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Imperial Roman Mobility and Migration at Velia (1st to 2nd c. CE) in Southern Italy

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Abstract:

Mobility and human migration are seen as hallmarks of Roman society. With increasing territorial expansion throughout the Mediterranean region during the Imperial Roman period, wider opportunities for both self-driven and forced mobility became possible. This study analyzes $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values from the dental enamel of 20 human second molars (M2) to examine for potential instances of mobility at the 1st to 2nd c. CE site of Velia, located on the Tyrrhenian coast of southern Italy. Velia served as a secondary port and was utilized for the shipment of goods, boat maintenance, fish processing and arboriculture. Bagplot analysis indicates that at least 10% (n=2/20) of the individuals sampled immigrated to Velia from non-local regions. The remaining 18 individuals show mixed signs of local residency and local mobility. Comparison of the Velia data with the contemporaneous southern Italian Imperial Roman (1st to 4th c. CE) site of Vagnari indicates a similar level of mobility to both sites. Though mobility is clearly evident among the individuals sampled from Velia, mobility to Velia appears to have been less common than to larger cosmopolitan sites, such as Portus, in proximity to the capital at Rome.

Highlights:

1. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ were used to assess mobility at Imperial Roman Velia

2. Bagplot analysis of $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values identified two individuals as non-local

3. Mobility at Velia appears relatively local

4. Areas of isotopic homogeneity may obscure regional origins and cases of mobility

5. Velia provides insight to mobility in Imperial Roman southern Italian contexts

Keywords: oxygen and strontium isotopes; Italian peninsula; Imperial Rome; Mediterranean; migration and mobility

Declarations of Interest: None

1. Introduction

The question of how do we conceptualize and identify migrants in ancient Roman contexts remains a core issue in modern Roman studies. Traditionally, migrants have been conceived of as outsiders coming in. More recent theorizations on mobility and human interaction have moved away from “us” and “them” conceptions to discuss mobility in terms of both variation in distance from an original homeland as well as transition in cultural continuity, placing qualifiers on what the distance an individual travelled means in terms of how they would have integrated into the social environs in which they ultimately came to reside (Albrecht 1972; Kearney 1986, 1995; Burmeister 2000; Brettel 2015; Moatti 2019). As Horden and Purcell (2000) contend, it is theoretically challenging to speak of the population of a city or region, given that on any given day there will be within the boundaries of a city, or imperial territory, hundreds of individuals who will not be there tomorrow, thousands who will not be there a year from now and tens of thousands who will have left the city over a decade. The converse can also be argued in terms of individuals who will arrive: in the Roman Imperial period it has been suggested that ~40% of adult Italian males over age 45 would have dwelt in a place different to their birthplace (Pearce 2010). A wide range of evidence, from epigraphy to burial style and chemical methods, have been utilized within Roman studies to identify mobile individuals and to qualify potential instances of and reasons for mobility.

From epigraphic and literary sources, it is clear that mobility events in the Roman circum-Mediterranean were common (Huttunen 1974; Wierschowski 1995; Noy 2000, 2010). One of the challenges of these sources, however, is that inscriptional evidence reflects only individuals who received burial commemoration and who explicitly had their experience of mobility documented, such as the rare case of Barates of Palmyrene origin and his wife Regina of Catuvellaunian origin (Noy 2010). Social and linguistic factors may have also played a role in the commemoration of homelands in epigraphic materials. It has been argued that some locations of origin may have carried greater potential stigma than others and as such were likely less frequently recorded, with Noy (2000) noting that it may be significant that the vast majority of Egyptians documented in the pagan civilian epitaphs are listed as having a connection to Alexandria and not Egypt.

Who then were the most likely to have their homelands commemorated? It has been argued that soldiers were the most likely to provide insight to their place of origin, having likely never intended to move to the military outpost where they ultimately perished (Noy 2000, 2010; Wierschowski 2001; Woolf 2013). In rare instances epigraphic materials can provide insights to multiple migrations, such as the epitaph discussed by Moatti (2006) of an artisan who made seventy-two journeys from Phrygia to Rome. Regionally specific names can also help identify potential cases of migration, though caution is needed as regionally specific names do not necessarily imply foreign origins as such names may simply be ancestral or family names (Maier 1953-1954; Cebeillac-Gervasoni 1996; Salomies 2002; Noy 2010). Documentation of foreign deities can also provide indirect evidence of nonlocal individuals in a region, such as the worship of Syrian storm gods along the Danube and Rhine frontiers (Fulford 2010; Hin 2013; Woolf 2013). The use of epigraphic evidence is, however, faced with the challenge that males are disproportionately represented over females, with Noy (2000) identifying 76.7% of Roman epigraphs as documenting males, whereas only 21.0% document females.

Similarly, literary sources, in many cases, provided a skewed representation of the nature of mobility. Typically written by social elites, literary accounts of mobility often have a distinct agenda: either embracing the merits of migration, recording prestigious and “exotic” foreigners, or vilifying various foreign groups; it is uncommon to find textual evidence regarding more mundane migrations (e.g. mobility related to work), even though it is clear from other sources, such as censuses and documents discussing trade, that employment-related migration was ubiquitous (Vallat 2001; Salomies 2002; Helttula 2007; Bruun 2010; Noy 2010; Hin 2013;

Woolf 2013). Ball (2000) likens this process of selective epigraphic commemoration and textual discussion to believing what you see on television, in that such evidence presents one perspective that must be treated with due caution as it is not always free of bias.

Burial style and grave goods have also long been a method for examining possible instances of foreignness and migration in archaeological contexts (Saxe 1970; Morris 1992; Fontana 2001; Sprague 2005; Pearce 2010; Wells 2013). However, as Pearce (2010) notes, caution is needed so as not to equate a culture-historical view of burial practices with a specific "people." Noy (2000) contends that there is very little evidence that groups with a common geographical origin ever established their own separate burial areas in Rome. This is further supported by the fact that there are, to date, no known ancient burial grounds reserved for "foreigners" at Rome, suggesting a degree of homogenization in burial that makes separating regional origins of buried individuals based on burial style alone unlikely (Nuzzo 1997).

With the advent of isotopic methodologies came the possibility to assess mobility events at an individual level based on preserved chemical values within skeletal materials. Though this method cannot attest to the name or precise homeland of origin, it does provide insight to mobility that can be developed in tandem with other methods to provide increasingly nuanced assessments of individual and group mobility events.

Initial isotopic studies of Imperial Roman mobility in Italy focussed on the area around Rome (e.g. Prowse et al. 2007; Killgrove 2010a, b; Killgrove and Montgomery 2016), with subsequent studies presenting data from broader pre-Roman and Roman contexts, such as those examining mobility and genetic diversity at Vagnari and Botromagno (Roman Silvium) in southern Italy (Prowse et al. 2010; Emery et al. 2018a, b). To varying degrees, these studies all documented instances of mobility. The distance of mobility and evident regions from which migrants emigrated however, are variable. The studies of Prowse et al. (2007) at Isola Sacra and Killgrove (2010a, b, c, 2013, 2014) and Killgrove and Montgomery (2016) at Casal Bertone and Castellaccio Europarco suggest a much more geographically diverse nature of mobility to the area around Rome in comparison to the more regionally-local mobility evident at Vagnari in southern Italy, though mobility from evidently distant locales was evident at this site as well (Prowse et al. 2010; Emery et al. 2018a, b). This diversity of mobility patterns brings into question the nature of migration to larger cosmopolitan centres, such as Rome, in comparison to mobility to more rural and provincial settings, such as those at Vagnari and Velia.

What remains clear regardless of the methodology employed, is that mobility was a common occurrence within Imperial Roman contexts. Who was mobile, the pattern of mobility, and the purpose of mobility remain much greater challenges to address substantively. The study presented herein utilizes oxygen ($\delta^{18}O_{dw}$) and strontium ($^{87}Sr/^{86}Sr$) values to provide an assessment of mobility at the Imperial Roman site of Velia (1st to 2nd c. CE). This study seeks to investigate the degree of mobility to Velia, a secondary port city where access to the Italian peninsula via coastal routes is expected to have resulted in higher rates of mobility compared to inland sites in southern Italy, such as Vagnari, but less frequent, and ostensibly less regionally diverse, than at primary ports and major cities, such as Portus and Rome.

1.2 The Site of Velia

Velia is located on a promontory on the Tyrrhenian coast of Italy in the Cilento of Lucania between the mouths of the rivers Alento and Fiumarella, 112 km southeast of Naples (Pellegrino 1957; Richardson 1976) **(Fig. 1)**. Velia (Elea) originated as a Phocaean colony known as Hyele in ca. 540 BCE, during which time construction concentrated in the area of the acropolis (Pellegrino 1957; Musti 1966; Cerchiai 2004; Mele 2006; Nenci and Vallet 2012).

Fig. 1: Map showing the location of the sites of Velia, Botromagno (Roman Silvium), and Vagnari.

Following incorporation into Roman territory in the 3rd c. BCE, development focussed in the southern quarter, including the establishment of a necropolis (Richardson 1976; Ermolli et al. 2013).

Numerous accounts of the ruins at Velia are provided by early travelers in the region, with the first known being that of Carletti in 1794 (Vecchio 2007). Ramage (1868) describes a number of the Roman ruins and Schleuning (1889) provides an early archaeological assessment of Velia, but it was not until 1927 that limited excavations began under the direction of Amedeo Maiuri, Superintendent of Campania (Vecchio 2007). Extensive excavation of the site was initiated in the 1960s with the research of Mario Napoli on the southern slope of the Phocaean acropolis (Napoli 1972; Krinzinger and Tocco Sciarelli 1997; Vecchio 2007). From 1969–1978 and throughout the 1990s, a systematic survey of the ruins of the Phocaean colony was undertaken by German and Austrian archaeological missions (Fiammenghi 1994; Krinzinger and Tocco Sciarelli 1997).

Archaeological research on the Roman contexts at Velia focussed in the southern part of the site, around the area of the Porta Marina Sud. Several houses, a building with a cryptoporticus, and early Imperial era structures flanking the road exiting the Porta Marina Sud were documented in this area (Krinzinger and Tocco Sciarelli 1997; Fiammenghi 2003; Fiammenghi and La Torre 2005). The Porta Marina Sud area is also the location of the Roman necropolis (ca. 1st to 2nd c. CE), identified along what Fiammenghi and La Torre (2005) refer to as a “street of burials” in proximity to the coast **(Fig. 2)**.

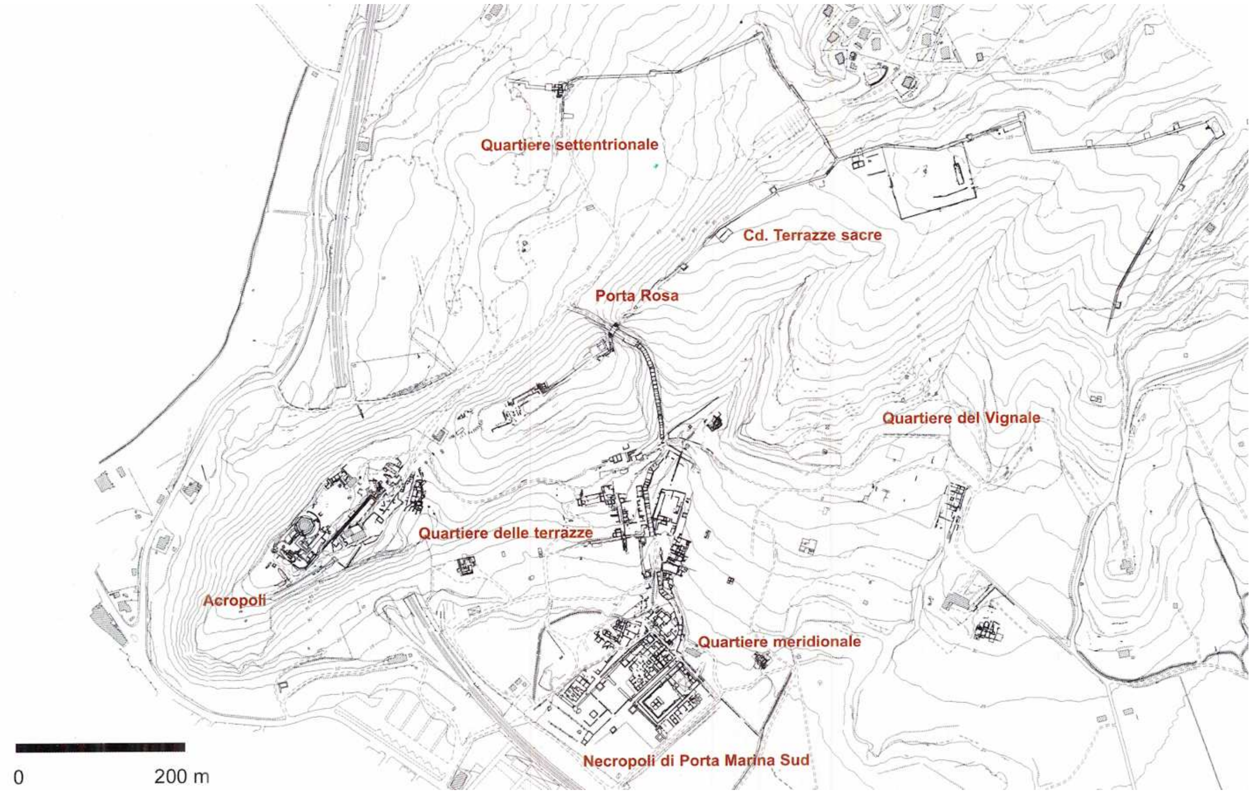

Fig 2. Velia site plan showing the Acropolis and Imperial Roman settlement, including the necropoli di Porta Marina Sud (as published in Greco 2003).

The Roman necropolis at Velia was investigated by Fiammenghi (2003), who notes that, up until the time of her research, the only known information about the necropolis had come from the works of Ebner (1962, 1970, 1978) who discusses a limited number of decontextualized funerary inscriptions. Excavations by Fiammenghi identified approximately 330 burials scattered over a 0.5 ha area with no apparent subdivisions of the cemetery (Fiammenghi and La Torre 2005).

