits. Previous studies suggested a change in the original Latin population of ancient Satricum as a result of migrating groups called the Volscians coming from the eastern mountainous hinterland of Latium. The purportedly relatively short occupation of Satricum (ca. 150 years) by the Volscians during the post-Archaic period increases the chance of identifying the first generation of migrants coming from the mountains. Individuals from three presumable Volscian necropoleis in Satricum are analyzed. Forty-three third molars were sampled for isotope and elemental analyses. All individuals appear to be "local" based on their strontium and oxygen isotope ratios. However, three individuals have statistically lower strontium isotope ratios than the rest, two of which originate from two intersecting graves. These two also have the lowest strontium concentrations, potentially suggesting they are spatially and possibly biologically related. At the group level, the strontium concentration data show a clear difference between the necropoleis. An additional difference is in the dental non-metric trait frequencies, with a biodistance analysis suggesting the necropoleis contain different gene pools (MMD score of 0.789). It is hard to determine if these data suggest (1) a population that experienced fast and marked gene flow between use of the necropoleis, or (2) a population with large, distinct kin groups using different necropoleis. Nonetheless, the data show that the 5th to 4th century BCE was a period of change in Satricum and this work paves the way for future research as we strive to understand the origins and identities of these peoples.

1. Introduction

The town of Satricum (present-day Le Ferriere) is an ancient Latin settlement, located ca. 60 km southeast of Rome in the province of Lazio, Italy. Satricum is situated on a tuff plateau on the western bank of the Astura river in the Pontine Plain, approximately ten kilometres from the coast. The site developed from a modest hamlet of huts in the 9th century BCE into a prosperous urban centre during the 6th century (Attema et al., 2011a,b; Bouma and van 't Lindenhout, 1997; Gnade, 1992, 2002, 2007; Tol, 2012; Maaskant-Kleibrink, 1992). The Latin necropolis of Satricum is situated at the northwest side of the town, with graves dating to the 8th and 7th centuries BCE (Fig. 1).

According to Roman literary sources, the town of Satricum underwent drastic changes due to an unstable time of continuous warfare in the post-Archaic period (Gnade, 2002, p. 160). The Latin town succumbed to military confrontations between Romans, Latins, and Volscians and was taken by the Volscians in 488 BCE following its destruction (Tol, 2012). Archaeological excavations in Satricum yielded

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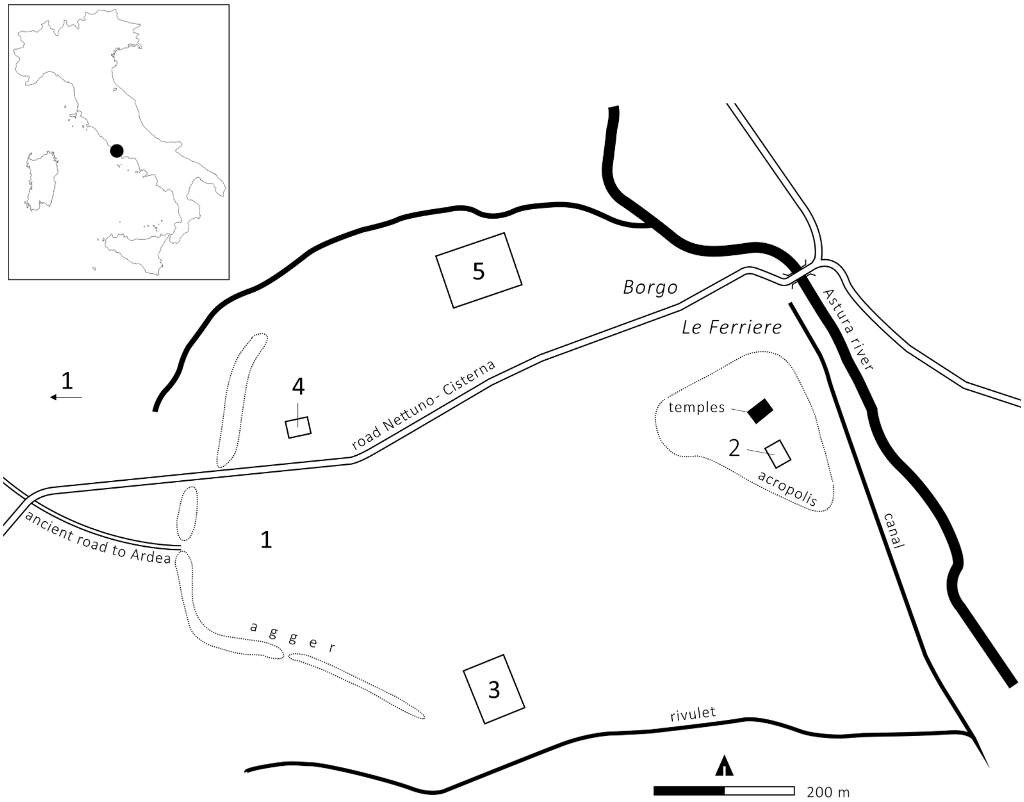

Fig. 1. Map of Satricum with 1 = Latin northwest necropolis, 2 = acropolis (acro) necropolis, 3 = southwest (SW) necropolis, 4 = Poggio dei Cavallari (PdC) necropolis, 5 = Roman villa (after Heldring, 1998, Fig. 1).

three burial grounds: the southwest necropolis (SW), the Poggio dei Cavallari necropolis (PdC), and the acropolis necropolis (acro). All three cemeteries are located within the city limits of 6th century Satricum (Gnade, 1992, 2002; Maaskant-Kleibrink, 1992; Maaskant-Kleibrink, 1987) (Fig. 1). Based on material culture, Gnade (1992, 2002) has attributed these cemeteries to new Volscian inhabitants of Satricum who occupied the town after its destruction in the beginning of the 5th century BCE until the town became a Roman colony in 385 BCE.

The Volscians, a pastoral people, are believed by some to have moved gradually from the Lepini mountains to the fertile Latial plains because of a need for a larger residential area for their expanding population (Stibbe, 1984). Alternatively, some scholars believe that this infiltration was more sudden or that the relationship between the Latin and Volscian populations shifted in the first decade of the 5th century, based upon their dramatic appearance in the literary sources (van Royen, 1992, p. 437–438). It remains unclear whether the Volscians were already present in the Latial plain before the 5th century and if the nature of their movement was violent or peaceful, organized or random, or a mixture thereof (Gnade, 2002, p. 140–143). The relatively short occupation of Satricum (ca. 150 years) during the post-Archaic period increases the chance of identifying the first generation of Volscian inhabitants of Satricum. Combining carbon, oxygen and strontium isotope analyses with strontium concentration measurements and dental morphological trait analysis, this study aims to shed light on the origins of the post-Archaic population(s) of Satricum.

Of the three necropoleis attributed to the Volscians, the southwest necropolis (SW) is the largest. It contains > 200 inhumation graves of which 167 were excavated. The deceased at the SW necropolis were placed in a supine position, with arms beside the body or crossed over the lower body and placed in rectangular graves oriented N-S or E-W (Gnade, 2002, p. 101–102). In 64 cases, archaeologists came across traces of coffins. The cemetery is homogeneously organized. In the northeast, the graves are orderly and well-spaced, and some are even in clear alignment; in the south the density of the graves increases, and in the southwest many intersecting graves are found (Gnade, 2002). Gnade (2002) states that these intersections could indicate descent groups. The small units of three to five graves, or pairs that intersect or lie side by side in the central and southern part of the necropolis, often have the same orientation. Each grave in these units seems to be of a consecutive date due to the differences in depth of the grave (Gnade, 2002, p. 108). The skeletal remains of 94 individuals were found in the necropolis (Hoogland, 1992). There is a predominance of young adults among the deceased (Hoogland, 1992; Rubini et al., 2002).

In the acropolis necropolis (acro), 35 inhumation graves were found and 11 were excavated (Gnade, 2002; Maaskant-Kleibrink, 1992). All graves were rectangular and had two main directions: NW-SE and NE-SW. The individuals were buried in a supine position, with the arms and legs adducted (Maaskant-Kleibrink, 1992). No traces of coffins were found.

In the Poggio dei Cavallari necropolis (PdC), 52 individuals have been excavated thus far. The graves and their material culture correspond to the other two necropoleis. The graves of the SW and PdC necropoleis both contain objects from the 5th century, but much of the material in the PdC necropolis seems to be from the middle of the 4th century BCE, meaning that the burial ground in any case was used for a longer period (Gnade, 2014, 2018). In addition, the burials seem richer in grave content and are somewhat bigger in size. All individuals were buried in a supine position and placed within an empty space, such as a coffin. In this cemetery, a prevalence of young adults is also attested (Gnade, 2012, 2018).

