ANCIENT LIVES IN MOTION

ANCIENT LIVES IN MOTION: A BIOARCHAEOLOGICAL EXAMINATION OF STABLE ISOTOPES, NONMETRIC TRAITS, AND HUMAN MOBILITY IN AN IMPERIAL ROMAN CONTEXT (1ST-3RD C. CE)

by

ROBERT JAMES STARK, B.A., M.A.

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment
of the Requirements for the Degree Doctor of Philosophy

**McMaster University **
November 2016

McMaster University DOCTOR OF PHILOSOPHY (2016) Hamilton, Anthropology
TITLE: Ancient Lives in Motion: A Bioarchaeological Examination of Stable Isotopes, Nonmetric Traits and Human Mobility in an Imperial Roman Context (1st-3rd c. CE)
AUTHOR: Robert James Stark, B.A. (Wilfrid Laurier University), M.A. (University of Alberta)
SUPERVISOR: Tracy Prowse
NUMBER OF PAGES: xx, 313

Abstract

This dissertation examines human mobility and population interactions at the Imperial Roman (ca. 1st–3rd c. CE) sites of Isola Sacra (SCR) at Portus, Velia in the Cilento of Italy, and Rue Jacques Brel Necropolis (JBR) in Saintes, France. Isotopes of oxygen ($\delta^{18}O_c$) and strontium ($^{87}Sr/^{86}Sr$) are used to assess instances of human mobility from the enamel of second molars (M2), providing a gauge of movement after age ~7–8 years. Nonmetric traits are employed in conjunction with isotopic perspectives to examine the nature of biological affinities and phenetic divergence between these three sites.

Isotopic results of this study indicate that a significant number of individuals, including females and children, were mobile towards the sites at which they were ultimately interred, with the highest estimates of mobility provided by $\delta^{18}O_c$ seeing rates between 25%–38% across the three sites. $^{87}Sr/^{86}Sr$ results provided lower estimates of mobility ranging from zero cases at Velia to 30% at JBR, while combined $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ analyses provided the lowest estimates of mobility ranging from zero cases at Velia to 20% at JBR. Such results suggest that a combined isotope approach may not necessarily increase the degree of mobility discrimination, bringing into question issues of regional homogeneity and overlap in $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ values for the regions examined. A further examination of $\delta^{18}O_c$ variation in M1 vs. M2 vs. M3 for a sub-sample of 20 individuals indicates that childhood mobility was taking place at Portus.

Nonmetric trait analysis provides insight to the nature of biological population similarity and divergence. Across the three sites SCR is the most similar to JBR and Velia, while Velia and JBR are the most dissimilar. The nature of these similarities suggests that overall the biological background of the people interred at JBR, SCR, and Velia is similar, but with unique regional phenetic differences indicating distinct biological populations at all three sites.

Using these multiple lines of evidence this dissertation emphasizes a significant degree of mobility and population heterogeneity across the Roman landscape. It is evident from the research findings presented here that with the expanding Roman empire mobility and population interaction remained staples of Roman life.

Acknowledgements

There are of course as many individuals and groups of individuals to acknowledge as there are pages in this dissertation. I have tried to remember and acknowledge all of them, and to all those individuals whom I have not acknowledged here in writing, still know that you have made a large impact on how I have developed over my numerous and continuing years as a student.

From inception to completion this dissertation would not have been possible without the wonderful mentors I had on my committee. Dr. Henry Schwarcz and Dr. Tristan Carter are both inspiring scholars who in their own different ways helped to shape and challenge me for the better in developing the ideas and findings presented herein. Dr. Tracy Prowse has been and continues to be a fantastic supervisor, incredible mentor, and pillar of support whose unfailing encouragement in all of my endeavours, regardless of their direct applicability, made navigating the doctoral maze a truly enriching experience. The guidance, generosity, good conversation, and enthusiasm of Martin Knyf and Dr. Alan Dickin in their respective isotope labs made diving into a new field for this project a true delight. Their respective efforts to initiate me into the complexities of isotope chemistry while making it all look seamlessly easy and having a great sense of humour throughout made this work a truly positive experience.

This research literally would not have been possible without the permissions granted to examine the skeletal collections from Isola Sacra, Velia, and Rue Jacques Brel Necropolis. For this I owe a debt of gratitude to Dr. Luca Bondiloi of the Museo Pigorini in Rome, who always made the days interesting and kept me thinking, and Dr. Dominique Castex in Bordeaux.

If you do not have the bricks to build a house the structure can never be completed. With this sentiment in mind, I owe an enormous acknowledgement to the outstanding and continual assistance of Kim Pickett and Erin Joyce of Mills library. Though but two individuals of a larger library team, Kim and Erin made receiving articles and books not in the McMaster catalogue a seamless process and went well above and beyond on countless occasions to help me in all my zany pursuits. Thank you both.

This research was made all the more realizable through the generous granting of research funding by a number of agencies including, the Social Sciences and Humanities Research Council (SSHRC) of Canada, the Ontario Graduate Scholarship (OGS), the Lemmermann Foundation, the Shelley Saunders Scholarship in Anthropology (McMaster University), McMaster University Department of Anthropology, the Shelley R. Saunders Thesis Research Grant, and the Italian Government Bursary for Foreign and I.R.E Students.

I have been in the department of Anthropology for many years now and in my time here I have continued to enjoy the company of those individuals I started the program with and to the many other students I have spent time with arriving in years after. Matthew Vincent Emery was the perfect polymath to wade through the ebb and flow of graduate life with; Geoffrey Sigalet and the 11146-77th, our adventures past, present, and future to come epitomize the open road and the freedom of the hills, DLV; the original quintet of Laura Lockau, Kyle, Meghna, and Kandace who I shared an office with for the first years; Madeleine Mant, whom I met in Edmonton and was delighted to see arrive at McMaster; my wonderful sister Erin and the Weir clan, who always supported and joked with me about becoming a doctor; Jerry, Tamas, Artur, Joanna and all the individuals at TT65 and Ghazali, you are wonderful to work with and have allowed me to broaden my horizons immeasurably; to the many and rotating teammates of Duco, Duco, Duco, especially Mary-Lynn, Daiana, Kari and David, many a fond Tuesday eve has been spent in good company at the Phoenix playing trivia.

There have been multifold educators instrumental in my development and desire to continue learning. Of the many there have been two whose guidance and exceptional ability to make the pursuit of knowledge a passion to whom I will forever be grateful: Ms. Mus, who was able to show that education is more than fractions and rote memorization, and Dr. P.M. Michèle Daviau, who opened the world of Near Eastern archaeology to my neophyte eyes at Wilfrid Laurier.

I have known Andrew (Rosy) Rees since I was ~13 and am glad that it is the same friendship today as it was then. An always welcome partner on any exploration, a true friend thro’n’through. Without comparison, Kandace Lynn Bogaert made and continues to make my entire doctoral era marvellous, with continually high spirits, a razor sharp wit, and a love of the outdoors, you are the best. To all the anthropologists and individuals I have met along the way, you have all made an impression in your own way and I am grateful for the company, making this process a worthwhile and enjoyable endeavour. To strive, to seek, to find, and not to yield.

.

Dedication

This dissertation is dedicated to my wonderful parents, Bob and Nancy Stark,
and to all those who have gone before me to light the path along the way.

Quotation Page

We do not need any other Tutankhamun's tomb with all its treasures. We need context. We need understanding. We need knowledge of historical events to tie them together. We don't know much. Of course we know a lot, but it is context that's missing, not treasures.
-Werner Herzog, *On the Birth of Art*

It is always depressing the first day in a very strange region knowing that weeks are to go by before one returns to the familiar, but after a few days (hold on and wait till they have passed) one has constructed the familiar in the very heart of the strange.
-Graham Greene, *In Search of a Character: Congo Journal*

Work keeps my mind occupied and one needs to have projects and objectives to meet–if not life has no meaning.
-João Biehl, *The Brazilian Response to Aids*

Table of Contents

List of Tables

List of Figures

List of Equations

Abbreviations

aDNA	ancient deoxyribonucleic acid
Ag	silver
Ba	barium
BCE	before common era
Bi	bismuth
C	carbon
Ca	calcium
CE	common era
CI	crystallinity index
CNRS	Centre national de la recherche scientifique
D	deuterium
FTIR	Fourier transformation infrared spectroscopy
GIRMS	gas source isotope ratio mass spectrometry
GNIP	Global Network of Isotopes in Precipitation
H	hydrogen
HCl	hydrogen chloride, hydrochloric acid
IAEA	International Atomic Energy Agency
IQR	interquartile range
IR	infrared
IRMS	isotope ratio mass spectrometer
JBR	Rue Jacques Brel Necropolis
KBr	potassium bromide
LA-MC-ICP-MS	laser ablation MC-ICP-MS
LEH	linear enamel hypoplasia
M	molar
MC-ICP-MS	multiple collector inductively coupled plasma mass spectrometry
MMD	mean measure of divergence
MRSI	McMaster Research for Stable Isotopologues
MSM	musculoskeletal marker
N	nitrogen
NBS	National Bureau of Standards
Nd	neodymium
NIST	National Institute of Standards and Technology
NMR	nuclear magnetic resonance
NMT	nonmetric trait
O	oxygen
P	phosphorus
PACEA	De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie
Pb	lead
PCA	principle components analysis

pH	potential of hydrogen
PPM	parts per million
Rb	rubidium
REE	rare earth elements
S	sulphur
SCR	Isola Sacra
SPSS	Statistical Package for the Social Sciences
Sr	strontium
STR	short tandem repeats
TIMS	thermal ionization mass spectrometry
VPDB	Vienna Pee Dee Belemnite
VSMOW	Vienna Standard Mean Ocean Water

Chapter 1–Introduction

Mobility and migration have remained issues of perennial interest both in modern and ancient contexts. Human mobility and the associated interaction of widespread and disparate populations formed a core component in the structuring and proliferation of the Roman Empire (See Chapter 4–On Mobility and the Roman Empire). This dissertation investigates the nature of mobility and biological affinity among three Imperial Roman (ca. 1st–3rd c. CE) sites using isotopes ($\delta^{18}O$, $^{87}Sr/^{86}Sr$) and heritable nonmetric dental and skeletal traits.

The research presented in this dissertation contributes a further line of evidence situated within larger frameworks dealing with Roman mobility and population interaction as evidenced through archaeological excavation, epigraphy, onomastics, textual accounts, and material culture, among various other fields of inquiry. Three main questions are addressed through isotopic and nonmetric trait perspectives in this dissertation. Who was moving and in what number? Where, on a regional level, did people move to and from? Based on nonmetric traits, how biologically similar were the residents of the three sites examined?

The initial suggestion of using strontium isotopes ($^{87}Sr/^{86}Sr$) to trace mobility was provided by Ericson (1985) and the use of oxygen ($\delta^{18}O$) shortly after in 1991 by Schwarcz and colleagues. Both $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ have seen widespread global use in the investigation of mobility among bioarchaeological samples (See Chapter 2–Isotopes). The seminal works of Prowse et al. (2007, 2010a) looking at Portus Romae, and subsequent works by Killgrove and colleagues (Killgrove 2010a,b; Killgrove and Montgomery 2016) looking at Rome, represent early forays into using isotopic methods to gauge mobility among skeletal samples from Roman contexts.

In terms of gauging Roman mobility, the introduction of stable isotope methodologies is a relatively new endeavour compared to more traditional textual methods of study (e.g. epigraphy), and marks a departure in both how mobility is identified and conceptualized. Where epigraphy and other textual methods of identifying mobility are inherently dependant on what individuals chose to record, stable isotope methods are less limited in that information can be gathered about the mobility of each individual sampled regardless of the presence or absence of epigraphic materials. Conversely however, isotopic methods cannot pinpoint from which specific city an individual may have migrated, thus stressing the complementary rather than antagonistic relationship between epigraphic and stable isotope methods of identifying mobility.

The use of nonmetric traits (NMT) to gauge the degree of biological affinity between skeletal samples has a rich history spanning centuries of research (See Saunders 1989; Saunders and Rainey 2008). The current use of nonmetric traits to investigate phenetic affinities between skeletal samples originates with the work of Grüneberg (1952, 1963, 1965) who was able to show the heritability of nonmetric skeletal traits in mice and their use for tracking relatedness among breeding populations. Though widely employed in the investigation of bioarchaeological materials, to date the use of nonmetric traits to examine Roman and earlier populations on the Italian peninsula has seen comparatively limited employment (e.g. Rubini et al. 1996, 1997, 2007; Coppa et al. 1998, 2007; Killgrove 2010; Iorio et al. 2012). The use of nonmetric traits pairs well with isotopic methods of investigation. Where isotopic results can provide insight to the regions where individuals resided during tooth formation, nonmetric traits can provide insight to the biological diversity of the populations sampled, allowing for insights to both mobility and relative biological divergence among the samples examined (See Chapter 3–Nonmetric Traits).

Three sites dating to the ca. 1st–3rd c. CE of the Imperial Roman era are examined in this dissertation. Isola Sacra (SCR) is the cemetery associated with the maritime port of Rome at Portus Romae (Portus). This site is located at the mouth of the Tiber river on the Tyrrhenian coast of Italy and served as a key harbour and transhipment location for products coming into and moving out of Rome proper. Velia is located on the Tyrrhenian coast in the Cilento of southern Italy. Velia was a secondary maritime port of the Roman empire, being smaller than Portus and less equipped to deal with large volume maritime traffic, but nonetheless a key locale for the shipment of goods, fish processing and arboriculture, as well as the maintenance of marine craft and associated industries. The Rue Jacques Brel necropolis (JBR) is a small inland site located in Saintes, France, ~120 km north of Bordeaux. The associated settlement of Rue Jacques Brel served as a minor regional industrial production location, predominantly for glass and pottery. These three sites were chosen in an attempt to examine a presumable cross section of Roman society, ranging from the main port servicing Rome at Portus Romae, to the increasingly parochial and provincial sites of Velia and Rue Jacque Brel (See Chapter 5–Materials and Methods).

Abundant aggregate evidence of mobility in the Roman era exists among textual and epigraphic materials. Yet there is limited individualized insights to mobility due to differential recording of mobility events based on the age, sex, ethnic origin, and status of individuals. Isotopic and nonmetric trait methods of investigating Imperial Roman era mobility and population divergence can contribute significant insights to ongoing discussions about who was mobile in the Imperial Roman era. To this end, this dissertation seeks to examine the nature of mobility on an individual level as well as the degree of population similarity across the three Imperial Roman sites examined.

Chapter 2–Isotopes and Migration

2.1–Introduction

Isotopic approaches to palaeomobility within anthropology have grown significantly over the last 30 years. Anthropological palaeomobility research mainly examines oxygen ($\delta^{18}O$) and strontium ($^{87}Sr/^{86}Sr$) variability, with other elements, such as lead (Pb) seeing increasing, though still less common, use (see Montgomery et al. 2000, 2010; Montgomery 2002). This chapter begins with an introduction and background to the different varieties of isotopes and their relevance to mobility research before moving on to focus on the use of oxygen and strontium isotopes within anthropological research for addressing issues of palaeomobility. This chapter ends with a brief discussion of potential future directions in isotopic palaeomobility research within anthropology.

2.2–Isotope Varieties and Instrumentation

2.2.1–Isotope Varieties

Isotopes are variations in atomic weight of a given element resulting from differences in the number of neutrons in the nucleus while maintaining the same number of protons and hence the same chemical properties (e.g. O has 8 protons, but ^{16}O has 8 neutrons, ^{17}O has 9 neutrons and ^{18}O has 10 neutrons) (Hoeffs 2004; Sharp 2007). Isotopes can be radioactive, stable, and radiogenic. Radioactive isotopes, like ^{14}C, are not used in palaeomobility studies as they decay over time and do not generate regional signatures (Dickin 2005; Faure and Mensing 2005).

2.2.1.1–Stable Isotopes

Stable isotopes (e.g. ^{16}O), are produced through nucleosynthesis, being the cosmic process by which pre-existing nucleons are fused and altered to form new elements and their isotopes (i.e. oxygen is generated through stellar nucleosynthesis from alpha and s-processes in stars), (Sharp 2007; Meyer et al. 2008). The ratio of one isotope to another (e.g. $^{18}O/^{16}O$) changes in relation to chemical processes in which either the lighter or heavier isotope is preferentially lost leading to a change in the isotope ratio of the original state and the reaction state (e.g.^{18}O is preferentially lost in precipitation due to its increased weight over ^{16}O) (Pollard et al. 2007; Brown and Brown 2011). This process is referred to as fractionation and is the definitive principle of stable isotope research (Urey 1947; Hoeffs 2004; Fry 2006).

2.2.1.2–Radiogenic Isotopes

Radiogenic isotopes are decay products of long lived radionuclides, forming through the loss of alpha (α) and beta (β) particles (e.g. $^{87}\mathrm{Rb}\rightarrow{}^{87}\mathrm{Sr}$) (Faure and Powell 1972; Bullen and Kendall 1998; de Laeter et al. 2003). Significant fractionation of radiogenic isotopes does not readily occur (Rankama 1954; Dickin 2005). As such, the ratio of radiogenic isotopes to non-radiogenic isotopes in any given location is dependent on the initial ratio (e.g. $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$), the initial concentration of elements (e.g. Sr and Rb), and the age of the underlying geology (i.e. time allowed for $^{87}\mathrm{Rb}\rightarrow{}^{87}\mathrm{Sr}$ decay) (Dickin 2005; Bentley 2006; Voerkelius et al. 2010).

Chemical elements can have both stable and radiogenic forms of a given isotope (Jäger and Hunziker 1979). This is particularly pertinent to the present discussion as the genesis of ^{87}Sr is both stable and radiogenic, thus ^{87}Sr is not totally absent before decay of ^{87}Rb, rather such decay contributes further ^{87}Sr to what is already present (Faure and Powell 1972; Bullen and Kendall 1998).

2.2.2–Instrumentation

Isotopic ratio measurements are conducted using isotope ratio mass spectrometers (IRMS), in which elemental ions are separated into a beam by electromagnets before being separated into individual beams based on the mass/charge ratio of ions (Dickin 2005). Such isotopic measurements can be undertaken on a thermal ionization mass spectrometer (TIMS), multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS), and gas-source isotope ratio mass spectrometer (GIRMS) (See Brenna et al. 1997; Wright 1999; Dickin 2005; Pollard et al. 2007; Sharp 2007; Eiler et al. 2013).

2.2.2.1–Thermal Ionization Mass Spec. (TIMS)

When using TIMS, samples must first be purified through cation exchange columns to isolate the desired element for mass spectrometric analysis. The elemental salt is then loaded onto a metal filament (e.g. tantalum) which, under vacuum, is raised to a temperature at which simultaneous volatilization and ionization occurs, allowing for mass spectrometric data collection (Dickin 2005).

2.2.2.2–Multi-Collector Inductively Coupled Plasma Mass Spec. (MC-ICP-MS)

MC-ICP-MS uses an inductively coupled plasma source to convert atoms to ions, which are then separated and detected by a mass spectrometer (Dickin 2005). Samples are heated in a gas plasma to achieve ionization (Dickin 2005). This is accomplished by the use of a plasma torch generated by radio-frequency to create intense eddy currents in a stream of ionized argon gas, allowing for the transmission of ~1 kilowatt of power into the plasma, raising its temperature to ~5000°C resulting in ionization of most elements, allowing for separation and collection (Houk 1986; Dickin 2005). One advantage of MC-ICP-MS is that samples do not have to be as intensively purified before they are introduced to the mass spectrometer, while a benefit of TIMS is that it allows for within-run correction due to smaller mass fractionation factors (Dickin 2005).

2.2.2.3–Gas-Source Isotope Ratio Mass Spec. (GIRMS)

Gas-source IRMS is a high precision method used for analyzing the isotopic composition of elements that can be introduced into the mass spectrometer in a gaseous state, in contrast to the solid state requirements of TIMS (Wright 1999). Gas-source IRMS is the basis for most stable isotope analyses of compounds containing the elements H,C,N,O, and S (Brenna et al. 1997; Eiler et al. 2013). The most common gas-source IRMS instrumentation used relies on a dual-inlet setup, where twin manifolds are employed to introduce respectively the unknown sample and the reference standard (Wright 1999). The gases are introduced to the ionization source, under vacuum, where the ions enter a flight tube before ultimately being separated by a magnetic field and detected at the end of their trajectories. The dual inlet system allows for rapid introduction and comparison of samples and standards under essentially identical instrument conditions (Wright 1999; Eiler et al. 2013).

2.3–Isotopic Perspectives on Palaeomobility in Anthropology

Palaeomobility research relies on region specific isotopic signatures to gauge where individuals may have resided during specific periods of skeletal formation (Katzenberg 2008). Individuals take on an isotopic signature (e.g. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$) based on the isotopic values of the foods and water they consume, which themselves have isotopic values reflective of the regions from which they are derived (Katzenberg 2008). The isotopic signature of any given individual is thus an average of the isotopic values consumed. If an individual's diet is comprised primarily of local foods and water, the isotopic values of that individual's skeletal tissues will reflect a local signature. However, the local signature of a given area may also be the local signature of another region where homogeneous isotopic values are present. This is a key difficulty in palaeomobility studies as one regional signature may overlap with another region due to similar underlying geology ($^{87}Sr/^{86}Sr$) or climate ($\delta^{18}O$), making distinctions difficult at times and as a result making it reasonable only to suggest non-local areas an individual may have come from, rather than definitively assigning specific geographic origins (See Knudson and Price 2007; Prowse et al. 2007; Bruun 2010; Killgrove 2010a,b).

The isotopic signature in dental enamel can be used as an indicator of residence for the period from birth up to ~17 years, when third molar crown development is complete (Hillson 1996). The isotopic signature of bone can also be used. Unlike teeth, which do not undergo turnover, the isotopic signature of bone can be used throughout an individual's lifetime, from birth to death, with the isotopic signature of bone preserving roughly the last 10–20 years of residency, which in terms of palaeomobility research can be equated with the last 10–20 years of an individual's life (Price et al. 1994b; Hill 1998; Parfitt 2002, 2004; Hedges 2007; Price and Burton 2011).

Rates of bone turnover are complicated and difficult to accurately estimate, varying between skeletal elements and individuals, being fundamentally driven by age, health, structural optimization, and biomechanical demands (Hill 1998; Parfitt, 2002, 2004; Gosman et al. 2011). It is commonly proposed that cancellous bone turns over at an increasingly rapid rate compared to cortical bone, though this concept has been criticized as an oversimplification (Parfitt 2002). Bone turnover is driven by both biological and geometric factors. Bone is remodeled to repair damaged bone and to optimize structural integrity (Parfitt 2002; Mescher 2013). At the same time the geometric surface-to-volume ratio of skeletal elements in regard to volume replacement/year also plays a role in turnover, with different skeletal elements and regions of skeletal elements (i.e. periosteal vs. intracortical, metaphysis vs. diaphysis) exhibiting variable rates of turnover (Parfitt 2002; Hedges et al. 2007).

Age is also a factor in bone remodeling. Bone collagen turnover has been shown to be more rapid in younger individuals, being between 10-30% per year in both male and female individuals 10-15 years of age, when modeling and remodeling occur at a faster pace to maintain proper longitudinal growth and bone integrity (Scheuer and Black, 2000; Hedges et al. 2007; Mescher 2013). As individuals age, rates of bone turnover slow with turnover rates among adult males decreasing from 3% per year to 1.5% per year between the ages of 20 and 80, while for the same age range in females the rate decreases from 4% per year to 3% per year (Hedges et al. 2007).

For all of these reasons, estimates of bone turnover/year are difficult to accurately formulate, necessitating the use of broad estimates from which skeletal elements and individuals may widely vary (Frost 1969; Parfitt 2002; Hedges 2007). Taking these factors of bone turnover into account, an estimate of ~10 to 20 years is a commonly accepted timeframe for complete bone turnover (Frost 1969; Stenhouse and Baxter 1979; Hill 1998; Manolagas 2000). Given this comparatively large 10–20 year window, it must also be taken into account that if an individual moves between isotopically heterogeneous regions and consumes isotopically heterogeneous dietary items over this 10–20 years the isotopic signal preserved in the bone will be an average of the values consumed, which may potentially prove challenging for accurate assessments of geographic residency.

2.3.1–Aspects of Skeletal Elements Used for Isotopic Analyses

Palaeomobility studies employing $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ examine the inorganic bioapatite (i.e. biogenic hydroxyapatite = $Ca_9(PO_4)_{4.5}(CO_3)_{1.5}(OH)_{1.5}$; bioapatite in bone= $Ca_9(PO_4, HPO_4)_6\ CO_3$) aspect of skeletal elements (Driessens and Verbeeck 1990; Rey et al. 1991a; Kolodny and Luz 1991; Arppe and Karhu 2005; Price and Burton 2011; Rabadjieva et al. 2011). Strontium ($^{87}Sr/^{86}Sr$) can be extracted from apatite as it can substitute for calcium (Ca), and thus it has the potential to be recovered from locations where Ca is found (Bentley 2006; Burton 2008; Price et al. 2015). Oxygen ($\delta^{18}O$) values can be derived from two locations within apatite - carbonate (CO_3) and phosphate (PO_4), (Elliot et al. 1985; Kolodny and Luz 1991; Price and Burton 2011).

Carbonate is more frequently used in stable isotope research, as it is cheaper and easier to isolate for sampling (Kohn and Cerling 2002; Chenery et al. 2012; Kenoyer et al. 2013). Carbonate oxygen (CO_3) can substitute for PO_4 and OH within bioapatites, but is also present in a more structurally ambiguous labile form, which is subject to significant diagenesis (Rey et al. 1991b; Kohn and Cerling 2002). This labile component can be removed through simple buffered acetic acid pretreatment leaving the more diagenetically resistant form of oxygen for dissolution in phosphoric acid (H_3PO_4) before mass spectrometric analysis (Land et al. 1980; McArthur et al. 1980; Koch et al. 1997; Kohn and Cerling 2002).

Phosphate (PO_4), though more expensive and complicated to isolate for sampling, is a more directly correlated gauge of $\delta^{18}O$ in the body (Schwarcz and Schoeninger 1991; Kohn and Cerling 2002; Chenery et al. 2012). Unlike CO_3, to analyze PO_4 oxygen isotope values samples must be treated through acid dissolution, typically nitric acid (HNO_3) or hydrogen fluoride (HF), before being purified, either through exchange columns or chemically to produce bismuth phosphate ($BiPO_4$) or silver phosphate ($AgPO_4$), after which time samples can be fluorinated, brominated, or thermally decomposed in the presence of C to produce carbon dioxide (CO_2) or carbon monoxide (CO), at which time the sample can be measured using mass spectrometry (Longinelli 1965; Wright and

Hoering 1989; Crowson et al. 1991; O’Neil et al. 1994; Stuart-Williams and Schwarcz 1995; Farquhar et al. 1997; Kohn and Cerling 2002; Vennemann et al. 2002).

The relationship between phosphate and drinking water in humans is well established, as phosphate is the main reservoir of oxygen within skeletal materials (~85%), whereas the relationship between carbonate and drinking water requires greater regression modeling (see discussion below) (Iacumin et al. 1996; Kohn and Cerling 2002; Daux et al. 2005; Chenery et al. 2012). Phosphate is typically believed to be more resistant to diagenetic alteration given the strong P-O bond in comparison to the less strong C-O bond found in carbonate, though it has been shown that enzyme mediated microbial action can result in phosphate oxygen exchange during interaction with water and secondary mineral precipitation (Stuart-Williams et al. 1996; Sharp et al. 2000; Zazzo et al. 2004; Brady et al. 2008; White et al. 2008–2009; Leach et al. 2010). Despite these differences, in the absence of diagenesis both carbonate and phosphate equally reflect the isotopic values preserved in skeletal tissues (Schwarcz et al. 2010).

2.3.2–Diagenesis

Post-depositional alteration, or diagenesis, is a major concern in isotopic research, described as “the problem that will not go away” (Sharp et al. 2000: 235). In the burial environment the isotopic signature of bones and teeth 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 1986; Stuart-Williams et al. 1996; Nielsen-Marsh and Hedges 2000; Ayliffe et al. 1992; Chenery et al. 2012). Diagenetic susceptibility is dictated by compositional structure. Bone has a significant organic component (i.e. collagen) that is subject to postmortem decay and microbial attack. Bone is very porous and composed of smaller poorly crystalline structures (a few tens to hundreds of nm in length, and 5 nm in thickness), allowing for easier isotopic exchange with the surrounding environment, with cancellous bone being more susceptible than cortical bone due to the potential for increased exposure to the surrounding burial matrix and therefore increased opportunity for microbial attack and isotopic exchange (Tuross et al. 1989; Price et al. 1992; Nielsen-Marsh and Hedges 2000; Kohn and Cerling 2002; Robinson et al. 2003; Bentley 2006; Burton 2008). In terms of dental remains, dentine is the most susceptible to diagenesis, as it is less porous than bone but similar in crystallite size, while enamel is largely believed to be resistant to diagenesis due to the larger (tens of nanometres thick and wide, and potentially hundreds of nanomtres long), 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 equilibration with the surrounding burial environment remains the key process for δ^{18}O diagenesis. For strontium, secondary Ca and Sr exchange with biogenic Sr through pore filling and concentration along microcracks and on the surface of bone, coupled with re-crystallization and re-mineralization of diagenetic Sr in hydroxyapatite, can create a highly deceptive diagenetic signature (Bentley 2006).

One way to examine biogenic Sr preservation is to measure the amount of Sr (ppm) in a given bone, as Sr in bone should initially be identical to that in enamel of the same individual, typically 50 to 300 ppm. The shape of the Sr/Ca curve and the Ca/P ratio = 2.1 can also be used as a further confirmation of potentially viable biogenic Sr preservation (Knudson et al. 2010; Burton et al. 2003; Sillen and LeGros 1991; Elias 1980).

In an attempt to develop a method for removing diagenetic Sr, several pioneering studies (e.g. Sillen 1986, Sealy et al. 1991, Sillen and Sealy 1995, Grupe 1999) have employed sequential leaching baths of 0.1 N buffered acetic acid (ph= 4.5). This approach hinges on the assumption that diagenetic Sr is more readily soluble in acid than biogenic Sr, allowing for diagenetic Sr to be separated from biogenic Sr (Bentley 2006; Snoeck et al. 2015). Though novel, this method has come under significant questioning on the basis that it neglects the concept of re-crystallization and assumes a divergence between diagenetic and biogenic Sr that requires further validation (Beard and Johnson 2000). The study of Beard and Johnson (2000) on Vietnam war burials particularly calls into question the validity of this method as the acetic acid leach method was unable to recover primary

Sr from skeletal material that was interred for ~20 years, providing damning implications for bone of significantly older age that has undergone diagenesis (Bentley 2006). The acid leach method has also been decried on the basis that there is no verification that all the diagenetic Sr will be removed, nor is there a reliable way to be certain that viable biogenic Sr has not also been removed during acid leaching (Tuross et al. 1989; Budd et al. 2000; Hoppe et al. 2003; Zazzo et al. 2004). For bone particularly, the difficulty of accurately identifying preserved biogenic Sr over diagenetic Sr requires significant validation testing to ensure that a viable $^{87}Sr/^{86}Sr$ signal is present, a factor that has resulted in a decrease in the use of bone for $^{87}Sr/^{86}Sr$ palaeomobility studies (Nelson et al. 1986; Hoppe et al. 2003; Bentley et al. 2004; Schwarcz et al. 2010; King et al. 2011), though some studies (e.g., Grupe et al. 1997; Schweissing and Grupe 2003; Nafplioti 2008, 2012; Conlee et al. 2009; Giblin et al. 2013) do still use bone.

To test for diagenesis several methods can be employed, including mercury intrusion porosimetry, to search for evidence of microbial attack (Jans et al. 2004); laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), which can highlight ion substitutions and elemental concentrations (Trueman et al. 2004; King et al. 2011); the presence of certain elements, such as uranium and rare earth elements (REE), at unnatural concentrations can help to indicate diagenetic alteration given the absence or very low concentrations of these elements in the living body (Hoohewerff et al. 2001; Knudson and Price 2007; Grandstaff and Terry 2009; Terry et al. 2009); micromilling and IR-ablation, which investigates structural alterations at the osteon level (Brady et al. 2008); comparison of burial matrix isotopic values to those of recovered human remains (Budd et al. 2000); nuclear magnetic resonance (NMR) and x-ray diffraction, which examine structural composition of bone (Lee et al. 1995; Salesse et al. 2013); Fourier transformation Raman (FT-Raman) spectroscopy, which uses vibrational frequencies to examine change and can also provide insight to the diagenetic presence of elements, unlike FTIR (King et al. 2011); and Fourier transformation infrared spectroscopy (FTIR) (Shemesh 1990). Of all these approaches it is Fourier transformation infrared spectroscopy (FTIR) that remains the most commonly employed method for assessing post-depositional diagenesis in bone and tooth, as FTIR is comparatively inexpensive and accessible, and to date, has been the most thoroughly investigated method for looking at archaeological skeletal element diagenesis (King et al. 2011; Webb et al. 2014).

FTIR uses vibrational frequencies to examine the nature of chemical bonds in a compound as gauged from infrared stimulated absorption characteristics at particular wavelengths along a spectrum (Shemesh 1990; Wright and Schwarcz 1996; Lebon et al. 2010; King et al. 2011). Based on the characteristics of the spectrum produced, a gauge of diagenetic alteration associated with re-crystallization can be ascertained through what is know as the crystallinity index (CI). This is a measure of the size and structural order of crystals, which is calculated based on phosphate peak splitting on the FTIR spectrum using the CI formula:

Equation 2.1–Crystallinity Index (after Shemesh 1990)

$$CI = (A_{565} + A_{605})/A_{595},$$

where A_x is the absorption at a certain point along the spectrum in cm^{-1} (Termine and Posner 1966; Weiner and Bar-Yosef 1990; Shemesh 1990; Trueman et al. 2004). Using this equation, a CI of 3.8 or less for biogenic apatite is ideal, with values above this indicating increasing diagenetic alteration associated with apatite re-crystallization (Shemesh 1990; Wright and Schwarcz 1996; King et al. 2011; Webb et al. 2014). In tandem with CI, the C/P ratio of carbonate (CO_3) to phosphate (PO_4) can be used to assess the addition of diagenetic carbonate by using:

Equation 2.2–C/P Ratio (after Wright and Schwarcz 1996)

$$C/P=A_{1415}/A_{1035,}$$

where A_{1415} is the CO_3 peak and A_{1035} is the main PO_4 peak on the FTIR spectrum (Wright and Schwarcz 1996; Wright et al. 2010). Taking stock of all of these diagenetic factors it is essential that bioarchaeological materials be assessed for diagenesis in order to ensure that an accurately preserved isotopic signature is being examined.

2.3.3–Oxygen ($\delta^{18}O$) Isotopes in Palaeomobility Research

2.3.3.1–Oxygen Isotopes

Oxygen is a naturally abundant element with three stable isotopes, ^{16}O (99.763%), ^{17}O (0.0375%) and ^{18}O (0.1995%) (Hoeffs 2004). Palaeomobility studies use regional variations in the ratio of $^{18}O/^{16}O$ to gauge human movements. As the ratio of $^{18}O/^{16}O$ is numerically small $^{18}O/^{16}O$ is presented using delta (δ) values in per mil (‰) increments, calculated as:

Equation 2.3–Calculation of Delta Values (after Hoeffs 2004)

$$\delta^{18}O = ((^{18}O/^{16}O_{sample}/^{18}O/^{16}O_{standard}) -1) \times 1000 \text{ (‰)},$$

where $^{18}O/^{16}O_{sample}$ is the ratio of the sample in question measured against the $^{18}O/^{16}O_{standard}$ ratio of an international standard (e.g. NBS-19 for VPDB $\delta^{18}O_{carbonate}$ = -2.2‰) (Sharp 2007; de Laeter et al. 2003). By using delta values, minor numerical variations that are significant can be more easily observed. The standardized scale for measuring $\delta^{18}O$ can be either Vienna standard mean ocean water (VSMOW) or Vienna Pee Dee Belemnite (VPDB) as established by the International Atomic Energy Agency (IAEA) (Preston 1992; ASOL 1995; Coplen et al. 1996).

Water (H_2O), and the water cycle, is the key medium through which oxygen isotope variation occurs and can be tracked (Bowen 2010). Pioneering research by Dansgaard (1964) showed that $\delta^{18}O$ of precipitation generally decreases with distance from a marine coastline, increase in elevation, decreasing temperature of precipitation and increasing latitude, with further potential effects due to humidity (Bowen 2010; Schwarcz et al. 2010). In continually hot climates (> ~25ºC) this trend breaks down and one must rely on the amount of precipitation, which Dansgaard (1964) also showed to follow a pattern of predictable $\delta^{18}O$ variability (e.g. low $\delta^{18}O$ in rainy periods and high $\delta^{18}O$ in dry periods). Taking account of these parameters global variability of $\delta^{18}O$ in meteoric water can be mapped using region specific data, typically compiled as part of the Global Network of Isotopes in Precipitation (GNIP) project (GNIP 2015).

As regional $\delta^{18}O$ values are driven by the hydrological cycle there can be many homogeneous regions that exhibit the same isotopic signature (e.g. for both Comacchio in northern Italy and Bari in southern Italy $\delta^{18}O$= -6.7‰) (Longinelli and Selmo 2003). For this reason $\delta^{18}O$ signatures are not unique, but rather are regional, necessitating that $\delta^{18}O$ signatures be interpreted parsimoniously and, when possible, in tandem with other regionally discriminative data (e.g. $^{87}Sr/^{86}Sr$) to help provide finer regional resolution.

2.3.3.2–Oxygen in the Body

Oxygen is incorporated into the skeleton predominantly through consumption of drinking water, with dietary water and atmospheric oxygen playing minor secondary roles (Hedges et al. 2006; Price and Burton 2011). The $\delta^{18}O$ signature of slower forming tissues (e.g. bone, enamel) forms in equilibrium with bulk body water (~37°C), which itself largely reflects drinking water (Luz et al. 1984; Preston 1992; Kohn and Cerling 2002; Ehleringer et al. 2008). In rapidly forming tissues (e.g. hair) $\delta^{18}O$ is much more variable, reflecting a complicated balance between water intake, body water and amino acids in keratin (see Ehleringer et al. 2008; Bowen et al. 2009; D’Ortenzio et al. 2015). Oxygen is released from the body in urine, sweat and exhaled vapour (CO_2), thus $\delta^{18}O$ in the human body is a balance between what comes in and what goes out (Prowse et al. 2007).

Palaeomobility research using oxygen operates on the premise that in antiquity drinking water would have been predominantly derived from rain water and local water sources resulting in individuals taking on a $\delta^{18}O$ signal that reflects their area of residency (Hedges et al. 2006). Variation in the $\delta^{18}O$ signal can occur from such processes as water storage, cooking, and fermentation due to preferential evaporation of ^{16}O (Daux et al.

2008; Warriner and Tuross 2009; Killgrove 2010a; Brettell et al. 2012a; Kendall et al. 2013; Britton et al. 2015), and due to breastfeeding, during which the enamel of developing teeth is enriched in ^{18}O resulting in 0.5 – 0.7‰ elevation of $\delta^{18}O$ compared to adult values (see Roberts et al. 1988; Herring et al. 1998; Wright and Schwarcz 1998, 1999; Knudson 2009). This occurs due to the fact that breast milk is enriched in ^{18}O compared to drinking water given the preferential loss of ^{16}O with the expulsion of body water (Roberts et al. 1988; Knudson 2009). Though these variations in $\delta^{18}O$ values occur, consumption of such products is not likely to form the exclusive intake of water in any given post-breastfeeding diet and thus it is expected that a signature consistent with the $\delta^{18}O$ value of local precipitation can still be obtained.

A potential inhibiting factor to this logic is the use and consumption of modified water sources. Looking at $\delta^{18}O_c$ variation in dental enamel between Iron Age, Roman period, and Early Medieval sites in coastal Croatia, Lightfoot et al. (2014) argue that modified water source exploitation (i.e. aqueducts and wine) in the Roman period may account for the degree of variability they observed between these three time periods. Aqueducts have the potential to alter local $\delta^{18}O$ values as water was often sourced from distant settings, possibly resulting in higher or lower $\delta^{18}O$ values in enamel depending on variation in altitude (see Ashby 1935; Passchier et al. 2011). In terms of Roman aqueducts the amount of water available is difficult to accurately estimate, both in quantity and who had access to aqueduct water (Bruun 1991). In the case of Rome, it is well known that before the aqueducts were constructed, local rainwater, springs, and even water from the Tiber river were used, and very probably were still significantly relied upon after the introduction of aqueducts, suggesting that even with the introduction of aqueducts local sources of water would still also have been utilized (Bruun 1991).

Lightfoot et al. (2014) also suggest that wine may in part account for the $\delta^{18}O$ variability observed, given the increase in access to and trade in wine during the Roman era. Though fermentation accounts for relatively little isotopic change (up to 1.7‰), isotopic fractionation associated with evapotranspiration between local waters and grape juice for wine production can be in the order of +7.2‰ (Dunbar 1982a,b; Ingraham and

Caldwell 1999). Despite the proposition of these potential sources of $\delta^{18}O$ variation in Roman Croatia, Lightfoot et al. (2014) do not provide strong confirmatory evidence that aqueducts or wine were the root cause of the variation they observed, but rather infer that they may have been, stressing overall that, regardless of the source of variation, caution and accounting for of potential anthropogenically modified water sources needs to be taken into account in any $\delta^{18}O$ examinations of palaeomobility. A way in which to potentially assuage this concern is to employ $\delta^{18}O$ in tandem with other regionally discriminative isotopes (i.e. $^{87}Sr/^{86}Sr$, $\delta^{34}S$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$).

2.3.3.3–Converting Oxygen Isotope Values

Bioapatite $\delta^{18}O$ values ultimately have to be converted to regional drinking water values, also referred to as meteoric water, to be comparable to oxygen isotopes values in precipitation (i.e. GNIP 2015). To accomplish this a series of conversion equations must be employed. Starting with the equation of Faure and Mensing (2005), $\delta^{18}O_{carbonate}$(VPDB) can be converted to $\delta^{18}O_{carbonate}$ (VSMOW) a step that is necessary as subsequent equations are based on VSMOW values:

Equation 2.4–Conversion of VPDB values to VSMOW values (after Faure and Mensing 2005)

$$\delta^{18}O_{c(VSMOW)} = 1.0309 \times \delta^{18}O_{c(VPDB)} + 30.91.$$

Following conversion to VSMOW, carbonate ($\delta^{18}O_c$) values can be converted to phosphate ($\delta^{18}O_p$) values. Isotopic research using $\delta^{18}O$ initially avoided using the carbonate oxygen component due to concerns about potentially significant diagenesis (see Section 2.3.1) and uncertainty that carbonate values were in equilibrium with body water, which is well established for phosphate oxygen values (Iacumin et al. 1996; Chenery et al. 2012). From a series of analyses on modern, archaeological, and fossil bones Iacumin et al. (1996) were able to show that carbonate and phosphate oxygen values in the body are linearly correlated, with an 8.5‰ offset between them, thus carbonate accurately reflects body water composition. Based on this finding Iacumin et al. (1996:Eqn. 2) were able to derive a regression equation for converting carbonate values to phosphate values:

Equation 2.5–Conversion of carbonate values to phosphate values (after Iacumin et al. 1996).

$$\delta^{18}O_p = 0.98 \times \delta^{18}O_c - 8.5.$$

Once carbonate values are converted to phosphate values the final step is to convert phosphate to drinking water ($\delta^{18}O_{dw}$) values. This step can be completed using a number of equations (i.e. Luz et al. 1984; Longinelli 1984; Levinson et al. 1987), though the most recent and widely used equation remains that of Daux et al. (2008:Eqn. 6):

Equation 2.6–Conversion of phosphate values to drinking water values (after Daux et al. 2008)

$$\delta^{18}O_{dw} = 1.54 \times \delta^{18}O_p - 33.72.$$

This series of conversion steps has remained a key method for comparing carbonate derived oxygen values to regional drinking water values. However, this approach has not been without its difficulties. With each step of the conversion an increasing degree of uncertainty is introduced, inherently increasing the potential error of calculations (Pollard et al. 2011; Chenery et al. 2012). To help limit this degree of error Chenery et al. (2012) analyzed $\delta^{18}O_c$ from the enamel of 51 archaeological teeth that had previously been examined for $\delta^{18}O_p$ and $^{87}Sr/^{86}Sr$. From these analyses Chenery et al. (2012) were able to establish a direct relationship between $\delta^{18}O_c$ and $\delta^{18}O_p$ in human dental enamel, which was then combined with the $\delta^{18}O_p$ to $\delta^{18}O_{dw}$ formula of Daux et al. (2008) to create a novel regression equation to convert $\delta^{18}O_c$ directly to $\delta^{18}O_{dw}$:

Equation 2.7–Conversion of carbonate values to drinking water (after Chenery et al. 2012)

$$\delta^{18}O_{dw} = 1.590 \times \delta^{18}O_c - 48.634.$$

By allowing for direct conversion of $\delta^{18}O_c$ to $\delta^{18}O_{dw}$ the degree of error that is introduced with each subsequent conversion, which Pollard et al. (2011) showed can range from ±1‰ to ±3.5‰ across several $\delta^{18}O_p$ to $\delta^{18}O_{dw}$ equations (i.e. Luz et al. 1984; Longinelli 1984; Levinson et al. 1987; Daux et al. 2008) with a potential additional error of ±0.28‰ when converting $\delta^{18}O_c$ to $\delta^{18}O_p$ (Chenery et al. 2012), can be reduced.

Another potential way to limit the error introduced by multiple conversions, as discussed by Pollard et al. (2011), would be to generate regional $\delta^{18}O_p$ values, thus removing the need to use drinking water values as they are the only globally mapped values at present. Pellegrini et al. (2016) attempted this process using a geostatistical model derived from $\delta^{18}O_p$ values in the teeth of 261 individuals interred at sites dating from the Chalcolithic to Early Bronze Age in Britain (ca. 2500–1500 BCE). This study resulted in the generation of a map of expected phosphate ($\delta^{18}O_p$) values that can be used in future research on this era in Britain in place of converted $\delta^{18}O_{dw}$ values. However, until $\delta^{18}O_p$ values can be generated for large regions, ideally globally, which is not likely to be anytime soon given the massive undertaking of such a global project, it is necessary to continue to use comparisons to $\delta^{18}O_{dw}$ values.

2.3.3.4–Anthropological Palaeomobility Research Using Oxygen

Early research by Luz et al. (1984) and Luz and Kolodny (1985) empirically shows that variations in $^{18}O/^{16}O$ occur in bone in relation to isotopic differences in dietary water. The work of Schwarcz et al. (1991), looking at $\delta^{18}O$ in bone phosphate of soldiers from the

War of 1812 at Snake Hill, initiated the use of $\delta^{18}O$ in palaeomobility research in anthropology. Following this initial study, the use of $\delta^{18}O$ for tracing migration in the past expanded steadily.

The works of White et al. (1998, 2000, 2002) and Spence et al. (2004) are some of the most extensive studies to use $\delta^{18}O_p$ exclusively, looking at non-local vs. local mobility and enclaves at Teotihuacan and surrounding Mesoamerican regions, as well as the impacts of Teotihuacan imperialism and cultural group interactions within Mexico and Guatemala. These respective works show how potent the use of $\delta^{18}O$ could be for gauging regional movement, and how even at the site level individuals from disparate geographical backgrounds could be identified.

Looking at Roman era samples, Nugent (2013) uses $\delta^{18}O_c$ to gauge the mobility of a single unsexed Roman individual known as Individual 21, who was recovered buried in a seated position inside a pithos with a number of high status Roman objects during excavations of an Iron Age site at Oğlanqala in Naxçivan, Azerbaijan. Based on a 2.58‰ difference between Individual 21 and archaeological rats, Nugent (2013) concludes that Individual 21 was likely non-local to the area of Oğlanqala. Individual 21 is the only Roman individual to be recovered from this site and the first Roman burial identified from the South Caucasus, providing a rare contribution to discussions of a region of the Roman Empire that is presently comparatively poorly understood (See Kennedy 1996; Woolf 1997; Khatchadourian 2008; Ristvet 2012).

Using exclusively $\delta^{18}O_c$ Lightfoot et al. (2014) examine potentially culturally induced variations in $\delta^{18}O$ signatures over time among individuals from Iron Age, Roman, and Early Medieval sites in coastal Croatia. A comparison of human and local faunal $\delta^{18}O$ values suggests that human $\delta^{18}O$ values from the Iron Age largely reflect local faunal values, while those of the Roman and Early Medieval periods vary significantly (Lightfoot et al. 2014). Such variation is attributed to widespread exploitation of water brought in by aqueducts from the Dinaric Alps during the Roman era with continued but decreasing exploitation into the Early Medieval period. The implications of this $\delta^{18}O$ study are significant as it provides a mechanism not only for gauging mobility but also a potential approach for looking at cultural variation in water exploitation over time (see also discussion in Section 2.3.3.2).

Prowse et al. (2007, 2010a) use $\delta^{18}O_c$ to explore mobility at the Imperial Roman sites of Isola Sacra (1st–3rd c. CE), and Vagnari (2nd–4th c. CE). These studies represent two of the first attempts to use $\delta^{18}O$ to look at Roman population mobility on the Italian peninsula. At Vagnari in Puglia, Prowse et al. (2010a) show how $\delta^{18}O$, coupled with mtDNA and grave type analysis, can help provide evidence of mobility that is not necessarily obtainable from burial style or grave goods alone, as several individuals at Vagnari clearly migrated there based on their non-local $\delta^{18}O$ signature, yet were also likely highly integrated into the community given their similar burial style to isotopically local individuals. This study shows how the combination of investigatory methods can help to provide more richly detailed insights to both mobility and cultural interactions in Roman antiquity.

At Isola Sacra, the cemetery of Portus, Prowse et al. (2007) show that ~33% of individuals examined were non-local based on their $\delta^{18}O_c$ signatures. The mobility observed includes potential instances of family migration, where children accompanied parents. This novel observation has strong implications as migration in the Roman era is predominantly discussed in terms of male mobility. Comparatively little discussion centres on women or children, making such an observation an important contribution to ongoing debates about the history and often problematized nature of Roman mobility in general and settlement at Portus in particular (e.g. Meiggs 1974; Bruun and Zevi 2002; Bruun 2010).

Along with their discussion of Roman mobility, Prowse et al. (2007) also provide data on local $\delta^{18}O$ signatures, derived from sampling teeth of modern residents of Rome. These data, along with the Italian data for regional variation in $\delta^{18}O$ of rainfall (Figure 2.1) presented by Longinelli and Selmo (2003), provide further contextual information that can aid future $\delta^{18}O$ research in the region.

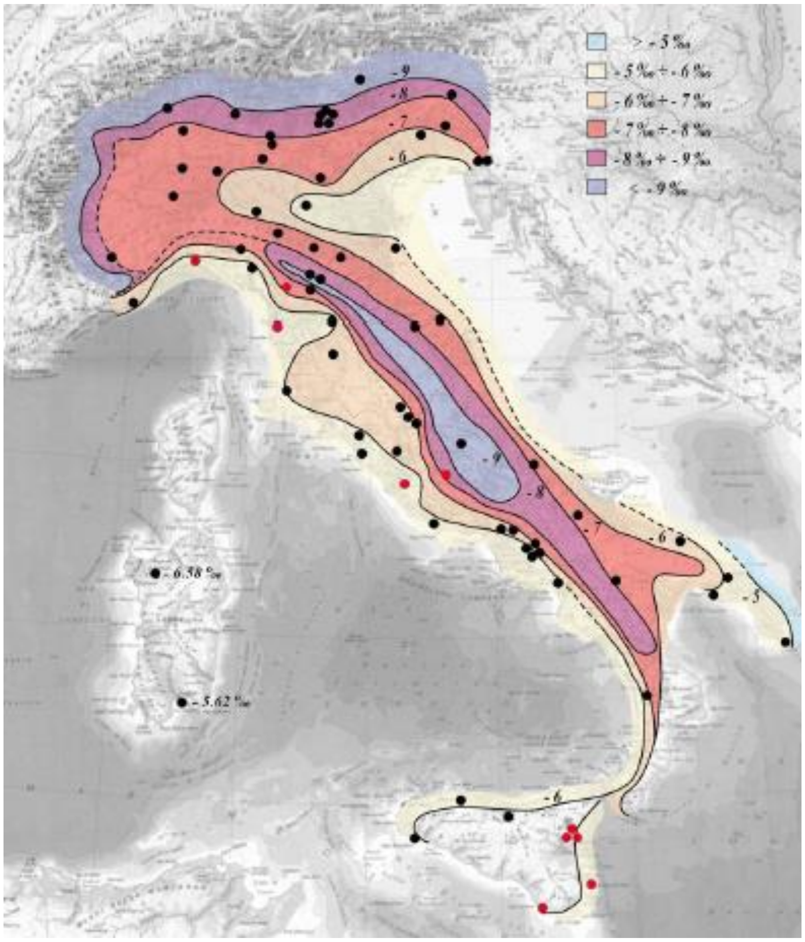

Figure 2.1–Mean oxygen isotopic ($\delta^{18}O$) variability of precipitation on the Italian peninsula. (Reprinted from Journal of Hydrology, vol. 270, Longinelli A., Selmo E., Isotopic Composition of Precipitation in Italy: A First Overall Map, pp. 75–88, Copyright (2003), with permission from Elsevier).

Despite the success of singular $\delta^{18}O$ studies a key difficulty of using only $\delta^{18}O$ to gauge mobility is the prevalence of $\delta^{18}O$ homogeneity over some geographic areas. As discussed above, $\delta^{18}O$ varies predictably and as a result several areas can have the same $\delta^{18}O$ signature, potentially making regional distinctions based on $\delta^{18}O$ alone difficult. This issue is made quite evident for Italy in the work of Longinelli and Selmo (2003), where $\delta^{18}O$ values are shown to vary between the coast and the Apennine mountains but are largely homogeneous from North to South. Thus an individual born in Genoa could potentially have the same $\delta^{18}O$ signature as an individual born in Palermo. In order to help address this limitation alternate approaches to gauging mobility (e.g. $^{87}Sr/^{86}Sr$) are needed.

2.3.4–Strontium ($^{87}Sr/^{86}Sr$) Isotopes in Palaeomobility Research

2.3.4.1–Strontium Isotope Abundances and Standards

There are four stable isotopes of strontium, ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), ^{88}Sr (~82.53%), and ^{87}Sr (~7.04%), which is also radiogenic (Malainey 2010; Bentley 2006). Sr enters the body through dietary consumption but serves no biological function, however, Sr can readily substitute for Ca in hydroxyapatite given its similar ionic radius (Sr =1.32 Å vs. Ca= 1.18 Å) and ionic charge of 2+ (Bentley 2006).

Strontium values are conventionally presented as a direct ratio (e.g. $^{87}Sr/^{86}Sr$= 0.703192) (Bentley 2006). Attempts have been made to use delta (δ) (Juarez 2008), and epsilon (ε) (Beard and Johnson 2000)[1] values for looking at $^{87}Sr/^{86}Sr$ within forensic contexts, ostensibly for reasons of small numerical differences between $^{87}Sr/^{86}Sr$ and for comparability to the geochemical literature (Beard and Johnson 2000; Dickin 2005). Direct ratio (i.e. $^{87}Sr/^{86}Sr$) values remain the most standard convention of data presentation across fields.

Due to its atomic size and the fact that ^{87}Sr is only 1.1% heavier than ^{86}Sr there is no observable fractionation between these isotopes at biological temperatures, allowing for the contributing $^{87}Sr/^{86}Sr$ of underlying geology to be preserved along the food chain (Bentley 2006; Malainey 2010). The standard against which $^{87}Sr/^{86}Sr$ is compared is strontium carbonate ($SrCO_3$) NIST SRM-987= 0.710260 ± 0.000010 (Moore et al. 1973, 1982; Knudson and Torres-Rouff 2009; Brand et al. 2014).

---

[1] $\delta=(R_{sample}/R_{standard}-1) \times 1000$; $\varepsilon^{87}Sr=([^{87}Sr/^{86}Sr]_{measured}/[^{87}Sr/^{86}Sr]_{BULK\ EARTH}-1) \times 10{,}000$ (**Equation. 2.8** – Calculation of Epsilon Values).

2.3.4.2–Regional Variation in $^{87}Sr/^{86}Sr$

Geologic ratios of $^{87}Sr/^{86}Sr$ 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 (e.g., >100 mya with high original $^{87}Rb/^{87}Sr$ content, such as granites) have $^{87}Sr/^{86}Sr$ values generally above 0.710, with the upper limit being ~0.750; rocks formed comparatively recently (i.e. <1–10 mya, such as igneous rocks with low original $^{87}Rb/^{87}Sr$) have low $^{87}Sr/^{86}Sr$ values, generally less than 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; Veizer 1989; Bentley 2006; Copeland et al. 2008; Malainey 2010; Bataille and Bowen 2012). Using such values, estimates of regional origins can be derived for palaeomobility research. Though variation in underlying geology can be region specific, regional homogeneity, in which similar underlying geology results in similar regional $^{87}Sr/^{86}Sr$ signatures, does occur and must be borne in mind when deriving palaeomobility interpretations (Bentley 2006; see also Section 2.3.5).

2.3.4.3–Bioarchaeological Consideration of Strontium

Studies utilizing Sr within the human body have a significant history. The work of Turekian and Kulp (1956) on Sr content in bone (ppm) marks an early point at which consideration of Sr in animal and human skeletons began. Early studies of Sr commonly sought to examine concentrations of Sr in the human skeleton in the form of Sr/Ca to look at diet (Sillen 1981; Sillen and Kavanagh 1982; Katzenberg 1984). Unlike $^{87}Sr/^{86}Sr$, Sr/Ca undergoes biopurification, where Ca is preferentially selected for over Sr the farther up the food chain a consumer sits, ostensibly allowing for a relative measure of dietary intake (i.e. meat vs. vegetables), with a larger amount of Sr present at lower trophic levels (i.e. herbivorous diets) and decreasing amounts of Sr at higher trophic levels (i.e. carnivorous diets) (Sillen and Kavanagh 1982; Burton et al. 2003). However, the use of Sr/Ca for palaeodietary studies suffers from wide regional variability in Sr and the fact that intermediate diets between herbivorous and carnivorous cannot be accurately determined, due to the fact that the largest contributor of Ca in the diet drives Sr/Ca in the body (Burton et al. 2003; Burton 2008). As meat is relatively low in Ca and Sr, large changes in meat consumption may still be masked by the overwhelmingly larger contribution of Ca and Sr from plants to the body, resulting in skeletal remains exhibiting broadly similar Sr/Ca regardless of mixed diet type, a fact which has undermined attempts to use Sr/Ca to quantitatively examine diet (see Elias 1980; Sillen and Kavanagh 1982; Burton et al. 1999, 2003; Burton 2008).

It is with the works of Ericson (1985, 1989) and Sealy et al. (1991) that the concept of using $^{87}Sr/^{86}Sr$ to look at palaeodiet (e.g. marine vs. terrestrial) and palaeomobility was first put forth. Early bioarchaeological studies employing $^{87}Sr/^{86}Sr$ to examine questions of palaeomobility were undertaken in the American Southwest (e.g., Price et al. 1994a; Ezzo et al. 1997) and in regard to the Bell Beaker culture (e.g., Price et al. 1994b; Grupe et al. 1999). Since the acceptance of $^{87}Sr/^{86}Sr$ as a viable method for tracing palaeomobility this approach has been applied globally. To date studies employing exclusively $^{87}Sr/^{86}Sr$ are well represented in the Caribbean where a number of researchers have investigated movement into the Caribbean and between the respective islands (Booden et al. 2008; Hofman et al. 2012; Laffoon et al. 2012; Laffoon and Hoogland 2012; Pestle et al. 2013). The exclusive use of $^{87}Sr/^{86}Sr$ in Europe has seen widespread investigation ranging from the first settlers of Iceland (Price and Gestsdóttir 2006) and Viking Denmark (Price et al. 2011), to the eastern Mediterranean looking at Minoan (Nafplioti 2008, 2012) and Frankish Greece (Lê 2006), to Neolithic-Copper Age Hungary (Giblin 2009; Giblin et al. 2013), Austria (Irrgeher et al. 2012), and Germany (Bentley et al. 2003, 2004; Turck et al. 2012), to Mid-Holocene Lake Baikal (Haverkort et al. 2008) and Celtic migration in Italy and Germany (Scheeres et al. 2013). The Levant, Arabian peninsula and Africa have also seen significant investigation with studies on Natufian Israel (Shewman 2004); Nile Valley Egypt and Sudan (Buzon 2007; Buzon and Simonetti 2013); Saharan Libya (Tafuri et al. 2006) and Saharan Niger, where Stowjanowski and Knudson (2011, 2014) compare $^{87}Sr/^{86}Sr$ values of M1 vs. M2 vs. M3 vs. bone at Gobero to gauge age related mobility; Byzantine St. Stephen's monastery in

Jerusalem (Sheridan and Greoricka); to fossil teeth at Swartkrans and Sterkfontein in South Africa (Copeland et al. 2010); to mobility in the Arabian peninsula, where Gregoricka (2013) looks at exchange networks during the Umm an-Nar (ca. 2700–2000 BCE) period in the United Arab Emirates. The Pacific, Asia, Mesoamerica and South America have also seen significant investigation using $^{87}Sr/^{86}Sr$. Shaw et al. (2009) look at Lapita culture in Papua New Guinea; Kusaka et al. (2009) at the association between mobility, ritual tooth ablation, and group identity in Jomon era Japan. Price et al. (2000) examine immigration at Teotihuacan, Price et al. (2015) look at Mesoamerican mobility at the sties of Campeche, Copan, Palenque, and Tikal; while Knudson et al. (2004) look at Tiwanaku migration in Bolivia and Peru, and Conlee et al. (2009) investigate mobility at Nasca, Peru.

Yet in terms of studies employing exclusively $^{87}Sr/^{86}Sr$ to investigate Roman era mobility there are comparatively few. Perry et al. (2008) investigate potential political refugees associated with Roman annexation of the Nabataean Kingdom in the 2nd c. CE at a religious sanctuary located along the *via Nova Traiana* known as Khirbet edh-Dharih in southwest Jordan. Of the 12 individuals analyzed using $^{87}Sr/^{86}Sr$ only one individual, an adult male, displayed a non-local $^{87}Sr/^{86}Sr$ signature suggesting an origin in the Jezreel valley of Israel (Perry et al. 2008).

Two other studies using $^{87}Sr/^{86}Sr$ to look at mobility in ancient Jordan have been undertaken. Jennings and Perry (2011) examine 28 individuals from the Byzantine maritime import and trade site of Aila, on the Gulf of Aqaba. Artefact and architectural diversity suggest this location was a major hub of cultural interaction in the region and a potentially important area of migration (Jennings and Perry 2001). Yet in spite of the diversity of foreign styles and objects all of the individuals examined were identified as local (Jennings and Perry 2011). Similar to the discussion of $\delta^{18}O$ at Vagnari by Prowse et al. (2010), in which individuals who appeared local based on grave treatment were actually identified as migrants to the site using $\delta^{18}O_c$, Jennings and Perry (2011) use $^{87}Sr/^{86}Sr$ to show how individuals identified as foreign based on artefacts were in reality local, suggesting a diffusion of styles rather than individuals.

Similar to the study by Jennings and Perry (2011) at Aila, Al-Shorman and el-Khouri (2011) use $^{87}Sr/^{86}Sr$ to examine migration at Late Roman/Byzantine Barsinia (ca. 4th–7th c. CE) in northern Jordan, where a lack of archaeological evidence indicating interaction with local groups suggested to excavators that this site was inhabited by migrants to the region who were involved with trade in the eastern Mediterranean. However, $^{87}Sr/^{86}Sr$ values indicate that all 12 individuals examined were local to the region of Barsinia. Al-Shorman and el-Khouri (2011) suggest that Barsinia may have been settled as part of a larger trend of urban groups moving into rural regions in the Levant at this time and developing self-sufficient settlements.

Leslie (2011, 2012) uses $^{87}Sr/^{86}Sr$ to examine mobility in the valley of Stymphalos, Greece among Late Roman/Early Byzantine (4-6th c. CE) and Late Medieval (14-15th c. CE) rural peasants interred at the sites of Stymphalos and Zaraka. Expanding on previous dietary isotopic research conducted by Pennycook (2008), which suggests non-local individuals were present in the valley of Stymphalos at this time, Leslie (2012) shows the presence of numerous non-local individuals, whom he proposes may have been seasonal farm laborers or itinerant individuals who died en route and were buried among the site ruins. Considering these results in tandem with $^{87}Sr/^{86}Sr$ evidence for non-local domesticated animals in the valley, Leslie (2012) further suggests that the valley of Stymphalos may have been part of a larger transhumance network, in contrast to classical views of Greek rural communities as insular with little mobility.

A key limitation that a number of the studies discussed above bring up is homogeneity of regional $^{87}Sr/^{86}Sr$ signatures. Similar to $\delta^{18}O$, $^{87}Sr/^{86}Sr$ variability is based on variations in underlying geology (Bentley 2006). As such, regions with similar geology may have similar $^{87}Sr/^{86}Sr$ signatures despite their geographically disparate locations. This point is well made by Perry et al. (2008) for Jordan where it was only truly possible to distinguish East-West regional variability using $^{87}Sr/^{86}Sr$ given the degree of North-South geological homogeneity. For this reason, just like the case with $\delta^{18}O$, it is recommended that $^{87}Sr/^{86}Sr$ analyses be undertaken with other predictably variable isotopes (e.g. $\delta^{18}O$) in order to try and limit regional isotopic signature homogeneity.

2.3.5–Defining the Local Range

A key component of isotopic palaeomobility studies is the definition of a local range. In terms of $\delta^{18}O$ the local range can be ascertained through the use of predictive programs such as GNIP (2015) and published maps and models of regional $\delta^{18}O$ variation (Dansgaard 1964; Longinelli and Selmo 2003; Gat 2005; Schwarcz 2007; Agarrwal et al. 2010; Bowen 2010). In an attempt to further refine local $\delta^{18}O$ values some researchers (e.g. Prowse et al. 2007; Keenleyside et al. 2011) have examined $\delta^{18}O$ values from modern teeth in the regions of their respective studies, with a local (i.e. consuming local water) intra-population range of ~±1‰ to be expected (Schwarcz et al. 2010). However, caution must also be taken in using modern tooth samples as global populations have increasingly come to rely on non-local water sources, which may affect local isotopic signatures (Bowen et al. 2005).

Defining the local range for $^{87}Sr/^{86}Sr$ is more difficult. The $^{87}Sr/^{86}Sr$ signature of a region is based on weathering of strontium bearing rocks and minerals in underlying geology, and to a limited extent atmospheric deposition, which is taken up into the soil and then into foodwebs of a region, ultimately reaching humans (Bentley 2006). On this basis expected $^{87}Sr/^{86}Sr$ values for a given region can be predicted from underlying geology. However, direct geologic $^{87}Sr/^{86}Sr$ signatures may not be the only source of $^{87}Sr/^{86}Sr$ in a human diet. Rather it is possible that an average human diet may include a variety of foodstuffs from areas with varying $^{87}Sr/^{86}Sr$ signatures, effectively creating an average of the $^{87}Sr/^{86}Sr$ values consumed. The different $^{87}Sr/^{86}Sr$ compositions of soils and their variable distribution may also introduce non-local $^{87}Sr/^{86}Sr$ values into a given region (Grousset et al. 1992; Price et al. 2002; Miyamoto et al. 2010; Wu et al. 2010).

Sea spray is another factor that must be considered. Sea spray droplets can be introduced into the atmosphere and to coastal landscapes through spume (i.e. the frothy foam of waves) droplet dispersal and when trapped air bubbles make their way to the surface and break, allowing for dispersal of marine isotopic values and integration into rainwater, which can contribute marine isotopic values that differ from local geological $^{87}Sr/^{86}Sr$ (Brown et al. 1995; Whipkey et al. 2000; Evans et al. 2010; Knudson et al.

2014b). Sea spray can include both marine and terrigenous (i.e. marine deposits eroded from land), particles, which can be transported inland by aeolian and atmospheric factors (Chesselet et al. 1972). Transportation and deposition of sea spray can vary with size of droplets, with salt and large water droplets travelling relatively shorter distances before being deposited, while smaller droplets can travel several kilometers or more inland, with sea spray sulphur being a particularly drastic example, having been documented up to a hundred kilometers inland (see discussion below) (Franzen 1990; Gustafsson and Franzen 1996; Zazzo et al. 2011). Coastal landforms also factor into sea spray, with increasing height and limited wind resulting in less distribution and deposition on proximate shorelines (Taylor and Wu 1992; Gat et al. 2003; Evans et al. 2010).

In terms of $\delta^{18}O$, sea spray is of little concern given the regional variability of $\delta^{18}O$ signatures as dictated by the hydrological cycle, as well as the fact that sea spray will not drastically alter primary drinking water $\delta^{18}O$ values, which provide the bulk of the $\delta^{18}O$ signature in skeletal tissues (Luz et al. 1984; Prowse et al. 2007). In terms of strontium, dietary intake is the key contributor of $^{87}Sr/^{86}Sr$ in the body (Bentley 2006; Knudson et al. 2014b). Given the standard value of sea water at ~0.7092, sea spray may unnaturally influence coastal $^{87}Sr/^{86}Sr$ values (Bentley 2006). As a result in coastal environments where sea spray is present values can become incorporated into the local soil and thus subsequently incorporated into plants, as well as surface deposition of sea spray strontium on the leaves of plants, both of which result in the introduction of sea spray $^{87}Sr/^{86}Sr$ values into local foodwebs, causing an averaging of local $^{87}Sr/^{86}Sr$ values with those of sea water (~0.7092) based on the proportion of diet that sea spray $^{87}Sr/^{86}Sr$ represents (Veizer 1989; Chadwick et al. 1999; Whipkey et al. 2000; Kusaka et al. 2009; Bentley 2006; Knudson et al. 2014b). In instances where crop production and animal grazing is undertaken away from coastal areas potential effects of sea spray may be avoided, while in areas proximate to the coast sea spray may be a factor but not necessarily in all cases or uniformly on all coasts, as shown from the UK study sites presented by Evans et al. (2010) where the most significant sea spray values are observed at sites along the western coast due to prevailing western winds.

To help limit the effects of potential environmental variation, $^{87}Sr/^{86}Sr$ palaeomobility studies strive to define local bioavailable $^{87}Sr/^{86}Sr$ values, which is to say the average $^{87}Sr/^{86}Sr$ available from dietary items in a given region (Bentley 2006). Researchers have utilized various materials from local soils and plants to faunal remains to gauge variability in regional $^{87}Sr/^{86}Sr$ signatures (Sillen et al. 1998; Bentley 2006). Ideally, it is recommended that archaeofauna tooth enamel be used, particularly local or commensal fauna, that have a limited dietary range and thus may provide a localized $^{87}Sr/^{86}Sr$ bioavailable signature that is believed to most closely approximate $^{87}Sr/^{86}Sr$ of an area that would have been bioavailable in human dietary foodwebs (Price et al. 2002; Bentley et al. 2004; Nafplioti 2011). The use of archaeofauna over modern fauna is recommended to avoid potentially significant skewing effects caused by the intake of Sr from anthropogenic sources, such as fertilizers and imported feed (Bentley et al. 2004; Bentley 2006).

Inclusion within a "local" range has traditionally been set at within two standard deviations from the mean (Price et al. 1994a) in an attempt to account for variable $^{87}Sr/^{86}Sr$ intake and intra-population variability, such as that presented by Knudson et al. (2004) from a study using guinea pigs raised in the same environment, yet showing intra-population variability of $^{87}Sr/^{86}Sr$ values ranging from 0.706121–0.706452.

Occasionally the local range may appear anomalous. Wright (2005) observes that individuals from Tikal, Guatemala had $^{87}Sr/^{86}Sr$ signatures significantly elevated (~0.70812) above the local bioavailable signature (~0.70779). Such elevation was attributed to the dietary use of sea salt, originally calculated as ~6.1 g/day, but since recalculated as ~9.2 g/day, an amount that would be difficult to consistently consume (Fenner and Wright 2014). Wright (2005) also notes that lime, a product used for nixtamalization, a cooking method in which foods such as corn are soaked and cooked in an alkaline solution, can significantly alter $^{87}Sr/^{86}Sr$ values. As such dietary practices that may affect $^{87}Sr/^{86}Sr$ need to be kept in mind when interpreting local signatures.

2.4–Trends in Investigation–Multiple Isotopes and Individuality

2.4.1–Multi-Isotope Approaches

As isotopic palaeomobility research within anthropology progresses there is increasing emphasis on the use of multiple isotopes to provide finer resolution to geographic origins. Multi-isotope approaches to palaeomobility typically employ a mix of $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$, $\delta^{13}C$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, as well as Sr/Ca, Ba/Ca, and trace elements (e.g. Bentley et al. 2007; Knudson and Price 2007; Knudson et al. 2012b; Gregoricka 2014, 2016). There is also an increasing movement to employ isotopes in tandem with ancient DNA (e.g. Wilson et al. 2007; Prowse et al. 2010a; Sofeso et al. 2012). Where one isotopic signature may identify ambiguous or multiple homogeneous geographic regions of origin, the use of a second, or more, isotopes/trace elements can allow for a narrowing of regions. As each of these isotopic signatures reflects a particular dietary and/or geographically variable system, be it geology for $^{87}Sr/^{86}Sr$ or precipitation for $\delta^{18}O$, the combined global variability of these isotopes can provide for greater regional discrimination (Knudson and Price 2007). The work of White et al. (2007) on sacrificial victims at Teotihuacan is an exemplar of this method. White et al. (2007) identify $^{87}Sr/^{86}Sr$ values from human skeletal remains that could have derived from a variety of geographic locations ranging from the Gulf of Mexico to the highlands and lowlands. However, when $^{87}Sr/^{86}Sr$ values are mapped against $\delta^{18}O$ a series of distinct regional clusters are more readily apparent for what were foreign sacrificial victims (White et al. 2007).

The use of dietary isotopes (i.e. $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) may also help to provide greater context in palaeomobility studies. Müldner et al. (2011) present research on the ‘Headless Romans’ from Britain using $\delta^{18}O$, $^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{15}N$. Among the individuals examined, several within the local $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ range are actually identified as non-local based on $\delta^{13}C$ values consistent with a C_4 diet, implying a non-British origin as C_4 foods were not cultivated in Britain at this time (Müldner et al. 2011).

In terms of multi-isotope studies from the Roman period, studies investigating mobility in the United Kingdom during the Roman era far outnumber any other region, with studies examining Hampshire cemetery at Roman Lankhills (Evans et al. 2006b; Eckardt et al. 2009); Roman York (Leach et al. 2009, 2010); a Roman Cemetery with a Mass Grave at 120–122 London Road, London (Chenery 2008); Roman Gloucester (Chenery et al. 2010); Roman Catterick in Yorkshire (Chenery et al. 2011); Romano-British Driffield Terrace, York (Müldner et al. 2011); a late Roman military burial at Dyke Hills, Oxfordshire (Booth 2014); Anglo-Saxon West Heslerton (Montgomery et al. 2005); Gravesend, Kent (Pollard et al. 2011); and Berinsfield, Oxfordshire (Hughes et al. 2014). Eckardt et al. (2014) present an overview of isotopic studies in Roman Britain.

In terms of continental Europe, Scheeres (2014) and Scheeres et al. (2014) examine Celtic migration in the 4th–3rd c. BCE from sites in Germany, France, Austria, Hungary, Romania, Switzerland, and the Czech Republic. Sofeso et al. (2012) investigate mobility during the decline of the Imperial Roman era (ca. 4th–5th c. CE) at Erding Kletthamer Feld, Upper Bavaria using $\delta^{18}O$, $^{87}Sr/^{86}Sr$, $\delta^{13}C$, $\delta^{15}N$ and aDNA. Initial hypotheses about this site suggested that the individuals identified may have been part of a military unit, a family or families, or a founder population from North of the Danube. Using isotopic signatures and aDNA Sofeso et al. (2012) show that though there was a degree of genetic relationship between several individuals, there is no strong confirmatory evidence that families were occupying this site. Using $^{87}Sr/^{86}Sr$ Sofeso et al. (2012) also dismiss the potential of a founder population from North of the Danube. Though not geographically distant, the variation in $^{87}Sr/^{86}Sr$ between the North and South of the Danube is significant enough that if individuals were arriving from this region their $^{87}Sr/^{86}Sr$ signature would be indicative, which was not the case at Erding. Based on the suite of isotopic signatures employed, 11/12 individuals are identified as local, with 1 individual potentially being non-local. On this basis and in tandem with the recovery of a Roman fibula, a typical item of Roman military apparel, Sofeso et al. (2012) conclude that Erding was most likely the site of a Roman military unit.

A number of multi-isotopic studies have explored Roman era mobility in the Near East. Dupras and Schwarcz (2001), using $\delta^{18}O_c$ and $\delta^{15}N$, examine mobility at the cemetery site of Kellis 2 (ca. 250 CE) in the Dakhleh Oasis, Egypt, identifying at least two non-local adult males, one of whom had leprosy. Dupras and Schwarcz (2001) conclude that the presence of such non-local males may have resulted from merchants moving between the Nile Valley and the Dakhleh Oasis, though the authors also state that the presence of an individual with leprosy suggests mobility to this site may not have been exclusively related to trade.

The works of Perry et al. (2009, 2011, 2012, 2013) and Perry (2009) investigate the potential importation of manual laborers to the Roman-Byzantine state run *Phaeno* mining camp at Khirbet Faynan, Jordan, during the 4th–7th c. CE using $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$. Only one adult male presented a non-local signature suggestive of origins in the Galilee region. The identification of predominantly local individuals at Faynan is significant as textual evidence typically associates the operation of Roman and Byzantine mining camps with non-local laborers, imported to work in mines as a form of criminal punishment (Perry et al. 2009). The local origins of the residents of Faynan suggest that financial considerations of employing local labor rather than transporting individuals over long distances may have played more of a role in the functioning of Roman and Byzantine mines than previously assumed (Perry et al. 2009, 2013). A number of individuals at Faynan also displayed skeletal levels of copper and lead (µg/g) well above ambient environmental levels. This observation allowed Perry et al. (2011, 2012, 2013) to further support their isotopic findings that the majority of individuals examined were local to the Faynan region. Considering the amounts of copper and lead in the respective skeletons of these individuals from Faynan, Perry and colleagues suggest that ten individuals with the highest copper and lead levels likely worked in the mines, while other individuals with less elevated copper and lead levels may have been involved in the running of the mining operations or were simply residents of the area exposed to mining related pollution (Perry et al. 2011, 2012, 2013). This use of copper and lead in tandem with $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ provides yet another degree of insight for not only distinguishing local vs. non-local individuals but also their potential social positions within a given community.

Turning to the Italian peninsula, to date it is only the work of Killgrove (2010a,b; 2013), looking at mobility in the *suburbium* of Rome, which has employed a multi-isotope approach. Killgrove (2010a,b, 2013) uses $\delta^{18}O$, $^{87}Sr/^{86}Sr$, and $\delta^{13}C$ to investigate mobility among the Roman lower classes, whose burials contained little to no artefactual evidence to suggest cultural affiliations, at the Republican/Imperial era sites of Castellaccio Europarco (4th BCE–2nd CE) and Casal Bertone (2nd–3rd CE). Of key importance, the work of Killgrove (2010a) shows that, where $\delta^{18}O$ varies from the coast to the Apennines, $^{87}Sr/^{86}Sr$, on a macro-level, roughly varies from North to South, particularly on the Tyrrhenian coast, where significant volcanic activity has occurred.

Killgrove (2010a,b, 2013) espouses transnationalism as a theoretical approach to look at the potential pull and push factors for why individuals moved towards Rome during this era. This approach is well suited to Roman mobility given the expansive size of Roman territory and conceptions of "Rome" as an entity being firmly associated with mobility and regional interaction (Killgrove 2010b). At Casal Bertone, Killgrove (2010a) reports that ~37% (15/41) of the individuals examined were non-local, while at Castellaccio Europarco ~29% (4/14) are identified as non-local, a figure that corresponds well with other regional studies, for instance, Prowse et al. (2007), where ~33% of the individuals sampled from Isola Sacra are identified as non-local. Killgrove (2010a,b) proposes that most of the non-local individuals identified appear to have migrated from areas relatively close to Rome, including Liguria, Tuscany, Lazio, the Apennines, Calabria, and further afield in North Africa, in rural-to-urban movements.

The use of multiple isotopes in palaeomobility studies, though having great potential, may not always alleviate the difficulties of isolating geographic origins. The work of Knudson and Price (2007) on Chiribaya origins in the Andes shows how even with the use of multiple isotopes and elements ($^{87}Sr/^{86}Sr$, $\delta^{18}O$, Sr/Ca, Ba/Ca) in the two valleys under consideration, the Ilo and Moquegua, are too isotopically and elementally ambiguous to allow for sufficient distinctions of residency. Such results show that in cases where migration within a homogeneous region is taking place, isotopic methods may not be able to accurately identify movement.

2.4.2– Individual Approach

Bioarchaeology has traditionally focused on analyses at the population level. Yet, there has been an increasing trend in bioarchaeology to look at the human experience on the smaller scale, placing individuals within the larger context of populations (e.g. Knudson and Stojanowski 2009; Knudson et al. 2012a). The use of such an individualized approach employing isotopes is embodied in the works of Müller et al. (2003) and Hoogewerff et al. (2001) on Ötzi, using $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{13}C$ and trace elements to provide an isotopic explication of the residence of Ötzi in the years leading up to his death. Similarly, Knudson et al. (2012a) examine the residential mobility of an Andean traveler buried in the Atacama of northern Chile using $^{87}Sr/^{86}Sr$, $\delta^{15}N$, $\delta^{18}O$, $\delta^{13}C$ and trace elements. From their analyses Knudson et al. (2012a) show that this individual likely traveled significantly in his lifetime, possibly in relation to trade or group mobility. Such insights show the value of isotopic analyses to the investigation of individual life histories and how such an approach can contribute to larger bioarchaeological discussions (see Sofaer 2006; Knudson and Stojanowski 2009; Lorentz 2008; Perry 2012).

2.4.3–Other Bodily Materials: Hair

Investigation of short term and multiple migrations lay at the heart of future developments of isotopic palaeomigraiton studies. Palaeomobility research traditionally relies on the identification of isotopic signatures that can provide insight to an individual's residence during the formation of teeth (up to ~17 years) and bone (the last 10–20 years of life) (Larsen 1998; Katzenberg 2008). It is possible to look at migration between periods of dental formation, by comparing isotopic values in multiple teeth that form at different times (e.g. 1st vs. 2nd vs. 3rd molars), helping to contextualize during which age range an individual may have been mobile (Prowse et al. 2007; Stojanowski and Knudson 2014). However, both bone and tooth are limited by the fact that they provide an average of the values consumed during formation, thus minute time periods of mobility cannot be accurately gauged, rather broad age ranges must be used for addressing at which stage in life an individual may have been mobile.

To help provide finer detail to mobility events, when possible researchers turn to hair to look at potential instances of multiple mobility over shorter time spans, in the order of weeks up to years, based on the 0.35 mm/day or ~1 cm/month rate of growth for scalp hair (Saitoh et al. 1970; Williams et al. 2011). Hair, a continually regenerating material, goes through a cycle of growth and rest allowing for incorporation of variable isotopic signatures at different places along the hair (i.e. the isotopic signature at the root can preserve a different isotopic signature than at the midshaft or tip), allowing for finer resolution of palaeomobility, as hair can be segmented and instances of isotopic change observed on a month by month basis (O'Connell et al. 2001; Dawber and van Neste 2004; Bol et al. 2007; Williams et al. 2011; Vautour et al. 2015).