Burial types at Velia ranged from simple earthen graves to monumental tombs and mausolea (Fiammenghi 2003; Fiammenghi and La Torre 2005). To date, only the earthen graves have been excavated, of which both cremations and inhumations were documented (Craig et al. 2009). Each grave contained a variable number and type of grave goods, though the exact type and distribution of grave goods is currently unknown as the necropolis has not been fully published. Both Fiammenghi (2003) and Craig (2009) note that evidence of variation in social status was not evident from burial contexts alone. Bioarchaeological examinations of the Roman skeletal remains from Velia have focused on dietary reconstruction (Craig et al. 2009), dental asymmetry (LaFleur 2011), palaeodemography, health status and working activities (Crowe et al. 2010; Sperduti et al. 2012; Bondioli et al. 2016; Marciniak et al. 2016), and age-related bone loss (Beauchesne and Agarwal 2014).

1.3* $\delta^{18}O$ *and* $^{87}Sr/^{86}Sr$ *Variation in Nature

The water cycle is the key medium through which oxygen isotope variation occurs and can be tracked: $\delta^{18}O$ of precipitation generally decreases with distance from a marine coastline, increase in elevation and latitude, and decrease in temperature of precipitation and increasing latitude, with further potential effects due to humidity (Dansgaard 1964; Gat 1996, 2005; Gat et al. 2003; Bowen 2010; Schwarcz et al. 2010). In continually hot climates (> ~25ºC) this trend breaks down and one must rely on the amount of precipitation, where low $\delta^{18}O$ values occur in rainy periods and high $\delta^{18}O$ in dry periods (Dansgaard 1964). Using these parameters, global variability of $\delta^{18}O$ in meteoric precipitation can be mapped using region specific data, such as those compiled as part of the Global Network of Isotopes in Precipitation (GNIP) project (GNIP 2015).

$^{87}Sr/^{86}Sr$ values in underlying geology are dependent upon time allowed for $^{87}Rb \rightarrow ^{87}Sr$ decay, with ^{87}Rb having a half-life of ~4.88 x 10^{10} years; initial $^{87}Sr/^{86}Sr$ ratio; and original concentrations of ^{87}Rb and ^{87}Sr (Faure and Mensing 2005; Dickin 2005). Rocks that are very old (i.e. >100 mya) with high original $^{87}Rb/^{87}Sr$ content have $^{87}Sr/^{86}Sr$ values generally >0.710, with the upper limit being ~0.750; rocks formed comparatively recently (<1–10 mya) with low original $^{87}Rb/^{87}Sr$ have low $^{87}Sr/^{86}Sr$ values, generally <0.704; the $^{87}Sr/^{86}Sr$ of river water varies with local geology, while marine water has had a value of ~0.7092 for at least the last 10,000 years (Faure and Powell 1972; DePaolo and Ingram 1985; Elderfield 1986; Veizer 1989; Bentley 2006; Copeland et al. 2008; Malainey 2010; Bataille and Bowen 2012; Zaky et al. 2019).

1.4* $\delta^{18}O$ *and* $^{87}Sr/^{86}Sr$ *in Dental Enamel and Dental Development

Oxygen and strontium in enamel reflect values integrated during dental development from the foods ($^{87}Sr/^{86}Sr$) an individual eats and the water ($\delta^{18}O$) they consume, with dietary water and atmospheric oxygen playing minor secondary roles (Bentley 2006; Hedges et al. 2006; Price and Burton 2002). $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ are integrated into bioapatite, ($Ca_9(PO_4)_{4.5}(CO_3)_{1.5}(OH)_{1.5}$), allowing for their use in tracing instances of mobility (Rey et al. 1991; Kolodny and Luz 1991; Arppe and Karhu 2005; Price and Burton 2011; Rabadjieva et al. 2011). Strontium ($^{87}Sr/^{86}Sr$) can substitute for calcium (Ca) in the body and does not undergo fractionation, providing a direct reflection of the values consumed (Bentley 2006; Burton 2008; Price et al. 2015). Oxygen ($\delta^{18}O$) undergoes fractionation in the body and can be derived from two locations within apatite: carbonate (CO_3) and phosphate (PO_4) (Elliot et al. 1985; Kolodny and Luz 1991; Daux et al. 2008; Price and Burton 2011).

Dental development begins *in utero* at ~14–20 weeks post-fertilization and proceeds until around age 17 (Scheuer and Black 2000; Hillson 1996). Crown initiation for the first permanent molar (M1) is underway by birth, for the second molar (M2) by ~2.5–3 yrs., and for the third molar (M3) by ~7-10 yrs.; crown development is complete for M1 by ~2.5–3 yrs., for M2 by ~7–8 yrs., and for M3 by ~10–17.5 yrs. (Schour and Massler 1940; Hillson 1996; Al Qahtani

2009). Possible late term *in utero* diet and breastfeeding, in the case of M1, and childhood diet contribute to $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values reflected in the permanent dentition (Christensen and Kraus 1965; Herring et al. 1998; Wright and Schwarcz 1998, 1999; Knudson 2009; Schuurs 2012). Accordingly, the isotopic signature in dental enamel of the permanent dentition can be used as an indicator of residence for the period from around birth until completion of dental development.

1.5 Diagenesis and Preservation of Isotopic Values

Within depositional contexts the isotopic values present in skeletal remains can progressively equilibrate towards the isotopic signature of the surrounding matrix due to isotopic exchange, sorption factors, crystallite growth, and re-crystallization, resulting from elemental commonalities between skeletal materials and the surrounding burial environment (Likins et al. 1960; Nelson et al. 1986; Ayliffe et al. 1992; Stuart-Williams et al. 1996). Bone is very porous, being composed of smaller poorly crystalline structures, and has a significant organic component that is subject to postmortem decay and microbial attack; enamel is more resistant to diagenesis due to the larger, less porous, and denser arrangement of apatite crystals (Kohn et al. 1999; Hedges 2002; Kohn and Cerling 2002; Hedges et al. 2006; Price 2008; King et al. 2011).

Isotopic exchange towards equilibrium with the surrounding burial environment remains the key process for $\delta^{18}O$ diagenesis; for $^{87}Sr/^{86}Sr$, secondary Ca and Sr exchange with biogenic Sr through pore filling and concentration along microcracks and on the bone surface, re-crystallization, and re-mineralization of diagenetic Sr in hydroxyapatite are the key forms of diagenesis (Budd et al. 2000; Bentley 2006). Given these characteristics of diagenesis, dental enamel is the preferred material for palaeomobility studies.

2. Materials and Methods

Adult second molars (M2) from 20 individuals (10 male and 10 female) were selected for assessing potential instances of mobility to the site of Velia utilizing $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values from dental enamel. Samples were collected from the Museo delle Civiltà (formerly the Museo Nazionale Preistorico Etnografico "L. Pigorini") in Rome. The collection is curated by the Servizio di Bioarchaeologia of the Museo delle Civiltà.

2.1 Age and Sex Estimation

Age and sex estimations were determined based on macromorphological skeletal traits. Morphology of the greater sciatic notch, ischiopubic ramus, ventral arc, subpubic concavity, and cranial morphology were used for establishing sex; pubic symphysis, sternal ends of ribs, auricular surface morphology, and cranial suture closure were utilized for establishing age (Acsádi and Nemeskéri 1970; Ferembach et al. 1977-79; Buikstra and Ubelaker, 1994; Nikita, 2017).

2.2 Dental Enamel Preparation

All 20 second molars were initially manually brushed to remove adhering debris before being submerged in individual containers of distilled water (dH_2O) and ultrasonicated for 10 minutes. Ultrasonication was repeated three times changing the water after each session. Following ultrasonication, teeth were allowed to dry before using a diamond tipped hand-held electric Dremel drill to remove enamel for sampling: ≥10 mg of powdered enamel for $\delta^{18}O$ analysis and ≥60 mg for $^{87}Sr/^{86}Sr$. After each use the drill bit was soaked in 0.25M hydrochloric acid (HCl) to avoid cross contamination. Enamel powder was collected in 1.5 ml plastic centrifuge microtubes.

2.3 δ¹⁸O Methodology

Enamel preparation for oxygen ($\delta^{18}O$) isotope analysis followed the protocols established in Koch et al. (1997). Collected enamel samples were treated with 0.04 ml of 2.5% bleach solution (NaClO) per mg of sample, agitated, and allowed to react for 24 hrs. Following this reaction, samples were centrifuged and rinsed with de-ionized water five times, centrifuging after each rinse. After rinsing, 0.04 ml of 1M acetic acid acetate buffer (CH_3COOH) per mg of sample was added to remove potential diagenetic secondary carbonates. Samples were agitated and allowed to react for up to 24hrs. Samples were centrifuged and rinsed five times with de-ionized water, centrifuging after each rinse. After the fifth rinse samples were centrifuged and the remaining water removed before allowing samples to dry.

This methodology should not detrimentally affect carbonate values, though recent research has shown the potential impacts of pre-treatment chemicals, reaction temperatures, and phosphoric acid concentrations in terms of variability in results (Snoeck and Pellegrini 2015; Pellegrini and Snoeck 2016; Demény et al. 2019). Direct comparisons of samples prepared using different protocols should accordingly be undertaken with caution. In the case of the present study, potential impacts of variability in preparation methodology do not form an issue of concern as both the Velia and Vagnari samples were prepared using the same protocols and were analyzed at the same laboratory.

Once dry, 2 mg of powdered enamel was weighed into stainless steel cups. Enamel powder was reacted with 100% phosphoric acid at 90°C in an autocarb analyzer to produce CO_2 gas, which was analyzed on a VG OPTIMA Isocarb isotope ratio mass spectrometer (IRMS) at the McMaster Research for Stable Isotopologues (MRSI) laboratory to measure $\delta^{18}O$ values. For each carousel containing 14 samples one sample was run in duplicate to monitor accuracy and reproducibility. The data collected are presented using delta values (δ) such that,

$$\delta^{18}O = (^{18}O/^{16}O)_{sample}/(^{18}O/^{16}O)_{standard} - 1,$$

where $(^{18}O/^{16}O)_{sample}$ indicates the sample analyzed and $(^{18}O/^{16}O)_{standard}$ indicates an international standard, herein measured relative to the Vienna Pee Dee Belmnite (VPDB) standard. The resultant values are presented in per mil (‰) notation.

2.4 ⁸⁷Sr/⁸⁶Sr Methodology

Enamel samples were dissolved in 1.2 ml of 2.5 M hydrochloric acid (HCl) and subsequently centrifuged for 10 minutes. Cation exchange was employed to complete strontium separation. Cation exchange columns were calibrated employing a “spiked” sample followed by 10 ml of deionized water to cleanse the cation exchange columns before use. A wash of 60 ml of 6 M HCl was introduced, followed by 10 ml of deionized water, and then finally 5 ml of 2.5 M HCl. Dissolved enamel solution for each individual was introduced into the exchange columns in 1 ml portions and was washed into the column using 1 ml of 2.5 M HCl, after which a wash of 3 ml of 2.5 M HCl was introduced. Waste sample matrix was eluted using 20 ml of 2.5 M HCl. After the 20 ml elution, 6 ml of 2.5 M HCl was introduced for strontium collection. Each dried sample was loaded onto a pre-treated single tantalum filament in dilute phosphoric acid (H_3PO_4) and sequentially inserted into a vacuum system. $^{87}Sr/^{86}Sr$ values were measured by dynamic multi-collection using a thermal ionization mass spectrometer (TIMS) in the School of Geography and Earth Sciences at McMaster University. Results were fractionation normalized to

$^{88}Sr/^{86}Sr$= .1194, with an average $^{87}Sr/^{86}Sr$= 0.71026±18 (1σ) for the NIST 987 Sr standard and internal precision (within-run precision) of ±0.0012–0.0018% (1σ) standard error based on 150 dynamic cycles.

2.5 FTIR

Preservation of biogenic apatite at Velia was assessed utilizing Fourier transformation infrared spectroscopy (FTIR) analysis of dental enamel from five individuals interred at Velia. FTIR was used for calculating crystallinity index (CI) where, CI = $(A_{565} + A_{605})/A_{595}$, A_x being absorbance at the wave number X in cm^{-1}; CI values ≤3.8 indicate preservation of biogenic apatite (Shemesh 1990; Wright and Schwarcz 1996). FTIR analysis was conducted at the McMaster Combustion Analysis and Optical Spectroscopy Facility. Samples were cleaned, enamel ground into a fine powder, passed through a #200 mesh sieve, combined with dry potassium bromide (KBr), ground, and compressed into pellets at 10,000 psi. Samples were analyzed using a Nicolet 6700 dry nitrogen purged FTIR, room temperature DTGS detector with extended KBr beam splitter, resolution 4 cm^{-1} (wavenumber) at 32 scans.

2.6 Predicted Strontium ($^{87}Sr/^{86}Sr$) and Oxygen ($\delta^{18}O_{dw}$) Values for Velia

The geology of Velia is a mixture of lower Miocene flysch, including limestone, sandstone, and dolomite; lower Pleistocene conglomerates; middle Pleistocene clays with peat; and sand with volcanic ashes, as well as more recent Holocene gravels and sand with beach gravels (Gelati et al. 1989; Guariglia 2011). Based on the predictive modeling of bioavailable $^{87}Sr/^{86}Sr$ variation in Italy presented by Emery et al. (2018a), Velia is located in a region where $^{87}Sr/^{86}Sr$ values between 0.7037-0.7088 are expected **(Fig. 3)**. To provide further refinement for the environs around Velia, $^{87}Sr/^{86}Sr$ values from nine archaeofaunal pig teeth, originally presented in Stark (2016), were utilized to establish an expected bioavailable $^{87}Sr/^{86}Sr$ range. Domesticated porcine species in southern Italy are known from as early as the Bronze Age, with Lucania, the region within which Velia is located, being a key region of pork supply during the Roman era (MacKinnon 2001; Lega et al. 2016). Swine are commonly fed grains and foodstuffs consistent with or similar to those used in human diets; resultant $^{87}Sr/^{86}Sr$ values can provide valuable insight to expected local bioavailable ranges.