1.1. Isotope and elemental analyses

Only a few isotopic studies have been conducted on ancient Italian sites mostly focussing on the Roman Period (Emery et al., 2018; Killgrove, 2010; Killgrove and Montgomery, 2016; Killgrove and Tykot, 2013; Prowse et al., 2007; Stark, 2017), with only a small number on

Neolithic and Bronze Age sites (Cavazzuti et al., 2019; Scheeres et al., 2013; Tafuri et al., 2016). Strontium ($^{87}Sr/^{86}Sr$) and oxygen isotope ratios ($\delta^{18}O$) are widely used to study mobility in past human populations (e.g. Budd et al., 2004; Copeland et al., 2011; Killgrove and Montgomery, 2016; Knudson et al., 2010; Laffoon and Hoogland, 2012; Snoeck et al., 2016). Commonly, individuals are categorized as local or non-local to the geographic region they are buried in, although the current trend is to try and go beyond this simplified dichotomy (e.g. Snoeck et al., 2018).

$^{87}Sr/^{86}Sr$ values are highly variable between geological formations due to the radioactive decay of rubidium-87 (^{87}Rb) into strontium-87 (^{87}Sr) and their initial Rb-Sr ratio. Soluble bioavailable Sr is transferred from the geologic system into the biosphere (soil, plants, animals, humans). $^{87}Sr/^{86}Sr$ values in the skeleton therefore relate to the bioavailable $^{87}Sr/^{86}Sr$ of the area where the consumed food was produced (Bentley, 2006).

Stable oxygen isotope ratios ($\delta^{18}O$) differ geographically as a result of the isotopic composition of available drinking water ($\delta^{18}O_{dw}$), which varies regionally according to temperature and other climatic parameters, such as distance from the coast, latitude, altitude, and evapotranspiration (Longinelli, 1984; Luz et al., 1984). $\delta^{18}O$ values in human bone and teeth reflect local water sources and can help assess the geographic origin of the studied non-local individuals (e.g. Bentley and Knipper, 2005; Killgrove and Montgomery, 2016; Knudson and Price, 2007; Schroeder et al., 2009). Stable oxygen isotope ratios are, hence, often used in tandem with strontium isotope ratios to assess the geographical origin of past populations.

Carbon isotope ratios ($\delta^{13}C$) reflect dietary practices and have been used in archaeological research for many decades (Vogel and Van Der Merwe, 1977). They are most commonly measured in the organic fraction of bone (i.e. collagen) or in tooth enamel. In tooth enamel, the carbon is present in the carbonate fraction of the inorganic bioapatite. Whereas $\delta^{13}C$ values in collagen are mainly indicative of dietary protein, in carbonate they reflect the carbon mix of all macronutrients (protein, carbohydrates, lipids) (Fernandes et al., 2012). Previous studies on Italian populations showed a range of $\delta^{13}C$ values from ca. −13 to ca. −10‰ in tooth enamel carbonate (Killgrove and Tykot, 2013; Prowse et al., 2005).

Elemental strontium concentrations can also be used to gather information on diet and possibly geographical origin. The Sr concentrations in human bone and teeth reflect the Sr concentrations of the food an individual consumed, which varies strongly between animals and plants, the latter usually having significantly higher Sr concentrations (Bocherens et al., 1994; Burton and Wright, 1995; Subar et al., 1998; Tuross et al., 1989). Sr concentrations in plants (and animals that eat those plants) are further influenced by their geographical origin (i.e. the geology in which they grow) (Wright, 2005), though the link between the strontium concentrations of soils, plants, animals, and humans is not straightforward and can be influenced by additional factors such as calcium concentration in soil (Snoeck et al., 2018). Still, Sr concentration may offer an additional tool to investigate mobility and diet (Montgomery et al., 2007).

To contextualize strontium and oxygen isotope ratios, it is crucial to characterize the surroundings of the studied area. In the surroundings of Satricum, the Pontine plain (where Satricum is located) and the Lepini mountains (where the Volscians originated) have distinctive geological and geographical features (Fig. 2) and are expected to have different $^{87}Sr/^{86}Sr$ signatures. To determine the local $^{87}Sr/^{86}Sr$ baseline signature of a site or region, previous studies use either (1) published $^{87}Sr/^{86}Sr$ ratio data from hydrological, faunal and geological samples, or (2) statistical analysis of the sample population $^{87}Sr/^{86}Sr$. For Rome, the latter is usually used due to the complexity of both the volcanic geology and the importation of drinks and irrigation water via aqueducts (Barbieri et al., 1979; Killgrove and Montgomery, 2016; Peccerillo, 2005, 2016, 2017; Stark, 2017; Voerkelius et al., 2010).

Satricum is situated on a tuff mound formed by ashes of the Latian Volcano (Middle Pleistocene volcanics) (Attema et al., 2011a,b; Duivenvoorden, 1992). The influence of the Astura river, which stems from the Colli Albani, and its tributaries also plays a major part in the geohydrological characteristics of Satricum. The $^{87}Sr/^{86}Sr$ of its alluvium should correspond to the $^{87}Sr/^{86}Sr$ of the primary formations from which the river derives, i.e. the Colli Albani. The pyroclastic rocks of the Colli Albani have $^{87}Sr/^{86}Sr$ ranging from 0.7090 to 0.7100 (Barbieri et al., 1979; Killgrove and Montgomery, 2016). Isotope results from ancient faunal remains found in this geographic area fall within the range expected from animals living on pyroclastic volcanic geology: 0.7093–0.7103 (Barbieri et al., 1979; Faure and Powell, 2012; Killgrove and Montgomery, 2016; Palombo et al., 2005).

The hinterland of Satricum, the pre-Apennines, consists of Mesozoic limestones and the more inland regions that belong to the Apennines have a geological bedrock of Meso-Cenozoic carbonates. The Mesozoic limestone rocks have an estimated Sr isotope signature ranging from 0.7072 to 0.7074 (Tafuri et al., 2016, p. 1052). The Meso-Cenozoic carbonates show values ranging from 0.7074 to 0.7090 (Tafuri et al., 2016, p. 1052). Frosinone, a Volscian town located in the Lepini mountains in the colluvial valley of the Sacco river, seems to be influenced by three geological units. In addition to being influenced by the two mountain ranges (Mesozoic limestones and Ceno-Mesozoic carbonates), the valley is also influenced by the Ernici volcanoes of the magmatic province. This could imply that the bioavailable $^{87}Sr/^{86}Sr$ in the Ernici-Roccamonfina magmatic province, and subsequently the colluvial plain of the Sacco, is highly variable due to the influence of a Mesozoic and Meso-Cenozoic carbonate bedrock and the magmatic substratum, probably posing a problem when comparing signatures with Satricum.

Recently, Emery and colleagues (2018) published a $^{87}Sr/^{86}Sr$ map of Italy using archaeological human and faunal data, modern wine, beef, cheese, tomato sauce, sediment, natural spring water, in addition to the soil and faunal results from their own study. According to this map, Satricum is located within the range of 0.7088 to 0.7095. The Lepini Mountains, from where the Volscians originated, fall within two isoscapes: 0.7088–0.7095 and 0.7072–0.7088. Some of the samples used by Emery et al. (2018) to create their $^{87}Sr/^{86}Sr$ map are composed of water and soils which do not directly represent the bioavailable $^{87}Sr/^{86}Sr$ (BASr) of the plants consumed by animals and humans (Ryan et al., 2018). Nevertheless, generally the pyroclastic rocks of the Colli Albani are more radiogenic than the limestone and carbonate hinterland. While it is clear that no optimal baseline is currently available to contextualize the $^{87}Sr/^{86}Sr$ results of the individuals of Satricum, for the purpose of this paper, the use of the range 0.7090–0.7103 as defined by Killgrove and Montgomery (2016, p. 12) is the most adequate and will hereafter be defined as the “local”-range.

Defining the local oxygen isotope signature is more straightforward. In Italy, the mountainous ridge of the Apennines in Central Italy controls the oxygen isotope values of precipitation (Giustini et al., 2016; Longinelli and Selmo, 2003). This results in a heavy isotope (^{18}O) depletion of 2 to 3‰ within the mountainous areas compared to the coastal strip of the Tyrrhenian sea where Satricum is situated (Giustini et al., 2016) (Fig. 3). A baseline value of −5.7 ± 0.4‰ was obtained for Satricum (41° 30.494 N, E: 12 44.524 and 42 m elevation) using the Online Isotopes in Precipitation Calculator (OIPC) (Bowen et al., 2005; Bowen and Revenaugh, 2003; Bowen and Wilkinson, 2002). This is consistent with the range given in the isomap of Giustini et al. (2016) (Fig. 3). Frosinone (N: 41 38.833, E: 13 20.909 and 195 m elevation) does not differ much from Satricum with a baseline value of −6.0 ± 0.3‰. This is slightly lower than the modelled range in Fig. 3, after the data of Giustini and colleagues (2016).