Though often absent from bioarchaeological contexts, with good preservation (e.g. arid desert, bogs, mountain tops) hair may be preserved for a significant period of time (Wilson et al. 2007; D'Ortenzio et al. 2015). Using hair from individuals sacrificed in the Andes during the Incan Empire, Wilson et al. (2007) show that several of the victims sacrificed had changes in their $\delta^{13}C$, δD and $\delta^{18}O$ signatures ~4.5 months before their death, while δD, $\delta^{18}O$ and $\delta^{34}S$ hair signatures suggest that individuals resided at different altitudes before death and that at ~6 months before death the $\delta^{34}S$ signatures of individuals begin to coincide, suggesting colocation of individuals at this time (Wilson et al. 2007). Such research, able to examine mobility on the scale of months, provides persuasive evidence for the continued development of isotopic research using hair for palaeomobility research.

2.4.4–Other Isotopes

2.4.4.1–Hydrogen

In recent years several studies have utilized global variation in hydrogen isotopes (δ^2H, also annotated as δD), to trace mobility among modern populations, with the work of Ehleringer et al. (2008) examining modern human hair, and the work of O'Brien and Wooller (2007) looking at hair and urine. Though both of these studies provide a positive outlook for the continued use of hydrogen isotopes, particularly in forensic contexts, hydrogen can be difficult to successfully employ given its relatively large exchangeable component (i.e. hydrogen bound with nitrogen and/or oxygen), with approximately 9%–16% of total hydrogen in keratin and ~22% in collagen being available for exchange at room temperature, resulting in rapid equilibration (Cormie and Schwarcz 1985; Cormie et al. 1994; Schwarcz and Schoeninger 1991; Bowen et al. 2009; Podlesak et al. 2008; Chesson et al. 2009; Topalov et al. 2012). Researchers thus must remain cautious to examine non-exchangeable hydrogen (i.e. hydrogen bound with carbon), as this aspect of hydrogen can remain non-exchangeable for potentially thousands of years (Schwarcz and Schoeninger 1991; Topalov et al. 2012).

To date hydrogen has seen almost no examination from skeletal apatites for palaeomobility research, possibly due to yields of H_2 too small to measure, and/or post-depositional diagenesis, with equilibration to the surrounding matrix being rapid due to the exchangeable nature of hydrogen in skeletal apatites (Holobinko et al. 2011). In their proof-of-concept study using modern and archaeological dental enamel, Holobinko et al. (2011) demonstrate that δD can be analyzed from enamel, but ultimately that the δD signature of enamel is not viable as a method for gauging geographic provenance. Though hydrogen can be used to trace mobility (i.e. from hair) it does not necessarily contribute any significant mobility information that cannot also be inferred from oxygen analyses, given the common trajectory of δD and $\delta^{18}O$ within the hydrological cycle (Dansgaard 1964; Rozanski et al. 1993; Gat 1996; Jouzel et al. 1997; Bowen et al. 2005; Chesson et al. 2009; Bowen 2010; Terzer et al. 2013).

2.4.4.2–Sulphur

Sulphur ($\delta^{34}S$) can be isolated from collagen and hair and has potential for tracing mobility, but has yet to be thoroughly developed (Richards et al. 2001, 2003; Valenzuela et al. 2011). Katzenberg and Krouse (1989) successfully use $\delta^{34}S$ from human hair to show the potential of this method for tracing mobility in forensic contexts. Bioarchaeologically, $\delta^{34}S$ has been examined from the hair of Egyptian and South American mummies by Macko et al. (1995) and Iversen et al. (1992), while Leach et al.

(1996) were the first to show the viability of using $\delta^{34}S$ from human bone collagen in their research on palaeodiet and mobility in the South Pacific. Though having potential for palaeomobility research, $\delta^{34}S$ can be problematic as very little sulphur is actually present in collagen (~0.16 wt%) and sulphur is subject to significant post-depositional degradation (Richards et al. 2001, 2003).

Sulphur is introduced into the body through dietary consumption and can be used to trace mobility as there is little fractionation along ascending food chains, allowing for geographically specific isotopic values to be preserved based on regional geology and atmospheric sulphur values (Peterson and Fry 1987; Richards et al. 2001, 2003; Hedges et al. 2006; Nehlich et al. 2014). The $\delta^{34}S$ of marine water is relatively uniform at ~+20‰, although significant variation exists in freshwater values (i.e. variability from -22‰ to +22‰ has been documented), providing a degree of variability that can be used to help identify regional mobility (Soloman et al. 1971; Rees et al. 1978; Peterson and Fry 1987; Nehlich et al. 2014). Sea spray distribution of $\delta^{34}S$ values can be extensive, as illustrated by Zazzo et al. (2011) where sea spray $\delta^{34}S$ values were documented up to ~100 km inland in some cases, potentially artificially altering local biogenic $\delta^{34}S$ values (Wadleigh et al. 1994). Caution is also required when attempting to derive regional $\delta^{34}S$ baselines from modern fauna, as anthropogenic sources of sulphur (i.e. industrial pollution) can adversely alter local biogenic signatures (Wadleigh et al. 1996; Zhao et al. 1998; Richards et al. 2001). What these studies, among others, show is that $\delta^{34}S$ has the potential to contribute unique regional information, particularly for looking at inland vs. coastal differences. However, there are limitations to the method, which may necessitate analyses of other isotopes (i.e. $\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$, $^{87}Sr/^{86}Sr$) in tandem with $\delta^{34}S$ (Richards et al. 2003).

2.4.4.3–Lead

Lead is present in small quantities in most of earth's rocks, soils, and waters with isotopic variability being dictated by underlying geology (Faure 1986; Montgomery et al. 2010). Isotopic analyses of lead employ three ratios in which the radiogenic ^{206}Pb, ^{207}Pb, and

^{208}Pb are compared to the non-radiogenic ^{204}Pb (i.e. ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb,^{208}Pb/^{204}Pb) to derive regional signatures (Gulson et al. 1997). Lead is introduced into the body through dietary consumption and inhalation allowing for regionally specific isotopic signatures to be preserved in apatite, where Pb may substitute for Ca (Faure 1986; Waldron 1983; Molleson et al. 1996; Gulson et al. 1997; Montgomery et al. 2010).

In pre-industrial societies lead signatures in the body reflect local lead values based on dietary consumption, allowing for regionally specific signatures to be used for palaeomobility studies (Montgomery et al. 2000). With the rise of industrialization and associated increased anthropogenic exploitation of lead, lead values in the body may more readily reflect the type of lead being industrially exploited, as anthropogenic lead isotope signatures will swamp local geological values given the comparatively low natural quantities of lead in foods and soils (Molleson et al. 1986; Montgomery et al. 2000). For this reason, Montgomery et al. (2005) note that following industrial exploitation of lead, lead isotope signatures may be more useful for tracing cultural affiliation based on the signatures of culturally exploited lead sources. Montgomery et al. (2010) make this argument in regard to migrants to Roman Britain. Given the large degree of lead exploitation at this time in southern Britain, individuals from this region exhibit an averaged lead isotope signature consistent with the isotopic signatures of industrially exploited lead (Montgomery et al. (2010). Based on this anthropogenic lead isotopic signature, individuals who migrated to Southern Britain during the Romano-British era could be separated by Montgomery and colleagues (2010) from local individuals based on the presence of a lead signature different than the local anthropogenic signature. Even if individuals were migrating to Roman Britain from a different region where lead was exploited, so long as the two exploited lead sources were isotopically dissimilar individuals from these different regions can still be distinguished.

This alternative approach to the use of lead isotope signatures also underlines one of the key difficulties in using lead isotopes. Because industrial exploitation of non-local lead sources (i.e. lead piping, use in cookware, lead acetate in wine) can provide deceptive local vs. non-local signatures it can be difficult to determine if the isotopic signature being interpreted is regionally authentic or corrupted from anthropogenic sources of non-local lead in antiquity, necessitating significant confirmatory testing of regional sources (Montgomery 2002; Montgomery et al. 2010; Aufderheide 1989). Furthermore, post-depositional contamination from lead exposure in the burial environment can significantly alter biogenic lead values, particularly from surface contamination (Waldron 1981, 1983; Montgomery et al. 2010). In practical terms lead isotopes are also difficult to employ, as they are costly and difficult to accurately analyze, requiring comparison and interpretation of multiple lead isotope signatures (i.e. $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$). Yet despite these difficulties when treated cautiously and undertaken with significant validation of signature authenticity, lead isotopes can provide a valuable avenue of inquiry, as the recent increase in lead isotope palaeomobility studies attests (i.e. Sakamoto 2000; Montgomery 2002; Montgomery et al. 2000, 2005, 2010).

2.4.4.4–Neodymium

There is the potential that neodymium ($^{143}Nd/^{144}Nd$), which varies with regional geology like $^{87}Sr/^{86}Sr$, may be viable as an isotopic means for assessing mobility (Pye 2004). To date the work of Schwarcz and Walker (2005) remains the only attempt to utilize Nd for palaeomobility research. The results of this study, on the original settlers of Iceland, suggest promising potential for the use of $^{143}Nd/^{144}Nd$. A major limitation to the use of Nd however, is the fact that Nd occurs in very minute amounts (e.g. parts per 10^4) and is not readily consumed in human dietary foodwebs (Shaw and Wasserburg 1985; Staudigel et al. 1985/86; Dickin 2005). Nd in marine water is ~1 million times lower than in rock, placing the average concentration of Nd in marine water at ~3 parts per trillion, thus, unlike the case of Sr, marine effects would not play a factor (Goldberg et al. 1963; Piepgras et al. 1979; Dicken 2005).

2.5–Conclusions

The isotopic study of palaeomobility has seen significant advancement in the last twenty years and continues to grow exponentially. The steady increase in such studies shows a growing acceptance and confidence in the validity and applicability of isotopic approaches to global palaeomobility, at least among bioarchaeologists. The potential development of further isotopic approaches to mobility (e.g. δD, $\delta^{34}S$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, $^{143}Nd/^{144}Nd$) suggests a healthy research future for isotopic palaeomobility studies. The future of palaeomobility studies lies in collaboration with other fields, as Bentley (2006) keenly points out, the use of migration isotopy need not be the only means and ends to questions of past migration. Rather, isotopic approaches to palaeomobility should continue to act as building blocks which are assembled along with other lines of evidence, such as non-metric traits (discussed in the following chapter), to provide for increasingly robust assessments of past cultural mobility and interactions.

Chapter 3–Nonmetric Traits

3.1–Introduction

Nonmetric traits are heritable discrete skeletal traits of anomalous development (e.g., septal aperture) that have a rich history of investigation in anthropology, allowing researchers to assess degrees of similarity (biodistance) between various groups based on shared traits. Nonmetric traits have been shown to be heritable (e.g. Grüneberg 1952, 1963, 1965; Chevrud and Buikstra 1981a,b) allowing for reasonable assessments of relatedness, though there remain debates over the degree of heritability, how to record traits, and the implications of nonmetric traits for assessing group similarity (See Saunders 1989; Saunders and Rainey 2008). This chapter examines the history of nonmetric trait research in anthropology before engaging with a number of debates regarding how nonmetric traits can be recorded, the nature of heritability, and the methods by which nonmetric traits can be used to calculate biodistance.

3.2–Human Developmental Variability and Nonmetric Traits

Biologically, there is a gamut of developmental variability that can be categorized. On one hand there are major anomalies (e.g. anencephaly), which are life threatening, while other developmental anomalies can range from severe to minor and, though physically evident, are not typically life threatening (e.g. phocomelia) (Brothwell and Powers 1968; Warkany 1971; Nishimura and Okamoto 1976; Spranger et al. 1982; Turkel 1989; Spranger 2002; Stevenson and Hall 2006; Keenleyside 2011). Lastly, there are minor traits of anomalous development that typically go unnoticed in the living individual, having little to no deleterious effects, and are often only observed serendipitously (See Tyrrell 2000; Saunders and Rainey 2008). It is to this category that nonmetric traits belong. Many nonmetric skeletal traits are influenced by and develop in relation to overlying soft tissue (Saunders and Rainey 2008). In this way, many traits reflect an intimate connection with the overall development of an individual.

Though these three broad categories of developmental anomalies result in drastically different physical manifestations, the underlying development relies on the similar premise of thresholds and environment. All of the anomaly types mentioned above may manifest due to similar genetic, epigenetic (Epstein et al. 2004), teratological and/or environmental factors (Warkany 1971; Cohen 1982; Capasso et al. 1999; Burnett 2005), providing a basis for understanding development of these traits as forming a continuum rather than falling into discrete categories (Turkel 1989). Developmental thresholds, being the main concept used to discuss nonmetric trait formation, will be addressed below.

Gathering nonmetric trait data for assessing group affinity is comparatively simple and less subject to intra- and inter- observer error compared to other methods such as metric means of analysis (Berry 1968; Molto 1979). Nonmetric traits can also be observed on fragmentary bones making them more versatile than what is required for standard metric measures (Buikstra and Ubelaker 1994; Tyrrell 2000; Pennefather-O'Brien 2006). In terms of cost, other than being time-consuming to record, nonmetric traits pose no significant financial cost to the investigator and there is no need to damage the skeletal material, as is required for aDNA studies (Tyrrell 2000; Judd 2009). Given these factors there is a bright future for the continued use of nonmetric traits in anthropology (Ossenberg 1992; Tyrrell 2000; Stojanowski and Schillaci 2006).

3.3–Classifying Nonmetric Traits

3.3.1–Nonmetric Trait Terminology

The nature of nonmetric traits, and the debate surrounding their description, is evident in the multiplicity of terms used to identify these skeletal anomalies. The term nonmetric traits has become the most commonly used term, though this does not preclude the use of a variety of other designations for such traits. The various designations used can largely be understood in terms of what is trying to be conveyed.

Grüneberg (1952) was the first to propose a mechanism-based term for such traits, using the term quasi-continuous to indicate that though these traits are not continuous in the same sense as metric traits, their distribution can generally be understood as following a continuous distribution of underlying liability that at a certain undefined point reaches a threshold and manifests phenotypically (Figure 3.1) (Cheverud et al. 1979; Eckhardt 1989). The concept of quasi-continuity is also apparent in the use of the terms semi-continuous (Reich et al. 1972) and quasidiscontinuous (Korey 1970; Thoma 1981).

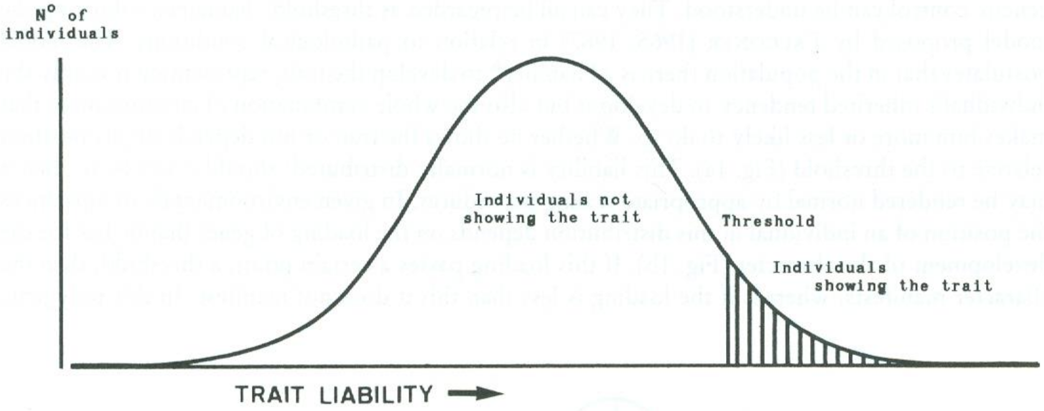

Figure 3.1. Single threshold model showing the distribution of liability towards the point of phenotypic manifestation at the threshold (reproduced with permission after Hauser G, De Stefano GF. 1989. Epigenetic Variants of the Human Skull. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart www.schweizerbart.de, p. 5, figure 1a).

Moving even further from the potential quasi-continuous mechanism of trait manifestation, several researchers choose to identify such traits as discontinuous, on the basis of the dichotomous manifestation of traits in the skeleton (i.e. they are either present or they are absent) (Brothwell 1959; Ossenberg 1969). The concept of dichotomy is the integral feature of most trait terms with the use of terms such as: discrete variations (Anderson 1968), binary traits (Corruccini 1974a), all-or-none attributes (Saunders 1989), discreta (Cesnys and Pavilonius 1982; Rösing 1982; Hermann et al. 1990), and dichotomous traits (Saunders and Rainey 2008).

Others researchers stress the contrast with metric traits (i.e. that nonmetric traits are either present or absent and are not linearly measured) through the use of terms such as nonmetrical traits (Brothwell 1959; Berry 1968; Prowse and Lovell 1996), nonmetric variants (Cheverud et al. 1979), and nonmetric traits (Sjøvold 1984). Various researchers have also chosen to adopt terms that stress the anomalous or variant nature of traits such as: anomalies (Le Double 1903; Anderson 1968), intrinsically innocuous minor skeletal variants (Hauser and De Stefano 1989), anatomical variants (Reinhard and Rösing 1985; Rösing 1986b; Hermann et al. 1990), minor anomalies (Hoyme 1994), informative morphogenetic variants (Méhes 1988; Pinsky 1985), microsigns (Aase 1981), mild errors of morphogenesis (Méhes 2000), and dysmorphology (Hallgrimsson et al. 2005), thus indicating that what is being observed are quantifiable variations from the expected skeletal norm.

Several terms in use are intended to describe the mechanism responsible for trait manifestation including threshold dichotomies (Wright 1968), threshold traits (Roff 1996, 1998), and threshold characteristics (Grüneberg 1963; Sjøvold 1977; Ossenberg 1981; Molto 1983). The term epigenetic is also used to suggest the manifestation of traits due to a combination of genetic and environmental factors in the form of epigenetic polymorphisms (Waddington 1956; Berry 1963), epigenetic variants (Berry and Berry 1967) and epigenetic traits (Hauser and De Stefano 1989). Such traits have also rarely been identified as atavisms (Ossenberg 1969; Saunders and Rainey 2008), suggesting their occurrence is linked with retention of trait features from common past ancestors.

The use of such a multiplicity of terms for the traits under examination suggests a common understanding of trait development, but also indicates multiple views by researchers on how traits should be classified (Saunders and Rainey 2008). Further compounding this difficulty is the fact that many researchers use the above-listed trait terms interchangeably, creating confusing interpretive situations. For instance, in the work of Brothwell (1959) the early part of the paper discusses the potential uses of discontinuous traits before moving on shortly after to the discussion of non-metrical traits, ostensibly referring to one and the same thing. Further confusion arises in the forward to the work of Capasso et al. (1999), wherein De Stefano and Hauser identify occupational musculoskeletal markers (MSM’s) as part of the nonmetric trait pantheon. Though MSM’s are similar in the sense of being either present or absent on bone, their etiology and formation process is largely driven by mechanical factors, not developmental variation. In an attempt to further qualify trait nomenclature Eckhardt (1989) categorizes quasi-continuous traits in the typical sense of Grüneberg (1952) to denote minor skeletal anomalies of little consequence, while discontinuous traits and skeletal anomalies are identified with more serious developmental anomalies such as spina bifida and Marfan syndrome, a rather atypical division of these typically synonymous terms.

Confusion over trait names and how traits should be defined has resulted in a multiplicity of widely ranging definitions (Saunders 1978; Hauser and De Stefano 1989). Several authors propose uniform definitions and systems of standardized nomenclature, yet little true agreement has been reached (Tyrrell 2000; Barnes 2008). Correnti et al. (1979) suggest that a Latin set of trait names be adopted and added to, so as to provide greater correspondence with overall scientific naming protocols, while Cesnys and Pavilonis (1982) propose an anatomo-topographical principle that would characterize traits in terms of morphological peculiarity (e.g. canalis hypoglossalis septus) (see also Hauser and De Stefano 1989; Barnes 1994, 2008; Cesnys and Tutkuviene 2007). Anderson (1987) calls for trait classification on etiological grounds, a proposal that is well meaning but difficult to fulfill given the lack of true etiological knowledge of trait development. As a result of these discrepancies in how traits should be named and categorized, the same trait is identified by different names in various works on nonmetric traits (e.g. when speaking of a sutural bone at lambda, Buikstra and Ubelaker (1994:89) call this trait an “apical bone” while the same trait in Hauser and De Stefano (1989:26) is referred to as an “ossicle at lambda”).

Despite the wide range of names, what all of these various terms are trying to encapsulate is that nonmetric traits are discrete, being present or absent, and variable. These terms also indicate that trait formation is based on the premise of a threshold, in which once development passes a certain undefined threshold point a trait will manifest to some degree. These terms also make clear that nonmetric trait formation occurs as a result of both genetic and environmental factors, allowing for nonmetric traits to be used to trace group affinities in antiquity.

3.3.2–Categories of Trait Development

A multitude of trait classifications have been proposed, however the majority of traits can be classified into four broad categories. The four categories are: (1) hyperostotic traits associated with excess bone growth (e.g. atlas bridging); (2) hypostotic traits associated with incomplete formation of bone or retention of embryonic forms (e.g. Inca bone); (3) sutural patterns/sutural bones that form in the sutures of the skull (e.g. sagittal ossicle); and (4) foramen variation is an abnormal quantity or morphology of foramina (e.g. double infraorbital foramen) (Ossenberg 1969; Hauser and De Stefano 1989; Larsen 1997; Schwartz 2007; Saunders and Rainey 2008).

3.4–Conceptualizing Nonmetric Traits, Liability, and Threshold Factors

Nonmetric trait studies are based upon the concepts of liability and threshold factors. These concepts are most prominently associated with the work of Grüneberg (1952, 1963) and Falconer (1965) and are the basis of modern nonmetric trait studies.

3.4.1–Liability

Liability refers to the propensity of individuals to exhibit traits as a result of their combined genetic and environmental predispositions (Falconer 1965; Tyrrell 2000). Falconer (1965) suggests a normal distribution of liability for populations, where the more predisposed an individual is to exhibiting a trait the further along the liability curve toward the threshold point of phenotypic manifestation that individual will be situated (Figure 3.1) (Fraser 1998; Tyrrell 2000). Liability cannot be measured directly and is thus an approximation of the propensity for the manifestation of any given trait within a breeding population (Fraser 1998). Inability to measure liability can be problematic in bioarchaeological samples as a number of individuals may be at increased likelihood of manifesting a trait, but of this group of individuals only a handful may phenotypically manifest the trait (Reich et al. 1972; Hauser and De Stefano 1989; Fraser 1998). This is further complicated by the fact that many nonmetric traits may be polygenic, being regulated by several genes, and potentially pleiotropic, which is the production of apparently unrelated effects by the same gene (Morton 1971; Hauser and De Stefano 1989). To deal with these problems trait correlations are calculated and highly correlated traits are removed from further analyses (see below).

3.4.2–Thresholds

In nonmetric trait studies the threshold refers to the point at which a trait becomes phenotypically visible (Falconer 1965; Hauser and De Stefano 1989). The threshold point is believed to be influenced by epigenetic factors and as such can vary within and between populations (Fraser 1976; Hallgrimsson et al. 2005; Barnes 2008). Various threshold models have been developed to account for this point of phenotypic manifestation, yet no one model is preferred by all researchers.

3.4.2.1–Single Threshold Model

Most nonmetric trait studies use a single threshold model, where a trait is discussed in terms of an absent/present dichotomy (Figure 3.1) (e.g., Falconer 1965; Cesnys 1982; Saunders and Rainey 2008; Ricaut et al. 2010). This method has been shown to provide viable data for assessing biodistance among past populations as well as serving as a genetic indicator, as the threshold point is believed to be more readily affected by genetic than environmental input (Carson 2006; Ricaut et al. 2010).

3.4.2.2–Double Threshold Model

The double threshold model suggests that an individual may be subject to a double threshold effect where the first threshold allows for manifestation of a trait on one side of the body (e.g. a septal aperture of the humerus in one arm), while crossing the second threshold point would result in bilateral phenotypic manifestation of a trait (e.g. a septal aperture in both humeri) (Figure 3.2). The double threshold concept has been used by various researchers (e.g. Hertzog 1968; Zegura 1975; Green 1979), with the work of Ossenberg (1981) most commonly being associated with this approach. Saunders (1989), in light of the work of Winder (1981), Korey (1970, 1980) and Saunders (1978), suggests that unilateral trait manifestation represents a transitional phase towards the point of bilateral expression, which increases with developmental age. However, McGrath et al. (1984) claim that this model is internally inconsistent as it suggests a side preference in trait development that is not apparent from other study results and conflicts with current understandings of nonmetric trait development (Polak 2003; Hallgrimsson et al. 2005).

Given the inability to provide a basis for showing how side preference development of traits in relation to thresholds occurs and the fact that biodistance studies rely on dichotomized data (i.e. present or absent) there is little need or benefit to a double threshold model, and as such the double threshold model is no longer commonly employed.

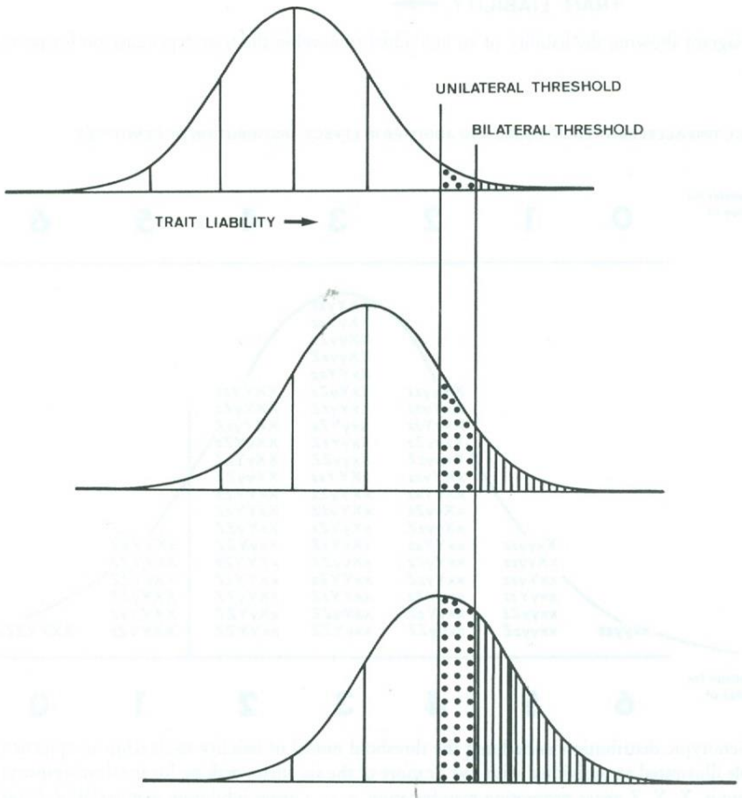

Figure 3.2. Double threshold model, showing the variable position of the unilateral and bilateral threshold points between three different groups (reproduced with permission after Hauser G, De Stefano GF. 1989. Epigenetic Variants of the Human Skull. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart www.schweizerbart.de, p. 6, figure 1c).

3.4.2.3–Multiple Threshold Model

In what appears to be an attempt to follow more closely the original proposal of nonmetric traits as quasi-continuous by Grüneberg (1952, 1963), there have been attempts to employ a multi-threshold model. Such a model suggests that rather than viewing traits as dichotomous they may be more readily understood on a scale of quasi-continuity, where with each threshold crossed a trait becomes increasingly stronger in manifestation yet remains discontinuous in terms of measurability (Figure 3.3) (Reich et al. 1972; Scott 1973, 1980; Hauser and De Stefano 1989; Turner et al. 1991; Kuba 2006). There is little evidence to support this model and even less clarity as to how to employ this model. As a result, the multi-threshold model has largely fallen out of use in anthropological research.

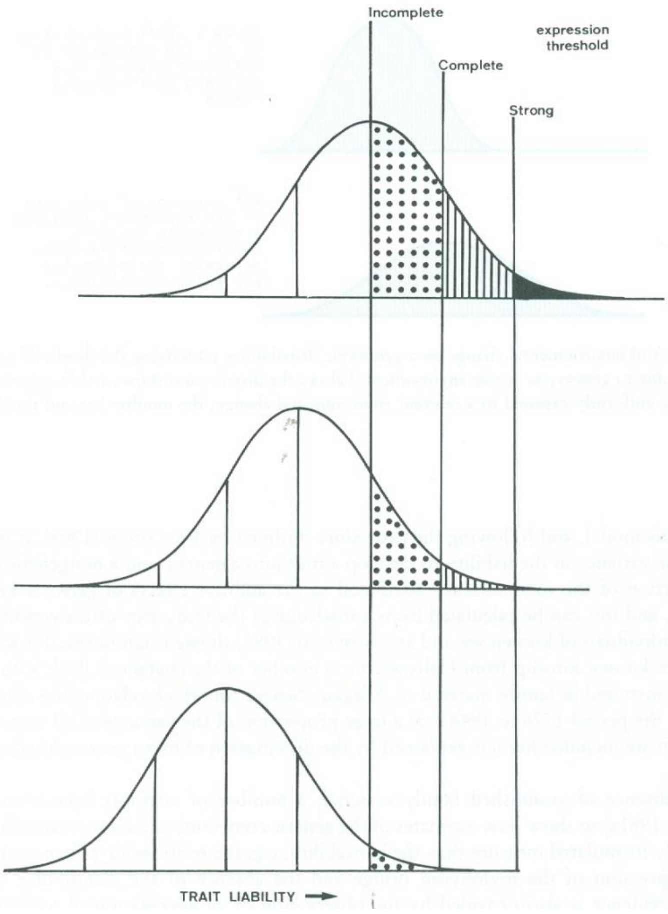

Figure 3.3 Multiple threshold model showing the various degrees of phenotypic trait manifestation beyond successive threshold points in three different groups (reproduced with permission after Hauser G, De Stefano GF. 1989. Epigenetic Variants of the Human Skull. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart www.schweizerbart.de, p. 7, figure 2a).

3.5–A Brief History of Nonmetric Trait Analysis

3.5.1–Early Studies of Nonmetric Traits

Early accounts of nonmetric traits date back to the era of Hippocrates (ca. 460–370 BCE), who detailed the presence of sutural bones (Le Double 1903; Eckhardt 1989). Beyond Hippocrates little is known of this type of observation until the era of Kercking (1670) who is commonly cited as the earliest of the modern anatomists to study nonmetric traits. Early anatomical and anthropological investigations of nonmetric traits were largely descriptive and often sought to fit anomalous or "atavistic" traits into biological theories of the day, such as race, acquired traits, universal morphological theory, which sought to show a united morphological plan within few set archetypes of human development, and recapitulation theory, which focusses on embryonic development claiming that humans pass through developmental stages of earlier ancestors during developmental progression towards adulthood, a contention most famously immortalized by Ernst Haeckel in the phrase "ontogeny recapitulates phylogeny" (see also Blumenbach 1776; Morton 1839; Henle 1855; Hyrtl 1859; Allen 1867; Anoutchine 1878; Haeckel 1879; Krause 1880; Bertelli 1892; Scott 1893; Steida 1894; Testut 1889; Dorsey 1897; Dixon 1900; Le Double 1903, 1906, 1912; Duckworth 1904; Quain 1908; Schultz 1919; Sullivan 1922; Oetteking 1930; Wood-Jones 1931a,b,c, 1934; Stallworthy 1932; Akabori 1933, 1934; Adams 1934; Keyes 1935; Mayr 1982; Gould 1977; Landman 1991; Balter 2000; Larsen 2006).

With the general demise of race and recapitulation theory, nonmetric trait investigations shifted away from looking at racial categorizations and transitioned, within anthropology, to focus on using these traits to look at group affinities and regional population differences (e.g. Hrdlicka 1916, 1920, 1932; Hooton 1930, Woo 1930; Snow 1948). Such studies demonstrate how the integration of nonmetric traits into anthropological models can have a beneficial impact on the robustness of past population affinity assessments.

It is the work of Grüneberg (1952) that truly establishes the validity of using nonmetric traits for studying population variation. Grüneberg (1952), through a series of studies on the dental development of mice, was able to show that the distribution of nonmetric traits follow a quasi-continuous distribution, where traits exhibit a continuous distribution liability made discontinuous by a threshold point, after which traits would phenotypically manifest to varying degrees of expression. Grüneberg (1952) posited that though traits are heritable, they do not follow a pattern of Mendelian inheritance, but rather result from the additive affects of many genes (i.e. polygenic) and environmental factors, contributing to the overall manifestation of a trait. Grüneberg (1952, 1963, 1965) illustrates this principle best through his research on third molar agenesis in mice, where he shows that the size of the tooth germ ultimately influences the chance of third molar manifestation, where a certain size has to be attained for the trait to manifest, this size being a threshold point. In mice with a tooth germ size below this threshold third molar agenesis occurs. Third molar agenesis is particularly common in large litters, where increasing numbers of mice have to vie for womb space and are on average smaller, thus inhibiting the development of the third molar.

Drawing upon the "New Anthropology" put forth by Washburn (1951,1953) and in light of Grüneberg's (1952) suggestion that nonmetric traits exhibit heritability, researchers started to apply the concepts of nonmetric trait inheritance to anthropological questions (Saunders and Rainey 2008; Stini 2010). The first anthropological study of this era to show the merits of nonmetric traits for differentiating between populations was that of Laughlin and Jørgensen (1956). Laughlin and Jørgensen (1956) analyzed the occurrence of cranial nonmetric traits in Greenlandic populations and showed that the use of nonmetric trait patterns confirmed previous hypotheses about different group migration routes around the island. Following the study of Laughlin and Jørgensen (1956), Brothwell (1959) examined global patterns of cranial nonmetric trait distribution, showing significant regional variability. These two early studies, providing evidence of regional and global nonmetric trait variability, reaffirmed the validity of using nonmetric traits to examine group variability thus providing the impetus for future nonmetric trait research.

3.5.2–Nonmetric Trait Studies of the 1960s

Following the work of Laughlin and Jørgensen (1956) and Brothwell (1959), nonmetric trait studies began to increase steadily with the introduction of Grüneberg's *The Pathology of Development* in 1963 and Falconer's (1965) seminal work on how disease manifests beyond a threshold due to an underlying liability. The concepts put forth by Grüneberg (1963) and Falconer (1965) propose a conceptualization of disease and development in which the manifestation of a pathology or an anomalous physical trait is mediated by a number of additive effects on a pre-determined genetic liability to phenotypically manifest a given trait (Jernvall and Jung 2000). On this premise one can conceptualize all of humanity as lying along a distribution curve for a given trait, and for those who fall beyond a certain threshold point on the curve that trait will manifest. This concept was investigated intensively in the 1960s by studies seeking to identify the mechanisms of inheritance and manifestation of nonmetric traits, typically through animal proxy studies (e.g. Truslove 1961; Grewal 1962a,b; Berry 1963; Berry and Searle 1963; Grüneberg 1965; Berry and Berry 1967; Berry 1968; Rees 1969a,b). Studies of this era sought to understand how traits manifest and how they could be classified so as to yield meaningful interpretations for studies of past populations (e.g. Howe and Parsons 1967; Yamaguchi 1967; Anderson 1968; De Villiers 1968; Hertzog 1968; Ossenberg 1969). It is during this period that attempts at developing standardized trait lists and trait categories, as discussed earlier in this chapter, began (e.g. Berry and Berry 1967; Yamaguchi 1967; Ossenberg 1969), as well as an initial proposition to use nonmetric traits to reconstruct familial relations (e.g. Ulrich 1969).

The 1960s also saw the development of significant cranial nonmetric trait research using the concept of epigenetics. The concept of epigenetics was first introduced in the work of Waddington (1956) as an explanation for developmental variability impacted by both genetic and environmental factors. At its rudimentary level the concept of epigenetics proposes that traits are not always formed solely due to heritable factors but rather in many cases represent a melding of both heritability and environmental factors, providing an explanation for variability of trait manifestation as well as variation in trait penetrance over time. In terms of nonmetric trait research, epigenetics was further developed by Berry and Searle (1963), and Berry (1963) using the threshold and liability principles of trait manifestation as proposed by Grüneberg (1963) and Falconer (1965), opening an avenue of research that remains the key method for present day nonmetric trait research. Grewal (1962b) was the first to propose applying significant statistical testing to nonmetric trait research to develop a repeatable approach for assessing group variability by comparing trait frequencies between populations. This result, as presented by Grewal (1962b) was achieved through the development of what is known as the Mean Measure of Divergence (MMD) by the statistician C.A.B. Smith (See below) (Nikita 2015).

3.5.3–Nonmetric Trait Studies of the 1970s

The 1970s saw increasing adoption of statistical methods for examining the level of divergence and differentiation between populations based on nonmetric traits. Methods suggested in the 1960s by Grewal (1962a,b), Berry and Berry (1967), and Berry (1968) saw increasing use. By the late 1970s an entire revolution of statistical means of differentiation had taken place particularly in the implementation and modification of the MMD for calculating the degree of relatedness of skeletal samples based on nonmetric trait similarity, a concept known as biodistance (Cybulski 1972; Birkby 1973; Sjøvold 1975, 1977; Green and Suchey 1976, 1979).

It was also during the 1970s that many questions began to appear over effects on nonmetric trait expression due to age (Korey 1970; Buikstra 1972; Corruccini 1974a; Self and Leamy 1978; Saunders and Popovich 1978; Saunders 1978), sex (Berry 1975; Ossenberg 1976; Muller 1977; Sjøvold 1977; Saunders 1978; Benassi-Graffi et al. 1979a,b; Cosseddu et al. 1979), cranial deformation, both pathological (e.g. cranial synostoses) and intentional (Ossenberg 1970; Cybulski 1972; El-Najjar and Dawson 1977), and inter-trait correlation (Kellock and Parsons 1970; McWilliams 1974; Suchey 1975; Sjøvold 1977). In light of, or possibly in spite of, the difficulties noted in this era, studies of nonmetric traits began to diversify, seeking to move beyond cranial nonmetrics and into infracranial and dental nonmetrics in the hopes of developing more robust approaches to biodistance (Scott 1973; Finnegan 1974, 1978; Saunders 1978; Penteado et al. 1986; Saunders and Rainey 2008).

3.5.4–Nonmetric Trait Studies of the 1980s and 1990s

Many of the same issues, which had been challenges during the 1970s, continued to appear in the 1980s and 1990s (Buikstra et al. 1990). One of the key contested issues that emerged in the 1980s was over the recording of traits. Before 1980 most studies relied on a self-defined system of trait recording, resulting in a lack of uniformity, and often making comparisons between studies difficult. With the publication of Ossenberg (1981), calling for recording of traits on the basis of bilateral expression, came the need to examine the meaning of recording systems and how they affect statistical calculations of biodistance (McGrath et al. 1984; Hauser and De Stefano 1989; Saunders 1989).

Developing upon the work of Ullrich (1969, 1972) and Pietrusewsky and Douglas (1992), Rösing (1986a,b) put forth the concept that if traits are sufficiently unique they may be used to reconstruct familial lines, a suggestion that would come to play a key role in later studies (e.g. Kuba 2006; Reed 2006). The 1980s and 1990s also saw continued development of infracranial and dental trait studies (e.g. Gunness-Hey 1980; Scott 1980; Winder 1981; Scott et al. 1983; Nichol and Turner 1986; Penteado et al. 1986; Anderson 1987; Scott and Turner 1997; Wood 1997; Prowse and Lovell 1996), and animal (Rhesus macaques) proxy studies (Cheverud and Buikstra 1981a,b, 1982; Richtsmeier et al. 1984). The 1980s–1990s were a time of seeking definition and uniformity of trait studies, harkening back to earlier approaches of trait standardization (e.g. Berry and Berry 1967; Yamaguchi 1967; Ossenberg 1969). Publications such as Hauser and De Stefano (1989), and Barnes (1994) provided atlases of various traits in an attempt to impel unification in how researchers classify, define and understand traits. In many ways, this was effective, as the majority of current studies rely predominantly on Hauser and De Stefano (1989) for cranial nonmetric traits, and the Arizona State University Dental Anthropology System (ASUDAS) of Turner et al. (1991) and Scott and Turner (1997) for dental nonmetric trait recording. Infracranial trait scoring remains more nebulous as there is presently no standard reference volume used for their recording.

3.5.5–Trends in Nonmetric Trait Studies in the new Millennium

With the new millennium a growing reemergence of nonmetric trait studies and interest in how nonmetric traits could be used once again took place (Brothwell 2000). Several studies sought to re-address the use of nonmetric traits for examining familial relationships, for example, Kuba (2006) employed dental and infracranial traits, while Reed (2006) attempted a cladistic analysis, and Case (2003) looked at hand and foot bone anomalies.

With increasing opportunities for conducting aDNA research, a number of studies have sought to examine the correlation between genetic and nonmetric trait data for examining biodistance (Corruccini et al. 2002). Ricaut et al. (2010) compared short-tandem repeats (STR), previously published by Keyser-Tracqui et al. (2003), from the Egyin Gol Necropolis, Mongolia, to cranial, infracranial, and dental nonmetric traits from the same site to examine correlations between the two methods for distinguishing family groups. Nonmetric traits were identified as being 50% as accurate as genetic tests for familial identification. Despite such low results the authors argued that genetic and nonmetric trait data were correlated when looking at the group level, but become more inefficient than aDNA when attempting to reconstruct familial relations (Ricaut et al. 2010), providing support for the continued use of nonmetric traits in biodistance studies at the group level, particularly when aDNA samples are unavailable (Veleminsky and Dobisikova 2005).

This conclusion was further re-enforced by the work of Hubbard et al. (2015) on living Kenyan populations of known ancestry using nuclear DNA and dental nonmetric traits to examine potential correlations and disparities in biodistance calculations. Hubbard et al. (2015) found that genetic and dental nonmetric trait data were highly correlated for distinguishing between regionally and ethnically distinct groups, but dental nonmetric traits were less correlated when the study looked at detailed relationships (i.e. intra-group variability), further showing that nonmetric traits are most useful for biodistance investigations at the group level.

Nonmetric trait studies in recent years have also been employed to investigate potential trade routes and migratory trajectories across long periods of time and significant distances, with the work of Ragsdale and Edgar (2014) looking at migration between Postclassic Mexican populations and the Southwestern United States, while McIlvaine et al. (2014) examined long term migration and interaction between Corinth in Greece and the colony of Apollonia in Albania. Nikita et al. (2012) investigated populations in the Sahara to determine the potential of group interaction and gene flow in relation to the Sahara as a possible geographic barrier during the Late Holocene. Nikita and colleagues (2012) were able to show that the Garamantes of the central Sahara exhibit significant isolation, suggesting a more insular as well as geographically isolated community, while the remaining populations grouped into two groups; those along the Nile and those proximate to the Mediterranean along the coastal regions of present day Algeria, Tunisia, and Egypt. From these results Nikita et al. (2012) interpret the Sahara as a significant barrier to group interaction and gene flow over the last ~4000 years of occupation.

Using dental nonmetric traits, Irish et al. (2014) examined group continuity among the Khoesan of South Africa. Bioarchaeological research suggests that there has been biological continuity among Khoesan groups since the period following the Pleistocene, which is supported by the findings of Irish et al. (2014), which showed that dental samples older than 2000 BP years do not vary significantly from more recent samples, suggesting a lack of gene flow. Similarly, Matsumura and Oxenham (2014) used dental nonmetric traits to examine the peopling and population history of East and Southeast Asia, using skeletal samples from the late Pleistocene up to the modern era. Based on their nonmetric trait findings the authors noted a general clinal center-to-periphery dispersal of groups over time, with two general groups, an early Southeast Asian group with similarities to Australian and Melanesian groups and a second distinct Northeast group, with dispersal over time possibly related to the spread of agriculture (Matsumura and Oxenham 2014).

A final area of study that has recently received increased attention is discussion of methods of calculating biodistance. Studies have been undertaken on the mean measure of divergence (MMD) and pseudo-D^2 of Mahalanobis (Irish 2010; Nikita 2015), as well as novel approaches to calculating MMD using R-script (Soltysiak 2011). What these studies show more than anything is that both MMD and D^2 remain robust measures that can be successfully used for quantifying biodistance.

3.5.6–Italian Peninsula Studies

In terms of research conducted on Italian populations there have been comparatively few investigations, with research mainly focusing on the Iron Age and Etruscan epochs and to a lesser extent consideration of Roman era expansion (e.g. Coppa et al. 1998; Rubini 1996; Rubini et al. 1997, 2007). What these studies as a group suggest is that historically the Apennine mountains were a significant barrier to East-West gene flow on the Italian peninsula. Over time, particularly beginning in the Roman period with greater development of roadways, sea based navigation, and imperial expansion, the Apennines became less of a barrier allowing for greater interaction among regional groups.

Gejvall and Henschen (1968) presented an account of two late Roman skeletons from Corinth they believe to be related based on the presence of similar skeletal malformations in both individuals. However, the authors provide little in terms of calculated biodistance. The research of Iorio et al. (2012) attempted to link epigraphic accounts of related individuals to the skeletal remains of individuals at the Imperial Roman mausolea of Collatina and Casal Bertone (ca. 1st-3rd c. CE). Iorio et al. (2012) found that though cranial nonmetric traits were useful for identifying clusters of individuals, their resolving power decreased when attempting to look at sub-group level relations.

Killgrove (2010a) also examined the use of nonmetric traits to calculate biodistance for identifying potential migrants to the Imperial Roman sites of Casal Bertone and Castellaccio Europarco in Rome. Killgrove (2010a) ultimately concluded that though nonmetric traits are useful for looking at group differentiation, isotopic methods remain the superior method for isolating instances of migration.

3.6–Issues of Sample Validity

For every nonmetric trait study issues of correlated effects due to age, sex, asymmetry, pathology, and inter-trait correlation must be assessed independently for each sample to ensure that all biasing factors are removed before sampling and calculating biodistance. This process is referred to as trait editing and can be completed through the use of statistical analyses (Corruccini 1974a; Buikstra 1980; Brothwell 1981; Brasili et al. 1999; Tyrrell 2000).

3.6.1–Age and Nonmetric Traits

Age as an influencing factor on the presence or absence and level of development of nonmetric traits has long been contested (Saunders and Rainey 2008). Several researchers, subscribing to the belief in double and multiple threshold models, suggest that age may be a biasing factor given the potential for further development of traits during the growth phase (e.g. Akabori 1933; Ossenberg 1969; Korey 1970; Buikstra 1972a,b; Birkby 1973; Corruccini 1974b; Ardito 1975; Carpenter 1976; Self and Leamy 1978; Sawyer et al. 1978; Saunders 1978; Scarsini et al. 1980; Winder 1981; Cesnys 1982). Others contend, however, that nonmetric traits are relatively independent of age effects (e.g. Perizonius 1979; Rösing 1982; Axelsson and Hedegaard 1985). Potential age effects can vary for each trait. To counter any potential age related issues, it is a common practice to avoid older and immature skeletal remains in nonmetric trait studies.

Immature remains are avoided due to the developing nature of the skeleton and the potential for liminal expressions of nonmetric traits, and on the basis that even though a trait does not manifest until maturity it can still be under genetic control (Rösing 1982; Saunders and Rainey 2008). As a general trend, hypostotic traits can diminish with age due to remodeling (Ossenberg 1969; Saunders 1978; Dodo 1986, 1980; Saunders 1989; Tocheri 2003). As such older individuals are avoided, with Tritsaroli (2011) arguing that individuals as young as 40 should be excluded, though this age of exclusion remains questionable, with most researchers choosing to exclude individuals who show signs of suture obliteration or similar evidence of age-related remodeling (e.g. Brasili-Gualandi and Gualdi-Russo 1989; Brasili et al. 1999; Cesnys 1982).

Though immature remains have traditionally been avoided, more recent research has successfully shown that a number of cranial and dental traits can be accurately recorded in juvenile skeletons. For instance Kawakubo et al. (2013) showed that the presence of caroticoclinoid and pterygospinous foramina can be accurately assessed from fetal crania, while Kitagawa (2000), and Lovell and Haddow (2007) were able to successfully record dental nonmetric traits from juvenile teeth, suggesting that with cautious validation it may be possible in future research to include certain trait observations from immature skeletons. Though these findings are encouraging caution is always imperative, for though certain traits may manifest early in life it is not necessarily the case that all traits used for gauging relatedness will be evident before the end of skeletal growth. This fact further emphasizes the need for researchers to rely on adult skeletal remains that have finished development (i.e. individuals >20 years old) for biodistance estimates.

3.6.2–Inter-Trait Correlations

Inter-trait correlation is believed to occur due to factors of pleiotropism, where different effects in development are precipitated by the same gene(s) resulting in a high degree of trait co-occurrence and hence high correlation of such traits (Grüneberg 1963; Hertzog 1968; Hauser and De Stefano 1989; Saunders 1989). Pairs of nonmetric traits can be statistically tested (e.g. chi-square) to examine for potential instances of inter-trait correlation (Sjøvold 1977; Molto 1983, 1985; McIlvaine et al. 2014). If traits are highly correlated, co-occurrence can skew the data by suggesting an independent trend in trait association that does not really exist, so efforts must be taken to select traits that are not falsely correlated and that can provide the greatest amount of insight to the degree of phenotypic diversity between sample groups (Ossenberg 1969; Sjøvold 1977; Saunders 1989). Fortunately inter-trait correlation is not a frequent occurrence, with most researchers noting that inter-trait correlation is limited and rarely reaches statistical significance in small samples, though as sample size increases inter-trait correlations may be more apparent (e.g. Woo 1950; Truslove 1961; Suzuki and Sakai 1960; Kellock and Parsons 1970; Jantz 1970; McWilliams 1974; Corruccini 1974a; Suchey 1975; Mouri

1976; Sjøvold 1977; Molto 1983, 1985; Prowse and Lovell 1995). There is also the potential that non-genetic factors may play a role in the correlation of traits as studies on diet (e.g. Searle 1954; Grüneberg 1963; Johnson 1965; Dahinten and Pucciarelli 1981, 1983) and environment have shown evidence of trait correlations (e.g. Greene 1967; Saunders 1989; Bergman 1993). Saunders (1989) stresses that simply because a trait is present before birth does not inherently indicate it is of genetic origin, as *in utero* environment and maternal diet can also contribute to the threshold and phenotypic manifestation of a given trait.

3.6.3–Pathology, Deformation, and Nonmetric Traits

It is important when considering nonmetric traits to differentiate between pathological and normal variation (see Mann and Hunt 2005). There has been little directed research to date that seeks to examine potential correlations between nonmetric traits and pathology (e.g. Bocquet-Appel 1984; Bergman 1987, 1993; Crubezy 1998; Saunders and Rainey 2008). However, various researchers have suggested that nonmetric traits may be overlooked as components of an underlying syndrome and/or congenital disorder (e.g. Cohen 1982; Turkel 1989; Barnes 1994; Burnett 2005; Graham 2007). Burnett (2005), developing upon the work of Barnes (1994), Turkel (1989) and Cohen (1982), argues that when cranial nonmetric traits are considered in isolation from the rest of the body there is the potential for overlooking what might be significant syndromic or congenital associations, such as the case originally presented by De Villiers (1968) of a woman with various cranial nonmetrics who was identified with no mention of a congenital disorder. Yet upon examination of the infracranial bones Burnett (2005) was able to show that this woman had osteogenesis imperfecta type III.

Several researchers have looked at the relationship between cranial deformation and nonmetric traits with variable results. Various studies suggest no significant correlation (e.g. Sullivan 1922; Cybulski 1972; Konigsberg et al. 1993), while others contend that significant correlation can be observed, typically on the basis of mechanical adaptation (e.g. Oetteking 1930; Ossenberg 1970; O’Loughlin 2004; Van Arsdale and Clark 2010). Yet other studies suggest limited effects with caveats regarding cranial regions and forms of deformation (e.g. craniosynostosis) (e.g. El-Najjar and Dawson 1977; White 1996; Graham 2007). Given the potential influence of pathology and deformation on nonmetric trait development, skeletons exhibiting marked pathology or deformation that are believed to have impacted the development of nonmetric traits are typically excluded from nonmetric analyses.

3.6.4¬Sex and Nonmetric Traits

Sex may play an influencing role on the development of nonmetric traits both in genetic and environmental terms, as there is the potential that sex linked genes may push a trait past the phenotypic threshold more readily in one sex than the other (Strouhal and Jungwirth 1979; Alvesalo 1997; Saunders and Rainey 2008). Such genetic and environmental factors can have different threshold points in different populations, thus differences in nonmetric trait manifestation by sex are highly population specific (Brasili et al. 1999). It has been proposed that in general males are more likely to exhibit hyperostotic traits, based on sexual dimorphism and robusticity, while females are more likely to exhibit hypostotic traits (Ossenberg 1969; Saunders 1978; Molto 1983; Donlon 2000), yet simple differences in body size do not appear to provide a full explanation for this trend, making the exact reason why sexually distinct traits may develop uncertain (Sjøvold 1977; Winder 1981).

The issue of sex remains contentious, as various studies have suggested that sex differences are random and not truly meaningful (e.g. Vecchi 1968; Reggio et al. 1969; Cybulski 1972; Cosseddu et al 1979; Scarsini et al. 1980), while others call for the separate recording of data by sex (e.g. Woo 1950; Berry 1975; Ossenberg 1976; Dahinten and Pucciarelli 1983; Milne et al. 1983), if not total removal of sex biased traits (e.g. Conner 1990; Konigsberg 1990a; Perizonius 1979; Finnegan 1978). To avoid potential biasing factors of sex differences three simple solutions have been proposed: (1) remove sex correlated traits from the study; (2) perform all distance studies by sex; and (3) keep the sex ratio in the sample at an artificially uniform level (Corruccini 1974a; Harris 1977; Finnegan 1978; Saunders 1989; Crubezy 1998; Tyrrell 2000). When it is possible to show that sex related traits have either been removed or are not an issue (e.g. using chi-squared), the sexes may be pooled into one sample for biodistance analysis (See Thoma 1981; Prowse and Lovell 1995; Irish 1997, 2005).

3.6.5–Asymmetry

Biological asymmetry may occur for a number of reasons. Fluctuating asymmetry (i.e. unilateral trait manifestation in cases where bilateral manifestation would be expected) is the type most commonly believed to occur with nonmetric traits (Ossenberg 1981; Polak 2003). Asymmetry of nonmetric traits is poorly understood and is commonly believed to result by chance due to epigenetic factors, or so called "developmental noise" (Ossenberg 1981; Saunders 1989; Scott and Turner 1997; Tyrrell 2000; Polak 2003; Burnett 2005; Willmore and Hallgrimsson 2005). It has been suggested that the dentition is the least likely to exhibit asymmetry due to the relatively short period of development and inability to remodel (Greene 1967; Hillson 1986, 1996; Kuba 2006).

In considering the unilateral expression of traits, Hauser and De Stefano (1989) warn that side of unilateral occurrence does not directly reflect developmental symmetry and should not be confused as such. Korey (1980) suggests that age may play a role, while Suchey (1975) argues that natural selection attempts to curtail asymmetry through strong canalization of traits, being the robustness or directedness of traits to manifest despite environment and developmental noise (see Waddington 1942). The concept of canalization is supported by the work of McGrath et al. (1984) which notes low heritability of asymmetry based on studies of Rhesus macaques, implying environmental factors as the cause of asymmetry. Hallgrimsson et al. (2005) note that rare traits (e.g. congenital anomalies), which can be population specific and dependent, more commonly manifest asymmetrically than common traits given their uncommon occurrence and likely decreased canalization. The findings of Hallgrimsson et al. (2005) may lend support to the argument of Suchey (1975) regarding canalization, that is, if most traits lack an asymmetrical distribution the notion of canalization would hold true, whereas for rare traits it is probable that due to the rarity of the trait occurrence the level of canalization may not be as strong, resulting in increasing occurrences of asymmetry (see Polak 2003). This is important in the context of nonmetric traits as nonmetric traits are anomalous developments, suggesting that once the threshold of phenotypic manifestation is passed the degree of canalization for these anomalous trait would be variable, making both instances of symmetry and asymmetry common and unpredictable (Trinkaus 1978; Saunders 1989; Hallgrimsson et al. 2005). Given these arguments asymmetry in nonmetric traits is commonly understood as random and not meaningful.

3.7–Methodological Considerations

3.7.1–Intra- and Inter- Observer Error

Accuracy of recording and repeatability play an integral role in the collection of nonmetric trait data (Thoma 1981; De Stefano et al. 1983, 1984; Nichol and Turner 1986; Saunders 1989; Gonzalez Jose et al. 2001). Observer error is a major factor that must be accounted for when sampling nonmetric traits (See Molto 1979; Buikstra and Ubelaker 1994). Blind tests of observation repeatability should be performed to ensure the accuracy of data collected (Buikstra and Ubelaker 1994). Observer error can be tested by randomized repeatability tests, wherein a series of nonmetric traits from the same individual are repeatedly scored on several occasions. The outcomes of such tests are then compared to see that the same results are gathered each time or to identify problem areas in which evidence of data recording discrepancy is apparent (Motlo 1983; Buikstra and Ubelaker 1994). Buikstra and Ubelaker (1994) recommend that for testing observer error the sub-sample used should be 10–20% of the entire sample and/or a minimum of 30 individuals. Most studies set the level of acceptable error at 90%–95%, though this percentage is ultimately up to each researcher's preference (Molto 1983; Korey 1970).

3.7.2–Methods of Recording Nonmetric Trait Data

There are three general schools of thought regarding methods of recording nonmetric traits, referred to here as the "individual method" the "bilateral method" and the "ranked method." To allow for meaningful calculations instances of both trait presence and absence must be recorded (Buikstra and Ubelaker 1994). Each study must define its own parameters (See El-Najjar and McWilliams 1978; Rösing 1986b; Gualdi-Russo et al. 1999; Hallgrimsson et al. 2005; Ricaut et al. 2010) and, as Korey (1980) notes, the individual vs. double/ranked methods ultimately make the researcher chose between the potential of including "genetically extraneous" material and the risk of excluding "genetically salient" material. Though no one method is fully correct or incorrect, nonmetric research has largely adopted the individual method.

3.7.2.1–Individual Method

The individual method records traits as present or absent with no special consideration for bilateral expression (Saunders 1989). Many researchers disagree with the idea that traits develop independently by side, and find separate recording of traits by side untenable, preferring to examine traits on an "individual" basis with an allowance for fluctuating asymmetry (McGrath et al. 1984; Molto 1983; Ossenberg 1981; Buikstra 1972a; Korey 1970). Sampling by sides may exaggerate non-genetic factors of trait formation and artificially inflate sample size, which can prove problematic for biodistance calculations (Ossenberg 1981). Alternatively, Tyrrell (2000) contended that in badly preserved skeletal material the use of the individual method may underestimate the true frequency of a trait in a given population. However, at the same time by adopting the individual method this allows researchers to record and use the presence of a given trait in biodistance calculation based upon any observation, thus still allowing for the use of highly fragmented remains where all elements may not be present.

3.7.2.2–Bilateral Method

The bilateral method is based on the concept of a double threshold and entails the recording of traits by side (Ossenberg 1981). This method is proposed as being able to maximize information from fragmentary remains while also taking into account side independence and genetic potential for asymmetry in a population (Ossenberg 1981; Finnegan and Rubison 1984), concepts that are refuted as unviable by McGrath et al. (1984) and Hallgrimsson et al. (2005) given the lack of evidence for side preference development of nonmetric traits. A key issue with this method is that, arguably, it unnecessarily inflates sample size (i.e. instead of recording the presence of a given trait in an individual it is now necessary to record both left and right traits, essentially doubling the sample recorded). However, this issue of inflated sample size has been resolved by using MMD in tandem with the correction factor of Green et al. (1979) (Ossenberg 1981; Harris 2008).

Hermann et al. (1990) suggested that to avoid over-inflating sample size unilateral traits can be recorded as 0.5 and bilateral as 1, while Korey (1970) recommended that crania in which both sides are not observable be removed from study. Konigsberg (1987) proposed that in cases where traits manifest bilaterally they should be recorded as present and in cases where unilateral manifestation occurs a randomization score should be used to determine if the trait should be scored as present or absent. Conner (1984) noted the possibility of using only one side for recording traits however, this method is less commonly employed as the choice to use only one side may create a biasing factor in and of itself by suggesting a degree of side preference and/or ignoring potential side preferences, making this method questionable in its efficacy.

3.7.2.3–Ranked Method

Based upon the concept of multiple thresholds, the ranked method is an attempt to record increasing genetic data and scaling of trait distribution by degree of expression (Saunders and Popovich 1978; Hauser and De Stefano 1989; Tocheri 2003; Kuba 2006). The use of a ranked method is most abundant in dental nonmetric trait studies where traits are recorded based on varying increments of manifestation and then dichotomized using breakpoints, which is not the case in cranial and infracranial nonmetrics (Turner 1975; Turner et al. 1991). Though the intention of this method is valiant it is generally held that the data gathered from such ranking are not significantly more informative than those derived from studies using a dichotomy approach, as there is currently no evidence to suggest that degree of trait expression is significantly correlated with increased liability or genetic influence (Turner 1991; Nichol and Turner 1986; Scott et al. 1983). Further, for the purpose of biodistance assessments the degree of trait manifestation is not as important as its presence within a given group. For this reason, the use of a ranked method is not widely used and may have greater success in future studies seeking to understand the degree of penetrance and phenotypic development of nonmetric traits. The lack of well-defined and arbitrarily imposed threshold breakpoints also makes the use of a ranked scale difficult (De Stefano et al. 1984; Fulginitti 1993).

3.8–Conceptualizing Relatedness–Biodistance

Biodistance, defined as the calculated degree of relatedness between groups, is the main topic of nonmetric trait inquiry in anthropology (see Stojanowski and Schillaci 2006; Saunders and Rainey 2008). The concept of biodistance is founded on the premise that individuals, and by logical extension populations, that are closely related will be more alike phenotypically than those that are not (Larsen 1997; Ubelaker 1999; Harris and Sjøvold 2004). Biodistance studies seek to measure this similarity by examining the biological divergence between groups, most commonly using the mean measure of divergence (MMD) or pseudo-D^2 of Mahalanobis (see below) (Stojanowski and Schillaci 2006; Irish 2010). Early biodistance studies largely sought to examine differences between populations in terms of continents or large geographic areas (e.g. Brothwell 1959). Such studies provided evidence to suggest that nonmetric traits were under sufficient genetic control to allow for differentiation between regional populations, however such studies were also so large and broad as to create types for given regions and thus neglected to consider internal variability. Progressing from this point, studies of biodistance began to look at a smaller scale of differentiating between regional and/or local groups in order to provide more robust interpretations of archaeological and historical renderings of past population interactions and migration (e.g. Cybulski 1972; Strouhal and Jungwirth 1979; Dodo 1992a,b; Prowse 1994; Prowse and Lovell 1995, 1996; Chapman and Gill 1997; Blom et al. 1998; Sutter and Mertz 2004; Hallgrimsson et al. 2004; Matsuma and Hudson 2005; Ullinger et al. 2005).

Drawing upon earlier works on heritability (e.g. Shepard 1893; Symmers 1894–1895; Ashley-Montagu 1937; Torgersen 1951a,b; Grüneberg 1952; Berry 1963) the concept of using nonmetric traits to identify families was introduced to anthropological biodistance studies in the work of Ullrich (1969). Many researchers have avoided such analyses, as it is commonly believed that nonmetric traits are too non-specific to be able to discriminate “close relations” (Berry 1975; Sjøvold 1984; Konigsberg 1990a; Tyrrell

2000). Despite such claims there is evidence to suggest that under the right circumstances familial reconstructions may be possible (see Borian et al. 1964; Molto 2001; Brothwell and Zakrzewski 2004; Graham 2007). Rösing (1986a,b) and Sjøvold (1977) proposed that if the nonmetric traits employed are sufficiently rare in occurrence then it may be possible to reconstruct familial relationships (e.g. Gejvall and Henschen (1968) used congenital cervical fusion to identify siblings). However, this method requires the presence of rare, typically congenital traits, which are an uncommon finding, resulting in this approach being little used.

Since the turn of the millennium several studies have sought to employ a suite of nonmetric traits from the crania, infracranial, and dental regions, in the hope of providing a stronger basis of discrimination for identifying familial relationships. Examining the well documented 18th and 19th century historic burials from Christ Church Spitalfields, England, both Kuba (2006), using dental and infracranial nonmetric traits, and Reed (2006), using a cladistic approach, sought to reconstruct the interred families. Unfortunately, the results of both studies suggest a lack of correlation between burial records and nonmetric trait reconstructions. Case (2003), using hand and foot bones, a method proposed previously in Case (1996) and Anderson (1987), expressed concerns over the potential of using nonmetric traits for family reconstruction, but suggested that there is significant potential for the use of hand and foot traits in future nonmetric trait studies (see also Anderson 1986–1987). Examining burials from Middenbeemster in the Netherlands, Leroux (2012) identified nine individuals who may have been related using a breakpoint of the presence of ≥5 shared dental nonmetric traits. Leroux (2012) proposed that the use of breakpoints may be the way forward for future kinship analyses. However, though novel, Leroux (2012) remains cautious about this method, as ultimately the nature of the kinship of the individuals identified could not be confidently determined. Lastly, Ricaut et al. (2010) found that genetic data remain more accurate at identifying family groups than nonmetric trait data, though they noted that nonmetric trait data still have potential for such studies at broader levels (see discussion above). These studies suggest future potential for the nonmetric trait methods proposed but show little positive progress for studies undertaken on familial relationships.

Bentley (1987, 1991) and Pietrusewsky and Douglass (1992) found that in cases where there is a known deposition history it may be possible to reconstruct family relatedness through nonmetric traits, burial patterning and grave goods. Developing upon this notion other researchers have devised methods of incorporating both spatial data along with burial goods, pathology, and records into nonmetric kinship analyses on an intra-cemetery and localized level (e.g. Finnegan 1972; Sjøvold 1978; Capasso 1985–86; Bondioli et al. 1986; Finnegan and Marcsik 1989; Vach and Alt 1993; Alt and Vach 1991, 1992, 1995; Spence 1996; Sjøvold 1995; Alt et al. 1996; Corruccini and Shimada 2002; Christensen 1997, 1998; Stojanowski and Schillaci 2006; Pennefather-O’Brien 2006; Pilloud 2009; Pilloud and Larsen 2011). Pilloud and Larsen (2011) extended the concept of intra-cemetery variability one step further to examine phenotypic patterning by neighborhood at Çatalhöyük, Turkey. This attempt yielded negative results, yet marks a novel approach to the use of nonmetric trait analyses on a small scale to look at group clustering and the formation of neighbourhoods.

In a separate but similar vein of inquiry several researchers have sought to examine residency patterns. Lane and Sublett (1972) and Spence (1974a,b) are most commonly associated with the use of nonmetric traits to examine marriage residency patterns. Lane and Sublett (1972) and Spencer (1974a,b) proposed that with specific marriage residency patterns (e.g. patrilocal, uxorilocal) there will be a level of skeletal trait homogenization in one sex with corresponding heterogeneity of traits in the opposite sex, allowing for inferences about marriage residence patterns and the social implications that such findings imply (see Konigsberg 2006; Pennefather-O’Brien 2006). These initial studies also helped to develop the concepts of local migration and *in situ* microevolution, which would become topics of significant interest for nonmetric trait research (see Ossenberg 1992; Stojanowski and Schillaci 2006; Konigsberg 2006). Marital residence studies, however, have been harshly criticized. Kennedy (1981) believed it to be unlikely that residence based trait homogenization would remain stable over extended periods of time as change would surely occur over time due to the genetic contributions of incoming marriage partners, while Cadien et al. (1974) argued that the time depth of samples may affect interpretations due to temporal variability. Despite these and other criticisms Konigsberg (2006) contends that such difficulties of interpretation may be accounted for through appropriate sampling and statistical modeling, implying a potential future for such studies.

When reviewing biodistance studies, it becomes clear that the most fruitful level of investigation for using nonmetric traits is at the group level. Attempts at familial reconstruction and inter-neighborhood examinations, though insightful, have shown that the degree of variability in nonmetric traits is not well enough understood to be of sufficient discrimination at smaller scales of analysis. For this reason, the majority of biodistance studies seek to examine differences between regional groups on a larger scale. It is also evident that when nonmetric traits can be coupled with other methods (e.g. burial analysis, epigraphy) there is the potential for increasingly finer resolution of group differentiation.

3.9–Statistical Approaches to Biodistance

Given the dichotomous nature of nonmetric traits, standard statistical approaches used in metric distance studies, such as principle components analysis (PCA), the D^2 of Mahalanobis (1930, 1936) and the work of Penrose (1947, 1953), have either been modified to suit dichotomous data or cannot be employed (Irish and Guatelli-Steinberg 2003; Pennefather-O'Brien 2006; Irish 2010; Pilloud and Larsen 2011). Early nonmetric biodistance studies sought to examine traits on a rudimentary level of trait-by-trait comparison, where distance was based on a 1:1 examination of presence or absence similarity (e.g. Anderson 1968), an approach that has fallen out of use due to the limitations it presents when examining large samples, multiple populations, and many traits.

As the use of nonmetric traits in biodistance studies increased, so to did attempts at developing statistical methods for accurately gauging the degrees of similarity and difference between groups, resulting in the use of multivariate analyses (Irish 2010). The most commonly employed statistical procedure in nonmetric trait biodistance studies is the mean measure of divergence (MMD) (see Equation. 3.1, after Irish 2010), where *r* is the number of traits used, while θ_{1i} and θ_{2i} are the transformed frequencies in radians of the i^{th} trait in the comparison groups, and n_{1i} and n_{2i} are the number of individuals scored for the i^{th} trait in the group.

Equation 3.1–Mean measure of divergence (after Irish 2010)

$$MMD = \frac{\sum_{i-1}^{r} (\theta_{1i} - \theta_{2i})^2 - ({}^{1}/_{(n_{1i} + {}^{1}/_{2})} + ({}^{1}/_{(n_{2i} + {}^{1}/_{2})})}{r}$$

The MMD statistic was first introduced by Grewal (1962b) and popularized within anthropology in the work of Berry and Berry (1967). Later researchers would adopt this initial procedure and refine the method and formulae in a number of ways resulting in a plethora of different, often conflicting and difficult to compare, approaches (e.g. Green and Suchey 1976; de Souza and Houghton 1977; Sjøvold 1977; Finnegan and Cooprider 1978; Harris and Sjøvold 2004; Harris 2008; Irish 2010). To resolve this problem, Irish (2010), proposed the adoption of a single MMD formula so that the results can more easily be compared between studies (see Equation 3.1 above).

MMD is a dissimilarity measure that is quantified on a scale ranging from 0 to 1, where proximity to 0 shows high similarity and proximity to 1 shows low similarity (Tyrrell 2000; Irish 2010). Using this scale the level of similarity and difference between divergent populations can be calculated where statistical significance occurs when MMD is equal to or greater than twice its standard deviation (see Harris and Sjøvold 2004 for formulae; Tyrrell 2000). MMD is designed to deal with dichotomous data in terms of percentage, not intervals or ratios, and has been extensively employed, as it is fairly robust and allows for ease of interpretation (Cybulski 1972; Harris and Sjøvold 2004; Turner and Elder 2006; Irish 2010). Early in the use of MMD it was realized that correlation between variance and trait frequency poses a difficulty for calculation (Harris and Sjøvold 2004). In an attempt to limit such association a series of transformation procedures have been suggested and generally adopted (see Green and Suchey 1976). The use of a frequency transformation, commonly referred to as an arcsin, angular or inverse sine transformation, helps to ensure a more stable variance, where the relative frequency of a trait in a given sample (p) is proportional to $1/n$, instead of p, and is commonly conducted following the formulae of Freeman and Tukey (1950) and Anscombe (1948) with further recommendations by Green and Suchey (1976). Using an angular transformation, the distance between samples can be represented as a projection onto a hypersphere, allowing for measurable inter-population distances (see Bhattacharyya 1946; Tyrrell 2000).

MMD has proven integral to biodistance studies. However, a number of concerns continue to arise with this formula, not the least of which is the frequent misuse and misinterpretation of MMD calculations and the fact that MMD does not account for inter-trait correlations (see Sjøvold 1977, 1985–86; Harris and Sjøvold 2004; Irish 2010). It is well established that small sample size can have an adverse effect on the calculation of MMD where the adjustment factor can be larger than the difference measured, creating a negative MMD (Harris and Sjøvold 2004; Sjøvold 1986). The negative value has no biological significance but is an artefact that indicates how calculation of MMD is dependent on sample size, or that the samples have identical frequencies, showing how distortion of discrimination ability increases with decreasing sample size (Green and Suchey 1976; Prowse and Lovell 1995; Relethford et al. 1997; Irish 2010). To alleviate such problems recommendations have been made to follow the suggestion of Sokal and Sneath (1963) that at least 60 and no less than 40 traits be used, yet in terms of anthropology such high trait levels are typically unattainable. To resolve this situation it is recommended that traits that do not provide for significant discrimination between groups be removed from analysis, seemingly harkening back to the previously presented concepts of Rösing (1986a,b), so as to avoid such negative values and enhance the discriminatory power of the traits remaining (Rohlf 1967; Armelagos et al. 1982; Harris and Sjøvold 2004; Irish 2010; Soltysiak 2011).

In an attempt at standardization, Sofaer et al. (1986) introduced what is known as standardized mean measure of divergence (sMMD). This procedure sought to provide standardized MMD results allowing for increased comparability of MMD calculations in cases where different traits were scored for different populations. This objective was accomplished by dividing the MMD by its standard deviation, a notion Harris and Sjøvold (2004) proposed as an attempt at analogy to conventional z-scores. Though this method has valiant intentions it has taken significant criticism, most recently by Harris and Sjøvold (2004), over what are identified as internally unsound calculations, suggesting that this method should be avoided in future biodistance studies.

Another method that has become increasingly popular in nonmetric trait studies is a dichotomized approach to the D^2 of Mahalanobis (1930, 1936). The D^2 measure of divergence was originally conceived of as a general measure of divergence between two populations based on uncorrelated metric variables (Sjøvold 1977) (Equation 3.2). It has been shown that by incorporating a tetrachoric correlation matrix, the typically continuous variable calculation of D^2 can be applied to noncontinuous data (Sjøvold 1984; Konigsberg 1990b; Konigsberg et al. 1993; Bedrick et al. 2000; Irish 2010), following the formula,

Equation 3.2–The D^2 measure of divergence (after Sjøvold 1977).

$$D_{ij}^{2} = \left(z_{ik} - z_{jk}\right)' T^{-1} \left(z_{ik} - z_{jk}\right)$$

where Z_{ik} is the threshold value corresponding to a trait frequency P_{ik} for trait *k* in site *i*, while Z_{jk} is the threshold value for trait *k* in site *i*, and T is a pooled tetrachoric correlation matrix between *k* traits (Konigsberg 1990b:60, Eqn. 11).

Though the MMD and D^2 provide similar insights to divergence there are differences. Where MMD requires counts (*k*) of positive observations out of total number of individuals (*n*), D^2 employs dichotomous data based on individuals to examine correlations within each group before being pooled by sample size to determine the weighted average correlation (Irish 2010). Samples are adjusted for phenotypic correlations between groups, allowing for undue weight on groups of characters that frequently occur to be avoided and representing the minimum possible distance between groups (Williams-Blangero and Blangero 1989; Konigsberg 1990b; Irish 2010). Though MMD and D^2 differ, after trait editing, MMD and D^2 appear to provide sufficiently similar results (Irish 2010; Nikita 2015).

Lastly, the Gower General Similarity Coefficient can be used to investigate nonmetric trait variability on an intra-group level following the statistic provided by Gower (1971) (Equation 3.3).

Equation 3.3–Gower General Similarity Coefficient (after Gower 1971).

$$S_{ij} = \frac{\sum_k W_{ijk} S_{ijk}}{\sum_k W_{ijk}}$$

where s_{ij} compares the cases *i* and *j*, S_{ijk} indicates the contribution provided by the *k*th variable, and w_{ijk} is either zero or one depending on whether the comparison is valid for the *k*th variable (see Killgrove 2010a:353). Gower's coefficient is useful for examining intra-population similarity as it generates a matrix to take into account traits that two individuals share, traits that one individual has and the other does not, and traits that neither individual has, providing an objective measure of similarity (Killgrove 2010a; Iorio et al. 2012). This method is helpful for identifying individuals with significantly different nonmetric traits within a given group, allowing for relative similarity distances to be approximated between individuals, but has been challenged for its potentially poor resolving power in biodistance discrimination (Killgrove 2010a).

3.10–Future Directions of Nonmetric Trait Research

Presently there are two foreseeable future directions in nonmetric trait studies, social and developmental. Developmentally, a key future direction for research lies in the understanding of trait development. Saunders (1989) suggested that studies might look at traits on an individual basis and seek to understand them from the point of ontogeny, from genesis to full development, possibly through prenatal imaging, fetal dissection and analysis of serial radiographs from living populations. This type of research has seen increasing investigation, with researchers such as Kawakubo et al. (2013) investigating the presence of nonmetric traits in fetal crania. A second approach to this suggestion is through genetics. The ability to sequence and examine entire genomes has become increasingly feasible and as such whole gene scanning may aid in identifying the underlying genetic contribution to various nonmetric traits (Larsen 1997; Hallgrimsson et al. 2005; Saunders and Rainey 2008).

There has also been a call for combining nonmetric traits with isotopic studies of strontium (Sr) and oxygen (O) to look at the possible relationship between methods of group distinction using NMTs and stable isotopes, as such an approach may help to provide a broader understanding of nonmetric traits in terms of population affinity and migration factors (Saunders and Rainey 2008). Though presently difficult, kinship reconstruction also remains an avenue of research that merits further investigation. Kuba (2006) notes that few studies have looked at cranial, infracranial and dental nonmetrics together, suggesting this approach may be useful for future studies (see also Case 2003, 2006; Reed 2006). The work of Burnett (2005) pointed out that significantly more research is needed into the continuum of variation and the use of nonmetric traits in relation to syndromes and congenital disorders in the past.

Lastly, there is a need to conduct a comprehensive study that looks at the various methods of recording traits (i.e. individual, bilateral, ranked) to see the actual difference in outcome that are produced by all three methods and associated statistical models of computation (Finnegan and Cooprider 1978). To my knowledge, there is no one study that has scored the same population by way of these different methods and then compared the results to examine for differences.

An avenue of investigation that may also be fruitful in future nonmetric trait studies is the integration of so-called “soft data” (e.g. epigraphy and historical documents) with nonmetric traits and other datasets (e.g. isotopic analyses, aDNA) (See Bruun 2010). Though desirable it is also clear that this approach is not always feasible, given the common lack of “soft data” and/or the inability to undertake chemical analyses. Despite these limitations it is hoped that, when possible, by combining these various datasets an increasingly robust method of analysis may be possible, allowing for greater biosocial insights to past populations.

3.11–Conclusions

Nonmetric traits have seen wide and varied use throughout the history of anthropology. The use of nonmetric traits has been highly contested, and at times all but abandoned. Such traits, even in light of more recent genetic evidence, have proven to be a sufficiently viable approach by which to examine relatedness and group differentiation among past populations. There remains significant potential for future research that continues to use and investigate nonmetric traits within bioarchaeological contexts.

Chapter 4–On Mobility and The Roman Empire

4.1–Introduction

The movement of people is a staple of all time periods and all regions of the globe. The extent of and impetus for movement however can be drastically different within and between groups and time periods. It is precisely at this junction that the nature of mobility and in particular migration, immigration, and emigration become entangled in larger cultural dialogues. This chapter examines the nature of human mobility on a broader theoretical level before engaging with aspects of mobility related to the Roman world.

4.2–Theoretical Perspectives on Migration

Mobility and migration are basic norms of human society throughout all periods of history (Naerebout 2014). The nature, type, and intention of human mobility can vary. While broadly speaking mobility refers to any movement, mobility in the migration literature is often used to connote short distance movement of individuals within a common cultural realm in a given territory (i.e. movement from city to suburb, travel for day labor) (Ortega Munõz 2015). Migration, and the associated terms of immigration and emigration, is typically defined as the movement of individuals in physical and social space beyond the boundaries of their cultural milieu (Albrecht 1972).

In the 19th century, Ravenstein (1885, 1889) observed that most individuals move only short distances and that the number of migrants diminishes with increasing distance, the so-called "friction of distance" model (Burmeister 2000). However, as Burmeister (2000) discusses in his synthesis of migration literature, this model neglects to take into account the social agency of migrants as well as the distinction between distance and social continuity (see also Albrecht 1972). What is important to take from this is that mobility and migration are not independent categories of movement; rather they represent attempts at defining different parts of a mobility spectrum that is influenced by both physical and social distances, a phenomenon for which there is no one defining feature other than movement (Kearney 1986; Horden and Purcell 2000; Brettell 2015). Migration is often not a singular, nor linear, event, as one does not simply leave one place and arrive at the other (Brettell 2015). Migration can be conceived of as a process of movement over variable periods of time during which migrants act and are acted upon by the various processes facilitating and hindering their onward and/or return movement, with previous migrants being increasingly likely to undertake subsequent migrations (Smith 1979; Anthony 1990; Brettell 2015). As there is less qualitative information available for why and how people moved in antiquity (Burmeister 2000), this chapter will variably use the terms mobility and migration when broadly discussing the movements of human groups over a physical landscape.

4.2.1–Modelling Migration Types

4.2.1.1–Types of Migration

To deal with the variety of movement types numerous theoretical models have been derived to qualify the nature of human mobility (e.g. Tilly 1978). These models however, are not meant to be rigid, but rather are meant to conceptualize different types of mobility strategies, providing insights to the nature of migration and socio-dynamics of populations. For instance, Sanjek (2003), focusing on the motives for migration, suggests that human migration can be disassembled into seven categories: expansion, refuge-seeking, colonization, enforced transportation, trade diaspora, labour diaspora, and emigration. In contrast, Gonzalez (1961), focuses on the temporality of migration, using five categories to contextualize migration in the Caribbean: seasonal, temporary non-seasonal, recurrent, continuous, and permanent.

The foundational model of human mobility articulated by Tilly (1978) presents four inter-related categories of migration that have been widely engaged with and expanded upon in numerous fields including sociology, cultural anthropology, archaeology and biological anthropology, among others. The categories presented by Tilly (1978) frame mobility based on the duration and distance from the original source location. Smith (2014a) argues that the model developed by Tilly (1978) is so enduring in the migration literature as it presents a heuristic device that advances scholarly understanding of the social context of human movement by breaking it down into coherent analytical categories.

4.2.1.1.1–Circular Migration

Circular migration occurs when individuals move through a series of established connections from their primary area of residence along a prescribed route to a second destination where they reside for some period of time before returning to their primary area of residence (Tilly 1978). This style of migration is commonly seen among merchant classes in which business is conducted at a number of locations away from a primary residence, thus taking individuals away for extended periods of time but ultimately with the knowledge that they will or intend to return (Tilly 1978). Research has shown that individuals who are involved in circular migrations are increasingly likely to continue to undertake further migrations, a process that Margolis (1995) conceptualized as "yo-yo migration" (Brettell 2015). Circular migration can be both a short term process and a long term process, as Brettell (2003) also discusses the occurrence of return migration, noting that 25% of some 16 million Europeans who came to the USA early in the 20th century eventually returned to Europe to live (Gmelch 1980).

4.2.1.1.2–Chain Migration

Chain migration is similar to circular migration in that individuals move from place to place through a series of pre-arranged connections or "links" in the chain (Tilly 1978). These links in the chain may be all pre-arranged or they may develop over an extended period of time where initial moves are made with subsequent back flow, allowing for multiple locations to be tested for the best possible location of movements (Tilly 1978). In time this method of forward and back migration establishes a number of links from a given community forming a network that allows for easier or more reliable migration (Kearney 1986). Chain migration by its nature also makes further migration easier, as with every new migrant to a given region it becomes easier for friends and family to follow as they will have places to stay along the route and better information on the new location as gathered by previous migrants (Massey et al. 1993). Such movement often results in the formation of micro-villages at the new location, epitomized by so called "Chinatowns" and "Little Koreas" (Tilly 1978; Sanjek 2003).