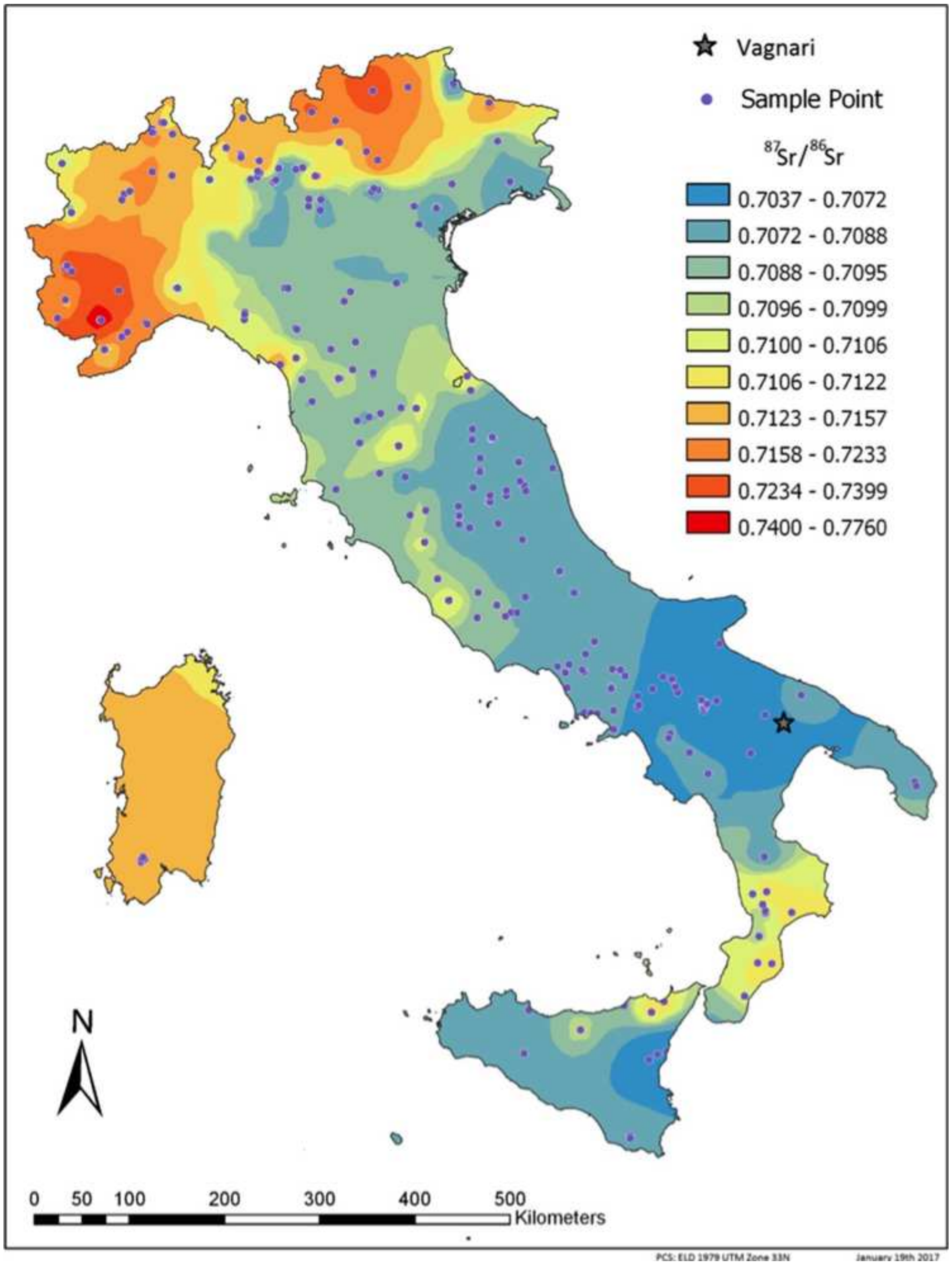

Fig. 3: Approximated distribution of bioavailable $^{87}Sr/^{86}Sr$ values for the Italian peninsula (as published in Emery et al. 2018)

In terms of $\delta^{18}O_{dw}$ variation, the data presented by Longinelli and Selmo (2003) place Velia within a region having expected $\delta^{18}O_{dw}$ values between -6‰ to -5‰. This predicted range was expanded in 2016 by Giustini and colleagues, to include values from -8‰ to -6‰ **(Fig. 4)**. Intra-population variation in local $\delta^{18}O$ values is generally accepted to be ~±1‰ (Schwarcz et al. 2010). To approximate the expected local value of meteoric precipitation at Velia and to facilitate comparison with GNIP and local $\delta^{18}O_{dw}$ datasets, $\delta^{18}O_{c}$ values were converted to $\delta^{18}O_{dw}$ following Chenery et al. (2012). Such values carry an uncertainty of ±1‰ (2σ) and are used as a guide for gauging the correspondence between individuals and their residential environment (Pollard et al. 2011; Chenery et al. 2012).

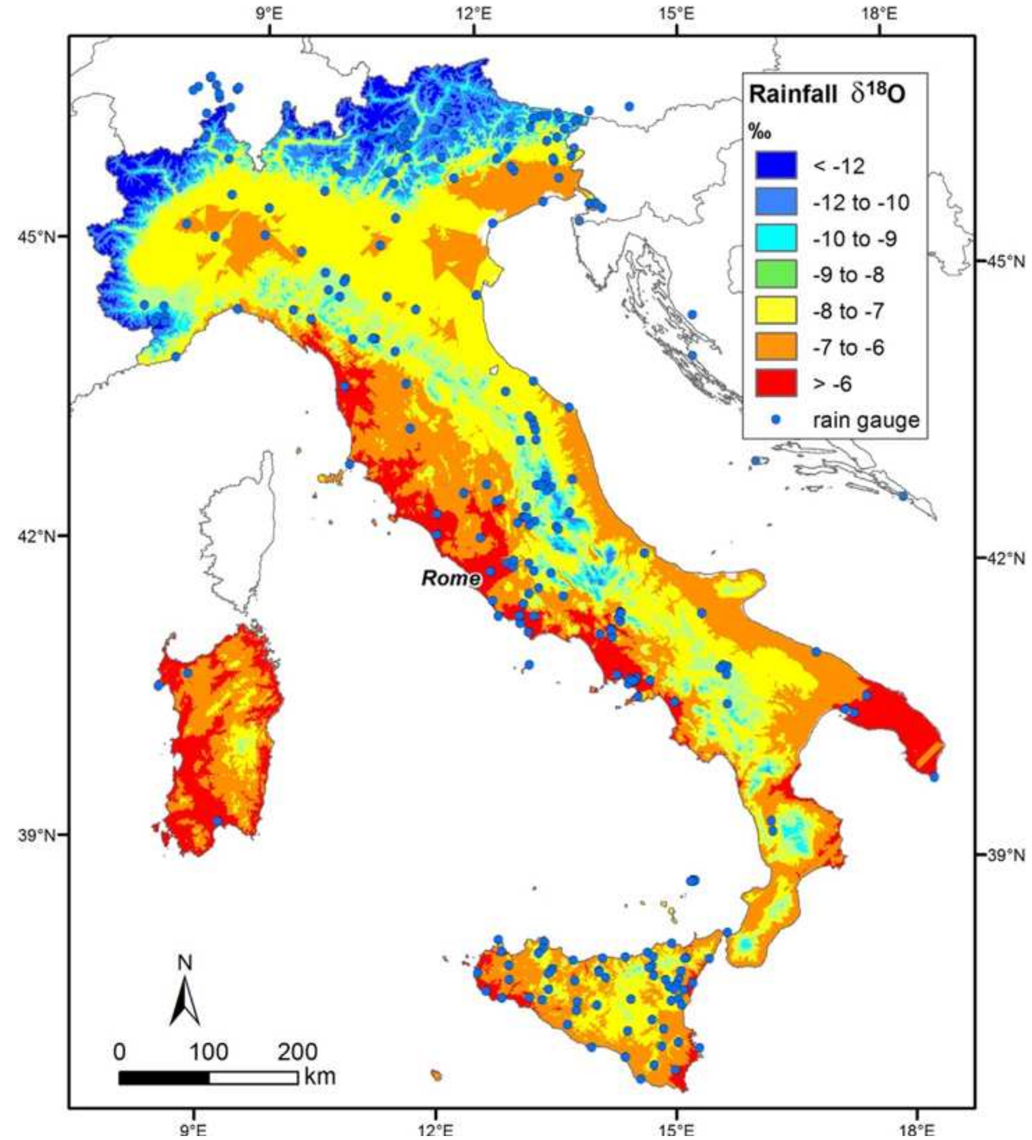

Fig. 4: Approximated distribution of δ^{18}O values in precipitation for the Italian peninsula (as published in Giustini et al. 2016).

2.7 Statistical Analyses

SPSS was used to examine for potentially significant differences in δ^{18}O and ^{87}Sr/^{86}Sr values between males and females and between age categories. A Shapiro-Wilk test was employed to gauge the normality of sample distribution. To assess for significant differences between male and female individuals, a t-test was utilized for normally distributed samples and the non-parametric Mann-Whitney U test was used for non-normally distributed samples. To examine for significant differences by age group, four age categories were established: 18-29, 30-39, 40-49, and 50+. An ANOVA test was employed for normally distributed samples and a non-parametric Kruskal-Wallis test for non-normally distributed samples (Ross 2010).

Identification of local vs. non-local individuals was determined using bagplot analysis **(Fig. 5)**. Bagplots provide a robust assessment of outliers utilizing three nested polygons known as the "bag," "fence", and "loop", which are based on a depth median, being the point with highest half space depth (visualized as a red starburst). The bag, indicated with dark blue, is established using a Tukey depth (centerpoint) and comprises ≤50% of the data points; the fence, which is not plotted, is formed by expanding the bag by a factor of three and serves to separate inliers from outliers; the resulting intermediary area between the bag and the fence, identified using light blue, is known as the loop. This loop area represents values that fall outside of the limits of the bag (i.e. values that have greater dispersion from the depth median) but are still within the established limits of the fence (i.e. are not statistical outliers). This method creates a robust threshold beyond which values can be considered confidently as outliers within a given sample (Rousseeuw et al. 1999; Gower et al. 2011; Lightfoot and O'Connell 2016).Generation of a bivariate bagplot was conducted using the R statistical package *aplpack* (Wolf 2018).

3. Results

3.1 CI Values and Defining Local Ranges

FTIR analysis yielded CI values of ≤3.8, indicating preservation of biogenic apatite within depositional contexts at Velia. Based on the $^{87}Sr/^{86}Sr$ values derived from nine archaeofaunal pig teeth from Velia, which were previously presented in Stark (2016), the expected bioavailable $^{87}Sr/^{86}Sr$ range for Velia was established by Stark (2016) as approximating 0.70783–0.70979 (2σ), a local range consistent with $^{87}Sr/^{86}Sr$ values predicted from underlying geology in regions surrounding Velia (Emery et al. 2018a). Such consistency suggests that the pig teeth utilized from Velia were not likely imported from a distant region. Based on the expected $\delta^{18}O_{dw}$ values of precipitation established by Giustini et al. (2016) in conjunction with the expected local values established by Prowse et al. (2007) for the site of Portus, located in the same isopleth as Velia further north on the Tyrrhenian coast of Italy, an expected local $\delta^{18}O_{dw}$ range for Velia was approximated as -8.9‰ to -4.8‰ (1σ).

3.2 $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ Variation among Individuals from Velia

Among the 20 individuals sampled from Velia, all of whom were interred in inhumation style graves, $\delta^{18}O_{dw}$ values varied from -1.3‰ (Velia 57) to -9.4‰ (Velia 211), a range of 8.1‰. $^{87}Sr/^{86}Sr$ values ranged from 0.70788 (Velia 57) to 0.70901 (Velia 211) (**Table 1**).

Table 1: Osteobiographic data, $\delta^{18}O_c$ VPDB, $\delta^{18}O_{dw}$ VSMOW, and $^{87}Sr/^{86}Sr$ for 20 individuals sampled from Velia

Individual	Sex	Age (yrs.)	M2 $\delta^{18}O_c$ VPDB (‰)	M2 $\delta^{18}O_{dw}$ VSMOW (‰)	$^{87}Sr/^{86}Sr$
Velia 57	M	30-35	-1.1	-1.3	0.70788
Velia 82	F	50+	-4.1	-6.2	0.70879
Velia 117	F	20-30	-5.6	-8.7	0.70880
Velia 134	F	20-30	-5.8	-9.0	0.70890
Velia 139	M	30-40	-4.6	-7.0	0.70839
Velia 146	M	43-55	-4.3	-6.5	0.70827
Velia 160	F	30-40	-4.9	-7.5	0.70866
Velia 169	M	30-40	-5.5	-8.4	0.70874

Velia 174	M	40-50	-4.7	-7.1	0.70869
Velia 181	F	50+	-4.7	-7.1	0.70866
Velia 182	M	25-30	-4.2	-6.3	0.70873
Velia 186	M	20-24	-3.6	-5.4	0.70857
Velia 194	M	30-40	-5.8	-9.1	0.70860
Velia 205	F	30-40	-2.4	-3.5	0.70868
Velia 211	M	30-35	-6.0	-9.4	0.70901
Velia 214	F	25-35	-5.5	-8.5	0.70822
Velia 222	M	30-40	-3.5	-5.3	0.70878
Velia 223	F	40-45	-5.4	-8.4	0.70875
Velia 270	F	40-50	-3.9	-5.9	0.70900
Velia 283	F	50+	-4.2	-6.4	0.70882

3.3 Normality and Significance

Mann-Whitney U (p=0.165) and t-test analyses (p=0.573) identified no significant differences between males and females at the 0.05 level. ANOVA (p=0.947) and Kruskal-Wallis (p=0.517) analyses identified no significant differences between age categories at the 0.05 level. Given the absence of statistically significant differences between age and sex categories, all samples were pooled.