Some climate change has occurred between now and ca. 500 BCE and has had its impact on $\delta^{18}O$ values of precipitation, although it remains minimal (Goudeau et al., 2015; van Joolen, 2003; Reale and Shukla 2000). Also, the hydrological conditions of ground and surface waters in the Pontine region have changed over time, since the

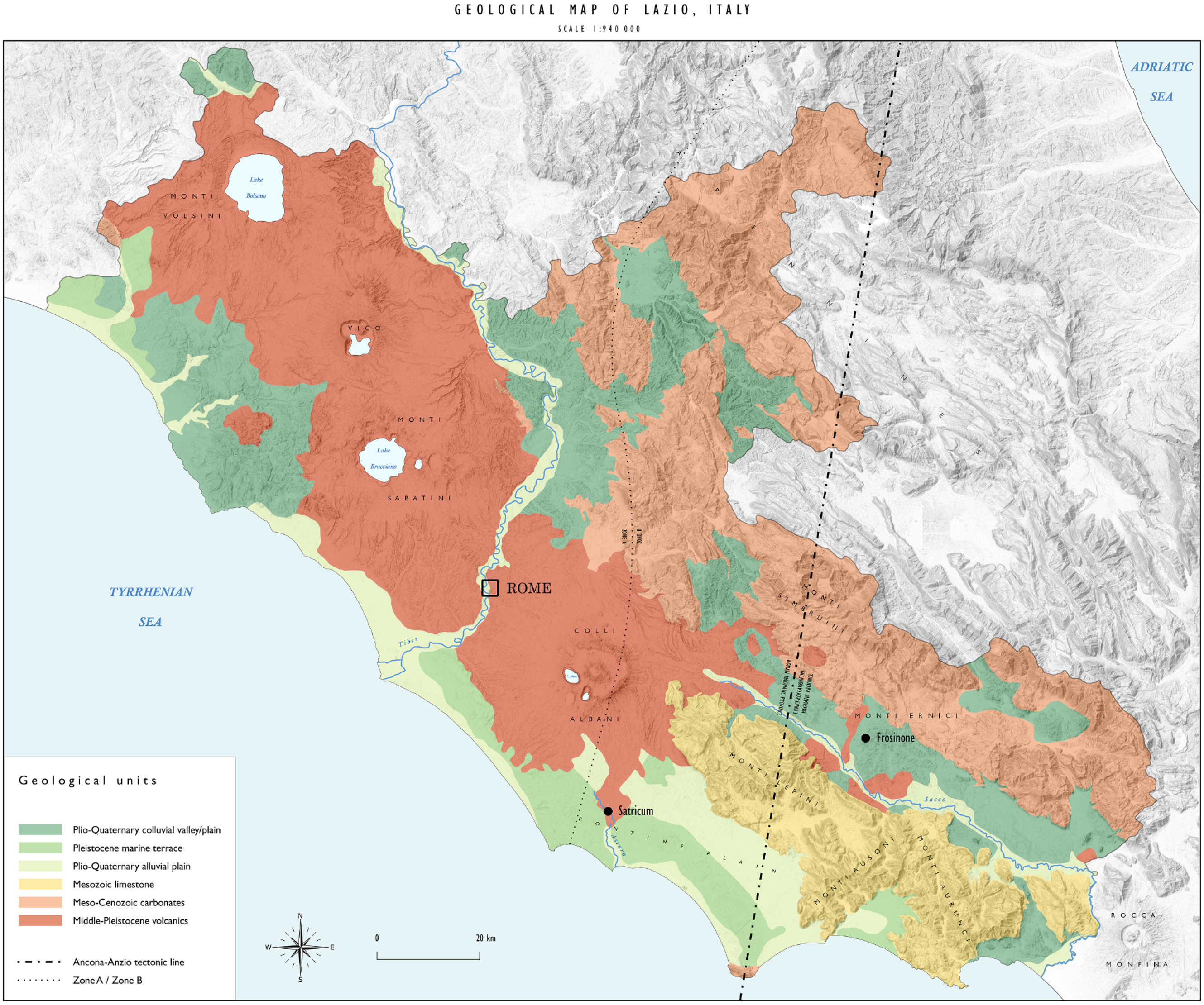

Fig. 2. Geological map of Lazio, Italy (after Barbieri et al., 1979; Duivenvoorden, 1992; Peccerillo, 2005, 2016, 2017; Sevink et al., 2013; Turi, 1986; URL 1; URL 2; MapSurfer ASTER GDEM-SRTM Hillshade by METI and NASA, Imagery GIScience Research Group at Heidelberg University).

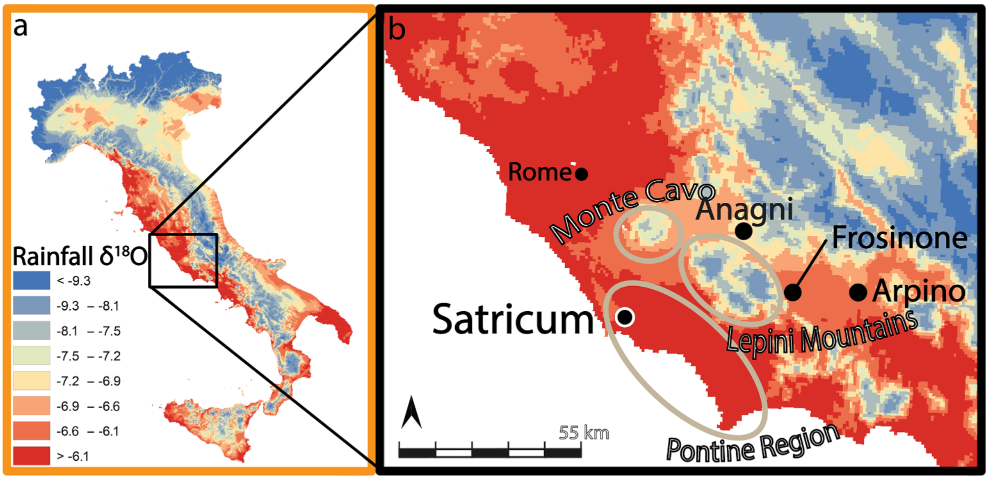

Fig. 3. Precipitation map after Giustini et al. (2016). Legend in ‰. The colour division is classified using the 'natural breaks' method with the software of ArcMap 10.2.2.

Satricum area used to be a marsh (van Joolen, 2003). Marshes are stagnant waters which are more subjected to evaporation and do not encounter much run-off. In contrast, the modern situation is controlled by human drainage systems, where evaporation does not influence the water much since it is already drained (run-off) before the depletion in ^{16}O has had a noticeable impact. The mean values of precipitation and ground water are therefore likely to be similar or slightly more enriched with heavy ^{18}O, compared to 2500 years ago. As such, it is safe to assume modern $\delta^{18}O$ values of precipitation can be used. Lightfoot and O'Connell (2016) propose the IQR method as the most appropriate method for identifying migrants under most archaeological circumstances. The "local"-range will therefore be defined as −8.7 to −2.3‰ $\delta^{18}O_{dw}$ VSMOW. It is determined by converting the 1.5IQR (interquartile range) relative to the mean values of the population after converting the carbonate values from tooth enamel to an estimated consumed drinking water value using the formula of Chenery et al. (2012):

$$\delta^{18}O_{dw} = 1.590 \text{ x } \delta^{18}O_c - 48.634$$

1.2. Biological affinities and dental non-metric traits

Most of the non-metric trait research in Italian populations has so far focused on Iron Age and Etruscan populations (e.g. Coppa et al., 1998; Rubini, 1996; Rubini et al., 2007, 1997) and, to a lesser extent, Roman populations (e.g. Stark, 2017). Besides these studies, there are also some studies focussing on Bronze Age communities (Cucina et al., 1999; Tafuri et al., 2003; Vargiu et al., 2009). Coppa and colleagues (1998) have primarily focussed on dental traits and Rubini (1996) and Rubini and colleagues (2007, 1997) on cranial traits.

All human dentitions are characterized by a basic blueprint but the teeth can vary in size and shape. Some of this variation is heritable and differences in the expression and frequency of certain dental traits can be used to estimate the degree of genetic similarity, or shared ancestry, between different populations (Scott and Turner, 1997). Dental non-metric traits, also called quasi-discontinuous or discrete traits, are variants in the crown or root, not measurable in a continuous manner, such as ridges, depressions, fissure patterns, and cusp numbers. Many dental non-metric traits are highly heritable. Based on the degree of similarity between the dental non-metric traits of two or more groups a measure called 'biodistance' can be estimated (Stark, 2017). Groups that have frequently exchanged genes through mating will have low biodistance scores indicating a high degree of genetic similarity (high biological affinity) whereas groups that rarely or never exchanged genes will have high biodistance scores indicating low genetic similarity. Thus, the analysis of dental non-metric traits shows biological relationships between populations and can track changes in phenetic (and hence genetic) affinity caused by mobility and migration. When distinct populations interbreed, the resulting mixed population will express convergent morphological trait frequencies; if two individuals from distinct genetic populations bred their offspring would have a mixture of dental non-metric traits indicative of both gene pools (Scott and Turner, 1997). A dental non-metric trait study of the Satricum teeth can assess how similar or dissimilar the assemblages are between necropoleis.