Anthony (1990) discusses a similar form of chain migration known as leapfrogging in which each successive individual or group succeeds the previous group, leapfrogging over them to push the migration chain farther establishing new locations along the line. Leapfrogging differs from chain migration as it relies less on endpoint aggregation and more on initial "scouts" who go forward from the larger group(s) to check out potential new locations and send information back allowing for larger groups to move to the new location, from which again scouts move forward to find further new migration points (Anthony 1990; Osborne 1991). Leapfrogging then is defined by cycles of fusion and fission of group members, forming a feedback loop and continually expanding.

Chain/leapfrog migration represents an engrained approach to systemic migration. Massey et al. (1993) discuss these types of migration as being a common part of "cultures of migration," in which migration becomes ingrained in the social fabric to the point that it is common, if not expected, for individuals to migrate. In some cases the readiness to migrate is associated with reaching adulthood (Massey et al. 1993; Sharpe 2014).

4.2.1.1.3 –Local Migration

Local migration encompasses short distance migration, movements between villages or across a town (Tilly 1978). Such migration, possibly better referred to as mobility (Mihailescu-Bîrliba 2009; Ortega Munõz 2015), is unlikely to have a significant effect on the individual moving, as cultural continuity and preservation of social ties with individuals from the previous residence are often maintained (Tilly 1978).

4.2.1.1.4 –Career Migration

Unlike local migration, career migration involves individuals and groups of individuals moving over extended distances on a permanent basis to fill opportunities for better employment, social standing, or service (e.g. diplomatic service, military service, etc…)

(Tilly 1978). Though similar to circular migration, career migration varies in that the expected return date is not known and it is not certain if individuals will return to their original places of residence, as they may find employment in yet another location or chose to stay in one of the locations where they have settled (Tilly 1978).

4.2.2–Migration Contingency Analysis and Frameworks

4.2.2.1–Informing the Choice to Move

The various migration categories and types established by Gonzalez (1961), Tilly (1978), and Sanjek (2003) provide models by which various forms of migration can be gauged. The following sections examine at greater length key aspects of migration theory and the various reasons and decision process behind why people migrate.

4.2.2.1.1–Perception-Action

Perception-action looks at the perception of mobility and the cyclical relationship between human perception and movement (Gibson 1979; Øvergåard 2008; Sager 2008). Though this field of research has implications for all forms of mobility, it is most strongly engaged with looking at long term and potentially no return migration.

Perception action seeks to address the perception that potential migrants have towards the process of migration and the ultimate endpoint of their movement (Swenson and Turvey 1991). Sager (2008) makes the argument that people do not move simply because they can, but rather, in situations of free will mobility (i.e. individuals who are free to chose whether or not to move), people move to locations that they perceive as viable and attractive. Øvergåard et al. (2008) extend this further by pointing out that action is a way of perceiving and perceiving is a way of acting, that is to say that the migration experiences individuals have inform future decisions to migrate, while the perception of what future migrations will be like informs the eventual action of migrating. The perceived viability and attraction of a location can be anything, ranging from viability for business success to more attractive than one’s present living conditions. In this way there is no one uniform perception of “there is better than here,” rather each individual’s perception will be based on unique criteria (Burmeister 2000; Sager 2008).

Burmeister (2000:547) contributes to this theoretical position in his discussion of "decision theories," which operate using the premise that in any situation potential migrants have only certain and ultimately limited information about their final end point migration destination. The choice to move is precipitated and predicated upon the perceptions individuals have in regard to their final end location, placing decisions as the key focal point of migration conceptualization. In this way the decision to migrate is not entirely objective given an inherent lack of facts about all possible difficulties in the endpoint location, thus all choices are subjective (Brummel 1979; Plane 1982; Anthony 1990). Such a decision-based model takes into account the social and behavioural side of the decision to migrate (Morril and Pitts 1967).

4.2.2.1.2–Push and Pull Factors

Classic conceptions of migration theory commonly employ a somewhat mechanistic push-pull model as the fulcrum for movement (Kearney 1986). These push and pull forces are used as counterpoints where on the home residence side there are factors that are disagreeable to the individual and thus push them towards leaving, while on the opposite side, the migration destination has attractive features which pull the potential migrant towards that location (Kearney 1986; Hin 2013; Brettell 2015). These factors need not be thought of as exclusively negative (i.e. push) and positive (i.e. pull). In many cases individuals do not fully wish to leave their residence but external factors (e.g. lack of a job, war, lack of opportunity for education, etc..) push them them away. In some cases (e.g. war, famine, pogrom) large groups of individuals may be "pushed" to migrate at one time, while in other instances (e.g. economic hardship) push factors may result in more individualized cases of migration. While conversely the "pull" location may or may not be that enticing, but rather may provide opportunities that encourage individuals to move there (e.g. a job, the ability to raise a family, the avoidance of discrimination and violence, etc…). Brown et al. (1977) contend that "pull" factors are not random but rather, similar to perception-action choices, are precipitated on the knowledge that potential migrants have about locations where they wish to go (i.e. perception that a job in location X will provide a better life). Push and pull factors are however ultimately subjective, as Hin (2013) argues, what pulls or pushes one individual or group of individuals may not equally do so to other individuals in the same situation. Further to this point, Hin (2013) points out that though choice is a factor in push-pull migration, there are countless instances in which voluntary migration is undertaken by choice in name only, where voluntary migration is precipitated by war or natural disaster, which can force individuals to migrate who in the absence of these factors would have no desire to emigrate. Push and pull factors as such are subject to highly variable decision processes, thresholds, and subjective interpretations.

4.2.2.1.3 –Cost Benefit Analysis

The cost benefit model of migration more readily uses a microeconomic scale to empower the decision processes of emigrants, whereas the dichotomy of the push-pull model suggests more macroeconomic motivators (i.e. individuals are pushed by circumstance beyond their direct control and pulled by motivators somewhere else) (Sjaastad, 1962; Todaro, 1969, 1976, 1989; Bogue 1977; Todaro and Maruszko, 1987). Cost benefit models look at the analyses individuals have to put into making the decision to move, such as the cost of travel between their present location and the ultimate locale, the cost of living at the desired location in comparison to their present location, and the location at which migration will bring the greatest return compared to the cost of moving there (Lee 1966; Borjas, 1990; Castles and Miller 1993; Massey et al. 1993). In this model we see decisions being made such that people direct their movement to locations in which the skill set they have will bring the greatest return, typically, though not exclusively, monetary, as it is clear that other factors such as adapting to a new work environment, social integration, etc… are also considered (Massey et al. 1993).

In more recent years the cost-benefit model has been further interrogated and refined to consider the decision making process from the family and/or community level rather than only at the individual level (Stark and Levhari 1982; Stark 1984, 1991; Katz and Stark, 1986; Taylor, 1986; Lauby and Stark, 1988). Where individuals may ultimately be the ones moving, it is much rarer to encounter situations in which an individual is the lone actor in this decision. Rather, Stark and Bloom (1985) propose that it is much more common that the cost-benefits of moving are weighed by a family and/or community, where both the net return versus cost to the individual and at the larger scale the benefit to the family and/or community can be maximized. In this way the ability to maximize returns can, arguably, be better orchestrated to do what is best for the family and/or community. This group cost-benefit model is believed to more closely approximate real world scenarios where more than just the individual is dependent on the return capital from their potential emigration (Massey et al. 1993).

4.2.2.1.4–The Bright Lights

The "bright lights" have also been investigated as a mechanism that attracts individuals, particularly young males, to migrate (Du Toit 1990). In this migration model emigrants leave their homes because the "bright lights" of a metropolis or boomtown promise more excitement, better opportunity, and the assumption of a brighter future (Gulliver 1957; Mayer 1961; Øvergåard 2008; Sager 2008). Emigrants leave their home region for the hope of something better but do not necessarily have any contacts or a job waiting in the migration locale (Bogue 1977; Du Toit 1990). As such it is the perception of the location that has the greatest pull at the proposed greatest benefit. The pull of these proposed benefits however, is not always genuine, as many times migrants find themselves in the metropolis with little recourse to employment and thus become stuck in a sort of limbo in which they cannot afford to go home but also are barely able to get by in the area they have chosen to move to (Lee 1966; Bogue 1977; Kearney 1986; Brettell 2015).

4.2.2.2–Networks

For all the categories and reasons why people migrate there remains the practicality of the actual movement. When considering how people move a key concept is the notion of networks (Wilson 1994; Brettell 2015). It is uncommon and unlikely that an individual decides to move from their residence to another location without having some system of contacts in place to form a series of points at which they can stay before making further progress (Du Toit 1990; Brettell 2015). This notion of a prepared route is stressed in the anthropological literature where it is made evident that migration is not a binary "home" and "away," but rather is most typically undertaken through a series of destination points, nodes, along the route (Du Toit 1990). Though there are surely instances in which quick migration occurs (i.e. forced expulsion, refugees fleeing conflict) when considering planned and intentional migration it is typical that individuals will move within networks of established contacts and routes (Du Toit 1990; Brettell 2015; Wilson 1994). When speaking of chain migration previously the notion of networks is evident (Tilly 1978). The development of enclaves (e.g. "Chinatowns") imply a series of links that have allowed individuals to reach these ultimate endpoints, thus individuals who have the same network of contacts often arrive in similar locations, allowing for the development of communities in the new location (Lomnitz 1976b, 1977; Tilly 1978; Kearney 1986; Appadurai 1996; Hin 2013).

Massey et al. (1993) posit that when migration networks work well they provide a situation in which travel along the network of established links is not random but is guided by the fact that at the end there is a job waiting or a high probability of employment, enhancing the perceived benefits of migration. With this the increased volume of individuals along any given network also help to increase the network size and access to it. Thus for the first individuals who migrate and begin to establish a network the risks are higher than for those who come via the same network later when there are many social ties, a formed community of common individuals, and also increased opportunity for employment, given the established positions that earlier individuals along the network have created (Kearney 1986; Massey et al. 1993). This increased development of a network also plays into the perception of movement, such that if an individual feels they can safely travel and have support along the route to a location where they are likely to get a job and be socially satisfied, then the perception of this move is likely to be encouraging and positive (Anthony 1990, 1992, 1997; Hakenbeck 2008; Sager 2008; Berttell 2015).

It is important to make clear that when discussing networks used by individuals these systems are not necessarily rigid bounded paths (Wilson 1994). Though the concept of a network suggests a set course, it is not necessarily the case that the same routes are taken by each individual. Rather one can conceive of networks of migration as a large and ever-expanding system of multifold nodes facilitating onward movement in which any given path can be equally repeated and altered by each subsequent migrant, and that with every individual a further node is potentially added to any given network of migration, allowing for continual expansion (Massey et al. 1993; Wilson 1994; Purcell 2005; Brettell 2015).

4.2.2.3–Cost

It is atypical for whole societies to move. It is much more common for certain segments of any given society to form a mobile “class” (Burmeister 2000). Human mobility, spanning the gamut from short term to permanent migration, is costly and is not always possible for all individuals (Grawert 1994). Excluding forced migrations (e.g. slavery) most individuals in societies facing economic hardship are increasingly less likely to be able to easily migrate (Noy 2000; Woolf 2013).

Migration is costly as the individual and/or group must be able to sustain themselves while moving (e.g. food, transportation, shelter, supplies, etc…). Migrants may sacrifice an income at their primary residence and may have a lag period in which employment and income at the final migration locale is not forthcoming upon arrival (Grawert 1994; Burmeister 2000). These difficulties can be costly and require a degree of monetary stability before an individual can undertake such a movement.

Conversely, there are also individuals who choose to migrate but do not have the appropriate funds. Such individuals may choose to move for countless reasons, often for safety or the hope of better employment/life (Castles and Miller 1993; Brettell 2015). Individuals who do not have enough initial funds to facilitate their movement may take on debts/borrow money to make the journey. This approach to migration can be a gamble in terms of being able to effectively pay back debts, which when not paid can result in significant financial setbacks and potential harm to the individual (Castles and Miller 1993; O’Connell Davidson 2013).

Migration also brings non-monetary costs. Ortega Munõz (2015) discusses the costs of migration in regard to potential death and physical harm along the route.

Migrants may face precarity due to false information, potentially resulting in encounters with disingenuous and abusive local hosts, employers, and/or the general receiving community (O'Connell Davidson 2013; Lewis et al. 2014). Acculturation may also be a cost. Though a much slower and subtle process, migrants may consider the costs of what their lives will be like outside of their home cultural settings as well as having to deal with new and potentially unexpected cultural norms at the migration locale (Manning 2005; Massey et al. 1993; Ortega Munõz 2015).

The cost of migration is intimately linked with the previously discussed notion of migration networks. Migration networks can significantly reduce, though not necessarily remove, the costs of migration. These networks often provide a degree of cultural continuity as well as shelter and local information, which has the potential to be paid for with informal labour (e.g. babysitting, farm labour, etc…) allowing migrants to save money, progress to their final destination at a reduced cost, and also potentially reduce culture shock (Brown et al. 1970; Fields 1975; Boyd 1989; Eades 1993; Pauseback 1995; Burmeister 2000; Junankar and Shonchoy 2013).

4.2.2.4-Migration: Males and Females

Migration research has historically and disproportionately focused on adult males, while female migration has traditionally been framed as being for purposes of family reunification, or to join males who previously migrated (Davis 1977; Marel 1980; Houstoun et a1. 1984; Pedraza 1991; Du Toit 1990; Burmeister 2000). This assumption is based on the notion of gender-specific selectivity of migration, where men are more likely to migrate for work than women, and where men are more able to migrate than women when assuming social models in which women are mainly responsible for children and the domestic realm (Houstoun et al 1984; Perdraza 1991).

This perspective, however, on who migrates remains difficult to align with modern and increasingly globalized evidence of female migration. If the United States of America is used as a model, after 1930, and for over half a century now, women have annually outnumbered men as legal immigrants (Houstoun et al 1984; Pedraza 1991). On a global scale, female migrants appear to be almost equal to male migrants according to estimates published by the World Bank that identify female migrants as 46.7%–48.4% of international migrants for the period from 1960 to 2010 (Ehrenreich and Hoschschild 2002; Morrison et al. 2008; Sharpe 2014).

With globalization female migration has become increasingly visible and driven by economic motivations (Van Hulst 2000; Sharpe 2014). This is not to discount the likelihood that female migration was taking place in antiquity, as isotopic research has increasingly shown (see Prowse et al. 2007), but rather to show that theories of female migration have transitioned away from being almost exclusively conceptualized in terms of being undertaken to join a male spouse and have increasingly focused on economic motivators as well as independent female migration, models which may be of significant use to developing frameworks of female mobility in antiquity.

A large portion of this increased female migration in the modern era has been a result of the demand for domestic workers and workers in medical and related fields (Lan 2006; Sharpe 2014). This has resulted in a number of different migration plans for females and their families. On one hand there are females leaving a home location for a foreign job in which the employment, often domestic work or nannies, prohibits movement of an entire family and thus to fulfill the contract females must move alone (Sharpe 2014; Lan 2006). In other scenarios, such as Japanese nurses living in Brazil moving back to Japan for employment, whole family migration has become common (Yamanaka 2000; Brody 2002).

From the migration literature it is clear that although a disproportionate focus has been placed on the migration of young economically motivated male individuals, there is significantly more nuance to who moves and why (Burmeister 2000). There are of course instances in which male migration outnumbers female migration and *vice versa*. The point being made here is that greater balanced consideration of who migrates is needed for all periods of history under consideration, as it is clear that both males and females migrate. It seems more reasonable to admit that humans are mobile and that the sex of who moves and the situations in which they move can vary widely, and as such each situation requires independent consideration.

4.2.2.5–Migration Paradigms

Taking into account the information discussed above, human mobility and migration in the literature is commonly discussed in terms of three macroscopic models: modernization theory, dependency theory, and more recently transnationalism (Kearney 1986, 1995; Brettell 2015). These three models form the core of the discussion presented in this section.

4.2.2.5.1–Modernization Theory

Modernization theory proposes a system in which rural to urban migration and subsequent backflow to home locations results in the progressive modernization of the rural landscape through the introduction of new, and supposedly superior, ideas and economic investments (Redfield 1941; Kearney 1986). Developing in the 1940s and 1950s, during an era of increasing industrialization, and remaining the key paradigm of migration into the 1970s, Kearney (1986) comments that modernization theory is essentially psychologistic, individualistic, microeconomistic, and ahistoric, putting the emphasis on individual actors and the role they play in microeconomic alterations of the "pre-modern" (i.e. rural) landscape into the "modern" (i.e. urban industrial) landscape.

Modernization theory at its core suggests a balance of labour to employment, where individuals from regions with little employment and abundant labor migrate to regions with abundant employment and limited labor, thus striking an equilibrium that benefits both regions (Brettell 2008, 2015). Following this move it is possible that the migrants will return after some time to their home location to employ the new skills they have learned and/or will ostensibly send funds back and invest in their home location, thus contributing to its "modernization" (Brettell 2008, 2015).

Modernization theory has been strongly criticized for being Eurocentric and for its conceptualization of residence zones into an "us-and-them" model, in which urbanization is meant to progressively overtake the ostensibly lesser and parochial qualities of rural economies, where civilization is being given to the uncivilized (Kearney 1986; Brettell 2015). Modernization theory has also been criticized for what is a fairly narrow perception of how applicable skills learned in the city will be transferable to the rural landscape and how migrants to the city spend their money (Brettell 2015). It is assumed that through remittances home and/or investment at home development will be facilitated (Cohen 1978; Gullette 2009, 2012, 2013). However, several researchers have argued that remittances can be limited and the purchase of self-sustaining items and luxury goods by the migrant at the migration locale is often pursued in preference to investment in development projects in the home community (Rhoades 1978; Gmelch 1980; Donnan and Werbner 1991; Gardener 1995).

In an attempt to reduce the “us-and-them” dichotomy several researchers propose more integrative systems to rural-urban migration, such as Uzzell’s (1979) “social village spread over thousands of miles,” Whiteford’s (1979) “spatially extended communities,” and Lomnitz’s (1976a) “ecological model.” These alterations of the modernization model hint at the later development of transnationalism theory (see below) in which instead of forming an “us-and-them” model, migrants from rural locations form a conduit to the urban locale, thus creating a social link between the two places resulting in the so-called social village spread over thousands of miles (Uzzell 1979; Kearnery 1986).

4.2.2.5.2–Dependency Theory

Dependency theory in migration research is presented as the converse perspective of modernization theory (Kearney 1986). Where modernization theory looks at migration and development from the urban perspective and is based on microeconomic situations leading to variable development for any given region, dependency theory considers migration macroscopically in terms of the effects it has on the peripheral society. It is toted as a theory that looks at the “development of underdevelopment,” in which peripheral regions (i.e. rural areas, underdeveloped nations, etc…) are exploited to meet the needs of the core (i.e. urban areas, developed nations) (Frank 1967; Kearney 1986; Deji 2012). Often linked with the work of Hans Singer and Raúl Prebisch, dependency theory developed in the 1950s as a Marxist counterpoint to modernization theory, in that dependency theory highlights the inequalities of the periphery-core dynamic and stresses that for this dynamic to change the periphery must strive to break ties with the core (Singer 1949; Toye and Toye 2003; Deji 2012).

Dependency theory focuses on the macroeconomic level of national and international demands for meeting economic needs and how migrants from various regions interplay with these demands (e.g. wealthy nations continue to gather wealth while poorer nations are exploited for material and human resources, providing cheap resources and labour to the core while contributing to continued underdevelopment and brain drain of the periphery) (Kearney 1986; Brettell 2008, 2015; Deji 2012). Dependency theory sees the exodus of viable labourers from the rural periphery to take on jobs in the urban core that can then help support their home locale (Brettell 2008). Unlike modernization theory in which urban migration is ultimately believed to spur development of the rural periphery, dependency theory assumes that the periphery is used to sustain the core and in the meantime creates a dependency of the periphery on remittances and limited economic gain provided from the core (Kearney 1986; Brettell 2008). While it is believed that emigration from the periphery to better paying jobs and increased opportunity in the core will help the home community, in reality it is often detrimental, as laborers who can fill jobs at home leave resulting in a decrease in production ability at the home location and the imposition of tasks upon individuals who remain in the community, both increasing the burden of labour shortages and decreasing the number of individuals potentially able to fill any given position (Brettell 2008, 2015). With the decrease in production ability and working age residents at the home locale individuals and regions become dependent on emigrants and aid program remittances to sustain their community (Kearney 1986). Though useful as a theory that helps to identify potential instances of exploitation and reasons for migration, dependency theory has largely disappeared as a model of migration, criticized for being difficult to operationalize and for oversimplifying what is a much more complicated issue of economic development and underdevelopment (Kearney 1986; James 1997).

4.2.2.5.3 –Transnationalism

Transnationalism attempts to move beyond binary models of periphery-core by suggesting that the process of migration and related economic structures can be more readily conceptualized in terms of interactions with extended communities and global mobility (Glick Schiller and Caglar 2011; Ross 2013). In this way transnationalism looks at the larger social picture. Connectedness, in a real physical sense, between home and away remains a key aspect of creating larger social fields of interaction between migrants, often referred to as transmigrants, along migration routes, where relationships, communication, and returns of remittances are variously maintained and periodically altered with new migration locations and interactions making home and migration locales one and the same in a larger social field, rather than uniquely separate spheres of interaction (Tilly 1978; Margolis 1995). Ross (2013) identifies this relationship as triadic, in which transmigrants are linked to one another by common social dynamics as well as to their home and migration locales (Glick Schiller et al. 1992).

The development of transnationalism perspectives in migration theory began in the 1990s in opposition to larger models of migration that fit individuals into places and processes rather than seeing individuals as being in flux, as modifiers of social developments in multi-dimensional global space with unbounded, often discontinuous and interpenetrating sub-spaces (i.e. individuals can fulfill more than one social role and space) (Appadurai 1991; Kearney 1995; Rouse 1995; Killgrove 2010a). Within the principles of transnationalism actors modify their surroundings and become players in shaping the realities of the settings in which they reside (Morawska 2003; Glick Schiller and Caglar 2011; Brettell 2015). In this way transnationalism presents a perspective in which the landscape is developed and modified by individuals and community shareholders. Individuals operate in social fields that transgress geographic, political, and cultural borders providing a context through which larger social issues such as diaspora communities and the interaction and integration of diverse groups within society can be investigated (Brah 1996; Vertovec 1997, 1999, 2001; Anthias 1998; Van Hear 2010; Ross 2013). Transnationalism focuses on aspects of the larger global social fabric, providing avenues for novel theorizations of space and place where the inter-connectivity of home and away is stressed rather than made into an arbitrary dichotomy (Basch et al. 1994; Laguerre 1998; Brettell 2015).

4.2.2.5.4–Diaspora Theory

Often discussed in tandem with transnationalism, diaspora theory examines community formation in migration locales among individuals of a common region or heritage who reside outside of their homeland (Butler 2001). Diaspora communities have variably been referred to as exile communities, sojourners, and overseas communities, re-enforcing the nature of these communities as having formed from some type of strife or exodus, of various origins, resulting in migration and community formation in a migration locale often with no opportunity for continued contact or return to the original location of origin (Butler 2001; Ross 2013; Bertz 2015). Unlike transnationalism where the individual remains interconnected between a migration location(s) and a homeland, maintaining ties in both areas and along the route, diaspora theory focusses on the maintenance of a connection to either a theoretical homeland, which may no longer physically exist or may be rooted in an ancient heritage, or to an actual country or region that still exists but from which individuals were made to leave and are unable to return (Armstrong 1976). This conception of diaspora remains the key theoretical framework of investigation, though it is also evident from the diaspora literature that there is no one singular definition that encompasses the entire conceptualization of what “diaspora” is and how it is manifested or should be categorized, lending a wide latitude of usage and interpretation to the term (see Butler 2001; Bentz 2010; Eckardt 2010; Bertz 2015).

Lilley (2004, 2006) discusses diaspora theory as a model for creating and maintaining identity in communities dispersed amongst other people, where one maintains a strong emotional but lack of physical connection to a homeland that one ostensibly wishes to return to but cannot. Braziel and Mannur (2003) contend that transnationalism has more to do with the movement of people and goods in relation to economies and capitalism, whereas diaspora has more to do with the displacement of people regardless of economic or capitalistic factors (Ross 2013). In this way transnationalism and diaspora are superficially different, though it is evident that the two categories need not be mutually exclusive as there is significant potential for overlap (Appadurai 1996; Vertovec 1997, 1999, 2001; Sanjek 2003; Van Hear 2010).

Seeking to move beyond binary models of diaspora, migration theory has turned towards looking at the experience of individuals and sub-groups within diaspora communities. Though individuals in a diaspora community may share a common background they do not necessarily experience the diaspora location in the same way. Integration within a migration location is mitigated by social factors and can result in hierarchies for various reasons, such that highly educated, wealthy, and high status individuals often have a smoother experience of migration, fitting themselves into generally higher social and employment positions, while individuals with less education and lack of initial wealth often have a migration experience of greater precarity (Brah 1996; Anthias 1998; Butler 2001; Cohen 2008; Brighton 2009).

Diaspora theory has historically been largely absent from archaeological inquiries, focusing mainly on African diaspora and more recently Irish and Asian diasporas (Lilley 2004; Ogundiran and Falola 2007; Ross 2013). In 2010 a volume edited by Hella Eckardt appeared on diaspora in the Roman era. The papers in this volume investigate migration within Roman contexts from numerous regions and time periods using epigraphy, burial style, isotopes, aDNA, and skeletal morphology. This volume marks a novel departure within Roman archaeology in that it provides a synthesis of multiple lines of evidence that are not often presented together. However, despite the high caliber of migration research presented in these papers, this volume ultimately falls short of its goal of providing a synthetic investigation of diaspora communities in the Roman era. This criticism is not meant to cast aspersions on the research in this volume, but rather to point out the difficulty of looking at diaspora in the past. Though it is apparent within each paper that mobility was a key factor throughout the Roman era none of the papers truly attempt to develop a diaspora perspective on Roman migration, with perhaps the closest approximations being provided by Webster (2010) and Hingley (2010), nor present compelling evidence of cohesive diaspora communities or evidence to suggest that the individuals who migrated wished to maintain a particular connection with their respective homelands. The paper by Noy (2010) uses the case of Barates of Palmyrene origin and his wife Regina of Catuvellaunian origin to discuss documentary evidence of homelands and migration, though even here it is not clear if this evidence simply points to these individuals wishing to make their heritage known or if they were truly part of a diaspora community, the evidence simply cannot say one way or the other. Further to this point is the issue of identifying specific diaspora communities. Noy (1998, 2000) and Tacoma (2014), looking at evidence for Jewish communities in Rome, both conclude that though there is some basis to suggest settlement clustering of Jewish groups within Trastevere at Rome there is equally evidence of Jewish individuals living and being buried elsewhere in the city, making ambiguous at best any evidence of diaspora. This presents the even more difficult to answer question of "are diaspora communities formed simply by the identification of group clustering or must the clustered group in and of itself identify with a diaspora mentality, and how can this be determined in antiquity?" That Roman migrants identified at a distance from their homeland are in some way part of a diaspora is a difficult argument to support. Conceptions of diaspora in antiquity are often framed in terms of it being impossible for transnationalism to have existed given limitations to keeping in contact with a homeland, yet there is evidence of maintained connectivity in the form of Roman soldiers stationed in Vindolanda sending letters home (Bowman, 1998), as well as evidence of individuals sending money back home (Andreau, 1999), supporting the argument that transnationalism did exist in ancient Roman society. Though this section has been critical of diaspora theory in Roman contexts, it is not meant to discount or discourage investigations of ancient diaspora but rather to re-enforce that evidence of diaspora needs to be compelling and is often difficult to identify.

4.3−Archaeology and Migration: A Brief Overview

Early conceptions of cultural interaction and diffusion in archaeology are commonly associated with the classificatory systems developed by Thomsen (1836) and Montelius (1899, 1903), who employ the *ex oriente lux* theory of cultural diffusion in which ideas and methods of production gradually spread from the East into Europe (Trigger 1997). This premise of cultural diffusion is a hallmark of archaeological inquiry in the first half of the 20th century, being developed upon in the "archaeological type cultures" of Gustaf Kossina (1911) and the works of V. Gordon Childe (1925, 1929, 1950), both of whom provide models for examining migration and diffusion of bounded "cultural groups" from archaeological evidence (Anthony 1990).

Such models of identifying cultural change fall squarely within the cultural-historical model of archaeological paradigms (Trigger 1997; Woolf 2013). Culture-historical models of migration use artefacts and site traits that are believed to be ethnically diagnostic to trace presumed instances of migration (Hakenbeck 2008; Wells 2013). Though these early models of gauging cultural interactions and migration saw significant use, being the main paradigm for explaining cultural change into the 1970s, they ultimately suffered from the assumption that certain archaeological materials (e.g. pottery, house architecture) are inherently indicative of an "ethnic group," overstating the bounded nature of cultural groups and neglecting the potential for the diffusion of ideas but not necessarily people (Anthony 1990; Burmeister 2000; Frachetti 2011; Woolf 2013). This phase of migration research within archaeology sees migration as generally chaotic and poorly understood, often linking cultural change with large scale invasions or waves of mass cultural group migration, a type of migration that is uncommon, as free migration in any given time period and group is most often undertaken by a small and select portion of the population (Vajda 1973-74; Rouse 1986; Anthony 1990; Chapman 1990; Hakenbeck 2008).

Realizing the limitations of a model that is based predominantly on the perception of migration as fairly rapid large-scale influxes of typological migrant groups, migration fell out of favour as an explanatory model of change within archaeological inquiry (Anthony 1990; Härke 1998, 2004). Yet as Clarke (1975) argues, so long as archaeology is concerned with the people who made the items recovered and not just the items themselves it is important to try and contextualize who produced these items.

Methods for examining migration within archaeological contexts changed significantly in the 1970s under the processual paradigm of archaeological inquiry (Anthony 1990, 1992, 1997; Härke 2004). In this period, investigations of migration shifted from identifying archaeological "types" to contextualizing migration through ethnographic and analytical quantitative models (Trigger 1997; Burmeister 2000). It is at this time that the rise of methods such as archaeogenetics and stable isotopes, among other approaches, begin to see use for tracing the potential origins of individuals identified at archaeological sites (Härke 2004; Hakenbeck 2008). These chemical indicators, among other quantitative measures, can be used to identify actual migrants and migration regions, as opposed to previously criticized attempts to infer migrants from artefacts and site types (Härke 2004; Hakenbeck 2008).

Moving beyond purely analytical approaches, more recent attempts at using chemical methods of identifying migration have sought to ground interpretations in larger social theories (e.g. diaspora, transnationalism, etc…), fitting individuals into larger discussions of context and history (Hakenbeck 2008). This era of post-processual modeling seeks to examine migration from multiple angles, moving beyond simple types and points of origin to provide greater problematization of who migrated, why migration was occurring, and how larger social issues of antiquity can be engaged (e.g. Killgrove 2010 a,b; Prowse et al. 2010a; Perry et al. 2011; Woolf 2013).

A criticism of archaeological migration research is a lingering question of the differences between pre- and post-industrial era migration (see Zelinsky 1971; Rouse 1986). The argument is situated in the uncertainty of whether industrial era migration is so drastically different in its nature as to be incomparable to pre-modern migration (Anthony 1990). The answer must be no. With increasing research and evidence from demography, epigraphy, grave goods research, genetics, isotopic methods, and various other fields (e.g. Noy 2000, 2010; Helttula 2007; Prowse et al. 2007, 2010a; Pearce 2008, 2010; Hin 2013) it is clear that though the volume and frequency of migration may have been different, the core concept that migration was a common event of life remains evidently true.

4.4–Ancient Roman Migration

4.4.1–Conceptualizing Migration In the Roman Era

Migration and mobility form an integral part of the development and expansion of the Roman Empire (Scheidel 2001; Hin 2013). Moatti (2006) suggests that instances of migration began to increase during the late Republic and into the Principate era as a result of the generally peaceful nature of the *pax Romana* allowing for easy mobility between regions. Textual accounts of migration by Roman authors note that migration took place throughout Italy and the empire with Rome being the ultimate migration destination, a migration process noted by Tacoma (2014) as involving people of all statuses on a massive scale and being an extremely unruly phenomenon (Hin 2013). Pliny (*Natural History*, 37.201), in attempting to justify the draw of Italy notes the beneficial climes of Italy, being easily reached by many peoples from many regions, its shores abounding with harbours, favourable winds and favourable light (Horden and Purcell 2000). Noy (2000) attempts to provide a degree of contextualization of several general trends of migration to Rome by looking at who was moving where, and from where, based on epigraphic and textual accounts. Noy (2000) notes that there were likely people moving to Rome from all conceivable areas of the empire. The majority of provincial soldiers who died and were commemorated at Rome and, to a lesser degree, civilian immigrants, were from Pannonia (Hungary), Germany, and Thrace (Bulgaria) (Noy 2000). Documented civilian immigrants at Rome commonly came from older provinces such as Gaul, Hispania, Egypt, and Asia Minor (Noy 2000). In later periods, Christian immigrants to Rome came mostly from Greece, Syria, and Palestine (Noy 2000; Killgrove 2010a), showing the multiplicity of known regions from which individuals emigrated.

As for the population of Imperial Rome, this remains highly contested with estimates ranging from 700,000 to 2 million, with a proposed average of just under 1 million between the 1st–3rd c. CE (Huttunen 1974; Frier 2001). The total population of Italy, inclusive of slaves, has been estimated at between 6.2−12.1 million based on the census of 28 BCE (Hin 2013), with estimates approaching 14–16 million during the era of Augustus (ca. 27 BCE−14 CE), and potentially increasing to 20 million by 47 CE, though this drastic increase may be more readily attributed to the granting of citizenship and manumission than to natural mechanisms of increase (Lo Cascio 1994a,b; Scheidel 2007). The total population of Imperial Roman territory is estimated to have risen from ~50 million in the time of Augustus to ~70 million in the era of Marcus Aurelius (ca.

161−180 CE), and possibly even higher depending on the assumed density of settlements and the method of population estimation employed (i.e. high-count) (Scheidel 2007; Garnsey and Saller 2014). For all of these population estimates it is evident that there is no clear consensus as to what the overall population of any given Roman region at any given time was.

Such logical estimates have been derived for the sake of approximation in attempts to be able to investigate further the social and demographic diversity of the Roman Empire (Hin 2013). Killgrove (2013) points out that various treatments of Roman mobility assume that most migration was short-distance and that adults, particularly women, lived their lives in roughly a 30 km. radius of their birth. Though this assumption is arguable, what is clear is that migration was occurring throughout the vast territory of the Roman Empire and that individuals were coming from all regions of Roman territory. Yet actual numerical values of the number of immigrants and the distance of movement to any one particular location in the Roman era are lacking, making qualifications of textual accounts and demographic estimates of mobility challenging (Hin 2013).

Given the presumed preference for migration to Rome, and the necessity of emigrants to Rome to avoid urban graveyard effects (i.e. when deaths outstrip births resulting in negative population growth), a large amount of the Roman migration literature focuses on migration to Rome and surrounding areas (e.g. Ostia), with less, though still significant discussion of migration and mobility in the territories (Moatti 2006; Killgrove 2010a). It is known that migration into Rome and ostensibly Roman territory had restrictions. In terms of settling in Rome, Moatti (2006) notes that there were various stipulations and criteria that immigrants had to meet. Foreign students at Rome required specific paperwork and a time limitation of two years was imposed. Though several accounts have testified to the relatively free nature of movement in the Roman territories (Whittaker 1989) there is evidence to the contrary, testifying that movement was not just heavily regulated at Rome but also, to varying degrees, in and between the outlying territories (Moatti 2006). Both Tacitus and Cassius Dio directly discuss regulations placed on German merchants, while ostraca from the *limes Tripolitanus* further document restrictions placed on movement of certain tribes between Roman territories (Moatti 2006). Though these controls may not have been universally applied to all peoples and may have been specifically targeted at certain “Barbarian” tribes, they nonetheless show that mobility was not entirely fluid and free in the Roman Empire (Moatti 2006). We even see examples of threats of exile to those who aid or harbour individuals illegally entering or residing in Roman territory (Moatti 2006). These restrictions mostly apply to individuals outside of the Empire and non-citizens. Mobility within the Imperial territories by Roman citizens surely would have been easier in terms of freedom of movement (Whittaker 1989; Hin 2013; Tacoma 2014). Here again though, we see that certain limitations and restrictions to migration may have hindered or prevented truly free mobility from the territories. We know from Woolf (1998) and Goudineau (1996) that the ability of individuals from outside of Rome to stand for election to magistracies in Rome was granted only under Augustus and Tiberius in 14 CE, while the liberty of Roman senators to move without permission was only granted in 49 CE, providing evidence that active restrictions on who could move into Rome and control of where Roman citizens could freely move remained a fact into the Imperial era.

Unlike other periods of history where there were large landless classes of individuals, leading to perpetual mobility, Erdkamp (2008) argues that mobility in the Roman era was most often undertaken for work or for the purpose of establishing a new residence, as Roman peasants more often owned land with fewer landless laborers and a generally smaller labor market (Smith 2014a). Roman migration is known to have been socially heterogeneous, not only confined to the lower classes of society emigrating for better livelihoods elsewhere. Rather, Roman migration encompassed elements from all sections of society, both for the purpose of bettering one’s life station and arguably as stakeholders in the Empire (Tacoma 2014). Stakeholders in the sense that countless individuals migrated as part of the expansion of the Roman Empire, settling in newly acquired territories, while others moved to take on administrative or entrepreneurial roles in various regions of the Empire (Goudineau 1996; Sweetman 2011; Woolf 2013). Conversely, it is also well known that a large degree of migration in the Roman era was forced, expelling conquered individuals from their homeland, enslaving others, and moving Roman settlers onto newly acquired lands (Tacoma 2014).

Identifying specific regional groups (i.e. foreigners) in Roman contexts remains a perennial challenge, as it is not typically possible to accurately isolate nonlocal individuals simply from their appearance in death (see discussion below). Aside from this limitation, the problem of identifying nonlocal individuals is further mired by the fact that there is only limited evidence of group clustering. Tacoma (2014) notes that there is no solid evidence of migrant clustering in Rome, both in the ruins and written sources. The closest example of immigrant clustering proposed by Tacoma (2014) is that of the Jews of Travstevere, a neighbourhood in Rome. However, despite the increased concentration of Jewish settlements in this area, the Jews of Trastevere lived among many other groups of people and thus aside from an increased density the identification of Jewish settlement “clustering” is minor if not nearly invisible. It is argued that the degree of occurrence and diverse nature of Roman immigration actively prevented the development of stronger forms of residential segregation (Noy 2000; Tacoma 2014). As Killgrove (2014) points out, physical mobility within the Empire was high and immigration was by no means exclusively unidirectional.

4.4.2–Getting to Rome

The territorial size of Imperial Rome was unparalleled in Europe until after the industrial revolution (Killgrove 2010b). The city of Rome was a key location to which migration occurred and an area for which significant evidence is available (e.g. census data, epigraphy, literary accounts) and for which disproportionately greater amounts of research has been conducted in comparison to other regions of the empire. This is to say that at present it is difficult to gauge the proportions of migration to various regions of Imperial Roman territory given the historic focus of migration research on Rome. It remains uncertain as such if Rome was the main goal of most migrations or if we simply have the greatest amount of information at present about migration to Rome (Noy 2000). In any case it is certain that migration was occurring in various forms and on a significantly large scale in the Imperial Roman era. With the *Pax Romana* and expanding road networks in the Imperial Roman era mobility to distant parts of the empire and beyond became increasingly feasible (Noy 2000; Williams 2001). Yet there remains comparatively little information on how individuals physically moved across the landscape (Horden and Purcell 2000; Noy 2000). The greatest information available relates to movement towards Rome proper (Horden and Purcell 2000), for which Noy (2000) estimates the percentage of free migrants in the 3rd CE at ~5%, with 2% being soldiers and their families and 3% civilian immigrants. These estimates however are derived by Noy (2000) from epigraphic and textual evidence, which has a significant bias in terms of what is preserved, who could afford epitaphs, and what they record, as well as the extent, thoroughness, and accuracy of official recording. Hin (2013) argues that this is the case because Rome in all reality was likely the main migration destination and because, even though migration was occurring throughout the reaches of Roman territory, migration into the provinces is believed to have been comparatively small, though this remains an unsubstantiated assumption at present.

Movement to Rome would have been undertaken either overland or by sea. Sea travel was the fastest and most direct means of travel, given the close proximity of Rome to the coast (Horden and Purcell 2000; Westley and Dix 2006; Gambin 2012). The cost of travel by sea was also relatively cheap and in many cases adult male passengers could work for their passage (André and Baslez 1993; Horden and Purcell 2000; Noy 2000; Gambin 2012). It is unclear if male passengers could work for the passage of an entire family or simply for a single fare, while the literature tacitly implies that women and children would have paid a fare as there are no accounts of similar work-for-fare situations, though it remains possible that this option may also have been available to women and children and is simply not overtly documented in presently available sources.

Gambin (2012) discusses sea route migration in practical terms noting that there is evidence that the various small Mediterranean islands were used both as markers along the route as well as short-term stopovers, where supplies could be re-stocked, respite taken, and protection from storms sought. Though it is well established that these islands were used, the precise routes on which they were incorporated is poorly understood

(Arnaud 2005, 2012). The emigration route to Rome thus likely started through a process of island hopping leading to the Italian peninsula. Noy (2000) notes that it took ~30 days to get to Rome from Egypt, an estimate that one could also cautiously apply to maritime travel of equal distance from other points around the Mediterranean. Sea routes though parsimonious were far from a guarantee of safety. Sea storms, dangerous tides, unexpected reefs and shoals, as well as potential pirate attacks were continual threats to sea going vessels (Gambin 2012).

Having successfully arrived at the Italian peninsula a number of gateway cities were used by emigrants to enter before heading to Rome. The ports of Ostia, Portus, Puetoli, and Brindisi served as initial introductions to life on the Italian peninsula (Noy 2000). Aside from their key role as maritime ports and centres of Roman trade, these coastal cities were also migration hubs and bottlenecks, where travelers going to Rome would have to navigate and negotiate onward passage (Horden and Purcell 2000).

Though this type of migration information is best documented for immigration to Rome it is not unfathomable that a similar process was in place for migration to other points of the empire, wherein potential emigrants would have to decide which route (overland or by sea) they would take, as well as how they would negotiate onward travel once they arrived at the coastal port destination. This process of negotiating passage and taking into account the viability as well as the perception of such processes is a ubiquitous feature of voluntary migrations throughout history (Moatti 2004; Moatti and Kaiser 2007; Constantakopoulou 2007; Malkin et al. 2009; Woolf 1998, 2001, 2013).

4.4.3 – Colonization

With Roman territorial expansion came the establishment of Roman colonies (*coloniae*) and the development of provincial territories (Woolf 2013). Unlike the Greek *apoikia* in which colonies largely formed independent polities, Roman colonization saw the establishment of administratively maintained territories in which Roman settlers and the development of “Roman” infrastructure (e.g. Roman city planning, creation of monuments, etc…) was undertaken, helping to emphasize the “Romanness” of the migration destination and ostensibly to varying degrees facilitate the continuity of settlers lifestyle abroad (Salmon 1969; Osborne 1998; Hurst and Owen 2005; Bispham 2006; Patterson 2006; Hin 2013; Woolf 2013). Though this development of a Roman appearance has been connoted with full integration into the Roman system it remains uncertain if the colonies were fully overseen, as Woolf (2011) points out there was no specific Roman government bureau responsible for overseeing colonial territories, with evidence that numerous territories were incorporated into the Roman empire through a change in name only (Lomas 2016).

To populate newly acquired territories, in part, Rome made use of mass movements of people often settling discharged soldiers and their families, first in Italy and then in the provinces, establishing a Roman presence in conquered regions (Vittinghof 1952; Clarke 1975; Williams 2001; Sweetman 2011). Roman soldiers, under the Empire, typically served for 20 years or more making settlement in a territory in which they served a potential after their discharge given the extent of social integration that one might undergo during an extended residency, though this is not to say that all 20 years would necessarily have been served in the same location (Woolf 2013). Expulsion of conquered groups and incentives for Roman settlers, such as land grants, especially during the wars against the Gauls of North Italy where thousands of families were settled, became a common practice for incorporating new territories (Goudineau 1996; Woolf 2013). There is evidence of mass settlement of conquered tribes in the frontier zones (Woolf 2011). Between the foundation of Narbonne in 118 BCE and the end of Augustus' reign, over 100 provincial communities had Roman colonialist settlers (Woolf 2011). Augustus (27 BCE−14 CE) claimed to have settled more than 300,000 veterans by giving them land or money as reward for military service; Sulla (82−80 BCE) purportedly gave Italian land to ~80,000 soldiers, while Caesar (49−44 BCE) gave land to ~50,000 soldiers (Woolf 2011). It is clear from such estimates that significant Roman civilian settlement was also commonly undertaken in the provinces following territorial expansion (Woolf 2013). Roman citizens were quick to seize new opportunities, moving to newly acquired territories of the Roman empire to expand existing businesses and to undertake entrepreneurial opportunities; we know of Italian potters moving to Gaul, Gauls moving into the Black Forest, and Dalmatians into Dacia to exploit the newly acquired mines, among others who migrated to exploit opportunities in new territories (Dondin-Payre and Raepsart-Charlier 1999; Vallat 2001; Woolf 2013).

Such population movement is important in terms of looking at Roman migration as not only did the development of Roman provincial territories result in the movement of individuals from these regions to Rome or other areas of the Empire, either as slaves or as free migrants, it also resulted in the settlement of individuals from Rome and extant Roman territories into the new region (Woolf 2011, 2013). This type of expansion and settlement resulted in the vast diversity of the Roman Empire, creating situations of significant mobility between various regions (Osborne 1998; Hurst and Owen 2005; Woolf 2013).

4.4.4–Slavery

When looking at migration in the Roman era, slavery has been a perennial difficulty. It is well known that Roman slavery was widespread and undertaken on a large scale, with the slave population of Imperial Rome constituting a significant minority group (Noy 2000; Scheidel 2005; Webster 2005; Tacoma 2014). However, calculating the number of slaves in Imperial Rome relies on demographic inferences derived from Roman censuses and textual accounts that are often difficult to interpret and may not be reliably accurate. What need be stressed here is that the figures derived for the size of the Roman slave population, and presented below, are not confirmable, but rather are estimates relying on numerous factors of calculation (i.e. birth rate, death rate, number of slaves captured in a given campaign, rates of manumission, etc…). Such Roman demographic data have the potential to introduce significant calculation error, resulting in contentious numerical variability between the respective models estimating the size of the Roman slave population and Roman demography in general.

The proportion of the population represented by slaves at Rome has been approximated at ~30%–40%, though other estimates have placed this number lower at ~16.6%–20% during the 1st c. CE (Huttunen 1974; Harris 1980; Noy 2000; Scheidel 2005). The actual number of slaves in the Roman Empire however, is difficult to approximate. There is consensus that the number was high, most likely over 1 million (Hin 2013). Scheidel (1997) suggests 6 million slaves in a population of 60 million on the eve of the Antonine plague (ca. 165–180 CE), with estimates for Roman Italy ranging from 2–4 million (Scheidel 2005), to 1.2–3 million in the Augustan era, with ~10% for the provinces, based on an extrapolation from Egyptian slaves (Harris 1999; Scheidel 1997; Killgrove 2010a; Webster 2005, 2008, 2010). Yet in terms of quantifying where individuals came from or tracking where they ultimately came to reside and were interred after death is much more complicated if not all but impossible (Noy 2000).

We know that slaves came from all points across the Empire, as well as from warfare and piracy, forming a very heterogeneous group comprised of men, women, and in various instances (e.g. foundlings) children (Harris 1980, 1999; Noy 2000; Killgrove 2010a). Where these slaves came from and in what proportion remains difficult to ascertain. There are various textual accounts of slaves coming from Cappadocia and Phrygia (Harris 1980). Yet as with so many texts, these accounts more often provide general and assumed details and are less concerned with the quantitative particulars of where slaves were actually coming from (Harris 1980). Two of the Punic wars (ca. 264 BCE–146 BCE) alone provided Rome with 75,000 slaves from North Africa (Bradley 1994). The earliest non-Italian slaves were likely from Gaul and Hispania, while slaves from Germany, Dalmatia, Pannonia, and Thrace began to arrive at Rome in large numbers in the early 1st c. CE (Killgrove 2010a). It is estimated that ~500,000 new slaves were required by the Roman Empire each year for the period between 50 BCE and 150 CE, while there were likely ~1.5 million slaves living on the Italian peninsula at the height of Rome (Scheidel 2005; Killgrove 2010a). Scheidel (2005) estimates that 300,000–450,000 slaves were present at any given time in the city of Rome, with an approximated 300,000 in other major Italian cities such as Pompeii, while ~600,000 additional slaves were involved in agriculture in rural regions of Italy (Scheidel 2005). Harris (1980, 1999) contends that most Roman writers believed the slaves they encountered, apart from *vernae* (the offspring of slaves), arrived at Rome from the provinces and not from outside the empire, suggesting a robust internal supply of slaves (Scheidel 2004, 2005; Woolf

2013). This point is made further by Harris (1999) who suggests that slaves would have to be constantly imported to satisfy Roman demands as it would not be possible to sustain the required number of slaves through the birth of *vernae* alone.

How then were slaves acquired? Harris (1999) proposes five possible routes: 1) children born to slave mothers (*vernae*), 2) persons enslaved in provincial or frontier wars, 3) persons imported across the frontiers, 4) the 'self-enslaved,' a form of Roman slavery in which individuals could self-enslave themselves for a period of time, typically due to financial hardship, and 5) abandoned infants (i.e. foundlings). It is also likely that the major sources of slaves changed over time, with increasing territory and respective depletion of older sources, thus it is expected that a multiplicity of regions would be represented in any slave holdings, of which Roman society had notoriously many (Woolf 2013).

What one must take away from this discussion of slavery is that slaves represent a significant unknown in Roman society. It is clear that there were many slaves in the Empire, but as to how these individuals can be identified in death remains challenging. Many slaves were manumitted, with some estimates placing manumission as low as six years after enslavement (Harris 1980, 1999). Among manumitted slaves it was common to remain in the location of enslavement, typically Rome, rather than return to an original homeland (Noy 2000). In freedom many former slaves may not choose to have an epitaph commemorating their former enslavement (Noy 2000, 2010). In this way it is possible that countless slaves have been unknowingly recovered from cemetery excavations and their former enslavement unknown.

4.5–Identifying Migrants in Ancient Rome

The question of "how do we conceptualize and identify migrants" in ancient Rome has lead to various avenues of inquiry (Horden in Purcell 2000: 382). The abundant amount of textual and archaeological evidence from Roman contexts has provided multiple lenses through which ancient population movements and interactions can be conceptualized. However, Rome is also an enigma in that it is difficult to speak of any one "Rome" as a whole unit (Ball 2000). 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. It has been suggested that in the Roman Imperial period ~40% of adult Italian males over age 45 would have dwelt in a place different to their birthplace (Pearce 2010). Hadji and Souvatzi (2014) argue that hyper-specialization in Mediterranean scholarship has resulted in insulated approaches that lack cross-disciplinary openness. It is in this sense that the methods used for identifying migrants in the Roman era have been problematized, as disparate methods used to gauge "foreignness" in ancient Rome have often lead to differing results that until recently have stood almost independently of one another (See Eckardt et al. 2010; Killgrove and Montgomery 2016).

4.5.1–Epigraphy and Literary Sources

Epigraphy, especially epitaphs, and literary sources remain a key source of evidence by which foreigners can be identified in Roman contexts (Huttunen 1974; Noy 2000, 2010). Yet this method is not without controversy, as historically epitaphs have been disassociated from the interred remains of the individuals they commemorate, and a large number of inscriptions have simply been lost to time (Morris 1992; Prowse et al. 2010a; Alston 2014). There is also the concern of accuracy and intention of what is recorded and who is commemorated, a difficulty that Ball (2000) likens to believing what you see on television, in that textual evidence must be treated with due caution as it is not always free of bias. By its nature epigraphy can only address materials that have been preserved and the select aspects of society that were commemorated on those materials (Alston 2014). An argument has been made that the farther afield from Rome one looks for epigraphic data the less there appears to be, suggesting that the epigraphic tradition may not have fully dispersed throughout all of Roman territory (Pearce 2010). Huttunen (1974) argues for a ratio of 66:1 for the number of residents of Imperial Rome compared to the number of epitaphs identified as of 1974, a ratio which has not likely decreased significantly since that time, posing a disparity that further challenges the use of epigraphic materials for generalized inferences about Roman populations.

Using epigraphy to identify “foreigners” relies on the recording of either specific geographical locations or regionally specific names/cultural elements (Salomies 2002; Helttula 2007; Bruun 2010). Regionally specific names can help identify potential cases of migration and social position, though caution is needed as regionally specific names do not necessarily imply foreign origins, but may simply be ancestral or family names (Maier 1953–1954; Salomies 2002; Noy 2010). There is also occasionally indirect epigraphic evidence of non-local individuals, such as the worship of foreign deities (Hin 2013). Woolf (2013) discusses evidence of the storm gods of Syrian cities (e.g. Doliche and Heliopolis) being worshipped along the Danube and Rhine frontiers, which may suggest non-local soldiers being stationed in this region (see also Fulford 2010).

Epigraphic evidence of migration remains the most likely in burial epitaphs, where individuals may choose to commemorate their place of origin (Huttunen 1974; Morris 1992; Noy 2000, 2010; Benelli 2001). It is only rarely, such as in the case presented by Noy (2010) on Barates of Palmyrene origin and his wife Regina of Catuvellaunian origin, that explicit geographic details are provided in epitaphs. It is also possible that there was a degree of stigma against certain homelands, in which case they may not have been obviously commemorated, such as Egypt. Egypt was a key source of Roman slaves, yet is notably unattested in extant epigraphic materials, suggesting social factors may have been at play in which geographic regions were recorded in epigraphic commemorations (Noy 2000). Noy (2010) argues that the lack of evidence for specific regional origins, particularly for second generation immigrants, may tie into the belief that individuals, at least those commemorated, would have been incentivized and benefited from adopting “Roman identities.”

Specific geographic recording in epitaphs is most common among soldiers (Noy 2000, 2010; Wierschowski 2001; Woolf 2013). Noy (2010) suggests that soldiers most often provided geographic locations in their epitaphs as soldiers who die while at a foreign post likely never truly intended to migrate there, thus the connection with a home region was never lost. While, arguably, voluntary emigrants over time may come to feel a closer connection with their adopted homelands and as a result often do not explicitly commemorate a birthplace (Noy 2000, 2010; Killgrove 2010a,b). In rare instances epigraphic material 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. However, not all individuals chose to or were financially able to provide epitaphs, and among those who could, many simply chose not to mention specific geographical origins or involvement with labor-related mobility (Noy 2000, 2010).

Epigraphy is also faced with the fact that males are disproportionately represented over females and there is a distinct lack of epigraphic evidence for family migration (Noy 2000). At Rome there are almost no freeborn female immigrants recorded (Noy 2000). From a study of pagan inscriptions Noy (2000) identified 76.7% of epigraphs as documenting males, whereas only 21.0% document females. Epigraphic evidence from Imperial Rome also rarely documents lower class individuals or slaves, all of whom made up a large percentage of immigrants (Killgrove 2010b).

Literary sources can also provide insights into potential instances of migration. Though there are multifold literary sources recording various aspects of Roman life these sources commonly lack in practical details that can be used to investigate instances of migration. Literary sources are often distinctly biased, written with a motive either embracing the merits of migration, recording prestigious and “exotic” foreigners, or vilifying various foreign groups (Noy 2000; Vallat 2001; Woolf 2013). Other than noting that foreign individuals were present in one region or the other literary sources are surprisingly sparse in terms of the numbers of individuals migrating, the accuracy of migrant origins, the duration and nature of migration, as well as accounts of integration into the community (Clarke 1975; Noy 2000). It can be very difficult to gauge the honesty, let alone accuracy, of Roman literary sources, particularly given the preponderance of accounts by Roman elites and their associated elitist views (Noy 2000; Vallat 2001; Hin 2013). It is also extremely difficult to find any information regarding more mundane migrations (e.g. related to work), even though it is clear from documents related to regulating trade that trade-related migration was ubiquitous (Woolf 2013).

With all of these difficulties addressed it is not my intention to claim that there is no value in textual sources. Rather it is important to know what can and cannot be gleaned from epigraphic and literary accounts and to be aware of biases. Though there are limitations, there are also benefits to epigraphy. When recorded, epigraphic accounts can provide evidence of migration from specific regions (Morris 1992; Noy 2010). Epigraphy is also useful for gaining greater insight to the socio-legal status of individuals, be they slave, ex-slave, free born, peregrinus/peregrina, single name, duo/tria nomen and cognomen, or unknown (Huttunen 1974; Noy 2000). Epigraphic and literary evidence remain most useful when looking at macroscopic trends and when employed in tandem with other methods for looking at population diversity. As Purcell (2005) contends, despite the invaluable insights of the epigraphic and literary material, it is ultimately the archaeological record that makes explanatory overviews of economic and social questions possible.

4.5.2–Burial Practices

The analysis of burial style and associated grave goods has been a long-standing method for examining possible instances of foreignness and migration in archaeological contexts (Saxe 1970; Morris 1992). Variability in the orientation of the grave, style of burial (e.g. cremations vs. inhumation), the type and variety of grave goods interred with an individual, and the position of the body within the burial are all indicators that are used to infer interment patterns of various “cultural” groups within a given context (Fontana 2001; Sprague 2005; Pearce 2010; Wells 2013). Burial practices help to supplement the limited evidence that can be gathered for migration from epigraphic and textual accounts. However, as Pearce (2010) intimates, caution is needed so as not to impose a culture-historical view of burial practices, wherein method of burial and accompanying grave goods are equated directly with specific “people.”

A number of difficulties in interpretation have arisen from this approach to identifying migrants in archaeological contexts. Part of the difficulty of identifying instances of migration through burial practices is partly empirical. Looking at Roman contexts, our knowledge of burial practices and their variation over time and space is uneven and limited (Pearce 2010). Within ancient Roman contexts there is clear evidence of various transitions in burial preference between cremation and inhumation over time (Morris 1992; Killgrove 2013). Cremation was the norm at Rome until the early 2nd c. CE, after which time inhumation began to dominate, though instances of both burial practices persist to varying degrees during the respective periods of cremation and inhumation popularity, not to mention different timeframes of burial type preference and retention in the wide ranging regions of the empire, further showing the difficulty of inferring affiliation based on burial type alone (Noy 1998, 2000). Another problem that is encountered with this approach to gauging migration is that the majority of cemeteries that have been excavated have come from urban, commonly upper class, contexts (Pearce 2010). As a result, insights gathered from such contexts may neglect to take into account burial style variation in rural regions and among specific elements of society (e.g. the military, slaves), while also providing data that may not be suitable to use for interpreting variable burial styles in different regions of the same cultural group (Pearce 2010).

The use of burial data to gauge the presence of non-local individuals is further complicated by instances of cultural integration. Many individuals who migrate over time take on various cultural traits of the migration locale (Benelli 2001; Brettell 2015). This acculturation can be both voluntary and ascribed both during life and in death, where larger social structures may be at play in how burial and commemoration is undertaken (Saxe 1970; Parker Pearson 1999; Pearce 2010). Noy (2000) contends that there is very little evidence that groups with a common geographical origin ever established their own separate burial areas at Rome, which is further supported by the fact that other than Jewish and Christian catacombs, there are to date no known burial grounds reserved for “foreigners” in antiquity 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). Even in the presence of potentially regionally unique grave goods, which may only be affordable to certain social echelons, and burial style, there is still no guarantee from this evidence alone that an individual was from any given region. This point is well illustrated in the work of Prowse et al. (2010a) whose isotopic investigation of individuals at the Imperial cemetery of Vagnari identified a number of individuals who were in fact foreign born and had migrated to the region, yet were buried in the same fashion as isotopically local individuals, suggesting cultural integration, even if only in death. Conversely, Cool (2010) notes that at Winchester Lankhills several females who appear "foreign" based on grave goods, in this case bracelets, actually have a local isotopic signature.

4.5.3–Bioarchaeological Methods

Bioarchaeological methods for identifying non-local individuals rely on a number of methodologies ranging from metric and nonmetric traits to isotopes and aDNA.

4.5.3.1–Nonmetric and Metric Traits

Nonmetric and metric trait analyses, as discussed in Chapter 3, have been widely used to distinguish potential groups based on variability in metric traits of the skeleton (e.g. long bone length, cranial dimensions, etc…), and nonmetric traits (e.g. metopism). These approaches provide a method by which variation in skeletal traits can be used to assess the presence of various biological groups within a skeletal sample from which instances of migration may potentially be inferred (Pietrusewsky 2008; Saunders and Rainey 2008). Metric and nonmetric trait analyses are excellent for the degree of repeatability of the methods (Pietrusewsky 2008; Saunders and Rainey 2008). However, nonmetric and metric traits are most useful for identifying groups rather than individuals. Thus assessments of local vs. non-local are at the group level and may not indicate migration but rather group heterogeneity, removing a degree of information about individuals and potential migration.

4.5.3.2–Isotopes

Isotopic approaches to palaeomigration, as discussed in Chapter 2, can help to provide greater insight to individual instances of migration. As individuals retain a chemical signature of their place of birth (enamel) and long term residence (bone) it is possible to look at where individuals were born compared to where they lived prior to death (Katzenberg 2008). This method provides rich insights into who migrated and at what relative life stage, allowing for questions of sex and age of migrants to be addressed in greater depth (Killgrove 2010b). Harbeck et al. (2011) present evidence that isotopic signatures of the light stable isotopes (e.g. C, N, O) preserve to ~300°C, while strontium is resistant to heat degradation up to ~1000°C, allowing for inhumation and cremation burials to be isotopically investigated (Montgomery 2002; Schurr et al. 2008; Schmidt 2008; Harvig et al. 2014).

Isotopic insights are limited by the difficulty of gauging multiple migrations. If an individual was involved in short term migration or moved to multiple locations over his lifetime, it is much harder to identify these migrations. Provided an individual resided in one location long enough to take on the local signature during dental development it is possible to examine for multiple migrations by using skeletal elements that form at different times (e.g. M1 vs. M2 vs. M3 vs. bone) (Prowse et al. 2007; Stojanowski and Knudson 2014). Isotopic values can also be challenging as the signals recovered may not be regionally unique, as signals are compared to compiled regional data in which regions with similar signals may occur necessitating that a parsimonious "best fit" model be used (Eckardt et al. 2010).

Despite these potential limitations, isotopic research provides significant individualized insights to regional origins and migration in antiquity, helping to both support and contradict other methods of identifying nonlocal individuals. Prowse et al. (2007) using oxygen isotopes to look at Imperial Roman migration to Portus, and Schweissing and Grupe (2003) looking at Late Roman migration in southern Germany using strontium isotopes, identify ~30% of individuals examined as nonlocal, a figure that fits well with demographic estimates of Roman migration (Scheidel 2004; Eckardt et al. 2010; De Ligt 2012; Hin 2013). Prowse et al. (2007) and Schweissing and Grupe (2003) also identify women and child immigrants to the respective sites examined, an occurrence that is difficult to accurately ascertain from the textual evidence alone (Rowland 1976; Birely 1979; Wierschowski 1995; Noy 2000; Killgrove 2010b; Hin 2013). Such findings provide increasing strength of argument for the continued use of isotopic methods for gauging the mobility of individuals.

4.5.3.3–Ancient DNA (aDNA)

Ancient DNA (aDNA) research is increasingly used for investigations of ancestry and population diversity (Stone 2008). Where isotopes provide information about which regions individuals may have migrated from, aDNA can provide information about the ancestry of individuals (Stone 2008). Prowse et al. (2010a) use aDNA to examine a number of individuals from the Imperial Roman site of Vagnari. As discussed previously, individuals from this site appear similar based on burial style despite some individuals being isotopically nonlocal. Not only were several individuals isotopically nonlocal, aDNA examination shows that several of the individuals interred at Vagnari exhibit nonlocal haplotypes, including a male of sub-Saharan African (haplogroup L) ancestry and a female of east Asian (haplogroup D) ancestry. Ottoni et al. (2011) examining skeletal remains from the 11th–13th c. CE site of Sagalassos in south-central Turkey show through aDNA analyses the primary ancestry of individuals from this site as being of Anatolian and Balkan heritage, with close associations to various other regions including Iran, Crimea, the Levant, and Southern Italy. Such findings further enrich earlier archaeologically derived arguments about the ancestry of inhabitants of this region and the role of Anatolia as a bridge between European and Asian groups. The use of aDNA can, however, be challenging as aDNA can be difficult to extract and suffers from degradation along with issues of contamination and the prohibitive costs of analysis (Stone 2008). Using aDNA also does not clarify if the individuals are recent migrants to a region or simply of a specific ancestry. The use of aDNA can help to provide increasingly individualized insights to the ancestry of past populations, which has the capacity to contribute to inferences about migration and regional population interactions at a given site.

4.6–Romanization

Having dealt with theoretical issues of gauging migration and Roman contexts of migration the final section of this chapter turns to the concept of Romanization. The notion of Romanization has broad implications for the ways in which social diversity and the expansion of Roman territory and associated culture is perceived and conceptualized in the Roman literature.

Romanization is concerned with the imposition of Roman culture onto conquered groups, not the simple inclusion of territories under Roman administration (Saddington 1991; Woolf 1998; Haeussler 2013). Beyond this broad generalization when one attempts to look at the specifics of how Rome changed culture and how this "Roman" culture was imposed on its subjects the notion of Romanization quickly becomes cloudy, becoming more of a buzz word or word magic as Purcell (2005) describes it, where fascination with the implications of a particular term impedes accurate analysis. The concept of Romanization is one of acculturation, where the residents of conquered territories have Roman culture imposed on them, not a two way process of cultural negotiation (i.e. hybridity, creolization) (Webster 2001; Wallace-Hadrill 2008; Haeussler 2013). This is the nature of the Romanization debate. We know that Rome existed and that it had cultural traits. We know that other cultures in various regions existed and had cultural traits, and we know that at some point Rome and many of these other cultures interacted. Yet we cannot say with any certainty the degree to which Rome as a conquering political force was able to impose a uniform "Romanness" onto its new subjects (Moatti 2006; Haeussler 2013). Romanization then becomes an ambiguous concept used to refer to complex phenomena that involve different structures in transition within a society, making clear distinctions of what is Roman versus non-Roman challenging (Benelli 2001; Hingley 2005; Van Dommelen and Terrenato 2007; Haeussler 2013; Smith 2014b). Naerebout (2014) goes so far as to argue that Romanization is a myth.

Vallat (2001) makes the pithy observation that genocide, witches and stakes, but also marriages, mixed children, food, and dressing tastes, weave relationships between the conquerors and the conquered. Outside of imposed macroscopic systems (e.g. taxes, governance) it is the later part of this sentence by Vallat (2001) that seems to be the most true of any possible instances of Romanization, in that if any such entity as Romanization exists, it is in the willful integration of Roman and non-Roman groups along with the elective adoption of Roman traits by local individuals, both those moving to Rome and in locations of Roman conquest (Goudineau 1996; Woolf 1998). For one can be nominally Romanized against their will in that they have come to live in Roman territory, or lived in a territory that eventually became Roman, but true Romanization relies on integration of cultural traits and practices (Saddington 1991). This process can be undertaken for various reasons. In many cases the marriage of settlers as well as soldiers stationed in the provinces to local individuals may have facilitated the development of Roman cultural practices in their households (Woolf 1998; Noy 2000; Vallat 2001). It has been argued that Roman cultural traits were often adopted as a coping and social advancement mechanism (Goudineau 1996; Woolf 1998). Adoption of Roman traits by provincial elites to better their standing within the Roman hierarchy, as well as to advance their social standings by allowing for greater acquisition of wealth and potential advancement in the Roman government have been put forth, an argument that gains even more strength following the granting of Roman citizenship to all free residents of the Empire by the edict of Caracalla in 212 CE (MacKendrick 1971; Goudineau 1996; Woolf 1998; Woolf 2000; Moatti 2006; Killgrove 2010a; Alston 2014). Woolf (1998) argues that little would have changed in the provinces after conquest. New towns were developed and various existing towns altered to have a more Roman architectural appeal, thus Romanizing the landscape and enticing Roman settlers (Woolf 2000; Hin 2013), but beyond these basic points actual personal life likely changed very little. People would still pay taxes, just to a new government, and rebellions would occasionally have to be quelled, but as far as the imposition of being Roman in daily life was concerned, there was likely little change. The majority of people would have still eaten what they ate before, would still wear the same clothes, and undertake the same daily tasks, being Romanized in name only (Terrenato 2005; Tacoma 2014). In this way Tacoma (2014) argues that simply attending the games (*ludi*) or witnessing the cultic rituals of Rome did not necessarily make one Roman, rather it was the daily encounters, the language of choice, cultural identity, dietary preferences, the *habitus* of being that more readily defines cultural affiliation (Bordieu 1977). Ball (2000) compounds this sentiment further by calling in to question what “Roman” is, noting that Rome is as much eastern as it is western, as much oriental as it is occidental, making it very hard to gauge how “Roman” migrants became as the definition of “Romanness” itself is inherently slippery.

This then is the problem that studies of Roman history and culture are faced with. Romanization has remained a key concept in one form or another in terms of looking at Roman expansion since the time of Haverfield (1905–1906, 1923). Scholars have wanted to trace the route by which “civilization was given to the barbarians,” the process by which the benefits of Rome were given to their lesser provincial populations (Saddington 1991; Webster 2001). The creeping determinism of Romanization has persisted for decades as an almost monolithic view of cultural interaction in the Roman era (Florovsky 1969; Sweetman 2007). The Romanization model looks at newly included territories of Roman expansion through Roman eyes, rather than seeking to look both from Roman and local views (Keay and Terrenato 2001; Terrenato 2005; Sweetman 2007; Naerebout 2014). Only relatively recently has the notion of Romaniziation been thoroughly challenged as a comparatively poor model for looking at cultural interaction, though Romanization to this day remains a highly pervasive concept that all discussions of Roman cultural expansion must seemingly address in some way.

With the general eschewing of Romanization in more recent writings on Roman culture and society, voices of other groups and consideration of social strategies in situations of conquest have come to the fore. Rather than taking a Roman-lens perspective many scholars have sought to look at how signs of Roman cultural introduction have been integrated, altered, and avoided by regional communities giving way to concepts of hybridity, mimicry, and creolization among others (Webster 2001; Bhabha 2004; Sweetman 2007; Van Dommelen and Terrenato 2007). This transition is important not only for considering how Roman culture was encountered by territorial groups but also for how mobile individuals encountered and adopted Roman cultural traits in their new environments.

The concept of mimicry is of significance to this discussion of migration (Bhabha 2004). Where creolization and hybridity (Webster 2001; Sweetman 2007; Van Dommelen and Terrenato 2007) have made significant advances in looking at how the interaction of Roman and local cultures has resulted in varied forms of cultural identity as well as the formation of new cultural identifiers on a macro-scale that blend aspects of both Roman and other cultural practices to give rise to novel cultural groups and signifiers (e.g. Gallo-Roman), mimicry provides a theoretical tool for looking at socio-cultural issues at the level of the individual.

Mimicry is a theoretical construct that seeks to look at the dualistic nature of identity, best seen in situations in which an individual or group of individuals of a given cultural affiliation live in a region of differing culture (Bhabha 2004). We see in these scenarios attempts at integration both formal (e.g. naturalization) and informal (e.g. learning a local language), at the migration location as well as strong preservation of connections to one’s own culture. It is at this junction that mimicry is situated. Mimicry is a sign of double articulation, in that for practical or personal reasons individuals choose to adopt elements of the culture in which they find themself living while also maintaining their original cultural identify (Bhabha 2004). This process can be undertaken for countless reasons and may be self-serving or may be for preservation and safety. Many immigrants may be forced or may elect to take on dominant cultural norms, while not necessarily ascribing their identity through such norms. Individuals may also take on attributes of the dominant culture so as to make friends or connections in the new setting. This can serve both practical and emotional roles, helping to provide for employment and advancement in the new setting as well as social support and avoidance of isolation (Woolf 2000; Bhabha 2004; Leonini and Rebughini 2012).

At the same time many immigrants maintain a link to the cultural practices of their respective homelands in some way. Earlier in this chapter so called “Chinatowns” were discussed (Tilly 1978; Sanjek 2003). The formation of such culturally distinct locations has a large role in the maintenance of cultural identities among immigrants as well as a perception of safety of the immigration location (Appadurai 1996; Sager 2008). This type of community development also touches upon the concepts of creolization and hybridity (Van Dommelen and Terrenato 2007). In these neighbourhoods of specific cultural groups individuals and communities are able to negotiate their position within the dominant culture of an area to which they have immigrated (Appadurai 1996). In this way new cultural identities develop. Variations of both cultures begin to be embodied in a new form (e.g. Tex-Mex food), while also having individuals who seek to maintain their identity through traditional cultural signifiers (Leonini and Rebughini 2012).

Yet such cultural modification and development is not always possible. In many instances the mimesis of cultural norms is for preservation. Bhabha (2004) discusses mimesis in terms of ambivalence. Individuals take on attributes of the dominant local culture to allow for survival and to be tolerated while more silently and personally maintaining ties to their "true" culture. Not all individuals who migrate wish to leave their home cultures, as is the case with many diaspora communities. Often as not individuals leave to find a better job or to avoid difficulties in a homeland (e.g. war) (De Haas 2008; Hin 2013; Brettell 2015). In this way mimesis provides an avenue for immigrants to any location to negotiate their position within the local culture while not disavowing their own cultural identity (Barth 1969; Bhabha 2004; Wimmer 2008).

These concepts, though perhaps seemingly tangential to the present discussion of identifying foreigners in Roman contexts, lay at the heart of debates about what it meant to be Roman and to be Romanized (King 2001; Webster 2001; Bhabha 2004). It is clear from the literature that what it meant to be Roman is a highly debatable question with multifold ways in which one may or may not be classified as "Roman." We see here the difficulty of both quantifying and qualifying culture. It is for this precise lack of certainty that scholars have largely turned away from categorizing certain sites or peoples as having been Romanized and have sought to look at the finer details of mixed representations in cultural elements as well as concrete evidence of from where geographically people were coming into Roman territorial holdings. As Appadurrai (1996) notes, stressing the dimensionality of culture rather than its substantiality permits our thinking of culture less as a property of individuals and groups and more as a heuristic device that we can use to talk about difference.

4.7–Summary

This chapter has examined the nature of human mobility and migration. Theoretical and practical considerations of the nature of human mobility, why people may or may not chose to migrate, as well as a number of practicalities and reasons behind migration have been considered in this chapter to provide context to the nature of this temporally and geographically ubiquitous human phenomenon. Moving from theoretical and practical considerations this chapter has looked at methods by which migration can be gauged in antiquity (e.g. isotopes, aDNA, NMTs, epigraphy, burials goods, etc…) and how these methods have and may in the future be combined to provide increasingly complex and nuanced insights to mobility in the past. Following these sections this chapter concludes with a discussion of mobility in the Imperial Roman era, both in terms of from where and to where, as well as how, and potentially why individuals were moving, and ultimately what it meant to be Roman and a part of Roman society at large.

Discussion of these topics has provided a theoretical and practical basis for the research presented in this dissertation on Imperial Roman migration, allowing a point of union between the data results from isotopic ($\delta^{18}O$, $^{87}Sr/^{86}Sr$) and nonmetric trait (NMT) research presented with broader theoretical models from anthropology, political theory, sociology, and geography, among other fields. This dissertation adopts a decidedly transnationalist perspective on mobility in Imperial Rome. Transnationalism as a migration model, in my opinion, is the most fully encompassing of human mobility, accounting for individual action and group heterogeneity without the imposition of larger rigid state models and macroeconomic actors that inhabit the theories of modernization and dependency theory. Transnationalism also provides for a similar contextualization of migration to diaspora theory while not restricting the scope of inquiry to diaspora communities, allowing for broader discussions of mobility events, identity, and group formation.

Chapter 5–Materials and Methods

5.1–Background to Sites Examined

5.1.1–Velia

5.1.1.1–Background to Velia

Velia lies on a promontory in the Cilento of Lucania, on the Tyrrhenian coast of Southern Italy between Cape Palinurus and Posidonia (Paestum) ~400 km south of Rome and ~100 km south of Naples (Figure 5.1) (Richardson 1976; Craig et al. 2009). The settlement of Velia is situated between the mouths of the rivers Alento to the North and Fiumarella to the South (Pellegrino 1957; Craig et al. 2009). Moving inland the area of Velia is encompassed by hilly countryside before transitioning into mountainous terrain with the peaks of Monte Stella (1300 m) to the north and Monte Gelbison (1706 m) to the south-east (Schmeidt 1970; Bencivenga Trillmich 1990; Craig et al. 2009; Crowe et al. 2010).

Figure 5.1–Locations of Velia, Isola Sacra (SCR), and Rue Jacques Brel necropolis (JBR) (Map image generated using Google Earth).

Velia was originally founded in ~540 BCE as a colony known as Hyele, referred to as Elea beginning in the 4th c. BCE, by Phocaeans fleeing Persian invasions in their homeland of Asia minor (Pellegrino 1957; Musti 1966; Cerchiai 2004; Mele 2006; Nenci and Vallet 2012). Following a productive Phocaean occupation, which saw construction focused in the area of the acropolis on a hilltop promontory 200 m asl, Elea was incorporated into Roman territory in the 3rd c. BCE at which time the site came to be referred to as Velia, seeing increased building in the southern quarter of the site and the development of the necropolis (Richardson 1976; Crowe et al. 2010; Ermolli et al. 2013). To date the majority of archaeological research at Velia has been conducted in the area of the Phocaean acropolis (Richardson 1976; Krinzinger and Tocco Sciarelli 1997).

Velia is often remembered as being a spa town where the likes of Cicero bathed, as well as being home to the philosopher Paramenides (ca. 5th c BCE) and a medical school (Nutton 1970; Richardson L. 1976; Fabbri and Trotta 1989; Bondioli and Sperduti 2011; Sperduti et al. 2012). Aside from these illustrious links, Roman Velia was a working town. The unencumbered hinterland at Velia provided the opportunity for the development of agriculture and arboriculture, with 80 hectares within the city walls permanently under cultivation (Pellegrino 1957; Greco 1979; Greco and Schnapp 1983, 1986; Craig et al. 2009). Velia had a plentiful supply of water given its riverine surroundings and was a minor though key maritime port south of Naples on the Tyrrhenian coast (Greco and Schnapp 1986; Greco 1999; Morel 1999; Mele 2006; Craig et al. 2009; Sperduti et al. 2012). Ramage (1868) notes that there were two ports at Velia, one close to the foot of the mountain, known as Lago di Castello, about a quarter mile from the sea, and the other called Porticello, at the mouth of the river, though the actual location of the port remains hypothetical (Krinzinger and Tocco Sciarelli 1997). With this port came associated industries and trades, including fishing and fish processing, ship construction, and ship repair (Craig et al. 2009; Sperduti et al. 2012).

Velia thrived into the Middle Ages eventually coming under Episcopal control (Pellegrino 1957; Craig et al. 2009). The decline and ultimate abandonment of the settlement at Velia is believed to have occurred due to increased marsh formation along the rivers inhibiting the use of the site as a port, with the account of Nicolò Carletti, who visited Velia in 1794, noting that the ports were unobservable (Vecchio 2007).

5.1.1.2–Excavations at Velia

Numerous accounts of the ruins at Velia are provided by early travelers in the region, with ostensibly the first modern account being that of Carletti in 1794 (Vecchio 2007). Ramage (1868) is of particular interest here as he provides an extended discussion of his encounters with “local excavators” who show him the ruins of the Roman necropolis.

Schleuning (1889) provides an early archaeological assessment of Velia, but it is not until 1927 that limited excavations at Velia began under the direction of Amedeo Maiuri, Superintendent of Campania (Vecchio 2007). Extensive excavation of the site began in the 1960s with the research of Mario Napoli (Vecchio 2007). Napoli’s research focused on excavating the Phocaean acropolis, identifying a number of buildings and rooms dating to the 6th–5th c. BCE along the southern slope (Napoli 1972; Krinzinger and Tocco Sciarelli 1997). During the period from 1969–1978 a systematic survey of the ruins of the Phocaean colony was undertaken by German and Austrian archaeological missions, with further research conducted by an Austrian mission throughout the 1990s once again focusing on the ruins of the acropolis (Fiammenghi, 1994; Krinzinger and Tocco Sciarelli 1997).

Turning to the Roman remains at Velia, significantly less is known. Research into the Roman occupation of Velia has largely focused on the area of the Porta Marina Sud, in the southern section of the site (Krinzinger and Tocco Sciarelli 1997; Fiammenghi 2003; Fiammenghi and La Torre 2005). In this area the ruins of several houses as well as a building with a cryptoporticus and numerous statues and inscriptions have been identified (Krinzinger and Tocco Sciarelli 1997). A series of buildings dating to the early Imperial era associated with the Roman necropolis were identified on either side of the road coming out of the Porta Marina Sud (Fiammenghi 2003). The Porta Marina Sud area is of key importance to the present discussion as it is here that the remains of the Roman necropolis dating to the 1st to 2nd c. CE were identified along what Fiammenghi and La

Torre (2005) refer to as a “street of burials” (Figure 5.2) in proximity to the coast (Craig et al. 2009).

5.1.1.3–The Roman Necropolis of Velia

Though early references to the presence of a Roman necropolis exist (see Ramage 1868; Napoli 1972), the Roman necropolis at Velia was not systematically investigated until the time of Fiammenghi (2003), whose full synthesis of the excavations of the area of the necropolis and Porta Marina Sud remains incomplete and unpublished due to her untimely death in 2007 (Figure 5.2). Fiammenghi (2003) notes that up until the time of her research the only known information about the necropolis comes from the works of Ebner (1970, 1978) who discusses a limited number of the decontextualized funerary inscriptions, further problematizing any attempts at linking funerary inscriptions with actual burials. Excavations by Fiammenghi identified ~330 burials, scattered over a 0.5 ha area with no apparent subdivisions of the cemetery, and with 54% of the skeletal remains recovered being subadults (Fiammenghi and La Torre 2005; Craig et al. 2009; Bondioli and Sperduti 2011).

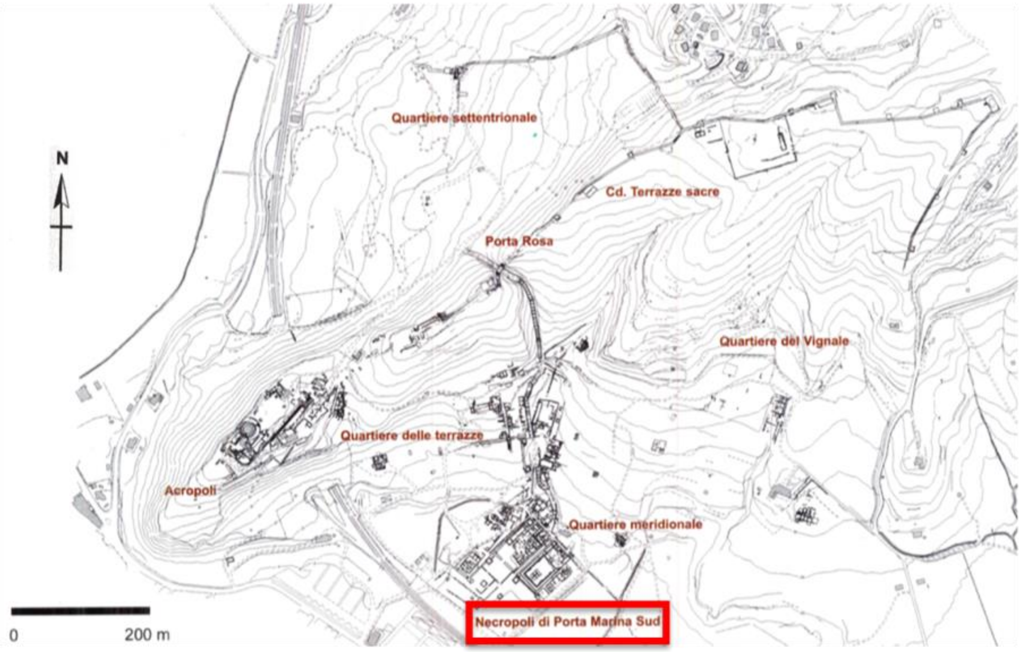

Figure 5.2–Location of the Roman Porta Marina Sud necropolis at Velia (Reproduced with permission after Greco 2003:table 1).