3.4 Local vs. Non-Local Individuals

Taking the expected local $\delta^{18}O_{dw}$ range into consideration on its own, two females (Velia 134, 205) and three males (Velia 57, 194, 211) fall outside of the expected local range, though Velia 134 and 194 are only slightly outside of the predicted local range. No individuals fall outside of the expected local bioavailable $^{87}Sr/^{86}Sr$ range based on the values provided by the pig teeth. A graphical representation of the expected local $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ ranges is presented in **Supplementary Fig. 1**.

The use of a bivariate bagplot identified two individuals as distinctly non-local: Velia 57 and Velia 214. Several individuals also fall between the fence and the loop which, though statistically considered local, may imply mobility towards Velia from geographically similar or proximate regions (**Fig. 5**).

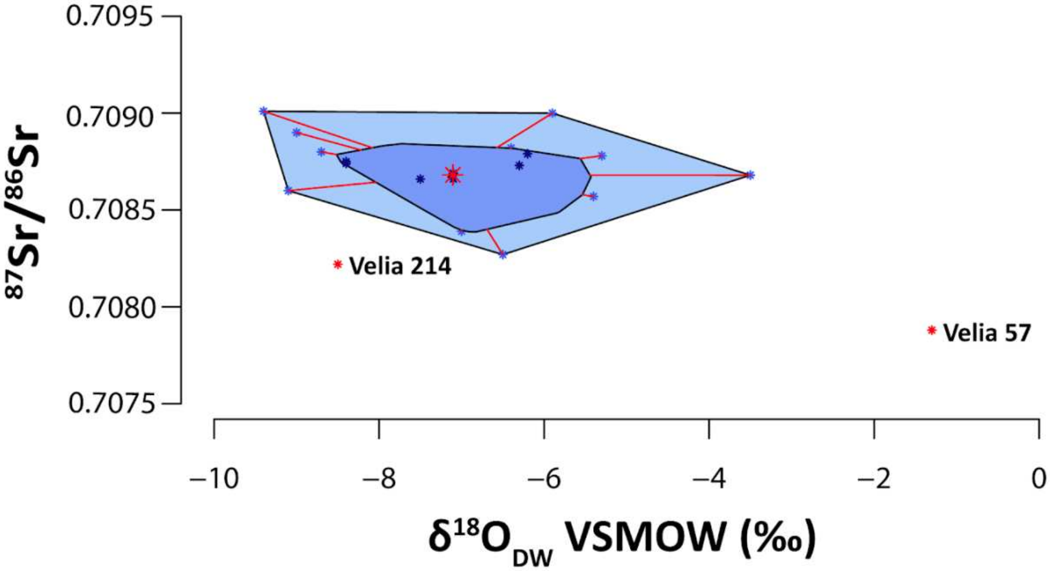

Fig. 5: Bagplot analysis of $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values for 20 individuals sampled from Velia. Distinct statistical outliers are shown as red dots and have been identified by their associated labels: Velia 57 and Velia 214.

4. Discussion

4.1 Water Sources at Velia

From its earliest inception as a Phocaean colony the water supply of Velia was provided by a mixture of rain water, stored in communal cisterns and pithoi, and local spring water channeled through canals from the surrounding *vallone del Frittolo* (Krinzinger 1986; Greco and De Simone 2012). This method of water collection was maintained into the Roman era, at which time a small aqueduct system and public fountains were built to increase the volume and distribution of water (Smith 1854; Ashby 1935; Greco and De Simone 2012). Given the local source of the spring water, the use of enclosed distribution piping, and the large size of the main cisterns minimizing evaporation, consumption of the drinking water at Velia would have provided local $\delta^{18}O_{dw}$ values.

4.2 $^{87}Sr/^{86}Sr$ Variability at Velia

Looking at the expected $^{87}Sr/^{86}Sr$ values for Velia from the generated bioavailable mapping of Emery et al. (2018a) and the previously analyzed archaeofaunal pig teeth of Stark (2016), it is clear that discrepancies exist between the expected values and the proximate geology of the Velia region. The predicted bioavailable range of $^{87}Sr/^{86}Sr$ values for Velia presented in Emery et al. (2018a) falls between ~0.7037 to 0.7072, a range into which none of the archaeofaunal or analyzed human teeth fall. Northeast of Velia is a zone in which predicted $^{87}Sr/^{86}Sr$ values range from 0.7072 to 0.7088, a range that more readily aligns with the values observed from most of the 20 individuals sampled. Such variation, particularly in light of the more variable $\delta^{18}O_{dw}$ observed, brings into question the nature of $^{87}Sr/^{86}Sr$ values at Velia. Three possibilities can be readily questioned: predicted bioavailable values, dietary sources, and sea spray.

The predictive baseline model presented by Emery et al. (2018a) utilized published bioavailable modern and archaeological $^{87}Sr/^{86}Sr$ datasets as well as fossil, sediment, and natural spring water values (n=199 data points). Using these values, a bioavailable map of the Italian peninsula was generated based on a bounded inverse distance weighting (IDW) interpolation. This map provides the first approximation of bioavailable values for the Italian peninsula but must also be used with caution as the values presented are derived from wide regions and interpolated across the predictive ranges. Emery et al. (2018a) recommend that, when available, local bioavailable $^{87}Sr/^{86}Sr$ values be utilized in tandem to supplement regional values provided by the bioavailable map. In the case of Velia, the generally lower predicted $^{87}Sr/^{86}Sr$ range for the area of Velia presented by Emery et al. (2018a) in comparison to the pig teeth values from Velia suggests that more nuanced local $^{87}Sr/^{86}Sr$ variation in southern Italy may be obscured by the larger regional trends interpolated from the values employed in the mapping.

The possibility of consuming staple foodstuffs developed in the hinterland of Velia, or potentially from regions further afield, and processed products such as garum may have played a role in the $^{87}Sr/^{86}Sr$ values reflected in the 20 second molars sampled. Craig et al. (2009) investigated diet at Velia and found that the primary diet appears to have been high in cereals with comparatively lower intake of meat/fish. They identified two distinct dietary groups: Group I, which exhibit $\delta^{15}N$ and $\delta^{13}C$ values indicative of high cereal consumption with lesser contributions from meat/dairy and minor fish/garum intake ($\delta^{13}C$ range= -20.0‰ to -19.0‰; $\delta^{15}N$ range= +6.4‰ to +9.6‰); Group II, which exhibits similar $\delta^{13}C$ values to Group I but $\delta^{15}N$ values >+9.6‰, suggesting greater contributions from meat/fish products. Of the 20 individuals sampled, only Velia 57 ($\delta^{15}N$=14.0‰) and Velia 169 ($\delta^{15}N$=11.3‰) fall within Group II. As previously noted, Velia 57 appears distinctly non-local. Velia 169 has an $^{87}Sr/^{86}Sr$ value consistent with the expected local range and similar to the remaining 18 individuals within Group I of Craig et al. (2009), suggesting that the potential impacts from elevated consumption of salty foods (e.g. garum) does not appear to have adversely influenced the resultant $^{87}Sr/^{86}Sr$ values (cf. Wright 2005; Fenner and Wright 2014). A Pearson correlation was undertaken to assess the degree of correspondence between $\delta^{15}N$ and $\delta^{13}C$ values published by Craig et al. (2009) and $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values presented herein. A distinct lack of correspondence is apparent (**Table 2**).

Table 2: Pearson correlation between $\delta^{18}O_{dw}$, $^{87}Sr/^{86}Sr$, $\delta^{15}N$, and $\delta^{13}C$ values from Velia

	$\delta^{18}O_{dw}$VSMOW	**$^{87}Sr/^{86}Sr$**
$\delta^{13}C$	0.22349	0.14448
$\delta^{15}N$	0.49768	-0.48048

Lastly, sea spray may have been a factor in the $^{87}Sr/^{86}Sr$ values of individuals from Velia. Sea spray may unnaturally influence coastal $^{87}Sr/^{86}Sr$ values, pushing values towards that of sea water (0.7092) with the addition of sea spray to consumed foodstuffs (Bentley 2006). Given the proposed reliance on foodstuffs from the inland territory of Velia it is unlikely that sea spray contributed significantly to the $^{87}Sr/^{86}Sr$ values documented (Veizer 1989; Chadwick et al. 1999; Whipkey et al. 2000; Kusaka et al. 2009; Bentley 2006; Knudson et al. 2014). This assumption is further validated by the finding that only two individuals at Velia (Velia 211, 270) exhibit values approximating marine $^{87}Sr/^{86}Sr$ values, suggesting that sea spray was not a major factor at

Velia. Though not evident in the individuals sampled, further analysis of floral, faunal, and human $^{87}Sr/^{86}Sr$ values may help to assess the potential of sea spray contributions at Velia (cf. Ryan et al. 2018).

4.3 Regions of Mobility

Based on the bivariate bagplot, at least 2 individuals (n=2/20, 10%) appear distinctly non-local to Velia: Velia 57 and Velia 214 (**Fig. 5**). Velia 57 has $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values consistent with an origin in a warmer region such as North Africa ($\delta^{18}O_{dw}$=-1.3‰; $^{87}Sr/^{86}Sr$=0.70788), a finding further supported by the comparatively high $\delta^{15}N$ at 14.0‰ and low $\delta^{13}C$ at -19.2‰ previously presented for this individual by Craig et al. (2009). Prowse et al. (2007) present evidence of a 40–50 year old male individual from Isola Sacra (SCR 617) with a $\delta^{18}O_c$ signature of -1.3‰ which they propose as being from North Africa, while the expected local $^{87}Sr/^{86}Sr$ range of 0.70732–0.70789 presented by Buzon et al. (2007) for Tombos aligns with that of Velia 57, providing additional substantiating evidence for a possible North African childhood residence of Velia 57. Though an origin in North Africa appears the most probable for this individual, it must also be kept in mind that other circum-Mediterranean regions where similar $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values are present cannot be entirely ruled out.

Velia 214 presents $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values suggestive of early life residency in the interior of the Italian peninsula. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{dw}$ values of this individual fit within both local ranges, suggesting residency in an area of proximate or similar geology and drinking water to Velia; statistically however, this individual falls outside of the bagplot loop indicating a distinct non-similarity to the rest of the sample. Based on the $\delta^{18}O_{dw}$ values presented in Giustini et al. (2016) and $^{87}Sr/^{86}Sr$ in Emery et al. (2018a), a residency of this individual in the foothills of the Apennine mountains or in the border region between Campania, Basilicata and Calabria provides the most parsimonious interpretation for childhood residency.

Three individuals (Velia 134, 194, 211) who fall outside of the local $\delta^{18}O_{dw}$ range, but who are not statistical outliers on the bagplot, have comparable $\delta^{18}O_{dw}$ (-9.4‰ to -9.0‰) and $^{87}Sr/^{86}Sr$ (0.70868 to 0.70901) values that suggest a similarity in residency during M2 development. The area around Vallo della Lucania, northeast of Velia, and the elevated inland border region between Campania, Basilicata and into Calabria exhibit a continuum of $\delta^{18}O_{dw}$ values that extends to -10‰ to -9.0‰ (Giustini et al. 2016). A parsimonious interpretation of the data, given the similar $^{87}Sr/^{86}Sr$ values of these three individuals to other local individuals at Velia, suggests it is probable that they arrived at Velia from these nearby regions, though not necessarily all from the same area. Similar $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values are recorded elsewhere: Schweissing and Grupe (2003a,b) report expected $^{87}Sr/^{86}Sr$ values between 0.70899 to 0.70992 for the area south of the Danube, while Sofeso et al. (2012) report $\delta^{18}O$ values ranging from -8.1‰ to -9.9‰ for the majority of individuals from the Imperial Roman site of Erding Kletthamer Feld; numerous others areas in the Apennine and Alp regions also present similar values. Such a distant origin of these three individuals, though not impossible, is less probable.

The remainder of the individuals sampled (n=15) appear local. The diversity of $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values represented among these 15 individuals does not suggest a singular place of residency. Rather, it appears that individuals sampled likely lived in and around the region of Velia and that local mobility events to Velia, where they were ultimately interred, were taking place. As these individuals all fall within the expected local $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ ranges, it is not possible to further delineate the potentiality of local mobility, or rather mobility within the expected local $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ ranges, though such events almost certainly occurred.

4.4 Interpreting "Foreigners" at Velia

What can be made of the evident foreigners at Velia? From a bagplot analysis of the isotopic data it is apparent that 10% (Velia 57 and 214) of the individuals examined are distinct outliers and can be considered non-local to the area of Velia up to at least the age of ~7-8 when M2 dental enamel development is complete. Three additional individuals (Velia 134, 194, 211), though statistically within the loop of the bagplot, exhibit $\delta^{18}O_{dw}$ values that suggest childhood residency at a location somewhat removed from the environs of Velia. It is important to keep in mind that the interpretation of $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values from bulk enamel represent the average of values integrated into the enamel structure over the period of formation and as such identification of mobility events from the timeframe of formation represents a broad picture of mobility.

In the case of Velia 57, who has a signal consistent with a childhood residency in North Africa, it is unclear what might have brought this male individual to Velia. Connections between Roman North Africa and peninsular Italy are well known (Rickman 1980; Bagnall and Frier 1994; Pomey 1997; Cherry 1998; De Ligt 2012). Aside from the port environs of Velia itself, access and mobility to Velia would also have been readily possible via the larger port of Puteoli at Naples, a key location for shipments from Alexandria (D'Arms 1974; Brunson 2002; Arnaud 2005, 2012). As Velia was a port city this may provide one part of the explanation as to why individual Velia 57 came to ultimately reside at Velia. Beyond this supposition, however, further rationale for the eventual residency of this individual at the site of Velia cannot be clearly elucidated from the evidence currently available. The case of Velia 214 appears to suggest a much more local mobility event.

Based on textual and epigraphic data Noy (2000) estimates the percentage of free migrants in 3rd CE Roman contexts at ~5%: 2% being soldiers and their families, and 3% being civilian immigrants. Hin (2013) argues that Rome was overwhelmingly the main migration destination for free migrants, with migration into the provinces believed to have been comparatively minor. Though precise homelands cannot be determined for the two non-local individuals identified at Velia, the approximated regional origins of Velia 57 and Velia 214 indicate that mobility to Velia was taking place from both relatively local (Velia 214) and evidently more distant (Velia 57) environs. Further analysis of a larger sample of individuals and faunal remains from Velia may help to refine the initial insights on mobility presented herein.