2. Materials and methods

2.1. Samples

A total of 43 third molars (M3s) were sampled from the three sites for carbon, oxygen and strontium isotopes, and strontium concentrations: 29 from SW, 13 from PdC, and two from acro. The third molar crowns initiate and terminate mineralization between the ages of 8 and 14 years (Scheuer and Black, 2000; White and Folkens, 2005). Due to the acidity of the soil only the enamel cusps were preserved (Rubini et al., 2002). For dental non-metric trait analyses a total of 39 individuals (total number of teeth = 779) were assessed. The sample consists of 17 individuals from PdC and 22 individuals from SW.

2.2. Elemental (Sr) and isotope (Sr, C & O) analyses

The bulk enamel sampling and subsequent chemical cleaning was done at the chemistry lab of the Laboratory for Human Osteoarchaeology at Leiden University using an engraver Proxxon no. 28,635 equipped with a diamond drill. The outer layer of enamel was removed with a diamond drill bit to create a clean surface of enamel from which the sample could be taken. This allowed the sampling of the inner enamel core, which is much less prone to diagenetic alterations that could influence the chemical composition (Budd et al., 2000; Burton, 2008; de Winter et al., 2019). Organic components were removed using a sodium hypochlorite solution (NaOCl) of ca. 2.5%, followed by three rinses with MilliQ water. Hereafter, the labile carbonates were removed by adding 1 M calcium acetate buffered acetic acid (1 mL per 10 mg of sample) and then the sample was rinsed as above (Laffoon, 2012).

The strontium separation process and mass spectrometry took place in a clean lab at the Department of Earth Sciences of the Vrije Universiteit Amsterdam (hereafter VU), the Netherlands, and at G-time clean laboratory at Université Libre de Bruxelles, Belgium (hereafter ULB). All enamel samples were loaded onto ion exchange columns comprising Sr-specific, crown ether resin (Eichrom Sr Spec) for separation of strontium ions.

At VU, 18 enamel samples were measured with a ThermoFisher-Scientific Triton-Plus, thermal ionization mass spectrometer (TIMS). Mass fractionation is automatically corrected for using the exponential law and the known $^{86}Sr/^{88}Sr$ ratio of 0.1194. The measurement of the international standard NBS-987 yielded an average of 0.710245 ± 19 (2SD for 6 analyses).

The remaining 25 samples were measured at ULB by Multi-Collector Inductively-Coupled-Plasma Mass-Spectrometry (MC-ICP-MS) on a Nu Plasma MC-ICP mass spectrometer (from Nu Instruments). During the course of this study, repeated measurements of the NBS-987 standard solution yielded $^{87}Sr/^{86}Sr = 0.710239 \pm 40$ (2SD for 12 analyses). All data were corrected for mass fractionation by internal normalization to $^{86}Sr/^{88}Sr = 0.1194$. In addition, after the measurements all the data were corrected using a standard double bracketing method with the recommended value of $^{87}Sr/^{86}Sr = 0.710248$ (Weis et al., 2006).

To check if the two different mass spectrometers yielded the same results, five samples (A6, P38, PXXVIII, S122, and S64b) which were already measured by TIMS were re-measured by MC-ICP-MS. The compared results have a difference ≤ 0.000018, which is lower than the 2SD observed on the repeated measurements of NBS-987 on both instruments.

Strontium concentrations were measured on all 43 samples. Samples were pre-treated as above and digested in Teflon beakers (Savillex) using subboiled 7 M HNO_3 at 120°C for 24 h, evaporated to near-dryness and subsequently digested with a drop of concentrated HNO_3. Following dilution with 3% HNO_3, Sr and Ca concentrations in the sample digests were determined using a Thermo Scientific Element 2 sector field ICP mass spectrometer at the Vrije Universiteit Brussel (VUB), Belgium, in low (^{88}Sr) and medium (^{42}Ca) resolution using Indium (In) as an internal standard and external calibration versus various reference materials (SRM1400, CCB01). The actual strontium concentrations were then calculated by normalizing the calcium data to 40%. Accuracy was evaluated by the analysis of two internal bioapatite standards (ENF and CBA). Based on repeated digestion and measurement of these reference materials, the analytical precision of the procedure outlined above is estimated to be better than 5% (1SD, n = 33 for CBA and n = 5 for ENF).

All 43 M3s were also analysed for stable carbon and oxygen isotope ratios, using a Thermo Finnigan Delta plus IRMS GasBench II Mass spectrometer at VU. The measurements are calibrated using known in-house standards (VICS, normalised to NBS 18, 19 and 20) which were measured in the same batch. Two in-house standards[1], substituting for the IAEA-CO1 standard, were used to assess the accuracy of the calculation. Three of the samples were run in a later batch and this set of measurements were standardised with the official IAEA-CO1 standard. The values were converted to $\delta^{13}C$ and $\delta^{18}O$ values using the following formula of Hoefs and Hoefs (2009):

$$\delta X = \left(\frac{R(sample) - R(standard)}{R(standard)}\right) \times 1000$$

Following Faure and Mensing (2005), $\delta^{18}O$ VPDB values were converted to VSMOW values. The formula presented by Chenery and colleagues (2012) was used in this study to convert enamel carbonate to estimated oxygen isotopic composition of ancient drinking water.

2.3. Dental non-metric trait analysis

The dental non-metric trait data derive from the tooth crown only as the roots were not adequately preserved to permit scoring. Moreover, because many of the teeth were loose (not in the jaws), traits that can only be scored when the teeth are in the mandible or maxilla were also excluded (winging and congenital absence). Individuals range in age from adolescent (13–17 years) to no older than 40 years of age. Older individuals are not included because the tooth crowns were too worn to observe non-metric traits; younger individuals were not included because the permanent teeth were still forming.[2] Teeth which exhibited pathologies, such as caries that hinder the scoring of certain traits, are not included.

The scoring of the traits was done using macroscopic observation based on the Arizona State University Dental Anthropology Scoring system (ASUDAS) by Turner et al. (1991). The traits are recorded using rank-scale 3-D reference plaques with minimum, maximum, and intermediate expressions, which help to standardize scoring (Scott and Turner, 1997; Turner et al., 1991). Fifteen traits are identified and scored on the maxillary teeth and twelve on the mandibular teeth. When antimeres (for example a left and right M2 of one individual) are present, and vary in expression, the one showing the higher degree of expression of each trait was chosen (Coppa et al., 1998; Scott and Turner, 1997; Turner et al., 1991). Turner et al. (1991) argue that the higher expression better reflects the genetic potential of the trait. Choosing the higher trait expression is standard in the field thus ensuring comparability between studies. To assess intra-observer agreement, which preferably lies between 90 and 95%, the teeth of 10 individuals (217 teeth; ~25% of the sample) were re-scored by the same observer. The first and second analyses were separated by four weeks. The first results were not viewed prior to re-scoring.

After scoring, all traits are dichotomized into the categories of present or absent, based on their estimated morphological thresholds (Turner, 1987, 1985). Dichotomization is necessary to allow statistical analyses, including the mean measure of divergence (MMD). For any non-metric trait that can be recorded on more than one tooth it is necessary to choose a key tooth as the basis for the frequency data for statistical analyses (Scott and Turner, 1997; Turner et al., 1991). This is because the same genes control the phenotypic expression of a trait on different teeth so that using the frequencies of a trait on every tooth upon which it was observed would exaggerate the importance of a trait based simply upon how many teeth it can be observed on (Scott and Turner, 1997; Sofaer et al., 1972). The tooth used for frequency counts corresponds to the one most commonly used by other researchers as presented in chapter five of Scott and Turner (1997).

To calculate the biodistance within Satricum, the MMD R-Script of Sołtysiak (2011) was used, which gives a dissimilarity measure that is quantified on a scale ranging from 0 to 1, where proximity to 0 indicates high similarity and proximity to 1 indicates low similarity (Sjøvold, 1977; Stark, 2017). The script generates a matrix of MMD for a set of non-metric trait frequencies. When the MMD is $>$ 2 standard deviations (SD) at the 0.025 level, the null hypothesis (group 1 = group 2), is rejected, meaning the difference is considered statistically significant (Irish, 2010; Sjøvold, 1977). The script also generates a list of the traits with two values for each trait, namely the mean MMD value and proportion of positive MMD. Sołtysiak (2011, p. 42) states that a negative MMD value indicates that the sample size may be too small and/or a given trait does not differentiate between samples (see also Harris and Sjøvold, 2004). Therefore, the traits that have a negative mean MDD are excluded in order to obtain clearer inter-population differentiation (Sołtysiak, 2011, p. 42).