Burial types at Velia range from simple earthen graves to monumental tombs and mausolea (Sperduti et al. 2012). To date only the earthen graves have been excavated (Craig et al. 2009). A number of earthen burial styles are present at Velia including cremations (n=29) and inhumations (n= 289). In total Craig et al. (2009) identify twenty-seven different burial types, which are classified into six categories: 1) simple earthen burials; 2) simple earthen burials covered with tiles or stones; 3) cappuccina, where an earthen burial has leaning roof tiles (tegulae) placed over the body forming a peak; 4) stone lined burials; 5) mausolea; and 6) enchytrismos, in which the remains of an infant were placed within a neck-handled ceramic vessel, commonly an amphora. Cremations include both deposited cremains and *busta* burials, in which the body was burned *in situ* (Craig et al. 2009; Sperduti et al. 2012). Each grave contained a variable number and type of grave goods, none of which could be used to infer social status, suggesting a lack of such distinctions in burial at Velia (Fiammenghi 2003; Craig 2009).

5.1.1.4–Bioarchaeological Research at Velia

To date bioarchaeological examinations of the Roman skeletal remains from Velia have focused on dietary reconstruction (Craig et al. 2009), dental asymmetry (LaFleur 2011), the presence of external auricular exostoses (EAE) (Crowe et al. 2010), and age related bone loss (Baeuchesne and Agarwal 2014).

LaFleur (2011) argues that the individuals from Velia experienced developmental stress resulting in cases of dental asymmetry. Dental asymmetry was more common in males than females with maxillary teeth experiencing greater developmental asymmetry. Similarly, research by Sperduti et al. (2012), Bondioli and Sperduti (2011), and Crowe et al. (2011) found that external auricular exostoses (EAE) were disproportionately more common in males than females, occurring in 35.3% of males in the Velia sample and zero females and subadults. Such disparity is argued as being the result of male involvement in maritime trades that would have exposed them to cold water environments on a regular basis. Beauchesne and Agarwal (2014) examined sex related patterns of cortical bone loss at Velia using radiogrammetry of the second metacarpal. This study found that females show a gradual decline in bone quantity beginning in middle age, while males show bone loss only in old age. Of interest is the lack of evidence of sex differences in bone loss in the oldest ages categories, confronting modern assumptions about age related bone loss in older women.

Craig et al. (2009) identify two groups of individuals based on diet. Group I is believed to have consumed a diet high in cereals with variable meat and dairy intake, and minor fish and garum consumption. Individuals in Group II consumed less plant foods and likely more meat and fish, enriching their nitrogen (δ^{15}N) signals. There is no archaeological evidence to suggest that this dietary difference was correlated with status, though the authors suggest that the different diet of Group II individuals may imply they were immigrants to Velia (Craig et al. 2009).

5.1.2–Isola Sacra

5.1.2.1–Background to Isola Sacra

Isola Sacra, and the associated necropolis thereon, is an artificial island located 23 km southwest of Rome (Figure 5.1) (Prowse et al. 2013). Isola Sacra is ~330 ha in area and is situated between the two ancient sites of Portus Romae and Ostia, extending 1.6 km from east to west and 2.6 km from north to south, and being bounded by the Tyrrhenian Sea to the west, by the Tiber River to the east and south, and by the Fossa Traiana to the north (Prowse et al. 2010b; Germoni et al. 2011). Isola Sacra is presently ~3 times larger than in the Roman era due to shoreline extension from fluvial and alluvial deposits from the Tiber, placing the modern coastline ~3 km further into the sea (Germoni et al. 2011).

Isola Sacra was created as a result of canal dredging for the fossa Traiana in 103 CE, which connected the Tiber River with the coast (Baldassare 1978). Burials in the necropolis on Isola Sacra are associated with Portus Romae, a site originally initiated under the Emperor Claudius, and completed between 42 CE and 64 CE (Keay et al. 2005b; Keay and Paroli 2011b). The area was further developed under the Emperor Trajan who had the fossa Traiana dredged and an additional inner harbor built, continuing the use of this area as the key port for transshipment along the Tiber river to and from

Rome, making the area of Ostia and Portus a key economic region for trade with Rome (Keay et al. 2005b).

5.1.2.2–Excavations at Isola Sacra

The earliest modern references to the necropolis at Isola Sacra date from the period between 1699–1744, though it was not until 1839 when several burials were first officially uncovered under a license granted to the Gugliemi family by the Camera Apostolica (Germoni et al. 2011). The first major excavation at Isola Sacra was undertaken from 1925–1940 by Calza, who focused on the structure and decoration of the monumental tombs (Calza 1940; Veloccia Rinaldi and Testini 1975). During the excavations of Calza a large number of skeletons were removed, disassociating them from their original burial contexts (Prowse et al. 2010b), and significantly disassociating the human remains from the epigraphic evidence at the site. Helttula (2007) published an update of Thylander's (1952) study of the epigraphic evidence from Isola Sacra, providing various insights to lives and regions of origin for a number of the individuals interred at Isola Sacra. Though of significant insight, unfortunately given the disassociated nature of the human remains and epigraphic materials at Isola Sacra, this information can only be used for theorizing at this point.

Following the research of Calza, excavations did not resume until 1973 when a joint project of the Archaeological Superintendency of Ostia, the University Institute of Oriental Studies at Naples, and the University of Rome 'La Sapienza,' led by Ida Baldassarre commenced, lasting until 1982 (Baldassare 1990). This project focused on further investigation and restoration of the monumental tombs, as well as excavation of the human remains removed and haphazardly reinterred by Calza (Angelucci et al. 1990; Baldassarre 1984, 1990; Baldassarre et al. 1985; Rossi et al. 1998).

From 1988–1989 excavation at Isola Sacra was undertaken as part of a regional water supply project. During this time the area between the monumental tombs was excavated, from which >600 burials, comprising single and multiple interments, were identified (Baldassare 1990). The skeletal remains recovered from the necropolis of Isola Sacra have been curated by the Museo Nazionale Preistorico Etnografico Luigi Pigorini in Rome since 1992. To date no final report of the site excavations has been published. More recent work on the landscape of Portus and Isola Sacra has been undertaken since 2005 by the British School at Rome as part of the larger Portus Project directed by Simon Keay of the University of Southampton (Germoni et al. 2011). The Portus Project investigates the ancient landscapes of Portus and surrounding regions, with the main focus being on the development of the Claudian and Trajanic harbor complexes, through survey, geomorphological investigation, archaeological prospection, and excavation, with the aim of providing a thorough reconstruction of the ancient landscape of this Roman maritime harbor complex (Keay et al. 2005a; Keay et al. 2009; Keay and Paroli 2011a).

A key insight provided by the Portus Project is the proposed identification of residential areas at Portus. Meiggs (1973) estimated that by the Severan era (ca. 193–235 CE) Portus would have had a population likely numbering in the thousands. A key challenge to this claim however, has been identifying where these inhabitants would have lived. Through geophysical survey the Portus Project has identified as series of buildings they propose are residential, being located in the southern part of the port between the Canale di Communicazione Trasverso side of the hexagonal port of Trajan and the Late Antique Episcopio towards the Fossa Traiana, an area of roughly 12 ha. (Keay and Millet 2005b). Other potential residential areas have been identified on the west side of the Canale di Communicazione Trasverso, and across the Fossa Traiana on the Isola Sacra though this settlement is only ~3 ha. in size, suggesting a smaller proportion of residents (Keay and Millet 2005b; Germoni et al. 2011). It is also possible that the upper floors of the various warehouses associated with the harbor complex at Portus may have been used for housing, though there is presently a lack of confirmatory evidence for such a potentiality (Keay and Millet 2005b).

5.1.2.3–The Necropolis of Isola Sacra.

Transportation between Ostia and Portus was provided by the via Flavia, which traverses 1.5 km across the Isola Sacra (Veloccia Rinaldi and Testini 1975; Germoni et al. 2011; Prowse 2013). It is along the Via Flavia that the burials of the Isola Sacra necropolis first developed, with the necropolis remaining in use from the 1st to 3rd c. CE (Figure 5.3)

(Germoni et al. 2011). With waning commercial activity around the port, use of the area of Isola Sacra began to decline during the 4th to 6th c. CE, eventually resulting in the area of Isola Sacra being covered by sand (Baldassarre 1978; Sperduti 1995; Prowse et al. 2010b).

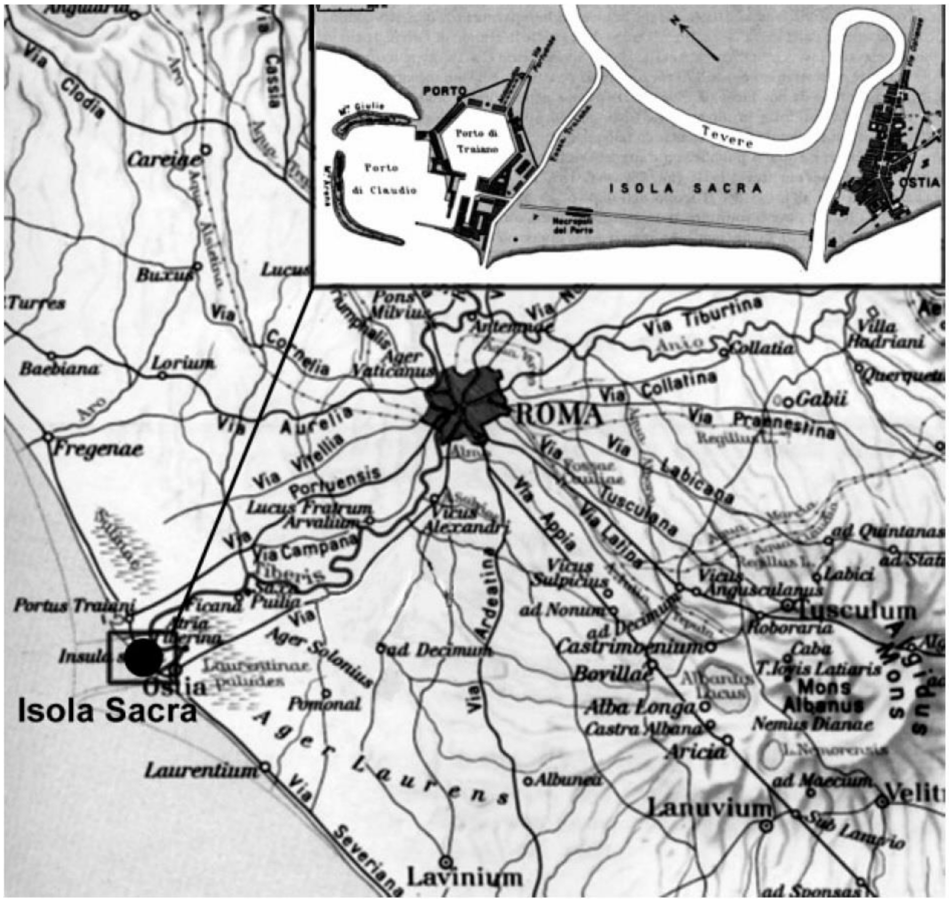

Figure 5.3–Location of the necropolis of Isola Sacra in relation to Portus and Ostia (Reproduced with permission after Prowse et al. 2007:511, fig 1).

Single burials were initially deposited on either side of the Via Flavia (Germoni et al. 2011). Over time with continued development of the necropolis larger funerary structures began to fill the available spaces forming various funerary complexes. The desire to build tombs that could be observed from the road accompanied by a gradual raising of the ground level resulted in various earlier burials being obscured and covered by later burials (Germoni et al. 2011). It has been noted however, that no systematic expansion of the burial ground was undertaken to accommodate burials of the 'poor,' though Calza originally proposed that the area behind the second row of monumental tombs was a 'field of the poor' (Angelucci et al. 1990; Prowse 2001, 2013). The chronological relationship between the various sections of the site is poorly understood, though it is evident that the oldest tombs (ca. 1st c CE) are located closest to the road (Baldassare 1984; Germoni et al. 2011), and there is evidence, though limited, from later periods of the necropolis for tombs being re-used (Baldassare 1984).

Aside from the well-known chambered tombs at Isola Sacra (n= 75; See Calza 1940), there are a number of other burial styles present, including: cappuccina burials, where terracotta tiles (tegulae) were leaned against each other to form a peak over the body; libation burials/adult amphorae burials, in which relatively intact amphorae were inserted into the ground above the interred individual; simple pit burials/soil and sand interments, in which the body was deposited into the ground with no accompanying coffin or protective structures; inhumations with associated coffin of wood or terracotta bricks; and in the case of subadults amphorae burials, where the broken pieces of amphorae were used to cover the body (Angelucci et al. 1990; Prowse 2001; Prowse et al. 2010b).

Based on epigraphic materials from the tombs at Isola Sacra it is believed that a large number of the individuals interred in the necropolis were employed as tradesmen, ship owners, merchants, workmen, and stevedores (Thylander 1951-52; Tonybee 1941; Sacco 1984; Helttula 2007; Prowse et al. 2010b). Based on these trades and the lack of reference to a local aristocracy, it has been proposed that the population of Portus Romae was likely middle class (Garnsey 1998, 1999).

Portus, as a major harbor and point of immigration, was a cosmopolitan area. Yet where individuals were arriving from still remains somewhat uncertain. There is onomastic evidence for individuals of African origin and ancestry involved with administration of the grain supply at Ostia and Portus (Cébeillac-Gervasoni 1996; Salomies 2002). From epigraphic materials at Portus and Isola Sacra, Sacco (1984) and Helttula (2007) identified numerous individuals who originated from circum-

Mediterranean and European locations including, Tunisia (*Karthago*), Egypt (*Alexandria*), Palestine (*Gaza*), France (*Aquitania*), Greece (*Rhodius*), Asia Minor (*Nicomedia*, *Prusa*), and various locations in Italy (e.g. *Ravenna, Roma*). This evidence supports the notion of Portus as a cosmopolitan environment. What this evidence lacks, is the ability to provide a true gauge of all the various regions from which individuals originated and at what life stage they migrated, as the regions identified by Sacco (1984) and Helttula (2007) are only those that where chosen to be commemorated epigraphically.

The skeletal remains of ~2000 individuals have been identified from the necropolis at Isola Sacra (Sperduti 1995). Many of these were recovered from the excavations of Calza, during which bodies were disinterred and decontextualized before being reinterred at random (Prowse et al. 2010b). Of the ~2000 individuals recovered approximately 800 have greater contextual data available for their original deposition contexts and have been catalogued by Sperduti (1995), forming a reference for bioarchaeological research (Prowse et al. 2010b). In terms of grave goods, Sperduti (1995) notes that most inhumations lacked grave goods, aside from a few instances of coins, lamps, and what are identified as 'female' ornaments. A digital database (http://www.ostia-antica. org/valkvisuals/index.htm) of the various excavated tombs of Isola Sacra has been created to provide an interactive platform to a significant amount of the research available to date on the Isola Sacra necropolis.

5.1.2.4– Bioarchaeological Research on the Roman Remains from Isola Sacra

Studies of the skeletal remains from Isola Sacra have been many and various including an aDNA investigation of the presence of thalassemia by Yang (1997), a synthesis of dental development and stress through the analysis of developmental defects in the primary dentition and microstructural enamel characteristics by Manzi et al. (1997), Rossi et al. (1998), and Hoover et al. (2005), a paleopathological analysis of Vitamin D deficiency and rickets in children by Wood (2003), an examination of age related bone loss by Cho and Stout (2003), and documentation of external auditory exostoses first by Manzi et al. (1991) and later by Crowe and colleagues (2010).

Of primary importance to the present study is the research of Prowse and colleagues (2004, 2005, 2007, 2010b). Prowse et al. (2004, 2005) used carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) to look at diet and age-related variability of diet. These studies found that the individuals of Portus Romae ate a mixed diet of marine and terrestrial foodstuffs, with the marine component possibly representing 10%–40% of the dietary intake. The combination of carbon and nitrogen data suggest that females were consuming a greater proportion of terrestrial C_3 plants, and that marine food made up a comparatively larger proportion of the male diet, while subadult diet appears to have been largely herbivorous, indicating a degree of gender and age-based differences in the diet (Prowse et al. 2011). Seeking to better understand childhood stress and the dietary impacts of breastfeeding and weaning, Prowse et al. (2008, 2010b, 2011) examined linear enamel hypoplasia (LEH), Wilson bands, and long bone growth, in tandem with $\delta^{13}C$ and $\delta^{15}N$ and Roman literary sources on childhood diet. These studies found that introduction of foods as part of a transitional diet at the time of weaning was taking place by 1–2 years of age, while weaning was complete by ~2.5 years, estimates consistent with the Roman literature. Prowse et al. (2008, 2010b, 2011) noted that subadults appeared to have had a more terrestrial diet post-weaning compared to adults, and although these infants likely experienced periods of developmental stress and had dental pathology associated with the weaning transition, their overall health was not significantly compromised.

The isotopic research of Prowse et al. (2007) examined instances of migration to the region of Portus using oxygen ($\delta^{18}O$). This study utilized modern teeth from Roman children to derive a local range (-4‰ to -6‰) that was employed to gauge the degree of mobility among individuals interred at Isola Sacra. Prowse et al. (2007) used both first (M1) and third (M3) molars to gauge at which life stage individuals may have moved. Using this approach they were able to identify that ~1/3 of the Isola Sacra sample examined were non-local and included females and males based on the $\delta^{18}O$ of the first molars, while the third molar data indicates that a number of the individuals examined moved to the area of Portus as children (i.e. between the period of M1 and M3 formation). One difficulty with this study however, is the question of breastfeeding. In their discussion of M1 δ^{18}O values Prowse et al. (2007) provide only limited mention of breastfeeding and weaning as a potential difficulty to δ^{18}O value interpretation. Breastfeeding results in higher δ^{18}O values of M1s by ~0.7‰ due to the fact that breast milk is enriched in ^{18}O over drinking water consumed by the individual breastfeeding (see Roberts et al. 1988; Wright and Schwarcz 1998, 1999; Knudson 2009; Prowse 2016). If Prowse et al. (2007) had considered breastfeeding, by adding 0.7‰ to M1 δ^{18}O values (see Prowse 2016), the number of non-local individuals would have changed from 20 to 17, a number still within comparable range to make their original estimate of ~1/3 of the sampled individuals as non-local reasonable. Based on their findings Prowse et al. (2007) assert that Imperial Roman era migration to Portus was undertaken by men, women, and children, potentially as family units, and not exclusively by adult males, as has often been proposed (see Wrigley and Schofield 1981; Landers 1993; Bruun 2010; Brettell 2015).

5.1.3–Rue Jacques Brel Necropolis

5.1.3.1–Background to the Jacques Brel Necropolis

The Rue Jacques Brel Necropolis is located on the north bank of the Charente river in the area of Saintes, Charente-Maritime, France, ~120 km north of Bordeaux and ~41 km east of the Bay of Biscay (Figure 5.1) (Baigl et al. 1997). Aside from the initial bioarchaeological research reported by Baigl (1995) and Baigl et al. (1997), to date the only other investigation of the skeletons from this site has been a brief mention about enthesopathies in Villotte (2006).

The original occupation of the area of the Rue Jacques Brel was associated with industrial production, serving as a minor regional production location (Baigl et al. 1997). The northern sector of the site was thought to form part of an artisanal district, believed to be associated with glass and pottery production (Baigl et al. 1997). This artisanal district is located directly next to the necropolis, a proximity which the excavators believe suggests the necropolis was originally established by this artisan community (Figure 5.4) (Baigl et al. 1997). The style of the structures at this site are consistent with settlement of the area in the 1st–2nd c. CE, with the production site developing first before the subsequent development of a cemetery complex, suggesting that the site was founded on previously unoccupied territory (Baigl et al. 1997).

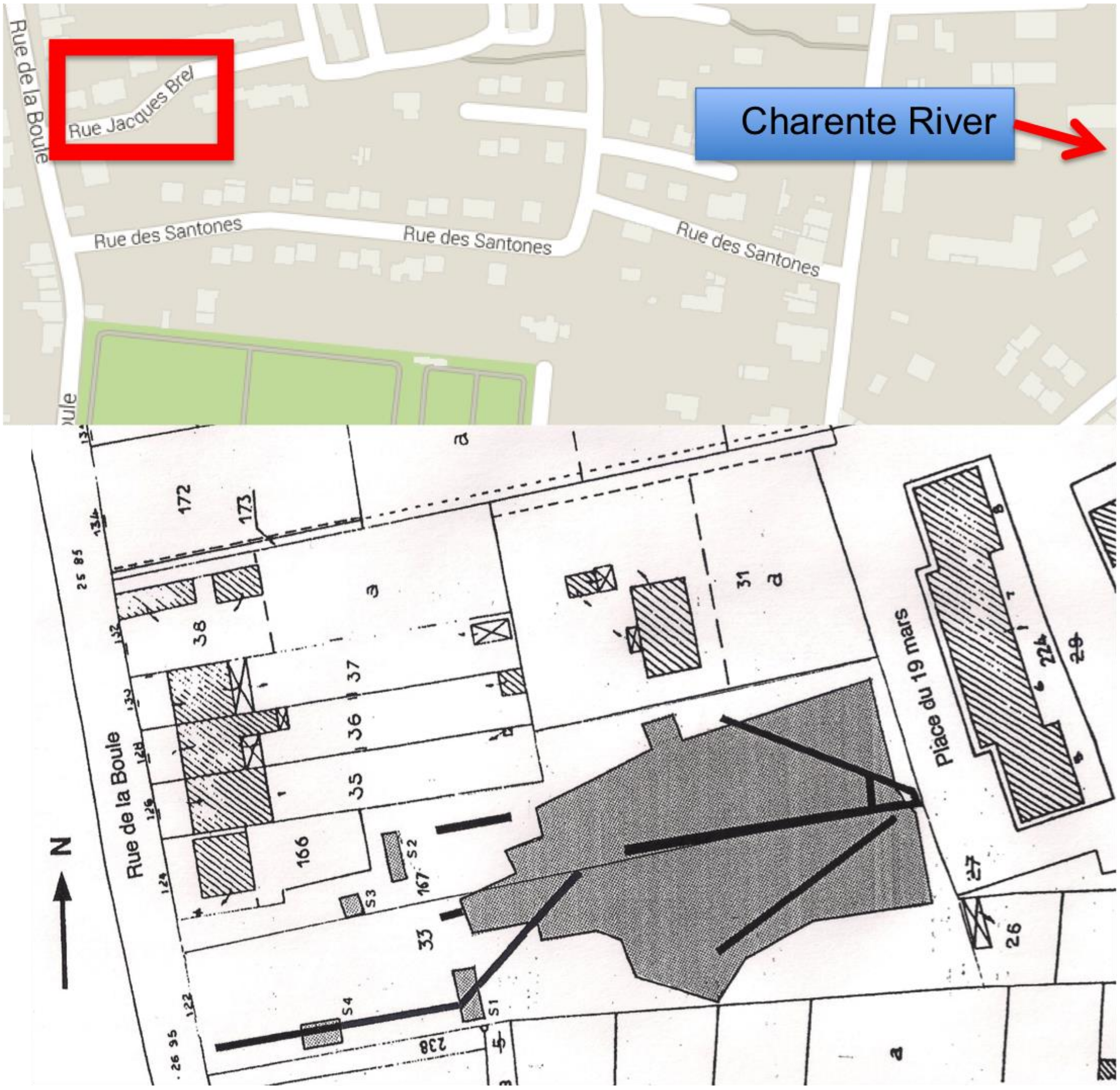

Figure 5.4–Area inside the red box in the upper image shows the location of Rue Jacques Brel in relation to the Charente river (~1km east) in Saintes, France (Map generated from Google Maps). The bounded solid grey area in the lower image shows the extent of excavation of the Rue Jacques Brel necropolis. The thick black lines visible indicate the location of initial archaeological test trenches (Reproduced after Baigl et al. 1997:fig. 1).

5.1.3.2–Excavation of the Jacques Brel Necropolis

The Rue Jacques Brel Necropolis is a small Imperial Roman era (ca. 1st–3rd CE) site that was initially identified in 1994 on an unoccupied parcel of land during archaeological evaluations under the direction of Jean-Francois Buisson to facilitate development of the Rue Jacques Brel roadway (Baigl 1995; Baigl et al. 1997). Excavations began in 1995 to establish the nature and dimensions of the site, with subsequent excavations beginning in 1996 and focusing on the necropolis (Baigl et al. 1997). Following excavation of this site the Rue Jacques Brel was paved and the area adjacent to the Rue Jacques Brel was developed as a residential area and remains so to this day (Baigl 1995).

5.1.3.3–The Necropolis of Rue Jacques Brel

The necropolis identified at this site is of significant importance as it is the only complete cemetery that has been identified to date in the area of Saintes (*Mediolanum Santonum*), the capital of Roman Aquitaine (Maurin 1978; Goudineau 1996; Baigl et al. 1997; Woolf 1998). The skeletal remains of the individuals from the Rue Jacques Brel necropolis are curated in the Université de Bordeaux and De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie (PACEA) research facilities in Pessac, France. In total 130 burials have been documented from the Rue Jacques Brel necropolis with 120 inhumations and 10 cremations (Baigl et al. 1997). It has been proposed that a number of the burials originally had stone foundations with a superstructure potentially of wood or a mixture of clay and hay as the excavators believe the foundations would not have been strong enough to support a stone superstructure (Baigl et al. 1997). A number of grave goods were identified during excavation, including ceramics, clothing elements (e.g. the outline and hobnails of shoes, buckles), and a coin from the reign of Vespasian (ca. 69–79 CE), placing the initial development of the necropolis in the 1st–2nd c. CE (Baigl et al. 1997). It is believed that the area of the necropolis was initially used for less formal burials in the 1st c. CE after which time the area began to see more regular use, developing into a necropolis in the mid-2nd c. CE (Baigl et al. 1997). It is apparent from this cemetery that for a period of time both inhumations and cremations were being used. The excavators proposed that cremations and inhumations were typical in the 1st–2nd c.

CE before inhumations began to dominate in the 2nd c. CE, ultimately becoming the exclusive burial practice by the 3rd c. CE (Baigl et al. 1997). The spacing of the tombs and the few cases in which burials cut across previous burials suggest that burials were formally laid out and may have originally been indicated by grave markers (Baigl et al. 1997).

5.2–Ageing and Sexing Methods

Ageing and sexing was undertaken following standard methods, and was completed for the samples from Isola Sacra and Velia by Dr. Alessandra Sperduti of the Museo Luigi Pigorini (Sperduti 1995), and for the Rue Jacques Brel Necropolis by Dr. Dominique Castex of the Centre national de la recherche scientifique (CNRS) laboratory of anthropology, Université Bordeaux 1 (Baigl et al. 1997). Sexing of adult individuals was variously undertaken using the criteria set out by Todd (1920); Phenice (1969), Ascádi and Nemeskéri (1970), Ferembach et al. (1977–1979); Meindl and Lovejoy (1985); Iscan and Loth (1986), and Burns (1999). Age was assessed using: degenerative changes to the pubic symphysis following Brooks and Suchey (1990); changes to the auricular surface of the innominate following Lovejoy et al. (1985); ecto- and endocranial suture closure following Angel (1980); morphological variation at the sternal end of the ribs following Iscan et al. (1984, 1985); and dental wear following Lovejoy (1985).

5.3–Isotopic Analyses

5.3.1–Collection of Dental Samples for Isotopic Analysis

Collection of adult (≥18 yrs.) second molars (M2) for isotopic sampling took place during 2012–2013 at the Museo Nazionale Preistorico Etnografico Luigi Pigorini in Rome, Italy and at the PACEA facilities of the Université Bordeaux 1 in Pessac, France. One second molar (M2) from each of a total sample of 139 individuals was collected from the sites of Isola Sacra (n= 80), Velia (n= 20), and Rue Jacques Brel Necropolis (n= 39) for $\delta^{18}O_c$ analysis. Of these 139 individuals sampled for $\delta^{18}O_c$, an approximately sex balanced random sample of 60 individuals (SCR= 20, JBR= 20, Velia= 20) were also analyzed for $^{87}Sr/^{86}Sr$ (Table 5.1). Individuals were sampled from all areas of the respective sites in an attempt to generate, as much as possible, a representative cross-sectional sample of the individuals interred at these three cemetery sites. Males and females were sampled as close to parity as was allowable by the representation and skeletal preservation of both sexes at the three sites examined. Each M2 was stored in a sealable plastic bag and labelled with identifying information. Second molars were selected to avoid any potential alteration in $\delta^{18}O_c$ values associated with breastfeeding, as is the case with first molars (Wright and Schwarcz 1998). Though individuals of various ages at death are represented in the present study it is important to keep in mind that initial M2 cusp formation begins at ~2.5 years after birth, while enamel formation of the second molar is complete between ~7–8 years after birth, providing a gauge of childhood residency during this time period regardless of age at death (Schour and Massler 1940; Al Qahtani 2009).

Table 5.1–Distribution, by sex and age, of samples examined for oxygen ($\delta^{18}O_c$) and strontium ($^{87}Sr/^{86}Sr$), from JBR, SCR, and Velia, presented as $\delta^{18}O_c$ ($^{87}Sr/^{86}Sr$) (see Table 6.2 for information on each individual).

	18-29 yrs.	**30-39 yrs.**	**40-49 yrs.**	**50+ yrs.**	**Total**
JBR					
Male	6 (3)	12 (5)	0 (0)	0 (0)	**18 (8)**
Female	5 (3)	16 (9)	0 (0)	0 (0)	**21 (12)**
Sub-Total	**11 (6)**	**28 (14)**	**0 (0)**	**0 (0)**	**39 (20)**
SCR					
Male	10 (1)	15 (4)	11 (4)	4 (0)	**40 (9)**
Female	13 (5)	17 (5)	9 (0)	1 (1)	**40 (11)**
Sub-Total	**23 (6)**	**32 (9)**	**20 (4)**	**5 (1)**	**80 (20)**
Velia					
Male	2 (2)	6 (6)	2 (2)	0 (0)	**10 (10)**
Female	2 (2)	3 (3)	2 (2)	3 (3)	**10 (10)**
Sub-Total	**4 (4)**	**9 (9)**	**4 (4)**	**3 (3)**	**20 (20)**
Overall Total	**38 (16)**	**69 (32)**	**24 (8)**	**8 (4)**	**139 (60)**

5.3.2–Initial Treatment for Isotope Sampling

All of the human second molars (M2) subjected to isotopic analyses were initially manually brushed to remove any adhering debris before being submersed in distilled water (dH_2O) and ultrasonicated for a period of 10 minutes. Ultrasonication was repeated three times changing the water in which each tooth was submersed for every bath, after which teeth were allowed to dry before being drilled to remove enamel for sampling.

5.3.3–Oxygen Isotope Methodology

The enamel of 139 adult second molars (M2) (SCR= 80, JBR= 39, Velia= 20) was submitted for oxygen ($\delta^{18}O$) isotope analysis following the protocols established in Koch et al. (1997). Each tooth was drilled removing ≥10 mg of dental enamel for sampling. Dental enamel was removed using a diamond tipped drill bit in a hand-held electric Dremel drill. After each use the drill bit was soaked in 0.25M hydrochloric acid (HCl) to avoid cross contamination. After weighing, enamel powder was collected in 1.5 ml plastic centrifuge microtubes.

Samples were treated with 0.04 ml of 2.5% bleach solution (NaClO) per mg of sample after which they were agitated and allowed to react for a period of up to 24 hrs. Following this reaction, samples were centrifuged and rinsed with de-ionized water five times, centrifuging after each rinse. Each sample next had 0.04 ml of 1M acetic acid acetate buffer (CH_3CO_2H) per mg of sample added to remove potential diagenetic secondary carbonates. Samples were agitated and allowed to react for a period of up to 24hrs. Samples were then 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.

Once the samples were dry, 2 mg of enamel powder was weighed into stainless steel cups. The 2 mg of enamel powder was then 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 test for accuracy and reproducibility, that is to say 13 samples and 1 duplicate were run with each carousel of samples. Oxygen carbonate values were measured in parts per mil (‰) relative to the Vienna Pee Dee Belmnite (VPDB) standard. These values were then converted to Vienna Standard Mean

Ocean Water (VSMOW) values and then to drinking water values, using the equations presented in Faure and Mensing (2005) and Chenery et al. (2012) respectively (See Chapter 2 for discussion of these equations).

Once converted to drinking water values, isotopic samples from all three sites in question were compared to GNIP (Global Network of Isotopes in Precipitation) and local $\delta^{18}O_{dw}$ data to examine the degree of correspondence between carbonate values and expected drinking water values in the regions under consideration. Though conversion to drinking water values (dw) provides a gauge of the correspondence between samples examined and meteoric precipitation there is also a degree of error in the order of ±1‰ that is generated when values are converted from $\delta^{18}O_c$ VPDB to $\delta^{18}O_{dw}$ VSMOW (Pollard et al. 2011; Chenery et al. 2012). For this reason $\delta^{18}O_{dw}$ converted values are used as a guide for gauging the correspondence between individuals and their presumed residential environment, while assessment of local vs. non-local individuals was determined using statistical methods of identifying outliers based on 1σ, 2σ, and Tukey Fence 1.5*IQR ranges (Prowse et al. 2007; Lightfoot and O’Connell 2016; Prowse 2016).

5.3.4¬Strontium Isotope Methodology

The enamel of 60 adult second molars (M2) (SCR= 20, JBR= 20, Velia= 20) was submitted for strontium ($^{87}Sr/^{86}Sr$) isotope analysis following the protocols established in Dickin (2005). Each tooth was drilled, removing ≥60 mg of dental enamel for sampling. Dental enamel was removed using a diamond tipped drill bit in a hand-held electric Dremel drill. After each use the drill bit was soaked in 0.25M hydrochloric acid (HCl) to avoid cross contamination. After weighing, enamel powder was collected in plastic centrifuge microtubes.

Enamel was initially dissolved in 1.2 ml of 2.5 M hydrochloric acid (HCl). Following full dissolution of the enamel in HCL acid samples were centrifuged for 10 minutes. Cation exchange was employed to complete the strontium separation. Cation exchange columns were calibrated by employing a test “spiked” sample allowing for the stage of Sr collection to be assessed (Dickin 2005). In order to cleanse the cation exchange columns before use 10 ml of deionized water was introduced, after which 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 to the exchange columns in 1 ml portions and was washed into the column using 1 ml of 2.5 ml 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 to the columns to collect the strontium. Strontium was collected in 4 ml intervals into Teflon beakers. Once the strontium phase was collected samples were placed under a heat lamp to dry to a solid state. Samples were next loaded onto a pre-treated single tantalum filament in dilute phosphoric acid, after which the samples were loaded in sequence in a vacuum system.

The ^{87}Sr/^{86}Sr values of the enamel samples was measured by dynamic multi-collection using a thermal ionization mass spectrometer (TIMS) in the School of Geography and Earth Sciences at McMaster University under the direction of Dr. Alan Dickin. Strontium results were fractionation normalized to ^{88}Sr/^{86}Sr= .1194, with an average ^{87}Sr/^{86}Sr =0.71026±0.000018 (1σ) for the NIST 987 Sr standard and internal precision (within-run precision) of ±0.00003 (2σ) standard error based on 150 dynamic cycles.

5.3.5–FTIR

Following the methods outlined in Wright and Schwarcz (1996), dental enamel from 20 (SCR= 10, JBR= 5, Velia= 5) individuals, randomly selected from within each site and proportionally sampled based on the overall number of individuals sampled from each site (i.e. more individuals were sampled from SCR than Velia and JBR, so 10 rather than 5 FTIR samples were run for this larger sample), was subjected to Fourier transformation infrared spectroscopy (FTIR) analysis at the McMaster Combustion Analysis and Optical Spectroscopy Facility to test for the presence of diagenetic alteration. Samples were first cleaned before the enamel was ground into a fine powder and passed through a #200 mesh sieve. Following this, enamel for each individual was combined with dry potassium bromide (KBr) and ground before being compressed into pellets at 10,000 psi. After this preparation 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 in order to obtain absorbance spectra for calculating crystallinity index (CI) (See Chapter 2 for discussion of CI).

5.4–Nonmetric Trait Analyses

5.4.1–Nonmetric Trait Data Collection

Nonmetric trait data collection was undertaken in 2012–2013 at the Museo Nazionale Preistorico Etnografico "Luigi Pigorini" in Rome, Italy and at the PACEA facilities of the Université Bordeaux 1 in Pessac, France. A total of 302 adult individuals were observed for a suite 57 nonmetric traits recorded at 177 loci. Individuals from each of the three sties examined were sampled based on skeletal preservation and approximating as closely as possible sex parity. From Isola Sacra (SCR), 189 individuals were recorded (M= 89; F= 100), from Velia 62 individuals were recorded (M= 34; F= 28), and from Rue Jacques Brel Necropolis (JBR) 51 individuals were recorded (M= 23; F= 28) to provide a biologically representative cross-section of these three sites for nonmetric trait MMD analyses (Table 5.2)

Table 5.2–Distribution, by sex and age, of samples examined for nonmetric traits from JBR, SCR, and Velia (see Appendix C for full listing of each individual).

	18-29 yrs.	**30-39 yrs.**	**40-49 yrs.**	**50+ yrs.**	**Total**
JBR					
Male	6	12	5	0	**23**
Female	7	17	3	1	**28**
Sub-Total	**13**	**29**	**8**	**1**	**51**
SCR					
Male	23	23	29	14	**89**
Female	25	30	37	8	**100**
Sub-Total	**48**	**53**	**66**	**22**	**189**
Velia					
Male	4	9	15	7	**35**
Female	7	4	9	7	**27**
Sub-Total	**11**	**13**	**24**	**14**	**62**
Overall Total	**72**	**95**	**98**	**37**	**302**

Dental nonmetric traits (n= 27) were recorded following the Arizona State University (ASU) standard score traits using associated scoring plaques according to Turner et al. (1991). Infra-cranial traits (n= 10) were selected and recorded based on the heritability profiles established in Anderson (1987) and Saunders (1978) where the proposed genetic component of development of a given trait was higher than 70% (7/10). Cranial nonmetric traits (n= 20) were recorded following the established trait lists in Buikstra and Ubelaker (1994), and Hauser and De Stefano (1989). Individuals scored were selected based on age (≥18 yrs.), degree of preservation, and representation of skeletal elements. A sub-sample of 139 individuals from among the 302 individuals recorded for nonmetric traits were analyzed for $\delta^{18}O_c$. Of these 139 individuals, 60 individuals were also analyzed for $^{87}Sr/^{86}Sr$.

5.4.2–Nonmetric Trait Scoring

Nonmetric traits were scored using present/absent criteria. Infracranial traits were scored as present or absent following standardized descriptions in Saunders (1978) and Anderson (1987). Cranial traits were scored as present or absent following standardized descriptions in Hauser and De Stefano (1989) and Buikstra and Ubelaker (1994). Dental traits were recorded using the standardized Arizona State University Dental Anthropology System (ASUDAS), which utilizes a series of plaques showing incremental variations in dental trait expression (Turner et al. 1991; Turner and Scott 1997). After recording, dental traits were dichotomized into present or absent categories using standardized breakpoints for MMD analysis (Turner 1985; Irish 2005, 2015).

In the case of bilateral traits (e.g. septal aperture in the humeri), traits were scored for both antimeres and then the side with the strongest expression was used in analysis, being the most discriminating of trait expression (Turner 1985; Schrader et al. 2014). In instances where only one antimere for a given trait could be observed in a given individual, that side was used for that individual as the highest potential trait expression (Turner 1985; Schrader et al. 2014). Each individual was examined for a suite of 57 traits (20 cranial, 10 infracranial, 27 dental).

5.4.3–Nonmetric Trait Analysis

Traits were analyzed using C.A.B Smith's Mean Measure of Divergence (MMD), which provides a gauge of similarity between groups of traits, where 0 represents complete similarity and 1 represents complete dissimilarity, and can be used with missing data (i.e. it can be used with incomplete skeletal samples). Calculation of the MMD was undertaken using the R-script (https://cran.r-project.org/) function presented by Soltysiak (2011). To accomplish this, two data sheets were created, one with the total number of individuals scored for a given trait and the second with the amount present for each trait. In both files the first row contains the names of each nonmetric trait and the first column records the names of samples to be compared. For R-script analysis, trait occurrences were documented as percentages. Given the relatively small sample size the Freeman and Tukey (1950) transformation and correction function was used (Green and Suchey 1976).

The R-script of Soltysiak (2011) generates four matrices. The first matrix provides values of traits utilized, giving the MMD for the single trait and the proportion of positive MMD values for the trait, providing a means by which to gauge the ability of each trait to discriminate between samples (See Harris and Sjøvold 2003). Traits were removed from further MMD analyses where no or all individuals were observed to have a given trait (i.e. 0 or 100), and where the number of observable individuals was <10 for any given sample. In cases where an MMD value was returned as negative or zero, such traits were edited from further MMD analyses. A negative MMD or zero for a given trait may indicate that sample size is too small or that the trait is poor for discriminating between samples. In the process of trait editing all values that showed the ability to discriminate between samples were initially run. Following a first run, samples with the highest degree of discrimination were utilized in subsequent runs to generate the most discriminatory MMD values. Through the process of trait editing a final 26 traits were determined to be the most discriminating for MMD analysis (see Results in Chapter 7). The remaining three matrices provided by the R-Script are comprised of the MMD matrix, standard deviations (Sjøvold 1973), and the statistical significance for each MMD value using two sided Z-scores counted as MMD/SD (Soltysiak 2011).

5.4.4–Intra-Observer Error

An intra-observer error test was conducted for each respective sample (i.e. separately for each of SCR, JBR, and Velia) to ensure that trait recording was accurate and repeatable. Intra-observer error testing followed the recommendations of Buikstra and Ubelaker (1994), and Molto (1983) where a re-analysis of 10–20% of total sample or a minimum of 30 individuals is recommended. A randomized sample of individuals to be re-examined from each site was established using a random number generator. Intra-observer tests were conducted a minimum of one month after the completion of initial trait recording allowing for sufficient time to pass between initial recording and intra-observer testing so as to avoid biasing the repeatability test due to recent analysis of any given set of skeletal remains. Repeatability of >90% was deemed suitable as sufficiently greater than random probability of repeat observation for the present study. For Velia 12/62 individuals (20% of total sample) were re-examined, for JBR 12/51 individuals (23.5% of total sample) were re-examined, and at SCR 30/189 individuals (16% of total sample) were re-examined for intra-observer error testing.

Chapter 6–Isotopic and Nonmetric Trait Results

Part 1–Isotopic Results

6.1– Significance Testing and Sample Preservation

6.1.1–Normality and Significance

Tests of significance were undertaken using SPSS to examine for potentially significant differences in $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ values between males and females and between age categories at all three sites. A Shapiro-Wilk test was initially employed to gauge the normality of sample distribution.

6.1.1.1–Significance of Sex

Where samples were normally distributed a t-test of significance was employed. For non-normally distributed samples the non-parametric Mann-Whitney U test of significance was employed. In all cases at all three sites there was no significant differences between males and females at the 0.05 level. Samples were pooled for the purpose of further isotopic analyses.

6.1.1.2–Age Related Significance

To examine for potentially significant differences in migration patterns based on age at death, individuals from all three sites were examined respectively for variation in $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ values based on four age categories: 18-29, 30-39, 40-49, and 50+. For samples where the data are normally distributed an ANOVA test was employed to examine for significant relationships, while in non-normally distributed samples the non-parametric Kruskal-Wallis test was employed. In all cases, except for $\delta^{18}O_c$ at Isola Sacra, there was no significant difference between age categories at the 0.05 level.

At Isola Sacra the non-local proportion of the sample for each age category exhibits no obvious trend of significant difference, with the 18–29 age category having 9/23 (39%) of individuals being non-local, at 30–39 years 11/32 (34%) are non-local, at

40–49 years 5/20 (25%) are non-local, while at 50+ years 3/5 (60%) are non-local. The increased number of nonlocal individuals in the 50+ category may be a result of the small sample size. To isolate where the significant difference was occurring an a posteriori Scheffe test was conducted to compare the four age categories. Scheffe analysis identified the greatest difference between age categories 18–29 and 40–49, while all other categories returned definitively non-significant values. Individuals in the age 18–29 category have $\delta^{18}O_c$ values from -8.5‰ to -3‰ representing a range of 5.5‰, while individuals in the 40–49 category have values from -6.2‰ to -3.1‰ representing a 3.1‰ range of values. These two categories represent the largest and smallest ranges of values respectively (See Chapter 8 for discussion of significant age related differences in $\delta^{18}O_c$ evident at Isola Sacra).

6.1.2–Dental Enamel Preservation

To test for any potential instances of diagenetic alteration to the enamel of the second molars (M2) sampled from Velia, Isola Sacra (SCR), and Rue Jacques Brel Necropolis (JBR), 20 dental enamel samples were submitted to FTIR analysis to assess the crystallinity index (CI) (Table 6.1). A CI value of 3.8 or less indicates a well preserved sample that has not been affected by diagenetic alteration (Shemesh 1990; Wright and Schwarcz 1996; King et al. 2011; Webb et al. 2014). All samples tested from Velia, JBR, and SCR have CI values of 3.8 or lower, so dental enamel from these sites has not undergone diagenetic apatite recrystallization.

Table 6.1: Crystallinity Index (CI) values for a sample of 20 second molars (M2) from individuals interred at Velia (n= 5), Rue Jacques Brel Necropolis (JBR) (n= 5), and Isola Sacra (SCR) (n= 10).

Sample	CI	Sample	CI	Sample	CI	Sample	CI
Velia 134	3.8	JBR 18	3.7	SCR 36	3.7	SCR 352	3.8
Velia 146	3.6	JBR 54	3.6	SCR 88	3.6	SCR 433	3.5
Velia 194	3.6	JBR 59B	3.6	SCR 133	3.5	SCR 470	3.8
Velia 205	3.3	JBR 64	3.5	SCR 160	3.8	SCR 500	3.6
Velia 214	3.7	JBR 106	3.5	SCR 201	3.5	SCR 678	3.8

6.2–Oxygen ($\delta^{18}O_c$) Results

Oxygen ($\delta^{18}O_c$) data (Table 6.2) were assessed against 1σ, 2σ, and 1.5*Interquartile range (IQR) ranges. Individuals that fall outside the 1σ range are identified as non-local (See Prowse et al. 2007, Prowse 2016), while those that fall outside of the 2σ and 1.5*IQR ranges provide even stronger confirmation that an individual was non-local during M2 formation (Lightfoot and O'Connell 2016).

Table 6.2–Second molar (M2) $\delta^{18}O_c$ (‰) VPDB, $\delta^{18}O_{dw}$ (‰) VSMOW, and $^{87}Sr/^{86}Sr$ values, sex, age, and burial type for individuals sampled from Rue Jacques Brel Necropolis (JBR), Isola Sacra (SCR), and Velia.

Site	M2 $\delta^{18}O_c$ VPDB	M2 $\delta^{18}O_{dw}$ VSMOW	$^{87}Sr/^{86}Sr$	Sex	Age	Burial Type
JBR						
JBR 8	-4.1	-6.2	0.70880	F	20+	C
JBR 16	-5.1	-7.8	0.70907	F	20-25	C
JBR 18	-3.7	-5.6	0.70865	F	30+	C
JBR 21	-4.0	-6.1		M	30+	I
JBR 23	-4.2	-6.4		F	30+	S
JBR 28b	-3.4	-5.0		F	30+	C
JBR 29	-3.5	-5.2		F	30+	C
JBR 34	-6.0	-9.3		F	18-19	S
JBR 35	-4.0	-6.0	0.71064	M	30+	C
JBR 40	-5.9	-9.1		F	30+	M
JBR 46	-6.2	-9.6	0.70891	M	30+	Sec.
JBR 54	-6.9	-10.8	0.71139	F	30+	M
JBR 55	-3.5	-5.2	0.70932	F	30+	C
JBR 56	-3.0	-4.4	0.70927	F	30+	C
JBR 59A	-5.2	-8.0		F	20+	S
JBR 59B	-4.5	-6.9		M	20+	S
JBR 62	-5.3	-8.1		F	30+	S
JBR 63	-5.7	-8.9	0.71276	M	20-25	C
JBR 64	-6.9	-10.8	0.71029	F	30+	C
JBR 66	-4.6	-7.0		F	30+	C
JBR 67	-3.9	-5.9		M	30+	S
JBR 76	-6.0	-9.3	0.71064	M	20+	C
JBR 82	-5.2	-8.0		M	25-30	C
JBR 84	-3.8	-5.7	0.70914	M	30+	C
JBR 85	-4.4	-6.7		F	30+	C
JBR 86	-3.2	-4.7	0.70869	F	30+	S
JBR 90	-5.1	-7.9		M	30+	C
JBR 98	-6.2	-9.6	0.71038	F	30+	I
JBR 101	-2.6	-3.7	0.70903	F	30+	C

JBR 103	-4.2	-6.3	0.70993	F	20+	C
JBR 105	-5.7	-8.9		M	30+	S
JBR 106	-5.2	-8.0	0.70912	M	30+	S
JBR 110	-3.0	-4.5	0.70812	F	30+	C
JBR 111	-5.0	-7.7	0.70898	M	30+	S
JBR 112	-3.3	-4.9		M	30+	C
JBR 115	-4.8	-7.3		M	20-25	C
JBR 116	-5.8	-9.0		M	30+	C
JBR 122	-5.3	-8.2	0.70881	M	20+	C
JBR 128	-5.1	-7.8		M	30+	C
SCR						
SCR 36	-7.7	-12.1		M	20-21	In.
SCR 68	-8.0	-12.5	0.70811	F	20-30	Cap.
SCR 75	-4.0	-6.0		M	20-23	Sand
SCR 88	-3.0	-4.3		M	50+	Sand
SCR 98	-4.8	-7.4		F	20-25	Cap.
SCR 99	-6.1	-9.5	0.70723	M	30-35	Cap.
SCR 106	-4.1	-6.2	0.70906	F	20-23	Cap.
SCR 127	-3.5	-5.2	0.70916	M	40+	In.
SCR 133	-6.4	-9.9		M	20-21	T
SCR 144	-5.7	-8.9		M	25-30	Cap.
SCR 160	-6.2	-9.7		F	40-50	In.
SCR 169	-4.9	-7.5		F	20-30	Sand
SCR 171	-7.2	-11.2	0.70835	M	30-40	Cap.
SCR 174	-7.6	-11.9	0.70887	M	30-40	T
SCR 181	-3.9	-5.9		M	40-45	C
SCR 190	-6.8	-10.7		F	25-30	Cap.
SCR 191	-5.2	-8.0		M	40-50	Am.
SCR 193	-4.0	-6.1		F	25-30	Am.
SCR 194	-3.4	-5.1		F	40-45	In.
SCR 196	-7.1	-11.1		M	20-25	U
SCR 199	-3.3	-4.9		F	35-40	U
SCR 201	-3.9	-5.9		F	35-40	Cap.
SCR 217	-3.5	-5.2		M	30-40	Am.
SCR 220	-3.3	-4.9		M	40-45	T
SCR 239	-4.9	-7.6		F	40-45	Sand
SCR 245	-5.2	-8.0	0.70797	F	35-40	Am.
SCR 250	-3.6	-5.3		M	40-50	Sand
SCR 251	-6.1	-9.4		M	30-40	Cap.
SCR 252	-4.0	-6.1		F	40-45	Sand
SCR 269	-3.2	-4.8	0.70918	F	35-40	T
SCR 272	-5.5	-8.5		F	30-35	Sand
SCR 282	-6.5	-10.2		M	30-40	Sand
SCR 285	-3.0	-4.4	0.70879	F	50+	In.
SCR 287	-6.5	-10.2	0.70905	F	30-40	Cap.
SCR 298	-4.4	-6.7		M	40-50	Sar.
SCR 301	-3.5	-5.2		M	30-40	Cap.
SCR 303	-3.9	-5.9		M	35-40	Cap.
SCR 312	-4.2	-6.3		F	35-40	S.Cap.
SCR 314	-3.3	-4.9		F	40-50	Sand
SCR 320	-8.5	-13.4	0.70966	F	20-25	In.

SCR 321	-4.5	-6.9	0.70908	F	30-35	Sand
SCR 324	-5.0	-7.7	0.70782	F	30-40	Cap.
SCR 326	-3.2	-4.7		F	35-40	S.Cap.
SCR 329	-3.5	-5.3		F	40-50	Cap.
SCR 330	-6.2	-9.7		F	20-25	T
SCR 334	-5.0	-7.7		F	30-35	Sand
SCR 343	-4.9	-7.4		M	20-25	In.
SCR 344	-6.2	-9.7		M	30-35	Sand
SCR 352	-7.2	-11.3		F	35-40	S.Cap.
SCR 361	-3.0	-4.4	0.70931	M	20-25	Cap.
SCR 362	-3.1	-4.6		F	40-50	T.
SCR 376	-7.5	-11.9	0.71052	M	35-40	In.
SCR 404	-6.8	-10.6		M	20-25	In.
SCR 411	-5.9	-9.2	0.70883	F	20-25	Cap.
SCR 430	-5.9	-9.1	0.70884	M	45-50	Sand
SCR 431	-6.0	-9.4		F	40-50	Col.
SCR 433	-3.5	-5.2		F	30-35	T
SCR 435	-4.1	-6.2		M	40-45	Sar.
SCR 442	-3.6	-5.4		F	30-40	T
SCR 443	-4.2	-6.3		F	40-50	T.
SCR 445	-3.3	-5.0		F	20-30	Col.
SCR 448	-5.5	-8.6		M	30-35	T.
SCR 452	-3.3	-4.9		F	30-40	T.
SCR 462	-3.5	-5.2		M	30-40	In.
SCR 463	-6.3	-9.9		M	30-40	T.
SCR 464	-4.8	-7.3		M	25-30	In.
SCR 467	-3.4	-5.1		F	30-35	Cap.
SCR 470	-3.5	-5.2		F	25-30	Sar.
SCR 479	-5.1	-7.9		F	30-40	T.
SCR 484	-6.1	-9.4	0.70923	F	25-30	Col.
SCR 485	-4.7	-7.2	0.70816	M	40-50	Col.
SCR 500	-6.3	-9.9		M	20-25	U.
SCR 525	-4.9	-7.5	0.70923	M	40-50	Am.
SCR 526	-5.3	-8.2		M	30-40	T.
SCR 562	-4.3	-6.6		M	50+	Cap.
SCR 602	-3.4	-5.1		F	25-30	Am.
SCR 678	-6.6	-10.4		M	50+	T.
SCR 698	-3.3	-4.9		M	40-50	U.
SCR 730	-5.8	-9.0		M	50+	U.
SCR 797	-6.3	-9.9		M	30-40	T.
Velia						
Velia 57	-1.1	-1.3	0.70788	M	30-35	In.
Velia 82	-4.1	-6.2	0.70879	F	50+	In.
Velia 117	-5.6	-8.7	0.70880	F	20-30	In.
Velia 134	-5.8	-9.0	0.70890	F	20-30	In.
Velia 139	-4.6	-7.0	0.70839	M	30-40	In.
Velia 146	-4.3	-6.5	0.70827	M	43-55	In.
Velia 160	-4.9	-7.5	0.70866	F	30-40	In.
Velia 169	-5.5	-8.4	0.70874	M	30-40	In.
Velia 174	-4.7	-7.1	0.70869	M	40-50	In.
Velia 181	-4.7	-7.1	0.70866	F	50+	In.
Velia 182	-4.2	-6.3	0.70873	M	25-30	In.

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

Am. = amphora burial, C = coffin, Cap. = cappucina, Col. = columbaria, I = indeterminate, In. = inhumation, M = monumental tomb, S= soil burial, Sand = sand burial, Sar. = sarcophagus, Sec. = secondary inhumation, S.Cap. = semi-cappucina, T. = tomb, U. = unknown.

6.2.1– Isola Sacra and Velia $\delta^{18}O_c$ Results

Given the nature of the Italian peninsula, being nearly symmetrical north to south and east to west, the distribution of predicted $\delta^{18}O_{dw}$ values of the peninsula are rather uniform resulting in large north to south areas of homogeneous $\delta^{18}O_{dw}$ values in precipitation (Longinelli and Selmo 2003). This is to say that from east to west the Italian peninsula rises steadily from the Tyrrhenian coast to the Apennines before gradually descending towards the Adriatic coast. From north to south the Italian peninsula extends from the base of the Alps rising to the Apennines forming a spine almost fully to the Ionian coast (Longinelli and Selmo 2003). Both Isola Sacra, at the mouth of the Tiber, and Velia, in the Cilento, are situated on the Tyrrhenian coast, which in terms of precipitation $\delta^{18}O_{dw}$ values places both sites within the same range of expected local values (Figure 2.1). Using $\delta^{18}O_c$ values from the deciduous dental enamel of a sample of 19 modern Roman individuals, Prowse et al. (2007) establish an expected local range for the area around Isola Sacra and Rome as being between -6‰ to -4‰, which Killgrove (2010a) later argues should be -5.8‰ to -3.7‰. At one standard deviation (1σ) the results of the current study largely correspond with this range, with the range at Isola Sacra being identified as -6.4‰ to -3.5‰ (Figure 6.1, Table 6.2), while at Velia the 1σ range was identified as -5.7‰ to -3.3‰ (Figure 6.2, Table 6.2). Based on these 1σ ranges 28/80 (35%) individuals sampled from Isola Sacra appear non-local, while at Velia 5/20 (25%)

individuals appear non-local. In an attempt to provide a more conservative degree of discrimination in assigning "local" vs. "non-local," $\delta^{18}O_c$ values were also gauged against 2σ, and inter-quartile range (IQR) values using the Tukey fence (Q1-1.5*IQR to Q3+1.5*IQR) method (Lightfoot and O'Connell 2016). At the 2σ level the Isola Sacra range is expanded to -7.8‰ to -2.0‰, at which 2/80 (2.5%) individuals were identified as non-local, while at Velia the range expands to -6.9‰ to -2.0‰, at which 1/20 (5%) individual appears non-local. Using 1.5*IQR the range for Isola Sacra expands to -10.1‰ to +0.45‰, identifying 0/80 individuals as non-local, while at Velia the range expands to -7.5‰ to -1.9‰, at which 1/20 (5%) individual appears non-local.

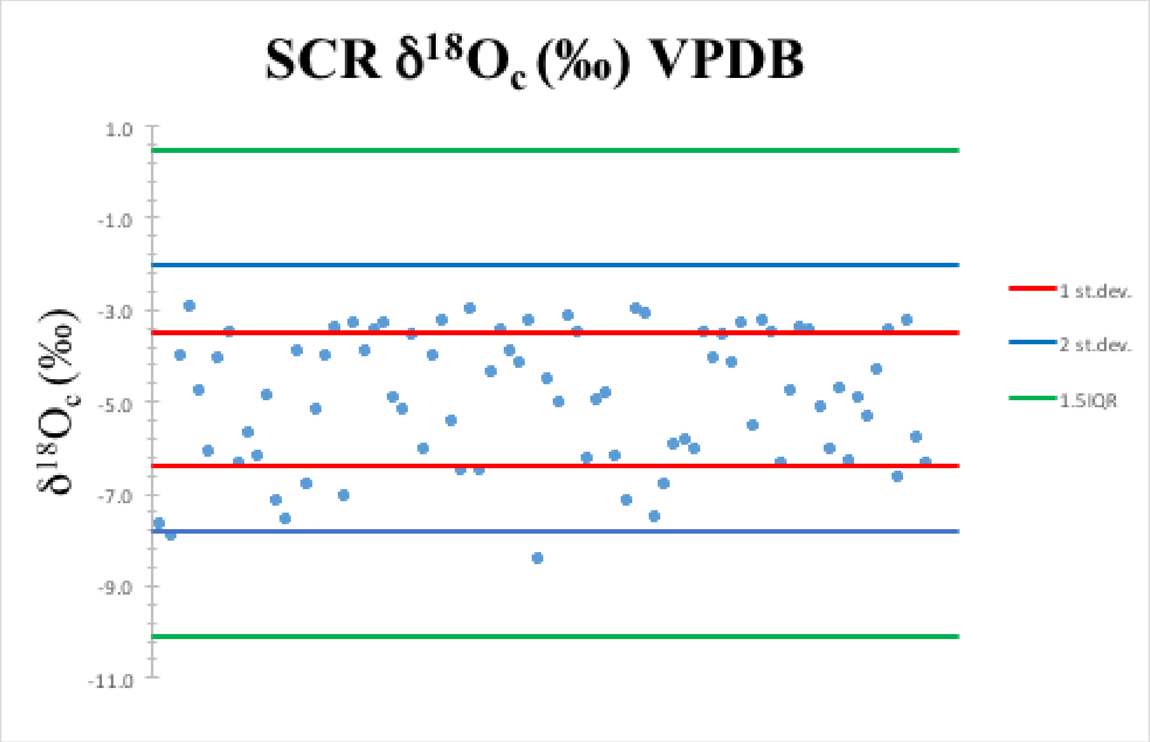

Figure 6.1–$\delta^{18}O_c$ (‰) VPDB results for Isola Sacra (SCR, n= 80), showing ranges for 1 standard deviation (1σ) in red, two standard deviations (2σ) in blue, and Tukey 1.5*IQR in green.

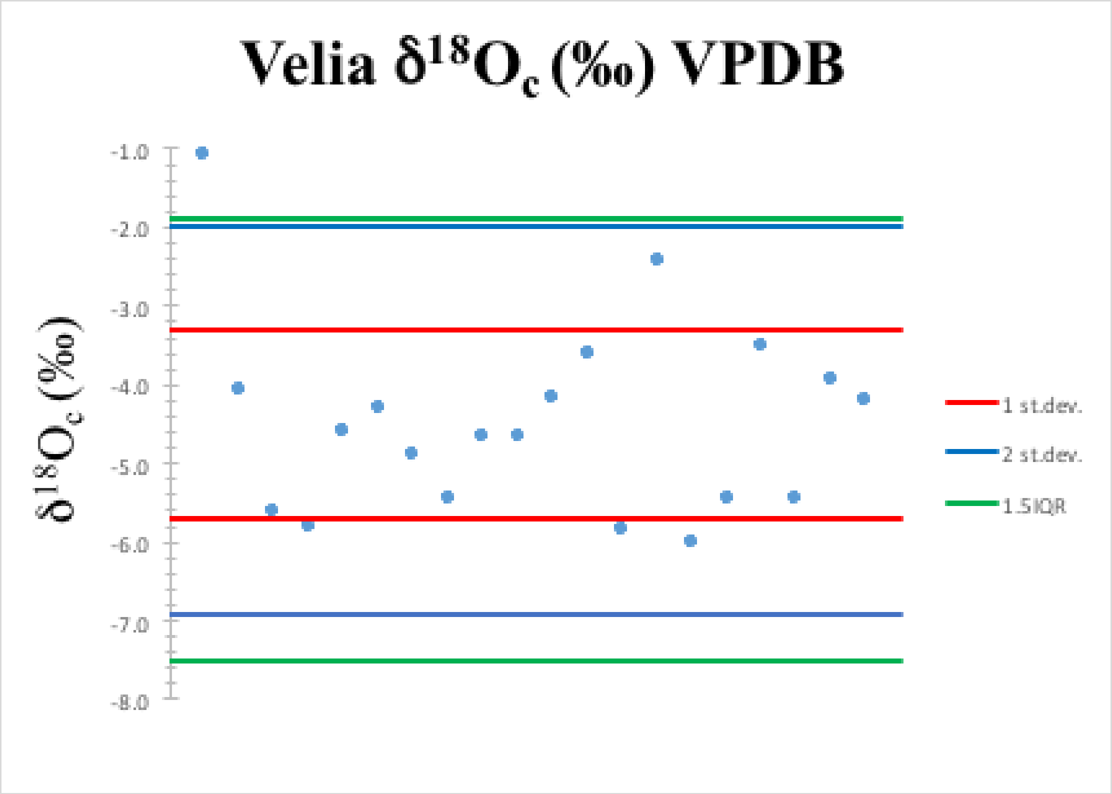

Figure 6.2–$\delta^{18}O_c$ (‰) VPDB results for Velia (n= 20), showing ranges for 1 standard deviation (1σ) in red, two standard deviations (2σ) in blue, and Tukey 1.5*IQR in green.

Looking at $\delta^{18}O_{dw}$, a degree of correspondence between $\delta^{18}O_c$ for Isola Sacra and Velia is evident when comparing converted $\delta^{18}O_{dw}$ values to precipitation data presented by Longinelli and Selmo (2003) for Italy (Table 6.2). At Isola Sacra the $\delta^{18}O_{dw}$ (1σ) range is -9.9‰ to -5.2‰, while at Velia the range is -8.9‰ to -4.8‰, providing respective ranges consistent with values expected on the Italian peninsula. However, as discussed above, these ranges are also subject to a degree of error in the order of ±1‰ generated through the conversion of $\delta^{18}O_c$ to $\delta^{18}O_{dw}$ values and are used here only as a gauge. Problematically, these $\delta^{18}O_{dw}$ (1σ) ranges also cover a majority of the range of expected $\delta^{18}O_{dw}$ values for the Italian peninsula. With that said, the converted $\delta^{18}O_{dw}$ values of a number of individuals suggest an origin from distant locales, including northern Europe (SCR 320) and north Africa (Velia 57) (See Table 6.2).

6.2.2–Comparison of $\delta^{18}O_c$ Signatures in M1 vs. M2 vs. M3 from Isola Sacra

In an attempt to address ongoing questions of potential childhood mobility at Isola Sacra, as previously suggested by Prowse et al. (2007) and contested most notably by Bruun (2010, 2016), the second molars (M2) of 20 individuals, whose M1 and M3 values were presented by Prowse et al. (2007), were analyzed as part of the present study following the maximum $\delta^{18}O_c$ range established by Prowse et al. (2007), and expanded by Killgrove (2010a), of -6.0‰ to -3.7‰ (Table 6.3). Original M1 values presented by Prowse et al. (2007) were corrected by 0.7‰ to take into account enrichment of ^{18}O associated with breastfeeding (See Wright and Schwarcz 1998).

Among the individuals sampled six individuals (Female= SCR 169, 201, 245, 479; Male= SCR 343, 464) present a local signature across all three molars, suggesting their lifetime residency in the area of Isola Sacra. Two individuals (Male= SCR 435, 525) migrated to the area of Isola Sacra after completion of their M1 (>2.5–3 yrs.) but before completion of their M2 (~7–8 yrs.) suggesting a young age of mobility. Four individuals (Female= SCR 320; Male= SCR 133, 174, 361) appear to have migrated to the area of Isola Sacra after the formation of their M2 (>7–8 yrs.) but before completion of their M3 (~10–17.5 yrs.). Of the 20 individuals examined, there are eight individuals who present a more ambiguous signature in that their M1s fall within the local range for Isola Sacra, suggesting that they may have been born and resided in this area, but have non-local M2 and/or M3 signatures, suggesting they were absent from the area of Isola Sacra during this time. Of these eight individuals two individuals (Female= SCR 68, 199) have non-local M2 and M3 signatures, suggesting mobility away from Isola Sacra around age 2.5–3 yrs. before returning to the area of Isola Sacra after completion of M3 development. One individual (Male= SCR 448) has a non-local M3 signature implying mobility away from Isola Sacra around age 7-10. Five of the eight individuals (Female= SCR 194; Male= 220, 250, 462, 500) have signatures in which their M1s are local, M2s have a non-local signature, and M3s have a local signature. This mixture of signals may suggest that these individuals spent the early years of their life in the environs of Isola Sacra, were absent from the area of Isola Sacra during M2 formation, before residing once again in the vicinity of Isola Sacra during M3 formation, suggesting a period of mobility from age ~2.5–7 years.

Table 6.3–Comparison of $\delta^{18}O_c$ (‰) VPDB in M1 vs. M2 vs. M3 for 20 individuals (male= 12, female= 8) from Isola Sacra. M1 and M3 data were originally presented in Prowse et al. (2007). M2 data are from the present study. Original M1 values, listed in the "M1" column, from Prowse et al. (2007) have been corrected by 0.7‰ (M1-0.7‰) to account for potential enrichment of ^{18}O associated with breastfeeding (see Wright and Schwarcz 1998). Values highlighted green fall within the local range of -6.0‰ to -3.7‰ for Isola Sacra as established by Prowse et al. (2007) and expanded by Killgrove (2010a). Ages associated with dental development are based on Schour and Massler (1940) where: crown formation, M1= birth, M2= 2.5–3 yrs., and M3= 7-10 yrs.; crown completion, M1= 2.5–3 yrs., M2= 7–8 yrs., M3= 10–17.5 yrs.

SCR $\delta^{18}O_c$ (‰) VPDB	**M/F**	**M1**	**M1-0.7‰**	**M2**	**M3**	**Assessment**
SCR 68	F	-5.3	-6.0	-8.0	-7.1	born local?, mobile before age ~7-8 yrs.
SCR 133	M	-6.9	-7.6	-6.4	-5.3	non-local until after age ~7-8 yrs.
SCR 169	F	-4.9	-5.6	-4.9	-4.2	local
SCR 174	M	-6.1	-6.8	-7.6	-5.8	non-local until after age ~7-8 yrs.
SCR 194	F	-4.7	-5.4	-3.4	-4.0	born local?, mobile from age ~2.5-7 yrs.
SCR 199	F	-4.8	-5.5	-3.3	-3.6	born local?, mobile before age ~7-8 yrs.
SCR 201	F	-4.1	-4.8	-3.9	-5.4	local
SCR 220	M	-4.7	-5.4	-3.3	-5.1	born local?, mobile from age ~2.5-7 yrs.
SCR 245	F	-5.3	-6.0	-5.2	-4.4	local
SCR 250	M	-4.7	-5.4	-3.6	-3.8	born local?, mobile from age ~2.5-7 yrs.
SCR 320	F	-7.5	-8.2	-8.5	-5.1	non-local until after age ~7-8 yrs.
SCR 343	M	-5.3	-6.0	-4.9	-5.6	local
SCR 361	M	-5.4	-6.1	-3.0	-4.2	non-local until after age ~7-8 yrs.
SCR 435	M	-6.9	-7.6	-4.1	-4.9	non-local until after age ~2.5-3 yrs.
SCR 448	M	-5.1	-5.8	-5.5	-6.3	born local?, mobile after age ~7-8 yrs.
SCR 462	M	-4.9	-5.6	-3.5	-4.4	born local?, mobile from age ~2.5-7 yrs.
SCR 464	M	-4.3	-5.0	-4.8	-4.3	local
SCR 479	F	-5.1	-5.8	-5.1	-5.1	local
SCR 500	M	-5.1	-5.8	-6.3	-4.2	born local?, mobile from age ~2.5-7 yrs.
SCR 525	M	-5.5	-6.2	-4.9	-4.4	non-local until after age ~2.5-3 yrs.

6.2.3–Rue Jacques Brel Necropolis $\delta^{18}O_c$ Results

Unlike the large north-south bands of uniform values observed on the Italian peninsula, $\delta^{18}O_{dw}$ values of France are more geographically variable given the location and diverse topography of the region. France is bounded by the Atlantic Ocean to the west, the English Channel and North Sea to the north, by the Pyrenees in the southwest, the Mediterranean in the south, and the Alps and the Rhine to the east. The region around Rue Jacques Brel Necropolis, in Saintes, France, has an average expected $\delta^{18}O_{dw}$ value of -7.0‰ to -5.0‰, and is situated in close proximity to regions in excess of this range based on values derived from GNIP data and snail shell carbonate (Figure 6.3) (Lécolle 1985; GNIP 2015).

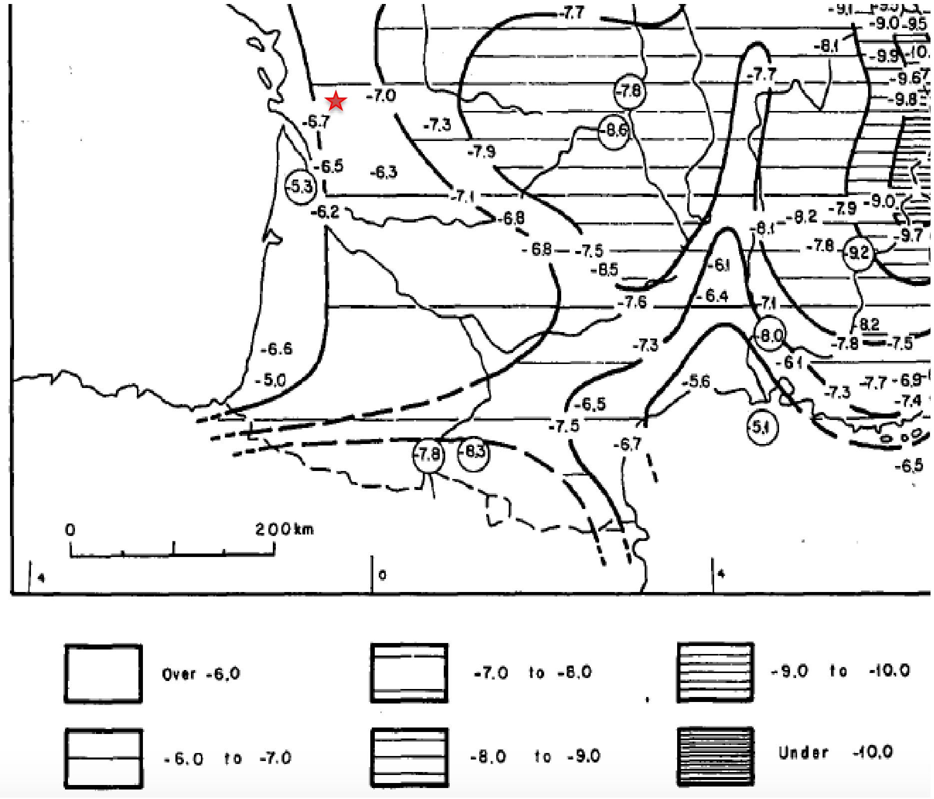

Figure 6.3–Partial $\delta^{18}O_{dw}$ (‰) VSMOW map of precipitation in France with red star indicating the location of the Rue Jacques Brel Necropolis (reprinted from Chemical Geology, vol. 58, Lécole P., The Oxygen Isotope Composition of Landsnail Shells as a Climatic Indicator: Applications to Hydrogeology and Paleoclimatology, 157–181, 1985, with permission from Elsevier).

For the samples examined from JBR, a $\delta^{18}O_c$ (1σ) range of -5.8‰ to -3.6‰ was established, for which 15/39 (38%) individuals appear non-local. At 2σ the $\delta^{18}O_c$ range expands to -6.9‰ to -2.5‰, reducing the number of apparent non-local individuals to 0/39, which is also true of the 1.5*IQR range at -7.9‰ to -1.3‰ (Figure 6.4, Table 6.2).

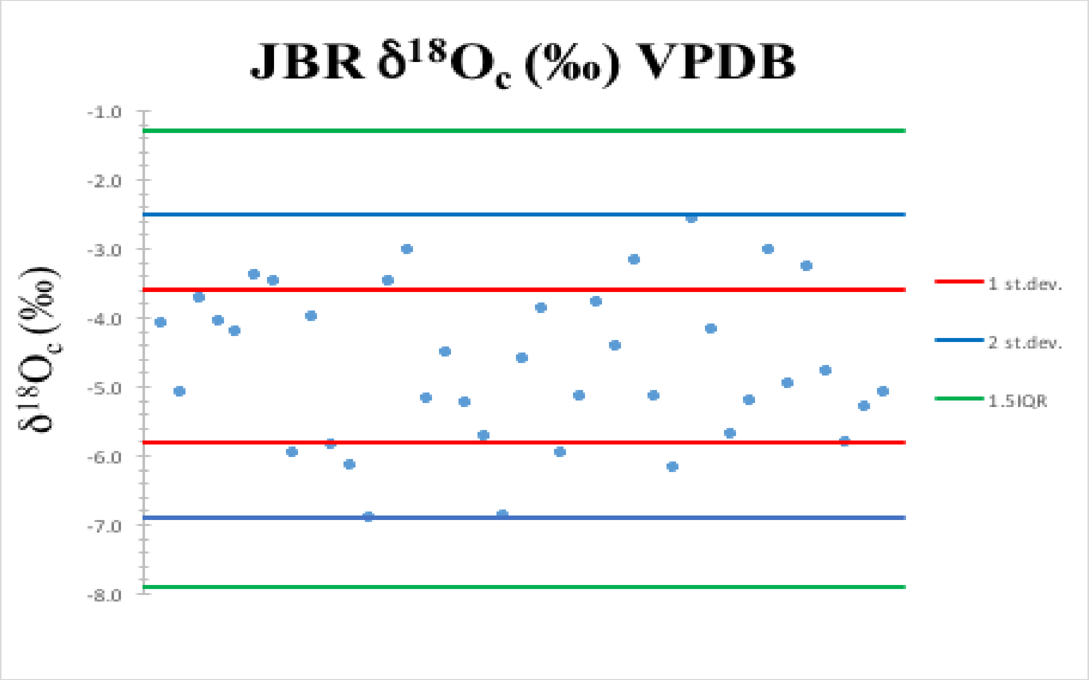

Figure 6.4–$\delta^{18}O_c$ (‰) VPDB results for Rue Jacques Brel Necropolis (JBR, n= 39), showing ranges for 1 standard deviation (1σ) in red, two standard deviations (2σ) in blue, and Tukey 1.5*IQR in green.

6.3–Strontium Results

6.3.1–Velia $^{87}Sr/^{86}Sr$ Results

The geology of Velia is a mixture of lower Miocene flysch, the so called "flysch of the Cilento," 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). A local $^{87}Sr/^{86}Sr$ range of expected bioavailable values for the area of Velia was derived by

Oliver Craig (pers. comm.) from a series of 9 archaeofaunal pig teeth, with a 2σ local range of 0.70784–0.70979 (Table 6.4). Taking this expected local range into consideration none of the individuals examined from Velia in the present study fall outside of the expected local $^{87}Sr/^{86}Sr$ range (Figure 6.5, Table 6.2).

Table 6.4–$^{87}Sr/^{86}Sr$ values of 9 pig teeth analyzed by Oliver Craig from Velia.

Sample	$^{87}Sr/^{86}Sr$	
VE-2	0.70831	
VE-3	0.70835	
VE-9	0.70837	
VE-6	0.70868	
VE-10	0.70886	
VE-8	0.70892	
VE-4	0.70894	
VE-5	0.70902	
VE-7	0.70989	
Average	**0.70881**	
2σ range	**0.70784**	**0.70979**

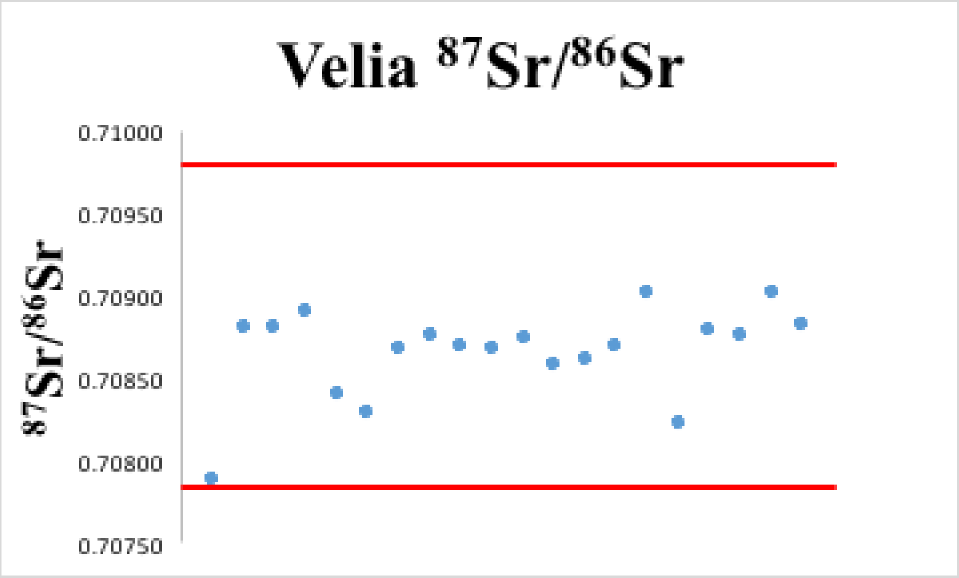

Figure 6.5–Strontium results for Velia (n= 20). Horizontal red lines indicate the expected local $^{87}Sr/^{86}Sr$ range (2σ).

6.3.2–Isola Sacra (SCR) $^{87}Sr/^{86}Sr$ Results

The region around Isola Sacra at the mouth of the Tiber river on the Tyrrhenian coast is comprised of continental and marine sediments almost everywhere later than the Middle Pliocene, being most commonly Holocene and Pleistocene sediments typified by gravels, clays, and sands. In close proximity along the Tiber river, Rome is situated in a region of dormant Pleistocene volcanic activity comprising lavas, ignimbrites and pyroclastic rocks associated with the Colli Albani and Monti Sabatini volcanic complexes, which overlay continental and marine sediments of similar geology to the area around Isola Sacra (Ogniben et al. 1975; Gelati et al. 1989; Giraudi 2011; Goiran et al. 2011; Killgrove and Montgomery 2016). Beginning in the late 1st c. CE a main source of drinking water at Portus was provided by a spring fed aqueduct originating in the hills around Ponte Galeria ~9 km. north of Portus along the via Portuensis, and running parallel along the Tiber (Petriaggi et al. 1995; Keay and Millett 2005a; Keay and Paroli 2011b). The Ponte Galeria area is typified by river conglomerates, marine gravels, sands, and mixed tuffs from the Alban hills (De Rita and Zarlenga 2001; Heiken et al. 2005).

A local range for the area of Isola Sacra has been derived from published results examining $^{87}Sr/^{86}Sr$ in the area around Rome and extending along the Tiber to the Tyrrhenian coast. Data were compiled from tests of mineral water values (Voerkelius et al. 2010), geology (Barbieri et al. 1979; Federico et al. 1994; Barbieri and Sappa 1997; Brems et al. 2013), examinations of paleofauna (Palombo et al. 2005; Pellegrini et al. 2008), and archaeofauna and local human values (Killgrove 2010a, 2013; Killgrove and Montgomery 2016). Taking these published values into consideration, which reflect the mixture of sedimentary Plio-Quaternary values of the coastal Tiber region, contributions from sea water (0.7092), as well as the increasingly volcanic signatures of the area surrounding the Tiber valley and forming a significant portion of the region around Rome, it was possible to establish an expected local range of between 0.70790–0.71030. This expected local range for Isola Sacra corresponds fairly well with the proposed statistical "non-local" identifier recommended by Grupe et al. (1997), as being any individuals that fall outside two standard deviations of the mean, which for the 20 individuals sampled from SCR in the present study provides an expected local range of

0.70737–0.71027. Based on the expected local range, 3/20 (15%) individuals sampled from Isola Sacra appear non-local (Figure 6.6, Table 6.2).