4.5 Mobility in Southern Italian Contexts

With Roman imperial expansion into southern Italy came the establishment of coastal ports and the extension of roadways, such as the Via Appia, making mobility to these regions and associated settlements increasingly possible (Garnsey and Saller 2014). The degree to which mobility varied between inland and coastal sites remains an area in need of further investigation (Lomas 1993, 2016; Greco 2003; Prowse et al. 2010). To date, the Imperial Roman sites of Vagnari (Prowse 2010; Emery et al. 2018a.b) and that of Velia, presented herein, are the only from southern Italian contexts to be investigated from an isotopic perspective.

Mobility to the inland site of Vagnari (1st to 4th c. CE), part of an Imperial Estate located near Gravina in the Basentello valley of Puglia where tile and iron production as well as development of interior lands took place, has been investigated using $\delta^{18}O$, $^{87}Sr/^{86}Sr$ and aDNA (Small and Small 2005; Prowse et al. 2010; Prowse 2016; Emery 2018a,b). Initial assessments of mobility using $\delta^{18}O$ identified >90% of the analyzed individuals as being from Vagnari, falling within the expected local range of -8‰ to -6‰ (Prowse et al. 2010; Prowse 2016). Employing $\delta^{18}O_{dw}$ in conjunction with a local bioavailable $^{87}Sr/^{86}Sr$ range of 0.70802-0.70901, as derived from soil, snail shell and ungulate teeth, Emery et al. (2018a) were able to show, using bagplot analysis, that 39/43 (90%) individuals were local: 25 individuals (58%) were identified as having $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values that indicate their residency directly at Vagnari, while an additional 34% were identified as from proximate environs in southern Italy. A small proportion of individuals (~7%) were indicated as having migrated to Vagnari from more distant areas. No significant differences were noted between males and females. Bagplot analysis identified four distinct outliers (Female: F130; Male: F67, F131, F231). The proposed origins of these outliers were identified as potentially North Africa or southern Spain (F130), northern Italy, and western Europe. The use of mtDNA evidence by Prowse et al. (2010) and Emery et al. (2018b) provides supplementary confirmation of the generally local nature of individuals interred at Vagnari. Among the mtDNA haplogroup profiles of the 30 individuals presented by Emery et al. (2018b) 28/30 (~93%) are consistent with a western Eurasian genetic background; the remaining 2/30 (~7%) individuals (F34 and F37) belong to haplogroup D4b1c, a grouping commonly found in eastern Eurasian populations. Though such genetic evidence cannot provide insight to specific mobility events, it nonetheless attests to haplogroup diversity at Vagnari, which has implications for past mobility events into the region.

Taking the evidence from Vagnari and Velia into account, a similar picture of mobility is evident at both sites. Both southern Italian sites exhibit similar rates of mobility at ~10% and a similar distribution based on the samples analyzed. Such a finding suggests that Roman Imperial era southern Italy saw a comparatively lesser degree of mobility than more urban and cosmopolitan sites such as Casal Bertone, Castellaccio Europarco and Portus, where the rate of non-local individuals identified approaches 33% (see Prowse et al. 2007; Killgrove 2010a, b; Killgrove and Montgomery 2016). Among local and non-local individuals identified at Velia and Vagnari a similar regional pattern also appears evident. At both sites the majority of individuals sampled appear local from the site environs, while a smaller, though still significant number of individuals, appear to have resided in environs directly proximate or within close proximity to the sites in question: at Velia the inland border region between Campania, Basilicata and into Calabria appears to have been a point of mobility; at Vagnari the region around the Basentello valley appears to have been a primary locale of mobility. A small proportion of non-local individuals at Vagnari and Velia appear to have been mobile from significantly distant regions, likely including North Africa (Velia 57) and North Africa or southern Spain (F130), as well as northern Italy and western Europe.

Such evidence indicates that while mobility in southern Italian Imperial Roman contexts does appear to have been less frequent, that distant mobility events were still taking place. The possible rationale behind such mobility events are so multifold—ranging from mobility for employment, government or military service, to enslavement, among others—that they cannot be readily delineated without further substantiating epigraphic and/or archaeological evidence (Noy 2000; Scheidel 1997, 2001, 2004, 2005, 2007; Webster 2008, 2010; Woolf 2016). What is evident based on the evidence from Vagnari and Velia, however, is that mobility within southern Italian Imperial Roman contexts does not appear to have been significantly different for coastal vs. inland access routes.

4.6 Isotopic Assessments of Mobility for the Italian Peninsula

The viability of using isotopes of oxygen and strontium for examining mobility within Roman contexts have been confirmed on numerous occasions (e.g. Prowse et al. 2007, Killgrove 2010 a,b; Killgrove and Montgomery 2016; Emery et al. 2018a, b). The application of this approach, however, is not without its challenges for identifying mobility within peninsular Italian contexts (cf. Bruun 2010). Regions of homogeneous $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values within the environs of the Italian peninsula present opportunities for the introduction of ambiguity in differentiating between local and non-local mobility depending on the regions in question. In terms of $\delta^{18}O_{dw}$, east to west mobility events can be comparatively easily differentiate, while large regions of homogeneous $\delta^{18}O_{dw}$ values exist in a north-south direction (Longinelli and Selmo 2003; Giustini et al. 2016). Conversely in the case of $^{87}Sr/^{86}Sr$, broadly speaking, north-south mobility is much more readily discernible compared to east-west mobility (cf. Emery et al. 2018a). The interplay of these two systems (i.e. $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$), when utilized in tandem, can mitigate the challenges of regional homogeneity, as has been previously demonstrated in the work of Killgrove and Montgomery (2016) and Emery et al. (2018a).

Though this brief synthesis of mobility events at Velia has shown a subset of individuals to have been non-local, it must also be borne in mind that mobility from proximate regions as well as mobility across regions with homogeneous isotopic values could also have been potentially occurring at Velia, but are not readily evident from isotopic evidence due to regional similarities in isotopic values. Further definition of expected local isotopic values and bioavailable ranges within peninsular Italy will help to reduce the impact such areas of isotopic homogeneity have on palaeomobility studies.

5. Conclusions

With increasing territorial expansion during the Imperial Roman era, ever greater opportunities for mobility were possible: both self-directed and enforced (Noy 2000; Scheidel 1997, 2001, 2004, 2005, 2007; Webster 2008, 2010; Woolf 2016). Regardless of the mechanism or impetus for mobility, the movement of people across the landscape is a defining feature of the Imperial Roman era. The southern Italian port of Velia is no exception. Though the study presented herein examines a relatively small subset of twenty individuals from the broader population of Velia, the identification of two distinct non-local outliers interred at Velia makes clear that individuals were mobile towards this site from both proximate and more distant regions. With additional sampling and isotopic analyses and integration of further datasets from archaeological and epigraphic materials it is hoped that an increasingly robust assessment of mobility events to Velia can be derived in future analyses.

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Bibliography

Al Qahtani SJ. 2009. Atlas of Human Tooth Development and Eruption. www.atlas.dentistry.qmul.ac.uk.

Arnaud, P, 2005. Les Routes de la Navigation Antique. Itineraires en Méditerranée. Éditions Errance, Paris.

Arnaud, P. 2012. L'Homme, le Temps et la Mer: Continuité et Changement des Routes Maritimes de et vers *Portus*. In: Keay, S., (Ed.), Rome, Portus and the Mediterranean. The British School at Rome, London, pp. 127-146.

Arppe L, Karhu JA. 2005. Paleoclimatological Signals in the Oxygen Isotope Composition of Mammoth Skeletal Remains from Finland and Western Russia. Geophysical Research Abstracts 7:04737.

Acsádi, G., Nemeskéri, J. 1970. History of Human Lifespan and Mortality. Akadémiai Kiadó, Budapest.

Ashby T. 1935. The Aqueducts of Ancient Rome, edited by I.A. Richmond. The Clarendon Press, Oxford.

Ayliffe LK, Lister AM, Chivas AR. 1992. The Preservation of Glacial-Interglacial Climatic Signatures in the Oxygen Isotopes of Elephant Skeletal Phosphates. Palaeogeography, Palaeoclimatology, Palaeoecology 99:179–191.

Bagnall RS, Frier B. 1994. The Demography of Roman Egypt. Cambridge University Press, Cambridge.

Ball W. 2000. Rome in the East: The Transformation of an Empire. Routledge, New York.

Barth F. (Ed.). 1969. Ethnic Groups and Boundaries: The Social Organization of Cultural Difference. George Allen and Unwin, London.

Bataille CP, and Bowen GJ. 2012. Mapping ^{87}Sr/^{86}Sr Variations in Bedrock and Water for Large Scale Provenance Studies. Chemical Geology 304-305:39-52.

Bentley RA. 2006. Strontium Isotopes from the Earth to the Archaeological Skeleton: A Review. Journal of Archaeological Method and Theory 13:135–187.

Bondioli L, Nava A, Rossi PF, Sperduti A. 2016. Diet and health in Central-Southern Italy during the Roman Imperial time. Acta Imeko, 5:19-25.

Bowen GJ. 2010. Isoscapes: Spatial Pattern in Isotopic Biogeochemistry. Annual Review of Earth and Planetary Sciences 38:161–187.

Brunson M. 2002. Encyclopedia of the Roman Empire, Revised Edition. Facts on File, New York.

Bruun C. 2010. Water, Oxygen Isotopes, and Immigration to Ostia-Portus. Journal of Roman Archaeology 23:109–132.

Budd P, Montgomery J, Barreiro B, Thomas RG. 2000. Differential Diagenesis of Strontium in Archaeological Human Dental Tissues. Applied Geochemistry 15:687-694.

Buikstra JE, Ubelaker DH. 1994. Standards for Data Collection from Human Skeletal Remains. Arkansas Archaeological Survey Research Series 44, Fayetteville.

Burmeister S. 2000. Archaeology and Migration: Approaches to an Archaeological Proof of Migration. Current Anthropology 41:539-567.

Cebeillac-Gervasoni M. 1996. Gli Africani ad Ostia, Ovvero le Mani sulla Citta. In: Montepaone C. (Ed.), L'Incidenza dell'Antico: Studi in Memoria di Ettore Lepore. Edizioni Luciano, Naples, pp. 557–567.

Cerchiai L. 2004. Elea (Velia). In: Cerchiai L, Jannelli L, Longo F. (Eds.), Die Griechen in Süditalien auf Spurensuche zwischen Neapel und Syrakus. Konrad Theiss Verlag GmbH, Stuttgart, pp. 82-89.

Chadwick OA, Derry LA, Vitousek PM, Huebert BJ, Hedin LO. 1999. Changing Sources of Nutrients During Four Million Years of Ecosystem Development. Nature 397:491497.

Chenery CA, Pashley V, Lamb AL, Sloane HJ, Evans JA. 2012. The Oxygen Isotope Relationship Between the Phosphate and Structural Carbonate Fractions of Human Bioapatite. Rapid Communications in Mass Spectrometry 26:309-319.

Cherry D. 1998. Frontier and Society in Roman North Africa. Clarendon Press, Oxford.

Christensen GJ, Kraus BS. 1965. Initial Calcification of the Human Permanent First Molar. Journal of Dental Research 44:1338–1342.

Copeland SR, Sponheimer M, le Roux PJ, Grimes V, Lee-Thorp JA, de Ruiter DJ, Richards MP. 2008. Strontium Isotope Ratios (^{87}Sr/^{86}Sr) of Tooth Enamel: A Comparison of Solution and Laser Ablation Multicollector Inductively Coupled Plasma Mass Spectrometry Methods. Rapid Communications in Mass Spectrometry 22:3187–3194.

Craig OE, Biazzo M, O'Connell T, Garnsey P, Martinez-Labarga C, Lelli R, Salvadei L, Tartaglia G, Nava A, Renò L, Fiammenghi A, Rickards O, Bondioli L. 2009. Stable Isotopic Evidence for Diet at the Imperial Roman Coastal Site of Velia (1st and 2nd Centuries AD) in Southern Italy. American Journal of Physical Anthropology 139:572-583.

Crowe F, Sperduti A, O'Connell TC, Craig OE, Kirsanow K, Germoni P, Macchiarelli R, Garnsey P, Bondioli L. 2010. Water-Related Occupations and Diet in Two Roman Coastal Communities (Italy, First to Third Century AD): Correlation Between Stable Carbon and Nitrogen isotope Values and Auricular Exostosis Prevalence. American Journal of Physical Anthropology 142:355-366.

D'Arms JH. 1974. Puteoli in the Second Century of the Roman Empire: A Social and Economic Study. The Journal of Roman Studies 64:104-124.

Dansgaard W. 1964. Stable Isotopes in Precipitation. Tellus 16:436–467.

Daux V, Lécuyer C, Héran MA, Amiot R, Simon L, Fourel F, Martineau F, Lynnerup N, Reychler H, and Escarguel. 2008. Oxygen Isotope Fractionation Between Human Phosphate and Water Revisited. Journal of Human Evolution 55:1138-1147.

De Ligt L. 2012. Peasants, Citizens and Soldiers: Studies in the Demographic History of Roman Italy 225 BC-AD 100. Cambridge University Press, Cambridge.

Dickin AP. 2005. Radiogenic Isotope Geology, Second Edition. Cambridge University Press, Cambridge.

Demény A, Gugora Ad, Kesjár D, Lécuyer C, Fourel F. 2019. Stable Isotope Analysis of the Carbonate Component of Bones and Teeth: The Need for Method Standardization. Journal of Archaeological Science 109: 104979.

DePaolo DJ, Ingram BL. 1985. High-Resolution Stratigraphy with Strontium Isotopes. Science 227.4689:938–941.

Ebner P. 1962. Scuole di Medicina a Velia e a Salerno. Apollo 2:125–136.

Ebner P. 1970. Nuove Iscrizioni di Velia. La Parola del Passato 25:262–267.

Ebner P. 1978. Altre Epigrafi e Monete di Velia. La Parola del Passato 33:61–73.

Elderfield H. 1986. Strontium Isotope Stratigraphy. Palaeogeography, Palaeoclimatology, Palaeoecology 57:71–90.