3. Results

3.1. Elemental and isotope analyses

The elemental and isotope results are presented in Table 1. The $^{87}Sr/^{86}Sr$ results range from 0.7096 to 0.7103, with a mean value of 0.7101, which fall within the expected $^{87}Sr/^{86}Sr$ range of 0.7090–0.7103 of the Colli Albani as suggested by Killgrove and Montgomery (2016). When using the range defined by the $^{87}Sr/^{86}Sr$ variation map of Italy composed by Emery et al. (2018) – 0.7088 to 0.7095 – all the individuals analysed here would be "non-locals" which is very unlikely, thus suggesting that the range defined by Killgrove and Montgomery (2016) is more appropriate for the current study.

Wright (2005) proposed a statistical approach to identify individuals that deviate from the general trend of the population based on the assumption that strontium isotope values of a "local" population show a normal or Gaussian distribution. As such, even if they still fall within the "local" range defined above, three individuals have significantly lower $^{87}Sr/^{86}Sr$ values than the rest of the population: S136, S176b and S163 (Fig. 4).

The 43 oxygen isotope samples show a normal distribution with an estimated mean value of drinking water of $-5.6 \pm 0.2‰$ (Chenery et al., 2012) (Fig. 4). This value falls within the expected range according to the isomap of Giustini et al. (2016). The same accounts for the OPIC baseline value of $-5.7 \pm 0.4‰$. All values fall within the range suggested by Lightfoot and O'Connell (2016) (1.5IQR in $\delta^{18}O_p$).

The strontium concentrations of the 43 samples are between 205 and 808 ppm. Similar values have been found in Neolithic individuals from Northern Spain measured by ICP-MS (Fernández-Crespo et al., 2020) and by micro x-ray fluorescence (μXRF) (de Winter et al., 2019). When comparing the mean values of SW (n = 28, M = 426 ppm, SD = 90) and PdC (n = 13, M = 634 ppm, SD = 111) with an independent samples *t*-test, SW has statistically significantly lower strontium concentrations than PdC (t(39) = -6.420, p = 0.000). Interestingly, the three samples that had lowest strontium isotope ratios (S136, S163 and S176b) are the three samples with the lowest strontium concentrations (Fig. 5).

The carbon isotopes range from -13.1 to $-9.3‰$ suggesting a primarily terrestrial-oriented C_3 diet but possibly including some C_4 and/or marine resources for some of the more elevated values. This range overlaps with the values observed for other populations from the region (Killgrove and Tykot, 2013; Prowse et al., 2005). The mean $\delta^{13}C$ value is slightly lower at PdC (n = 13, $-12.2 \pm 1.1‰$, 2SD) than at SW (n = 28, $-11.8 \pm 1.8‰$, 2SD), but is not statistically different when using an independent samples *t*-test (t(38) = 1.389, p = 0.173). All

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[1] The Carrara Marmor standard is a marble powder with an ^{18}O value of $-1.88‰$, the REI was received by the VU lab via a third party and has an ^{18}O of $-7.83‰$. The values are less well calibrated but can still indicate the precision. The combination of both increases the reliability, even though it is not an accredited international standard (R. van Baal, personal communication, 2016).

[2] Only 3% of the scored teeth have a wear score (Brothwell, 1989) higher than 3+.

Table 1

Converted $\delta^{18}O_C$ (VPDB-VSMOW), $\delta^{18}O_{dw}$, $^{87}Sr/^{86}Sr$ and [Sr] values for 43 individuals from Satricum. *[Sr] data obtained by normalizing the calcium data to 40%.

SITE	SAMPLE ID	TOMB	δ^{13}C VPDB (‰)	SD	δ^{18}Oc VPDB (‰)	SD	δ^{18}Oc VSMOW (‰)	δ^{18}Odw VSMOW (‰)	^{87}Sr/^{86}Sr batch 1 (VU)	2σ	^{87}Sr/^{86}Sr batch 2 (ULB)	2σ	[Sr] ppm*
Acropolis	1	**A6**	−12.2	0.13	−3.8	0.12	27.0	−5.8	0.710102	0.000009	0.710118	0.000005	542
	2	**A7**	−12.0	0.17	−4.0	0.28	26.8	−6.0	0.710095	0.000009			586
Poggio dei Cavallari	3	**P33**	−12.8	0.08	−3.2	0.14	27.7	−4.7			0.710113	0.000008	602
	4	**P38**	−12.4	0.12	−4.1	0.13	26.7	−6.1	0.71012	0.000008	0.710104	0.000008	692
	5	**P40**	−12.9	0.15	−2.7	0.12	28.1	−3.9			0.710040	0.000008	808
	6	**P48**	−11.6	0.15	−4.2	0.11	26.6	−6.3			0.710233	0.000008	632
	7	**P51**	−12.0	0.16	−3.8	0.19	27.0	−5.7	0.710043	0.000009			497
	8	**PXI**	−11.9	0.06	−3.6	0.10	27.2	−5.4	0.710045	0.000008			383
	9	**PXIV**	−12.4	0.12	−3.1	0.18	27.7	−4.6			0.710239	0.000008	710
	10	**PXXIXB**	−12.4	0.11	−2.1	0.15	28.7	−2.9			0.710043	0.000007	712
	11	**PXXIXC**	−12.9	0.14	−3.8	0.10	27.0	−5.7			0.710110	0.000008	747
	12	**PXXVIII**	−11.4	0.10	−4.6	0.16	26.1	−7.1	0.710123	0.000009	0.710111	0.000008	643
	13	**PXXXB**	−12.2	0.08	−3.6	0.09	27.2	−5.3			0.710137	0.000006	577
	14	**PXXXIII**	−12.6	0.09	−3.2	0.15	27.6	−4.7			0.710111	0.000008	592
	15	**PXXXIX**	−11.2	0.18	−3.7	0.24	27.1	−5.5			0.710015	0.000008	650
Southwest	16	**S109**	−12.8	0.14	−4.7	0.10	26.0	−7.3	0.710145	0.000008			527
	17	**S11**	−12.9	0.20	−3.6	0.18	27.2	−5.4			0.710125	0.000011	496
	18	**S116**	−11.5	0.11	−3.0	0.13	27.8	−4.5	0.710188	0.000009			520
	19	**S122**	−12.3	0.11	−3.7	0.13	27.1	−5.6	0.710172	0.000009	0.710168	0.000008	427
	20	**S123**	−13.1	0.08	−2.8	0.09	28.0	−4.1			0.710284	0.000034	421
	21	**S129**	−12.1	0.07	−2.6	0.07	28.2	−3.7	0.710170	0.000009			410
	22	**S131**	−12.7	0.14	−4.2	0.11	26.6	−6.3	0.710107	0.000009			339
	23	**S134**	−9.4	0.15	−3.3	0.17	27.5	−4.8			0.710129	0.000006	411
	24	**S135**	−12.6	0.17	−3.5	0.15	27.3	−5.2			0.710128	0.000009	421
	25	**S136**	−12.5	0.10	−3.1	0.12	27.7	−4.5			0.709892	0.000009	248
	26	**S137**	−12.0	0.11	−4.0	0.12	26.8	−6.1			0.710097	0.000010	437
	27	**S138**	−12.0	0.16	−4.6	0.17	26.2	−7.0			0.710133	0.000008	449
	28	**S139**	−11.4	0.10	−4.4	0.10	26.4	−6.6	0.710135	0.000009			480
	29	**S140**	−11.5	0.22	−4.2	0.21	26.6	−6.3			0.710217	0.000008	473
	30	**S141**	−11.9	0.29	−4.2	0.18	26.6	−6.3	0.710094	0.000008			470
	31	**S156**	−11.3	0.16	−3.4	0.11	27.4	−5.0			0.710145	0.000009	514
	32	**S157b**	−11.1	0.17	−3.6	0.10	27.2	−5.3	0.710134	0.000007			542
	33	**S159b**	−11.7	0.19	−4.9	0.29	25.8	−7.5			0.710098	0.000007	453
	34	**S160b**	/	/	−3.8	0.30	27.0	−5.7			0.710139	0.000007	491
	35	**S163**	−10.7	0.16	−4.1	0.15	26.7	−6.2			0.709614	0.000006	205
	36	**S164**	−11.3	0.09	−3.8	0.07	27.0	−5.7			0.710025	0.000009	382
	37	**S167**	−10.0	0.19	−4.1	0.18	26.7	−6.3			0.710188	0.000009	530
	38	**S169**	−12.8	0.11	−4.6	0.10	26.1	−7.1			0.710279	0.000008	446
	39	**S176b**	−12.7	0.10	−4.2	0.14	26.6	−6.3			0.709641	0.000008	226
	40	**S179**	−11.4	0.18	−4.5	0.15	26.2	−6.9	0.710113	0.000008			340
	41	**S23**	−11.9	0.08	−3.0	0.09	27.9	−4.3	0.71008	0.000008			460
	42	**S64b**	−12.9	0.32	−2.8	0.13	28.0	−4.1	0.710206	0.000009	0.710188	0.000008	469
	43	**S9**	−10.6	0.16	−4.3	0.20	26.5	−6.5			0.710138	0.000008	330
		MEAN	−12.0	0.14	−3.7	0.15	27.1	−5.6	0.710122		0.710097		495

isotopic data together with other supporting information from this study has been added to the IsoArcH database (Salesse et al., 2018; URL 3).