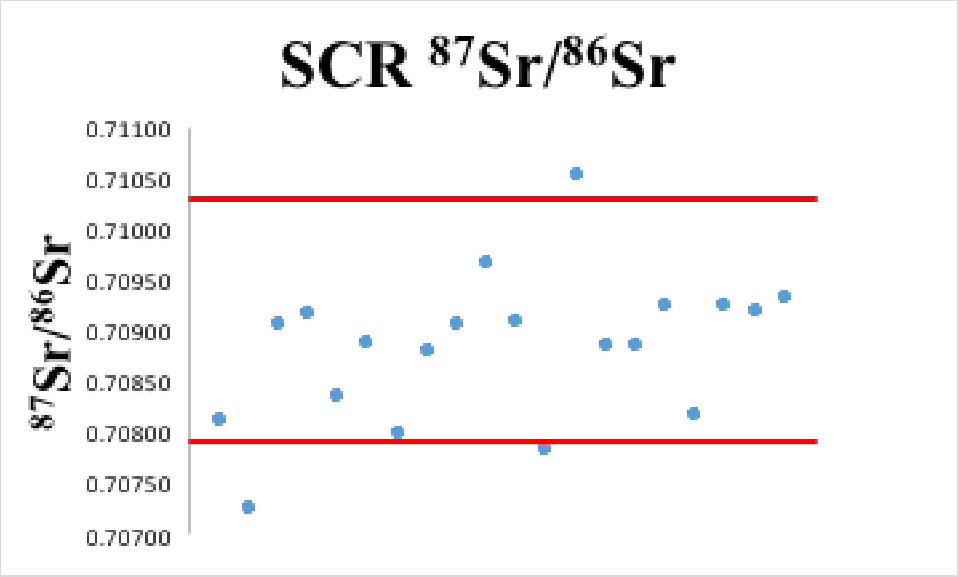

Figure 6.6–Strontium results for Isola Sacra (SCR, n= 20). Horizontal red lines indicate the expected $^{87}Sr/^{86}Sr$ local range (2σ).

6.3.3–Rue Jacques Brel Necropolis (JBR) $^{87}Sr/^{86}Sr$ Results

Saintes, France, where JBR is located, is situated in a region of predominantly Late Cretaceous geology, namely Santonian-Campanian, Saintes being the namesake of the Santonian geological age. Saintes is situated between areas dominated by Jurassic geology in the north, beginning around Saint-Jean-d’Angély, and Pliocene-Pleistocene geology in the south, beginning around Bordeaux. The region around Saintes is dominated by limestones, including fossiliferous, bioclastic and argillaceous, with some gravely areas, clay, marl, and riverine Holocene sands (Kelly 2007; Aquilina et al. 2013; Willmes et al. 2014; OneGeology 2016).

Based on bioavailable $^{87}Sr/^{86}Sr$ values of soils and biota compiled by Willmes et al. (2014) as part of the Isotopic Reconstruction of Human Migration (IRHUM) project, the area around Saintes has an expected $^{87}Sr/^{86}Sr$ range of 0.70760–0.71000 (Figure 6.7), a range that is further supported by the soil and plant samples presented by Kelly (2007).

Based on this expected range 6/20 (30%) of the individuals sampled for $^{87}Sr/^{86}Sr$ from JBR have a non-local signature (Figure 6.8, Table 6.2).

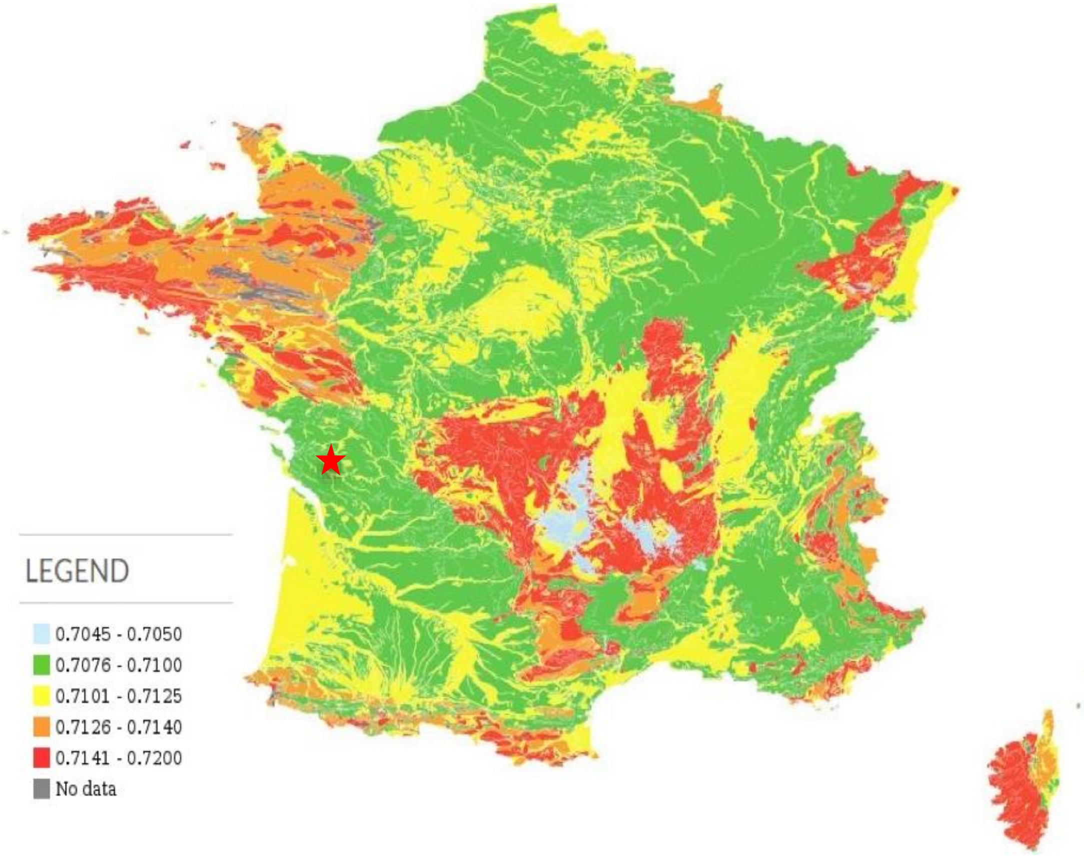

Figure 6.7– $^{87}Sr/^{86}Sr$ value map of France, red star indicates the location of Rue Jacques Brel Necropolis (strontium range data and map used under Creative Commons 3.0 License from IRHUM–Isotopic Reconstruction of Human Migration, Willmes et al. 2014).

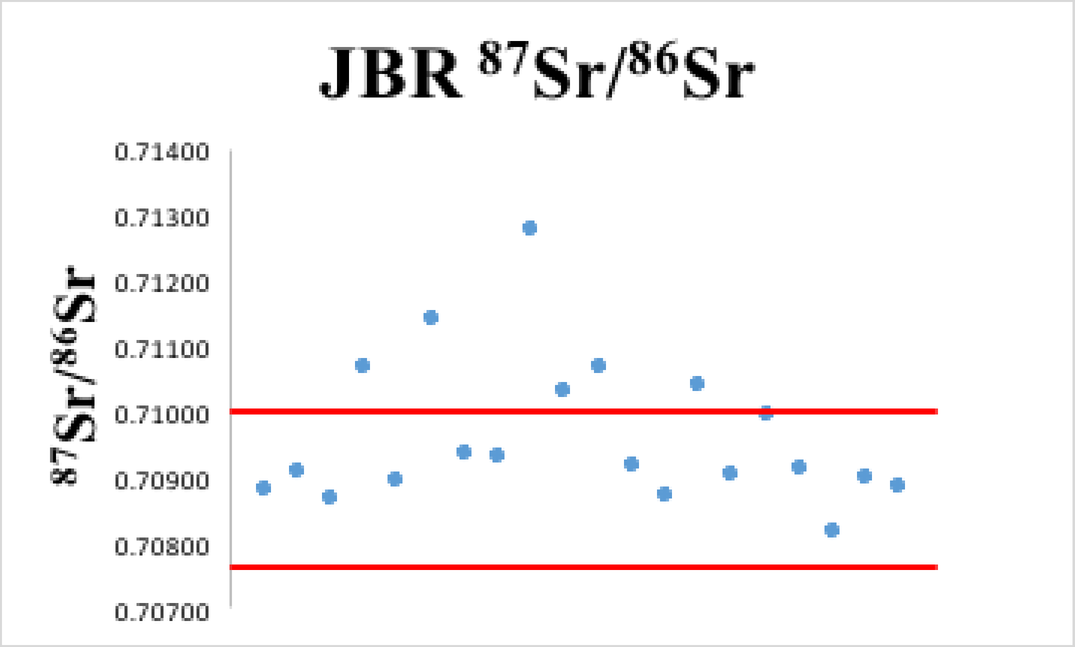

Figure 6.8–Strontium results for Rue Jacques Brel Necropolis (JBR, n= 20). Horizontal red lines indicate the expected $^{87}Sr/^{86}Sr$ local range (2σ).

6.4–Combined $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ Results

6.4.1–Combined Isotopic Results for Rue Jacques Brel Necropolis (JBR)

Of the twenty individuals sampled for both $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ from Rue Jacques Brel Necropolis (JBR) eight individuals (Male= JBR 84, 106, 111, 122; Female= JBR 8, 16, 18, 103) fall within the local range for both $\delta^{18}O_c$ (1σ) and $^{87}Sr/^{86}Sr$ (Figure 6.9, Table 6.2). Five individuals (Female= JBR 55, 56, 86, 101, 110) fall within the local $^{87}Sr/^{86}Sr$ range but have enriched non-local $\delta^{18}O_c$ (1σ) signatures. One individual falls within the local $^{87}Sr/^{86}Sr$ range but has a non-local depleted $\delta^{18}O_c$ (1σ) signature. Two individuals (Male= JBR 35, 63) fall within the local $\delta^{18}O_c$ (1σ) range but outside of the local $^{87}Sr/^{86}Sr$ range. There are four non-local individuals (Male= JBR 76; Female= JBR 54, 64, 98) who fall outside of both the local $^{87}Sr/^{86}Sr$ and $\delta^{18}O_c$ (1σ) ranges, having enriched

$^{87}Sr/^{86}Sr$ signatures and lower $\delta^{18}O_c$ (1σ) signatures. None of the individuals sampled fall outside of the 2σ or 1.5*IQR $\delta^{18}O_c$ ranges.

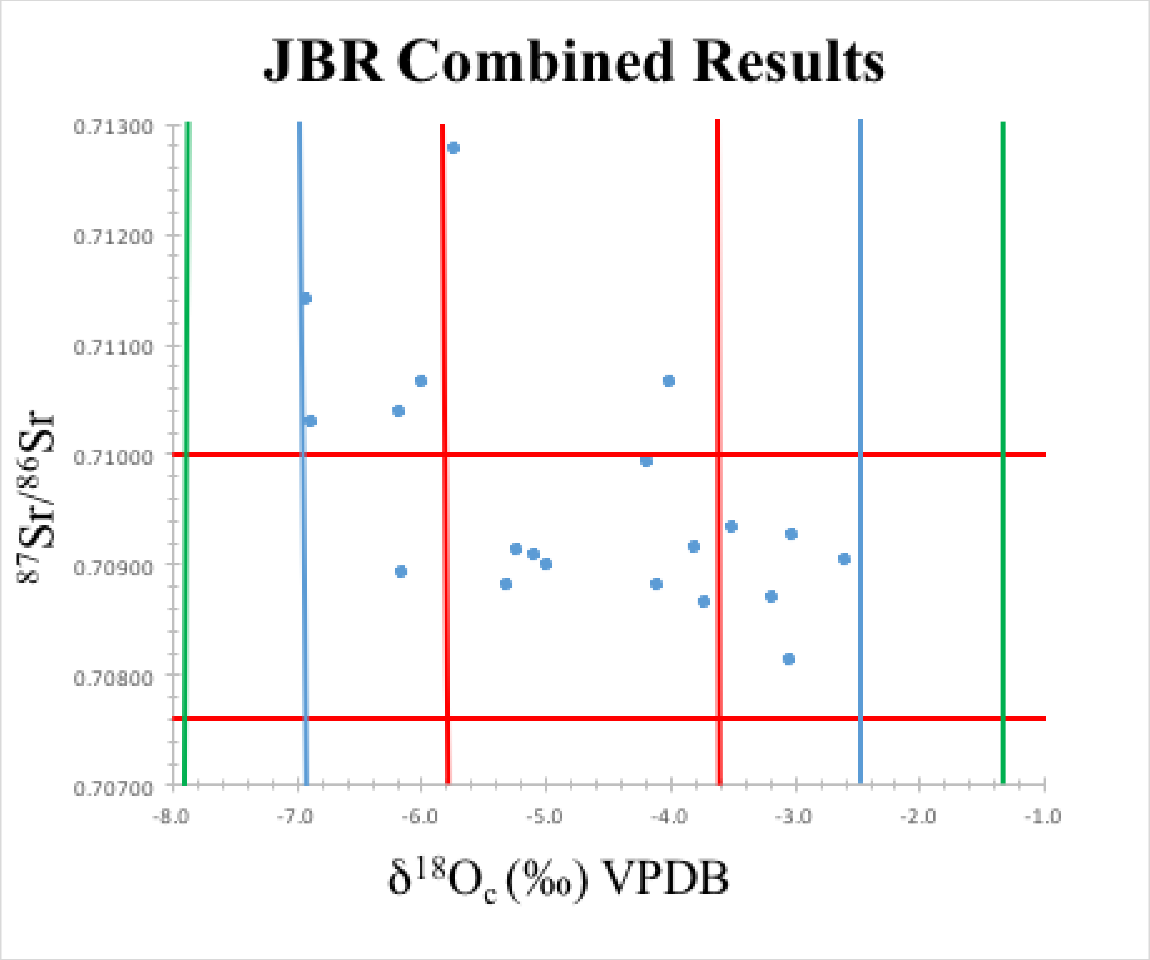

Figure 6.9–Combined $\delta^{18}O_c$ (‰) VPDB and $^{87}Sr/^{86}Sr$ results for Rue Jacques Brel Necropolis (JBR) with expected local $^{87}Sr/^{86}Sr$ (2σ) (horizontal red lines), $\delta^{18}O_c$ (1σ) (vertical red lines), $\delta^{18}O_c$ (2σ) (vertical blue lines), and $\delta^{18}O_c$ 1.5*IQR (vertical green lines).

6.4.2–Combined Isotopic Results for Isola Sacra

Of the twenty individuals sampled for both $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ from Isola Sacra nine individuals (Male = SCR 127, 430, 485, 525; Female= 106, 245, 321, 411, 484), fall within both the local $\delta^{18}O_c$ (1σ) and $^{87}Sr/^{86}Sr$ ranges (Figure 6.10, Table 6.2). Two individuals (Male= SCR 99; Female= SCR 324) fall within the local $\delta^{18}O_c$ (1σ) range but outside of the local $^{87}Sr/^{86}Sr$ range. Six individuals (Male= SCR 171, 174, 361; Female=

SCR 269, 285, 287) fall within the local $^{87}Sr/^{86}Sr$ range but outside of the $\delta^{18}O_c$ (1σ) range. Two individuals (Female= SCR 68, 320) fall within the local $^{87}Sr/^{86}Sr$ range but outside of the $\delta^{18}O_c$ (2σ) range. One individual (Male= SCR 376) falls outside both the local $^{87}Sr/^{86}Sr$ and $\delta^{18}O_c$ (1σ) ranges. None of the individuals sampled fall outside of the 1.5*IQR $\delta^{18}O_c$ range.

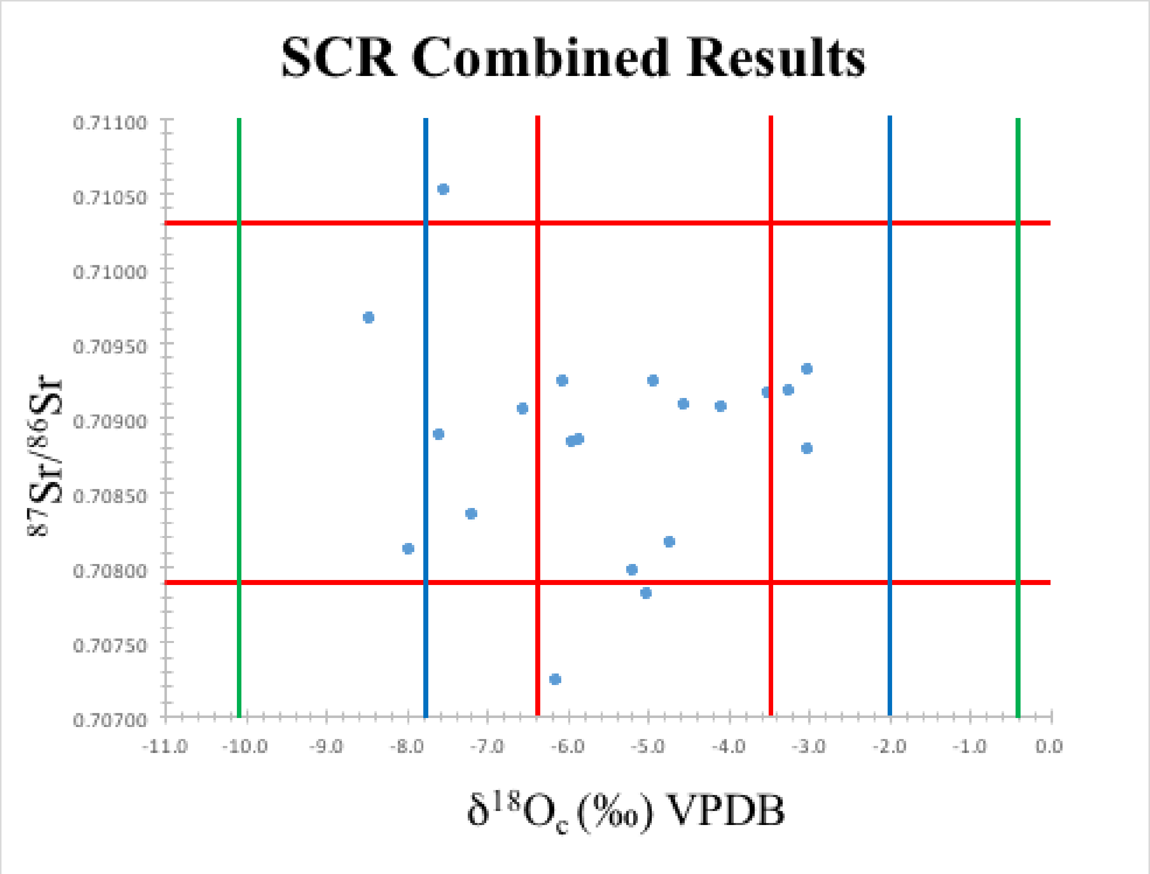

Figure 6.10– Combined $\delta^{18}O_c$ (‰) VPDB and $^{87}Sr/^{86}Sr$ results for Isola Sacra (SCR) with expected local $^{87}Sr/^{86}Sr$ (2σ) (horizontal red lines), $\delta^{18}O_c$ (1σ) (vertical red lines), $\delta^{18}O_c$ (2σ) (vertical blue lines), and $\delta^{18}O_c$ 1.5*IQR (vertical green lines).

6.4.3–Combined Isotopic Results for Velia

At Velia of the 20 individuals sampled for $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$, fifteen individuals (Male= SCR 139, 146, 160, 169, 174, 182, 186, 222; Female= SCR 82, 117, 181, 214, 223, 270, 283) fall within the local $\delta^{18}O_c$ (1σ) and $^{87}Sr/^{86}Sr$ ranges (Figure 6.11, Table 6.2). Four individuals (Male= SCR 194, 211; Female= 134, 205) fall within the local ^{87}Sr/^{86}Sr range and outside of the local $\delta^{18}O_c$ (1σ) range. One individual (Male= SCR 57) falls within the local ^{87}Sr/^{86}Sr range but outside of both the 2σ and 1.5*IQR $\delta^{18}O_c$ ranges.

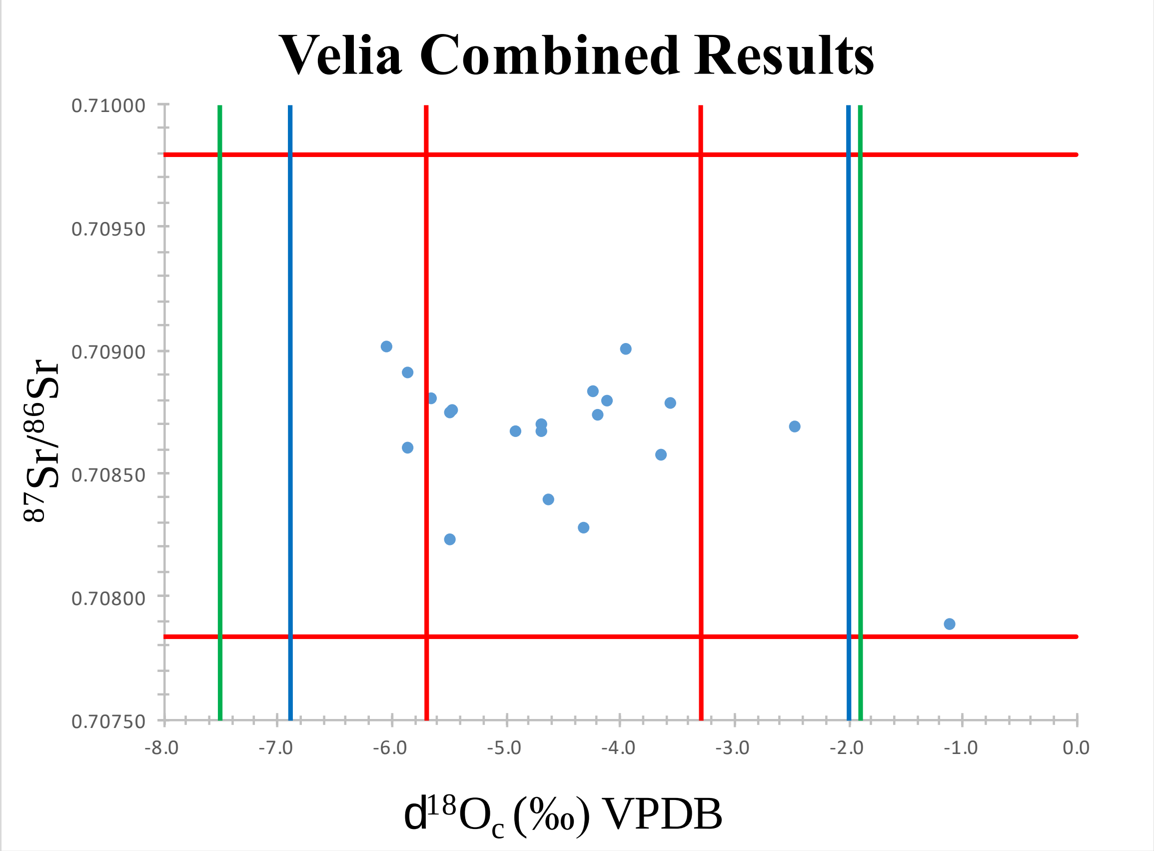

Figure 6.11– Combined $\delta^{18}O_c$ (‰) VPDB and ^{87}Sr/^{86}Sr results for Velia with expected local ^{87}Sr/^{86}Sr (2σ) (horizontal red lines), $\delta^{18}O_c$ (1σ) (vertical red lines), $\delta^{18}O_c$ (2σ) (vertical blue lines), and $\delta^{18}O_c$ 1.5*IQR (vertical green lines).

6.5–Summary of Isotopic Results

Based on the results of the samples isotopically analyzed from Isola Sacra, Velia, and Rue Jacques Brel Necropolis there are clear indications of mobility among women and men at all three sites. The proportion of mobile individuals evident at all three sites varies with the isotopic method used, with $\delta^{18}O_c$ suggesting the largest number of mobile individuals, while ^{87}Sr/^{86}Sr and combine oxygen and strontium suggest a lower number of mobile individuals (Table 6.5). Though these methods are complementary, regional variation in one or the other isotopic signature may over or underestimate the number of mobile individuals depending on which region(s) individuals moved from and between during M2 formation, as well as potentially due to regional isotopic signal homogeneity and factors such as sea spray, imported foods, and variable water source exploitation.

Table 6.5–Non-local individuals from SCR, JBR, and Velia identified by isotopic analyses.

Non-Local Individuals	**$\delta^{18}O_c$ (1σ)**	**$^{87}Sr/^{86}Sr$**	**Combined**
SCR	28/80 (35%)	3/20 (15%)	1/20 (5%)
JBR	15/39 (38%)	6/20 (30%)	4/20 (20%)
Velia	5/20 (25%)	0/20 (0%)	0/20 (0%)

From the data gathered through M1 vs. M2 vs. M3 analysis it is evident that childhood mobility was occurring among a number of the individuals who were ultimately interred at Isola Sacra. The results of this multi-tooth analysis suggest several patterns of mobility as well as numerous potential regions of mobility and migration. The implications of the isotopic signatures of the respective individuals examined in this study will be discussed in greater depth in tandem with the nonmetric trait results in Chapter 8–Discussion.

Part 2–Nonmetric Trait Results

6.6–Nonmetric Traits

6.6.1–Trait Selection

An examination of nonmetric traits was undertaken on a sample of 302 individuals, 51 individuals from Rue Jacques Brel necropolis (JBR), 62 individuals from Velia, and 189 individuals from Isola Sacra (SCR) to assess the degree of phenetic similarity and divergence between these sites (Table 5.2).

To achieve this objective, cranial (Hauser and De Stefano 1989; Buikstra and Ubelaker 1994), infra-cranial (Anderson 1987; Saunders 1989), and dental (Turner et al. 1991; Scott and Turner 1997) nonmetric traits were examined. From a suite of 57 traits (20 cranial, 10 infracranial, 27 dental) observed across 177 loci 26 traits were identified through the MMD R-Script of Soltysiak (2011) as the most discriminatory for the purpose of mean measure of divergence (MMD) analysis (Table 6.6, see Appendix D for a full list of traits recorded).

Table 6.6–Nonmetric traits (NMT) used for conducting MMD analyses of the individuals from JBR, SCR, and Velia, showing: number present/total observed (%), intra-observer results, and break points (after Turner et al. 1991; Scott and Turner 1997) for scoring traits where, P= present, A= absent. CVBFT= cervical vertebrae bipartite transverse foramen.

Trait	JBR	SCR	Velia	Intra-Observer	Break Point
Metopic Suture	2/25 (8.0%)	6/117 (5.2%)	9/39(23.1%)	54/54 (100%)	P/A
Parietal Foramen L.	13/26 (50%)	44/122 (36.1%)	15/41(36.6%)	52/54 (96%)	P/A
Coronal ossicle R.	1/18 (5.6%)	7/97 (7.3%)	0/29 (0.0%)	54/54 (100%)	P/A
Saggittal ossicle	0/17 (0.0%)	2/100 (2.0%)	3/35 (8.6%)	53/54 (98%)	P/A
Apical ossicle	2/19 (10.6%)	14/103 (13.6%)	0/33 (0.0%)	53/54 (98%)	P/A
Lambdoidal ossicle L.	4/19 (21.1%)	52/110 (47.3%)	13/37 (35.2%)	50/54 (93%)	P/A
Asterionic ossicle R.	0/16 (0.0%)	9/85 (10.6%)	3/30 (10.0%)	51/54 (94%)	P/A
Inca Bone	2/25 (8.0%)	2/113 (1.8%)	0/40 (0.0%)	54/54 (100%)	P/A
Divided hypoglossal canal L.	12/31(38.8%)	27/100 (27.0%)	17/39 (43.6%)	52/54 (96%)	P/A
Tympanic dihiscence R.	4/29 (13.8%)	10/121 (8.3%)	1/43 (2.4%)	54/54 (100%)	P/A
Mental foramen R.	33/34(97.1%)	106/126 (84.2%)	54/55 (98.2%)	53/54 (98%)	P/A
Mylohyoid bridge L.	3/29 (10.4%)	27/120 (22.5%)	15/54 (27.8%)	51/54 (94%)	P/A
Atlas foramen double R.	0/28 (0.0%)	3/96 (3.2%)	6/43 (14.0%)	51/54 (94%)	P/A
Retro-articular bridge R.	1/19 (5.3%)	9/87 (10.4%)	12/38 (31.6%)	53/54 (98%)	P/A
CVBFT R.	10/20(50.0%)	30/92 (32.7%)	11/44 (25.0%)	50/54 (92%)	P/A
Supracondylar spur R.	3/42 (7.2%)	3/163 (1.9%)	1/63 (1.6%)	54/54 (100%)	P/A
Calcaneal facet divided L.	16/30(53.4%)	52/135 (38.6%)	29/66 (44.0%)	50/54 (93%)	P/A
Interruption grove UI2L	3/15 (20.0%)	10/84 (12.0%)	13/30 (43.4%)	51/54 (94%)	≥ Grade 1
Tuberculum dentale UI2R	0/13 (0.0%)	2/83 (2.5%)	8/32 (25.0%)	54/54 (100%)	≥ Grade 1
Canine mesial ridge UCR	0/21 (0.0%)	1/92 (1.1%)	4/36 (11.2%)	53/54 (98%)	≥ Grade 1–3
Cusp 5 UM2R	2/23 (8.7%)	8/105 (7.7%)	0/34 (0.0%)	54/54 (100%)	Grade 1-5
C2.parastyle UM1R	0/19 (0.0%)	0/101 (0.0%)	3/29 (10.4%)	53/54 (98%)	≥ Grade 1
Premolar ling. Cusp LP2R	6/28 (21.5%)	13/103 (12.7%)	3/48 (6.3%)	53/54 (98%)	≥ Grade 1
Groove Y LM1R	24/25(96.0%)	88/109 (80.8%)	16/39 (41.1%)	50/54 (93%)	Y-pattern
Cusp 7 LM1R	0/24 (0.0%)	7/93 (7.6%)	1/37 (2.8%)	54/54 (100%)	Grade 1-4
Enamel extension UM3L	3/17 (17.7%)	0/79 (0.0%)	0/39 (0.0%)	50/54 (93%)	≥ Grade 2–3

Numerous traits can occur bilaterally in respective antimeres (e.g. tuberculum dentalae) however only one side is used in MMD analysis to avoid false correlation and overrepresentation caused by essentially recording the same trait in two locations. The same is true of traits that occur on multiple elements (e.g. enamel extension). In these cases both sides and all elements in which a trait occurs are initially recorded and then the most discriminating of the trait locations is utilized in the final MMD analysis. As a result of this process of utilizing traits in one antimere and one element, coupled with removal of the least discriminatory traits, the number of traits used in MMD analysis was reduced to 26 highly discriminatory traits, allowing for the most robust MMD analysis results. For the approximately sex balanced sample of 302 individuals examined from SCR, JBR, and Velia (see Table 5.2) no disparity in trait manifestation between the sexes was evident at the 0.05 level using chi-squared. Given the absence of sex bias in trait manifestation, males and females were pooled for MMD biodistance calculation (see Irish 1997, 2005). Intra-observer test results for all traits employed in MMD analysis was >90% providing a degree of confidence and reproducibility significantly greater than random probability, indicating that the traits utilized in MMD analysis for this study have been accurately recorded and represented.

6.6.2–MMD Results

Based on the MMD analyses using the R-Script presented by Soltysiak (2011) a matrix of phenetic divergence was derived (Table 6.7). MMD matrices utilize 0 to signify high similarity of compared samples, while 1 indicates high dissimilarity. Values between 0 and 1 indicate varying degrees of divergence between compared samples (Sjøvold 1977).

Table 6.7–Matrix of MMD values for JBR, SCR, and Velia. Values in yellow below the diagonal are MMD values, values in green above the diagonal are standard deviations (SD), with 2*SD in brackets. For all three sites the MMD is >2*SD, thus rejecting the null hypothesis that Sample Population 1 = Sample Population 2 at the 0.025 level (Sjøvold 1977; Irish 2005).

Combined Traits MMD	**JBR**	**SCR**	**Velia**
JBR		0.01586 (0.03172)	0.02042 (0.04084)
SCR	0.04258		0.01004 (0.02008)
Velia	0.1955	0.13916	

Using the protocol established in Sjøvold (1977) all MMD values in the present study reject the null hypothesis, being that the compared samples are the same (P1 = P2), at the 0.025 confidence level when the MMD value is greater than two times the standard deviation (2*SD) (Irish 2005). This qualification has been met by all three samples in the present study, indicating that the three samples are biologically distinct from one another. For the MMD comparison of JBR, SCR, and Velia it is evident that the degree of divergence between the three sites overall is rather small, with all three sites appearing relatively similar, suggesting a broadly uniform biological background composition of these three sites. Based on the MMD results it is evident that JBR and SCR are more similar than SCR and Velia, while JBR and Velia are the most biologically dissimilar.

6.6.3–MMD Analyses of Individual Trait Regions

In an attempt to gauge the input of the various regions of trait formation (i.e. cranial, infra-cranial, and dental), individual MMD runs were conducted using the R-Script of Soltysiak (2011) for the most discriminating traits from each region (Table 6.8). Based on the results of this sub-analysis the same pattern of divergence remains largely evident as with the combine trait MMD analysis, where JBR and SCR are the most similar to each other and SCR and Velia are more divergent yet still more similar to each other than JBR and Velia, which remain the most divergent in all MMD runs. A biological relationship that can be represented as JBR→SCR←Velia.

From the sub-analyses it appears evident that the three different regions contribute different levels of discrimination, with dental traits suggesting the greatest degree of divergence. The pattern of divergence remains highly similar across all three trait regions, with the exception of the MMD using cranial traits where the divergence between Velia and SCR, and Velia and JBR are nearly equal. When using cranial and infra-cranial traits alone the divergence between JBR and SCR falls within 2*SD, suggesting a high degree of biological homogeneity between these two samples (Sjøvold 1977). When using dental nonmetric traits, the relationship between JBR and SCR rejects the null hypothesis that P1=P2 at the 0.025 level. Velia rejects the null hypothesis that P1=P2 at the 0.025 level in all cases when gauged against both JBR and SCR, having MMD values >2*SD across all traits and the overall greatest degree of divergence between samples.

Table 6.8– Matrix of MMD values according to infra-cranial, cranial, and dental nonmetric traits for JBR, SCR, and Velia. Values in yellow below the diagonal are MMD values, values in green above the diagonal are standard deviations (SD), with 2*SD in brackets.

Infra-Cranial (traits= 9)	***JBR***	***SCR***	***Velia***
JBR		0.02264 (0.04528)	0.02815 (0.05630)
SCR	0.01066		0.01473 (0.02946)
Velia	0.12199	0.04867	
Cranial (traits= 13)	***JBR***	***SCR***	***Velia***
JBR		0.02109 (0.04218)	0.02785 (0.05570)
SCR	0.03979		0.01401 (0.02802)
Velia	0.07289	0.07589	
Dental (traits= 13)	***JBR***	***SCR***	***Velia***
JBR		0.02579 (0.05158)	0.03211 (0.06422)
SCR	0.060048979		0.01528 (0.03056)
Velia	0.3405	0.14482	

6.7–Nonmetric Trait Results Summary

Overall when gauging MMD values across trait types the same pattern of divergence is present as when using the combined traits from all three regions for MMD analysis. There is a clear biological divergence between the three sites examined, with Velia being the most dissimilar. When considered in the broader scope of regional and global variation the three sites suggest a relatively similar biological background, indicating that though biologically distinct, the phenetic history of these sites appear to have more in common than not.

Chapter 7–Discussion

7.1–Mobility and Isotopic Perspectives

The results of isotopic analyses using $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ have yielded a number of insights regarding the nature of mobility at SCR, JBR, and Velia. The isotopic evidence gathered clearly shows that males, females, and children were mobile at these sites. This chapter discusses the implications of these findings as well as the types of mobility events evident among the individuals examined from these three sites. This chapter provides a larger synthesis of the data results presented through discussion of differences in childhood mobility between M1 vs. M2 vs. M3 molars, as well as implications for female mobility in the Roman landscape, and insights to possible regions from which individuals may have migrated based on their M2 isotopic signature. This chapter also looks at isotopic signatures and water sources in regard to their ability to draw inferences about regional origins, as well as using grave goods and epigraphic evidence to connect isotopic instances of non-local status with individuals buried at these three sites. Lastly, discussion is provided regarding the use of nonmetric traits, previous nonmetric trait studies from Roman contexts, and the implications of the nonmetric trait results from the present dissertation. The discussion provided in this chapter provides a greater depth of insight to the nature of human mobility at SCR, JBR, and Velia, providing a testament to mobility events consistent with a transnational process of human movement and networks of relations across the Imperial Roman landscape.

7.1.1–M1 vs. M2 vs. M3 and Childhood Mobility at Isola Sacra

7.1.1.1–Childhood Mobility

Childhood mobility in the Imperial Roman era remains a contentious issue. Textual and epigraphic sources provide little insight to childhood mobility and as a result when relied upon exclusively imply limited childhood mobility (Bruun 2010, 2016). Instances of adoption, enslavement, seasonal mobility, and employment have all been identified from epigraphic and textual sources as potential mechanisms for childhood mobility

(Edmonson 1987; Erdkamp 2016; Holleran 2016; Tacoma and Tybout 2016). Isotopic investigations have shown that childhood mobility was in fact a reality of the Roman landscape (Prowse et al. 2007, 2010a; Prowse 2016; Killgrove and Montgomery 2016). The question then is to what degree children were mobile and to what end. Based on the $\delta^{18}O_c$ signatures of M1 vs. M2 vs. M3 for a sample of 20 individuals from Isola Sacra there are clear instances of both male and female childhood mobility, as well as children who remained local throughout their dental development. Of the non-local children, a number of different patterns of mobility are apparent.

7.1.1.2–Local Individuals

Six individuals, 30% of the sample, have signatures within the local $\delta^{18}O_c$ range for Isola Sacra across all three teeth suggesting long term residency in the region. Variation in $\delta^{18}O_c$ across all three molars among these individuals reaches a maximum of 1.6‰ in the case of SCR 245. A 1‰ variation from the $\delta^{18}O_c$ mean is expected in sedentary populations (Longinelli 1984; Daux et al. 2008). This suggests that while local, variable water and food sources and/or preparation thereof (i.e. stewing, brewing) may have been exploited by individuals such as SCR 245, or that mobility within the local region was undertaken such that the individual remained in the local $\delta^{18}O_c$ region but may not have resided at the same locale for the entire time (Brettell et al. 2012a,b) allowing for an averaging of $\delta^{18}O_c$ values within the local range.

It also remains possible, given instances of isotopic homogeneity, that these individuals simply fall within the expected local range but were mobile from regions with similar $\delta^{18}O_c$ signatures. These individuals have been identified here as local following what is believed to be the most parsimonious interpretation.

7.1.1.3–Local M1, Non-Local M2 and M3

Two individuals, 10% of the sample, with non-local M2 and M3 signatures appear to have been absent from the area around Portus from not long after birth until after ~18 years old. It is impossible to say if these individuals returned shortly after M3 formation or if they returned significantly later in life. The fact that these two individuals returned to

Portus after M3 formation may imply that they originally resided at Portus and left to accompany a family member stationed abroad, possibly for work, diplomatic, or military service (Hoffman 1995; Hassall 1999; Allison 2006a,b; Prowse et al. 2007; Hin 2016; Holleran 2016; Tacoma and Tybout 2016). Both individuals in this mobility category are female, which may have implications as to the nature of mobility undertaken. It is possible these women returned to Portus as brides (Tacoma and Tybout 2016). For females, marriage in the Roman era generally took place after puberty (~12–14 years) with marriage in the teenage years being the most typical, though there is epigraphic evidence that marriage before puberty, potentially as early as 6 years of age, did take place (Shaw 1987). Marriage at such a young age may not have been common, but it was also not expressly legally prohibited nor entirely socially unacceptable (Hopkins 1965; Shaw 1987). It is also possible that these female individuals were mobile for work or, if travelling with family, simply returned home following cessation of foreign work/service of a family member (Garnsey and De Ligt 2016). Based on their M2 and M3 $\delta^{18}O_c$ signatures, these two individuals resided in different locations. The $\delta^{18}O_c$ signature of SCR 68 is consistent with residency in a cooler environment such as the interior of Italy, particularly northern Italy, and/or mountainous regions such as the Apennines or Alps, while the $\delta^{18}O_c$ signature of SCR 199 is consistent with residency in a warmer potentially coastal region, such as North Africa or the Eastern Mediterranean (Longinelli and Selmo 2003; GNIP 2015).

7.1.1.4–Non-Local M1, Local M2 and M3

The two individuals (SCR 435, 525), both male, who fall into this category suggest settlement at Portus at a young age. The $\delta^{18}O_c$ signatures of both of these individuals' M1s are lower compared to the expected local range, implying they migrated to Portus from a cooler non-coastal region, possibly the interior of the Italian peninsula (Longinelli and Selmo 2003). The purpose for migration is uncertain, though slavery, adoption, and family mobility, among other possibilities cannot be ruled out (Harris 1980; Bagnall and Frier 1994; Scheidel 1997; Tacoma and Tybout 2016).

7.1.1.5–Non-Local M1 and M2, Local M3

The four individuals, or 20% of the sample, in this category moved to the area of Portus after age ~7–8 years. The $\delta^{18}O_c$ signature of SCR 133 (male) suggests a progressive move towards the Italian coast. An M1 $\delta^{18}O_c$ signature of -7.1‰ and an M2 of -6.4‰ may indicate that this individual was born in the north or interior of the Italian peninsula, moved after M1 formation toward the coast, and ultimately ended up in a coastal locale by the time M3 formation was taking place around age 10 years. SCR 174 (male) has M1 and M2 signatures consistent with a similar residency, potentially in the interior of the Italian peninsula. SCR 320 (female) has a more complicated $\delta^{18}O_c$ signature with M1 and M2 signatures of -8.2‰ and -8.5‰, respectively, suggesting a uniform location of residency in a more northerly region such as southern Germany (Cortecci and Longinelli 1968; Longinelli and Cortecci 1970; Siegenthaler et al. 1970; Schwarcz and Cortecci 1974; GNIP 2015), before moving after age ~7–8 years old to a region with an $\delta^{18}O_c$ value consistent with that of Portus. Finally, SCR 361 (male) has an interesting signature in that $\delta^{18}O_c$ of M1 is only 0.1‰ lower than the local SCR range, suggesting residency in the area of Portus, while $\delta^{18}O_c$ M2 is higher at -3.0‰. This suggests a move of significant distance between completion of M1 and M2 (i.e., between the ages of 2.5–3 years and 7–8 years), and subsequent M3 completion ~10–17.5 years, when this individual would have ostensibly been residing in the region of Portus. The presence of an M2 value of -3.0‰ suggests residency in a warmer region such as North Africa, with similar values commonly recorded in Algeria, Tunisia and Egypt (GNIP 2015). This substantial change in $\delta^{18}O_c$ may be evidence that this individual was involved with the grain supply of Rome from North Africa either actively, as a young laborer, or possibly accompanying a parent involved in the grain trade or other overseas duties requiring mobility between the two locations (Rickman 1980; Pomey 1997; De Ligt and Tacoma 2016).

7.1.1.6–Local M1 and M2, Non-Local M3

The M3 $\delta^{18}O_c$ signature of SCR 448 (male) is -6.3‰. Such a signature may suggest that this individual did not move very far from the region of Portus and may in fact have been residing in and around the environs of Rome, which has an annual average $\delta^{18}O_{dw}$ of

-5.7‰ (Longinelli and Selmo 2003), and its hinterland for the extent of M3 development. The aqueduct at Portus is known to have exploited water from the region of Ponte Galeria (see 7.3.1 below), while Rome is known to have exploited several sources of water through aqueduct construction (Ashby 1935; Killgrove and Montgomery 2016). Given the similarity to the expected local signature for Portus it is possible that this individual was locally mobile between Portus and Rome, perhaps in association with transhipment along the Tiber, resulting in an averaging effect of his $\delta^{18}O_c$ signature.

7.1.1.7–Local M1 and M3, Non-Local M2

The five individuals, 25% of the sample, who have a non-local M2 but local M1 and M3 $\delta^{18}O_c$ signatures suggest several scenarios. The non-local signature of the M2s suggests that these individuals were away for a significant period of time but ultimately returned within a few years, allowing for the establishment of a local M3 signature. This pattern of $\delta^{18}O_c$ values may imply that these individuals were mobile with a parent, or adult, involved in long distance trade or stationed at a foreign post requiring years of absence from the area of Portus before returning (Hadley and Hemer 2011). Given the commercial nature of Portus it is not improbable that younger children were taken with a parent or as young apprentice workers for an extended period while engaging in trade away from Portus (Tacoma and Tybout 2016). Interestingly 4 out of 5 of these individuals (SCR 194, 220, 250, 462) have M2 $\delta^{18}O_c$ signatures between -3.6‰ and -3.3‰, suggesting mobility to a similar region. As was noted previously, individuals exhibiting $\delta^{18}O_c$ values in this range may have been mobile to North Africa, potentially as part of the grain supply network for Rome (Rickman 1980; Prowse et al. 2007; De Ligt and Tacoma 2016). The remaining individual (SCR 500) has an M2 $\delta^{18}O_c$ signature of -6.3‰, suggesting a similar residency pattern to SCR 448, potentially in the areas around Portus and Rome.

7.1.1.8–Interpreting Childhood Mobility

The analysis of M1 vs. M2 vs. M3 $\delta^{18}O_c$ signatures has shown that childhood mobility was not only taking place but that, based on this sample, it was occurring fairly regularly. It must however, be kept in mind and reiterated that though isotopic methods of analysis can indicate whether an individual was mobile or not during periods of their lifetime, isotopic methods cannot attest to the motivation behind why a person was moving (Bruun 2010, 2016). For this, one must turn to corroborating evidence in the historical, epigraphic, and archaeological literature, which has been the basis of the suggested reasons for mobility presented here. What can be taken away from the findings presented here is that not only was Portus and the area around Rome a key destination of mobility for individuals of all ages and sexes (See Noy 2000), it was also a place from which individuals departed and went elsewhere, creating an environment in which individuals and groups of individuals were both coming in and going out, a place of both centripetal and centrifugal mobility, seeing people arriving and leaving for various periods of time before returning. Such a finding confirms more recent views of increasingly transnational mobility in the Roman world, where individuals can occupy more than one role at a time and can maintain ties to both their current residence location as well as previous and future locations, creating a web of connectivity rather than a unidirectional line of singular mobility events (Appadurai 1991; Killgrove 2010a,b, 2014; Glick Schiller and Caglar 2011; Ross 2013).

As discussed previously in Chapter 2, and further below in Section 7.2, it is possible that a number of the children who appear to have been born locally (local M1), and moved away from Portus (non-local M2 and/or M3), before returning to the area of Portus, were in fact not born at Portus but were born in a region of homogeneous $\delta^{18}O_{dw}$ values, potentially changing their mobility experience from circular to multi-stage directional. To examine this potentiality it would be of value in a future study to further investigate the M1 vs. M2 vs. M3 $^{87}Sr/^{86}Sr$ signatures of individuals in this category to see if their respective $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ values align. In the present study only six of the individuals (SCR 68, 174, 245, 320, 361, 525) included in the M1 vs. M2 vs. M3 study were also examined, using second molars, for $^{87}Sr/^{86}Sr$. The second molars of all six individuals fall within the local Isola Sacra $^{87}Sr/^{86}Sr$ range. None of these six individuals fall into the category of local M1, non-local M2, local M3, and as such do not shed any further light on the potential mobility patterns of these individuals. The only individual for which $^{87}Sr/^{86}Sr$ may provide further information in the present case is SCR 68. This individual has an M1 in the local $\delta^{18}O_c$ range and non-local M2 and M3, with a local $^{87}Sr/^{86}Sr$ signature of 0.70811 from her M2. Based on the M1 $\delta^{18}O_c$ signature it appears this individual left Portus to reside in the environs of northern Italy extending into southern Germany, where similar $^{87}Sr/^{86}Sr$ values are expected, before returning to Portus as an adult. It is also possible that this individual was born in the area of coastal northwestern Italy (a region in the same $\delta^{18}O_{dw}$ zone as Portus) before moving into the region of Piedmont/Lombardy and on to southern Germany, regions where $\delta^{18}O$ values of -7.0‰ to -8.0‰ are expected, before ultimately coming to reside in the environs of Portus where this individual was interred (Gelati et al. 1989; Longinelli and Selmo 2003). What this interpretation shows, is that in cases of overlapping or homogenous isotopic signatures more than one interpretation of mobility may be possible. It remains equally plausible that SCR 68 undertook circular mobility (being born at Portus, left, and then chose to return later in life), as it does that SCR 68 was born elsewhere on the Italian coast, moved into the cooler northern environs, before ultimately migrating to Portus.

Though it is possible, in several instances, to provide multiple interpretations of the mobility events evident among these individuals, it is also clear that these individuals were not simply migrating to Portus and not looking back, though surely some did just this. Rather in several cases, comprising men, women, and children, individuals came and went. To what end these mobility events were undertaken is not permitted by isotopic insights, but what is clear is that they happened, be it for trade, slavery, work, mobility to accompany a spouse or family member, or simply to travel to a homeland before returning to Portus, creating a cosmopolitan tapestry of mobility events consistent with transnationalism models of human migration among the individuals interred at Isola Sacra (Brettell 2015; De Ligt and Tacoma 2016).

7.1.2–Childhood Mobility and Sex

The results of M1 vs. M2 vs. M3 $\delta^{18}O_c$ signature analysis very clearly show that not only were children mobile at various ages and arguably in various types of mobility events, but also that both male and female children were mobile. Of the twenty individuals sampled for this study 4/8 (50%) females and 10/12 (83%) males show evidence of some form of childhood mobility. Rates of mobility between males and females are comparably similar across all categories except for those individuals who have local M1 and M3 $\delta^{18}O_c$ signatures, but a non-local M2 signature. In this category males outnumber females 4:1. Though a sample of twenty individuals is small, a four-fold difference between males and females suggests a sex-based variation in mobility patterns. Participation in circular mobility connected to long distance trade is generally held to have been more common among males than females (Noy 2000; Bruun 2010, 2016; Woolf 2016). This may be the most parsimonious interpretation for explaining this variability in mobility between males and females in this category.

7.1.4–Age Related Variability in $\delta^{18}O_c$ Signatures at Isola Sacra

In the 18–29 age category both higher and lower non-local $\delta^{18}O_c$ signatures are present (9/23, 39% non-local), implying that individuals who died at this age were migrating to Rome from multiple regions. Evidence of individuals from more northerly and/or higher altitude climes, potentially Germany (i.e. SCR 361, 602) where $\delta^{18}O_c$ values of -8.5‰ are common (GNIP 2015), as well as individuals potentially from North Africa (i.e. SCR 68, 320), where $\delta^{18}O_c$ values of -3.1‰ are typical of coastal Algeria, Tunisia, and Egypt (GNIP 2015), are present among the individuals in this younger age category. Whereas in the 40–49 age category the only non-local individuals present (5/20, 25% non-local) have $\delta^{18}O_c$ values implying residency in warmer regions, again possibly as far as North Africa. Excluding the small sample of individuals age 50+, there is a 14% difference in the number of nonlocal individuals in the 18–29 age category compared to the 40–49 age category. This may suggest that the individuals in the 40–49 age category were originally predominantly local and were buried in the region of Portus, while younger individuals buried at Portus may have died as a result of labouring in the region, while those who did not die in this age category may have moved to other locales or returned home.

Such multifold regional origins among individuals 18–29 years old at death may suggest a pattern of mobility as well as some insight to the nature of mobility events at Isola Sacra. Among the two youngest age categories, 18–29 and 30–39, the greatest diversity of regional signatures is evident, while in the older two age categories significantly less diversity of regional signatures is observed. Based on this pattern of signatures it can be argued that the individuals in the younger age categories may have been more often comprised of individuals who migrated to Portus for work. Perhaps the younger two age categories represent an increased occurrence of death among nonlocal individuals. One can hypothesize that at such a young age these individuals may have been mobile towards Portus to pursue employment opportunities in the physically demanding harbour environs (e.g. stevedores) or business ventures. Portus was a working port that drew migrants, male and female, from all over the empire (Bruun 2010, 2016; Salomies 2002, Prowse et al. 2007). From the present sample there are four male and five female non-local individuals aged between 18 and 29 years. Aldrete and Mattingly (1999) estimate that ~3000, if not significantly more, porters worked in the harbours at Rome, which may account for part of the employment draw for males, while Treggiari (1979) notes multifold opportunities recorded for females in Roman contexts, including the environs of Rome and Ostia/Portus, where instances of female employment, including cases of non-local females, are recorded in the form of weavers, gold leaf manufacturing, hoteliers, produce sellers, entertainers, prostitutes, and midwives, among others jobs. If this hypothesis that younger non-local individuals in the Isola Sacra cemetery were involved in more intensive labour they may have been exposed to increasing precarity through lack of access to medical services, potential low income, and lack of a local support network, resulting in death at a younger age. Older nonlocal individuals may have been fully integrated into the community, worked in less precarious jobs, or simply been buried at Isola Sacra due to a lack of funds or lack of interest in being returned home for burial, though repatriation of human remains is known to have occurred to and from Rome (Tybout 2016). Though these potentialities remain speculative at this time the variation in $\delta^{18}O_c$ values by age category nonetheless suggests a pattern of mobility diversity between younger and older age categories at Isola Sacra, a pattern that is not comparably evident at JBR or Velia, and may be reflective of the more cosmopolitan nature of Portus and nearby Rome.

7.1.5–Female Mobility

Female mobility in the Roman world remains a perennially contested issue, with the classical view being that female mobility, especially independent mobility, would have been highly limited in the Imperial Roman era (Bruun 2016; Woolf 2016). Yet at all three sites examined in this thesis, from which males and females were equally or very comparably sampled (SCR= 40 males and 40 females; JBR= 18 males and 21 females; Velia= 10 males and 10 females), female and male mobility rates are virtually identical. At Isola Sacra 15 females were mobile compared to 14 males; at Velia 2 females were mobile to 3 males; and at Rue Jacques Brel necropolis 8 females were mobile to 8 males. The dominant discourse on female mobility in the Roman literature is that women would have moved predominantly as slaves or brides (Bruun 2016; Tacoma and Tybout 2016). In more recent times the view that females were limited in their mobility has come under increasing scrutiny (See Prowse et al. 2007; Foubert 2016; Holleran 2016). Aside from slavery the view that women were simply mobile as brides does not hold entirely true. Women were certainly mobile as brides, especially given the predominance of virilocal marriage patterns in the Roman era coupled with the potential for sojourning businessmen and soldiers returning home with foreign brides (Hoffman 1995; Hassall 1999; Allison 2006a,b; Ivlera 2016; Tacoma and Tybout 2016). But why were women not seen as mobile otherwise? Hin (2016) proffers the explanation that female mobility for employment would have been limited compared to male mobility given that a majority of employment opportunities ostensibly open to women would have been conducted by slaves. Female mobility is also arguably poorly understood in Roman contexts in part due to the general obscuring of females through a lack of attestation in the epigraphic record (Bruun 2016; Holleran 2016). Though perhaps not as frequently memorialized, female mobility is present in the epigraphic record. A recent study of epigrams from North Africa identified seven funeral epigrams referring to female migration (Handoume 2006; Bruun 2016), while in the Greek East 30 epigrams have been documented that attest to female mobility (Tacoma and Tybout 2016). From Hellenistic and Roman Athens, Hin (2016) asserts that the sex ratio of migrants to this area was roughly equal. Yet despite these lines of evidence various authors remain steadfast in their assertions that “women in particular…almost never moved except in the company of their male relatives or owners" (Woolf 2016:461).

Though this view is still widely held, it is clear from epigraphic and isotopic sources that, though perhaps commemorated to a lesser degree than men, women too were independently mobile and mobile for employment. Evidence is presented by Holleran et al. (2016) of female mobility to mining towns to work as retailers, in dining establishments, and in some instances potentially even in mining. Zerbini (2016) notes that mobility as athletes, entertainers, and theatre performers also provided potential conduits for female mobility. Treggiari (1979) provides a synthesis of epigraphic attestations of a number of employment positions filled by females, including as hoteliers, poulterers, clothes production, gold leaf production, hairdressing, produce sellers, perfumers, spinning wool, shoemaking, among other fields. In several cases presented by Treggiari (1979) women from distant lands are attested in various labour positions. At Rome there is epigraphic evidence of a seller of beans from Beirut, a baker from Carthage, and a seed seller from Praeneste (~35 km. east of Rome). It is also possible that men and women were travelling for work together. Treggiari (1979) asserts that men involved with trades often sought wives who either already worked in the trade or were keen to do so. It is assumed by Treggiari (1979) that in such situations the men would often produce (i.e. craft gold leaf, farm produce) and women would work in the market or the retail side of the business, though it is also clear that women in various instances were involved with the production side of trades suggesting a fluid labour market for female employment. As Treggiari (1979:76) points out "it is unnecessary to suppose that any of these rarely [epigraphically] attested women was a unique female practitioner of her trade."

Prostitution is another avenue mentioned as a common form of employment necessitating the mobility of women, with known prostitution rings operating among the various Roman military forts and in settlement areas spread across the Roman landscape, most famously at the *Lupanar* of Pompeii (Treggiari 1979; James 1984; McGinn 2002, 2004; Foubert 2016; Holleran 2016). Though prostitution is attested in the literature and in some cases in terms of archaeological remains of brothels, it is not clear which female individuals were prostitutes on an individual level. As Treggiari (1979:76) puts it “it is natural that prostitutes do not mention their job on their tombstone.”

Thousands of skilled and unskilled laborers were continuously needed to complete the various construction projects ongoing in the Roman empire as well as to fulfill the needs and market demands of residents. Such demand provided ample opportunity for both male and female labour related mobility (Treggiari 1979; Erdkamp 2016).

In the present study there is clear evidence of male and female mobility, and in a few cases it is possible that men and women were travelling together. The case of SCR 282 (Male, 30–40) and SCR 287 (Female, 30–40) may suggest companions given these individuals share the same $\delta^{18}O_c$ signature and are in the same age range (Table 7.3). The similar assigned burial numbers (i.e. 282 and 287) suggest that these burials are located close together (SCR 282 being buried in a sand grave and SCR 287 in a cappucina grave), though there is no further evidence one way or the other to confirm any particular relationship between these two individuals. The same may be said of Velia 134 (Female, 20–30) and Velia 194 (Male, 30–40), having the same $\delta^{18}O_c$ and similar $^{87}Sr/^{86}Sr$ signatures, and being similarly aged (Table 7.3). Yet simple correspondence of locale does not inherently indicate two individuals travelled together. At Velia it is not possible to determine if these individuals were buried together or in close proximity to one another given the presently unpublished results of excavations in the Roman necropolis. It is equally plausible in both of these cases, at SCR and Velia, that these individuals are simply from the same homeland. With that said, what is evident from the data presented in this dissertation is that regardless of the means of mobility, females, just as males, were mobile.

7.1.6–Regional Mobility

One of the key assumptions in initiating the present study was that with increasing distance from Rome and with ostensibly increasing parochial site location there would be decreasing mobility and decreasing diversity of regions from which individuals may have been mobile. Yet this does not appear to be the case. All three sites have similar rates of non-local individuals. The case of Rue Jacque Brel Necropolis is illustrative. At this site, a large proportion of the non-local individuals (9/17, 53%) appear to have been mobile towards JBR from surrounding regions in what is modern France. This type of mobility towards an urban centre is a common concept, precipitated by multifold circumstances, in regional mobility studies as previously discussed in Chapter 4 of this dissertation (Kearney 1986; Brettell 2008, 2015) and was likely one of the key mobility factors at JBR. Given the industrial nature of JBR, individuals may have been drawn from the surrounding regions to work in the production facilities of this area. Though JBR is itself a small regional site, it is nonetheless located in Mediolanum Santonum, a major Gallo-Roman city at the centre of Roman Aquitania, providing a further argument for why centripetal mobility towards this area was occurring (Maurin 1976, 1978; Woolf 1998; Killgrove and Montgomery 2016). Similar mobility on a broader regional scale is also evident at Isola Sacra and Velia. The nature of mobility at these two sites appears to be much more broadly cosmopolitan. Given the port and commerce nature of Velia and Portus the influx of non-local individuals from all points of the empire would have been more easily facilitated in terms of both employment and access by sea. Based on the results of the previously discussed M1 vs. M2 vs. M3 study, movement towards Portus was clearly not only centripetal but also centrifugal, with individuals not only arriving at but also departing from this site. Portus was not just the final destination but a hub of transnational mobility, where individuals were coming and going and returning on a regular basis, including males, females, and children.

7.2–Regional Isotopic Signatures

7.2.1–δ^{18}O Regional Homogeneity

An issue of concern that became clear in the process of examining $\delta^{18}O_c$ values from Velia and SCR is the nature of $\delta^{18}O_c$ regional homogeneity on the Italian peninsula. As discussed previously in Chapter 2 and elsewhere in this dissertation, the geography of Italy is such that large north to south regions exhibit highly similar isotopic signatures, making assessments of mobility and residency between regions with the same $\delta^{18}O_c$

signature challenging (Longinelli and Selmo 2003). It is possible that within the local $\delta^{18}O_c$ range of -6.4‰ to -3.5‰ at SCR and -5.7‰ to -3.3‰ at Velia that a number of the individuals identified as local may in fact have been non-local, having migrated to these sites from regions of homogeneous $\delta^{18}O_c$ values. From Helttula (2007) it is known that an individual buried in Isola Sacra was from Ravenna, in northeastern Italy. Based on the correspondence between assigned burial numbers and the recovery location of this specific epitaph, this individual is not part of the present sample. However, in theory if included in the present sample this individual would likely be isotopically indistinguishable from an individual born in the region of Portus. Despite the significant distance between the two sites (~384 km. NE of Portus across the Apennines), Ravenna falls into the same $\delta^{18}O_c$ isocline as Portus (Longinelli and Selmo 2003; GNIP 2015).

This concern of regional homogeneity is further compounded when the confidence range for local vs. non-local individuals is expanded. Using 2σ or 1.5*IQR ranges (as discussed by Lightfoot and O'Connell 2016), these approaches provide increasingly confident estimates of non-local individuals. Yet, in the present study when such measures were employed the 2σ range at SCR encompasses almost the entire $\delta^{18}O_c$ variation range for the Italian peninsula, outside of the higher Apennine and Alpine regions, while the 1.5*IQR range, at -10.1‰ to +0.45‰, includes all $\delta^{18}O_c$ values not only for Italy but for most of continental Europe and North Africa, making only migrants from parts of the far north or possibly Saharan Africa potentially identifiable. This is not to say that the 1.5*IQR method does not have merit, as Lightfoot and O'Connell (2016) have clearly shown that is does. Rather it is to suggest caution and further testing of this method in disparate geographic and isotopically diverse regions to gain insight to the applicability and practicability of the conservative estimates provided by this method.

7.2.2–^{87}Sr/^{86}Sr in Coastal Mediterranean Contexts

A key challenge that was apparent in using $^{87}Sr/^{86}Sr$ values was large territories of $^{87}Sr/^{86}Sr$ signature distribution and the presence of homogeneous $^{87}Sr/^{86}Sr$ signatures. Similar to $\delta^{18}O_c$, regions of $^{87}Sr/^{86}Sr$ homogeneity frequently exist, allowing for two locations to manifest similar bioavailable signatures despite a lack of geographical proximity. Though inland circum-Mediterranean geology varies, when looking at sites from coastal or near coastal environments in the Mediterranean where limestone is abundant, instances of regional signature homogeneity become increasingly challenging to parse given the coeval geological development of these regions over time (Biju-Duval et al. 1974; Gelati et al. 1989; Dixon and Robertson 1996). This is evident in a number of the individuals from the present study (e.g. Velia 134, 194), where the $^{87}Sr/^{86}Sr$ signature of an individual can equally suggest residency in Lebanon as coastal Italy, among other coastal locations throughout the Mediterranean and surrounding inland regions.

A further issue with distinguishing non-local individuals using $^{87}Sr/^{86}Sr$ is broad regionality. Looking at France and the bioavailable data generated by Willmes et al. (2014) there are five broad $^{87}Sr/^{86}Sr$ regions for the entire 643,801 km^2 of France. Of these five regions $^{87}Sr/^{86}Sr$ values between 0.7076–0.7125 dominate the majority of the landscape, making the potential for identifying mobility within these broad geographical zones using a 2σ range difficult.

To an extent these problems of regionality are unavoidable. To limit such problems future research would benefit from increasing focus on regional provenancing studies to provide baseline bioavailable $^{87}Sr/^{86}Sr$ data, such as has already been done from Greece by Nafplioti (2011) and for France by Willmes et al. (2014). The work of Willmes and colleagues (2014) is an excellent example of such research. This open source project focussing on France has compiled $^{87}Sr/^{86}Sr$ values of organic and inorganic samples from across the country to generate a $^{87}Sr/^{86}Sr$ bioavailable database. This open source database can be contributed to by future researchers to further refine and define the bioavailable $^{87}Sr/^{86}Sr$ regions of France, which can be integrated into GIS mapping. Such a project would be well worth extending into other regions.

7.2.3–Combining Oxygen and Strontium in Imperial Roman Mobility Studies

By combining $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ analyses one aspires to reduce the degree of regional homogeneity that each method presents as each system operates independently of the other. For Italy the logic is that $\delta^{18}O_c$ varies east to west while $^{87}Sr/^{86}Sr$ varies broadly north to south (Killgrove and Montgomery 2016). However, the combination of methods also introduces the question as to which isotope provides the greatest discrimination of mobility. When combined the number of non-local individuals at JBR, SCR, and Velia drop drastically, with the highest estimate of 4/20 (20%) being apparent at JBR. Yet this level of mobility is comparatively low compared to $\delta^{18}O_c$ non-local estimates, which vary from 28% to 38%, and $^{87}Sr/^{86}Sr$ estimates, which were as high as 30% at JBR. One of the difficulties of the combined method is the nature of regional similarity addressed in the previous two sections. Where a number of individuals appear non-local based on $\delta^{18}O_c$, but local based on $^{87}Sr/^{86}Sr$ making the combined non-local rate quite low and bringing into question which method provides the strongest assessment of locality.

7.3–Water Sources and $\delta^{18}O$

7.3.1–Portus

By the later part of the 1st c. CE the water supply at Portus was provided by an aqueduct sourced from springs in the region of Ponte Galeria ~9 km. north of Portus along the via Portuensis, and running parallel along the Tiber (Petriaggi et al. 1995; Keay and Millett 2005a; Keay and Paroli 2011b). This water source would have been further supplemented by contributions from rain water with water being stored in local wells and cisterns for easy access and to prevent evaporation (Prowse et al. 2007). The local origin of the Ponte Galeria water source is unlikely to have contributed significantly different $\delta^{18}O_c$ values to the expected local range for individuals at Portus (Longinelli and Selmo 2003).

7.3.2–JBR

By 20 CE the area of JBR was served by an aqueduct sourced from springs in the hills of Le Douhet ~14 km. NE of Saintes on the right bank of the Charente river (Triou 1968; Maurin 1976). The course of the aqueduct ran largely underground before it entered Saintes (Maurin 1976). This local source of drinking water falls within the same $\delta^{18}O_{dw}$ zone as JBR. Given its proximity to JBR it is not expected that this drinking water would have introduced a non-local signature of $\delta^{18}O_c$ into the diets of individuals residing at JBR (Lécole 1985).

7.3.3–Velia

From its earliest inception as a Phocaean colony the water supply of Velia was provided by a mixture of rain water, stored in large stone lined communal cisterns and in pithoi in the home, and exploitation of local spring water through canals from the surrounding hills in the *vallone del frittolo* (Krinzinger 1986; Greco and De Simone 2012). This system of cisterns and sources of water exploitation were maintained into the Roman era during which time a small aqueduct system was built to facilitate an increase in the volume and distribution of water, as well as the development of public fountains (Smith 1854; 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, the drinking water exploited by the inhabitants of Velia and associated $\delta^{18}O_c$ signature for this site would have been local (Greco and De Simone 2012).

7.4–Burial Style and Grave Good Variability

Of the three sites examined for this study only SCR and JBR provide any substantial information about the nature of the burials. At Isola Sacra knowledge of burial types is available though the specific location of each burial within the necropolis and associated grave goods, which Sperdutti (1995) notes as being largely absent from the inhumation burials, remains unclarified pending final publication. Rue Jacques Brel necropolis provides the most information in regard to burial type and grave goods, with the distribution of burials and grave goods present in each burial clearly delineated.

In the necropolis of Isola Sacra 12 burial types were employed (See Table 6.2). Several of the 12 styles are highly similar (e.g. sand vs. soil burial). Of these 12 styles non-local individuals are present in 8 (Table 7.1). The burial types in which non-local individuals are not present are also the least common burial types for local individuals (e.g. sarcophagus). Though these variations in burial style may have implications for status in life (Angelucci et al. 1990), they do not indicate variation in burial style between local and non-local individuals. The same can be said about the relative location of burials. Given the current lack of a final excavation report for the cemetery at Isola Sacra it is presently only possible to infer the relative proximity of burials to one another based on the sequence of assigned burial numbers. For the 30 non-local individuals identified at SCR there is no apparent clustering of non-local burials. The assigned burial numbers for these non-local individuals range from SCR 36 to SCR 698 with no sequential clustering of numbers in between, indicating a non-specific distribution and intermingling of local and non-local individuals interred at Isola Sacra.

Table 7.1–summary of the types of burials in which non-local individuals were identified at Isola Sacra.

	Female	**Male**	***Total***
Inhumation	3	3	**6**
Cappuccina	5	3	**8**
Unknown	1	2	**3**
Amphora	1	0	**1**
Columbaria	1	0	**1**
Tomb	3	3	**6**
Semi-Cappuccina	1	1	**2**
Sand	1	2	**3**
Total	**16**	**14**	**30**

At JBR simple soil cut graves with stone linings were the norm for all individuals, local and non-local, with individuals being buried in a mixture of wooden coffins and simply in the soil. There is no evidence of segregation of non-local burials, as the graves of non-local individuals are dispersed equally throughout the cemetery in no apparent pattern among the local individuals (Fig. 7.1).

The same can be said of the grave goods. Individuals interred at JBR were typically buried with some variation of pottery (e.g. a plate, oenochoe, cup), shoes and associated hob nails, coins, metal objects (arrow points, pins, buckles), and occasionally glass and other objects such as bone pins and game tokens. The type and average quantity of grave goods at JBR are highly similar for local and non-local individuals as well as for males and females, indicating a lack of distinction in burial (Table 7.2; Appendix E).

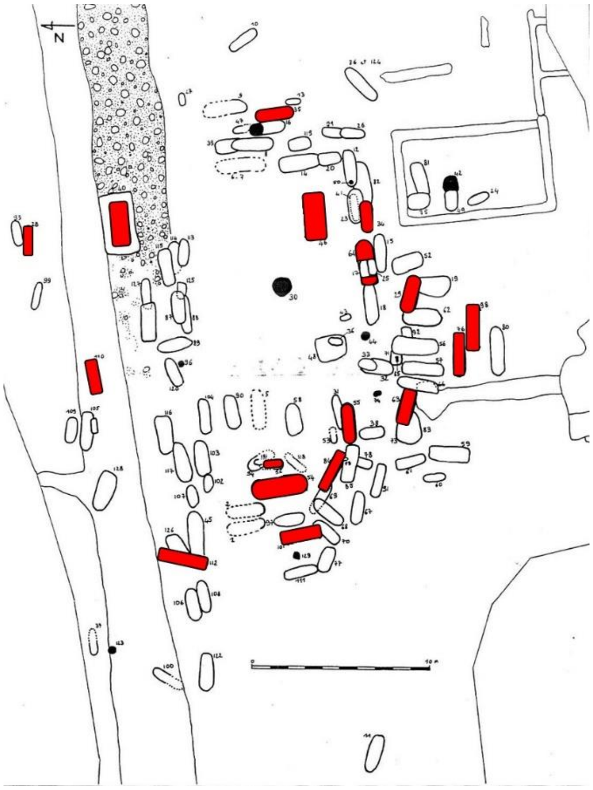

Figure 7.1–Distribution of local and non-local graves at Rue Jacques Brel necropolis (JBR). Non-local graves (N=17) are highlighted in red. Local graves are unhighlighted (After Baigl et al. 1997:fig. 18).

This finding in regard to burial type and grave goods at both SCR and JBR was also the case at Imperial Roman Vagnari where isotopically non-local (F42a, F49, F95, F96a, F130, F131) and isotopically local individuals were buried in the same fashion (Prowse et al. 2010a). At Isola Sacra and JBR the lack of differentiation between local and non-local individuals brings forth a number of questions and insights. It is quite possible, if not likely in many cases, that non-local individuals were simply integrated into the community, at least as far as burial is concerned. This may particularly be the case when one takes into consideration the evidence of early childhood mobility at Isola Sacra discussed previously in this chapter.

Table 7.2–Distribution of grave goods between local and non-local individuals at JBR. The number of grave goods presented in each category indicates the lowest and highest number of items in a given burial for each grave good type (Data compiled from Baigl et al. 1997).

JBR Grave Goods	**Local**	**Non-Local**
Pottery		
M	1–7	2–7
F	1–3	2–8
Coins		
M	0	1–3
F	1–7	1
Nails		
M	20-384	2-170
F	1-297	41-160
Shoes		
M	1	1
F	1–2	1–2
Glass		
M	0	1
F	0	0
Metal		
M	1–2	1–6
F	1–4	0
Other		
M	0	3
F	2	1

When examining burial styles and grave goods, questions of acculturation remain persistent yet hard to quantifiably address (Pearce 2010; Prowse et al. 2010a). Though individuals appear isotopically non-local does not inherently mark them as being culturally apart. Given the vast expanse of the Roman empire it is quite possible that many of the isotopically non-local individuals were in reality culturally local (Barth 1969; Brettell 2015), that is to say that simply being from a non-local environment does not inherently indicate that such individuals would have been culturally different or separate from the "local" culture, as cultural locality cannot be strictly traced along geographic or isotopic lines. That said, it still remains possible that the isotopically non-local individuals maintained a foreign identity in life through preserved links with a homeland and in death were buried in the local style because they married a local individual, or they chose to go with the local style as they did not have a strong bond to a particular style of burial, or perhaps their homeland did not have a uniquely different burial practice. It is also possible that a non-local individual was buried in the "local" style out of practical necessity. What these somewhat nebulous statements are pointing out is that short of substantiating evidence such as a culturally/regionally specific burial style, a regionally unique name (Noy 2000), or specific mention of a homeland in an epitaph (Hin 2013, 2016) it remains challenging to confidently identify culturally non-local individuals from burial style alone. What the present, and other, isotopic studies contribute to ongoing debates on Roman mobility is the ability to identify and quantify the burials of non-local individuals and potential instances of mobility with or without outward manifestations of foreignness, one of the key goals for future research stressed by Woolf (2016).

7.5–Where Were People Coming From?

A perennial question of isotopic studies in bioarchaeology is "where were people coming from?" Based on the isotopic data presented in this thesis the quick answer is "all over." At all three sites examined it is evident from the data that migration was taking palace from and to various regions, with strong indications of individuals arriving from, or going to, the environs of North Africa and likely northern or higher altitude Europe. Yet specific points of origin are not readily available due to various regions having similar isotopic signatures. For the three skeletal samples examined in this thesis (JBR, SCR, and Velia) it is evident from the isotopic results of $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ analyses that a number of individuals were non-local (Table 7.3). The following sections provide a discussion on the potential regions from which individuals may have migrated (See Appendix F for regional GNIP values).

Several individuals have been identified as non-local based on either their $\delta^{18}O_c$ or $^{87}Sr/^{86}Sr$ signature even though they fall within the local range for the other tested isotope (i.e. they are non-local for one isotope but not the other). This does not undermine inferences of locality for, as discussed above in Section 7.2, it is evident that there are many instances of large geographic regions with homogenous signatures for $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$. For this reason, it is possible that an individual may be non-local to a particular site for one isotopic signature, but may appear local for the other isotopic signature because the non-local region they are coming from varies isotopically for one of the isotopes but is in a homogenous region for the other. For this reason, when an individual appears non-local for one isotope it provides the inference that this person is indeed non-local (e.g. SCR 36, SCR 99). Instances in which an individual is non-local for both isotopes (e.g. SCR 376) simply provide greater confidence and can allow for increasingly refined insights to potential regional origins (i.e. based on both $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ signatures) from which a given individual may have arrived.

Table 7.3–Summary of the non-local individuals identified from SCR, JBR, and Velia, based on isotopic values of second molars (M2), with possible regions of origin. Values highlighted yellow are non-local at 1σ, values highlighted green are non-local at 2σ, values highlighted purple are non-local at 1.5*IQR, values highlighted in blue are non-local for $^{87}Sr/^{86}Sr$.

SCR	**□δ^{18}Oc (‰) VPDB**	**$^{87}Sr/^{86}Sr$**	**Sex**	**Age**	**Possible Origin**
36	-7.7		M	20-21	Italian Interior, Alps, Germany
68	-8.0	0.70811	F	20-30	Italian Interior Southern Germany
88	-3.0		M	50+	North Africa
99	-6.1	0.70723	M	30-35	Around Rome, Lebanon, Gaul
171	-7.2	0.70835	M	30-40	Italian Interior, Alps, Germany
174	-7.6	0.70887	M	30-40	Italian Interior, Alps, Germany
190	-6.8		F	25-30	Italian Interior
194	-3.4		F	40-45	North Africa
196	-7.1		M	20-25	Italian interior, Alps, Germany
199	-3.3		F	35-40	North Africa
220	-3.3		M	40-45	North Africa
269	-3.2	0.70918	F	35-40	North Africa
282	-6.5		M	30-40	Italian Interior, Levant
285	-3.0	0.70879	F	50+	North Africa
287	-6.5	0.70905	F	30-40	Italian Interior
314	-3.3		F	40-50	North Africa
320	-8.5	0.70966	F	20-25	Southern Germany
324	-5.0	0.70782	F	30-35	Around Rome, Lebanon, Gaul
326	-3.2		F	35-40	North Africa
352	-7.2		F	35-40	Italian Interior, Germany
361	-3.0	0.70931	M	20-25	North Africa, Greece, Asia Minor
362	-3.1		F	40-50	North Africa
376	-7.5	0.71052	M	35-40	Italian Interior
404	-6.8		M	20-25	Italian Interior, Levant

445	-3.3		F	20-30	North Africa, Palmyra
452	-3.3		F	30-40	North Africa, Palmyra
467	-3.4		F	30-35	North Africa
602	-3.4		F	25-30	North Africa
678	-6.6		M	50+	Italian Interior, Levant
698	-3.3		M	40-50	North Africa, Palmyra
Velia					
57	-1.1	0.70788	M	30-35	Egypt, Nubia, Nile Valley
134	-5.8	0.70890	F	20-30	Coastal Italy, Greece, Asia Minor, Coastal Lebanon
194	-5.8	0.70860	M	30-40	Coastal Italy, Greece, Asia Minor, Coastal Lebanon
205	-2.4	0.70868	F	30-40	North Africa
211	-6.0	0.70901	M	30-35	Interior Italy, Asia Minor
JBR					
28b	-3.4		F	30+	North Africa, Palmyra
29	-3.5		F	30+	North Africa
34	-6.0		F	18-19	Aquitaine basin
35	-4.0	0.71064	M	30+	Armorican Massif, Massif central
40	-5.9		F	30+	Aquitaine Basin
46	-6.2	0.70891	M	30+	Aquitaine Basin
54	-6.9	0.71114	F	30+	Aquitaine Basin
55	-3.5	0.70932	F	30+	North Africa
56	-3.0	0.70927	F	30+	North Africa
63	-5.7	0.71276	M	20-25	Paris Basin/Armorican Massif
64	-6.9	0.71029	F	30+	Pyrennes
76	-6.0	0.71064	M	20+	Armorican Massif Massif Central
86	-3.2	0.70869	F	30+	North Africa
98	-6.2	0.71038	F	30+	Aquitaine Basin
101	-2.6	0.70903	F	30+	North Africa
110	-3.0	0.70812	F	30+	North Africa
112	-3.3		M	30+	North Africa, Palmyra

7.5.1–Rue Jacques Brel Necropolis

A majority of the non-local individuals from JBR appear to be migrants from surrounding regions in Gaul, located in what is modern day France. Two individuals (JBR 35, 76) have $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ values most consistent with an origin in the Armorican Massif region of northwestern France. Similar $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ values to the Armorican Massif are also present in the Massif Central of south central France, and potentially the foothills around the massif resulting from fluvial deposits of siliciclastic detritus (Wilmes et al. 2014; GNIP 2015; Rougier et al. 2016). One individual (JBR 63) appears to have resided on the boundary of the western Paris basin of north-central France and the

Armorican Massif (Willmes et al. 2014). Clustering of Gallo-Roman settlements in eastern Brittany, in the heart of the Armorican massif, was most notable around Rennes, Corseul, and Vannes (Langouët and Jumel 1987, 1991; Naas 1991; Woolf 1998), potential areas from which individuals may have moved to JBR. Five individuals (JBR 34, 40, 46, 54, 98) have isotopic signatures consistent with residency in the Aquitaine basin of south-central France, the region in which JBR is located, which may suggest comparatively local migration towards JBR. The dental enamel of one individual (JBR 64) has a lower $\delta^{18}O_c$ signature coupled with an $^{87}Sr/^{86}Sr$ signature of 0.71038 suggesting residency in the Pyrennes region of southwestern France, northeastern Spain, and Andorra (Willmes et al. 2104; GNIP 2015). Though it appears that migration to JBR had a significant component from within Gallo-Roman territory, it is uncertain the degree of cultural continuity that would have existed between migrants from these regions. Historically the various regions of Roman Gaul, comprised of Armorica (Lugdunensis), Aquitania, and Narbonensis are known to have had their own respective cultural affinities (Woolf 1998; MacMullen 2000). One might expect as such that aspects of regional cultural identities, to varying degrees, may have been maintained by individuals who moved to JBR. This statement remains speculative however, as there is no concrete evidence, either textual or artefactual, of such maintained regional cultural identities at JBR to confirm or deny such a potentiality.

Eight individuals at JBR (JBR 28b, 29, 55, 56, 86, 101, 110, 112) present $\delta^{18}O_c$ signatures that are suggestive of origins in warmer climates (GNIP 2015). The $\delta^{18}O_c$ signatures of these individuals, and the five cases in which $^{87}Sr/^{86}Sr$ analysis was undertaken, are most consistent with migration from North Africa, while two individuals (JBR 28b, 112) have signatures that are also consistent with the average annual precipitation value for Palmyra, which may suggest an origin in the Near East (Killgrove 2010a; GNIP 2015; Killgrove and Montgomery 2016). Signatures in the -3.2‰ range have a degree of ambiguity in France as the annual average GNIP (2015) value for Monaco is -3.2‰, yet such values are not characteristic of surrounding areas along the northern Mediterranean coast, making an origin in North Africa, where such values are typical, much more likely (See Appendix F).

7.5.2–Velia

At Velia two of the individuals examined (Velia 57, 205) have $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ signatures consistent with an origin in North Africa, potentially somewhere in the Nile Valley. Prowse et al. (2007) present evidence of a 40–50 year old male individual (SCR 617) with a $\delta^{18}O_c$ signature of -1.3‰ which they propose as being from North Africa. Velia 57 also falls within the expected local $^{87}Sr/^{86}Sr$ range of 0.70732–0.70789 for Tombos presented by Buzon et al. (2007), further implying a North African/Nile Valley origin of this individual. Velia 205 may also have resided in North Africa, though not necessarily in the same region as Velia 57. The lower $\delta^{18}O_c$ signature of Velia 205 implies residency in a cooler locale or area of higher elevation than Velia 57. The $^{87}Sr/^{86}Sr$ signature of Velia 205 fits within the unpublished expected local range of 0.70835–0.70900 for Leptiminus, Tunisia (Burton et al. pers. comm.), suggesting a potential origin in this region.