Emery MV, Stark R, Murchie TJ, Elford S, Schwarcz H, Prowse TL. 2018a. Mapping the origins of imperial Roman workers (1st–4th century CE) at Vagnari, southern Italy, using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ variability. American Journal of Physical Anthropology 166:837-850.

Emery MV, Duggan AT, Murchie TJ, Stark RJ, Klunk J, Hider J, Eaton K, Karpinski E, Schwarcz HP, Poinar HN, Prowse TL. 2018b. Ancient Roman Mitochondrial Genomes and Isotopes Reveal Relationships and Geographic Origins at the Local and Pan-Mediterranean Scales. Journal of Archaeological Science: Reports 20:200-209.

Ermolli ER, Romano P, Ruello MR. 2013. Human-Environment Interactions in the Southern Tyrrhenian Coastal Area: Hypotheses from Neapolis and Elea-Velia. In: Harris WV. (Ed.), The Ancient Mediterranean Environment Between Science and History. Brill, Leiden, pp. 213-231.

Faure G, Mensing TM, 2005. Isotopes: Principles and Applications, Third Edition. Wiley, Hoboken.

Faure G, Powell JL. 1972. Strontium Isotope Geology. Springer-Verlag, Berlin.

Fenner J, Wright L. 2014. Revisiting the Strontium Contribution of Sea Salt in the Human Diet. Journal of Archaeological Science 44:99103.

Ferembach D, Schwidetzky I, Stoukal M. 1977-79. Raccomandazioni per la Determinazione dell'Etá e del Sesso sullo Scheletro. Rivista di Antropologia 60:5-51.

Fiammenghi CA. 2003. La Necropoli di Elea Velia: Qualche Osservazione Preliminare. Quaderni del Centro Studi Magna Grecia 1:29-48.

Fiammenghi CA, La Torre C. 2005. L'edificio Funerario Numero 1 dalla Necropoli di Porta Marina Sud di Velia. In: Brandt B, Krinzinger F. (Eds.), Synergia: Festschrift für Friedrich Krinzinger. Phoibos, Vienna, pp. 25–35.

Fontana S. 2001. Leptis Magna. The Romanization of a Major African City Through Burial Evidence. In: Keay S., Terrenato N. (Eds.), Italy and the West Comparative Issues in Romanization. Oxbow Books, Oxford, pp. 161-172.

Garnsey P., Saller R. 2014. The Roman Empire: Economy, Society, and Culture. University of California Press, Oakland.

Gat JR. 1996. Oxygen and Hydrogen Isotopes in the Hydrological Cycle. Annual Review of Earth and Planetary Sciences 24:225-262.

Gat JR. 2005. Some Classical Concepts of Isotope Hydrology: "Rayleigh Fractionation, Meteoric Water Lines, the Dansgaard Effects (Altitude, Latitude, Distance From the Coast and Amount Effects) and the D-Excess Parameter. Aggarwal PK, Gat JR and Froehlich KFO, (eds.) Isotopes in the Water Cycle: Past, Present and Future of a Developing Science. Springer, Dordrecht, The Netherlands: 127-139.

Gat JR, Froehlich KFO, (Eds.) Isotopes in the Water Cycle: Past, Present and Future of a Developing Science. Springer, Dordrecht, The Netherlands: 127-139.

Gat JR, Klein B, Kushnir Y, Roether W, Wernli H, Yam R, Shemesh A. 2003. Isotope Composition of Air Moisture Over the Mediterranean Sea: An Index of the Air-Sea Interaction Pattern. Tellus 55:953-965.

Gelati R, Brambilla F, Napolitano A. 1989. Map #6 Geologia, Atlante Tematico d'Italia. Touring Club Italiano, Consiglio Nazionale delle Ricerche.

Giustini, F., Brilli, M., Patera, A., 2016. Mapping oxygen stable isotopes of precipitation in Italy. Journal of Hydrology: Regional Studies 8: 162–181. http://dx.doi.org/10.1016/j.ejrh.2016.04.001.

GNIP 2014 = Global Network of Isotopes in Precipitation (GNIP). http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html.

Gower, J., Gardner-Lubbe, S., le Roux, N., 2011. Understanding Biplots. Wiley & Sons Ltd., Chichester.

Greco E. 1975. Velia e Palinuro: Problemi di Topografia Antica. MEFRA 87:81-142.

Greco E. 1999. Velia: Città delle Acque. In: Krinzinger F., Tocco G. (Eds.), Akten des Kongresses "La Ricerca Archeologica a Velia" (Rom, 1-2 Juli 1993). Austrian Academy of Sciences Press, Vienna, pp. 73-84.

Greco E, Schnapp A. 1983. Moio della Civitella et le Territoire de Velia. MEFRA 95:381-415.

Greco E, Schnapp A. 1986. Fortification et Emprise du Territoire: Le Cas de Velia. In: Leriche P, Tréziny H. (Eds.), La Fortification dans l'Histoire du Monde Grec. Éditions du CNRS, Paris, pp. 209-212.

Greco G. (Ed.) 2003. Elea-Velia Le Nuove Ricerche: Atti del Convegno di Studi, Napoli 14 Dicembre 2001. Naus Editoria, Pozzuoli.

Greco G, De Simone D. 2012. Velia: Città delle Acque. Water Supply/Water System. In: D'Agostino S. (Ed.), Storia dell'Ingegneria. Nessuno, Naples, pp. 601–624.

Guariglia E. 2011. Parco Archeologico e Antiquarium di Velia Progetto di Musealizzazione dell'Acropoli. Facoltà di Architettura e Società Corso di Laurea Specialistica in Architettura, Politecnico di Milano.

Hedges REM. 2002. Bone Diagenesis: An Overview of Processes. Archaeometry 44:319–328.

Hedges REM, Stevens RE, Koch PL. 2006. Isotopes in Bone and Teeth. In: Leng MJ. (Ed.), Isotopes in Palaeoenviromental Research. Developments in Paleoenvironmental Research 10. Springer, Dordrecht, pp. 117–146.

Helttula A. 2007. Le Iscrizioni Sepolcrali Latine Nell'Isola Sacra. Acta Instituti Romani Finlandiae 30. Institutum Romanum Finlandiae, Roma.

Herring DA, Saunders SR, Katzenberg MA. 1998. Investigating the Weaning Process in Past Populations. American Journal of Physical Anthropology 105:425–439.

Hillson S. 1996. Dental Anthropology. Cambridge University Press, Cambridge.

Hin S. 2013. The Demography of Roman Italy, Population Dynamics in an Ancient Conquest Society 201 BCE-14 CE. Cambridge University Press, Cambridge.

Hin S. 2016. Revisiting Urban Graveyard Theory: Migrant Flows in Hellenistic and Roman Athens. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 234–263.

Horden P., Purcell N. 2000. The Corrupting Sea: A Study of Mediterranean History. Blackwell Publishers, Malden.

Huttunen P. 1974. The Social Strata in the Imperial City of Rome: A Quantitative Study of the Social Representation in the Epitaphs, Published in the *Corpus Inscriptionum Latinarum*, Volumen VI. University of Oulu, Oulu.

Kearney M. 1986. From the Invisible Hand to the Visible Feet: Anthropological Studies of Migration and Development. Annual Review of Anthropology 15:331-361.

Kearney M. 1995. The Local and the Global: The Anthropology of Globalization and Transnationalism. Annual Review of Anthropology 24:547-565.

Killgrove K. 2010a. Migration and Mobility in Imperial Rome. Unpublished Doctoral Dissertation, University of North Carolina at Chapel Hill.

Killgrove K. 2010b. Identifying Immigrants to Imperial Rome Using Strontium Isotope Analysis. In: Eckardt, H. (Ed.), Roman Diasporas: Archaeological Approaches to Mobility and Diversity in the Roman Empire. Journal of Roman Archaeology Supplementary Series 78. Journal of Roman Archaeology, Portsmouth, pp. 157–174.

Killgrove K. 2010c. Response to C. Bruun “Water, Oxygen Isotopes and Immigration to Ostia-Portus”. Journal of Roman Archaeology 23:133–136.

Killgrove K. 2013. Biohistory of the Roman Republic: The Potential of Isotope Analysis of Human Remains. Post-Classical Archaeologies 3: 41-62.

Killgrove K. 2014. Bioarchaeology in the Roman Empire. In: Smith, C., (Ed.), Encyclopedia of Global Archaeology. Springer, doi: 10.1007/978-1-4419-0465-2, pp. 876-882.

Killgrove K. Montgomery J. 2016. All Roads Lead to Rome: Exploring Human Migration to the Eternal City Through Biochemistry of Skeletons from Two Imperial-Era Cemeteries (1st–3rd c. AD). PLoS ONE 11: e0147585. doi:10.1371/journal.pone.0147585.

King CL, Tayles N, Gordon KC. 2011. Re-examining the Chemical Evaluation of Diagenesis in Human Bone Apatite. Journal of Archaeological Science 38:2222-2230.

Knudson KJ. 2009. Oxygen Isotope Analysis in a Land of Environmental Extremes: The Complexities of Isotopic Work in the Andes. International Journal of Osteoarchaeology 19:171–191.

Knudson KJ, Webb E, White C, Longstaffe FJ. 2014. Baseline Data for Andean Palaeomobility Research: A Radiogenic Strontium Isotope Study of Modern Peruvian Agricultural Soils. Archaeological and Anthropological Sciences 6:205219.

Kohn MJ, Schoeninger MJ, Barker WW. 1999. Altered States: Effects of Diagenesis on Fossil Tooth Chemistry. Geochimica et Cosmochimica Acta 18:2737-2747.

Kohn MJ, Cerling TE. 2002. Stable Isotope Compositions of Biological Apatite, Phosphates. In: Kohn ML, Rakovan J, Hughes JM. (Eds.), Geochemical, Geobiological, and Materials Importance. Reviews in Mineralogy and Geochemistry 48:455–488.

Kolodny Y, Luz B. 1991. Oxygen Isotopes in Phosphates of Fossil Fish–Devonian to Recent. In: Taylor HP, O’Neil JR, Kaplan IR. (Eds.), Stable Isotope Geochemistry: A Tribute to Samuel Epstein. The Geochemical Society Special Publication 3. The Geochemical Society, San Antonio, pp. 105–119.

Krinzinger F. 1986. Velia. Grabungsbericht 1983–1986. Römische Historische Mitteilungen 28:31–56.

Krinzinger F, Tocco Sciarelli G. 1997. Velia. Enciclopedia dell'Arte Antica, Classica e Orientale. Istituto della Enciclopedia Italiana, Rome.

Kusaka S, Ando A, Nakano T, Yumoto T, Ishimaru E, Yoneda M, Hyodo F, Katayama K. 2009. A Strontium Isotope Analysis on the Relationship Between Ritual Tooth Ablation and Migration Among the Jomon People in Japan. Journal of Archaeological Science 36:2289–2297.

LaFleur M. 2011. Fluctuating Dental Asymmetry at the Imperial Roman Necropolis of Velia. Unpublished Master of Arts Thesis, California State University, Sacramento.

Lega C, Fulgione D, Genovese A, Rook L. 2016. Like a Pig Out of Water: Seaborne Spread of Domestic Pigs in Southern Italy and Sardinia During the Bronze and Iron Ages. Heredity 118:154-159.

Lightfoot E, O'Connell TC. 2016. On the Use of Biomineral Oxygen Isotope Data to Identify Human Migrants in the Archaeological Record: Intra-Sample Variation, Statistical Methods and Geographical Considerations. PLoS ONE 11(4): e0153850.

Likins RC, McCann HG, Posner AS, Scott DB. 1960. Comparative Fixation of Calcium and Strontium by Synthetic Hydroxyapatite. The Journal of Biological Chemistry 235:21522156.

Lomas K. 1993. Rome and the Western Greeks, 350 BC–AD 200. Conquest and Acculturation in South Italy. Routledge, London.

Lomas K. 2016. Magna Graecia 270 BC–AD 200. In: Cooley AE. (Ed.), A Companion to Roman Italy. Wiley Blackwell, Malden, pp. 253–268.

Longinelli A, Selmo E. 2003. Isotopic Composition of Precipitation in Italy: A First Overall Map. Journal of Hydrology 270:75–88.

MacKinnon M. 2001. High on the Hog: Linking Zoooarchaeological, Literary and Artistic Data for Pig Breeds in Roman Italy. American Journal of Archaeology 105:649-673.

Malainey ME. 2010. A Consumer's Guide to Archaeological Science: Analytical Techniques. Springer, New York.

Marciniak S, Prowse TL, Herring DA, Klunk J, Kuch M, Duggan AT, Bondioli L, Holmes EC, Poinar HN. 2016. *Plasmodium falciparum* malaria in 1st-2nd c. C.E. Southern Italy. Current Biology 26:1220-1222.

Mele A. 2006. L'Identità di Elea: da Platone a Stradone. In: Velia: Atti del Quarantacinquesimo Convegno di Studi Sulla Magna Grecia: Taranto, Marina di Ascea 21-25 Settembre 2005. Istituto per la Storia e l'Archeologia della Magna Grecia, Taranto, pp. 65-91.

Moatti, C., 2006. Translation, Migration, and Communication in the Roman Empire: Three Aspects of Movements in History. Classical Antiquity 25, 109-140.

Moatti, C., 2019. Mobility in the Roman World: New Concepts, New Perspectives. In: Zerbini, A., Yoo, J. (Eds.), Migration, Diaspora and Identity in the Near East from Antiquity to the Middle Ages. Ashgate, Farnham, pp. 15-25.

Musti D. 1966. Testi e Monumenti. PdelP 21:310-335.

Nelson BK, DeNiro MJ, Schoeninger MJ, DePaolo DJ, Hare PE. 1986. Effects of Diagenesis on Strontium, Carbon, Nitrogen, and Oxygen Concentration and Isotopic Composition of Bone. Geochimica et Cosmochimica Acta 50:1941–1949.

Nikita E. 2017. Osteoarchaeology: A Guide to the Macroscopic Study of Human Skeletal Remains. Academic Press, London.

Noy D. 2000. Foreigners at Rome: Citizens and Strangers. Gerald Duckworth & Co. Ltd, London.