3.2. Dental non-metric trait analysis

Out of the 217 teeth which were scored twice, 12 teeth (5.5%) were scored differently in the separate sessions. In these cases, the second scoring is preferred because it was done at a more experienced stage of the observer. The intra-observer agreement is 94.5%, indicating that the non-metric traits were consistently recorded. In Table 2 a summary of the observable maxillary and mandibular trait frequencies of the Satricum population can be found.

Dental non-metric traits that have a 100% presence in Satricum are the metacone and hypocone on the first molars. Moreover, the metacone on the third molar was almost always present in the Satricum assemblage (96.9%). Usually the first molar hypocone is relatively absent (20–35%) in Western Eurasian populations and highly present in Sub-Saharan Africa, Australia, New Guinea (absence 0–10%) (Scott and Turner, 1997, p. 236). This trait is therefore very interesting for further research. Besides the already mentioned traits, all individuals in the Satricum population have four or more cusps on their lower second molars and third molars. Four-cusped lower molars are also more frequently present in Western Eurasian populations than others (Scott and Turner, 1997, p. 236). Furthermore, first molar cusp 7, and third molar cusp 6 and cusp 7 are absent. In general, the Satricum population corresponds quite well with the trait frequencies in Eurasian populations according to Scott and Turner (1997, p. 236).

The Satricum assemblage is divided into two groups based on cemetery to assess differences in trait frequencies (Table 2). In general, SW has higher trait frequencies than PdC. When looking at the 18 traits present on the key teeth used in the MMD analysis (marked with (*) in Table 2), the same trend can be seen (Fig. 6). The maxillary traits such as shovelling, tuberculum dentale, and molars with cusp number 5, are more present in SW than PdC. Furthermore, Carabelli's trait and premolar mesial and distal cusps are absent in PdC, but are strongly present in SW. The mandibular teeth also show differences in key tooth trait frequencies between the necropoleis. Again, SW has many higher trait frequencies than PdC. Similar to the upper molars, the lower molars of the SW in general have more cusps than PdC. Also, the anterior fovea is more present in SW than in PdC. The protostylid does not have a high trait frequency in PdC. In SW, when using score one as the breakpoint, the protostylid on the first molar is present in approximately half of the population. It should be kept in mind that the number of observable teeth was in some cases rather small, which could

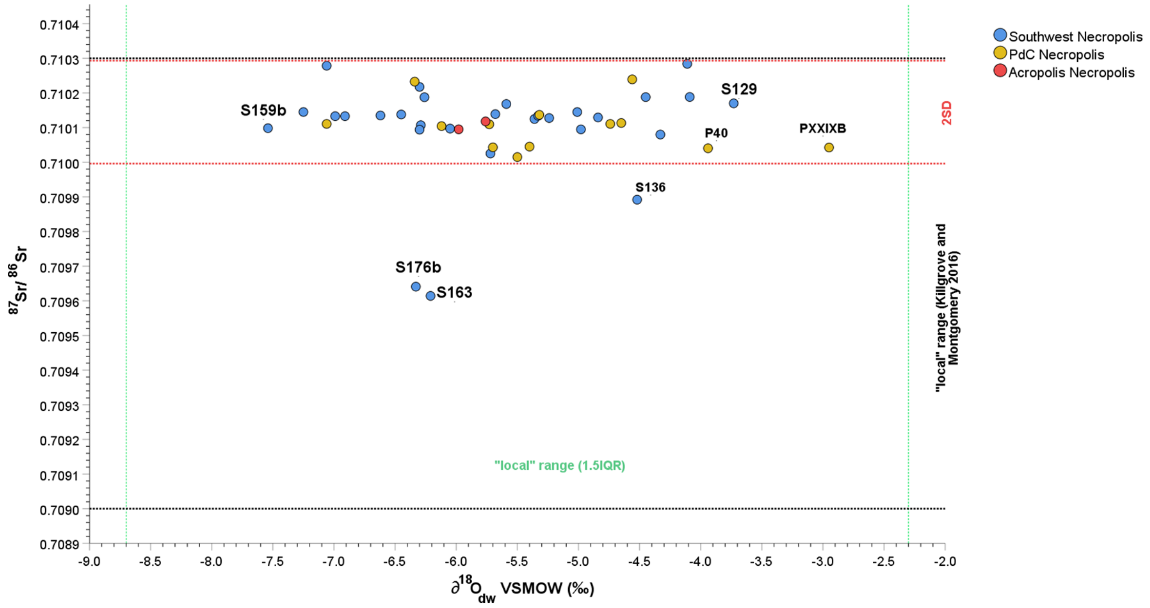

Fig. 4. Strontium and oxygen isotope data from Satricum in comparison with estimated local $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ ranges (vertical and horizontal lines, respectively).

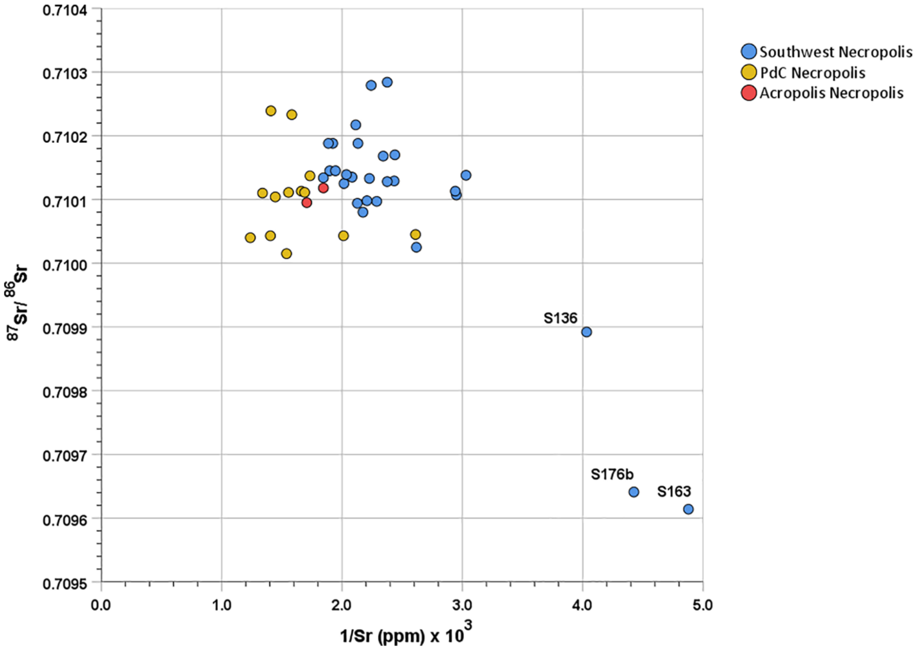

Fig. 5. $^{87}Sr/^{86}Sr$ vs. $1/Sr*10^3$ of the three necropoleis.

result in a trait frequency that is not actually representative of the population.

The R-script by Sołtysiak (2011) was run two times to filter out the traits with a negative MMD value. Eighteen traits were included in the final MMD analysis (Table 2). The results find the two groups to be biologically dissimilar, thus rejecting the null hypothesis at the 0.025 confidence level (PdC = SW), when the MMD > 2SD (Irish, 2010; Sjøvold, 1977). The comparison between the two Satricum necropoleis gives a MMD value of 0.7879 (2SD = 0.1341), indicating high dissimilarity.