Velia 134 and 194 present signatures consistent with a number of regions. The $\delta^{18}O_c$ values of these individuals are only 0.1‰ outside of the expected local range, while their $^{87}Sr/^{86}Sr$ signatures fit within the local range, suggesting that these two individuals may have resided at a locale not significantly further inland from the area of Velia. With such a high degree of similarity to the local $\delta^{18}O_c$ range within run IRMS precision cannot be ruled out as factor in these cases. It is also possible given the similarity of regional signatures that these individuals migrated towards Velia from the eastern Mediterranean. Coastal Lebanon is a mixture of Quaternary, Cretaceous and Miocene geology, with much of the coast comprised of thick marine limestone deposits, providing a landscape with similar $^{87}Sr/^{86}Sr$ values to Velia (Veizer 1989; Walley 1998). A $\delta^{18}O_c$ signature of -5.8‰ is also characteristic of the environment of Lebanon (GNIP 2015; Appendix F). It is known that merchants from Tyre in Phoenicia traded in southern Italy, having established a base at Puetoli (Bruun 2016), while Treggiari (1979) documented a bean seller at Rome who was from Beirut. Given its proximity to Puetoli and the harbour nature of Velia it is quite possible that individuals from the Lebanon region could have been present at this site. Velia 211 has a signature that may suggest an origin from the interior of the Italian peninsula. It is also possible that this individual was from the area of Asia Minor, given their $\delta^{18}O_c$ signature of -6.0‰ (GNIP 2015).

7.5.3–Isola Sacra

Mobility towards Portus based on the sample examined herein appears to have taken place from multiple locations around the Empire. Two younger females (SCR 68, 320) appear to have migrated from somewhere in the regions of Southern Germany, having $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ signatures corresponding with this region (Grupe et al. 1997; Knipper at al. 2010; Oelze et al. 2012; Scheeres et al. 2013). The regions of Germania are known to have been a common source of military migrants to the area of Rome (Noy 2000). It is not improbable that these two females accompanied military partners, or that they were simply mobile on their own for work or to visit/join family, nor can slavery be ruled out (Killgrove 2010a; Tacoma and Tybout 2016). Six individuals (SCR 36, 171, 174, 196, 352, 376) have $\delta^{18}O_c$ signatures indicative of residency in a cooler and more elevated region, possibly the alpine regions of northern Italy and surrounding territories.

There are six individuals (SCR 99, 190, 282, 324, 404, 678) whose signatures imply either residency in the vicinity of Rome and coastal Italy, or perhaps residency in similar climatic and geological regions in the Levant or Gaul. The $^{87}Sr/^{86}Sr$ signature of SCR 324 falls within the Monti Simburini range presented by Killgrove and Montgomery (2016), suggesting that this individual may have lived in the area around Monti Simburini. SCR 99 has a $\delta^{18}O_c$ signature consistent with the area around Rome, having an $^{87}Sr/^{86}Sr$ signature within the expected local range for Castellacio Europarco (Killgrove and Montgomery 2106). The isotopic signature of SCR 99 is also consistent with the Lebanon coast that, as mentioned previously, is a known region from which merchants travelled to Rome (Bruun 2016). This individual also has a signature consistent with the Paris Basin area of France, in what would have been part of Roman Gaul. What cases like SCR 99 highlight is that, isotopically pinpointing any one specific home territory can be challenging, particularly without any further corroborating information (e.g. epitaphs).

The remaining individuals (SCR 88, 194, 199, 220, 269, 285, 314, 326, 361, 362, 445, 452, 467, 602, 698) have $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ signatures consistent with residency in a drier hotter climate. Many of these individuals appear to have arrived in the region of Portus from somewhere in North Africa. Migrants from Roman North Africa (i.e. Mauretania, Numidia, Cyrene, and Egypt) are estimated to have accounted for approximately 10% of the population of Rome, typically arriving as civilians, not to mention other routes of arrival such as slavery (Harris 1980; Noy 2000; Killgrove 2010a). This reality is not surprising given the known interactions between the ports of Rome and North Africa for the purpose of trade and specifically to facilitate the grain supply (Rickman 1980; De Ligt and Tacoma 2016). Onomastic and textual investigations by Salomies (2002), Cebeillac-Gervasoni (1996), and Treggiari (1979) provide evidence of African individuals residing at Ostia and Rome, while at Vagnari in Puglia Prowse et al. (2010) identified a male of sub-Saharan African (haplogroup L) ancestry, implying that African mobility within the Roman Empire was not uncommon. Of these potentially North African individuals several also have signatures consistent with other possible regions of origin. SCR 361 has a signature that also suggests a potential origin in the areas of Greece and/or Asia Minor (Garvie-Lok 2009; Nafplioti 2011; Leslie 2012). Three individuals of this group (SCR 445, 452, 698) have $\delta^{18}O_c$ signatures of -3.3‰, the annual average of precipitation in Palmyra, Syria. Noy (2010) discusses the case of Barates of Palmyrene heritage, resident at South Shields in Britain. Such epigraphic evidence attests to the presence of Palmyrene individuals at distant locales outside of Palmyra. Given the commercial nature of Portus and known interactions both with the Near East and Levantine coast it is not implausible that one or all of these three individuals arrived from the region of Palmyra (Ball 2000; Zerbini 2016).

These various regional origins based on isotopic similarities are further supported by the extant epigraphic evidence available from Isola Sacra presented by Thylander (1951-52), Sacco (1984), and Helttula (2007). One must be cautious with such epigraphic evidence as it is not always possible to ascertain from these epigraphic accounts if the material refers specifically to individuals who migrated from the listed region or if it refers to a general ancestral homeland and was used by second and later generations resident at Portus (Holleran 2016). The geographic areas documented by Helttula (2007) include Carthage in North Africa, Laurente Lavinates (on the Tyrrhenian coast between Ostia and Lavinium, ~25 km. from Rome), Ostia, Ravenna, Rome, Portus, Gaul (*Aquitanica Pro[vincia]*), Rhodes and Olympia in Greece, as well as Nicomedia in Asia Minor.

Though such evidence is helpful for pointing out regions of potential origin for individuals interred at Isola Sacra it is not possible to directly link the skeletal remains examined for this study with the epigraphic materials. An attempt was made to link the inscriptions listing geographic locations with the individuals from SCR isotopically analyzed in this dissertation. Helttula (2007) provides information on from which tomb or area of Isola Sacra each inscription originated. Of the fifteen inscriptions with geographic regions documented seven were found in disturbed contexts and cannot be assigned to a specific tomb. The remaining eight inscriptions were recovered from eight different tomb complexes during early investigations and excavation of the site by Calza (1940) and do not correspond with any of the individuals examined in this dissertation. As a result, unfortunately, the epigraphic evidence of non-local individuals provided by these inscriptions cannot be directly connected with the isotopic evidence of non-local individuals presented in this dissertation. Though a direct connection between isotopic and epigraphic evidence could not be made in the present study, the isotopic signatures of the individuals examined and the epigraphic evidence from where individuals were coming from do correspond in terms of similar regional origins from which individuals were mobile towards the area of Portus, further supporting the complementary nature of these two approaches. Future research should continue to attempt to link available epigraphic accounts of mobility with isotopically identified instances of mobility to provide increasingly robust assessments of Roman mobility.

7.6–Nonmetric Traits

7.6.1–Implications of MMD Results at SCR, JBR, and Velia

In discussing nonmetric traits it is important to keep in mind that MMD results reflect the larger biological tapestry of a region. In this way the MMD results generated in this thesis attest to the overall biological composition of a region and do not directly testify to the mobility of any given individual. Thus, unlike isotopes, nonmetric traits provide an insight to the general interaction between groups over time. Though several nonmetric trait studies have been undertaken to date on Roman and Italian context sites (e.g. Rubini et al. 1997, 2007; Coppa et al. 1998, 2007) previous nonmetric studies cannot be directly compared due to the use of differing traits and calculation methodologies (i.e. Rubini et al. 1997, 2007 utilize cranial traits, while Coppa et al. 1998 rely on dental traits). The present study had access to the skeletal remains from three sites and based on these sites it is possible to draw insights regarding the nature of biological divergence between these three areas of the Imperial Roman landscape.

Given the nature of Portus as a hub of migration in and out of Rome and the proximity of Portus to Rome it is evident that the population of this site was comprised of a not insignificant proportion of individuals from various non-local geographic regions, as attested in the historic literature (Noy 2000), from the isotopic evidence presented here, and elsewhere (Prowse et al. 2007), and epigraphically (Thylander 1951-52; Sacco 1984; Helttula 2007). In contrast, unlike Portus at the heart of the Roman trade network, it can be argued that the locations of Velia and JBR were more parochial (Terpstra 2013; Noy 2000). This is not to say that JBR or Velia were cut off from in and out migration or diversity of biological populations, as it is quite clear that both of these sites received non-local individuals, but rather to note that these sites were smaller and located in comparatively rural regions.

Biological dispersion and Roman era expansion is a key issue that is apparent not only in the present study but in earlier nonmetric trait research as well. Rubini et al. (1997) examined Etruscan biodiversity compared to surrounding Italic contexts, noting that Etruscans appear to have the highest biological continuity with modern Tuscans.

Roman and Etruscan samples in this study were surprisingly similar, prompting the hypothesis that with Roman expansion regional similarities to Roman settlers began to manifest. Looking at Iron Age contexts Rubini et al. (2007) observed that the Apennines served as a geographical barrier to gene flow, with distinct regional groups on the Adriatic and Tyrrhenian coasts but a lack of trans-Apennine similarity. Yet, moving forward to the late Iron Age and into the Roman era, Coppa et al. (1998) found that the Apennines were not a significant barrier to gene flow. The key argument regarding this transition from isolation to integration in the Roman era is attributed to the expansionary policies of the Roman empire, coupled with the development of extensive road networks throughout the Italian territory, providing for easier access and ample opportunity for gene flow across the Apennines.

For the Tyrrhenian coast of Italy Rubini et al. (2007) observed a distinct division between the biological continuity of north-central and southern populations, which they propose resulted from different regional settlement histories. This contention had been espoused previously by Piazza et al. (1988) in their study of the genetic diversity of Italy, which showed that the southern territories colonized as part of Magna Graecia preserved a distinct genetic dissimilarity to other regions further north on the Italian peninsula well into the Roman Imperial era (Lomas 2016).

Turning to the present study it is possible that the individuals sampled from Isola Sacra and JBR appear more biologically similar than Velia and JBR, and SCR and Velia, despite the closer proximity of the later two sites, due to increased interactions between the maritime hub of Portus and Gaul. Gaul was the first non-Mediterranean territory to be incorporated into the expanding Roman landscape, becoming a Roman colony in 43 BCE, after which time relations between Gaul and Rome became much more significant (Godineau 1996; Woolf 1998; Thorne 2013). Such interaction would have been facilitated, at least in part, by the exploitation of slaves, trade mobility, and stationing of military personnel in both regions, as well as increasing social and economic interaction between Rome and Gaul into the Imperial era (Harris 1980; Goudineau 1996; Woolf 1998, 2000; Dondin-Payre and Raespart-Charlier 1999).

Turning to Velia, the demographic transition following Roman colonization of Magna Graecia is hard to quantify. Beginning in the 1st c. CE. sites in Magna Graecia were often settled by former Roman soldiers, though in several cases the establishment of Roman colonies in Magna Graecia was facilitated by a change in name only (Lomas 2016). The degree of biological divergence between SCR and JBR to Velia may in part result from the origin of Velia as a Phocaean Greek colony, with individuals travelling from the coast of Asia Minor to settle on the Southern Tyrrhenian coast of Italy (Pellegrino 1957; Musti 1966; Cerchiai 2004; Mele 2006; Nenci and Vallet 2012). This original population would have facilitated the persistence of a non-Italic biological legacy in the area of Velia (Cerchiai 2004; Mele 2006; Nenci and Vallet 2012). It is known that Velia transitioned into a Roman settlement, yet to what degree newly arrived settlers displaced the original population remains uncertain. The limited epigraphic record from Velia seems to suggest that the Greek nature of the site persisted into, and potentially beyond, the 1st c. CE, as there is evidence of one Cornelius Gemellus holding both official Roman and Greek posts, as well as the persistence of the Greek healing cult of Apollo Oulios (Ebner 1962, 1970; Pugliese Carratelli 1970; Lomas 2016).

The increased biological dissimilarity between SCR and JBR to the former Magna Graecia colony at Velia fits the model espoused by Piazza et al. (1988) and Coppa et al. (1998). The MMD results do not suggest that these sample populations are significantly divergent. The dissimilarity between JBR, SCR, and Velia is significant, but not so significant as to suggest a drastic biological dissimilarity, such as would be expected from two populations that never biologically interacted. Rather the phenetic similarity between these three groups suggests a general commonality in breeding population with regional differences. All three sites fell under the aegis of the Roman empire. It is not surprising that JBR, SCR, and Velia are broadly similar given the intensive infrastructure of the Roman Empire. Further to this point if one considers the importation of slaves to Portus, with significant amounts derived from continental Europe (Harris 1980; Scheidel 1997), coupled with the free mobility of individuals to this main port of Rome, it is not surprising that the greatest similarity would be between SCR and JBR and SCR and

Velia, as SCR is the most cosmopolitan of these three sites and as a result is the most fitting hub into which the biological spokes of provincial and distant territories of the Roman empire, such as Velia and JBR, fit.

Unlike isotopes that rely on residence in a certain region to acquire a signature, nonmetric traits are heritable, thus residency is less important than the interaction of populations over time. It is for this reason, perhaps, that the similarity between SCR and JBR given the historic interactions between these regions, is greater than the similarity between Velia and JBR, two comparatively parochial sites that would have had little reason to interact with each other.

7.6.2–Challenges of Utilizing Nonmetric traits

In using nonmetric traits to examine group heterogeneity in this thesis one limitation that quickly became evident was small sample size and a limited number of sites. Small sample size is an issue in nonmetric trait studies because with nonmetric traits scorable for less than ~10 individuals, results can become skewed in terms of the amount of variation that appears. In terms of the number of skeletal samples examined, it is advisable that in future studies examining biological diversity in Imperial Roman contexts the number of sites utilized be expanded to include samples from numerous provincial and distant regions, particularly North Africa and the eastern regions of the Roman empire, to see if the trends of biological variation observed in the present study hold true among increasingly distant sites.

Chapter 8–Conclusions

This thesis has examined the Imperial Roman era sites of Isola Sacra (SCR), Rue Jacques Brel Necropolis (JBR), and Velia with the intention of gauging the degree of mobility apparent in conjunction with an assessment of the biological diversity of these sites based on nonmetric traits. With the rapid expansion of the Roman Empire came increasing mobility on a level more akin to modern global mobility than to any previous time period preceding the Roman era. Historical and epigraphic texts provide accounts of regions from which individuals were mobile and how various groups interacted, yet quantification of mobility from Roman contexts has remained an ongoing challenge. When faced with the skeletal remains of individuals in archaeological contexts the ability to make specific links with historico-textual descriptions becomes increasingly problematic, necessitating that methods such as isotopic analysis be employed.

The isotopic perspectives presented in this thesis address this persistent difficulty directly. Through the use of $\delta^{18}O_c$ and $^{87}Sr/^{86}Sr$ it has been possible to provide an individual by individual assessment of potential regions from which mobility was taking place, helping to fill in the mosaic of Roman mobility and to provide further context to the regional interactions of individuals from across the expansive Empire. A key area that this research has addressed is female and childhood mobility. Due to a general lack of commemoration and explicit discussion of women and children in the classical and epigraphic literature the role of mobility in these individual's lives is often obscured, precipitating theories and discussions about a lack of mobility among women and children and a dependency on male counterparts to accompany them. The present study has shown that not only were women mobile from various regions but also that the nature and age of mobility was variable and in most cases female mobility was comparable to male mobility, or at the very least, where not comparable, was far from non-existent. The same has been shown to be true for a sample of children from Isola Sacra. Based on variable signatures in the first vs. second vs. third molars of twenty children numerous instances and ostensibly different "types" of mobility have been identified. A number of children were clearly mobile at very young ages while others appear to have undergone circular mobility, leaving Portus as children and returning as adults. The causal reason for these events remains uncertain. It is possible these young individuals were taken by parents to a foreign region, or were taken with a merchant adult to engage in overseas trade, either tacitly as the accompanying child/ward of a merchant or quite potentially actively as a merchant laborer. Yet what is not uncertain is that these children were mobile. This pattern of mobility deserves to be investigated further in subsequent research. The number of mobility events evident among a small sample of 20 individuals suggests a larger trend. That childhood mobility was not a rare or isolated phenomena, but rather, much like male and female adults, male and female children were mobile across the Roman landscape.

The mobility events identified from individuals of all ages suggest a significant degree and various types of mobility at various life stages at SCR, JBR, and Velia. As much as results are presented in a binary fashion as local and non-local it is clear that the process of mobility and migration in the Imperial Roman era is not an all or nothing proposition. This dissertation has argued that along with long distance mobility, local, regional, and return mobility would have been realities of human movement in the Imperial Roman era, creating a cosmopolitan environment of transnational mobility allowing for the expansion and exploitation of manifold mobility networks and the establishment and maintenance of social ties at numerous and varying locales. With increasing ranges of confidence (2σ, 1.5*IQR) there are less non-local individuals, as the regions considered "non-local" become increasingly distant and dissimilar to the "local" locale. In this way we see that local vs. non-local mobility is much more a continuum of human movement across the landscape and a contextualization of distances travelled being equated with whether or not an individual is local. It is important as such to keep such caveats in mind and to realize that local and non-local are categorical as much as they are fluid concepts and are not explicit designators of human existence.

Along with the beneficial aspects of isotopic research it is evident there are also limitations, as isotopic signatures can be obscured by uncontrollable factors of regional similarities. For the individuals that appear non-local at the three sites examined there is a clear isotopic signature that indicates a region other than the site of burial as the origin of this individual at a certain life point. Yet for all these individuals there are also individuals that fall within the local range of each site that may have been non-local, as they may have been mobile from isotopically similar regions. This difficulty touches upon one of the key challenges of bioarchaeological mobility research in that for the quantification that is possible, there is a degree of ambiguity due to regionally similar isotopic signatures. It is possible to provide regional assessments of where individuals migrated from based on isotopic values in rainwater ($\delta^{18}O_{dw}$) and underlying geology ($^{87}Sr/^{86}Sr$) yet it if individuals are mobile within regions of similar isotopic signatures they will not necessarily be identified as non-local. It also remains difficult to isolate with a high degree of certainty the specific city an individual was mobile from. Though these are limitations they are not inhibitions to using this method as isotopic evidence can provide a degree of personalized evidence not possible with more traditional methods of epigraphy and burial style, allowing for mobility at any given site with preserved human remains to be conceptualized from the individualized level of its inhabitants.

This study has also shown that epigraphic and isotopic methods can be complementary. In the case of SCR the limited epigraphic information available with insight to regions of known origins for individuals buried at Isola Sacra helped to provide a further piece of data that was used to suggest and support potential regions of origin (e.g. North Africa) based on corresponding isotope data. Epigraphic data can also help to point out locations that might not otherwise be considered. The point and case in the present study being Palmyra. The distant location of this site compared to SCR and JBR in terms of mobility would parsimounsiously suggest a less likely point of origin. Yet the work of Noy (2010) provides concrete evidence that migrants from Palmyra were present in Romano-Britain, providing a basis to suggest that they may also be present at JBR and SCR. In this way the textual data available can help to contextualize and suggest points of origin that can be supported through isotopic methodologies.

For all the benefits of isotopic methods we cannot reasonably attest from isotopic data alone the degree of integration or exclusion from a community that a non-local individual would have experienced. It is at this crux that isotopic examination is best situated within broader anthropological methodologies (e.g. burial and grave good style, theoretical models of mobility and identity etc…) to gain insights to how non-local individuals may have been integrated and acculturated at various residency locales.

Moving forward, in the foreseeable future isotopic bioarchaeological studies of Roman contexts would benefit from two areas of inquiry. The first, as has been discussed at length previously, is the continued need to integrate epigraphic, archaeological and bioarchaeological methods in the hope of providing increasingly nuanced and robust interpretations. The second area of inquiry that would benefit from further attention is the need to generate bioavailable ^{87}Sr/^{86}Sr data. As it stands most bioavailable ^{87}Sr/^{86}Sr data is generated on a site by site or region by region basis for specific study purposes. This is of course very helpful but also makes inter-regional comparisons between sites challenging. Broader regional bioavailable ^{87}Sr/^{86}Sr studies such as those presented by Nafplioti (2011) and Willmes et al. (2014) for Greece and France respectively allow not only single site comparisons but also broader regional studies. Such bioavailable ^{87}Sr/^{86}Sr provenience studies are invaluable to the field as a whole.

Turning to nonmetric traits the results of this dissertation have provided a number of insights regarding this methodology and the sites of SCR, JBR, and Velia. The biological results of this distance study suggest a degree of underlying homogeneity of samples with region variations. Given the results of the isotopic study suggesting significant mobility to all three sites it is possible that the biological diversity at all three sites is roughly similar, while regionally unique population contributions resulted in the greater dissimilarity of JBR to Velia. It can be said, as has been previously discussed by Coppa et al. (1998) and Rubini et al. (2007), that with Roman expansion increasing biological similarity would have been taking place as a result of the mass mobility of individuals to and from Rome as well as the increased potential for regular gene flow provided by the increasingly robust infrastructure and transportation networks generated under the Roman empire. What future research needs to confirm or contest this assertion is a wider set of samples. With increased inclusion of provincial and distant sites this trend of biological averaging could be better examined, and it might be possible to further suggest where this process was most prominent based on the degree of MMD similarity and dissimilarity by region.

The Roman empire was a complex and convoluted environment that any one method of examination would be found wanting to define and encapsulate in all aspects. The arguments and results presented in this thesis offer a number of insights and contributions that can be interwoven with other means of examining mobility and can be built upon by future research. Regardless of one's perspective on who was moving and why they were moving, more than anything what this dissertation contributes is that people were moving.

References Cited

Aase JM. 1981. The Dysmorphology Detective. Pediatric Annals 20:38–43.

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

Adams C. 2016. Migration in Roman Egypt: Problems and Possibilities. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 264–284.

Adams JL. 1934. The Supracondyloid Variation in the Human Embryo. Anatomical Record 59:315–333.

Aggarwal PK, Araguás-Araguás LJ, Groening M, Kulkarni KM, Kurttas T, Newman BD, Vitvar. 2010. Global Hydrological Isotope Data and Data Networks. 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. 33–50.

Akabori E. 1934. Septal Aperture in Japanese, Ainu and Koreans. American Journal of Physical Anthropology 18:395–400.

Akabori E. 1933. Crania Nipponica Recentia. Japanese Journal of Medical Science, Anatomy 4:61–318.

Albrecht G. 1972. Soziologie der geographischen Mobilität: Zugleich ein Beitrag zur Soziologie des sozialen Wandels. Enke, Stuttgart.

Allen H. 1867. On Certain Features in the Conformation of the Mammalian Skull. Proceedings of the Academy of Natural Science 19:11–19.

Allison PM. 2006a. Artifact Distribution Within the Auxillary Fort at Ellingen: Evidence for Building Use and for the Presence of Women and Children. Bericht der Römisch-Germanischer Kommission 87:387–452.

Allison PM. 2006b. Mapping for Gender. Interpreting Artefact Distribution Inside 1st Century and 2nd Century A.D. Forts in Roman Germany. Archaeological Dialogues 13:1–20.

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

Al-Shorman A, El-Khouri L. 2011. Strontium Isotope Analysis of Human Tooth Enamel from Barsinia: A Late Antiquity Site in Northern Jordan. Archaeological and Anthropological Sciences 3:263–269.

Alston, R., 2014. Aspects of Roman History, 31 BC–AD 117. Routledge, New York.

Alt KW, Pichler S, Vach W, Huckenbeck W, Stloukal M. 1996. Early Bronze Age Family Burial from Velke Pavlovice: Verification of Kinship Hypothesis by Odontologic and Other Nonmetric Traits. Homo 46:256–266.

Alt KW, Vach W. 1995. Odontologic Kinship Analysis in Skeletal Remains: Concepts, Methods and Results. Forensic Science International 74:99–113.

Alt KW, Vach W. 1992. Non-Spatial Analysis of "Genetic Kinship" in Skeletal Remains. In: Schader M. (ed.), Analyzing and Modeling Data and Knowledge: Proceedings of the 15th Annual Conference of the "Gesellschaft für Klassifikation e. V." Springer-Verlag, Berlin, pp. 247–256.

Alt KW, Vach W. 1991. The Reconstruction of Genetic Kinship in Prehistoric Burial Complexes: Problems and Statistics. In: Bock H, Ihm P. (Eds.), Classification, Data Analysis and Knowledge Organization: Models and Methods with Applications. Springer-Verlag, Berlin, pp. 299–310.

American Society of Limnology and Oceanography (ASLO). 1995. New Manuscript Guidelines for the Reporting of Stable Hydrogen, Carbon, and Oxygen Isotope-Ratio Data. Limnology and Oceanography 40:1182.

Anderson JE. 1968. Skeletal "Anomalies" as Genetic Indicators. In: Brothwell DR. (Ed.), The Skeletal Biology of Earlier Human Populations. Symposia of the Society for the Study of Human Biology vol. 8. Pergamon Press, Oxford, pp.135–147.

Anderson T. 1987. Postcranial Nonmetric Variation: The Examination of a Neglected Subject. Unpublished MA Thesis, University of Sheffield.

Anderson T. 1986–87. A Medieval Bipartite Cuneiform I with Attempted Unilateral Fusion. Ossa: International Journal of Skeletal Research 13:39–48.

André, JM, Baslez, MF. 1993. Voyager dans l'Antiquité. Fayard, Paris.

Andreau J. 1999. Banking and Business in the Roman World. Cambridge University Press, Cambridge.

Angel JL. 1980. Physical Anthropology: Determining, Sex, Age, and Individual Features. In: Cockburn A, Cockburn E. (Eds.), Mummies, Disease and Ancient Cultures. Cambridge University Press, Cambridge, pp. 241–257.

Angelucci S, Baldassarre I, Bragantini I, Lauro MG, Mannucci V, Mazzoleni A, Morselli C, Taglietti F. 1990. Sepolture e riti nella necropoli dell'Isola Sacra. Bollettino di Archeologia 5-6:50-113.

Anoutchine DN. 1878. Sur la Conformation du Pterion chez Diverses Races Humaines et les Primates. Bulletin de la Société d’Anthropologie 1:330–333.

Anscombe FJ. 1948. The Transformation of Poisson, Binomial, and Negative-Binomial Data. Biometrika 35:246–254.

Anthias F. 1998. Evaluating “Diaspora”: Beyond Ethnicity? Sociology 32:557–580.

Anthony, D.W., 1990. Migration in Archaeology: The Baby and the Bathwater. American Anthropologist 92, 895–914.

Anthony DW. 1992. The Bath Refilled: Migration in Archaeology Again. American Anthropologist 94:174–176.

Anthony DW. 1997. Prehistoric Migration as Social Process. In: Chapman J, Hamerow H. (Eds.), Migration and Invasion in Archaeological Explanation (British Archaeological Reports International Series 664) Archaeopress, Oxford, pp. 21–32.

Appadurai A. 1991. Global Ehtnoscapes: Notes and Queries for a Transnational Anthropology. In: Fox R., (Ed.), Recapturing Anthropology. School of American Research Press, Santa Fe, pp. 191–210.

Appadurai, A., 1996. Modernity at Large: Cultural Dimensions of Globalization. University of Minnesota Press, Minneapolis.

Aquilina L, Girard V, Henin O, Bouhnik-Le Coz M, Vilbert D, Perrichot V, Néraudeau D. 2013. Amber Inorganic Geochemistry: New Insights into the Environmental Processes in a Cretaceous Forest of France. Palaeogeography, Palaeoclimatology, Palaeoecology 369:220–227.

Ardito G. 1975. I caratteri epigenetici del cranio in due gruppi di antichi Egizi: osservazioni sulla validita e limitazioni del metodo. Archivo per l’Antropologia e la Etnologia 105:169–181.

Armelagos GJ, Carlson DS, Van Gerven DP. 1982. The Theoretical Foundations and Development of Skeletal Biology. In: Spencer F. (Ed.), A History of American Physical Anthropology: 1930–1980. Academic Press, New York, p. 305–328.

Armstrong JA. 1976. Mobilized and Proletarian Diasporas. American Political Science Review 70:393–408.

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.

Arnoldus-Huyzendveld A, Keay S, Millet M, Zevi F. 2005. Background to Portus. In: Keay S, Millett M, Paroli L, Strutt K. (Eds.), Portus An Archaeological Survey of the Port of Imperial Rome. The British School at Rome, London, pp. 11–42.

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.

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

Ashley-Montagu MFA. 1937. The Medio-Frontal Suture and the Problem of Metopism in the Primates. Journal of the Royal Anthropological Institute of Great Britain and Ireland 67:157–201.

Aufderheide AC. 1989. Chemical Analysis of Skeletal Remains. In: Iscan MY, Kennedy KAR. (Eds.), Reconstruction of Life From the Skeleton. Alan R. Liss, New York, pp. 237−260.

Axelsson G, Hedegaard B. 1985. Torus Palatinus in Icelandic Schoolchildren. American Journal of Physical Anthropology 67:105–112.

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.

Baigl JP, Farago-Szekeres B, Roger J. 1997. Saintes: La Necropole de la Rue Jacques Brel. SRA Poitou-Chartenes, Poitiers.

Baldassarre I. 1978. La necropoli dell'Isola Sacra, Quaderni de 'La Ricerca Scientifica' 100:3–20.

Baldassarre 1.1984. Una necropoli imperiale Romana: proposte di lettura. Annali di Archeologia e Storia Antica 6:141-149.

Baldassarre I. 1990. Nuove ricerche nella necropolis dell'Isola Sacra. Quaderni di Archeologia Etrusco-Italica 19:164–172.

Baldassarre I, Bragantini I, Dolciotti AM, Morselli C, Taglietti F, Taloni M. 1985. La necropoli delllsola Sacra. Campagne di scavo 1976-1979. Quademi de T^a Ricerca Scientifica' 112:261-302.

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

Balter M. 2000. Genetics: Was Lamarck Just a Little Bit Right? Science 288.5463:38.

Barbieri M, Masi U, Tolomeo L. 1979. Origin and Distribution of Strontium in the Travertines from Latium (Central Italy). Chemical Geology 24:181–8.

Barbieri M, Sappa G. 1997. Application of Geochemical and Isotopic Analysis Methods (87Sr/86Sr) in Hydrogeological Characterization of Some Springs in Simbruini Mountains (Italy). In Beddow JK (Ed.), Proceedings of the International Symposium on Geology and Environment, pp. 77–81.

Barrett SR. 1997. Anthropology: A Student's Guide to Theory and Method. University of Toronto Press, Toronto.

Barnes E. 2008. Congenital Anomalies. In: Pinhasi R, Mays S. (Eds.), Advances in Human Palaeopathology. John Wiley and Sons Ltd., Chichester, p. 329–362.

Barnes E. 1994. Developmental Defects of the Axial Skeleton in Paleopathology. University Press of Colorado, Niwot.

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.

Beard BL, Johnson CM. 2000. Strontium Isotope Composition of Skeletal Material can Determine the Birth Place and Geographic Mobility of Humans and Animals. Journal of Forensic Sciences 45:1049–1061.

Beauchesne P, Agarwal SC. 2014. Age-Related Cortical Bone Maintenance and Loss in an Imperial Roman Population. International Journal of Osteoarchaeology 24:15–30.

Bedrick EJ, Lapidus J, Powell JF. 2000. Estimating the Mahalanobis Distance from Mixed Continuous and Discrete Data. Biometrics 56:394–401.

Benassi-Graffi E, Facchini F, Brasili-Gualandi P, Gualdi-Russo E. 1979a. Sulle ossa soprannumerarie del cranio. Nota preliminarie. Antropologia Contemporanea 2:311–314.

Benassi-Graffi E, Facchini F, Brasili-Gualandi P, Gualdi-Russo E. 1979b. Ricerche sulle ossa soprannumerarie del cranio. Quaderni di Anatomia Pactica 35:321–331.

Bencivenga Trillmich C. 1990. Elea: Problems of the Relation Between City and Territory. In: Descoeudres JP. (Ed.), Greek Colonists and Native Populations: Proceedings of the First Australian Congress of Classical Archaeology Held in Honour of Emeritus Professor A.D. Trendall, Sydney, 9–14 July 1985. Humanities Research Centre Canberra, Clarendon Press, Oxford, pp. 365–371.

Benelli E. 2001. The Romanization of Italy Through the Epigraphic Record. In: Keay S., Terrenato N. (Eds.), Italy and the West Comparative Issues in Romanization. Oxbow Books, Oxford, pp. 7–16.

Bentley GR. 1987. Kinship and Social Structure at Early Bronze Age 1A Bab dh-Dhra', Jordan: A Bioarchaeology Analysis of Mortuary and Dental Data. Unpublished Ph.D. Dissertation, University of Chicago.

Bentley GR. 1991. A Bioarchaeological Reconstruction of the Social and Kinship Systems at Early Bronze Age Bab dh-Dhra', Jordan. In: Gregg SA. (Ed.), Between Bands and States. Southern Illinois University at Carbondale, Center for Archaeological Investigations Occasional Paper 9.

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

Bentley RA, Krause R, Price TD, and Kaufmann B. 2003. Human Mobility at the Early Neolithic Settlement of Vaihingen, Germany: Evidence from Strontium Isotope Analysis. Archaeometry 45(3): 471-486.

Bentley RA, Price TD, Stephan E. 2004. Determining the 'Local' ^{87}Sr/^{86}Sr Range for Archaeological Skeletons: A Case Study from Neolithic Europe. Journal of Archaeological Science 31:365–375.

Bentley, RA., Buckley HR, Spriggs M, Bedford S, Ottley CJ, Nowell GM, Macpherson CG, Pearson DG. 2007. Lapita Migrants in the Pacific's Oldest Cemetery: Isotopic Analysis at Teouma, Vanuatu. American Antiquity 72, 645–656.

Bentley RA, Cox K, Tayles N, Higham C, Macpherson C, Nowell, Cooper, Hayes. 2009. Community Diversity at Ban Lum Khao, Thailand: Isotopic Evidence from the Skeletons. Asian Perspectives 48:79–97.

Bentz AS. 2010. National Identity and Diaspora: Tibetan Refugees in India. In Arslan S, Schwieger P. (Eds.), Tibetan Studies an Anthology. PIATS 2006: Tibetan Studies: Proceedings of the Eleventh Seminar of the International Association for Tibetan Studies, Königswinter 2006. International Institute for Tibetan and Buddhist Studies GmbH, pp. 93–116.

Bergman P. 1993. The Occurrence of Selected Non-Metrical Traits of the Skull in Relation to *Cribra Orbitalia* and Grave Equipment. Variability and Evolution 2/3:63–75.

Bergman P. 1987. *Cribra Orbitalia* und ausgewählte Discreta der Schädel aus dem Reihengräberfeld von Milicz, Niederschlesen (12–14 Jh.) unter Berücksichtigung der Grabausstattung. Acta Musei Nationalis Pragae 43:103–108.

Bernard SG. 2016. Food Distributions and Immigration in Imperial Rome. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 50–71.

Berry RJ. 1963. Epigenetic Polymorphism in Wild Populations of *Mus musculus*. Genetical Research 4:193–200.

Berry AC, Berry RJ. 1967. Epigenetic Variation in the Human Cranium. Journal of Anatomy 101:361–379.

Berry RJ. 1968. The Biology of Non-Metrical Variation in Mice and Men. In: Brothwell DR. (Ed.), The Skeletal Biology of Earlier Human Populations. Symposia of the Society for the Study of Human Biology vol. 8. Pergamon Press, Oxford, pp. 103–133.

Berry AC. 1974. The Use of Non-Metrical Variations of the Cranium in the Study of Scandinavian Population Movements. American Journal of Physical Anthropology 40:345–358.

Berry AC. 1975. Factors Affecting the Incidence of Non-Metrical Skeletal Variants. Journal of Anatomy 120:517–535.

Berry RJ, Searle AG. 1963. Epigenetic Polymorphism of the Rodent Skeleton. Proceedings of the Zoological Society of London 140:557–615.

Bertelli D. 1892. Forami Mentonieri nell'Uomo ed in Altri Mammiferi. Monitore Zoologico Italiano 3:52–55, 80–83, 89–99.

Bertz N. 2015. Diaspora and Nation in the Indian Ocean: Transnational Histories of Race and Urban Space in Tanzania. University of Hawai'i Press, Honolulu.

Bhabha HK. 2004. The Location of Culture. Routledge, London.

Bhattacharyya A. 1946. On A Measure of Divergence Between Two Multinomial Populations. Sankhya 7:401–406.

Biju-Duval B, Letouzey J, Montadert L, Courrier P, Mugniot JF, Sancho J. 1974. Geology of the Mediterranean Sea Basins. In: Burk CA. (ed.), The Geology of Continental Margins. Springer-Verlag, New York, pp. 695–721.

Birkby WH. 1973. Discontinuous Morphological Traits of the Skull as Population Markers in the Prehistoric Southwest. Unpublished Ph.D. Dissertation, University of Arizona.

Bispham E. 2006. Coloniam Deducere: How Roman Was Roman Colonization During the Middle Republic. In: Bradley G., Wilson JP. (Eds.), Greek and Roman Colonization. Origins, Ideologies, and Interactions. Classical Press of Wales, Swansea, pp. 73–160.

Blom DE, Hallgrimsson B, Keng L, Loza de Cerna MC, Buikstra JE. 1998. Tiwanaku 'Colonization'. Biological Implications for Migration in the Moquegua Valley, Peru. World Archaeology 30:238–261.

Blumenbach JF. 1776. De Generis Humani Varietate Nativa. Kietrich, Göttingen.

Bocquet-Appel JP. 1984. Biological Evolution and History in 19th Century Portugal. In: Van Vark GN, Howells WW. (Eds.), Multivariate Statistical Methods in Physical Anthropology. D. Reide, Boston, pp. 289–321.

Bogue DJ. 1977. A Migrant's Eye View of the Costs and Benefits of Migration to a Metropolis. In: Brown AA, Neuberger E. (Eds.), Internal Migration: A Comparative Perspective. Academic Press, New York, pp. 167–182.

Bondioli L, Corruccini RS, Macchiarelli R. 1986. Familial Segregation in the Iron Age Community of Alfedena Abruzzo, Italy, Based on Osteodental Traits. American Journal of Physical Anthropology 71:393–400.

Bondioli L, Macchiarelli R, Salvadei L, Passarello P. 1995. Paleobiologia del'Età Romana Imperiale: Il Progetto "Isola Sacra." In: Peretto C, Milliken S. (Eds.), XI Congresso degli Antropologi Italiani. L'Adattamento Umano all'Ambiente. Passato e Presente. C. Iannone, Isernia, pp. 78–79.

Bondioli L, Sperduti A. 2011. Comunità dei Morti e Individui Scheletrici: Dallo Studio di Popolazioni alla Ricostruzione della Storia Biologica Individuale. In: Nizzo V. (Ed.), Dalla Nascita alla Morte: Antropologia e Archeologia a Confronto, Atti dell'Incontro Internazionale di Studi in onore di Claude Lévi-Strauss, 21 Maggio 2010, Museo Nazionale Preistorica Etnografico "Luigi Pigorini," Roma. Casa Editrice, Roma, pp. 431–459.

Booden MA, Panhuysen RGAM, Hoogland MLP, de Jong HN, Davies GR, Hofman CL. 2008. Tracing Human Mobility with 87Sr/86Sr at Anse Á la Gourde, Guadeloupe. In: Hofman CL, Hoogland MLP, van Gijn AL. (Eds.), Crossing the Borders: New Methods and Techniques in the Study of Archaeological Materials from the Caribbean. University of Alabama Press, Tuscaloosa, pp. 214–225.

Bol R, Marsh J, Heaton THE. 2007. Multiple Stable Isotope (^{18}O, ^{13}C, ^{15}N and ^{34}S) Analysis of Human Hair to Identify the Recent Migrants in a Rural Community in SW England. Rapid Communications in Mass Spectrometry 21:2951–2954.

Booth P. 2014. A Late Roman Military Burial from Dyke Hills, Dorchester on Thames, Oxfordshire. Britannia 45:243–273.

Bordieu, P., 1977. Outline of a Theory of Practice. Cambridge University Press, Cambridge.

Borjas G. 1990. Friends or Strangers: The Impact of Immigrants on the U.S. Economy. Basic Books, New York.

Borian TV, Attwood CR, Jaconette JR. 1964. Anterior Fontanelle Bone in Siblings. American Journal of Diseases of Children 108:625–626.

Boric D, Price T. 2013. Strontium Isotopes Document Greater Human Mobility at the Start of the Balkan Neolithic. Proceedings of the National Academies of Science U.S.A 110:3298–3303.

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

Bowen GJ, Winter DA, Spero HJ, Zierenberg RA, Reeder MD, Cerling TE, Ehleringer JR. 2005. Stable Hydrogen and Oxygen Isotope Ratios of Bottled Waters of the World. Rapid Communications in Mass Spectrometry 19:3442–3450.

Bowen GJ, Ehleringer JR, Chesson LA, Thompson AH, Podlesak DW, Cerling TE. 2009. Dietary and Physiological Controls of the Hydrogen and Oxygen Isotope Ratios of Hair from Mid-20th Century Indigenous Populations. American Journal of Physical Anthropology 139:494–504.

Bowman A. 1998. Life and Letters on the Roman Frontier: Vindolanda and its People. Routledge, New York.

Boyd M. 1989. Family and Personal Networks in International Migration: Recent Developments and New Agendas. International Migration Review 23:638–70.

Bradley K. 1994. Slavery and society at Rome. Cambridge: Cambridge University Press.

Brady AL, White CD, Longstaffe FJ, Southam G. 2008. Investigating Intra-Bone Isotopic Variations in Bioapatite Using IR-Laser Ablation and Micromilling: Implications for Identifying Diagenesis? Palaeogeography, Palaeoclimatology, Palaeoecology 266:190–199.

Brah A. 1996. Cartographies of Diaspora: Contesting Identities. Routledge, London.

Brand WA, Coplen TB, Vogl J, Rosner M, Prohaska T. 2014. Assessment of International Reference Materials for Isotope-Ratio Analysis (IUPAC Technical Report). Pure and Applied Chemistry 86:425–467.

Brasili-Gualandi P, Gualdi-Russo E. 1989. Discontinuous Traits of the Skull: Variations on Sex, Age, Laterality. Anthropologischer Anzeiger 47:239–250.

Brasili P, Zaccagni L, Gualdi-Russo E. 1999. Scoring of Non-Metric Cranial Traits: A Population Study. Journal of Anatomy 195:551–562.

Braziel JE, Mannur A. 2003. Nation Migration, Globalization: Points of Contention in Diaspora Studies. In: Braziel JE, Mannur A. (Eds.), Theorizing Diaspora: A Reader. Blackwell, Malden, pp. 1–22.

Brems D, Ganio M, Latruwe K, Balcaen L, M Carremans, Gimeno D, Silvestri A, Vanhaecke F, Muchez P, Degryse P. 2013. Isotopes on the Beach, Part 1: Strontium Isotope Ratios as a Provenance Indicator for Lime Raw Materials Used in Roman Glass Making. Archaeometry 55:214–234.

Brettell, C., 2003. Anthropology and Migration: Essays on Transnationalism, Ethnicity, and Identity. Altamira Press, Walnut Creek.

Brettell, CB., 2008. Theorizing Migration in Anthropology: The Social Construction of Networks, Identities, Communities, and Globalscapes. In: Brettell, C.B., Hollified, J.F., (Eds.), Migration Theory: Talking Across Disciplines, 2nd Edition. Routledge, New York, pp. 113–159.

Brettell CB. 2015. Theorizing Migration in Anthropology: The Cultural, Social, and Phenomenological Dimensions of Movement. In: Brettell CB, Hollifield JF. (Eds.), Migration Theory: Talking Across Disciplines, 3rd Edition. Routledge, New York.

Brettell R, Montgomery J, Evans J. 2012a. Brewing and Stewing: The Effect of Culturally Mediated Behaviour on the Oxygen Isotope Composition of Ingested Fluids and the Implications for Human Provenance Studies. Journal of Analytical Atomic Spectrometry 27:778-785.

Brettell R, Evans J, Marzinzik S, Lamb A, Montgomery J. 2012b. Impious Easterners: Can Oxygen and Strontium Isotopes Serve as Indicators of Provenance in Early Medieval European Cemetery Populations? European Journal of Archaeology 15:117−145.

Brighton SA. 2009. Historical Archaeology of the Irish Diaspora: A Transnational Approach. University of Tennessee Press, Knoxville.

Britton K, Fuller BT, Tütken T, Mays S, Richards MP. 2015. Oxygen Isotope Analysis of Human Bone Phosphate Evidences Weaning Age in Archaeological Populations. American Journal of Physical Anthropology 157:226–241.

Brody B. 2002. Opening the Door: Immigration, Ethnicity, and Globalization in Japan. Routledge, New York.

Brooks S, Suchey JM. 1990. Skeletal Age Determination Based on the *Os Pubis,* a Comparison of the Acsárdi-Nemeskeri and Suchey-Brooks Methods. Human Evolution 5:227−238.

Brothwell DR. 1959. The Use of Non-Metrical Characters of the Skull in Differentiating Populations. In: Schaeuble J, Schaefer U. (Eds.), Bericht über die 6 Tagung der Deutschen Gesellschaft für Anthropologie in Kiel, 30.7 bis 2.8, 1958. Musterschmidt-Verlag, Göttingen, p.103–109.

Brothwell DR. 1981. Digging Up Bones: The Excavation, Treatment and Study of Human Skeletal Remains, Third Edition. Cornell University Press, Ithaca.

Brothwell DR. 2000. Studies on Skeletal and Dental Variation: A View Across Two Centuries. In: Cox M, Mays S. (Eds.), Human Osteology: In Archaeology and Forensic Science. Cambridge University Press, Cambridge, p. 1–6.

Brothwell D, Powers R. 1968. Congenital Malformations of the Skeleton in Earlier Man. In: Brothwell DR. (Ed.), The Skeletal Biology of Earlier Human Populations. Symposia of the Society for the Study of Human Biology vol. 8. Pergamon Press, Oxford, p. 173–203.

Brothwell D, Zakrzewski S. 2004. Metric and Non-Metric Studies of Archaeological Human Bone. In: Brickley M, McKinley JI. (Eds.), Guidelines to the Standards for Recording Human Remains. IFA Paper 7. BABAO/IFA, Southampton, p. 27–33.

Brown E, Colling A, Park D, Phillips J, Rothery D, Wright J. 1995. Seawater: Its Composition, Properties and Behaviour, Second Edition. Pergamon Press, Oxford.

Brown JS, Schwarzweller HK, Mangalam JJ. 1970. Kentucky Mountain Migration and the Stem-Family: An American Variation on a Theme by Le Play. In: Jansen, CJ. (Ed.), Readings in the Sociology of Migration. Pergamon Press, Oxford, pp. 93–120.

Brown LS, Gustavus SO, Malecki EJ. 1977. Awareness Space Characteristics in a Migration Context. Environment and Behavior 9:335–348.

Brown T, Brown K. 2011. Biomolecular Archaeology: An Introduction. Wiley-Blackwell, Chichester.

Brubaker R. 2005. The “Diaspora” Diaspora. Ethnic and Racial Studies 28:1–19.

Brummel AC. 1979. A Model of Intraurban Mobility. Economic Geography 55:338–352.

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

Bruun C. 2016. Tracing Familial Mobility: Female and Child Migrants in the Roman West. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 176–204.

Bruun C, Zevi G. (eds.). 2002 Ostia e Portus nelle loro relazioni con Roma. Acta Instituti Romani Finlandiae 27. Institutum Romanum Finlandiae, Roma, pp. 11–32.

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

Budd P, Chenery D, Montgomery J, Evans J, Powlesland D. 2003. Anglo-Saxon Residential Mobility at West Heslerton, North Yorkshire, U.K. From Combined O- and Sr-isotope Analysis. In: Holland G, Tanner SD. (Eds.), Plasma Source Mass Spectrometry: Applications and Emerging Technologies. Royal Society of Chemistry, Cambridge, pp. 198–208.

Budd P, Millard A, Chenery C, Lucy S, Roberts. 2004. Investigating Population Movement by Stable Isotope Analysis: A Report From Britain. Antiquity 78:127–141.

Buikstra JE. 1972a. Hopewell in the Lower Illinois River Valley: A Regional Approach to the Study of Biological Variability and Mortuary Activity. Unpublished Ph.D. Dissertation, University of Chicago.

Buikstra JE 1972b. Techniques for Coping with the Age-Regressive Nature of Non-Metric Traits. American Journal of Physical Anthropology 37:431–432.

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

Buikstra JE, Frankenberg SR, Konigsberg LW. 1990. Skeletal Biological Distance Studies in American Physical Anthropology: Recent Trends. American Journal of Physical Anthropology 82:1–7.

Bullen TD, Kendall C. 1998. Tracing of Weathering Reactions and Water Flowpaths: A Multi-Isotope Approach. In: Kendall C, McDonnell JJ. (Eds.), Isotope Tracers in Catchment Hydrology. Elsevier, Amsterdam, pp.611–646.

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

Burnett SE. 2005. Developmental Variation in South African Bantu: Variant Co-Occurrence and Skeletal Asymmetry. Unpublished Ph.D. Dissertation, Arizona State University.

Burns KR. 1999. Forensic Anthropology Training Manual. Prentice Hall, Engelwood Cliffs.

Burton J. 2008. Bone Chemistry and Trace Element Analysis. In: Katzenberg MA, Saunders SR. (Eds.), Biological Anthropology of the Human Skeleton, Second Edition. Wiley-Liss, Hoboken, pp. 443–460.

Burton JH, Price TD, Middleton WD. 1999. Correlation of Bone Ba/Ca and Sr/Ca Due to Biological Purification of Calcium. Journal of Archaeological Science 26:609–616.

Burton JH, Price TD, Cahue L, Wright LE. 2003. The Use of Barium and Strontium Abundances in Human Skeletal Tissues to Determine their Geographic Origins. International Journal of Osteoarchaeology 13:88–95.

Butler KD. 2001. Defining Diaspora, Refining a Discourse. Diaspora 10:189–219.

Buzon M, Simonetti A, Creaser R. 2007. Migration in the Nile valley during the New Kingdom period: a preliminary strontium isotope study. Journal of Archaeological Science 34:1391–1401.

Buzon MR, Bowen GJ. 2010. Oxygen Isotope Analysis of Migration in the Nile Valley. Archaeometry 52:855–868.

Buzon MR, Conlee CA, Bowen GJ. 2011. Refining Oxygen Isotope Analysis in the Nasca Region of Peru: An Investigation of Water Sources and Archaeological Samples. International Journal of Osteoarchaeology 21:446–455.

Buzon M, Simonetti A. 2013. Strontium isotope (^{87}Sr/^{86}Sr) variability in the Nile Valley: identifying residential mobility during ancient Egyptian and Nubian sociopolitical changes in the New Kingdom and Napatan Period. American Journal of Physical Anthropology 151:1-9.

Cadien JD, Harris EF, Jones WP, Mandarino LD. 1974. Biological Lineages, Skeletal Populations, and Microevolution. Yearbook of Physical Anthropology 18:194–201.

Calza G. 1940. La Necropoli del Porto di Roma nell'Isola Sacra. Istituto Nazionale di Archeologia e Storia dell'Arte. Libreria dello Stato, Rome.

Capasso L. 1985–86. Familiar Relationship Reconstruction in the Burials "Circles" of the Alfedena Necropolis (Iron Age: L'Aquila, Italy), Using the Mobility and Topographic Distribution of Non-Malignant Osseous Neoplasm. Ossa: International Journal of Skeletal Research 12:3–7.

Capasso L, Kennedy KAR, Wilczak CA. 1999. Atlas of Occupational Markers on Human Remains. Journal of Paleontology, Monographic Publication 3. Edigrafital S.p.a., Teramo.

Carpenter JC. 1976. A Comparative Study of Metric and Nonmetric Traits in a Series of Modern Crania. American Journal of Physical Anthropology 4:337–343.

Carson EA. 2006. Maximum-Likelihood Variance Components Analysis of Heritabilities of Cranial Nonmetric Traits. Human Biology 78:383–402.

Case DT. 1996. Developmental Defects of the Hands and Feet. Unpublished MA Thesis, Arizona State University.

Case DT. 2003. Who's Related to Whom? Skeletal Kinship Analysis in Medieval Danish Cemeteries. Unpublished Ph.D. Dissertation, Arizona State University.

Castles S, Miller MJ. 1993. The Age of Migration: International Population Movements in the Modern World. Macmillan Press, Basingstoke.

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.

Cesnys G. 1982. Side Difference of Non-Metric Cranial Traits in the 1st–2nd Millennia A.D. Lithuanian Materials. Homo 33:201–210.

Cesnys G, Pavilonis S. 1982. On the Terminology of Non-Metric Cranial Traits (Discreta). Homo 33:125–130.

Cesnys G, Tutkuviene J. 2007. Topographical Approach to Kinship Assessment Within Population According to Discrete Cranial Traits: the 5th–6th cc. Plinkaigalis Cemetery. Acta Medica Lituanica 14:7–16.

Chadwick OA, Derry LA, Vitousek PM, Huebert BJ, Hedin LO. 1999. Changing Sources of Nutrients During Four Million Years of Ecosystem Development. Nature 397:491–497.

Chantraine J, Chêne F, Nehlig P, Rabu D. 2005. Carte Géologique de la France à 1/1 000 000 6e Édition Révisée 2003, BRGM, Orléans.

Chapman P, Gill GW. 1997. Easter Island Origins: Non-Metric Cranial Trait Comparison Between Easter Island and Peru. Rapa Nui Journal 11:58–63.

Chapman T. 1990. Migration Revived. Journal of Danish Archaeology 9:214–218.

Chenery C. 2008. Oxygen and Strontium Analysis of Tooth Enamel (NERC Isotope Geoscience Laboratory Report Series No. 221). In: Simmonds A, Márquez-Grant N, Loe L, (Eds.), Life and Death In A Roman City, Excavation of a Roman Cemetery with a Mass Grave at 120–122 London Road, Gloucester. Oxford Archaeology Monographs No. 6. Oxford Archaeological Unit, Oxford, pp. 150–153.

Chenery C, Müldner G, Evans J, Eckardt H, Lewis M. 2010. Strontium and Stable Isotope Evidence for Diet and Mobility in Roman Gloucester, UK. Journal of Archaeological Science 37:150–163.

Chenery C, Eckardt H, Müldner G. 2011. Cosmopolitan Catterick? Isotopic Evidence for Population Mobility on Rome’s Northern Frontier. Journal of Archaeological Science 38:1525–1536.

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.

Chesselet R, Morelli J, Buat-Menard P. 1972. Variations in Ionic Ratios Between Reference Sea Water and Marine Aerosols. Journal of Geophysical Research, 77:5116-5131.

Chesson LA, Podlesak DW, Cerling TE, Ehleringer JR. 2009. Evaluating Uncertainty in the Calculation of Non-Exchangeable Hydrogen Fractions Within Organic Materials. Rapid Communications in Mass Spectrometry 23:1275–1280.

Cheverud JM, Buikstra JE, Twichell E. 1979. Relationships Between Non-Metric Skeletal Traits and Cranial Size and Shape. American Journal of Physical Anthropology 50:191–198.

Cheverud JM, Buikstra JE. 1981a. Quantitative Genetics of Skeletal Nonmetric Traits in the Rhesus Macaques on Cayo Santiago. I. Single Trait Heritabilities. American Journal of Physical Anthropology 54:43–49.

Cheverud JM, Buikstra JE. 1981b. Quantitative Genetics of Skeletal Nonmetric Traits in the Rhesus Macaques on Cayo Santiago. II. American Journal of Physical Anthropology 54:51–58.

Cheverud JM, Buikstra JE. 1982. Quantitative Genetics of Skeletal Nonmetric Traits in the Rhesus Macaques of Cayo Santiago. III. Relative Heritability of Skeletal Nonmetric and Metric Traits. American Journal of Physical Anthropology 59:151–155.

Childe VG. 1925. The Aryans: A Study of Indo-European Origins. Routledge and Kegan Paul, London.

Childe VG. 1929. The Dawn of European Civilization. Routledge and Kegan Paul, London.

Childe VG. 1950. Prehistoric Migrations in Europe. Serie A: Forelesninger 20. Institutet for Sammenlignende Kulturforskning, Oslo.

Cho H, Stout SD. 2003. Bone Remodelling and Age-Associated Bone Loss in the Past: A Histomorphometric Analysis of the Imperial Roman Skeletal Population of Isola Sacra. In: Agarwal S, Stout S. (Eds.), Bone Loss and Osteoporosis: An Anthropological Perspective. Kluwer Academic, New York, pp. 207–228.

Christensen AF. 1998. Skeletal Evidence for Familial Interments in the Valley of Oaxaca, Mexico. Homo 49:273–288.

Christensen AF. 1997. Cranial Non-Metric Variation in North and Central Mexico. Anthropologischer Anzeiger 55:15–32.

Clarke G. 1975. Popular Movements and Late Roman Cemeteries. World Archaeology 7:46–56.

Cohen MM. 1982. The Child With Multiple Birth Defects. Raven Press, New York.

Cohen, R., 1978. Ethnicity: Problem and Focus in Anthropology. Annual Review of Anthropology 7: 379–403.

Cohen R. 2008. Global Diaspora: An Introduction, 2nd ed. Routledge, London.

Conner MD. 1984. Population Structure and Biological Variation in the Late Woodland of Westcentral Illinois. Unpublished Ph.D. Dissertation, University of Chicago.

Conner MD. 1990. Population Structure and Skeletal Variation in the Late Woodland of West-Central Illinois. American Journal of Physical Anthropology 82:31–43.

Constantalopoulou C. 2007. The Dance of the Islands. Insularity, Networks, The Athenian Empire and the Aegean World. Oxford University Press, Oxford.

Cool, HEM., 2010. Finding the Foreigners. 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. 27–44.

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 Spectometry 22:3187–3194.

Copeland SR, Sponheimer M, Lee-Thorp JA, le Roux PJ, de Ruiter DJ, Richards MP. 2010. Strontium Isotope Ratios in Fossil Teeth from South Africa: Assessing Laser Ablation MC-ICP-MS Analysis and the Extent of Diagenesis. Journal of Archaeological Science 37:1437–1446.

Coplen TB, De Bièvre P, Krouse HR, Vocke D, Gröning M, Rozanski K. 1996. Ratios for Light Element Isotopes Standardized for Better Interlaboratory Comparison. Eos 77:255.

Coppa A, Cucina A, Mancinelli D, Vargiu R, Calcagno JM. 1998. Dental Anthropology of Central-Southern, Iron Age Italy: The Evidence of Metric vs. Nonmetric Traits. American Journal of Physical Anthropology 107:371–386.

Coppa A, Cucina A, Lucci M, Macinelli D, Vargiu R. 2007. Origins and Spread of Agriculuture in Italy: A Nonmetric Dental Analysis. American Journal of Physical Anthropology 133:918–930.

Cormie A, Schwarcz HP. 1985. Stable Hydrogen Isotope Analysis of Bone Collagen has Potential for Paleoclimatic Research. Geological Society of America Annual Meeting, Orlando, Florida 17:553.

Cormie AB, Schwartz HP, Gray J. 1994. Determination of the Hydrogen Isotopic Composition of Bone Collagen and Correction for Hydrogen Exchange. Geochimica et Cosmochimica Acta 58:365-375.

Correnti V, Passarello P, Vécchi F. 1979. Discontinuous Morphological Traits of the Human Skeleton: A Proposal for an International Nomenclature in Latin. Homo 30:126–127.

Corruccini RS. 1976. The Interaction Between Nonmetric and Metric Cranial Variation. American Journal of Physical Anthropology 44:285–294.

Corruccini RS. 1974a. An Examination of the Meaning of Cranial Discrete Traits for Human Skeletal Biological Studies. American Journal of Physical Anthropology 40:425–446.

Corruccini RS. 1974b. The Relation Between Ponderal Index and Discrete Traits and Measurements of the Skull. Human Biology 46:219–231.

Corruccini RS, Shimada I. 2002. Dental Relatedness Corresponding to Mortuary Patterning at Huaca Loro, Peru. American Journal of Physical Anthropology 117:118–121.

Corruccini RS, Shimada I, Shinoda K. 2002. Dental and mtDNA Relatedness Among Thousand Year-Old Remains from Huaca Loro, Peru. Dental Anthropology 16:9−14.

Cortecci G, Longinelli A., 1970. Isotopic Composition of Sulfate in Rain Water, Pisa, Italy. Earth and Planetary Science Letters 8: 36–40.

Cosseddu GC, Floris G, Vona G. 1979. Sex and Side Differences in the Minor Non-Metrical Cranial Variants. Journal of Human Evolution 8:685–692.

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, Sperdutti 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.

Crowson RA, Showers WJ, Wright EK, Hoering TC. 1991. Preparation of Phosphate Samples for Oxygen Isotope Analysis. Analytical Chemistry 63:2397-2400.

Crubezy E. 1998. Interactions entre Facteurs Bio-Culturels, Pathologie et Caractères Discrets. Docteur en Medicine These. Université de Montpellier I.

Cybulski JS. 1972. Skeletal Variability in British Columbia Costal Populations: A Descriptive and Comparative Assessment of Cranial Morphology. Unpublished Ph.D. Dissertation, University of Toronto.

Dahinten SL, Pucciarelli HM. 1981. Effect of Sex, Age and Nutrition on Discontinuous Traits from Rat Skull. Acta Anatomica 110:159–163.

Dahinten SL, Pucciarelli HM. 1983. Effects of Protein-Calorie Malnutrition During Suckling and Post-Weaning Periods on Discontinuous Cranial Traits in Rats. American Journal of Physical Anthropology 60:425–430.

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.

Davis K. 1977. The Effect of Outmigration on Regions of Origin. In: Brown AA, Neuberger E. (Eds.), Internal Migration: A Comparative Perspective. Academic Press, New York, pp. 147–166.

Dawber RPR, Van Neste D. 2004. Hair and Scalp Disorders: Common Presenting Signs, Differential Diagnosis and Treatment. Informa Healthcare, London.

De Haas H. 2008. The Myth of Invasion: The Inconvenient Realities of African Migration to Europe. Third World Quarterly 29:1305–1322.

Deji OF. 2012. Gender and Rural Development Volume 2: Advanced Studies. Lit Verlag GmbH & Co., Vienna.

De Laeter JR, Böhlke JK, de Bièvre P, Hidaka H, Peiser HS, Rosman KJR, Taylor PDP. 2003. Atomic Weights of the Elements: Review 2000 (IUPAC Technical Report). Pure and Applied Chemistry 75:683–800.

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

De Ligt L, Tacoma LE. 2016. Approaching Migration in the Early Roman Empire. In: De Ligt L., Tacoma LE. (Ed.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 1–22.

DePaolo DJ, Wasserburg GJ. 1976a. Nd Isotopic Variations and Petrogenetic Models. Geophysical Research Letters 3:249–252.

DePaolo DJ, Wasserburg GJ. 1976b. Inferences About Magma Sources and Mantle Structure From Variations of ^{143}Nd/^{144}Nd. Geophysical Research Letters 3:743–746.

De Rita D, Zarlenga F. 2001. Middle Pleistocene Geology of the "Bassa Campagna Romana." In Cavarretta G, Gioia P, Mussi M, Palombo MR. (Eds.), The World of Elephants: Proceedings of the 1st International Congress, Rome 2001. Consiglio Nazionale delle Richerche, Rome, pp. 38–42.

De Stefano GF, Hauser G, Guidotti A, Rossi S, Gualdi-Russo E, Brasili-Gualandi P. 1983. Inter-Observer Variability in the Interpretation of the "Discrete" Characters of the Skull. Anthropos 10:184–194.

De Stefano GF, Hauser G, Guidotti A, Rossi S, Gualdi-Russo E, Brasili-Gualandi P. 1984. Reflections on Interobserver Differences in Scoring Non-Metric Cranial Traits (With Practical Examples). Journal of Human Evolution 13:349–355.

DeVilliers H. 1968. The Skull of the African Negro. University Witwtaersrand Press, Johannesburg.

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

Di Lernia, S., Tafuri, M. (2013) 'Persistent deathplaces and mobile landmarks: the Holocene mortuary and isotopic record from Wadi Takarkori (SW Libya). Journal of Anthropological Archaeology 32:1–15.

Dixon JE, Robertson AHF. 1996. The Geological Evolution of the Eastern Mediterranean. Geological Society Special Publication 17. Geological Society, London.

Dodo Y, Ishida H, Saitou N. 1992a. Population History of Japan: A Cranial Nonmetric Approach. In: Akazawa T, Aoki K, Kimura T. (Eds.), The Evolution and Dispersal of Modern Humans in Asia. Hokusen-sha, Tokyo, p. 479–492.

Dodo Y, Ishida H. 1992b. Consistency of Nonmetric Cranial Trait Expression During the Last 2000 Years in the Habitants of the Central Islands of Japan. Journal of the Anthropological Society of Nippon 100:417–423.

Dondin-Payre M., Raespart-Charlier MT. (eds.). 1999. Cités, Municipes, Colonies. Le Processus d'Urbanization en Gaule et en Germanie sous le Haut Empire. Publications de la Sorbonne, Paris.

Donlon DA. 2000. The Value of Infracranial Nonmetric Variation in Studies of Modern *Homo sapiens*: An Australian Focus. American Journal of Physical Anthropology 113:349–368.

Donnan H., Werbner P. (eds.). 1991. Economy and Culture in Pakistan: Migrants and Cities in a Muslim Society. St. Martin's Press, New York.

Dorsey GA. 1897. Wormian Bones in Artificially Deformed Kwakiutl Crania. American Anthropologist 10:169–173.

D'Ortenzio L, Brickley M, Schwarcz HP, Prowse T. 2015. You Are Not What You Eat During Physiological Stress: Isotopic Evaluation of Human Hair. American Journal of Physical Anthropology DOI: 10.1002/ajpa.22722.

Duckworth WLH. 1904. Morphology and Anthropology. Cambridge University Press, Cambridge.

Dunbar J. 1982a. A Study of the Factors Affecting the $^{18}O/^{16}O$ Ratio of the Water of Wine. Zeitschrift für Lebensmittel Untersuchung und Forschung 174:355–359.

Dunbar J. 1982b. Oxygen Isotope Studies on Some New Zealand Grape Juices. Zeitschrift für Lebensmittel Untersuchung und Forschung 175:253–257.

Dupras TL, Schwarcz HP. 2001. Strangers in a Strange Land: Stable Isotope Evidence for Human Migration in the Dakhleh Oasis, Egypt. Journal of Archaeological Science 28:1199–1208.

Du Toit B. 1990. People on the Move: Rural-Urban Migration with Special Reference to the Third World: Theoretical and Empirical Perspectives. Human Organization 49:305–319.

Eades JS. 1993. Strangers and Traders: Yoruba Migrants, Markets, and the State in Northern Ghana. University Press for the International African Institute, Edinburgh.

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

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

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

Eckardt H. (ed.). 2010. Roman Diasporas: Archaeological Approaches to Mobility and Diversity in the Roman Empire. Journal of Roman Archaeology Supplementary Series 78. Journal of Roman Archaeology, Portsmouth.

Eckardt H, Chenery C, Booth P, Evans JA, Lamb A, Müldner G. 2009. Oxygen and Strontium Isotope Evidence for Mobility in Roman Winchester. Journal of Archaeological Science 36:2816–2825.

Eckardt H, Chenery C, Leach S. Lewis M, Müldner G, Nimmo E. 2010. A Long Way From Home: Diaspora Communities in Roman Britain. In: Eckardt (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. 99–130.

Eckardt, H., Müldner, G., Lewis, M. 2014. People on the Move in Roman Britain. World Archaeology 46, 534–550.

Eckhardt RB. 1989. Evolutionary Morphology of Human Skeletal Characteristics. Anthropologischer Anzeiger 47:193–228.

Edmonson JC. 1987. Two Industries in Roman Lusitania. Mining and Garum Production. BAR International Series 362. Oxford University Press, Oxford.

Ehleringer JR, Bowen GJ, Chesson LA, West AG, Podlesak DW, Thure EC. 2008. Hydrogen and Oxygen Isotope Ratios in Human Hair are Related to Geography. Proceedings of the National Academy of Sciences 105:2788–2793.

Ehrenreich B, Hochschild AR. (eds.) 2002. Global Woman: Nannies, Maids and Workers in the New Economy. Metropolitan Books, New York.

Elias M. 1980. The Feasibility of Dental Strontium Analysis for Diet-Assessment of Human Populations. American Journal of Physical Anthropology 63:1–4.

Elliot JC, Holcomb DW, Young RA. 1985. Infrared Determination of the Degree of Substitution of Hydroxyl by Carbonate Ions in Human Dental Enamel. Calcified Tissue International 37:372–375.

El-Najjar MY, Dawson GL. 1977. The Effect of Artificial Cranial Deformation on the Incidence of Wormian Bones in the Lambdoidal Suture. American Journal of Physical Anthropology 46:155–160.

El-Najjar MY, McWilliams KR. 1978. Forensic Anthropology: The Structure, Morphology and Variation of Human Bone and Dentition. Charles C. Thomas, Springfield.

Epstein CJ, Erickson RP, Wynshaw-Boris A (ed.). 2004. Inborn Errors of Development: The Molecular Basis of Clinical Disorders of Morphogenesis. Oxford Monographs on Medical Genetics 49. Oxford University Press, New York.

Ericson JE. 1985. Strontium Isotope Characterization in the Study of Prehistoric Human Ecology. Journal of Human Evolution 14:503–514.

Ericson JE. 1989. Some Problems and Potentials for Strontium Isotope Analysis for Human and Animal Ecology. In: Rundel PW, Ehleringer JR, Nagy KA. (Eds.), Stable Isotopes in Ecological Research. Springer-Verlag, New York, pp. 252–259.

Erdkamp P. 2016. Seasonal Labour and Rural-Urban Migration in Roman Italy. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 33–49.

Erdkamp PPM. 2008. Mobility and Migration in Italy in the Second Century BC. In: De Ligt L, Northwood S. (Eds.), People, Land and Politics: Demographic Developments and the Transformation of Roman Italy 300 BC-AD 14. Brill, Leiden, pp. 417–449.

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.

Evans J, Chenery C, Fitzpatrick AP. 2006a. Bronze Age Childhood Migration of Individuals Near Stonehenge, Revealed by Strontium and Oxygen Isotope Tooth Enamel Analysis. Archaeometry 48:309–321.

Evans J, Stoodley N, Chenery C. 2006b. A Strontium and Oxygen Isotope Assessment of a Possible Fourth Century Immigrant Population in a Hampshire Cemetery, England. Journal of Archaeological Science 33:265–272.

Evans JA, Montgomery J, Wildman G, Boulton N. 2010. Spatial Variations in Biosphere 87Sr/86Sr in Britain. Journal of the Geological Society 167:1–4.

Ezzo JA, Johnson CM, Price TD. 1997. Analytical Perspective on Prehistoric Migration: A Case Study from East-Central Arizona. Journal of Archaeological Science 29:499–520.

Fabbri M, Trotta A. 1989. Scuola-Collegio di Età Augustea: l'Insula II di Velia. Giorgio Bretschneider, Rome.

Falconer DS. 1965. The Inheritance of Liability to Certain Diseases, Estimated from the Incidence Among Relatives. Annals of Human Genetics 29:51–76.

Farquhar GD, Henry BK, Styles JM. 1997. A Rapid On-line Technique for Determination of Oxygen Isotope Composition of Nitrogen-containing Organic Matter and Water. Rapid Communications in Mass Spectrometry 11:1554-1560.

Faure G. 1986. Principles of Isotope Geology, Second Edition. John Wiley and Sons Ince., New York.

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

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

Federico M, Peccerillo A, Barbieri M, Wu T. 1994. Mineralogical and Geochemical Study of Granular Xenoliths from the Alban Hills Volcano, Central Italy: Bearing on Evolutionary Processes in Potassic Magma Chambers. Contributions to Mineralogy and Petrology 115(4):384–401.

Fenner J, Wright L. 2014. Revisiting the Strontium Contribution of Sea Salt in the Human Diet. Journal of Archaeological Science 44:99−103.

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.

Fields, G. 1975. Rural-Urban Migration, Urban Unemployment and Underemployment, and Job Search Activities in LDC's. Journal of Development Economics 2:165-188.

Finnegan MJ. 1972. Population Definition on the Northwest Coast by Analysis of Discrete Character Variation. Unpublished Ph.D. Dissertation, University of Colorado.

Finnegan MJ. 1974. Discrete Non-Metric Variation of the Post-Cranial Skeleton in Man. American Journal of Physical Anthropology 40: 135–136.

Finnegan MJ. 1978. Non-Metric Variation of the Infracranial Skeleton. Journal of Anatomy 125:23–37.

Finnegan M, Cooprider K. 1978. Empirical Comparison of Distance Equations Using Discrete Traits. American Journal of Physical Anthropology 49:39–46.

Finnegan M, Rubison RM. 1984. Multivariate Distances and Multivariate Classification Systems Using Non-Metric Traits in Biological Studies. In: Van Vark GN, Howells WW. (Eds.), Multivariate Statistical Methods in Physical Anthropology. D. Reide, Boston, p. 69–80.

Finnegan M, Marcsik A. 1989. Biological Distance in the 5–11th Centuries Populations Using Non-Metric Frequency Data. Acta Biologica Szegediensis 35:163–174.

Florovsky G. 1969. The Study of the Past. In: Nash RH. (Ed.), Ideas of History. Dutton, New York, pp. 351–369.

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.

Foubert L. 2016. Mobile Women in *P.Oxy*. and the Port Cities of Roman Egypt: Tracing Women's Travel Behaviour in Papyrological Sources. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 285–304.

Frank AG. 1967. Capitalism and Underdevelopment in Latin America. Monthly Review Press, New York.

Franklin JL. 1984. Games and a Lupanar: Prosopography of a Neighborhood in Ancient Pompeii. The Classical Journal 81:319–328.

Franzen LG. 1990. Transport, Deposition and Distribution of Marine Aerosols Over Southern Sweden During Dry Westerly Storms. Ambio 19:180-188.

Fraser FC. 1976. The Multifactorial/Threshold Concept–Uses and Misuses. Teratology 14:267–280.

Fraser FC. 1998. Some Underlooked Properties of the Multifactorial/Threshold Model. American Journal of Human Genetics 62:1262–1265.

Freeman MF, Tukey JW. 1950. Transformations Related to the Angular and Square Root. Annals of Mathematical Statistics 21:607–611.

Frier, B.W., 2001. More is Worse: Some Observations on the Population of the Roman Empire. In: Scheidel, W., (Ed.), Debating Roman Demography. Brill, Leiden, pp. 139–159.

Frost H. 1969. Tetracycline-Based Histological Analysis of Bone Remodeling. Calcified Tissues Research 3:211-237.

Fry B. 2006. Stable Isotope Ecology. Springer, New York.

Fulford, M., 2010. Roman Britain: Immigration and Material Culture. 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. 67−78.

Fulginitti LC. 1993. Discontinuous Morphological Variation at Grasshopper Pueblo, Arizona. Unpublished Ph.D. Dissertation, The University of Arizona.

Gambin, T., 2012. Central Mediterranean Islands and Satellite Ports from Ancient Rome. In: Keay, S., (Ed.), Rome, Portus and the Mediterranean. The British School at Rome, London, pp. 147−151.

Garnsey P. 1998. The People of Isola Sacra. In: Rossi IPF, Bondioli L, Geusa G, Macchiarelli R. (Eds.), Enamel Microstructure and Developmental Defects of the Primary Dentition. Osteodental Biology of the People of Portus Romae (Necropolis of Isola Sacra, 2nd–3rd Cent. AD). CD-ROM. Soprintendenza Speciale al Museo Nazionale Preistorico Etnogrfico 'L. Pigorini", Rome, pp. 1–4.

Garnsey P. 1999. The People of Isola Sacra. In: Bondioli L, Macchiarelli R. (Eds.), Digital Archives of Human Paleobiology, Osteodental Biology of the of the People of Portus Romae (Necropolis of Isola Sacra, 2nd–3rd Cent. AD), vol. 1, Enamel Microstructure and Developmental Defects of the Primary Dentition. Soprintendenza Speciale al Museo Nazionale Preistorico Etnogrfico 'L. Pigorini", Rome.

Garnsey P, De Ligt L. 2016. Migration in Early-Imperial Italy: Herculaneum and Rome Compared. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 72–94.

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

Garvie-Lok SJ. 2009. Population Mobility at Frankish Corinth: Evidence from Stable Oxygen Isotope Ratios of Tooth Enamel. In: Schepartz LA, Fox SC, Bourbou C. (Eds.), New Directions in the Skeletal Biology of Greece. Hesperia Supplement 43. The American School of Classical Studies at Athens, Princeton, pp. 245–256.

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. In: 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, 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.

Gejvall NG, Henschen F. 1968. Two Late Roman Skeletons With Malformation and Close Family Relationship from Ancient Corinth. Opuscula Athenia 8:179–193.

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

Germoni P, Millet M, Keay S, Reynolds J, Strutt K. 2011. The Isola Sacra: Reconstructing the Roman Landscape. In: Keay S, Paroli L. (Eds.), Portus and Its Hinterland: Recent Archaeological Research. Archaeological Monographs of the British School at Rome 18. The British School at Rome, London, pp. 231–260.

Geusa G, Bondioli L, Capucci E, Cipriano A, Grupe G, Savorè C, Macchiarelli R. 1999. Osteodental Biology of the People of Portus Romae (Necropolis of Isola Sacra, 2nd–3rd Cent. AD). II. Dental Cementum Annulations and Age at Death Estimates. Digital Archives of Human Paleobiology, 2. Museo Nazionale "L. Pigorini," Rome (CD-ROM, E-LISA, Milano). ISBN-88-87563-01-2.

Giblin JI. 2009. Strontium Isotope Analysis of Neolithic and Copper Age Populations on the Great Hungarian Plain. Journal of Archaeological Science 36: 491-497.

Giblin JI, Knudson KJ, Bereczki Z, Pálfi G, Pap I. 2013. Strontium Isotope Analysis and Human Mobility During the Neolithic and Copper Age: A Case Study from the Great Hungarian Plain 40:227–239.

Gibson, J.J., 1979. The Ecological Approach to Visual Perception. Houghton Mifflin, Boston.

Giraudi C. 2011. La Geologia dell'Argo Portuense nell'Ambito dell'Evoluzione del Delta del Tevere. In: Keay S, Paroli L. (Eds.), Portus and Its Hinterland: Recent Archaeological Research. Archaeological Monographs of the British School at Rome 18. The British School at Rome, London, pp. 21–30.

Glick Schiller N, Basch L, Blanc-Szanton C. (eds.). 1992. Towards a Transnational Perspective on Migration: Race, Class, Ethnicity, and Nationalism Reconsidered. The New York Academy of Sciences, New York.

Glick Schiller N, Caglar A. (eds.). 2011. Locating Migration: Rescaling Cities and Migrants. Cornell University Press, Ithaca.

Gmelch, G., 1980. Return Migration. Annual Review of Anthropology 9, 135–159.

GNIP 2015 = Global Network of Isotopes in Precipitation (GNIP). http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html. Last Updated 07/05/2015.

Goiran JP, Salomon F, Tronchère H, Carbonel P, Djerbi H, Ognard C. 2011. Caractéristiques Sédimentaires du Bassin Portuaire de Claude: Nouvelles Données Pour la Localisation des Ouvertures. In: Keay S, Paroli L. (Eds.), Portus and Its Hinterland: Recent Archaeological Research. Archaeological Monographs of the British School at Rome 18. The British School at Rome, London, pp. 31–45.

Goldberg ED, Koide M, Schmidt RA, Smith RH. 1963. Rare Earth Distributions in the Marine Environment. Journal of Geophysical Research 68:4209–4217.

Gonzalez NL. 1961. Family Organization in Five Types of Migratory Wage Labor. American Anthropologist 63:1264–1280.

Gonzalez Jose RG, Dahinten S, Hernandez M. 2001. The Settlement of Patagonia: A Matrix Correlation Study. Human Biology 73:233–248.

Gosman JH, Stout SD, Larsen CS. 2011. Skeletal Biology Over the Life Span: A View From the Surfaces. Yearbook of Physical Anthropology 54:86–98.

Goude G, Castorina F, Herrscher E, Cabut S, and Tafuri MA. 2012. First Strontium Isotope Evidence of Mobility in the Neolithic of Southern France. European Journal of Archaeology 15: 421-439.

Goudineau, C., 1996. Gaul. In: Bowman, A.K., Champlin, E., Lintott, A., (Eds.), The Cambridge Ancient History Volume 10: The Augustan Empire, 43 BC–AD 69. Cambridge University Press, Cambridge, pp. 464–502.

Gould SJ. 1977. Ontogeny and Phylogeny. Harvard University Press, Cambridge.

Gower J. 1971. A General Coefficient of Similarity and Some of its Properties. Biometrics 27:857–871.

Graham JM. 2007. Smith's Recognizable Patterns of Human Deformation, Third Edition. Saunders Elsevier, Philadelphia.

Grandstaff DE, Terry DO. 2009. Rare Earth Element Composition of Paleogene Vertebrate Fossils From Toadstool Geologic Park, Nebraska, USA. Applied Geochemistry 24:733–745.

Grawert E. 1994. Vergleich der Forschungsergebnisse. In: Grawer E. (Ed.), Wandern oder bleiben? Lit, Hamburg, pp. 217–229.

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 Richerche: 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.

Green RF, Suchey JM. 1976. The Use of Inverse Sine Transformations in the Analysis of Non-Metric Data. American Journal of Physical Anthropology 45:61–68.

Green RF, Suchey JM, Gokhale DV. 1979. The Statistical Treatment of Correlated Bilateral Traits in the Analysis of Cranial Material. American Journal of Physical Anthropology 50:629–634.

Greene DL. 1967. Genetics, Dentition and Taxonomy. University of Wyoming Publications 33:93–168.

Gregoricka LA. 2013. Residential Mobility and Social Identity in the Periphery: Strontium Isotope Analysis of Archaeological Tooth Enamel from Southeastern Arabia. Journal of Archaeological Science 40, 452–464.

Gregoricka LA. 2014. Assessing Life History from Commingled Assemblages: The Biogeochemistry of Inter-Tooth Variability in Bronze Age Arabia. Journal of Archaeological Science 47, 10–21.

Gregoricka LA. 2016. Human Response to Climate Change During the Umm an-Nar/Wadi Suq Transition in the United Arab Emirates. International Journal of Osteoarchaeology 26:211–220.

Grewal MS. 1962a. The Development of an Inherited Tooth Defect on the Mouse. Journal of Embryology and Experimental Morphology 10:202–211.

Grewal MS. 1962b. The Rate of Genetic Divergence of Sublines in the C57BL Strain of Mice. Genetical Research 3:226-237.

Grupe G, Price TD, Schröter P, Söllner F, Johnson CM, Beard BL. 1997. Mobility of Bell Beaker People Revealed by Sr Isotope Ratios of Tooth and Bone: A Study of Southern Bavarian Skeletal Remains. Applied Geochemistry 12:517–525.

Grupe G, Price TD, Schröter P, Söllner F. 1999. Mobility of Bell Beaker People Revealed by Sr Isotope Ratios of Tooth and Bone: A Study of Southern Bavarian Skeletal Remains: A Reply to the Comments by Peter Horn and Dieter Müller-Sohnius. Applied Geochemistry 14:271–275.

Grüneberg H. 1952. Genetical Studies on the Skeleton of the Mouse IV. Quasi-Continuous Variation. Journal of Genetics 51:95–114.

Grüneberg H. 1963. The Pathology of Development. Blackwell, Oxford.

Grüneberg H. 1965. Genes and Genotypes Affecting the Teeth of the Mouse. Journal of Embryology and Experimental Morphology 14:137–159.

Gualdi-Russo E, Brasili P, Tasca A. 1999. Scoring of Nonmetric Cranial Traits: A Methodological Approach. Journal of Anatomy 195:543–550.