Noy D. 2010. Epigraphic Evidence for Immigrants at Rome and in Roman Britain. In: Eckardt H. (Ed.), Roman Diasporas: Archaeological Approaches to Mobility and Diversity in the Roman Empire. Journal of Roman Archaeology Supplementary Series 78. Journal of Roman Archaeology, Portsmouth, pp. 13–26.

Nuzzo D. 1997. Preatti: Provinciali a Roma nelle Testimonianze dell'Epigrafia Sepolcrale Tardoantica. XI Congresso Internazionale di Epigrafia Greca e Latina. Rome, 18-24 September. Edizioni Quasar, Rome, pp. 705-712.

Pearce, J., 2010. Burial, Identity and Migration in the Roman World. In: Eckardt, H. (Ed.), Roman Diasporas: Archaeological Approaches to Mobility and Diversity in the Roman Empire. Journal of Roman Archaeology Supplementary Series 78. Journal of Roman Archaeology, Portsmouth, pp. 79-98.

Pellegrini M, Snoeck C. 2016. Comparing bioapatite pre-treatments for isotopic measurements: Part 2−impact on carbon and oxygen isotope compositions. Chemical Geology 420:88−96.

Pellegrino CS. 1957. Greek Elea-Roman Velia. Archaeology 10:2-10.

Pollard AM, Pellegrini M, Lee-Thorp JA. 2011. Technical Note: Some Observations on the Conversion of Dental Enamel $\delta^{18}O_p$ Values to $\delta^{18}O_w$ to Determine Human Mobility. American Journal of Physical Anthropology 145:499−504.

Pomey P. (ed.). 1997. La Navigation dans l'Antiquité. Édisud, Aix-en-Provence.

Price TD. 2008. Isotopes and Human Migration: Case Studies in Biogeochemistry. In: Schutkowski H., (Ed.), Between Biology and Culture. Cambridge University Press, Cambridge, pp. 243-272.

Price TD, Burton JH, Bentley RA. 2002. The Characterization of Biologically-Available Strontium Isotope Ratios for Investigation of Prehistoric Migration. Archaeometry 44:117–135.

Price TD, Burton JH, Fullagar PD, Wright LE, Buikstra JE, Tiesler V. 2015. Strontium Isotopes and the Study of Human Mobility Among the Ancient Maya. In: Cucina A. (Ed.), Archaeology and Bioarchaeology of Population Movement among the Prehispanic Maya. Springer, New York, pp. 119132.

Prowse TL. 2016. Isotopes and Mobility in the Ancient Roman World. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 205–233.

Prowse TL, Schwarcz HP, Garnsey P, Knyf M, Macchiarelli R, Bondioli L. 2007. Isotopic Evidence for Age-Related Immigration to Imperial Rome. American Journal of Physical Anthropology 132:510–519.

Prowse TL, Barta JL, von Hunnius TE, Small AM. 2010. Stable Isotope and Mitochondrial DNA Evidence for Geographic Origins on a Roman Estate at Vagnari (Italy). In: Eckardt H., (Ed.), Roman Diasporas: Archaeological Approaches to Mobility and Diversity in the Roman Empire. Journal of Roman Archaeology Supplementary Series 78. Journal of Roman Archaeology, Portsmouth, pp. 175–197.

Rabadjieva D, Tepavitcharova S, Sezanova K, Gergulova R, Titorenkova R, Petrov O, Dyulgerova E. 2011. Biomimetic Modifications of Calcium Orthophosphates. In: Pramatarova L. (Ed.), On Biomimetics. InTech, Rijeka, pp.135162.

Ramage CT. 1868. Ramage in South Italy. The Nooks and By-Ways of Italy. Wanderings in Search of its Ancient Remains and Modern Superstitions. E. Howell, Liverpool.

Rey C, Frèche M, Heughebaert JC, Lacout JL, Lebugle A, Szilagyi J, Vignoles M. 1991. Apatite Chemistry in Biomaterial Preparation, Shaping and Biological Behaviour. In: Bonfield W, Hastings GW, Tanner KE. (Eds.), Bioceramics, Volume 4, Proceedings of the 4th International Symposium on Ceramics in Medicine, London, UK, September 1991. Butterworth-Heinemann Ltd., Oxford, pp. 57-64.

Richardson L. 1976. Elea later Velia, Campania, Italy. In: Stillwell R, MacDonald WL, McAlister MH (Eds.), The Princeton Encyclopedia of Classical Sites. Princeton University Press, Princeton, pp. 295–296.

Rickman GE. 1980. The Grain Trade Under the Roman Empire. Memoirs of the American Academy in Rome 36:261–275.

Ross SM. 2010. Introductory Statistics, Third Edition. Elsevier, Amsterdam.

Rousseeuw PJ, Ruts I, Tukey JW. 1999. The Bagplot: A Bivariate Boxplot. The American Statistician 53:382–387.

Ryan S.E., Snoeck C., Crowley Q.G., Babechuk M.G. 2018. ^{87}Sr/^{86}Sr and Trace Element Mapping of Geosphere-Hydrosphere-Biospehere Interactions: A Case Study in Ireland. Applied Geochemistry 92:209–224.

Salomies O. 2002. People in Ostia: Some Onomastic Observations and Comparisons with Rome. In: Bruun C, Zevi G. (Eds.), Ostia e Portus Nelle Loro Relazioni con Roma. Acta Instituti Romani Finlandiae 27. Institutum Romanum Finlandiae, Roma, pp. 135–159.

Saxe AA. 1970. Social Dimensions of Mortuary Practices. Unpublished Doctoral Dissertation, University of Michigan.

Scheidel W. 1997. Quantifying the Sources of Slaves in the Early Roman Empire. The Journal of Roman Studies 87:159-169.

Scheidel, W., 2001. Progress and Problems in Roman Demography. In: Scheidel, W. (Ed.), Debating Roman Demography. Brill, Leiden, pp. 1-81.

Scheidel, W., 2004. Human Mobility in Roman Italy, I: The Free Population. The Journal of Roman Studies 94:1-26.

Scheidel, W., 2005. Human Mobility in Roman Italy II: The Slave Population. The Journal of Roman Studies 95:64-79.

Scheidel W. 2007. Roman population size: the logic of the debate. VICI Conference, Peasants, Citizens and Soldiers: The Social, Economic and Demographic Background to the Gracchan Land Reforms, University of Leiden, June 28-30, 2007.

Scheuer L, Black S. 2000. Developmental Juvenile Osteology. San Diego, Elsevier Academic Press.

Schour I, Massler M. 1940. Studies in Tooth Development: The Growth Pattern of Human Teeth. Journal of the American Dental Association 27:1778–1792; 1918–1931.

Schuurs A. 2012. Pathology of the Hard Dental Tissues. Hoboken, John Wiley & Sons, Ltd.

Schwarcz HP, White CD, Longstaffe FJ. 2010. Stable and Radiogenic Isotopes in Biological Archaeology: Some Applications. In: West JB, Bowen GJ, Dawson TE, Tu KP. (Eds.), Isoscapes: Understanding Movement, Pattern, and Process on Earth Through Isotope Mapping. Springer, New York, pp. 335–356.

Schweissing MM, Grupe G. 2003a. Stable Strontium Isotopes in Human Teeth and Bone: A Key to Migration Events of the Late Roman period in Bavaria. Journal of Archaeological Science 30:1373-1383.

Schweissing MM, Grupe G. 2003b. Tracing Migration Events in Man and Cattle by Stable Strontium Isotope Analysis of Appositionally Grown Mineralized Tissue. International Journal of Osteoarchaeology 13:96–103.

Shemesh A. 1990. Crystallinity and Diagenesis of Sedimentary Apatites. Geochimicha et Cosmochimica Acta 54: 2433-2438.

Small CM, Smal AM. 2005. Defining an Imperial Estate: The Environs of Vagnari in South Italy. In: Attema PAJ, Nijboer A, Zifferero A. (Eds.), Papers in Italian Archaeology VI. Communities and Settlements from the Neolithic to the Early Modern Period. Oxford, Oxbow, pp. 894-902.

Smith W. (Ed.). 1854. Dictionary of Greek and Roman Geography. London.

Snoeck C, Pellegrini M. 2015. Comparing bioapatite carbonate pre-treatments for isotopic measurements: Part 1–impact on structure and chemical composition. Chemical Geology 417:394–403.

Sofeso C, Vohberger M, Wisnowsky A, Päffgen B, Harbeck M. 2012. Verifying Archaeological Hypotheses: Investigations on Origin and Genealogical Lineages of a Privileged Society in Upper Bavaria from Imperial Roman Times (Erding, Kletthamer Feld). In: Kaiser E, Burger J, Schier W. (Eds.), Population Dynamics in Prehistory and Early History: New Approaches Using Stable Isotopes and Genetics. De Gruyter, Berlin, pp. 113-130.

Sperduti A, Bondioli L, Garnsey P. 2012. Skeletal Evidence for Occupational Structure at the Coastal Towns of Portus and Velia (1st-3rd c. A.D.). In: Schrüfer-Kolb I. (Ed.), More than Just Numbers?: The Role of Science in Roman Archaeology. Journal of Roman Archaeology, Portsmouth, pp. 53-70.

Stark, R. J. 2016. Ancient Lives in Motion: A Bioarchaeological Examination of Stable Isotopes, Nonmetric Traits, and Mobility in an Imperial Roman Context (1st–3rd century CE). Unpublished Doctoral Dissertation, McMaster University. https://macsphere.mcmaster.ca/handle/11375/20937

Stuart-Williams HLQ, Schwarcz HP, White CD, Spence MW. 1996. The Isotopic Composition and Diagenesis of Human Bone from Teotihuacan and Oaxaca, Mexico. Palaeogeography, Palaeoclimatology, Palaeoecology 126:1-14.

Vallat JP. 2001. The Romanization of Italy: Conclusions. In: Keay S, Terrenato N. (Eds.), Italy and the West Comparative Issues in Romanization. Oxbow Books, Oxford, pp. 102-110.

Veizer J. 1989. Strontium Isotopes in Seawater Through Time. Annual Review of Earth and Planetary Sciences 1:141–167.

Webster J. 2008. Less Beloved. Roman Archaeology, Slavery, and the Failure to Compare. Archaeological Dialogues 15:103-149.

Webster J. 2010. Routes to Slavery in the Roman World: A Comparative Perspective on the Archaeology of Forced Migration. In: Eckardt, H. (Ed.), Roman Diasporas: Archaeological Approaches to Mobility and Diversity in the Roman Empire. Journal of Roman Archaeology Supplementary Series 78. Journal of Roman Archaeology, Portsmouth, pp. 45–65.

Whipkey CE, Capo RC, Chadwick OA, Stewart BW. 2000. The Importance of Sea Spray to the Cation Budget of a Coastal Hawaiian soil: A Strontium Isotope Approach. Chemical Geology 168:37–48.

Wolf HP. 2018. Another Plot Package: ‘Bagplots’, ‘Iconplots’, ‘Summaryplots’, Slider Functions and Others. Version 1.3.2. Accessed online at: https://CRAN.R-project.org/package=aplpack.

Woolf G. 2013. Diasporas and Colonization in Classical Antiquity. In: Ness I. (Ed.), The Encyclopedia of Global Human Migration. Wiley-Blackwell, Chichester, pp. 1201-1215.

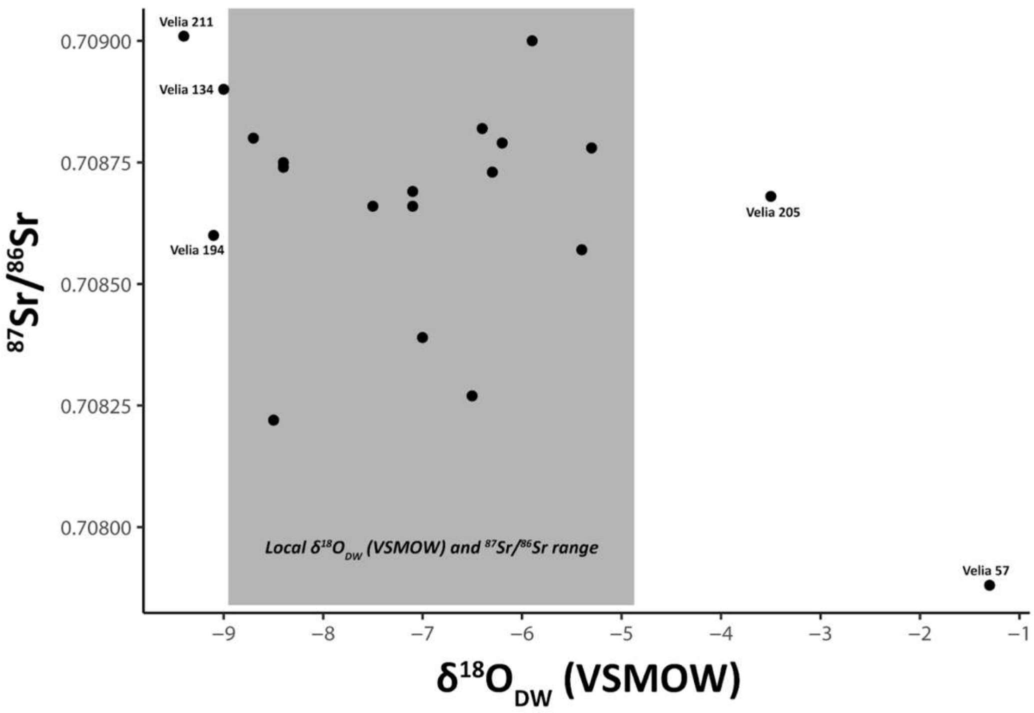
Woolf G. 2016. Movers and Stayers. In: De Ligt L, Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 438–461.

Wright LE. 2005. Identifying Immigrants to Tikal, Guatemala: Defining Local Variability in Strontium Isotope Ratios of Human Tooth Enamel. Journal of Archaeological Science 32:555–566.

Wright LE, Schwarcz HP. 1996. Infrared and Isotopic Evidence for Diagenesis of Bone Apatite at Dos Pilas, Guatemala: Palaeodietary Implications. Journal Archaeological Science 23:933–944.