4. Discussion

This study combines elemental and isotope analyses of tooth enamel samples with dental non-metric traits from post-Archaic populations from three different necropoleis of Satricum. The overall oxygen and strontium isotope results fall within the defined "local" ranges. However, the Latial plain and the mountainous hinterland might not have sufficiently different $\delta^{18}O_{dw}$ ranges to be able to discriminate between individuals originating from either area. Several studies have also indicated that populations can have much more variable $\delta^{18}O$ values presumably based on underlying baseline variability (Lightfoot and O'Connell, 2016). Therefore, an origin in the Lepini mountains cannot, based on oxygen isotopes alone, be ruled out because of the overlap in $^{18}O_{dw}$ ranges. Still, the strontium isotope ratios show an extremely narrow range and thus, the considerably wide spread of the $\delta^{18}O$ values is more likely to be a result of intra-population variation caused by metabolism and differences in diet and cultural practices (e.g. Brettell et al., 2012).

While a local origin cannot be excluded, both the strontium concentration results and dental non-metric trait data show a significant difference between the individuals of the PdC and those of the SW necropoleis. The Sr concentrations, which are generally high for all three necropoleis, are significantly higher in PdC than in SW. This could

Table 2
Breakpoint, frequency in % and P/N (P = present; N = sample size) of maxillary and mandibular nonmetric dental traits of the Satricum population. Items marked with (*) are used in the MMD analysis.

TRAIT	BREAKPOINT	SATRICUM TOTAL		POGGIO DEI CAVALLARI NECROPOLIS		SOUTHWEST NECROPOLIS	
		%	P/N	%	P/N	%	P/N
MAXILLA							
I1 Labial curve*	3–4/0–4	38.9	(7/18)	60.0	(3/5)	30.8	(4/13)
I2 Labial curve	3–4/0–4	28.6	(8/28)	25.0	(3/12)	31.3	(5/16)
I1 Shovel*	3–6/0–6	15.4	(2/13)	0.0	(0/3)	20.0	(2/10)
I2 Shovel	3–6/0–6	8.3	(2/24)	0.0	(0/10)	14.3	(2/14)
I1 Double shovel*	2–6/0–6	4.8	(1/21)	16.7	(1/6)	0.0	(0/15)
I2 Double shovel	2–6/0–6	6.7	(2/30)	15.4	(2/13)	0.0	(0/17)
I1 Tuberculum dentale	1–4/0–4	33.3	(4/12)	0.00	(0/3)	44.4	(4/9)
I2 Tuberculum dentale	1–4/0–4	48.0	(12/25)	9.1	(1/10)	73.3	(11/15)
C Tuberculum dentale*	1–4/0–4	56.3	(18/32)	0.0	(0/12)	85.7	(18/20)
C Mesial ridge	1–3/0–3	0.0	(0/32)	0.0	(0/11)	0.0	(0/21)
C Distal accessory ridge*	2–5/0–5	21.9	(7/32)	16.7	(2/12)	23.8	(5/20)
PM3 Mesial and distal cusps*	1/0–1	28.6	(8/28)	0.0	(0/8)	40.0	(8/20)
PM4 Mesial and distal cusps	1/0–1	30.0	(9/30)	0.0	(0/10)	45.0	(9/20)
PM3 Distosaggital ridge	1/0–1	0.0	(0/29)	0.0	(0/10)	0.0	(0/19)
M1 Metacone	2–5/0–5	100.0	(26/26)	100.0	(10/10)	100.0	(16/16)
M2 Metacone	2–5/0–5	100.0	(29/29)	100.0	(12/12)	100.0	(17/17)
M3 Metacone	2–5/0–5	96.9	(31/32)	100.0	(14/14)	94.4	(17/18)
M1 Hypocone	2–5/0–5	100.0	(25/25)	100.0	(9/9)	100.0	(16/16)
M2 Hypocone*	2–5/0–5	86.2	(25/29)	75.0	(9/12)	94.1	(16/17)
M3 Hypocone	2–5/0–5	56.3	(18/32)	50.0	(7/14)	61.1	(11/18)
M1 Cusp 5*	1–5/0–5	76.0	(19/25)	33.3	(3/9)	100.0	(16/16)
M2 Cusp 5	1–5/0–5	46.4	(13/28)	8.3	(1/12)	70.6	(12/17)
M3 Cusp 5	1–5/0–5	22.6	(7/31)	0.0	(0/14)	38.9	(7/18)
M1 Carabelli*	2–7/0–7	23.1	(6/26)	0.0	(0/10)	37.5	(6/16)
M2 Carabelli	2–7/0–7	14.8	(4/27)	0.0	(0/10)	23.5	(4/17)
M3 Carabelli	2–7/0–7	3.1	(1/31)	0.0	(0/13)	5.6	(1/18)
M1 Parastyle	1–5/0–5	32.0	(8/25)	33.3	(3/9)	31.3	(5/16)
M2 Parastyle*	1–5/0–5	14.8	(4/27)	0.0	(0/10)	23.5	(4/17)
M3 Parastyle	1–5/0–5	22.6	(7/31)	0.0	(0/13)	38.9	(7/18)
I2 Peg-shaped	2/0–2	0.0	(0/27)	0.0	(0/11)	0.0	(0/16)
M3 Peg-shaped*	2/0–2	9.4	(3/32)	0.0	(0/14)	15.8	(3/18)
PM3 Odontome	1/0–1	0.0	(0/29)	0.0	(0/9)	0.0	(0/20)
PM4 Odontome	1/0–1	0.0	(0/31)	0.0	(0/10)	0.0	(0/21)
MANDIBLE							
I1 Shovel	2–3/0–3	7.1	(1/14)	0.0	(0/8)	16.7	(1/6)
I2 Shovel	2–3/0–3	10.0	(2/20)	0.0	(0/8)	16.7	(2/12)
C DAR	2–5/0–5	36.7	(11/30)	0.0	(0/12)	61.1	(11/18)
PM3 Lingual cusps	2–9/0–9	59.3	(16/27)	9.1	(1/11)	93.8	(15/16)
PM4 Lingual cusps*	2–9/0–9	58.6	(17/29)	8.3	(1/12)	94.1	(16/17)
M1 Groove pattern	Y/Y, X, +	78.3	(18/23)	87.5	(7/8)	73.3	(11/15)
M2 Groove pattern*	Y/Y, X, +	20.7	(6/29)	14.3	(1/14)	26.7	(4/15)
M3 Groove pattern	Y/Y, X, +	38.1	(8/21)	16.7	(1/6)	46.7	(7/15)
M1 cusp #	6/4–6	8.7	(2/23)	0.0	(0/8)	13.3	(2/15)
M2 cusp #	4/4–6	100.0	(28/28)	100.0	(13/13)	100.0	(15/15)
M3 cusp #	4/4–6	95.0	(19/20)	100.0	(6/6)	92.9	(13/14)
M1 Deflecting wrinkle*	2–3/0–3	30.0	(6/20)	14.3	(1/7)	38.5	(5/13)
M1 Protostylid*	1–7/0–7	39.1	(9/23)	0.0	(0/8)	60.0	(9/15)
M1 Protostylid	2–7/0–7	0.0	(0/24)	0.0	(0/9)	0.0	(0/15)
M2 Protostylid	1–7/0–7	7.1	(2/28)	7.7	(1/13)	6.7	(1/15)
M2 Protostylid	2–7/0–7	3.6	(1/28)	7.7	(1/13)	0.0	(0/15)
M3 Protostylid	1–7/0–7	40.9	(9/22)	16.7	(1/6)	50.0	(8/16)
M3 Protostylid	2–7/0–7	9.1	(2/22)	0.0	(0/6)	12.5	(2/16)
M1 Cusp 5*	3–5/0–5	73.9	(17/23)	87.5	(7/8)	66.7	(10/15)
M2 Cusp 5	3–5/0–5	10.7	(3/28)	7.7	(1/13)	13.3	(2/15)
M3 Cusp 5	3–5/0–5	5.0	(1/20)	0.0	(0/6)	7.1	(1/14)
M1 Cusp 6*	3–5/0–5	8.7	(2/23)	0.0	(0/8)	13.3	(2/15)
M2 Cusp 6	3–5/0–5	7.1	(2/28)	7.7	(1/13)	6.7	(1/15)
M3 Cusp 6	3–5/0–5	0.0	(0/20)	0.0	(0/6)	0.0	(0/14)
M1 Cusp 7	1–4/0–4	0.0	(0/23)	0.0	(0/8)	0.0	(0/15)
M2 Cusp 7	1–4/0–4	3.6	(1/28)	7.7	(1/13)	0.0	(0/15)
M3 Cusp 7	1–4/0–4	0.0	(0/20)	0.0	(0/6)	0.0	(0/14)
PM3 Odontome	1/0–1	0.0	(0/27)	0.0	(0/11)	0.0	(0/16)
PM4 Odontome	1/0–1	0.0	(0/29)	0.0	(0/12)	0.0	(0/17)
M1 Anterior fovea*	2–4/0–4	37.5	(9/24)	12.5	(1/8)	50.0	(8/16)

indicate a difference in diet, perhaps a more meat/fish or calcium-rich based diet for those from SW versus a more plant-based diet for those buried at PdC. This might be caused by different subsistence strategies, catchment areas, or diet preferences. The slightly lower $\delta^{13}C$ values seen at PdC compared to SW might suggest the same trend, however, the difference is very small (0.4‰).