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

Gulliver PH. 1957. Nyakusa Labour Migration. Rhodes-Livingstone Institute Bulletin 21:32–63.

Gulson BL, Jameson W, Gillings BR. 1997. Stable Lead Isotopes in Teeth as Indicators of Past Domicile–A Potential New Tool in Forensic Science? Journal of Forensic Science 42:787–791.

Gunness-Hey M. 1980. The Koniag Eskimo Presacral Vertebral Column: Variations, Anomalies and Pathologies. Ossa: International Journal of Skeletal Research 7:99–118.

Gustafsson MER, Franzen LG. 1996. Dry Deposition and Concentration of Marine Aerosols in a Coastal Area, SW Sweden. Atmospheric Environment 30:997-989.

Hadji, A., Souvatzi, S., 2014. Space and Time in Mediterranean Prehistory and Beyond. In: Souvatzi, S., Hadji, A., (Eds.), Space and Time in Mediterranean Prehistory. Routledge, New York, pp. 1–31.

Hadley DM, Hemer KA. 2011. Microcosms of Migration: Children and Early Medieval Population Movement. Childhood in the Past 4:63–78.

Haeckel E. 1879. The Evolution of Man: A Popular Exposition on the Principal Points of Human Ontogeny and Phylogeny, Third Edition. Appleton, New York.

Haeussler, R., 2013. Becoming Roman? Diverging Identities and Experiences in Ancient Northwest Italy. Left Coast Press, Walnut Creek.

Hakenbeck S. 2008. Migration in Archaeology: Are We Nearly There Yet? Archaeological Review from Cambridge 23:9–26.

Hallgrimsson B, ó Donnabhain B, Walters GB, Cooper DML, Gudbjartsson D, Stefansson K. 2004. Composition of the Founding Population of Iceland: Biological Distance and Morphological Variation in Early Historic Atlantic Europe. American Journal of Physical Anthropology 124:257–274.

Hallgrimsson B, ó Donnabhain B, Blom DE, Lozada MC, Willmore KT. 2005. Why are Rare Traits Unilaterally Expressed?: Trait Frequency and Unilateral Expression for Cranial Nonmetric Traits in Humans. American Journal of Physical Anthropology 128:14–25.

Hamdoune C. 2006. Mouvements de Population dans les Carmina Funéraires Africanes. In: Akerraz A., Ruggeri P., Siraj A., Vismara C. (Eds.), L'Africa Romana Mobilità delle Persone e dei Populi, Dinamiche Migratorie, Emigrazioni ed Immigrazioni nelle Province Occidentali dell'Impero Romano. Atti del XVI Convegno di Studio. Carocci, Rome, pp. 1001–1020.

Harbeck M, Schleuder R, Schneider J, Wiechmann I, Schmahl WW, Grupe G. 2011. Research Potential and Limitations of Trace Analyses of Cremated Remains. Forensic Science International 204:191–200.

Härke H. 1998. Archaeologists and Migrations. Current Anthropology 39:19–45.

Härke H. 2004. The Debate on Migration and Identity in Europe. Antiquity 78:453–456.

Harris E. 1977. Anthropologic and Genetic Aspects of the Dental Morphology of Solomon Islanders, Melanesia. Unpublished Ph.D. Dissertation, Arizona State University.

Harris EF. 2008. Statistical Applications in Dental Anthropology. In: Irish JD, Nelson GC. (Eds.), Technique and Application in Dental Anthropology. Cambridge University Press, Cambridge, p. 35–67.

Harris EF, Sjøvold T. 2004. Calculation of Smith's Mean Measure of Divergence for Intergroup Comparisons Using Nonmetric Data. Dental Anthropology 17:83–93.

Harris WV. 1980. Towards a Study of the Roman Slave Trade. In: D'Arms JH, Kopff EC. (Eds.), The Seaborne Commerce of Ancient Rome: Studies in History and Archaeology. Memoirs of the American Academy in Rome 36:117‒140.

Hassall MWC. 1999. Homes for Heroes: Married Quarters for Soldiers and Veterans. In: Goldsworthy A., Haynes I. (Eds.), The Roman Army as a Community. Journal of Roman Archaeology Supplement 34, Portsmouth, pp. 35–40.

Hauser G, De Stefano GF. 1989. Epigenetic Variants of the Human Skull. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Haverfield F. 1905–1906. The Romanization of Roman Britain. Proceedings of the British Academy 1905–06:185–217.

Haverfield F. 1923. The Romanization of Roman Britain, Fourth Edition. Clarendon Press, Oxford.

Haverkort CM, Weber A, Katzenberg MA, Goriunova OI, Simonetti A, Creaser RA. 2008. Hunter-Gatherer Mobility Strategies and Resource Use Based on Strontium Isotope (^{87}Sr/^{86}Sr) Analysis: A Case Study From Middle Holocene Lake Baikal, Siberia. Journal of Archaeological Science 35:1265–1280.

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.

Hedges R, Clement J, Thomas C, O'Connell T. 2007. Collagen Turnover in the Adult Femoral Mid-Shaft: Modeled from Radiocarbon Tracer Measurements. American Journal of Physical Anthropology 133:808-816.

Heiken G, Funiciello R, De Rita D. 2005. The Seven Hills of Rome: A Geological Tour of the Eternal City. Princeton University Press, Princeton.

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

Hemer KA, Evans JA, Chenery CA, Lamb AL. 2013. Evidence of Early Medieval Trade and Migration Between Wales and the Mediterranean Sea Region. Journal of Archaeological Science 40:2352‒2359.

Hemer KA, Evans JA, Chenery CA, Lamb AL. 2014. No Man is an Island: Evidence of Pre-Viking Age Migration to the Isle of Man. Journal of Archaeological Science 52:242−249.

Hermann B, Grupe G, Hummel S, Piepenbrink H, Schutkowski. 1990. Prähistorische Anthropologie: Leitfaden der Feld- und Labormethoden. Springer-Verlag, Berlin.

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

Hertzog KP. 1968. Associations Between Discontinuous Cranial Traits. American Journal of Physical Anthropology 29:397–404.

Hill P. 1998. Bone Remodelling British Journal of Orthodontics 25:101-107.

Hillson S. 1986. Teeth. Cambridge University Press, Cambridge.

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.

Hingley, R., 2005. Globalizing Roman Culture: Unity, Diversity and Empire. Routledge, New York.

Hingley R. 2010. Tales of the Frontier: Diasporas on Hadrian's Wall. 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. 227–243.

Hodell DA, Quinn RL, Brenner M, Kamenov G. 2004. Spatial Variation of Strontium Isotopes (^{87}Sr/^{86}Sr) in the Maya Region: A Tool for Tracking Ancient Human Migration. Journal of Archaeological Science 31:585–601.

Hoeffs J. 2004. Stable Isotope Geochemistry, Fifth Edition. Springer-Verlag, Berlin.

Hoffmann B. 1995. The Quarters of the Legionary Centurions of the Principate. Britannica 26:107–151.

Hofman CL, Hoogland MLP, Mickleburgh HL, Laffoon JE, Weston DA, Field MH. 2012. Life and Death at Precolumbian Lavoutte, Saint Lucia, Lesser Antilles. Journal of Field Archaeology 37:209–225.

Holobinko A, Meier-Augenstein W, Kemp HF, Prowse T, Ford SM. 2011. ^{2}H Stable Isotope Analysis of Human Tooth Enamel: A New Tool for Forensic Human Provenancing? Rapid Communications in Mass Spectrometry 25:910–916.

Holleran C. 2016. Labour Mobility in the Roman World: A Case Study of Mines in Iberia. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 95–137.

Hoogewerff J, Papesch W, Kralik M, Berner M, Vroon P, Miesbauer H, Gaber O, Künzel K, Kleinjans J. 2001. The Last Domicile of the Iceman from Hauslabjoch: A Geochemical Approach Using Sr, C and O Isotopes and Trace Element Signatures. Journal of Archaeological Science 28:983–989.

Hooton EA. 1930. Indians of the Pecos Pueblo: A Study of their Skeletal Remains. Yale University Press, New Haven.

Hoover KC, Corruccini RS, Bondioli L, Macchiarelli R. 2005. Exploring the Relationship Between Hypoplasia and Odontometric Asymmetry in Isola Sacra, An Imperial Roman Necropolis. American Journal of Human Biology 17:752–764.

Hopkins MK. 1965. The Age of Roman Girls at Marriage. Population Studies 18:309–327.

Hoppe KA, Koch PL, Furutani TT. 2003. Assessing the Preservation of Biogenic Strontium in Fossil Bones and Tooth Enamel. International Journal of Osteoarchaeology 13:20–28.

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

Houstoun MF, Kramer RG, Barrett, JM. 1984. Female Predominance of Immigration to the United States Since 1930: A First look. International Migration Review 18:908-963.

Howe WL, Parsons PA. 1967. Genotype and Environment in the Determination of Minor Skeletal Variants and Body Weight in Mice. Journal of Embryology and Experimental Morphology 17:282–292.

Hoyme HE. 1994. Minor Anomalies: Diagnostic Clues to Aberrant Human Morphogenesis. In: Markow TE. (Ed.), Developmental Instability: Its Origins and Evolutionary Implications, Proceedings of the International Conference on Developmental Instability: Its Origins and Evolutionary Implications, Tempe, Arizona 14–15 June 1993. Kluwer Academic Publishers, Dordrecht, p. 309–317.

Hrdlicka A. 1916. Physical Anthropology of the Lenape or Delaware, and of the Eastern Indians in General. Bureau of American Ethnology Bulletin 62.

Hrdlicka A. 1920. Shovel-Shaped Teeth. American Journal of Physical Anthropology 3:429–465.

Hrdlicka A. 1932. The Humerus: Septal Apertures. Anthropologie Prague X:31–96.

Hubbard AR, Guatelli-Steinberg D, Irish JD. 2015. Do Nucelar DNA and Dental Nonmetric Data Produce Similar Reconstructions of Regional Population History? An Example from Modern Coastal Kenya. American Journal of Physical Anthropology DOI: 10.1002/ajpa.22714.

Hughes S, Millard A, Lucy S, Chenery C, Evans J, Nowell G, Pearson D. 2014. Anglo-Saxon Origins Investigated by Isotopic Analysis of Burials from Berinsfield, Oxfordshire, UK. Journal of Archeological Science 42:81–92.

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 Inscriptorum Latinarum, Volumen VI. University of Oulu, Oulu.

Hyrtl J. 1859. Lehrbuch der Anatomie des Menschen, Sixth Edition. Braumüller, Wien.

Iacumin P, Bocherens H, Mariotti A, and Longinelli A. 1996. Oxygen Isotope Analysis of Co-Existing Carbonate and Phosphate in Biogenic Apatite: A Way to Monitor Diagenetic Alteration of Bone Phosphate? Earth and Planetary Sciences Letters 142: 1-6.

IAEA (2001). GNIP Maps and Animations, International Atomic Energy Agency, Vienna. http://isohis.iaea.org.

Ingraham NL, Caldwell EA. 1999. Influence of Weather on the Stable Isotopic Ratios of Wines: Tools for Weather/Climate Reconstruction? Journal of Geophysical Research 104:2185–2194.

Iorio A, Battistini A, De Angelis F, Caldarini C, Di Giannantonio S, Pantano W, Catalano P. 2012. New Insights from the Study of Non-Metric Traits of the Human Skull. Journal of Biological Research 85:236–238.

Irish JD. 1997. Characteristic High- and Low-Frequency Dental Traits in Sub-Saharan African Populations. American Journal of Physical Anthropology 102:455–467.

Irish JD. 2005. Population Continuity vs. Discontinuity Revisited: Dental Affinities Among Late Paleolithic Through Christian-Era Nubians. American Journal of Physical Anthropology 128:520–535.

Irish JD. 2010. The Mean Measure of Divergence: Its Utility in Model-Free and Model-Bound Analyses Relative to the Mahalanobis D^2 Distance for Nonmetric Traits. American Journal of Human Biology 22:378–395.

Irish JD, Guatelli-Steinberg D. 2003. Ancient Teeth and Modern Human Origins: An Expanded Comparison of African Plio- Pleistocene and Recent World Dental Samples. Journal of Human Evolution 45:113–144.

Irish JD, Black W, Sealy J, Ackermann RR. 2014. Questions of Khoesan Continuity: Dental Affinities Among the Indigenous Holocene Peoples of South Africa. American Journal of Physical Anthropology 155:33–44.

Irrgeher, J., Teschler-Nicola, M., Leutgeb, K., Weiß, C., Kern, D., Prohaska, T. 2012. Migration and Mobility in the Latest Neolithic of the Traisen Valley, Lower Austria: Sr Isotope Analysis. 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. 199–211.

Iscan M, Loth S, Wright R. 1985. Age Estimation from the Rib by Phase Analysis: White Females. Journal of Forensic Science 30:853–863.

Iscan M, Loth S. 1986. Estimation of Age and Determination of Sex from the Sternal Rib. In: Reichs K. (Ed.), Forensic Osteology: Advances in the Identification of Human Remains. Charles C. Thomas, Springfield, pp. 68–89.

Iversen ER, Tierzen LL, Matzner S. 1992. Human Dietary Reconstruction Based on C, N, and S Stable Isotopes During an 8000 Year Chronosequence in the Atacama Desert, Chile. Proceedings of the South Dakota Academy of Science 71:160.

Jäger E, Hunziker JC. 1979. Lectures in Isotope Geology. Springer-Verlag, Berlin.

James P. 1997. Postdependancy? The Third World in an Era of Globalism and Late-Capitalism. Alternatives: Global, Local, Political 22:205–226.

Jans MME, Nielsen-Marsh CM, Smith CI, Collins MJ, Karsa H, 2004. Characterisation of Microbial Attack on Archaeological Bone. Journal of Archaeological Science 31:87–95.

Jennings CJ, Perry MA. 2011. Assessing the Effects of Local Geological Variation on Strontium Isotopes from 4th–5th Century A.D. Aila, Jordan. American Journal of Physical Anthropology 144 Suppl. 52:178.

Jernvall J, Jung HS. 2000. Genotype, Phenotype, and Developmental Biology of Molar Tooth Characters. Yearbook of Physical Anthropology 43:171−190.

Johnson EM. 1965. Nutritional Factors in Mammalian Teratology. In: Wilson JG, Warkany J. (Eds.), Teratology: Principles and Techniques. The University of Chicago Press, Chicago, p.113–130.

Jouzel J, Froehlich K, Schotterer U. 1997. Deuterium and Oxygen-18 in Present-Day Precipitation: Data and Modelling. Hydrological Sciences 42:747−763.

Juarez CA. 2008. Strontium and Geolocation, The Pathway to Identification for Deceased Undocumented Mexican Border-Crossers: A Preliminary Report. Journal of Forensic Sciences 53:46–49.

Junankar PN, Shonchoy A. 2013. The Informal Labour Market in India: Transitory or Permanent Employment for Migrants? Discussion Paper No. 7587. The Institute for the Study of Labour (IZA), Bonn.

Katz E, Stark O. 1986. Labor Migration and Risk Aversion in Less Developed Countries. Journal of Labor Economics 4:131−149.

Katzenberg MA. 1984. Chemical Analysis of Prehistoric Human Bone From Five Temporally Distinct Populations in Southern Ontario. National Museum of Man Mercury Series Archaeological Survey of Canada Paper 129. National Museums of Canada.

Katzenberg MA. 2008. Stable Isotope Analysis: A Tool for Studying Past Diet, Demography, and Life History. In: Katzenberg MA, Saunders SR. (Eds.), Biological Anthropology of the Human Skeleton, Second Edition. Wiley-Liss, Hoboken, pp. 413–441.

Katzenberg MA, Krouse HR. 1989. Application of Stable Isotope Variation in Human Tissues to Problems in Identification. Canadian Society of Forensic Science Journal 22:7−19.

Kawakubo Y, Dodo Y, Kuraoka A. 2013. Two Hyperostotic Non-Metric Traits, Corticoclinoid Foramen and Ptrygospinous Forman, Which Appear at an Early Developmental Stage in the Human Cranium. Anthropological Science 121:123−130.

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.

Keay S, Millet M, Paroli L, Strutt K (eds.). 2005a. Portus: An Archaeological Survey of the Port of Imperial Rome. British School at Rome, Rome.

Keay S, Millett M, Patterson H. 2005b. Introduction. In: Keay S, Millett M, Paroli L, Strutt K. (Eds.), Portus An Archaeological Survey of the Port of Imperial Rome. The British School at Rome, London, pp. 1–9.

Keay S, Earl G, Hay S, Kay S, Ogden J, Strutt KD. 2009. The Role of Integrated Geophysical Survey Methods in the Assessment of Archaeological Landscapes: The Case of Portus. Archaeological Prospection 16:154–166.

Keay S, Paroli L (eds.) 2011a. Portus and its Hinterland. British School at Rome, Rome.

Keay S, Paroli L. 2011b. Introduction. In: Keay S, Paroli L. (Eds.), Portus and Its Hinterland: Recent Archaeological Research. Archaeological Monographs of the British School at Rome 18. The British School at Rome, London, pp. 1–19.

Keenleyside A. 2011. Congenital Aural Atresia in an Adult Female from Apollonia Pontica, Bulgaria. International Journal of Paleopathology 1:63–67.

Keenleyside A, Schwarcz HP, Panayotova K. 2011. Oxygen Isotopic Evidence of Residence and Migration in a Greek Colonial Population on the Black Sea. Journal of Archaeological Science 38:2658–2666.

Kellock WL, Parsons PA. 1970. A Comparison of the Incidence of Minor Non-Metrical Cranial Variants in Australian Aborigines with Those of Melanesia and Polynesia. American Journal of Physical Anthropology 33:235–240.

Kelly TE. 2007. Strontium Isotope Tracing in Animal Teeth at the Neanderthal Site of Les Pradelles, Chartene, France. Research School of Earth Sciences, Australian National University.

Kennedy DL.1996. The Parthia and Rome: Eastern Perspectives. In: Kennedy DL. (Ed.), The Roman Army in the East. Journal of Roman Archaeology Supplementary Series 18, Ann Arbor, pp. 67-90

Kennedy KAR. 1981. Marriage Patterns in an Archaic Population: A Study of Skeletal Remains from Port-au-Choix, Newfoundland. Archaeological Survey of Canada, Mercury Series Paper No. 104. National Museum of Man Mercury Series, Ottawa.

Kenoyer JM, Price TD, and Burton JH. 2013. A New Approach to Tracking Connections Between the Indus Valley and Mesopotamia: Initial Results of Strontium Isotope Analysis From Harappa and Ur. Journal of Archaeological Science 40:2286-2297.

Kercking T. 1670. Spicilegium Anatomicum. Andreas Frisius, Amsterdam.

Keyes JEL. 1935. Observations on 4000 Optic Foramina in Human Skulls of Known Origin. Archives of Opthalmology 13:538–568.

Keyser-Tracqui C, Crubézy E, Ludes B. 2003. Nuclear and Mitochondrial DNA Analysis of a 2,000-year-old Necropolis in the Egyin Gol Valley of Mongolia. American Journal of Human Genetics 73:247–260.

Khatchadourian L. 2008. Making Nations from the Ground Up: Traditions of Classical Archaeology in the South Caucasus. American Journal of Archaeology 112: 247-278.

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 A. 2001. Vercingetorix, Asterix and the Gauls: Gallic Symbols in French Politics and Culture. In: Hingley R. (Ed.), Images of Rome Perceptions of Ancient Rome in Europe and the United States in the Modern Age. Journal of Roman Archaeology Supplement 44. Journal of Roman Archaeology, Portsmouth.

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

Kitagawa Y. 2000. Nonmetric Morphological Characters of Deciduous Teeth in Japan: Diachronic Evidence of the Past 4000 Years. International Journal of Osteoarchaeology 10:242–253.

Knipper C, Maurer AF, Peters D, Meyer C, Brauns M, Galer SJG, von Freeden U, Schöne B, Meller H, Alt KW. 2010. Mobility in Thuringia or Mobile Thuringans: A Strontium Isotope Study from Early Medieval Central Germany. In: Kaiser E, Burger J, Schier W. (Eds.), Population Dynamics in Prehistory and Early History. New Approaches by Using Stable Isotopes and Genetics. De Gruyter, Berlin, pp. 287–310.

Knudson KJ. 2004. Tiwanaku Residential Mobility in the South Central Andes: Identifying Archaeological Human Migration Through Strontium Analysis. Unpublished Ph.D. Dissertation, University of Wisconsin at Madison, Wisconsin.

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, Price TD, Buikstra JE, Blom DE. 2004. The Use of Strontium Isotope Analysis to Investigate Tiwanaku Migration and Mortuary Ritual in Bolivia and Peru. Archaeometry 46:5–18.

Knudson KJ, Price TD. 2007. Utility of Multiple Chemical Techniques in Archaeological Residential Mobility Studies: Case Studies From Tiwanaku–and Chiribaya–Affiliated Sites in the Andes. American Journal of Physical Anthropology 132:25–39.

Knudson KJ, Torres-Rouff C. 2009. Investigating Cultural Heterogeneity in San Pedro de Atacama, Northern Chile, Through Biogeochemistry and Bioarchaeology. American Journal of Physical Anthropology 138:473–485.

Knudson KJ, Stojanowski CM. (eds.). 2009. Bioarchaeology and Identity in the Americas: Bioarchaeological Interpretations of the Human Past: Local, Regional, and Global. University Press of Florida, Gainseville.

Knudson KJ, Williams SR, Osborn R, Forgey K, Williams PR. 2009. The Geographic Origins of Nasca Trophy Heads Using Strontium, Oxygen, and Carbon Isotope Data. Journal of Anthropological Archaeology 28:244–257.

Knudson KJ, Pestle WJ, Torres-Rouff C, and Pimentel G. 2012a. Assessing the Life History of an Andean Traveller Through Biogeochemistry: Stable and Radiogenic Isotope Analyses of Archaeological Human Remains From Northern Chile. International Journal of Osteoarchaeology, 22,423–434.

Knudson KJ, O’Donnabhain B, Carver C, Cleland R, Price TD. 2012b. Migration and Viking Dublin: Paleomobility and Paleodiet Through Isotopic Analyses. Journal of Archaeological Science 39:308–320.

Knudson KJ, Goldstein PS, Dahlstedt A, Somerville A, Schoeninger MJ. 2014a. Paleomobility in the Tiwanaku Diaspora: Biogeochemical Analyses at Rio Muerto, Moquegua, Peru. American Journal of Physical Anthropology 155, 405–421.

Knudson KJ, Webb E, White C, Longstaffe FJ. 2014b. Baseline Data for Andean Palaeomobility Research: A Radiogenic Strontium Isotope Study of Modern Peruvian Agricultural Soils. Archaeological and Anthropological Sciences 6:205–219.

Knudson KJ, Torres-Rouff C, Stojanowski CM. In Press. Investigating Human Responses to Political and Environmental Change Through Paleodiet and Paleomobility. American Journal of Physical Anthropology DOI: 10.1002/ajpa.22694.

Koch PL, Tuross N, Fogel ML. 1997. The Effects of Sample Treatment and Diagenesis on the Isotopic Integrity of Carbonate in Biogenic Hydroxylapatite. Journal of Archaeological Science 24:417-429.

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.

Konen H. 2001. Die Schiffsbauer und Werften in den Antiken Häfen von Ostia und Portus. Münstersche Beiträge zur Antiken Handelsgeschichte 20:1–36.

Konigsberg LW. 1987. Population Genetic Models for Interpreting Prehistoric Intra-Cemetery Biological Variation. Unpublished Ph.D. Dissertation, Northwestern University.

Konigsberg LW. 1990a. Temporal Aspects of Biological Distance: Serial Correlation and Trend in a Prehistoric Skeletal Lineage. American Journal of Physical Anthropology 82:45–52.

Konigsberg LW. 1990b. Analysis of Prehistoric Biological Variation Under a Model of Isolation by Geographic and Temporal Distance. Human Biology 62:49–70.

Konigsberg LW. 2006. A Post-Neumann History of Biological and Genetic Distance Studies in Bioarchaeology. In: Buikstra JE, Beck LA. (Eds.), Bioarchaeology: The Contextual Analysis of Human Remains. Academic Press, New York, p. 263–279.

Konigsberg LW, Kohn LAP, Cheverud JM. 1993. Cranial Deformation and Nonmetric Trait Variation. American Journal of Physical Anthropology 90:35–48.

Korey KA. 1970. Characteristics of the Distributions of Non-Metric Variants of the Skull. Unpublished MA Thesis, University of Chicago.

Korey KA. 1980. The Incidence of Bilateral Nonmetric Skeletal Traits: A Reanalysis of Sampling Procedures. American Journal of Physical Anthropology 53:19–23.

Kossinna, G. 1911. Die Herkunft der Germanen. Zur Methode der Siedlungsarchäologie. Kabitzsch, Würzburg.

Krause W. 1880. Anatomische Varietaten. Hahn'sche Hofbuchhandlung, Hanover.

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.

Kuba CL. 2006. Nonmetric Traits and the Detection of Family Groups in Archaeological Remains. Unpublished Ph.D. Dissertation, Arizona State University.

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.

Labuhn I. 2014. Climate Variability in Southwest France During the Last 2000 Years : Proxy Calibration and Reconstruction of Drought Periods Based on Stable Isotope Records from Speleothems and Tree Rings. Earth Sciences. Université Paris Sud - Paris XI.

Laffoon, J.E., de Vos, B.R., 2011. Diverse Origins, Similar Diets: An Integrated Isotopic Perspective from Anse à la Gourde, Guadeloupe. In: Hofman CL, van Duijvenbode A. (Eds.), Communities in Contact: Essays in Archaeology, Ethnohistory & Ethnography of the Amerindian Circum-Caribbean. Sidestone Press, Leiden, pp. 187–204.

Laffoon JE, Davies GR, Hoogland MLP, and Hofman CL. 2012. Spatial Variation of Biologically Available Strontium Isotopes (^{87}Sr/^{86}Sr) in an Archipelagic Setting: A Case Study from the Caribbean. Journal of Archaeological Science 39: 2371-2384.

Laffoon JE, Hoogland, MLP. 2012. Migration and Mobility in the Circum-Caribbean: Integrating Archaeology and Isotopic Analysis. In: Kaiser E, Burger J, Schier W. (Eds.), Population Dynamics in Prehistory and Early History. New Approaches by Using Stable Isotopes and Genetics. De Gruyter, Berlin, pp. 337—353.

Laffoon JE, Valcárcel Rojas R, Hogman CL. 2013. Oxygen and Carbon Isotope Analysis of Human Dental Enamel from the Caribbean: Implications for Investigating Individual Origins. Archaeometry 55:742–765.

Laguerre MS. 1998. Diasporic Citizenship: Haitian Americans in Transnational America. St. Martin’s Press, New York.

Lan PC. 2006. Global Cinderellas: Migrant Domestics and Newly Rich Employers in Taiwan. Duke University Press, Durham.

Land LS, Lundelius EL Jr., Valastro S. 1980. Isotopic Ecology of Deer Bones. Palaeogeography Palaeoclimatology Palaeoecology 32:143-151.

Landers J. 1993. Death and the Metropolis: Studies in the Demographic History of London 1670–1830. Cambridge University Press, Cambridge.

Landman OE 1991. The Inheritance of Acquired Characteristics. Annual Review of Genetics 25:1–20.

Lane RA, Sublett AJ. 1972. Osteology of Social Organization in a Residence Pattern. American Antiquity 37:186–201.

Langouët L. (ed.). 1987. Les Coriosolites un Peuple Armoricain de la Periode Gauloise à l’Epoque Gallo-Romaine. Le Centre, Saint-Mallo.

Langouët L. (ed.). 1991. Terroirs, Territoires et Campagnes Antiques. La Prospection Archéologique en Haute Bretagne. Traitment et Synthèse des Données. RAO Supplément 4. Revue Archéologique de l’Ouest, Rennes.

Larsen CS. 1997. Bioarchaeology: Interpreting Behavior from the Human Skeleton. Cambridge Studies in Biological Anthropology 21. Cambridge University Press, Cambridge.

Larsen CS. 2006. The Changing Face of Bioarchaeology: An Interdisciplinary Science. In: Buikstra JE, Beck LA. (Eds.), Bioarchaeology: The Contextual Analysis of Human Remains. Academic Press, New York, p. 359–374.

Lauby J, Stark O. 1988. Individual Migration as a Family Strategy: Young Women in the Philippines. Population Studies 42:473–486.

Laughlin WS, Jørgensen J. 1956. Isolate Variation in the Greenlandic Eskimo Crania. Acta Genetica 6:3–12.

Lê, M. 2006. Frankish Invader or Acculturated Greek? Investigating Birthplace and Cultural Integration at a 13th Century in Corinth Using Strontium Isotope Analysis. Unpublished MA Thesis, University of Alberta.

Leach BF, Quinn CJ, Lyon GL. 1996. A Stochastic Approach to the Reconstruction of Prehistoric Human Diet in the Pacific Region from Bone Isotope Signatures. Tahingu: Records of the Museum of New Zealand Te Papa Tongarewa 8:1−54.

Leach S, Lewis M, Chenery C, Müldner G, Eckardt H. 2009. Migration and Diversity in Roman Britain: A Multidisciplinary Approach to the Identification of Immigrants in Roman York, England. American Journal of Physical Anthropology 140:546–561.

Leach, S., Eckardt, H., Chenery, C., Müldner, G., Lewis, M. 2010. A Lady of York: Migration, Ethnicity and Identity in Roman Britain. Antiquity 84, 131−145.

Leblon M, Reiche I, Bahain JJ, Chadefaux C, Moigne AM, Frölich F, Sémah F, Schwarcz HP, Falguères C. 2010. New Parameters for the Characterization of Diagenetic Alterations and Heat-Induced Changes of Fossil Bone Mineral Using Fourier Transform Infrared Spectrometry. Journal of Archaeological Science 37:2265−2276.

Lécole P. 1985. The Oxygen Isotope Composition of Landsnail Shells as a Climatic Indicator: Applications to Hydrogeology and Paleoclimatology. Chemical Geology 58:157–181.

LeDouble AP. 1903. Traité des Variations des Os du Crâne de l'Homme. Vigot Frères, Paris.

LeDouble AF. 1906. Traité des Variations des Os de la Face de l'Homme. Vigot Frères, Paris.

LeDouble AF. 1912. Traité des Variations de la Colonne Vertebral de l'Homme. Vigot Frères, Paris.

Lee AP, Klinowski J, Marseglia EA. 1995. Application of Nuclear Magnetic Resonance Spectroscopy to Bone Diagenesis. Journal of Archaeological Science 22:257−262.

Lee ES. 1966. A Theory of Migration. Demography 3:47−57.

Leonini L., Rebughini P. 2012. The Consumption Styles of Immigrant Families in Italy: Identifications, Status, and Practices. Family and Consumer Sciences Research Journal 41:161−171.

Leroux H. 2012. The Use of Dental Nonmetric Traits for Intracemetary Kinship Analysis and Cemetery Structure Analysis from the Site of Middenbeemster, the Netherlands. M.Sc. Thesis, Leiden.

Leslie, B.G., 2012. Residential Mobility in the Rural Greek Past: A Strontium Isotope Investigation. MA Thesis, University of Alberta.

Leslie B, Garvie-Lok S, Creaser R. 2011. Residential Mobility in the Rural Greek Past: A Strontium Isotope Investigation. American Journal of Physical Anthropology 144 Suppl. 52:197–198.

Levinson AA, Luz B, Kolodny Y. 1987. Variations in Oxygen Isotopic Compositions of Human Teeth and Urinary Stones. Applied Geochemistry 2:367–371.

Lewis H, Dwyer P, Hodkinson S, Waite L. 2014. Hyper-Precarious Lives: Migrants, Work and Forced Labour in the Global North. Progress in Human Geography 1‒21, DOI: 10.1177/0309132514548303.

Lightfoot E, Slaus M, O'Connell TC. 2014. Water Consumption in Iron Age, Roman, and Early Medieval Croatia. American Journal of Physical Anthropology 154:535‒543.

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 235:2152‒2156.

Lilley I. 2004. Diaspora and Identity in Archaeology: Moving Beyond the Black Atlantic. In: Meskell L, Preucel RW. (Eds.), A Companion to Social Archaeology. Blackwell, Malden, pp. 287–312.

Lilley I. 2006. Archaeology, Diaspora and Decolonization. Journal of Social Archaeology 6:28–47.

Lo Cascio E. 1994a. The Size of the Roman Population: Beloch and the Meaning of the Augustan Census Figures. Journal of Roman Studies 84:23‒40.

Lo Cascio E. 1994b. La Dinamica della Popolazione in Italia da Augusto al III Secolo. L'Italie d'Auguste à Dioclétien. Rome 91‒125.

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.

Lomnitz L. 1976a. An Ecological Model for Migration Studies. In: Guillet D, Uzzell DJ. (Eds.), New Approaches to the Study of Migration. Rice University, Houston, pp. 131−146.

Lomnitz L. 1976b. Migration and Networks in Latin America. In: Portes A, Browning H. (Eds.), Current Perspectives in Latin American Urban Research. University of Texas Press, Austin, pp. 133−150.

Lomnitz L. 1977. Networks and Marginality: Life in a Mexican Shantytown. Academic, New York.

Longinelli A. 1965. Oxygen Isotopic Composition of Orthophosphate from Shells of Living Marine Organisms. Nature 207:716-719.

Longinelli A. 1984. Oxygen Isotopes in Mammal Bone Phosphate: A New Tool for Paleohydrological and Paleoclimatological Research? Geochimica et Cosmochimica Acta 48:385–390.

Longinelli A, Cortecci G. 1970. Isotopic Abundance of Oxygen and Sulfur in Sulfate Ions from River Water. Earth and Planetary Science Letters 7:376–380.

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

Lorentz K. 2008. From Bodies to Bones and Back: Theory and Human Bioarchaeology. In: Schutkowski H., (Ed.), Between Biology and Culture. Cambridge University Press, Cambridge, pp. 273−303.

Lovell NC, Haddow S. 2007. Nonmetric Traits of Deciduous Dentitions from Bronze Age Tell Leilan, Syria. International Journal of Dental Anthropology 11:1−21.

Lovejoy CO. 1985. Dental Wear in the Libben Population: Its Functional Pattern and Role in the Determination of Adult Skeletal Age at Death. American Journal of Physical Anthropology 68:47−56.

Lovejoy CO, Meindl RS, Pryzbeck TR, Mensforth RP. 1985. Chronological Metamorphosis of the Auricular Surface of the Ilium: A New Method for the Determination of Adult Skeletal Age at Death. American Journal of Physical Anthropology 68:15−28.

Luz B, Kolodny Y. 1985. Oxygen Isotope Variations in Phosphate of Biogenic Apatites, IV. Mammal Teeth and Bone. Earth and Planetary Science Letters 75:29–36.

Luz B, Kolodny Y, Horowitz M. 1984. Fractionation of Oxygen Isotopes Between Mammalian Bone-Phosphate and Environmental Drinking Water. Geochimica et Cosmochimica Acta 48:1689–1693.

Macchiarelli R, Bondioli L. 1999. Multimedia Dissemination of the "Isola Sacra" Human Paleobiological Project: Reconstructing lives, habits, and deaths of the "Ancient Roman People" by means of advanced investigative methods. In: Guarino A. (Ed.), Proceedings of the 2nd International Congress on "Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean Basin. Elsevier, Paris, pp. 1075–1080.

MacKendrick P. 1971. Roman France. G. Bell and Sons, London.

MacMullen R. 2000. Romanization in the Time of Augustus. Yale University Press, New Haven.

Macko SA, Engel MH, Andrusevich V, Lubec G, O'Connell TC, Hedges R. 1999. Documenting the Diet in Ancient Human Populations Through Stable Isotope Analysis of Hair. Philosophical Transactions of the Royal Society of London, Series B 354:65–76.

Mahalanobis PC. 1930. On Tests and Measures of Group Divergence. Journal of the Asiatic Society of Bengal 26:541–588.

Mahalanobis PC. 1936. On the Generalised Distance in Statistics. Proceedings of the National Institute of Sciences of India. 12:49.

Maier FG. 1953–1954. Bevölkerungsgeschitchte und Inschriftenstatistik. Historia Zeitschrift für alte Geschichte 2:318–351.

Mann RW, Hunt DR. 2005. Photographic Regional Atlas of Bone Disease: A Guide to Pathologic and Normal Variation in the Human Skeleton. Charles C. Thomas, Springfield.

Manning P. 2005. Migration in World History. Routledge, New York.

Manolagas SC. 2000. Birth and Death of Bone Cells: Basic Regulatory Mechanisms and Implications for the Pathogenesis and Treatment of Osteoporosis. Endocrine Reviews 21:115-137.

Manzi G, Santandrea E, Passarello P. 1997. Dental Size and Shape in the Roman Imperial Age: Two Examples from the Area of Rome. American Journal of Physical Anthropology 102:469-479.

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

Marel K. 1980. Inter- und intraregionale Mobilität: Eine empirische Untersuchung zur Typologie der Wanderer am Bespiel der Wanderungsbewegungen der Städte Mainz–Wiesbaden 1973–1974. Boldt, Boppard.

Margolis M. 1995. Transnationalism and Popular Culture: The Case of Brazillian Immigrants in the United States. Journal of Popular Culture 29:29–41.

Marzano A. 2007. Fish Salting Versus Fish Breeding: The Case of Roman Italy. BAR International Series 1686. Archaeopress, Oxfrod, pp. 301–313.

Massey DS, Arango J, Graeme H, Kouaouci A, Pellegrino A, Taylor JE. 1993. Theories of International Migration: A Review and Appraisal. Population and Development Review 19:431–466.

Matsuma H, Hudson MJ. 2005. Dental Perspectives on the Population History of Southeast Asia. American Journal of Physical Anthropology 127:182–209.

Matsumura H, Oxenham MF. 2014. Demographic Transitions and Migration in Prehistoric East/Southeast Asia Through the Lens of Nonmetric Dental Traits. American Journal of Physical Anthropology 155:45–65.

Maurin L. 1976. Mediolanum Santonum (Saintes) Charente-Maritime, France. In: Stillwell R., MacDonald W.L., McAlister M.H. (Eds.), The Princeton Encyclopedia of Classical Sites. Princeton University Press, Princeton.

Maurin L. 1978. Sainted Antique, des Origines à la Fin du Vie Siècle Après J-C. Musée Archéologique de Saintes, Saintes.

Mayr E. 1982. The Growth of Biological Thought. Harvard University Press, Cambridge.

McArthur JM, Coleman ML, Bremner JM. 1980. Carbon and Oxygen Isotopic Composition of Structural Carbonate in Sedimentary Francolite. Journal of the Geological Society, London 137:669-673.

McCarthy, M., Montgomery, J., Lerwick, C., Buckberry, J. 2015. Were There Vikings in Carlisle? In: Harding, S.E., Griffiths, D., Royles, E. (Eds.), Vikings: Interdisciplinary Approaches to The Scandinavian Heritage of North-West England. CRC Press, Boca Raton, pp. 137–147.

McGinn TAJ. 2002. Pompeian Brothels and Social History. In: McGinn T, Carafa P, de Grummond N, Bergmann B, Najbjerg T. (Eds.), Pompeian Brothels, Pompeii's Ancient History, Mirrors and Mysteries, Art and Nature at Oplontis, and the Herculaneum

‘Basilica.’ Journal of Roman Archaeology Supplement 47. Journal of Roman Archaeology, Portsmouth, pp. 7–46.

McGinn TAJ. 2004. The Economy of Prostitution in the Roman World: A Study of Social History and the Brothel. University of Michigan Press, Ann Arbor.

McGrath JW, Cheverud JM, Buikstra JE. 1984. Genetic Correlations Between Sides and Heritability of Asymmetry for Nonmetric Traits in Rhesus Macaques on Cayo Santiago. American Journal of Physical Anthropology 64:401–411.

McIlvaine BK, Schepartz LA, Larsen CS, Sciulli PW. 2014. Evidence for Long-Term Migration on the Balkan Peninsula Using Dental and Cranial Nonmetric Data: Early Interaction Between Corinth (Greece) and its Colony at Apollonia (Albania). American Journal of Physical Anthropology 153:236–248.

McWilliams KR. 1974. Gran Quivira Pueblo and Biological Distance in the U.S. Southwest. Unpublished Ph.D. Dissertation, Arizona State University.

Méhes K. 1988. Informative Morphogenetic Variants in the Newborn Infant. Akadémiai Kiadó, Budapest.

Méhes K. 2000. Mild Errors of Morphogenesis in Malignancy: Macroscopic Manifestation of Genetic Instability? Medical and Pediatric Oncology 34:111–112.

Meiggs R. 1973. Roman Ostia. Clarendon Press, Oxford.

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

Meindl RS, Lovejoy CO. 1985. Ectocranial Suture Closure: A Revised Method for the Determination of Skeletal Age at Death Based on the Later-Anterior Sutures. American Journal of Physical Anthropology 68–57–66.

Mescher AL. 2013. Junquira’s Basic Histology, 13th Edition. The McGraw-Hill Companies, Inc., Columbus.

Meyer BS, Nittler LR, Nguyen AN, Messenger S. 2008. Nucleosynthesis and Chemical Evolution of Oxygen. In: Mittlefehldt DW, Jones JH. (Eds.), Oxygen in the Solar System. Reviews in Mineralogy and Geochemistry 68. Mineralogical Society of America Geochemical Society of America, Chantilly, pp. 31–54.

Mihailescu-Bîrliba, L., 2009. La Mobilité Interne en Mésie Inférieure Selon les Sources Épigraphiques. In: Tsetskhladze, G.R., Atasoy, S., Avram, A., Dönmez, S., Hargrave, J., (Eds.), The Bosphorus: Gateway Between the Ancient West and East (1st Millennium BC–5th Century AD), Proceedings of the Fourth International Congress on Black Sea Antiquities, Istanbul, 14th–18th September 2009. BAR International Series 2517. Archaeopress, Oxford, pp. 185–195.

Milne N, Schmitt LH, Freedman L. 1983. Discrete Trait Variation in Western Australian Aboriginal Skulls. Journal of Human Evolution 12:157–168.

Mitchell PD, Millard AR. 2009. Migration to the Medieval Middle East with the Crusades. American Journal of Physical Anthropology 140:518–525.

Moatti C. (ed.). 2004. La Mobilité des Personnes en Méditerranée de l'Antiquité a l'Époque Moderne. Procédures de Contrôle et Documents d'Identification. École Francaise de Rome, Rome.

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

Moatti C., Kaiser W. (eds.). 2007. Gens de Passage en Méditerranée de l'Antiquité à l'Époque Moderne. Procédures de Contrôle et d'Identification. Maisonneuve and Larose, Paris.

Molleson TI, Eldridge D, Gale N. 1986. Identification of Lead Sources by Stable Isotope Ratios in Bones and Lead From Poundbury Camp, Dorset. Oxford Journal of Archaeology 5:249–253.

Molto JE. 1979. The Assessment and Meaning of Intraobserver Error in Population Studies Based on Discontinuous Cranial Traits. American Journal of Physical Anthropology 51:333–344.

Molto JE. 1983. Biological Relationships of Southern Ontario Woodland Peoples: The Evidence of Discontinuous Morphology. Archaeological Survey of Canada, Mercury Series Paper No. 117. National Museum of Man Mercury Series, Ottawa.

Molto JE. 1985. Simultaneous Occurrences of Discontinuous Cranial Traits: Some Theoretical and Practical Considerations for Population Studies. Canadian Revue of Physical Anthropology 4:57–65.

Molto JE. 2001. The Comparative Skeletal Biology and Paleoepidemiology of the People from Ein Tirghi and Kellies Dakhleh, Egypt. In: Marrow CA, Mills JA. (Eds.), The Oasis Papers. Oxbow Books, Oxford, p. 81–100.

Montelius O. 1899. Der Orient und Europa. Königliche Akademie der schönen Wissenschaften, Geschichte und Altertumskunde, Stockholm.

Montelius O. 1903. Die Typologische Methode. Selbstverlag, Stockholm.

Montgomery J. 2002. Lead and Strontium Isotope Compositions of Human Dental Tissues as an Indicator of Ancient Exposure and Population Dynamics. Unpublished Ph.D. Dissertation, University of Bradford, England.

Montgomery J, Budd P, Evans J. 2000. Reconstructing the Lifetime Movements of Ancient People: A Neolithic Case Study from Southern England. European Journal of Archaeology 3, 370–385.

Montgomery, J., Evans, J.A., Powlesland, D., Roberts, C.A. 2005. Continuity or Colonization in Anglo-Saxon England? Isotope Evidence for Mobility, Subsistence Practice, and Status at West Heslerton. American Journal of Physical Anthropology 126, 123–138.

Montgomery J, Evans J, Chenery S, Pashley V, Killgrove K. 2010. "Gleaming, White and Deadly": Using Lead to Track Human Exposure and Geographic Origins in the Roman Period in Britain. In: Eckardt (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. 199–226.

Montgomery J, Grimes V, Buckberry J, Evans JA, Richards MP, Barrett JH. 2014. Finding Vikings with Isotope Analysis: The View from Wet and Windy Islands. Journal of the North Atlantic 7, 54–70.

Moore LJ, Moody JR, Barnes IL, Gramlich JW, Murphy TJ, Paulsen PJ, Shields WR. 1973. Trace Determination of Rubidium and Strontium in Silicate Glass Standard Reference Materials. Analytical Chemistry 45:2384–2387.

Moore LJ, Murphy TJ, Barnes IL, Paulsen PJ. 1982. Absolute Isotopic Abundance Ratios and Atomic Weight of a Reference Sample of Strontium. Journal of Research (NBS) 87:1–8.

Morawska E. 2003. Disciplinary Agendas and Analytic Strategies of Research on Immigrant Transnationalism: Challenges of Interdisciplinary Knowledge. International Migration Review 37:611–640.

Morel JP. 1999. Hyélè Revue à la Lumière de Massalia. In: Krinzinger F, Tocco G. (Eds.), Neue Forschungen in Velia. Akten des Kongresses "La Ricerca Archeologica a Velia" (Rom 1–2 Juli 1993). Austrian Academy of Sciences Press, Vienna, pp. 11–22.

Morel JP. 2006. Un Demi-Siècle de Recherches sur Velia et les Phocéens d'Occident. In: Velia. Atti del Quarantacinquesimo Convegno di Studi sulla Magna Grecia. Taranto-Marina di Ascea 21−25 Settembre 2005, pp. 23−61.

Morris I. 1992. Death-Ritual and Social Structure in Classical Antiquity. Cambridge University Press, Cambridge.

Morrison AR, Schiff M, Sjöblom M. 2008. Overview. In: Morrison AR, Schiff M, Sjöblom M. (Eds.), The International Migration of Women. The World Bank, Washington, pp. 1−10.

Mouri T. 1976. A Study of Non-Metrical Cranial Variants of the Modern Japanese in the Kinki District. Journal of the Anthropoloigcal Society of Nippon 84:191–203.

Müldner G, Montgomery J, Cook G, Ellam R, Gledhill A, Lowe C. 2009. Isotopes and Individuals: Diet and Mobility Among the Medieval Bishops of Whithorn. Antiquity 83:1119−1133.

Müldner G, Chenery C, Eckardt H. 2011. The 'Headless Romans': Multi-Isotope Investigations of an Unusual Burial Ground From Roman Britain. Journal of Archaeological Science 38:280–290.

Muller H. 1977. Caractères non-métriques du squelette de la tête chez les populations médiévales de Thoiry (Ain, France) et de Bavois (Vaud, Suisse). Archives Suisses d'Anthropologie Générale 41:123–164.

Müller W, Fricke H, Halliday AN, McCulloch MT, Wartho JA. 2003. Origin and Migration of the Alpine Iceman. Science 302:862–866.

Murail P, Bruzek J, Braga J. 1999. A New Approach to Sexual Diagnosis in Past Populations, Practical Adjustments from Van Vark's Procedure. International Journal of Osteoarchaeology 9:39-53.

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

Naas P. 1991. Les Campagnes Gallo-Romaines de la Civitas de Venetes. In: Langouët L. (ed.), Terroirs, Territoires et Campagnes Antiques. La Prospection Archéologique en Haute Bretagne. Traitment et Synthèse des Données. RAO Supplément 4. Revue Archéologique de l'Ouest, Rennes, pp. 143–156.

Naerebout, F.G., 2014. Convergence and Divergence. In: de Kleijn, G., Benoist, S., (Eds.), Integration in Rome and in the Roman World, Proceedings of the Tenth Workshop of the International Network Impact of Empire, Lille, June 23−25, 2011. Brill, Leiden, pp. 263−281.

Nafplioti A. 2008. 'Mycenaean' Political Domination of Knossos Following the Late Minoan IB Destructions on Crete: Negative Evidence from Strontium Isotope Ratio Analysis (87Sr/86Sr). Journal of Archaeological Science 35:2307–17.

Nafplioti A. 2011. Tracing Population Mobility in the Aegean Using Isotope Geochemistry: A First Map of Local Biologically Available ^{87}Sr/^{86}Sr Signatures. Journal of Archaeological Science 38:1560–1570.

Nafplioti A. 2012. Late Minoan IB Destructions and Cultural Upheaval of Crete: A Bioarchaeological Perspective. 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. 241–263.

Napoli M. 1972. Guide Velia. Di Mauro Editore, Cava dei Tirreni.

Necropolis of Isola Sacra, The. 20/05/2013. Retrieved from http://www.ostia-antica.org/valkvisuals/index.htm.

Nehlich O, Oelze VM, Jay M, Conrad MC, Stäuble H, Teegen WR, Richards MP. 2014. Sulphur Isotope Ratios of Multi-Period Archaeological Skeletal Remains from Central Germany: A Dietary and Mobility Study. Anthropologie (Brno) 52:15–33.

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.

Nenci G, Vallet G. 2012. Bibliografia Topografica della Colonizzazione Greca in Italia e nelle Isole Tirreniche. Torre Castelluccia-Zambrone, Rome.

Nichol CR, Turner CG II. 1986. Intra- and Interobserver Concordance in Classifying Dental Morphology. American Journal of Physical Anthropology 69:299–315.

Nicholls R, Furlong J, Montgomery J, Evans J, Witcher R, Faustoferri A. 2013. An Isotopic Investigation for the Practice of Transhumance in Iron Age Italy. 15th Annual Conference of the British Association for Biological Anthropology and Osteoarchaeology, 13th–15th September, University of York.

Nikita E. 2015. A Critical Review of the Mean Measure of Divergence and Mahalanobis Distances Using Artificial Data and New Approaches to the Estimation of Biodistances Employing Nonmetric Traits. American Journal of Physical Anthropology 157:284–294.

Nikita E, Mattingly D, Lahr MM. 2012. Sahara: Barrier or Corridor? Nonmetric Cranial Traits and Biological Affinities of North African Late Holocene Populations. American Journal of Physical Anthropology 147:280–292.

Nielsen-Marsh CM, Hedges REM. 2000. Patterns of Diagenesis in Bone I: The Effects of Site Environments. Journal of Archaeological Science 27:1139–1150.

Nishimura H, Okamoto N, Tanimura T, Ikeda T. 1976. Sequential Atlas of Human Congenital Malformations: Observations of Embryos, Fetuses and Newborns. Igaku Shoin Ltd., Tokyo.

Noy, D., 1998. Where Were the Jews of the Diaspora Buried? In: Goodman, M., (Ed.), Jews in a Graeco-Roman World. Clarendon Press, Oxford, pp. 75–89.

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.

Nugent SE. 2013. Death on the Imperial Frontier: An Osteobiography of Roman Burial from Oglanqala, Azerbaijan. MA Thesis, The Ohio State University.

Nutto V. 1970. The Medical School of Velia. Parola Passato 25:211–225.

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.

O’Brien DM, Woolleer MJ. 2007. Tracking Human Travel Using Stable Oxygen and Hydrogen Isotope Analyses of Hair and Urine. Rapid Communications in Mass Spectrometry 21:2422–2430.

O’Connell Davidson J. 2013. Troubling Freedom: Migration, Debt, and Modern Slavery. Migration Studies 1:176–195.

O’Connell TC, Hedges REM, Healey MA, Simpson AHRW. 2001. Isotopic Comparison of Hair, Nail and Bone: Modern Analyses. Journal of Archaeological Science 28:1247–1255.

Oelze VM, Koch JK, Kupke K, Nehlich O, Zäuner S, Wahl J, Weise SM, Rieckhoff S, Richards MP. 2012. Multi-Isotopic Analysis Reveals Individual Mobility and Diet at the Early Iron Age Monumental Tumulus of Magdalenenberg, Germany. American Journal of Physical Anthropology 148:406–421.

Oetteking B. 1930. Craniology of the North Pacific Coast. American Museum of Natural History Memoir 15, New York.

Ogundiran A, Falola T. 2007. Pathways in the Archaeology of Transatlantic Africa. In: Ogundiran A, Falola T. (Eds.), Archaeology of Atlantic Africa and African Diaspora. Indiana University Press, Bloomington, pp. 3–45.

O'Loughlin VD. 2004. Effects of Different Kinds of Cranial Deformation on the Incidence of Wormian Bones. American Journal of Physical Anthropology 123:146–155.

O'Neil JR, Roe LJ, Reinhard E, Blake RE. 1994. A Rapid and Precise Method of Oxygen Isotope Analysis of Biogenic Phosphate. Israel Journal Earth Sciences 43:203-212.

OneGeology 2016. OneGeology Portal www.onegeology.org.

Ogniben L, Parotto M, Praturlon A. 1975. Structural Model of Italy: Maps and Explanatory Notes. Consiglio Nazionale delle Richerche, Roma.

Ortega Munõz A. 2015. The Use of Theoretical and Methodological Bases in Population Movements' Studies: *Paleo* and *Archaeo* Demographic Approaches. In: Cucina A. (Ed.), Archaeology and Bioarchaeology of Population Movement Among the Prehispanic Maya. Springer, New York, pp. 59‒69.

Osborne R. 1991. The Potential Mobility of Human Populations. Oxford Journal of Archaeology 10:231‒252.

Osborne R. 1998. Early Greek Colonisation? The Nature of Greek Settlement. In: Fisher NRE, van Wees H. (Eds.), Archaic Greece. New Approaches and New Evidence. Duckworth, London, pp. 251‒270.

Ossenberg NS. 1969. Discontinuous Morphological Variation in the Human Cranium. Unpublished Ph.D. Dissertation, University of Toronto.

Ossenberg NS. 1970. The Influence of Artificial Cranial Deformation on Continuous Morphological Traits. American Journal of Physical Anthropology 33:357–372.

Ossenberg NS. 1976. Within and Between Race Distances in Population Studies Based on Discrete Traits of the Human Skull. American Journal of Physical Anthropology 45:701–716.

Ossenberg NS. 1981. An Argument for the Use of Total Side Frequencies of Bilateral Nonmetric Skeletal Traits in Population Distance Analysis: The Regression of Symmetry on Incidence. American Journal of Physical Anthropology 54:471–479.

Ossenberg NS. 1992. Microevolutionary Parallels in the Population History of Japan and Aboriginal North America: The Evidence of Cranial Nonmetric Traits. In: Hanihara K. (Ed.), Japanese as a Member of the Asian and Pacific Populations. International Research Symposium 4. International Research Center for Japanese Studies, Kyoto, p. 65–78.

Øvergåard, K.I., Bjørkli, C.A., Hoff, T., 2008. The Bodily Basis of Control in Technically Aided Movement. In: Bergmann, S., Hoff, T., Sager, T., (Eds.), Spaces of Mobility: The Planning, Ethics, Engineering and Religion of Human Motion. Equinox, Oakville, pp. 101–123.

Palombo M, Filippi M, Iacumin P, Longinelli A, Barbieri M, Maras A. 2005. Coupling Tooth Microwear and Stable Isotope Analyses for Palaeodiet Reconstruction: The Case Study of Late Middle Pleistocene Elephas (Palaeoloxodon) Antiquus Teeth from Central Italy (Rome Area). Quaternary International 126:153–170.

Parfitt, A.M., 2002. Misconceptions (2): Turnover Is Always Higher in Cancellous Than Cortical Bone. Bone 30, 807–809.

Parfitt, A.M., 2004. What is the Normal Rate of Bone Remodelling? Bone 35, 1–3.

Parker Pearson M. 1999. The Archaeology of Death and Burial. Phoenix Mill, Sutton.

Passchier C, Van Opstal D, Schram W, Sürmelihindi G. 2011. ROMAQ: The Atlas Project of Roman Aqueducts. www.romaq.org.

Patterson JR. 2006. Colonization and Historiography. The Roman Republic. In: Bradley G., Wilson JP. (Eds.), Greek and Roman Colonization. Origins, Ideologies, and Interactions. Classical Press of Wales, Swansea, pp. 189–218.

Pauseback PH. 1995. Aufbruch in eine Neue Welt: Die Auswanderung aus den schleswig-holsteinischen Kreisen Husum, Eiderstedt und Tondern in die Vereinigten Staaten in königlich-preussischer Zeit (1867–1914). Nordfriisk Instituut, Bredstedt.

Pearce, J., 2008. Burial Evidence from Roman Britain The Un-Numbered Dead. In: Scheidel, J., (Ed.), Pour une Archéologie du Rite Nouvelles Perspectives de L'archéologie Funéraire. Collection de L'école Francaise de Rome 407. École Francaise de Rome, pp. 29–42.

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.

Pedraza S. 1991. Women and Migration: The Social Consequences of Gender Annual Review of Sociology 17:303–325.

Pellegrini M, Donahue RE, Chenery C, Evans J, Lee-Thorp J, Montgomery J, Mussi M. 2008. Faunal Migration in Late-Glacial Central Italy: Implications for Human Resource Exploitation. Rapid Communications in Mass Spectrometry 22(11):1714–1726.

Pellegrini M, Pouncett J, Jay M, Parker Pearson M, Richards MP. 2016. Tooth Enamel Oxygen "Isoscapes" Show a High Degree of Human Mobility in Prehistoric Britain. Science Reports 6:34986, doi:10.1038/srep34986.

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

Pennefather-O'Brien E. 2006. Biological Affinities Among Middle Woodland Populations Associated with the Hopewell Horizon. Unpublished Ph.D. Dissertation, Indiana University.

Penteado CV, Duarte E, Meciano Filho J, Stabille SR. 1986. Non-Metric Traits of the Infracranial Skeleton. Anatomischer Anzeiger (Jena) 162:47–50.

Penrose LS. 1947. Some Notes on Discrimination. Annals of Eugenics 13:228–237.

Penrose LS. 1953. Distance, Size and Shape. Annals of Eugenics 18:337–343.

Perizonius WRK. 1979. Non-Metric Cranial Traits: Sex Differences and Age Dependence. Journal of Human Evolution 8:679–684.

Perry M. 2009. Crossing Jordan: Tracing Human Migration in Classical Period Jordan Using Strontium and Oxygen Isotopes. Studies in the History and Archaeology of Jordan X:165–176.

Perry, M. (ed) 2012. Bioarchaeology and Behaviour: The People of the Ancient Near East. University Press of Florida, Gainesville.

Perry M, Coleman D, Delhopital N. 2008. Mobility and Exile at 2nd Century A.D. Khirbet edh-Dharih: Strontium Isotope Analysis of Human Migration in Western Jordan. Geoarchaeology: An International Journal 23:528–549.

Perry M, Coleman D, Dettman D, al-Shiyab A. 2009. An Isotopic Perspective on the Transport of Byzantine Mining Camp Laborers Into Southwestern Jordan. American Journal of Physical Anthropology 140:429–441.

Perry M, Coleman D, Dettman D, Grattan J, al-Shiyab A. 2011. Condemned to *Metallum*? The Origin and Role of 4th‒6th Century A.D. *Phaeno* Mining Camp Residents Using Multiple Chemical Techniques. Journal of Archaeological Science 38:558‒569.

Perry M, Coleman D, Dettman D, al-Shiyab A. 2012. Condemned to Mettalum?: Illuminating Life at the Byzantine Mining Camp at Phaeno in Jordan. In: Perry, M. (ed.), Bioarchaeology and Behaviour: The People of the Ancient Near East. University Press of Florida, Gainesville, pp. 115‒137.

Perry M, Coleman D, al-Shiyab A. 2013. "Damnatio ad Metallum": Investigating the Origin and Role of Phaeno Mining Camp Residents Using Multiple Chemical Techniques. In: Lozada, M., O'Donnabhain, B. (eds.), The Dead Tell Tales: Essays in Honor of Jane E. Buikstra. Cotsen Institute of Archaeology Press, Los Angeles, pp. 145‒153.

Pestle W, Simonetti A, Curet L. 2013. ^{87}Sr/^{86}Sr Variability in Puerto Rico: Geological Complexity and the Study of Paleomobility. Journal of Archaeological Science 40:2561-2569.

Peterson BJ, Fry B. 1987. Stable Isotopes in Ecosystem Studies. Annual Review of Ecology, Evolution, and Systematics 18:293–320.

Petriaggi R, Bonacci G, Corbonara A, Vittori MC, Vivarelli ML, Vori P. 1995. Scavi a Ponte Galeria: nuove acquisizioni sull'acquedoto di Porto e sulla topografia del territorio Portuense. Arch Laz 12:361–373.

Phenice TW. 1969. A Newly Developed Visual Method of Sexing in the Os Pubis. American Journal of Physical Anthropology 30:297–301.

Piepgras DJ, Wasserburg GJ, Dasch EJ. 1979. The Isotopic Composition of Nd in Different Ocean Masses. Earth and Planetary Science Letters 45:223–236.

Pietrusewsky M. 2008. Metric Analysis of Skeletal Remains: Methods and Applications. In: Katzenberg MA, Saunders SR. (Eds.), Biological Anthropology of the Human Skeleton, Second Edition. Wiley-Liss, Hoboken, pp. 487–532.

Pietrusewsky M, Douglas MT. 1992. The Skeletal Biology of an Historic Hawaiian Cemetery: Familial Relationships. Homo 43:245–262.

Pilloud MA. 2009. Community Structure at Neolithic Çatalhöyük: Biological Distance Analysis of Household, Neighborhood, and Settlement. Unpublished Ph.D. Dissertation, Ohio State University.

Pilloud MA, Larsen CS. 2011. “Official” and “Practical” Kin: Inferring Social and Community Structure from Dental Phenotype at Neolithic Çatalhöyük, Turkey. American Journal of Physical Anthropology 145:519–530.

Pinsky L. 1985. Informative Morphogenetic Variants: Minor Congenital Anomalies Revisited. In: Kalter H. (Ed.), Issues and Reviews in Teratology. Plenum Press, New York, p. 135–170.

Plane D. 1982. An Information Theoretic Approach to Estimation of Migration Flows. Journal of Regional Science 22:441−456.

Podlesak DW, Torregrossa AM, Ehleringer JR, Dearing MD, Passey BH, Cerling TE. 2008. Turnover of Oxygen and Hydrogen Isotopes in the Body Water, CO_2, Hair, and Enamel of a Small Mammal. Geochimica et Cosmochimica Acta 72:19‒35.

Polak M. (ed.). 2003. Developmental Instability (DI): Causes and Consequences. Oxford University Press, Oxford.

Pollard M, Batt C, Stern B, Young SMM. 2007. Analytical Chemistry in Archaeology. Cambridge University Press, Cambridge.

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.

Preston T. 1992. The Measurement of Stable Isotope Natural Abundance Variations. Plant, Cell and Environment 15:1091–1097.

Price TD, Blitz J, Burton JH, Ezzo J. 1992. Diagenesis in Prehistoric Bone: Problems and Solutions. Journal of Archaeological Science 19:513–529.

Price TD, Johnson CM, Ezzo JA, Burton JH, Ericson JA. 1994a. Residential Mobility in the Prehistoric Southwest United States: A Preliminary Study Using Strontium Isotope Analysis. Journal of Archaeological Science 24:315–330.

Price TD Grupe G, Schroter P. 1994b. Reconstruction of Migration Patterns in the Bell Beaker Period by Stable Strontium Isotope Analysis. Applied Geochemistry 9:413–417.

Price TD, Manzanilla L, MiddleWH. 2000. Residential Mobility at Teotihuacan: A Preliminary Study Using Strontium Isotopes. Journal of Archaeological Science 27:903–914.

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, Gestsdottir H. 2006. The First Settlers of Iceland: An Isotopic Approach to Colonisation. Antiquity 80:130–144.

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. 2011. An Introduction to Archaeological Chemistry. Springer, New York.

Price TD, Frei KM, Dobat AS, Lynnerup N, Bennike P. 2011. Who Was in Harold Bluetooth’s Army? Strontium Isotope Investigation of the Cemetery at the Viking Age Fortress at Trelleborg, Denmark. Antiquity 85:476–489.

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. 119–132.

Prowse TL. 1994. Biological Affinities of Ancient Egyptians and Nubians: An Analysis of Cranial Nonmetric Traits. Unpublished MA Thesis, University of Alberta.

Prowse TL. 2001. Isotopic and Dental Evidence for Diet from the Necropolis of Isola Sacra (1st–3rd Centuries AD), Italy. Ph.D. Dissertation, McMaster University.

Prowse TL. 2011. Diet and Dental Health Through the Life Course in Roman Italy. In: Agarwal SC, Glencross BA. (Eds.), Social Bioarchaeology. Wiley-Blackwell, Chichester, pp. 410–437.

Prowse TL. 2013. Isola Sacra. In: Bagnall RS, Brodersen K, Champion CB, Erskine A, Huebner SR. (Eds.), The Encyclopedia of Ancient History. Blackwell Publishing, Hoboken, pp. 3520–3521.

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 T, Lovell NC. 1995. Biological Continuity Between the A- and C-Groups in Lower Nubia: Evidence from Cranial Nonmetric Traits. International Journal of Osteoarchaeology 5:104–114.

Prowse T, Lovell NC. 1996. Concordance of Cranial and Dental Morphological Traits and Evidence for Endogamy in Ancient Egypt. American Journal of Physical Anthropology 101:237–246.

Prowse TL, Schwarcz HP, Saunders S, Bondioli L, Macchiarelli R. 2004. Isotopic Paleodiet Studies of Skeletons from the Imperial Roman Cemetery of Isola Sacra, Rome, Italy. Journal of Archaeological Science 31:259–272.

Prowse TL, Schwarcz HP, Saunders S, Macchiarelli R, Bondioli L. 2005. Isotopic Evidence for Age-Related Variation in Diet from Isola Sacra, Italy. American Journal of Physical Anthropology 128:2–13.

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, Saunders SR, Schwarcz HP, Garnsey P, Macchiarelli R, Bondioli L. 2008. Isotopic and Dental Evidence for Infant and Young Child Feeding Practices in an Imperial Roman Skeletal Sample. American Journal of Physical Anthropology 137:294–308.

Prowse TL, Barta JL, von Hunnius TE, Small AM. 2010a. 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.

Prowse T, Saunders S, Fitzgerald C, Bondioli L, Macchiarelli R. 2010b. Growth, Morbidity, and Mortality in Antiquity. In: Moffat T, Prowse T. (Eds.), Human Diet and Nutrition in Biocultural Perspective Past Meets Present. Berghahn Books, New York, pp. 173–196.

Pugliese Carratelli G. 1970. Ancora su φωλαρχοζ. Parola del Passato 25:243–248.

Purcell N. 2005. Colonization and Mediterranean History. In: Hurst H., Owen S. (Eds.), Ancient Colonizations Analogy, Similarity and Difference. Duckworth, London, pp. 115–139.

Pye K. 2004. Isotope and Trace Element Analysis of Human Teeth and Bones for Forensic Purposes. In: Pye K., Croft DJ. (Eds.), Forensic Geoscience: Principles, Techniques and Applications. Geological Society, London, Special Publication 232, pp. 215–236.

Quain J. 1908. Quain’s Elements of Anatomy. Longmans Green, London.

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.135–162.

Ragsdale CS, Edgar HJH. 2014. Cultural Effects of Phenetic Distances Among Postclassic Mexican and Southwest United States Populations. International Journal of Osteoarchaeology DOI: 10.1002/oa.2394.

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.

Rankama K. 1954. Isotope Geology. Pergamon Press, London.

Ravenstein EG. 1885. The Laws of Migration. Journal of the Royal Statistical Society 48:167–235.

Ravenstein EG. 1889. The Laws of Migration. Journal of the Royal Statistical Society 52:241–305.

Redfield R. 1941. The Folk Culture of Yucatan. University of Chicago, Chicago.

Reed JC. 2006. The Utility of Cladistic Analysis of Nonmetric Traits for Biodistance Analysis. Ph.D. University of Pittsburgh, Pittsburgh.

Rees CE, Jenkins WJ, Monster J. 1978. The Sulphur Isotopic Composition of Ocean Water Sulphate. Geochimica et Cosmochimica Acta 42:377–381.

Rees JW. 1969a. Morphologic Variation in the Cranium and Mandible of the White-tailed Deer. Journal of Morphology 128:95–112.

Rees JW. 1969b. Morphologic Variation in the Mandible of the White-tailed Deer. Journal of Morphology 128:113–130.

Reggio G, Masali M, Chiarelli B. 1969. Caratteri epigenetici del cranio degli antichi Egizi e loro interesse etnico. Rivista di Antropologia 56:199–202.

Reich T, James JW, Morris CA. 1972. The Use of Multiple Thresholds in Determining the Mode of Transmission of Semi-Continuous Traits. Annals of Human Genetics 36:163–184.

Reinhard R, Rösing FW. 1985. Ein Literaturüberblick über Definitionen diskreter Merkmale/anatomischer Varitanten am Schädel des Menschen, Selbstverlag, Ulm.

Relethford JH, Crawford MH, Blangero J. 1997. Genetic Drift and Gene Flow in Post-Famine Ireland. Human Biology 69:443–465.

Rey C, Frèche M, Heughebaert JC, Lacout JL, Lebugle A, Szilagyi J, Vignoles M. 1991a. 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 Cermaics in Medicine, London, UK, September 1991. Butterworth-Heinemann Ltd., Oxford, pp. 57–64.

Rey C, Renugopalakrishnan V, Shimizu M, Collins B, Glimcher MJ. 1991b. A Resolution-enhanced Fourier Transform Infrared Spectroscopic Study of the Environment of the CO32-ion in the Mineral Phase of Enamel During its Formation and Maturation. Calcified Tissue International 49:259-268.

Rhoades RE. 1978. Foreign Labor and German Industrial Capitalism 1871–1978: The Evolution of a Migratory System. American Ethnologist 5:553–575.

Ricaut FX, Auriol V, Von Cramon-Taubadel N, Keyser C, Murail P, Ludes B, Crubézy E. 2010. Comparison Between Morphological and Genetic Data to Estimate Biological Relationship: The Case of the Egyin Gol Necropolis (Mongolia). American Journal of Physical Anthropology 143:355–364.

Richards MP, Fuller BT, Hedges REM. 2001. Sulphur Isotopic Variation in Ancient Bone Collagen from Europe: Implications for Human Palaeodiet, Residence Mobility and Modern Pollutant Studies. Earth and Planetary Science Letters 191:185–190.

Richards MP, Fuller BT, Sponheimer M, Robinson T, Ayliffe L. 2003. Sulphur Isotopes in Palaeodietary Studies: A Review and Results from a Controlled Feeding Experiment. International Journal of Osteoarchaeology 13:37–45.

Richardson L. 1976. Elea later Velia, Campania, Italy. In: Stillwell R., MacDonald W.L., McAlister M.H. (Eds.), The Princeton Encyclopedia of Classical Sites. Princeton University Press, Princeton.

Richtsmeier JT, Cheverud JM, Buikstra JE. 1984. The Relationship Between Cranial Metric and Nonmetric Traits in the Rhesus Macaques from Cayo Santiago. American Journal of Physical Anthropology 64:213–222.

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

Ristvet L, Gopnik H, Bakhshaliyev V, Lau H, Ashurov S, Bryant R. 2012. On the Edge of Empire: 2008 and 2009 Excavations at Oğlanqala, Azerbaijan. American Journal of Archaeology 116:321-362.

Roberts SB, Coward WA, Ewing G, Savage J, Cole TJ, Lucas A. 1988. Effect of Weaning on Accuracy of Doubly Labeled Water Method in Infants. American Journal of Physiology: Regulatory, Integrative and Comparative Physiology 254:R622–627.

Robinson S, Nicholson RA, Pollard AM, O'Connor TP. 2003. An Evaluation of Nitrogen Porosimetry as a Technique for Predicting Taphonomic Durability in Animal Bone. Journal of Archaeological Science 30:391–403.

Roff DA. 1996. The Evolution of Threshold Traits in Animals. The Quarterly Review of Biology 71:3–35.

Roff DA. 1998. Evolution of Threshold Traits: The Balance Between Directional Selection, Drift and Mutation. Heredity 80:25–32.

Rogué J. 1966. Recherches sur l'Oranisation du Commerce Maritime en Méditerranée. S.E.V.P.E.N., Paris.

Rohlf FJ. 1967. Correlated Characters in Numerical Taxonomy. Systematic Zoology 16:109–126.

Roselaar ST. 2016. State-Organized Mobility in the Roman Empire: Legionaries and Auxillaries. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 138–158.

Rösing FW. 1982. Discreta des menschilichen Skeletts-ein kritischer Überlick. Homo 33:100–125.

Rösing FW. 1986a. Kinship Analysis. Group Report. In: Herrmann B. (Ed.), Innovative Trends in Prehistoric Anthropology. Mitteilungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte Band 7. Color-Druck G. Baucke, Berlin, p.95–98.

Rösing FW. 1986b. Kith or Kin? On the Feasibility of Kinship Reconstruction in Skeletons. In: David AR. (Ed.), Science in Egyptology. Manchester University Press, Manchester, p. 223–237.

Ross DE. 2013. An Archaeology of Asian Transnationalism. University Press of Florida, Gainesville.

Rossi PF, Bondioli L, Geusa G, Macchiarelli R. 1998. Enamel Microstructure and Developmental Defects of the Primary Dentition. Osteodental Biology of the People of Portus Romae (Necropolis of Isola Sacra, 2nd–3rd Cent. AD). I, CD-ROM, Soprintendenza Speciale al Museo Nazionale Preistorico Etnografico "L. Pigorini", Roma.

Rougier G, Ford M, Christophoul F, Bader AG. 2016. Stratigraphic and Tectonic Studies in the Central Aquitaine Basin, Northern Pyrenees: Constraints on the Subsidence and Deformation History of a Retro-Foreland Basin. Comptes Rendus Geoscience 348:224–235.

Rouse R. 1986. Migrations in Prehistory: Inferring Population Movement from Cultural Remains. Yale University Press, New Haven.

Rouse R. 1995. Thinking Through Transnationalism: Notes on the Cultural Politics of Class Relations in the Contemporary United States. Public Culture 7:353–402.

Rowland, R.J., 1976. Foreigners in Roman Britain. Acta Archaeologica Academiae Scientiarum Hungaricae 28:443–447.

Rozanski K, Araguas-Araguas L, Gonfiantini R. 1993. Isotopic Patterns in Modern Global Precipitation. In: Swart PK, Lohmann KC, McKenzie J, Savin S., (Eds.), Climate Change in Continental Isotopic Records. Washington, DC: Am. Geophys. Union, pp. 1–36.

Rubini M. 1996. Biological Homogeneity and Familial Segregation in the Iron Age Population of Alfedena (Abruzzo, Italy), Based on Cranial Discrete Traits Analysis. International Journal of Osteoarchaeology 6:454–462.

Rubini M, Bonafede E, Mogliazza S, Moreschini L. 1997. Etruscan Biology: The Tarquinian Population 7th–2nd Century BC (Southern Etruria, Italy). International Journal of Osteoarchaeology 7:202–211.

Rubini M, Mogliazza S, Corruccini ST. 2007. Biological Divergence and Equality During the First Millennium BC in Human Populations of Central Italy. American Journal of Human Biology 19:119–131.

Sacco G. 1984. Iscrizioni Greche d’Italia: Porto. Edizioni di Storia e Letterature, Rome.

Saddington, D.B., 1991. The Parameters of Romanization. In: Maxfield, V.A., Dobson, M.J. (Eds.), Roman Frontier Studies, Proceedings of the XVth International Congress of Roman Frontier Studies. University of Exeter Press, Exeter, pp. 413–418.

Sager, T., 2008. Freedom as Mobility: Implications of the Distinction Between Actual and Potential Travelling. In: Bergmann, S., Hoff, T., Sager, T., (Eds.), Spaces of Mobility: The Planning, Ethics, Engineering and Religion of Human Motion. Equinox, Oakville, pp. 243–267.

Saitoh M, Uzuka M, Sakamoto M. 1970. Human Hair Cycle. Journal of Investigative Dermatology 54:65–81.

Sakamoto M. 2000. Lead Concentrations and Isotopic Compositions From Isola Sacra, Italy. Unpublished MA Thesis, University of Michigan.

Salesse K, Urzel V, Dufour E, Castex D, Bruzek J, Dufourc EJ. 2013. Validation of Bone Apatite Purification Protocols for Stable Isotope Analysis in Bioarchaeology by Solid-State Nuclear Magnetic Resonance Spectrometry. American Journal of Physical Anthropology 150 S56:239.

Saller RP. 1994. Patriarchy, Property and Death in the Roman Family. Cambridge University Press, Cambridge.

Salmon ET. 1969. Roman Colonization Under the Republic. Thames and Hudson, London.

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.

Sanjek R. 2003. Rethinking Migration, Ancient to Future. Global Networks 3:315–336.

Saunders SR. 1978. The Development and Distribution of Discontinuous Morphological Variation of the Human Infracranial Skeleton. Archaeological Survey of Canada, Mercury Series Paper No. 81. National Museum of Man, Ottawa.

Saunders SR. 1989. Nonmetric Skeletal Variation. In: Iscan MY, Kennedy KAR. (Eds.), Reconstruction of Life from the Skeleton. Alan R. Liss, New York, p. 95–108.

Saunders SR, Popovich F. 1978. A Family Study of Two Skeletal Variants: Atlas Bridging and Clinoid Bridging. American Journal of Physical Anthropology 49:193–203.

Saunders S, Hoppa RD, Macchiarelli R, Bondioli L. 2000. Investigating Variability in Human Dental Development in the Past. Anthropologie (Brno) 38:101–107.

Saunders SR, Rainey DL. 2008. Nonmetric Trait Variation in the Skeleton: Abnormalities, Anomalies and Atavisms. In: Katzenberg MA, Saunders SR. (Eds.), Biological Anthropology of the Human Skeleton, Second Edition. Wiley-Liss, Hoboken, p. 533–559.

Sawyer DR, Allison MJ, Elzay RP, Pezzia A. 1978. The Mylohyoid Bridge of Pre-Columbia Peruvians. American Journal of Physical Anthropology 48:9–16.

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

Scarsini C, Rossi V, Messeri P. 1980. Caratteri cranici discontinui in Sardi di Nuoro. Seminario di Scienze Antropologiche 2:1–68.

Scheeres, M., 2014. High Mobility Rates During the Period of the “Celtic Migrations”? $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ Evidence from Early La Tène Europe. PhD Dissertation, Johannes Gutenberg-Universität Mainz.

Scheeres, M., Knipper, C., Hauschild, M., Schönfelder, M., Siebel, W, Vitali, D., Pare, C., and Alt, K.W. 2013. Evidence for “Celtic Migrations”? Strontium Isotope Analysis at the Early La Tène (LT B) Cemeteries of Nebringen (Germany) and Monte Bibele (Italy). Journal of Archaeological Science 10: 3614-3625.

Scheeres, M., Knipper, C., Hauschild, M., Schönfelder, M., Siebel, W., Pare, C., Alt, K.W. 2014. “Celtic Migrations”: Fact or Fiction? Strontium and Oxygen Isotope Analysis of the Czech Cemeteries of Radovesice and Kutná Hora in Bohemia. American Journal of Physical Anthropology 155, 496–512.

Scheidel W. 1997. Quantifying the Sources of Slaves in the Roman Empire. 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. 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. Elsevier Academic Press, London.

Schmeidt G. 1970. Contributo alla Ricostruzione della Situazione Geotopografica di Velia nell’Antichità. PdelP 25:65–92.

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.

Schrader S, Buzon M, Irish J. 2014. Illuminating the Nubian 'Dark Age': A Bioarchaeological Analysis of Dental Non-Metric Traits During the Napatan Period. Journal of Comparative Human Biology 65:267–280.

Schroeder H, O'Connell TC, Evans JA, Shuler KA, Hedges REM. 2009. Trans-Atlantic Slavery: Isotopic Evidence for Forced Migration to Barbados. American Journal of Physical Anthropology 139:547–557.

Schwarcz HP. 2007. Tracing Unidentified Skeletons Using Stable Isotopes. Forensic Magazine June/July.

Schwarcz HP, Cortecci G. 1974. Isotopic Analyses of Spring and Stream Water Sulfate from the Italian Alps and Apennines. Chemical Geology 13:285–294.

Schwarcz HP, Gibbs L, Knyf M. 1991. Oxygen Isotopic Analysis as an Indicator of Place of Origin. In: Pfeiffer S, Williamson RF. (Eds.), Snake Hill: An Investigation of a Military Cemetery From the War of 1812. Dundurn Press, Toronto, pp. 263–268.

Schwarcz HP, Schoeninger MJ. 1991. Stable Isotope Analyses in Human Nutritional Ecology. Yearbook of Physical Anthropology 34:283–321.

Schwarcz HP, Walker P. 2005. Strontium and Neodymium Isotope Ratios as Tracers of Human Migration in Iceland. Canadian Association for Physical Anthropology Newsletter 2005.1:25–26.

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.

Schwartz JH. 2007. Skeleton Keys: An Introduction to Human Skeletal Morphology, Development, and Analysis, Second Edition. Oxford University Press, Oxford.

Schweissing MM, Grupe G. 2003. 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.

Schultz AH. 1919. Der Canalis Cranio-Pharyngeus Persistens Beim Mensch und bei den Affen. Gegenbaurs Morphologisches Jahrbuch Leipzig 50:417–426.

Scott GR. 1973. Dental Morphology: A Genetic Study of American White Families and Variation in Living Southwest Indians. Unpublished Ph.D. Dissertation, Arizona State University.

Scott GR. 1980. Population Variation of Carabelli's Trait. Human Biology 52:63–78.

Scott GR, Potter RHY, Noss JF, Dahlberg AA, Dahlberg T. 1983. The Dental Morphology of Pima Indians. American Journal of Physical Anthropology 61:13–31.

Scott GR, Turner CG II. 1997. The Anthropology of Modern Human Teeth: Dental Morphology and its Variations in Recent Human Populations. Cambridge University Press, Cambridge.

Sealy JC, Van Der Merwe NJ, Sillen A, Kruger FJ, Krueger WH. 1991. ^{87}Sr/^{86}Sr as a Dietary Indicator in Modern and Archaeological Bone. Journal of Archaeological Science 18:399–416.

Searle AG. 1954. Genetical Studies on the Skeleton of the Mouse XI. The Influence of Diet on Variation within Pure Lines. Journal of Genetics 52:413–424.

Self SG, Leamy L. 1978. Heritability of Quasi-Continuous Skeletal Traits in a Random Bred Population of House Mouse. Genetics 88:109–120.

Sharp ZD, Atudorei V, Furrer H. 2000. The Effect of Diagenesis on Oxygen Isotope Ratios of Biogenic Phosphates. American Journal of Science 300:222–237.

Sharp Z. 2007. Principles of Stable Isotope Geochemistry. Pearson Prentice Hall, Upper Saddle River.

Sharpe MO. 2014. Postcolonial Citizens and Ethnic Migration. The Netherlands and Japan in the Age of Globalization. Palgrave Macmillan, New York.

Shaw BD. 1987. The Age of Roman Girls at Marriage: Some Reconsiderations. The Journal of Roman Studies 77:30-46.

Shaw BJ, Summerhayes GR, Buckley HR, and Baker JA. 2009. The Use of Strontium Isotopes as an Indicator of Migration in Human and Pig Lapita Populations in the Bismarck Archipelago, Papua New Guinea. Journal of Archaeological Science 36: 1079-1091.