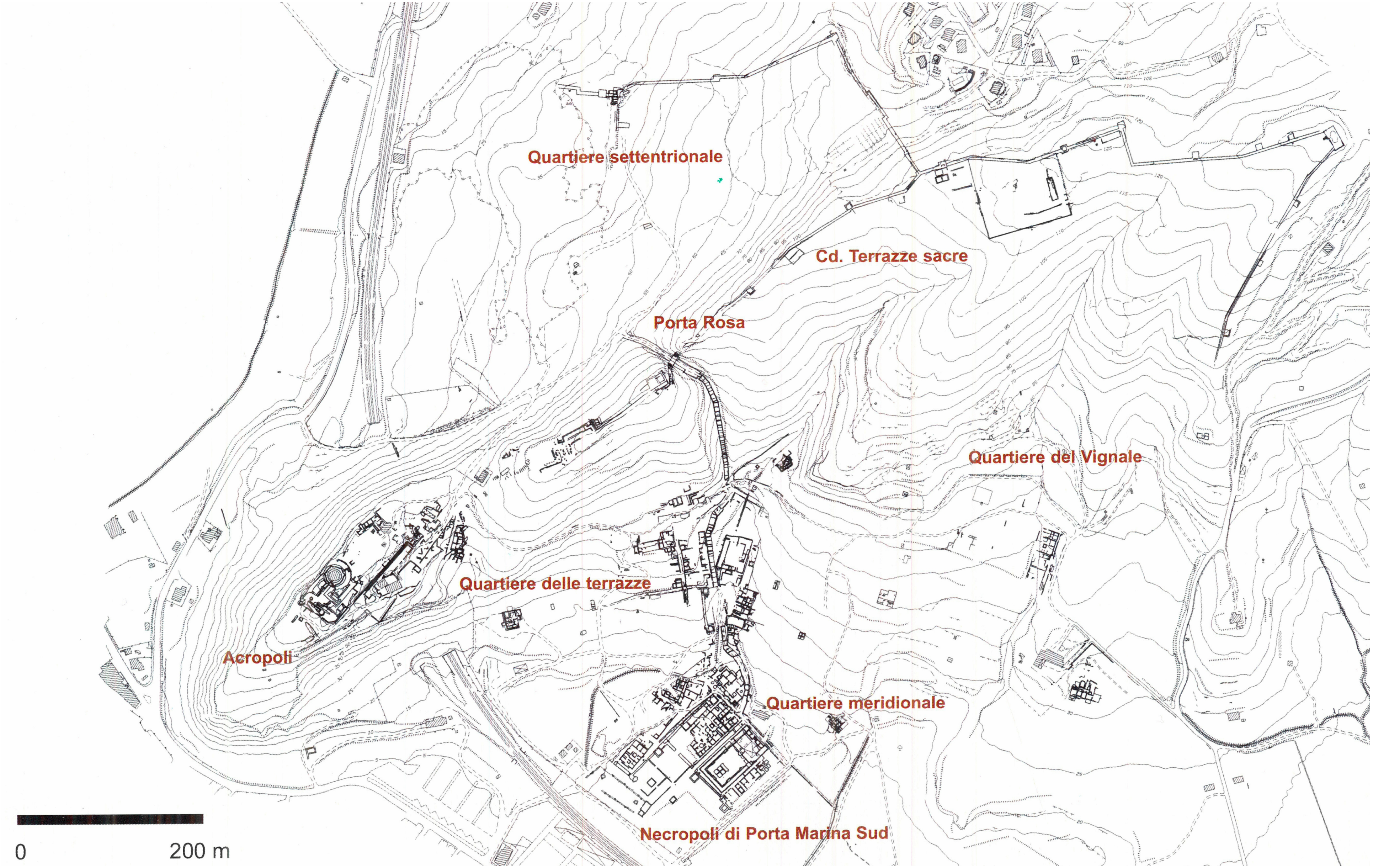
Wright LE, Schwarcz HP. 1998. Stable Carbon and Oxygen Isotopes in Human Tooth Enamel: Identifying Breastfeeding and Weaning in Prehistory. American Journal of Physical Anthropology 106:1–18.

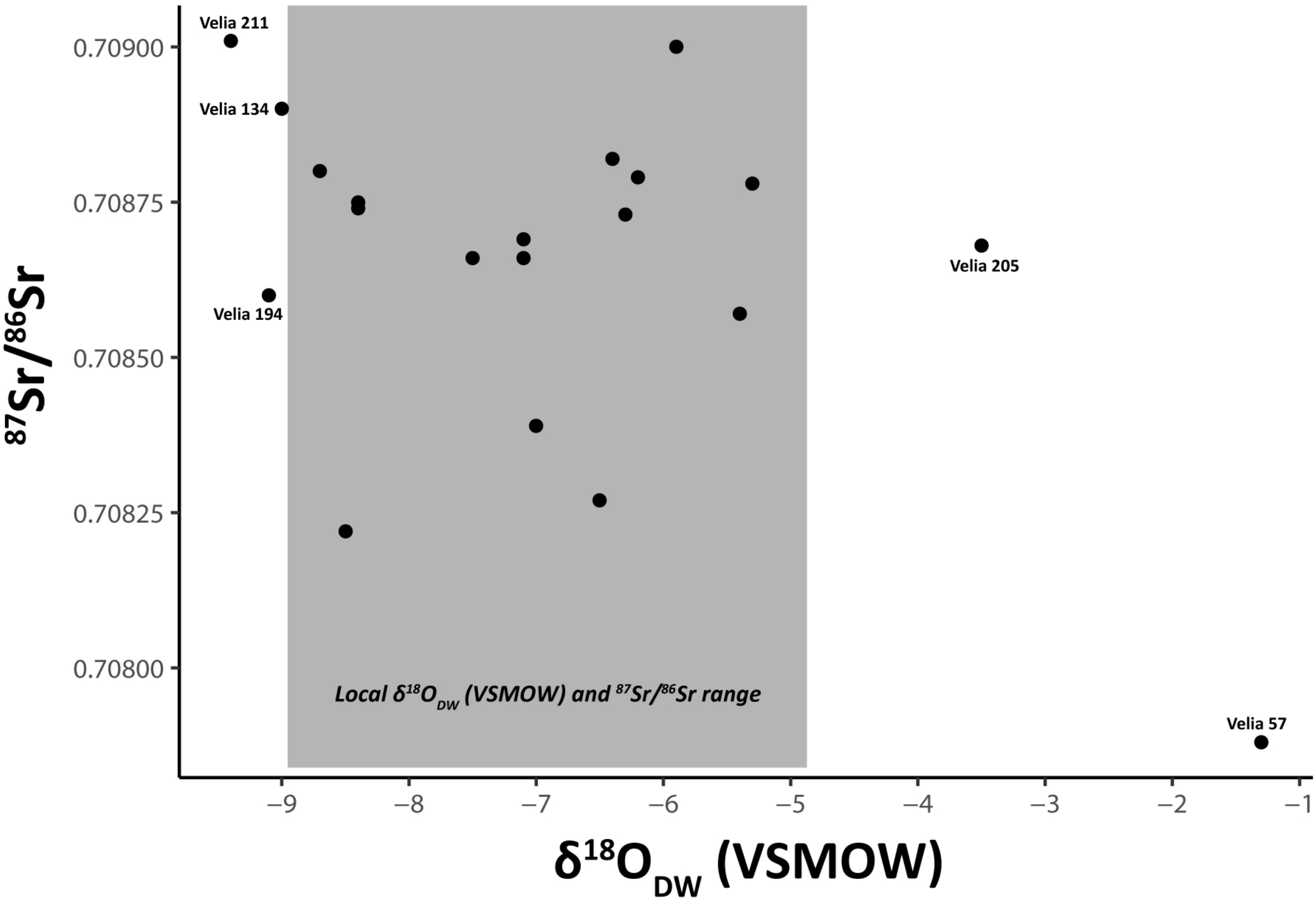
Zaky AH, Brand U, Buhl D, Blamey N, Bitner MA, Logan A, Gaspard D, Popov A. 2019. Strontium Isotope Geochemistry of Modern and Ancient Archives: Tracer of Secular Change in Ocean Chemistry. Canadian Journal of Earth Sciences 56:245–264.

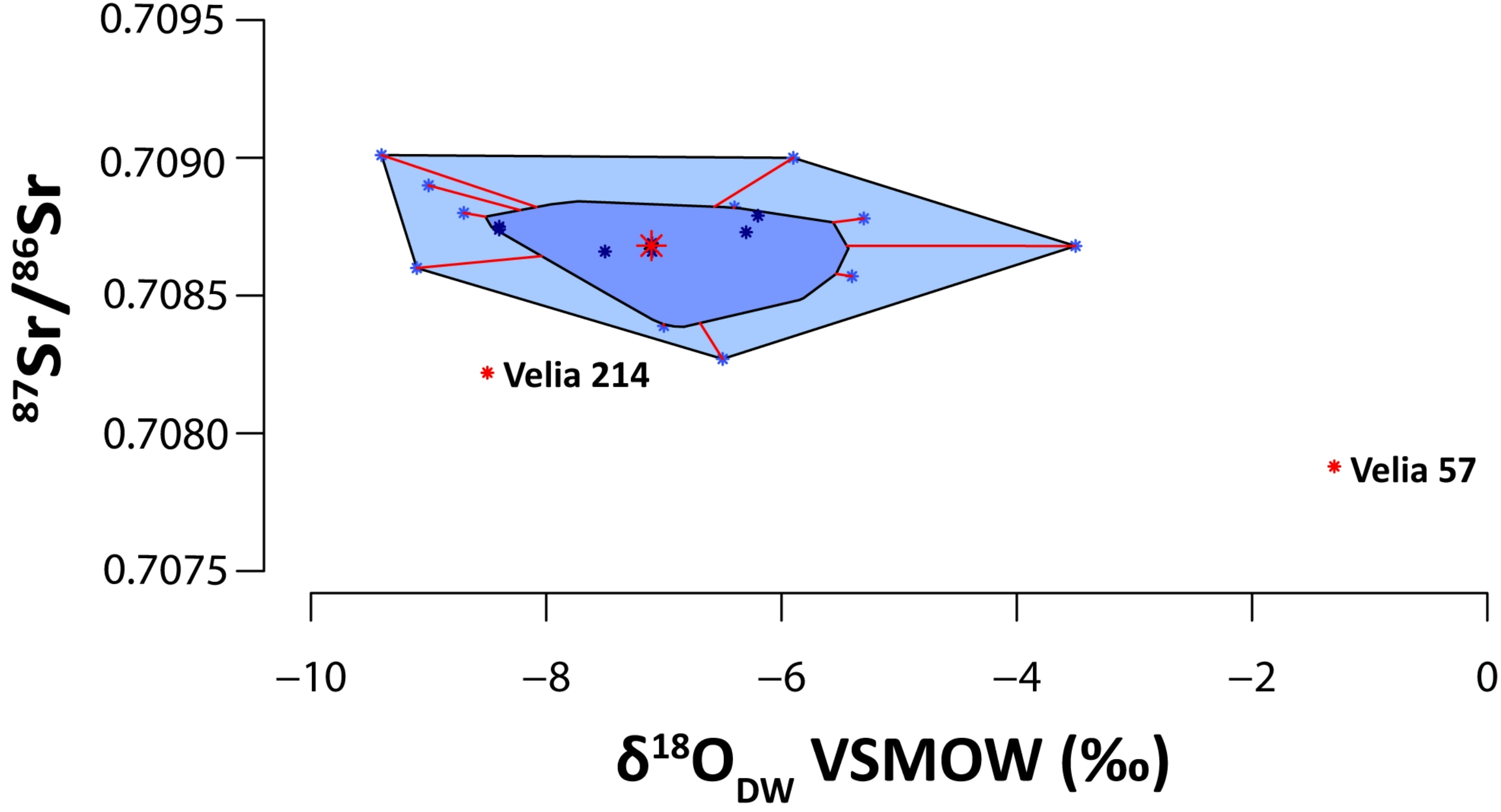


Supplementary Fig. 1: Scatter plot showing the distribution of $\delta^{18}O_{dw}$ and $^{87}Sr/^{86}Sr$ values for the 20 individuals sampled from Velia against the expected local ranges (grey box). Individuals who fall outside of the local range have been labelled.


Germany
Switzerland
Austria
Hungary
Slovenia
Croatia
Bosnia &
Herzegovina
Milan
Turin
France
Italy
Adriatic Sea
Corsica
Rome
Vagnari &
Botromagno
Bari
Naples
Taranto
Sardinia
Tyrrhenian
Sea
Velia
Ionian
Sea
Sicily
Algeria
Tunisia
N
0
200
400
600
800
km


Quartiere settentrionale
Cd. Terrazze sacre
Porta Rosa
Quartiere del Vignale
Quartiere delle terrazze
Acropoli
Quartiere meridionale
Necropoli di Porta Marina Sud
0
200 m


Velia 211
Velia 134
Velia 194
Velia 205
Velia 57
Local $\delta^{18}O_{DW}$ (VSMOW) and $^{87}Sr/^{86}Sr$ range
0.70900
0.70875
0.70850
0.70825
0.70800
$^{87}Sr/^{86}Sr$
−9
−8
−7
−6
−5
−4
−3
−2
−1
$\delta^{18}O_{DW}$ (VSMOW)


0.7095
0.7090
0.7085
0.7080
0.7075
$^{87}Sr/^{86}Sr$
Velia 214
Velia 57
−10
−8
−6
−4
−2
0
$\delta^{18}O_{DW}$ VSMOW (‰)

Author Statement

Robert Stark: conceptualization; project administration; methodology; validation; formal analysis; investigation; visualization; writing – original draft and review & editing; funding acquisition

Matthew Emery: conceptualization; visualization; writing – review & editing; formal analysis

Henry Schwarcz: conceptualization; writing – review & editing

Alessandra Sperduti: resources; writing – review & editing

Luca Bondioli: resources; writing – review & editing

Oliver E. Craig: resources; writing – review & editing

Tracy Prowse: supervision, funding acquisition, methodology; writing – review & editing