The dental non-metric trait analysis gives a statistically significant biological distance of 0.7879 between the SW and PdC necropoleis,

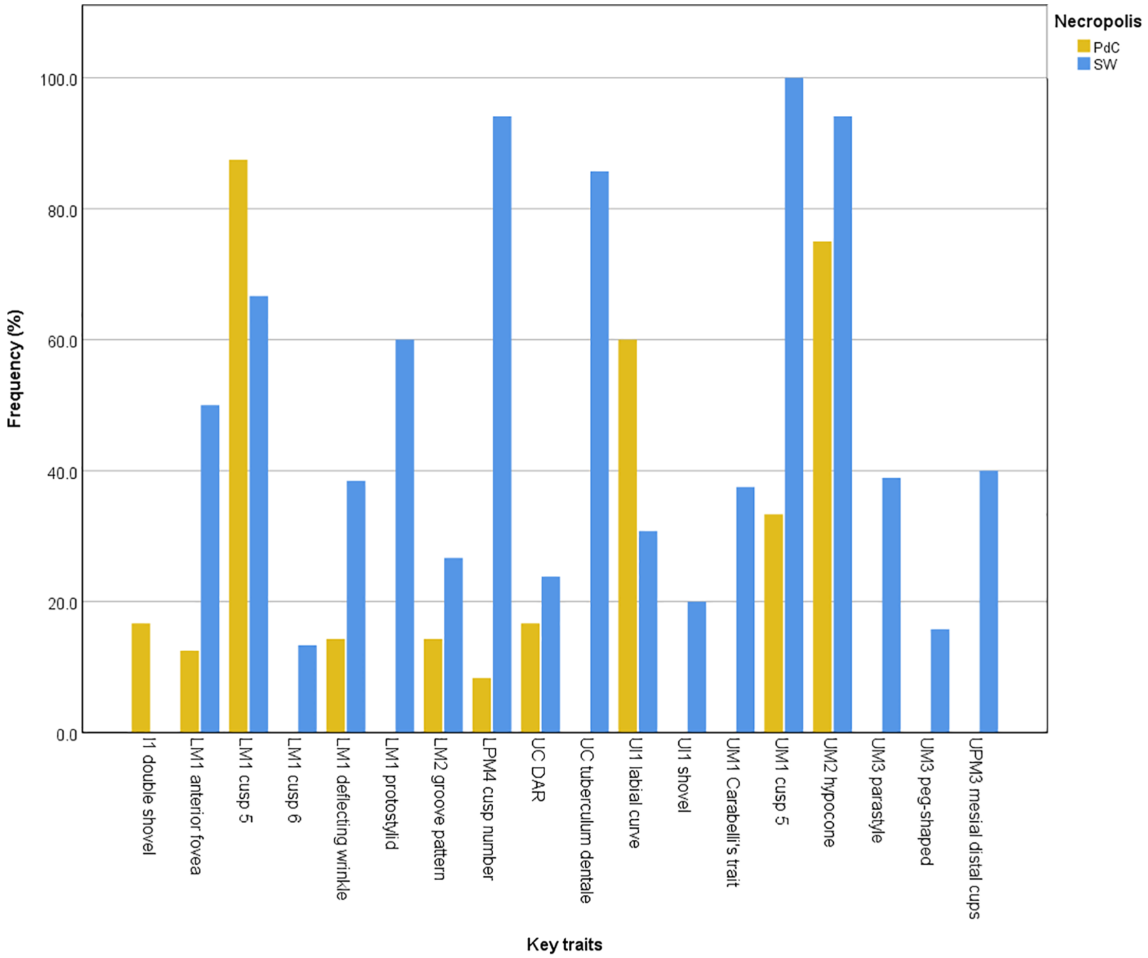

Fig. 6. Key trait frequencies (%) for PdC and SW.

which strongly suggests the presence of two different gene pools. It can be proposed that the dental non-metric trait frequencies of the two necropoleis differ because the PdC necropolis was used for a longer period of time, in which a gene flow event took place within Satricum. There is a further scenario that could explain the different non-metric trait frequencies of the two necropoleis, which involves the use of specific burial grounds by different groups within the Satricum population. Perhaps one large family group or lineage was buried in only one necropolis and the other necropolis was similarly used according to familial ties.

The material culture evidence may help distinguish among options. The burial practices across all necropoleis are very similar. The material culture within the necropoleis is also very similar. However, the PdC necropolis had a greater variety of grave goods and a greater number of pots. This could suggest a somewhat different group, but of the same cultural background, made use of the PdC necropolis, which would fit with the idea of marked gene flow occurring between the use of the SW and PdC necropoleis. This could also be consistent with different familial groups using the different necropoleis, Gnade (2014, 2018) suggestion that intersecting graves represent family members may also be support for the idea of the use of different necropoleis by different kin groups.

In the SW necropolis three individuals stand out based on both their strontium isotopes and concentrations (S136, S163 and S176b). Two of the outliers (S163 and S176) are intersecting graves, interpreted by Gnade (2002) as burials of members of one family. It is to be noted that the three tombs are lying in the northeast part of the necropolis which has been interpreted as the location of the earliest burials in the necropolis (Gnade, 2002, p. 108–109). While their strontium and oxygen isotope ratios cannot exclude a local origin, the fact that they are the only three individuals with strontium isotope values lower than 0.7100 and strontium concentrations lower than 250 ppm suggest that, in their adolescence, they had a different diet compared to the rest of the population. Since the δ^{13}C values are not higher or lower than the rest of the individuals buried in the necropolis, a change in food type is unlikely but they might have consumed some food originating from another catchment area than the others. This is also in line with having a lower strontium isotope ratio closer to the values found in the less radiogenic mountainous hinterland.

Looking at these results it is hard to determine whether the Satricum post-Archaic data are more suggestive of (1) a population that changed over time as a result of gene flow, or (2) a population that contained different kin groups that used different necropoleis. Unfortunately, the ^{87}Sr/^{86}Sr and δ^{18}O data did not allow us to confidently distinguish between individuals who lived as children in the Pontine plain (where Satricum is located) or the Lepini mountains (where the Volscians originated) and there are few ^{87}Sr/^{86}Sr and δ^{18}O outliers that offer insight into the origins of the post-Archaic Satricum peoples. Nonetheless, interesting differences in strontium concentrations that correspond with the few potential ^{87}Sr/^{86}Sr non-locals, and the dental non-metric and strontium concentration differences between the two largest necropoleis suggest that something was definitely going on with the population of Satricum in the 5th to 4th century BCE

5. Conclusion and future research

New bioarchaeologial data from human dental elements from post-Archaic Satricum gives insight regarding the ethno-cultural identity of the population. Strontium isotope ratios suggest that three individuals could have originated from a different location, of which two are spatially and possibly biologically related. A difference between cemeteries is also visible at the group level. The dental non-metric trait frequencies of the Satricum population are consistent with burial of two different gene pools. While the dental non-metric analysis does not support or refute the hypothesis of a Volscian presence in Satricum *per se*, it does indicate a shift or difference between the buried individuals during the 5th to 4th century BCE, also observed in the strontium concentration results. Future research is needed to determine the geographic origin(s) of the different biological groups. An extended dental non-metric trait analysis of Satricum, with a larger sample size and including all three necropoleis, and other 'Volscian' sites located in the mountainous hinterland (i.e. Frosinone), could bring forth new insights into the biological continuity or discontinuity at Satricum. Future aims also include the analysis of more samples (enamel, bone, faunal remains, and plant samples as proxy) for isotopic research from Satricum and Frosinone. Moreover, the research could benefit from the possible application of additional isotopes useful in assessing migration and mobility, such as lead and sulphur, and diet, such as carbon and nitrogen in bone collagen. Finally, organic preservation at Satricum is often quite poor, but should elements of good preservation be excavated, ancient DNA analyses could offer much insight into the biological relatedness and hence origins of the peoples of ancient Satricum.

CRediT authorship contribution statement

Amanda Sengeløv: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **Giswinne van de Wijdeven:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Writing - review & editing. **Christophe Snoeck:** Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing - original draft, Writing - review & editing. **Jason Laffoon:** Conceptualization, Methodology, Resources, Supervision, Writing - review & editing. **Rens de Hond:** Conceptualization, Visualization, Writing - original draft, Writing - review & editing. **Marijke Gnade:** Conceptualization, Funding acquisition, Resources, Supervision, Writing - review & editing. **Andrea Waters-Rist:** Conceptualization, Methodology, Resources, Supervision, Validation, Writing - original draft, Writing - review & editing.

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