Shaw B, Buckley H, Summerhayes G, Anson D, Garling S, Valentin F, Mandui H, Stirling C, Reid M. 2010. Migration and Mobility at the Late Lapita Site of Reber-Rakival (SAC), Watom Island Using Isotope and Trace Element Analysis: A New Insight Into Lapita Interaction in the Bismarck Archipelago. Journal of Archaeological Science 37:605–613.

Shaw, B., Buckley, H., Summerhayes, G., Stirling, C., Reid, M. 2011. Prehistoric Migration at Nebira, South Coast of Papua New Guinea: New Insights into Interaction Using Isotope and Trace Element Concentration Analyses. Journal of Anthropological Archaeology 30, 344–358.

Shaw HF, Wasserburg GJ. 1985. Sm–Nd in Marine Carbonates and Phosphates: Implications for Nd Isotopes in Seawater and Crustal Ages. Geochimica et Cosmochimica Acta 49:503–518.

Shepherd FJ. 1893. Symmetrical Depressions on the Exterior Surface of the Parietal Bones. Journal of Anatomy and Physiology 27:501–504.

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

Sheridan SG, Gregoricka LA. 2015. Monks on the Move: Evaluating Pilgrimage to Byzantine St. Stephen’s Monastery Using Strontium Isotopes. American Journal of Physical Anthropology 158:581–591.

Shewman L. 2004. Natufian Settlement Systems and Adaptive Strategies: The Issue of Sedentism and the Potential of Strontium Isotope Analysis. In: Delage C., (Ed.), The Last Hunter-Gatherers in the Near East. John and Erica Hedges Ltd., Oxford, pp. 55–94.

Siegenthaler V, Oeschger H, Tongiorgi E. 1970. Tritium and Oxygen-18 in Natural Water Samples from Switzerland. In: Isotope Hydrology, Proceedings of Vienna, Symposium. International Atomic Energy Agency, Vienna, pp. 373–385.

Sillen A. 1981. Strontium and Diet at Hayonim Cave, Israel: An Evaluation of the Strontium/Calcium Technique for Investigating Prehistoric Diets. Unpublished Ph.D. Dissertation, University of Pennsylvania.

Sillen A. 1986. Biogenic and Diagenetic Sr/Ca in Plio-Pleistocene Fossils in the Omo Shungura Formation. Paleobio 12:311–323.

Sillen A, Kavanagh M. 1982. Strontium and Paleodietary Research: A Review. Yearbook of Physical Anthropology 25:67–90.

Sillen A, Sealy JC. 1995. Diagenesis of Strontium in Fossil Bone: A Reconsideration of Nelson et al. (1986). Journal of Archaeological Science 22:313–320.

Sillen A, Hall G, Richardson S, Armstrong R. 1998. ^{87}Sr/^{86}Sr Ratios in Modern and Fossil Food-Webs of the Sterkfontein Valley: Implications for Early Hominid Habitat Preference. Geochimica et Cosmochimica Acta 62:2463–2473.

Singer HW, 1949. Economic Progress in Underdeveloped Countries. Social Research: An International Quarterly of Political and Social Science 16.1:1-11.

Sjaastad LA. 1962. The Costs and Returns of Human Migration. Journal of Political Economy 70S:80–93.

Sjøvold T. 1973. The Occurrence of Minor Non-Metrical Variants in the Skeleton and Their Quantitative Treatment for Population Comparisons. Homo 24:204-233.

Sjøvold T. 1975. Allocation of Single or Some Few Individuals to One of Two or More Groups by Means of Non-Metrical Variants in the Skeleton. Ossa: International Journal of Skeletal Research 2:41–46.

Sjøvold T. 1977. Non-Metrical Divergence Between Skeletal Populations: The Theoretical Foundation and Biological Importance of C.A.B. Smith's Mean Measure of Divergence. Ossa: International Journal of Skeletal Research 4 Suppl. 1:1–133.

Sjøvold T. 1978. Anthropological Relations Within the Scandinavian Peninsula During Mediaeval Times and Following Centuries. Collegium Antropologicum 2:132–147.

Sjøvold T. 1984. A Report on the Heritability of Some Cranial Measurements and Non-Metric Traits. In: Van Vark GN, Howells WW. (Eds.), Multivariate Statistical Methods in Physical Anthropology. D. Reide, Boston, p. 223–246.

Sjøvold T. 1985-86. Book Reviews. Ossa: International Journal of Skeletal Research 12:221–230.

Sjøvold T. 1986. Infrapopulation Distances and Genetics of Non-Metrical Traits. In: Herrmann B. (Ed.), Innovative Trends in Prehistoric Anthropology. Mitteilungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte Band 7. Color-Druck G. Baucke, Berlin, p. 81–93.

Sjøvold T. 1995. Testing Assumptions for Skeletal Studies by Means of Identified Skulls from Hallstatt, Austria. In: Saunders SR, Herring A. (Eds.), Grave Reflections: Portraying the Past Through Cemetery Studies. Canadian Scholar's Press, Toronto, p. 241–281.

Slovak NM, Paytan A, Wiegnd BA. 2009. Reconstructing Middle Horizon Mobility Patterns on the Coast of Peru Through Strontium Isotope Analysis. Journal of Archaeological Science 157–165.

Smith CAB. 1972 Coefficients of Biological Distance. By T.S. Constandse-Westerman. Annals of Human Genetics 36:241-245.

Smith ME. 2014a. Peasant Mobility, Local Migration and Premodern Urbanization. World Archaeology 46:516–533.

Smith ST. 2014b. Desert and River: Consumption and Colonial Entanglements in Roman and Late Antique Nubia. In: Dijkstra JHF, Fisher G. (Eds.), Inside and Out Interactions Between Rome and the Peoples on the Arabian and Egyptian Frontiers in Late Antiquity. Peeters Leuven, pp. 91–109.

Smith TR. 1979. A Note on the Consequences of Risk Aversion and Age for Duration of Stay Effects in a Heterogeneous Population. Geographical Analysis 11:183–188.

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

Snoeck C, Lee-Thorp J, Schulting R, de Jong J, Debouge W, Mattielli N. 2015. Calcine Bone Provides a Reliable Substrate for Strontium Isotope Ratios as Shown by an Enrichment Experiment. Rapid Communications in Mass Spectrometry 29:107–114.

Snow CE. 1948. Indian Knoll Skeletons of Site OHZ. University of Kentucky Reports in Anthropology, Lexington.

Sofaer JA, Smith P, Kaye E. 1986. Affinities Between Contemporary and Skeletal Jewish and Non-Jewish Groups Based on Tooth Morphology. American Journal of Physical Anthropology 70:265–275.

Sofaer JR. 2006. The Body as Material Culture: A Theoretical Osteoarchaeology. Cambridge University Press, Cambridge.

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.

Sokal RR, Sneath PH. 1963. Principles of Numerical Taxonomy. Freeman and Co., San Francisco.

Soloman M, Rafter TA, Dunham KC. 1971. Sulphur and Oxygen Isotope Studies in the Northern Pennines in Relation to Ore Genesis. Applied Earth Science 80:259–276.

Soltysiak A. 2011. Technical Note: An R Script for Smith's Mean Measure of Divergence. Bioarchaeology of the Near East 5:41–44.

Spence MW. 1974a. Residential Patterns and the Distribution of Skeletal Traits in Teotihuacan, Mexico. Man (New Series) 9:262–273.

Spence MW. 1974b. The Study of Residential Practices Among Prehistoric Hunters and Gatherers. World Archaeology 5:346–357.

Spence MW. 1996. Nonmetric Trait Distribution and the Expression of Familial Relationships in a Nineteenth Century Cemetery. Northeast Anthropology 52:53–67.

Spence M, White CD, Rattray ED, Longstaffe FJ. 2004. Un análysis de las proportiones de los isótopos en los entieros del Barrio de los Commerciantes. La Segunda Mesa Redonda de Teotihuacan. Centro de Estudios Teotihuacanos, Instituto Nacional de Anthropologia e Hisotria, Mexico City, pp. 453–492.

Sperduti A. 1995. I Resti Scheletrici Umani Della Necropoli Di Eta Romano-Imperiale Di Isola Sacra (I–III) Sec. D.C.. PhD Thesis, Department of Animal and Human Biology, Universita` 'La Sapienza', Roma.

Sperduti A, Bondioli L, Garnsey P. 2012. Skeletal Evidence for Occupational Structure at the Coastal Towns of Portus and Velia (1^{st}–3^{rd} 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.

Spranger J, Benirschke K, Hall JG, Lenz W, Lowry RB, Opitz JM, Pinsky L, Schwarzacher HG, Smith DW. 1982. Errors of Morphogenesis: Concepts and Terms. Recommendations of an International Working Group. Journal of Pediatrics 100:160–165.

Spranger JW, Brill PW, Poznanski A. 2002. Bone Dysplasias: An Atlas of Genetic Disorders of Skeletal Development, Second Edition.. Oxford University Press, New York.

Sprague R. 2005. Burial Terminology: A Guide for Researchers. AltaMira Press, Walnut Creek.

Stark O. 1984. Migration Decision Making: A Review Article. Journal of Development Economics 14:251–259.

Stark O. 1991. The Migration of Labor. Basil Blackwell, Cambridge.

Stark O, Bloom DE. 1985. The New Economics of Labor Migration. American Economic Review 75:173–178.

Stark O, Levhari D. 1982. On Migration and Risk in LDCs. Economic Development and Cultural Change 31:191–196.

Staudigel H, Doyle P, Zindler A. 1985/86. Sr and Nd Isotope Systematics in Fish Teeth. Earth and Planetary Science Letters 76:45–56.

Stenhouse M, Baxter M. 1979. The Uptake of Bomb ^{14}C in Humans. In: Berger R, Suess H. (Eds.), Radiocarbon Dating. University of California Press, Berkley, pp. 324-341.

Stevenson RE, Hall JG. (eds.). 2006. Human Malformations and Related Anomalies, Second Edition. Oxford University Press, Oxford.

Stini WA. 2010. Sherwood L. Washburn and "The New Physical Anthropology". In: Little MA, Kennedy KAR. (Eds.), Histories of American Physical Anthropology in the Twentieth Century. Lexington Books, Lanham, p. 173–185.

Stojanowski CM, Schillaci MA. 2006. Phenotypic Approaches for Understanding Patterns of Intracemetery Biological Variation. Yearbook of Physical Anthropology 49:49–88.

Stojanowski CM, Knudson KJ. 2011. Biogeochemical Inferences of Mobility of Early Holocene Fisher-Foragers From the Southern Sahara Desert. American Journal of Physical Anthropology 146:49–61.

Stojanowski C, Knudson K. 2014. Changing Patterns of Mobility as a Response to Climatic Deterioration and Aridification in the Middle Holocene Southern Sahara', American Journal of Physical Anthropology 154:79–93.

Strouhal E, Jungwirth J. 1979. Paleogenetics of the Late Roman-Early Byzantine Cemeteries at Sayala, Egyptian Nubia. Journal of Human Evolution 8:699–703.

Stuart-Williams HLQ, Schwarcz HP. 1995. Oxygen Isotopic Analysis of Silver Orthophosphate Using a Reaction with Bromine. Geochimica et Cosmochimica Acta 59:3837-3841.

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.

Suchey JM. 1975. Biological Distance of Prehistoric Central California Populations Derived from Non-Metrical Traits of the Cranium. Unpublished Ph.D. Dissertation, University of California.

Sullivan LR. 1922. The Frequency and Distribution of Some Anatomical Variants in American Crania. Anthropological Papers of the American Museum of Natural History 23:203–258.

Sutter RC, Mertz L. 2004. Nonmetric Cranial Trait Variation and Prehistoric Biocultural Change in the Azapa Valley, Chile. American Journal of Physical Anthropology 123:130–145.

Suzuki M, Sakai T. 1960. A Familial Study of Torus Palatinus and Torus Mandibularis. American Journal of Physical Anthropology 18:263–272.

Sweetman RJ. 2007. Roman Knossos: The Nature of a Globalized City. American Journal of Archaeology 111:61–81.

Sweetman RJ. (ed.). 2011. Roman Colonies in the First Century of their Foundation. Oxbow Books, Oxford.

Swenson, R., Turvey, M.T., 1991. Thermodynamic Reasons for Perception-Action Coupling. Ecological Psychology 3, 317–348.

Symmers W.ST.C. 1894–1895. A Skull with Enormous Parietal Foramina. Journal of Anatomy and Physiology 29:329–330.

Symonds L, Price TD, Keenleyside A, Burton J. 2014. Medieval Migrations: Isotope Analysis of Early Medieval Skeletons on the Isle of Man. Medieval Archaeology 58, 1–20.

Tacoma, L.E., 2014. Migrant Quarters at Rome. In: de Kleijn, G., Benoist, S., (Eds.), Integration in Rome and in the Roman World, Proceedings of the Tenth Workshop of the International Network Impact of Empire, Lille, June 23–25, 2011. Brill, Leiden, pp. 127–144.

Tacoma LE, Tybout RA. 2016. Moving Epigrams: Migration and Mobility in the Greek East. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 345–389.

Tafuri MA, Bentley RA, Manzi G, di Lernia S. 2006. Mobility and Kinship in the Prehistoric Sahara: Strontium Isotope Analysis of Holocene Human Skeletons from the Acacus Mts. (Southwestern Libya). Journal of Anthropological Archaeology 25:390–402.

Taylor JE. 1986. Differential Migration, Networks, Information and Risk. In: Stark O. (Ed.), Research in Human Capital and Development, Vol. 4, Migration, Human Capital, and Development. JAI Press, Greenwich, pp. 147-171.

Taylor NJ, Wu J. 1992. Simultaneous measurements of spray and sea salt. Journal of Geophysical Research 97:7355–7360.

Termine JD, Posner AS. 1966. Infrared Analysis of Rat Bone: Age Dependency of Amorphous and Crystalline Mineral Fractions. Science 153:1523–1525.

Terpstra T. 2013. Trading Communities in the Roman World: A Micro-Economic and Institutional Perspective. Brill, Leiden.

Terrenato N. 2005. The Deceptive Archetype: Roman Colonialism in Italy and Postcolonial Thought. In: Hurst H., Owen S. (Eds.), Ancient Colonizations Analogy, Similarity and Difference. Duckworth, London, pp. 59–72.

Terry DO, Grandstaff DE, Lukens WE, Beasley BA. 2009. The Use of Rare Earth Element Signatures in Vertebrate Fossils as a Tool to Investigate Fossile Poaching; A Cooperative Effort Between Nebraska National Forest and Temple University. In: Foss, Cavin, Brown, Kirkland, Santucci, (Eds.), Proceedings of the Eight Conference on Fossil Resources. Utah Geological Service, Salt Lake City.

Terzer S, Wassenaar LI, Araguás-Araguás LJ, Aggarwal PK. 2013. Global Isoscapes for δ^{18}O and δ^{2}H in Precipitation: Improved Prediction Using Regionalized Climatic Regression Models. Hydrological and Earth Systems Sciences 17:4713–4728.

Testut L. 1889. Traité d’Anatomie Humaine. Doin and Cie, Paris.

Thoma A. 1981. The Pattern of Quasi-Continuous Variation in *Homo sapiens*. Journal of Human Evolution 10:303–310.

Thomsen CJ. 1836. Ledetraad Til Nordisk Oldkyndighed. Kjöbenhavn. S.L. Møllers bogtr.

Thorne J. 2013. Gaul (Tres Galliae). In: Bagnall RS, Brodersen K, Champion CB, Erskine A, Huebner SR. (Eds.), The Encyclopedia of Ancient History. Blackwell, Oxford, pp. 2857–2861.

Thylander EA. 1951–52. Inscriptions de Port d’Ostie (Acta Instituti Romani Regni Sueciae 8, IV:1). C.W.K. Gleerup, Lund.

Tilly, C., 1978. Migration in Modern European History. In: McNeill, W.H., Adams, R.S., (Eds.), Human Migration: Patterns and Policies. Indiana University Press, Bloomington, pp. 48–72.

Tocheri MW. 2003. The Effects of Aging on the Development and Expression of Nine Cranial Hyperostotic Nonmetric Traits. Unpublished MA Thesis, Arizona State University.

Todaro MP. 1969. A Model of Labor Migration and Urban Unemployment in Less- Developed Countries. The American Economic Review 59:138–48.

Todaro MP. 1976. Internal Migration in Developing Countries. International Labor Office, Geneva.

Todaro MP.1989. Economic Development in the Third World. Longman, New York.

Todaro MP, Maruszko L. 1987. Illegal Migration and US Immigration Reform: A Conceptual Framework. Population and Development Review 13:101–114.

Todd TW. 1920. Age Changes in the Pubis Bone. I. The White Male Pubis. American Journal of Physical Anthropology 3:467–470.

Topalov K, Schimmelmann A, Polly PD, Sauer PE. 2012. Stable Isotope Application in Bone Collagen and Emphasis on Deuterium/Hydrogen Ratios. In: Verbeek CJR. (Ed.), Products and Applications of Biopolymers. InTech, Rijeka, pp. 141–162.

Torgersen J. 1951a. The Developmental Genetics and Evolutionary Meaning of the Metopic Suture. American Journal of Physical Anthropology 9:193–205.

Torgersen J. 1951b. Hereditary Factors in Sutural Patterns of the Skull. Acta Radiologica 36:374–382.

Treggiari S. 1979. Lower Class Women in the Roman Economy. Florilegium 1:65–86.

Trigger BG. 1997. A History of Archaeological Thought. Cambridge University Press, Cambridge.

Triou A. 1968. Les Aqueducs Gallo-Romains de Saintes (Charente-Maritime). Gallia 26:119–144.

Trinkaus E. 1978. Bilateral Asymmetry of Human Skeletal Non-Metric Traits. American Journal of Physical Anthropology 49:315–318.

Tritsaroli P. 2011. Artificial Cranial Modification on a Female Skeleton from the Byzantine Site of Maroneia (Thrace, Greece). International Journal of Osteoarchaeology 21:464–478.

Trueman CNG, Behrensmeyer AK, Tuross N, Weiner S. 2004. Mineralogical and Compositional Changes in Bones Exposed on Soil Surfaces in Amboseli National Park, Kenya: Diagenetic Mechanisms and the Role of Sediment Pore Fuids. Journal of Archaeological Science 31:721–739.

Truslove GM. 1961. Genetical Studies on the Skeleton of the Mouse. XXX. A Search for Correlations Between Some Minor Variants. Genetical Research 2:431–438.

Turck R, Kober B, Kontny J, Haack F, Zeeb-Lanz A. 2012. “Widely Travelled People” at Herxheim? Sr Isotopes as Indicators of Mobility. 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.149–163.

Turekian KK, Kulp JL. 1956. Strontium Content of Human Bone. Science 124:405–407.

Turkel SJ. 1989. Congenital Abnormalities in Skeletal Populations. In: Iscan MY, Kennedy KAR. (Eds.), Reconstruction of Life from the Skeleton. Alan R. Liss, New York, p. 109–127.

Turner BL, Kamenov GD, Kingston JD, Armelagos GJ. 2009. Insights Into Immigration and Social Class at Machu Picchu, Peru Based on Oxygen, Strontium and Lead Isotopic Analysis. Journal of Archaeological Science 36:317–332.

Turner CG II. 1975. A Method of Calculating Non-Metric Trait Frequencies Using Adjustable Loading Coefficients with Standard Ranked Scales. American Journal of Physical Anthropology 42:335.

Turner CG II. 1985. Expression Count: A Method for Calculating Morphological Dental Trait Frequencies by Using Adjustable Weighting Coefficients with Standard Ranked Scales. American Journal of Physical Anthropology 68:263–267.

Turner CG II, Nichol CR, Scott GR. 1991. Scoring Procedures for Key Morphological Traits of the Permanent Dentition: The Arizona State University Dental Anthropology System. In: Kelley MA, Larsen CS. (Eds.), Advances in Dental Anthropology. Wiley-Liss, New York, pp. 13–32.

Turner CG II, Elder J. 2006. Dentition of the Batak People of Palawa Island, the Philippines: South Asian Negrito Origins. In: Oxenham M, Tayles N. (Eds.), Bioarchaeology of Southeast Asia. Cambridge University Press, Cambridge, pp. 172–188.

Tuross N, Behrensmeyer AK, Eanes ED. 1989. Strontium Increases and Crystallinity Changes in Taphonomic and Archaeological Bone. Journal of Archaeological Science 16:661–672.

Tybout RA. 2016. Dead Men Walking: The Repatriation of Mortal Remains. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 390–437.

Tyrrell A. 2000. Skeletal Nonmetric Traits and the Assessment of Inter- and Intra- Population Diversity: Past Problems and Future Potential. In: Cox M, Mays S. (Eds.), Human Osteology in Archaeology and Forensic Science. Cambridge University Press, Cambridge, pp. 289–306.

Ubelaker DH. 1999. Human Skeletal Remains: Excavation, Analysis, Interpretation, Third Edition. Manuals on Archeology 2. Taraxacum, Washington.

Ullinger JM, Sheridan SG, Hawkey DE, Turner CG II. 2005. Bioarchaeological Analysis of Cultural Transition in the Southern Levant Using Dental Nonmetric Traits. American Journal of Physical Anthropology 128:466–476.

Ullrich H. 1969. Interpretation morphologisch-metrischer Ähnlichkeiten an ur- und frühgeschichtlichen Skeletten in verwandtschaftlicher Hinsicht. Zeitschrift für Archäologie 3:48–88.

Ullrich H. 1972. Anthropologische Untersuchungen zur Frage nach Entstehung und Verwandtschaft der thüringischen, bömischen und mährischen Annjetitzer. Das Gräberfeld von Großbrembach, Teil 1. Böhlau, Weimar.

Urey HC. 1947. The Thermodynamic Properties of Isotopic Substances. Journal of the Chemical Society. January: 562–581.

Uzzell DJ. 1979. Conceptual Fallacies in the Rural-Urban Dichotomy. Urban Anthropology 8:333‒350.

Vach W, Alt KW. 1993. Detection of Kinship Structures in Prehistoric Burial Sites Based on Odontological Traits. In: Andersen J, Madsen T, Scollar I. (eds.), Computing the Past– Computer Applications and Quantitative Methods in Archaeology. Aarhus University Press, Aarhus, p. 287–292.

Vajda L. 1973/74. Zur Frage der Völkerwanderungen. Paideuma 19/20:5‒53.

Valenzuela LO, Chesson LA, O'Grady SP, Cerling TE, Ehleringer JE. 2011. Spatial Distributions of Carbon, Nitrogen and Sulfur Isotope Ratios in Human Hair Across the Central United States. Rapid Communications in Mass Spectrometry 25:861‒868.

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.

Van Arsdale AP, Clark JL. 2010. Re-Examining the Relationship Between Cranial Deformation and Extra-Sutural Bone Formation. International Journal of Osteoarchaeology 22:119‒126.

Van Dommelen P, Terrenato N. 2007. Introduction: Local Cultures and the Expanding Roman Republic. In: van Dommelen P, Terrenato N. (Eds.), Articulating Local Cultures: Power and Identity Under the Expanding Roman Republic. Journal of Roman Archaeology Supplementary Series 63. Journal of Roman Archaeology, Portsmouth, pp. 7–12.

Van Hear N. 2010. Migration. In: Knott K., McLoughlin S. (Eds.), Diasporas: Concepts, Intersections, Identities. Zed Books, London, pp. 34–38.

Van Hulst H. 2000. A Continuing Construction of Crisis. Antilleans, Especially Curacaoans, in the Netherlands. In: Vermeulen H., Penninx R. (Eds.), Immigrant

Integration: The Dutch Case. Het Spinhuis, Amsterdam, pp. 93−122.

Vautour G., Poirier A., Widory D. 2015. Tracking Mobility Using Human Hair: What Can We Learn From Lead and Strontium Isotopes? Science and Justice 55:63−71.

Vecchi F. 1968. Sesso e variazioni di caratteri discontinui del cranio. Rivista di Antropologia 55:283–290.

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

Veleminsky P, Dobisikova M. 2005. Morphological Likeness of the Skeletal Remains in a Central European Family from 17th to 19th Century. Homo 56:173–196.

Veloccia Rinaldi ML, Testini P. 1975. Richerche Archeologiche nell'Isola Sacra. Istituto Nazionale d'Archeologia e Storia dell'Arte, Rome.

Vennemann TW, Fricke HC, Blake RE, O'Neil JR, Colman A. 2002. Oxygen Isotope Analysis of Phosphates: A Comparison of Techniques for Analysis of Ag3 PO4. Chemical Geology 185:321−336.

Vertovec S. 1997. Three Meanings of "Diaspora," Exemplified Among South Asian Religions. Diaspora 6:277−299.

Vertovec S. 1999. Conceiving and Researching Transnationalism. Ethnic and Racial Studies 22:447–462.

Vertovec S. 2001. Transnationalism and Identity. Journal of Ethnic and Migration Studies 27:573–582.

Villotte S. 2006. Connaissances Médicales Actuelles, Cotation des Enthésopathies: Nouvelle Méthode. Bulletins et Mémoires de la Société d'Anthropologie de Paris 18:1-2.

Vittinghof F. 1952. Römische Kolonisation und Bürgerrechtspolitik unter Caesar und Augustus. Verlag der Akademie der Wissenschaften und der Literatur, Mainz.

Voerkelius S, Lorenz GD, Rummel S, Quétel C, Heiss G, Baxter M, Brach-Papa C, Deters-Itzelsberger P, Hoelzl S, Hoogewerff J, Ponzevera E, Van Bocxstaele M, Ueckermann H. 2010. Strontium Isotopic Signatures of Natural Mineral Waters, the Reference to a Simple Geological Map and its Potential for Authentication of Food. Food Chemistry 118:933–940.

Vollmer R. 1976. Rb-Sr and U-Th-Pb Systematics of Alkaline Rocks: The Alkaline Rocks from Italy. Geochimica et Cosmochimica Acta 40(3):283–295.

Waddington CH. 1942. Canalization of Development and the Inheritance of Acquired Characters. Nature 150:563–565.

Waddington CH. 1956. The Principles of Embryology. Allen and Unwin, London.

Wadleigh MA, Schwarcz HP, Kramer JR. 1994. Sulphur Isotope Tests of Seasalt Correction Factors in Precipitation: Nova Scotia, Canada. Water, Air, and Soil Pollution 77:1–16.

Wadleigh MA, Schwarcz HP, Kramer JR. 1996. Isotopic Evidence for the Origin of Sulphate in Coastal Rain. Tellus 48B:44–59.

Waldron HA. 1981. Postmortem Absorption of Lead by the Skeleton. American Journal of Physical Anthropology 55:395–398.

Waldron HA. 1983. On the Post-Mortem Accumulation of Lead by Skeletal Tissues. Journal of Archaeological Science 10:35–40.

Walley CD. 1998. The Geology of Lebanon: A Summary. Digital Documentation Center, American University of Beirut, http://ddc.aub.edu.lb/projects/geology/geology-of-lebanon/

Warkany J. 1971. Congenital Malformations: Notes and Comments. Year Book Medical Publishers, Inc., Chicago.

Warriner C, Tuross N. 2009. Alkaline Cooking and Stable Isotope Tissue-Diet Spacing in Swine: Archaeological Implications. Journal of Archaeological Science 36:1690–1697.

Washburn SL. 1951. The New Physical Anthropology. Transactions of the New York Academy of Science 13(Series II):298–304.

Washburn SL. 1953. The Strategy of Physical Anthropology. In: Kroeber A. (Ed.), Anthropology Today. University of Chicago Press, Chicago, p. 714–727.

Weaver DS, Perry GH, Macchiarelli R, Bondioli L. 2000. A Surgical Amputation in 2nd Century Rome. Lancet 356:686.

Webb EC, White CD, Longstaffe FJ. 2014. Investigating Inherent Differences in Isotopic Composition Between Human Bone and Enamel Bioapatite: Implications for Reconstructing Residential Histories. Journal of Archaeological Science 50:97–107.

Webster J. 2001. Creolizing the Roman Provinces. American Journal of Archaeology 105:209–225.

Webster J. 2005. Archaeologies of Slavery and Servitude: Bringing 'New World' Perspectives to Roman Britain. Journal of Roman Archaeology 18:161−179.

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.

Weiner S, Bar-Yosef O. 1990. States of Preservation of Bones from Prehistoric Sites in the Near East: A Survey. Journal of Archaeological Science 17:187−196.

Wells P.S. 2013. Introduction, Rome Beyond its Frontiers: Imports, Attitudes, and Practices. In: Wells P.S., (Ed.), Rome Beyond its Frontiers: Imports, Attitudes, and Practices. Journal of Roman Archaeology Supplement 94. Journal of Roman Archaeology, Portsmouth, pp. 7−14.

Westley K, Dix J. 2006. Coastal Environments and Their Role in Prehistoric Migrations. Journal of Maritime Archaeology 1:9−28.

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.

White CD. 1996. Sutural Effects of Fronto-Occipital Cranial Modification. American Journal of Physical Anthropology 100:397–410.

White TD, Spence MW, Stuart-Williams HLQ, Schwarcz HP. 1998. Oxygen Isotopes and the Identification of Geographical Origins: The Valley of Oaxaca Versus the Valley of Mexico. Journal of Archaeological Science 25:643–655.

White CD, Spence MW, Longstaffe FJ, Law KR. 2000. Testing the Nature of Teotihuacan Imperialism at Kaminaljuyu Using Phosphate Oxygen Isotope Ratios. Journal of Anthropological Research 56:535–558.

White CD, Longstaffe FJ, Spence MW, Stuart-Williams H, Law KR. 2002. Geographic Identities of the Sacrificial Victims from the Feathered Serpent Pyramid, Teotihuacan: Implications for the Nature of State Power. Latin American Antiquity 13:217–236.

White CD, Spence MW, Longstaffe FJ, Law KR. 2004a. Demography and Ethnic Continuity in the Tlailotlacan Enclave of Teotihuacan: The Evidence From Stable Oxygen Isotopes. Journal of Anthropological Archaeology 23:385–403.

White CD, Storey R, Longstaffe FJ, Spence MW. 2004b. Immigration, Assimilation, and Status in the Ancient City of Teotihuacan: Stable Isotopic Evidence From Tlajinga 33. Latin American Antiquity 15:176–198.

White C, Longstaffe FJ, Law KR. 2004c. Exploring the Effects of Environment, Physiology and Diet on Oxygen Isotope Ratios in Ancient Nubian Bones and Teeth. Journal of Archaeological Science 31:233‒250.

White CD, Price TD, Longstaffe FJ. 2007. Residential Histories of the Human Sacrifices at the Moon Pyramid, Teotihuacan: Evidence From Oxygen and Strontium Isotopes. Ancient Mesoamerica 18:159–172.

White C, Spence M, Longstaffe FJ, Rattray E, Storey R. 2008–2009. The Teotihuacan Dream: an Isotopic Study of Economic Organization and Immigration. Occasional Publication of the London Chapter, OAS 9. Ontario Archaeology 85–88: 279–297.

Whiteford L. 1979. The Borderland as an Extended Community. In: Camara F, Kemper RV. (eds.), Migration Across Frontiers: Mexico and the United States. SUNY Institute for Mesoamerican Studies, Albany, pp. 127‒137.

Whittaker D. 1989. Les frontières de l’Empire romain. Université de Besançon, Besançon.

Wierschowski, L., 1995. Die regionale Mobilität in Gallien nach den Inschriften des 1. bis 3. Jahrhunderts n. Chr. Quantitative Studien zur Sozial- und Wirtschaftsgeschichte der westlichen Provinzen des Römischen Reiches, Steiner, Stuttgart.

Wierschowski L. 2001. Fremde in Gallien-“Gallier” in der Fremde: dei Epigraphisch Bezeugte Mobilität in, von und nach Gallien vom 1. Bis 3. Jh. n. Chr.: (Texte-Übersetzungen-Kommentare). F. Steiner, Stuttgart.

Williams JHC. 2001. Roman Intentions and Romanization: Republican Northern Italy, c. 200‒100 BC. In: Keay S., Terrenato N. (Eds.), Italy and the West Comparative Issues in Romanization. Oxbow Books, Oxford, pp. 91‒101.

Williams LJ, White CD, Longstaffe FJ. 2011. Improving Stable Isotopic Interpretations Made From Human Hair Through Reduction of Growth Cycle Error. American Journal of Physical Anthropology 145:125‒136.

Williams-Blangero S, Blangero J. 1989. Anthropometric Variation and the Genetic Structure of the Jirels of Nepal. Human Biology 61:1‒12.

Willmes M, Mcmorrow L, Kinsley L, Armstrong R, Aubert M, Eggins S, Falguères C, Maureille B, Moffat I, Grün R. 2014. The IRHUM (Isotopic Reconstruction of Human Migration) Database – Bioavailable Strontium Isotope Ratios for Geochemical Fingerprinting in France. Earth Systems Science Data 6:117–122.

Willmore KE, Hallgrimsson B. 2005. Within Individual Variation: Developmental Noise Versus Developmental Stability. In: Hallgrimsson B, Hall BK. (Ed.), Variation: A Central Concept in Biology. Elsevier Press, New York, p. 191–218.

Wilson AS, Taylor T, Ceruti MC, Chavez JA, Reinhard J, Grimes V, Meier-Augenstein W, Cartmell L, Stern B, Richards MP, Worobey M, Barnes I, Gilbert TP. 2007. Stable Isotope and DNA Evidence for Ritual Sequences in Inca Child Sacrifice. Proceedings of the National Academy of Sciences 104:16456–16461.

Wilson TD. 1994. What Determines Where Transnational Labor Migrants Go? Modifications in Migration Theories. Human Organization 53:269–278.

Wimmer A. 2008. The Making and Unmaking of Ethnic Boundaries: A Multi-level Process Theory. American Journal of Sociology 113:970–1022.

Winder SC. 1981. Infracranial Nonmetric Variation: An Assessment of its Value for Biological Distance Analysis. Unpublished Ph.D. Dissertation, Indiana University.

Woo TL. 1930. A Study of Seventy-One Ninth Dynasty Egyptian Skulls from Sedment. Biometrika 22:65–93.

Woo JK. 1950. Torus Palatinus. American Journal of Physical Anthropology 8:81–111.

Wood C. 2003. An investigation of the prevalence of rickets among subadults from the Roman necropolis of Isola Sacra, Italy. MA Dissertation, McMaster University.

Wood LS. 1997. Morphological Variation in the Vertebral Column of Indigenous Peoples of the Arctic and American Northwest. Unpublished Ph.D. Dissertation, Queen’s University, Ontario.

Wood-Jones F. 1931a. The Non-Metrical Morphological Characters of the Skull as Criteria for Racial Diagnosis. I. General Discussion of the Morphological Characters Employed in Racial Diagnosis. Journal of Anatomy 65:179–195.

Wood-Jones F. 1931b. The Non-Metrical Morphological Characters of the Skull as Criteria for Racial Diagnosis. II. The Non-Metrical Morphological Characters of the Hawaiian Skull. Journal of Anatomy 65:368–378.

Wood-Jones F. 1931c. The Non-Metrical Morphological Characters of the Skull as Criteria for Racial Diagnosis. Part III. The Non-Metrical Morphological Characters of the Skulls of Prehistoric Inhabitants of Guam. Journal of Anatomy 65:438–445.

Wood-Jones F. 1934. The Non-Metrical Morphological Characters of the Skull as Criteria for Racial Diagnosis. IV. The Non-Metrical Morphological Characters of the Northern Chinese Skull. Journal of Anatomy 68:96–108.

Woolf G. 1997. Beyond Romans and Natives. World archaeology 28:339-350.

Woolf, G., 1998. Becoming Roman: The Origins of Provincial Civilization in Gaul. Cambridge University Press, Cambridge.

Woolf G. 2000. Urbanization and its Discontents in Early Roman Gaul. In: Fentress E. (Ed.), Romanization and the City Creation, Transformation, and Failures. Journal of Roman Archaeology Supplementary Series 38. Journal of Roman Archaeology, Portsmouth, pp. 115−131.

Woolf G. 2001. The Roman Cultural Revolution in Gaul. In: Keay S., Terrenato N. (Eds.), Italy and the West Comparative Issues in Romanization. Oxbow Books, Oxford, pp. 173−186.

Woolf G. 2011. Afterword: Catastrophe and Aftermath. In: Sweetman RJ. (Ed.), Roman Colonies in the First Century of their Foundation. Oxbow Books, Oxford, pp. 150−159.

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 EK, Hoering TC. 1989. Separation and Purification of Phosphates for Oxygen Isotope Analysis. Carnegie Institution of Washington Yearbook 88:137-141.

Wright S. 1968. Evolution and the Genetics of Populations, Vol. 1, Genetic and Biometric Foundations. University of Chicago Press, Chicago.

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.

Wright LE, Valdés JA, Burton JH, Price TD, Schwarcz HP. 2010. The Children of Kaminaljuya: Isotopic Insight Into Diet and Long Distance Interaction in Mesoamerica. Journal of Anthropological Archaeology 29:155–178.

Wrigley EA, Schofield RS. 1981. The Population History of England 1541–1671: A Reconstruction. Cambridge University Press, Cambridge.

Yamaguchi B. 1967. A Comparative Osteological Study of the Ainu and the Australian Aborigines. Australian Institute of Aboriginal Studies Occasional Papers 10, Human Biology Series 2. Australian Institute of Aboriginal Studies, Canberra.

Yamanaka K. 2000. I Will Go Home, But When?": Labor Migration and Circular Diaspora Formation by Japanese Brazilians in Japan. In: Douglass M., Roberts GS. (Eds.), Japan and Global Migration: Foreign Workers and the Advent of a Multicultural Society. Routledge, New York, pp. 123–152.

Yang D. 1997. DNA Diagnosis of Thalassemia from Ancient Italian Skeletons. Ph.D. Dissertation, McMaster Univeriesty.

Zazzo A, Lecuyer C, Mariotti A. 2004. Experimentally-Controlled Carbon and Oxygen Isotope Exchange Between Bioapatites and Water Under Inorganic and Microbially-Mediated Conditions. Geochimica et Cosmochimica Acta 68:1–12.

Zazzo A, Monahan FJ, Moloney AP, Green S, Schmidt O. 2011. Sulphur Isotopes in Animal Hair Track Distance to Sea. Rapid Communications in Mass Spectrometry 25:2371–2378.

Zhao FJ, Spiro B, Poulton PR, McGrath SP. 1998. Use of Sulfur Ratios to Determine Anthropogenic Sulfur Signals in a Grassland Ecosystem. Environmental Science and Technology 32:2288–2291.

Zegura SL. 1975. Taxonomic Congruence in Eskimoid Populations. American Journal of Physical Anthropology 43:271–284.

Zerbini A. 2016. Human Mobility in the Roman Near East: Patterns and Motives. In: De Ligt L., Tacoma LE. (Eds.), Migration and Mobility in the Early Roman Empire. Brill, Leiden, pp. 305–344.

Zvelebil, M., Lillie, M.C., Montgomery, J., Lukes, A., Pettitt, P., Richards, M.P. 2012. The Emergence of the LBK: Migration, Memory and Meaning at the Transition to Agriculture. 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. 133–148

Appendix A–Calculated δ^{18}O Values

Site	VPDB (‰)	VSMOW* (‰)	Phosphate† (‰)	$\delta^{18}O_{dw}$ § (Daux) (‰)	$\delta^{18}O_{dw}$ §§ (Chenery) (‰)	Difference Daux vs. Chenery (‰)
JBR						
JBR 8	-4.1	26.7	17.7	-6.5	-6.2	-0.3
JBR 16	-5.1	25.7	16.7	-8.1	-7.8	-0.3
JBR 18	-3.7	27.1	18.0	-5.9	-5.6	-0.4
JBR 21	-4.0	26.7	17.7	-6.5	-6.1	-0.3
JBR 23	-4.2	26.6	17.5	-6.7	-6.4	-0.3
JBR 28b	-3.4	27.4	18.4	-5.4	-5.0	-0.4
JBR 29	-3.5	27.3	18.3	-5.6	-5.2	-0.4
JBR 34	-6.0	24.8	15.8	-9.4	-9.3	-0.2
JBR 35	-4.0	26.8	17.8	-6.4	-6.0	-0.3
JBR 40	-5.9	24.9	15.9	-9.3	-9.1	-0.2
JBR 46	-6.2	24.6	15.6	-9.7	-9.6	-0.2
JBR 54	-6.9	23.8	14.8	-10.9	-10.8	-0.1
JBR 55	-3.5	27.3	18.3	-5.6	-5.2	-0.4
JBR 56	-3.0	27.8	18.7	-4.9	-4.4	-0.4
JBR 59A	-5.2	25.6	16.6	-8.2	-8.0	-0.2
JBR 59B	-4.5	26.3	17.2	-7.2	-6.9	-0.3
JBR 62	-5.3	25.5	16.5	-8.3	-8.1	-0.2
JBR 63	-5.7	25.0	16.0	-9.1	-8.9	-0.2
JBR 64	-6.9	23.8	14.8	-10.9	-10.8	-0.1
JBR 66	-4.6	26.2	17.1	-7.3	-7.0	-0.3
JBR 67	-3.9	26.9	17.9	-6.2	-5.9	-0.3
JBR 76	-6.0	24.7	15.7	-9.5	-9.3	-0.2
JBR 82	-5.2	25.6	16.6	-8.2	-8.0	-0.2
JBR 84	-3.8	27.0	18.0	-6.1	-5.7	-0.4
JBR 85	-4.4	26.4	17.3	-7.0	-6.7	-0.3
JBR 86	-3.2	27.6	18.6	-5.1	-4.7	-0.4
JBR 90	-5.1	25.6	16.6	-8.2	-7.9	-0.2
JBR 98	-6.2	24.5	15.6	-9.8	-9.6	-0.2
JBR 101	-2.6	28.2	19.2	-4.2	-3.7	-0.5
JBR 103	-4.2	26.6	17.6	-6.7	-6.3	-0.3
JBR 105	-5.7	25.0	16.0	-9.0	-8.9	-0.2
JBR 106	-5.2	25.5	16.5	-8.3	-8.0	-0.2
JBR 110	-3.0	27.8	18.7	-4.9	-4.5	-0.4
JBR 111	-5.0	25.8	16.8	-7.9	-7.7	-0.3
JBR 112	-3.3	27.5	18.5	-5.3	-4.9	-0.4
JBR 115	-4.8	26.0	17.0	-7.6	-7.3	-0.3
JBR 116	-5.8	24.9	15.9	-9.2	-9.0	-0.2
JBR 122	-5.3	25.4	16.4	-8.4	-8.2	-0.2
JBR 128	-5.1	25.7	16.6	-8.1	-7.8	-0.2

SCR						
SCR 36	-7.7	23.0	14.0	-12.1	-12.1	0.0
SCR 68	-8.0	22.7	13.8	-12.5	-12.5	0.0
SCR 75	-4.0	26.8	17.7	-6.4	-6.1	-0.3
SCR 88	-3.0	27.9	18.8	-4.8	-4.3	-0.4
SCR 98	-4.8	26.0	16.9	-7.6	-7.4	-0.3
SCR 99	-6.1	24.6	15.6	-9.7	-9.5	-0.2
SCR 106	-4.1	26.7	17.7	-6.5	-6.2	-0.3
SCR 127	-3.5	27.3	18.3	-5.6	-5.2	-0.4
SCR 133	-6.4	24.3	15.3	-10.1	-9.9	-0.1
SCR 144	-5.7	25.0	16.0	-9.1	-8.9	-0.2
SCR 160	-6.2	24.5	15.5	-9.8	-9.7	-0.2
SCR 169	-4.9	25.9	16.8	-7.8	-7.5	-0.3
SCR 171	-7.2	23.5	14.5	-11.3	-11.2	-0.1
SCR 174	-7.6	23.1	14.1	-12.0	-11.9	0.0
SCR 181	-3.9	26.9	17.9	-6.2	-5.9	-0.3
SCR 190	-6.8	23.9	14.9	-10.8	-10.7	-0.1
SCR 191	-5.2	25.5	16.5	-8.3	-8.0	-0.2
SCR 193	-4.0	26.7	17.7	-6.4	-6.1	-0.3
SCR 194	-3.4	27.4	18.3	-5.5	-5.1	-0.4
SCR 196	-7.1	23.6	14.6	-11.2	-11.1	-0.1
SCR 199	-3.3	27.5	18.5	-5.3	-4.9	-0.4
SCR 201	-3.9	26.9	17.8	-6.3	-5.9	-0.3
SCR 217	-3.5	27.3	18.3	-5.6	-5.2	-0.4
SCR 220	-3.3	27.5	18.4	-5.3	-4.9	-0.4
SCR 239	-4.9	25.8	16.8	-7.8	-7.6	-0.3
SCR 245	-5.2	25.6	16.5	-8.2	-8.0	-0.2
SCR 250	-3.6	27.2	18.2	-5.7	-5.3	-0.4
SCR 251	-6.1	24.7	15.7	-9.6	-9.4	-0.2
SCR 252	-4.0	26.7	17.7	-6.5	-6.1	-0.3
SCR 269	-3.2	27.6	18.5	-5.2	-4.8	-0.4
SCR 272	-5.5	25.3	16.3	-8.7	-8.5	-0.2
SCR 282	-6.5	24.2	15.2	-10.3	-10.2	-0.1
SCR 285	-3.0	27.8	18.8	-4.8	-4.4	-0.4
SCR 287	-6.5	24.2	15.2	-10.3	-10.2	-0.1
SCR 298	-4.4	26.4	17.3	-7.0	-6.7	-0.3
SCR 301	-3.5	27.3	18.3	-5.6	-5.2	-0.4
SCR 303	-3.9	26.9	17.8	-6.2	-5.9	-0.3
SCR 312	-4.2	26.6	17.6	-6.7	-6.3	-0.3
SCR 314	-3.3	27.5	18.5	-5.3	-4.9	-0.4
SCR 320	-8.5	22.2	13.2	-13.3	-13.4	0.0
SCR 321	-4.5	26.2	17.2	-7.2	-6.9	-0.3
SCR 324	-5.0	25.7	16.7	-8.0	-7.7	-0.3
SCR 326	-3.2	27.6	18.6	-5.1	-4.7	-0.4
SCR 329	-3.5	27.3	18.2	-5.6	-5.3	-0.4
SCR 330	-6.2	24.5	15.5	-9.9	-9.7	-0.2
SCR 334	-5.0	25.8	16.7	-7.9	-7.7	-0.3
SCR 343	-4.9	25.9	16.9	-7.7	-7.4	-0.3
SCR 344	-6.2	24.5	15.5	-9.9	-9.7	-0.2
SCR 352	-7.2	23.5	14.5	-11.4	-11.3	-0.1

SCR 361	-3.0	27.8	18.8	-4.8	-4.4	-0.4
SCR 362	-3.1	27.7	18.7	-5.0	-4.6	-0.4
SCR 376	-7.5	23.1	14.2	-11.9	-11.9	0.0
SCR 404	-6.8	23.9	14.9	-10.7	-10.6	-0.1
SCR 411	-5.9	24.8	15.8	-9.4	-9.2	-0.2
SCR 430	-5.9	24.9	15.9	-9.3	-9.1	-0.2
SCR 431	-6.0	24.7	15.7	-9.6	-9.4	-0.2
SCR 433	-3.5	27.3	18.2	-5.6	-5.2	-0.4
SCR 435	-4.1	26.7	17.7	-6.5	-6.2	-0.3
SCR 442	-3.6	27.2	18.2	-5.7	-5.4	-0.4
SCR 443	-4.2	26.6	17.6	-6.7	-6.3	-0.3
SCR 445	-3.3	27.5	18.4	-5.4	-5.0	-0.4
SCR 448	-5.5	25.2	16.2	-8.8	-8.6	-0.2
SCR 452	-3.3	27.5	18.5	-5.3	-4.9	-0.4
SCR 462	-3.5	27.3	18.3	-5.6	-5.2	-0.4
SCR 463	-6.3	24.4	15.4	-10.0	-9.9	-0.1
SCR 464	-4.8	26.0	16.9	-7.6	-7.3	-0.3
SCR 467	-3.4	27.4	18.4	-5.4	-5.1	-0.4
SCR 470	-3.5	27.3	18.3	-5.6	-5.2	-0.4
SCR 479	-5.1	25.6	16.6	-8.1	-7.9	-0.2
SCR 484	-6.1	24.7	15.7	-9.6	-9.4	-0.2
SCR 485	-4.7	26.0	17.0	-7.5	-7.2	-0.3
SCR 500	-6.3	24.4	15.4	-10.0	-9.9	-0.1
SCR 525	-4.9	25.8	16.8	-7.8	-7.5	-0.3
SCR 526	-5.3	25.4	16.4	-8.4	-8.2	-0.2
SCR 562	-4.3	26.5	17.4	-6.9	-6.6	-0.3
SCR 602	-3.4	27.4	18.3	-5.5	-5.1	-0.4
SCR 678	-6.6	24.1	15.1	-10.5	-10.4	-0.1
SCR 698	-3.3	27.5	18.5	-5.3	-4.9	-0.4
SCR 730	-5.8	24.9	15.9	-9.2	-9.0	-0.2
SCR 797	-6.3	24.4	15.4	-10.0	-9.9	-0.1
Velia						
Velia 57	-1.1	29.8	20.7	-1.8	-1.3	-0.6
Velia 82	-4.1	26.7	17.7	-6.5	-6.2	-0.3
Velia 117	-5.6	25.1	16.1	-8.9	-8.7	-0.2
Velia 134	-5.8	24.9	15.9	-9.2	-9.0	-0.2
Velia 139	-4.6	26.2	17.1	-7.3	-7.0	-0.3
Velia 146	-4.3	26.5	17.5	-6.8	-6.5	-0.3
Velia 160	-4.9	25.9	16.8	-7.8	-7.5	-0.3
Velia 169	-5.5	25.3	16.3	-8.7	-8.4	-0.2
Velia 174	-4.7	26.1	17.1	-7.4	-7.1	-0.3
Velia 181	-4.7	26.1	17.1	-7.4	-7.1	-0.3
Velia 182	-4.2	26.6	17.6	-6.6	-6.3	-0.3
Velia 186	-3.6	27.2	18.1	-5.8	-5.4	-0.4
Velia 194	-5.8	24.9	15.9	-9.2	-9.1	-0.2
Velia 205	-2.4	28.4	19.3	-4.0	-3.5	-0.5
Velia 211	-6.0	24.7	15.7	-9.5	-9.4	-0.2
Velia 214	-5.5	25.3	16.3	-8.7	-8.5	-0.2
Velia 222	-3.5	27.3	18.2	-5.6	-5.3	-0.4

Velia 223	-5.4	25.3	16.3	-8.6	-8.4	-0.2
Velia 270	-3.9	26.9	17.8	-6.3	-5.9	-0.3
Velia 283	-4.2	26.6	17.5	-6.7	-6.4	-0.3

[*] VSMOW (‰) values following Faure and Mensing (2005) $\delta^{18}O_{c(VSMOW)} = 1.0309 \times \delta^{18}O_{c(VPDB)} + 30.91$.

[†] Phosphate values (‰) following Iacumin et al. (1996) $\delta^{18}O_p = 0.98 \times \delta^{18}O_c - 8.5$.

[§] Drinking water (dw) values (‰) following Daux et al. (2008) $\delta^{18}O_{dw} = 1.54 \times \delta^{18}O_p - 33.72$.

[§§] Drinking water (dw) values (‰) following Chenery et al. (2012) $\delta^{18}O_{dw} = 1.590 \times \delta^{18}O_c - 48.634$.

Appendix B–Nonmetric Traits Employed

Cranial Traits

- Metopic suture (MS)
- Supraorbital notch (SN)
- Supraorbital Foramen (SF)
- Infraorbital Suture (IS)
- Multiple Infraorbital Foramen (MIF)
- Zygomatic Foramen (ZF)
- Parietal Foramen (PF)
- Sutural Bones
    - Epiteric (ESB)
    - Coronal (CSB)
    - Bregma (BSB)
    - Saggital (SSB)
    - Apical (ASB)
    - Lambda (LSB)
    - Asterion (AsSB)
    - Occipital Mastoid (OM)
    - Parietal Notch (PN)
- Inca Bone (IB)
- Condylar Canal (CC)
- Divided Hypoglossal Canal (DH)
- Foramen Ovale (FO)
- Foramen Spinosum (FS)
- Pterygospinous Bridge (PSB)
- Pterygoid Alar bridge (PAB)
- Tympanic Dihiscence (TD)
- Mastoid Foramen (MASF)
- Mental Forman (MENF)
- Mandibular Torus (MT)
- Mylohyoid Bridge (MB)

Infracranial Traits

- Atlas Foramen Divided (AFD)
- Atlas Posterior Bridge (APB)
- Atlas Lateral Bridge (ALB)
- Retroarticular Bridging (RAB)
- Cervical vertebrae Bifurcated Tail (CVBFT) ???
- Sternal Foramen (SF)
- Supracondylar Spur (SS)
- Acetabular Crease (AC)
- Calcaneus Facet Form (CFF)
- First Cuneiform Facet Divided (C1FD)

Dental Traits

Maxillary Traits

- Incisor Winging (W)
- Incisor Labial Curve (LC)
- Shovelling (Shov)
- Double Shovelling (DShov)
- Interruption Groove (IG)
- Incisor and Canine Tuberculum Dentale (ICtd)
- Canine Mesial Ridge (CMR)
- Upper Canine Distal Accessory Ridge (UCDAR)
- Premolar Mesial and Distal Cusps (PMDC)
- Metacone (MC)
- Hypocone (HC)
- Upper Cusp 5 (C5)
- Carabelli's Trait (CT)
- Parastyle (PAR)
- Upper Enamel Extension (UEE)

Mandibular Traits

- Lower Canine Distal Accessory Ridge (LCDAR)
- Premolar Lingual Cusp Variation (PLCV)
- Anterior Fovea (AF)
- Groove Pattern (GP)
- Molar Cusp Number (MCN)
- Deflecting Wrinkle (DW)
- Distal Trigonoid Crest (DTC)
- Protostylid (PS)
- Lower Cusp 5 (LC5)
- Lower Cusp 6 (LC6)
- Lower Cusp 7 (LC7)
- Lower Enamel Extension (LEE)

Appendix C–Demography of Sample Examined for Nonmetric Trait Analysis

Site	Ind.	M/F	Age	Site	Ind.	M/F	Age	Site	Ind.	M/F	Age
JBR											
JBR	8	F	20+	SCR	181	M	40-45	SCR	485	M	40-50
JBR	10	F	20+	SCR	185	F	40-50	SCR	486	M	35-40
JBR	14	M	40+	SCR	188	M	20-30	SCR	500	M	20-25
JBR	16	F	20-25	SCR	190	F	25-30	SCR	501	F	30-40
JBR	18	F	30+	SCR	191	M	40-50	SCR	503	M	40-45
JBR	21	M	30+	SCR	193	F	25-30	SCR	510	F	30-40
JBR	23	F	30+	SCR	194	F	40-45	SCR	521	M	20-21
JBR	28A	F	35-40	SCR	196	M	20-25	SCR	525	M	40-50
JBR	28B	F	35-45	SCR	199	F	35-40	SCR	526	M	30-40
JBR	29	F	30+	SCR	201	F	35-40	SCR	549	F	40-45
JBR	31	M	30+	SCR	215	M	35-40	SCR	553	M	20-30
JBR	34	F	18-19	SCR	216	M	20-21	SCR	562	M	50+
JBR	35	M	30+	SCR	217	M	30-40	SCR	575	M	20-25
JBR	40	F	30+	SCR	220	M	40-45	SCR	590	M	50+
JBR	45	F	35-40	SCR	221	M	40-45	SCR	602	F	25-30
JBR	46	M	30+	SCR	226	F	20-21	SCR	603	M	40-50
JBR	54	F	30+	SCR	227	F	50+	SCR	607	F	40-50
JBR	55	F	30+	SCR	232	M	40-50	SCR	608	F	40-45
JBR	56	F	30+	SCR	233	F	50+	SCR	616	M	40-50
JBR	59A	F	20+	SCR	239	F	40-45	SCR	617	M	40-50
JBR	62	F	30+	SCR	241	F	40-50	SCR	668	M	40-45
JBR	63	M	20-25	SCR	243	F	30-35	SCR	669	F	40-45
JBR	64	F	35-40	SCR	245	F	35-40	SCR	670	M	35-40
JBR	66	F	35-40	SCR	246	F	40-45	SCR	678	M	50+
JBR	67	M	40+	SCR	250	M	40-50	SCR	679	M	20-23
JBR	73	F	40-45	SCR	251	M	30-40	SCR	682	M	45-50
JBR	76	M	20+	SCR	252	F	40-45	SCR	686	M	35-40
JBR	80	F	25-30	SCR	261	M	50+	SCR	689	M	20-21
JBR	81	F	40-45	SCR	264	M	50+	SCR	691	F	30-40
JBR	82	M	25-30	SCR	269	F	35-40	SCR	692	M	25-30
JBR	84	M	30-40	SCR	272	F	30-35	SCR	698	M	40-50
JBR	85	F	30+	SCR	281	F	40-50	SCR	699	F	40-50
JBR	86	F	30+	SCR	282	M	30-40	SCR	711	F	40-50
JBR	90	M	35-40	SCR	285	F	50+	SCR	715	M	45-50
JBR	98	F	30+	SCR	286	M	30-40	SCR	717	M	40-50
JBR	101	F	30+	SCR	287	F	30-40	SCR	729	M	50+
JBR	103	F	25-30	SCR	288	M	45-50	SCR	730	M	50+
JBR	104	M	30+	SCR	291	F	45-50	SCR	797	M	30-40
JBR	105	M	30+	SCR	294	F	40-50	**Velia**			
JBR	106	M	30+	SCR	295	F	45-50	Velia	43	M	40-50
JBR	110	F	40-45	SCR	296	F	30-35	Velia	51	M	50+
JBR	111	M	30+	SCR	298	M	40-50	Velia	57	M	30-35
JBR	112	M	35-40	SCR	301	M	30-40	Velia	58	M	50+
JBR	113	F	50+	SCR	303	M	35-40	Velia	64	M	40-50
JBR	115	M	20-25	SCR	304	F	20+	Velia	70	M	30-35

JBR	116	M	30+	SCR	305	F	20-25	Velia	71	F	40-50
JBR	117	M	40-45	SCR	306	F	20-25	Velia	75	M	50+
JBR	122	M	20+	SCR	307	F	40-45	Velia	78	F	20-25
JBR	124	M	45-50	SCR	312	F	35-40	Velia	80	F	40-50
JBR	126	M	25-30	SCR	314	F	40-45	Velia	81	F	50+
JBR	128	M	40+	SCR	320	F	20-25	Velia	82	F	50+
SCR				SCR	321	F	30-35	Velia	83	F	40-50
SCR	15	F	50+	SCR	323	F	50+	Velia	86	M	40-50
SCR	18	F	25-30	SCR	324	F	30-40	Velia	87	M	50+
SCR	35	M	20-25	SCR	325	M	20-25	Velia	94	F	50+
SCR	36	M	20-21	SCR	328	F	35-40	Velia	99	F	50+
SCR	37	M	50+	SCR	329	F	40-50	Velia	100	M	40-50
SCR	39	F	50+	SCR	330	F	20-25	Velia	102	M	40-50
SCR	44	M	40-45	SCR	331	M	30-35	Velia	105	F	20-25
SCR	52	F	25-30	SCR	334	F	30-35	Velia	109	M	40-50
SCR	55	F	40-45	SCR	340	F	25-30	Velia	113	M	50+
SCR	59	F	35-40	SCR	343	M	20-25	Velia	117	F	20-30
SCR	60	F	50+	SCR	344	M	30-35	Velia	118	M	20-25
SCR	67	F	45-50	SCR	352	F	35-40	Velia	119	M	30-40
SCR	68	F	20-30	SCR	353	F	20-25	Velia	131	M	50+
SCR	69	F	30-40	SCR	358	F	30-35	Velia	134	F	20-30
SCR	75	M	20-23	SCR	361	M	20-25	Velia	136	F	35-40
SCR	76	M	40-50	SCR	362	F	40-50	Velia	137	F	40-50
SCR	77	M	35-40	SCR	363	F	40-45	Velia	139	M	30-40
SCR	79	F	20-30	SCR	376	M	35-40	Velia	140.1	M	43-55
SCR	84	F	40-50	SCR	404	M	20-25	Velia	146	M	43-55
SCR	86	M	20-25	SCR	409	F	30-40	Velia	151	F	40-50
SCR	88	M	50+	SCR	411	F	20-25	Velia	152	M	40-50
SCR	90	M	25-30	SCR	416	F	20-21	Velia	154	F	50+
SCR	97	M	40-50	SCR	417	F	40-45	Velia	155.III	M	50+
SCR	98	F	20-25	SCR	419	F	40-50	Velia	157.1301	M	40-50
SCR	99	M	30-35	SCR	421	F	30-35	Velia	160	F	30-40
SCR	105	F	40-50	SCR	422	F	45-50	Velia	164	M	25-30
SCR	106	F	20-23	SCR	430	M	45-50	Velia	169	M	30-40
SCR	113	F	20+	SCR	431	F	40-50	Velia	171	M	45-50
SCR	123	F	20+	SCR	433	F	30-35	Velia	174	M	40-50
SCR	127	M	40+	SCR	434	F	30-40	Velia	176	M	40-50
SCR	128	F	30-35	SCR	435	M	40-45	Velia	181	F	50+
SCR	133	M	20+	SCR	437	F	50+	Velia	182	M	25-30
SCR	134	M	50+	SCR	438	M	50+	Velia	186	M	20-24
SCR	142	M	30-35	SCR	439	M	40-45	Velia	188	F	20-23
SCR	143	M	40-50	SCR	440	M	50+	Velia	189	M	30-40
SCR	144	M	25-30	SCR	442	F	30-40	Velia	193	F	40-50
SCR	145	M	45-50	SCR	443	F	40-50	Velia	194	M	30-40
SCR	148	F	40-50	SCR	445	F	20-30	Velia	200	F	25-30
SCR	150	F	40-50	SCR	448	M	30-35	Velia	203	F	35-40
SCR	152	F	40-50	SCR	452	F	30-40	Velia	205	F	30-40
SCR	158	M	40-45	SCR	462	M	30-40	Velia	211	M	30-35
SCR	159	F	40-50	SCR	463	M	30-40	Velia	214	F	25-35
SCR	160	F	40-50	SCR	464	M	25-30	Velia	222	M	30-40
SCR	161	F	30-40	SCR	466	F	40-50	Velia	223	F	40-45
SCR	169	F	20-30	SCR	467	F	30-35	Velia	241	F	40-50

SCR	171	M	30-40	SCR	470	F	25-30	Velia	270	F	40-50
SCR	173	F	40-45	SCR	479	F	30-40	Velia	283	F	50+
SCR	174	M	30-40	SCR	482	M	50+	Velia	287	M	40-50
SCR	179	M	50+	SCR	484	F	25-30	Velia	290	F	40-50
SCR	180	M	20-25								

Appendix D–List of Nonmetric Traits Examined

Nonmetric trait names are presented in the first column. Each trait is presented as number present/number of individuals observed (percentage). L = Left, R= Right, CVBFT= cervical vertebrae bipartite transverse foramen.

Trait	JBR	SCR	Velia
Metopic Suture	2/25 (8.0%)	6/117 (5.2%)	9/39 (23.1%)
Supra-Orbital Notch L.	16/20 (80%)	87/116 (75%)	34/43 (79.1%)
Supra-Orbital Notch R.	15/22 (68.2%)	87/109 (79.9%)	34/46 (74.0%)
Supra-Orbital Foramen L.	8/21 (38.1%)	59/117 (50.5%)	22/42 (52.4%)
Supra-Orbital Foramen R.	11/23 (47.9%)	46/112 (41.1%)	21/44 (47.8%)
Infra-orbital Suture L.	0/3 (0%)	15/63 (23.9%)	10/39 (25.7%)
Infra-Orbital Suture R.	0/1 (0%)	13/56 (23.3%)	8/38 (21.1%)
Multi Infra-Orbital Foramen L.	1/3 (33.4%)	4/68 (5.9%)	5/40 (12.5%)
Multi Infra-Orbital Foramen R.	0/1 (0%)	4/62 (6.5%)	4/40 (10%)
Zygomatic Foramen L.	26/30 (86.7%)	91/106 (85.9%)	33/40 (82.5%)
Zygomatic Foramen R.	32/33 (97%)	96/110 (87.3%)	37/41 (90.3%)
Parietal Foramen L.	13/26 (50%)	44/122 (36.1%)	15/41(36.6%)
Parietal Foramen R.	12/27 (44.5%)	57/122 (46.8%)	20/38 (52.7%)
Epiteric Ossicle L.	0/0 (0%)	2/51 (4%)	1/29 (3.5%)
Epiteric Ossicle R.	0/2 (0%)	3/49 (6.2%)	1/25 (4.0%)
Coronal Ossicle L.	0/16 (0%)	6/100 (6.0%)	0/33 (0%)
Coronal Ossicle R.	1/18 (5.6%)	7/97 (7.3%)	0/29 (0.0%)
Bregmatic Ossicle	0/18 (0%)	1/96 (1.1%)	0/34 (0%)
Saggittal Ossicle	0/17 (0.0%)	2/100 (2.0%)	3/35 (8.6%)
Apical Ossical	2/19 (10.6%)	14/103 (13.6%)	0/33 (0.0%)
Lambdoidal Ossicle L.	4/19 (21.1%)	52/110 (47.3%)	13/37 (35.2%)
Lamdboidal Ossicle R.	7/20 (35%)	51/108 (47.3%)	16/40 (40.0%)
Asterionic Ossicle L.	1/15 (6.7%)	10/84 (12.0%)	6/32 (18.8%)
Asterionic Ossicle R.	0/16 (0.0%)	9/85 (10.6%)	3/30 (10.0%)
Occipital Mastoid Ossicle L.	0/14 (0%)	3/85 (3.6%)	1/34 (3%)
Occipital Mastoid Ossicle R.	0/15 (0%)	4/87 (4.6%)	2/29 (6.9%)
Parietal Notch Ossicle L.	2/15 (13.4%)	4/87 (4.6%)	2/29 (6.9%)
Parietal Notch Ossicle R.	1/16 (6.3%)	7/85 (8.3%)	3/31 (9.7%
Inca Bone	2/25 (8.0%)	2/113 (1.8%)	0/40 (0.0%)
Condylar Canal L.	2/3 (66.7%)	29/59 (49.2%)	18/34 (53.0%)
Condylar Canal R.	3/4 (75%)	34/59 (57.7%)	21/36 (58.4%)
Divided Hypoglossal Canal L.	12/31 (38.8%)	27/100 (27.0%)	17/39 (43.6%)
Divided Hypoglossal Canal R.	14/35 (40.0%)	29/96 (27.1%)	15/38 (39.5%)
Foramen Ovale L.	0/3 (0.0%)	0/48 (0.0%)	0/26 (0.0%)
Foramen Ovale R.	0/2 (0.0%)	1/51 (2.0%)	1/29 (3.5%)
Foramen Spinosum L.	0/3 (0.0%)	10/48 (20.9%)	8/26 (30.8%)
Foramen Spinosum R.	0/2 (0.0%)	8/53 (15.1%)	17/29 (58.7%)
Pterygo-Spinous Bridge L.	0/3 (0.0%)	5/48 (10.5%)	9/23 (39.2%)
Pterygo-Spinous Bridge R.	0/2 (0.0%)	7/51 (13.8%)	10/29 (34.5%)
Pterygo-Alar Bridge L.	0/3 (0.0%)	8/48 (16.7%)	9/27 (33.4%)
Pterygo-Alar Bridge R.	0/2 (0.0%)	8/50 (16.0%)	14/29 (48.3%)
Tympanic Dihiscence L.	1/27 (3.8%)	15/134 (11.2%)	6/48 (12.5%)

Tympanic Dihiscence R.	4/29 (13.8%)	10/121 (8.3%)	1/43 (2.4%)
Mastoid Foramen L.	20/22 (91.0%)	105/114 (92.2%)	45/53 (85.0%)
Mastoid Foramen R.	24/26 (92.4%)	93/104 (89.5%)	41/47 (87.3%)
Mental Foramen L.	31/32 (96.9%)	106/127 (84.2%)	54/55 (98.2%)
Mental Foramen R.	33/34 (97.1%)	106/126 (84.2%)	54/55 (98.2%)
Mandibular Torus L.	2/32 (6.3%)	9/123 (7.4%)	7/56 (12.5%)
Mandibular Torus R.	1/34 (3.0%)	12/128 (9.4%)	5/52 (9.7%)
Mylohyoid Bridge L.	3/29 (10.4%)	27/120 (22.5%)	15/54 (27.8%)
Mylohyoid Bridge R.	5/28 (17.9%)	17/120 (14.2%)	5/37 (13.6%)
Atlas Foramen Double L.	0/32 (0.0%)	4/99 (4.1%)	6/45 (13.4%)
Atlas Foramen Double R.	0/28 (0.0%)	3/96 (3.2%)	6/43 (14.0%)
Atlas Posterior Bridge L.	4/29 (13.8%)	11/96 (11.5%)	4/38 (10.6%)
Atlas Posterior Bridge R.	2/28 (7.2%)	15/93 (16.2%)	3/37 (8.2%)
Atlas Lateral Bridge L.	0/26 (0.0%)	0/95 (0.0%)	1/41 (2.5%)
Atlas Lateral Bridge R.	1/23 (4.4%)	1/93 (1.1%)	2/39 (5.2%)
Retro-Articular Bridge L.	2/20 (10.0%)	12/89 (13.5%)	9/42 (21.5%)
Retro-Articular Bridge R.	1/19 (5.3%)	9/87 (10.4%)	12/38 (31.6%)
CVBFT L.	8/20 (40.0%)	33/96 (34.4%)	13/45 (28.9%)
CVBFT R.	10/20(50.0%)	30/92 (32.7%)	11/44 (25.0%)
Sternal Foramen	0/6 (0.0%)	2/40 (5.0%)	4/33 (12.2%)
Supracondylar Spur L.	2/42 (4.8%)	6/164 (3.7%)	1/61 (1.7%)
Supracondylar Spur R.	3/42 (7.2%)	3/163 (1.9%)	1/63 (1.6%)
Acetabular Crease L.	8/42 (19.1%)	24/131 (18.4%)	11/50 (22.0%)
Acetabular Crease R.	12/41 (29.3%)	24/129 (18.7%)	9/46 (19.6%)
Calcaneal Facet Divided L.	16/30 (53.4%)	52/135 (38.6%)	29/66 (44.0%)
Calcaneal Facet Divided R.	18/40 (45.0%)	51/142 (36.0%)	25/65 (38.5%)
First Cuneiform Facet Divided L.	0/25 (0.0%)	1/94 (1.1%)	1/50 (2.0%)
First Cuneiform Facet Divided R.	0/25 (0.0%)	2/92 (2.2%)	2/54 (3.8%)
Winging UI1R	1/8 (12.5%)	3/70 (4.3%)	2/31 (6.5%)
Winging UI1L	1/9 (11.2%)	5/55 (9.1%)	3/26 (11.6%)
Labial Curve UI1R	2/13 (15.4%)	16/85 (18.9%)	8/34 (23.6%)
Labial Curve UI1L	4/16 (25.0%)	17/73 (23.3%)	8/30 (26.7%)
Shoveling UI1R	0/11 (0.0%)	0/84 (0.0%)	0/35 (0.0%)
Shoveling UI1L	0/14 (0.0%)	0/72 (0.0%)	0/31 (0.0%)
Double Shoveling UI1R	0/13 (0.0%)	0/84 (0.0%)	0/35 (0.0%)
Double Shovelling UI1L	0/16 (0.0%)	0/73 (0.0%)	0/32 (0.0%)
Interruption Grove UI1R	0/12 (0.0%)	3/85 (3.6%)	4/34 (11.8%)
Interruption Grove UI2L	3/15 (20.0%)	10/84 (12.0%)	13/30 (43.4%)
Interruption Grove UI2R	3/14 (21.5%)	15/84 (12.0%)	10/31 (32.3%)
Interruption Grove UI2L	3/15 (20.0%)	10/84 (12.0%)	13/30 (43.4%)
Tuberculum Dentale UI1R	2/12 (16.7%)	12/85 (14.2%)	5/35 (14.3%)
Tuberculum Dentale UI1L	3/15 (20.0%)	12/72 (16.7%)	4/31 (13.0%)
Tuberculum Dentale UI2R	0/13 (0.0%)	2/83 (2.5%)	8/32 (25.0%)
Tuberculum Dentale UI2L	0/15 (0.0%)	1/83 (1.3%)	4/31 (13.0%)
Tuberculum Dentale UCR	1/22 (4.6%)	5/99 (5.1%)	5/41 (12.2%)
Tuberculum Dentale UCL	0/17 (0.0%)	4/88 (4.6%)	4/39 (10.3%)
Canine Mesial Ridge UCR	0/21 (0.0%)	1/92 (1.1%)	4/36 (11.2%)
Canine Mesial Ridge UCL	0/16 (0.0%)	0/84 (0.0%)	2/33 (6.1%)
Canine Distal Accessory Ridge UCR	1/21 (4.8%)	5/93 (5.4%)	2/36 (5.6%)
Canine Distal Accessory Ridge UCL	1/16 (6.3%)	5/84 (6.0%)	3/32 (9.4%)
Premolar m & d Cusps UP1R	0/20 (0.0%)	0/106 (0.0%)	0/42 (0.0%)
Premolar m & d Cusps UP1L	0/23 (0.0%)	0/91 (0.0%)	0/42 (0.0%)
Premolar m & d Cusps UP2R	0/20 (0.0%)	0/100 (0.0%)	0/39 (0.0%)

Premolar m & d Cusps UP1L	0/19 (0.0%)	0/90 (0.0%)	0/39 (0.0%)
Hypocone UM1R	0/20 (0.0%)	1/101 (1.0%)	0/31 (0.0%)
Hypocone UM1L	0/18 (0.0%)	0/88 (0.0%)	0/28 (0.0%)
Hypocone UM2R	6/23 (26.1%)	28/105 (26.7%)	11/33 (33.4%)
Hypocone UM2L	6/25 (24.0%)	23/99 (23.3%)	11/35 (31.5%)
Hypocone UM3R	6/16 (37.5%)	29/74 (39.2%)	8/22 (36.4%)
Hypocone UM3L	8/18 (44.5%)	28/62 (45.2%)	6/20 (30.0%)
Cusp 5 UM1R	0/19 (0.0%)	10/101 (10.0%)	2/31 (6.5%)
Cusp 5 UM1L	0/17 (0.0%)	7/88 (8.0%)	4/27 (14.9%)
Cusp 5 UM2R	2/23 (8.7%)	8/105 (7.7%)	0/34 (0.0%)
Cusp 5 UM2L	1/25 (4.0%)	6/99 (6.1%)	4/35 (11.5%)
Cusp 5 UM3R	3/17 (17.7%)	10/75 (13.4%)	3/22 (13.7%)
Cusp 5 UM3L	6/19 (31.6%)	10/63 (15.9%)	2/20 (10.0%)
Carabelli Cusp UM1R	1/20 (5.0%)	10/98 (10.3%)	0/30 (0.0%)
Carabelli Cusp UM1L	0/18 (0.0%)	7/87 (8.1%)	0/27 (0.0%)
Parastyle UM1R	0/19 (0.0%)	0/101 (0.0%)	3/29 (10.4%)
Parastyle UM1L	0/18 (0.0%)	0/89 (0.0%)	2/27 (7.5%)
Parastyle UM2R	1/23 (4.4%)	0/105 (0.0%)	1/33 (3.1%)
Parastyle UM2L	1/24 (4.2%)	0/98 (0.0%)	1/37 (2.8%)
Parastyle UM3R	0/17 (0.0%)	3/75 (4.0%)	1/21 (4.8%)
Parastyle UM3L	1/19 (5.3%)	3/62 (4.9%)	1/21 (4.8%)
Premolar Lingual Cusp LP1R	1/30 (3.4%)	2/96 (2.1%)	4/49 (8.2%)
Premolar Lingual Cusp LP2L	3/30 (10%)	2/90 (2.3%)	4/51 (7.9%)
Premolar Lingual Cusp LP2R	6/28 (21.5%)	13/103 (12.7%)	3/48 (6.3%)
Premolar Lingual Cusp LP2L	5/26 (19.3%)	15/103 (14.6%)	4/48 (8.4%)
Anterior Fovea LM1L	1/21 (4.8%)	7/89 (7.9%)	1/35 (2.9%)
Anterior Fovea LM1R	1/23 (4.4%)	7/84 (8.4%)	2/37 (5.5%)
Groove Y LM1R	24/25(96.0%)	88/109 (80.8%)	16/39 (41.1%)
Groove Y LM1L	21/25 (84%)	91/114 (79.9%)	14/40 (35.0%)
Groove Y LM2R	5/28 (17.9%)	32/91 (35.2%)	6/28 (21.5%)
Groove Y LM2L	8/26 (30.8%)	30/101 (29.8%)	11/42 (26.2%)
Cusp 7 LM1R	0/24 (0.0%)	7/93 (7.6%)	1/37 (2.8%)
Deflecting Wrinkle LM1L	0/22 (0.0%)	0/94 (0.0%)	0/36 (0.0%)
Deflecting Wrinkle LM1R	0/23 (0.0%)	0/90 (0.0%)	1/35 (2.9%)
Distal Trigonid Crest LM1L	0/22 (0.0%)	0/94 (0.0%)	0/36 (0.0%)
Protostylid LM1L	0/22 (0.0%)	1/97 (1.1%)	1/37 (2.8%)
Protostylid LM1R	0/24 (0.0%)	1/92 (1.1%)	1/34 (3.0%)
Protostylid LM2L	0/32 (0.0%)	1/105 (0.95%)	0/44 (0.0%)
Protostylid LM2R	1/30 (3.4%)	1/106 (0.94%)	0/47 (0.0%)
Protostylid LM3L	0/18 (0.0%)	3/81 (3.8%)	3/38 (7.9%)
Protostylid LM3R	1/21 (4.8%)	1/77 (1.3%)	1/34 (3.0%)
Cusp 5 LM1L	17/21 (81.0%)	68/98 (69.4%)	21/38 (55.3%)
Cusp 5 LM1R	21/24 (87.5%)	69/91 (75.9%)	19/36 (52.8%)
Cusp 5 LM2L	2/32 (6.3%)	10/106 (9.5%)	0/45 (0.0%)
Cusp 5 LM2R	3/29 (10.4%)	7/108 (6.5%)	3/48 (6.3%)
Cusp 5 LM3L	6/18 (33.4%)	22/81 (27.2%)	7/39 (18.0%)
Cusp 5 LM3R	8/22 (36.4%)	26/79 (33.0%)	6/36 (16.7%)
Cusp 6 LM1L	0/21 (0.0%)	1/98 (1.1%)	0/40 (0.0%)
Cusp 6 LM1R	0/24 (0.0%)	2/92 (2.2%)	0/36 (0.0%)
Cusp 6 LM2L	0/32 (0.0%)	1/106 (0.94%)	0/45 (0.0%)
Cusp 6 LM2R	0/29 (0.0%)	1/108 (0.92%)	0/48 (0.0%)
Cusp 6 LM3L	0/17 (0.0%)	2/81 (2.5%)	1/39 (2.6%)
Cusp 6 LM3R	1/21 (4.8%)	3/79 (3.8%)	3/36 (8.4%)

Cusp 7 LM1L	1/21 (4.8%)	3/98 (3.1%)	0/38 (0.0%)
Cusp 7 LM1R	0/24 (0.0%)	7/93 (7.6%)	1/37 (2.8%)
Cusp 7 LM2L	0/32 (0.0%)	0/106 (0.0%)	0/45 (0.0%)
Cusp 7 LM2R	0/29 (0.0%)	0/108 (0.0%)	0/48 (0.0%)
Cusp 7 LM3L	0/17 (0.0%)	2/82 (2.5%)	0/40 (0.0%)
Cusp 7 LM3R	0/21 (0.0%)	1/79 (1.3%)	0/36 (0.0%)
Enamel extension UM1L	0/23 (0.0%)	2/96 (2.1%)	0/39 (0.0%)
Enamel extension UM3R	2/26 (7.7%)	1/90 (1.2%)	0/38 (0.0%)
Enamel extension UM2L	8/33 (24.3%)	1/103 (0.97%)	0/44 (0.0%)
Enamel extension UM2R	6/33 (18.2%)	3/105 (2.9%)	0/48 (0.0%)
Enamel extension UM3L	3/17 (17.7%)	0/79 (0.0%)	0/39 (0.0%)
Enamel extension UM3R	1/21 (4.8%)	0/77 (0.0%)	0/35 (0.0%)

Appendix E– Grave Goods Identified at Rue Jacques Brel Necropolis (JBR)*

Grave	***Sex (M/F)***	***Age***	***Pottery***	***Coins***	***Nails***	***Shoes***	***Glass***	***Metal***	***Other***	***“Other” items***
8	F	20+	3							
12	I	5-9	7							
13	I	I						1		
14	M	25+	2					1		
16	F	20-25						1		
17	I	1-4	6	1	7	1				
18	F	30+	3		297	1		1		
19	F	25+	3		12	1		1		
20	I	1-4	6							
21	M	30+	1							
26	I	5-9	1							
30	I	I	2	1	14	1				
35	M	30+	1							
38	I	0-1	6					2		
39	I	I	2					1		
40	F	30+		1					1	game token
41	I	5-9	8		96	1	1			
42	I	I	4		40	1				
43	I	I	2							
45	F	25+	3	1	125	1		4		
46	M	30+	2	1						
48	I	1-4	6	1	5	1				
49	I	1-4	4							
50	I	I	2							
51	I	I	2							
52	I	1-4	6							
54	F	30+		1	135	1				
56	F	30+			110	1				
57	I	15-19	2						1	bone needle
58	I	5-9	4		90	1		1		
62	F	30+		7	234/90	2		3	2	intaglio
63	M	20-25			20	1		1		
64	F	30+	8		160	2				
67	M	30+	1		156	1				
68	F	20+	1		15	1				
69	F	30+			45	1				
70	I	1-4	2					1		

71	I	10-14			28	1				
73	F	20+						3		
76	M	20+	3		170	1		1		
77	F	20+			73	1				
78	I	20+	5		35	1				
80	F	30+			1			1		
82	M	25-30	2		384	1				
83	I	5-9						1		
84	M	30+						1		
87	I	20+	4		1	1	1	1		
89	I	20+	1							
90	M	30+	7							
92	I	5-9	1							
94	I	20+	1							
96	I	I	1							
97	I	1-4		2				1		
98	F	30+			41	1				
101	F	30+	5							
103	F	20+	3		112	1				
105	M	30+			71	1				
108	I	5-9	1		36	1				
109	I	15-19		4	234/ 90	2		1		
110	F	30+	2							
112	M	30+	7	3	2	1	1	6	3	3 eggs
114	M	20+			160	1				
115	M	20-25	3					2		
116	M	30+	3		117	1				
117	M	30+				1				
119	I	5-9			98	1				
120	I	1-4	3							
121	I	0-1	1							
122	M	20+			70	1		1		
123	I	I	2		1					
124	I	I	6		168	2				
125	I	0-1	1							
126	M	25+				1				
128	M	30+	1		150	1				

*only graves with specified grave goods present have been listed here. Data on grave goods was compiled from Baigl et al. (1997). Individuals identified as non-local based on isotopic analyses ($\delta^{18}O$, $^{87}Sr/^{86}Sr$) are highlighted in yellow. M= male, F= female, I= indeterminate. All ages are in years.

Appendix F– Annual $\delta^{18}O_{dw}$ Averages of Precipitation Derived from GNIP Data

Country	GNIP Station	$\delta^{18}O$
Algeria	Algiers (CN)	-3.2‰
	Ouargla	-4.2‰
	Assekrem	-3.0‰
	Beni-Abbes	-0.08‰
Austria	Vienna	-9.7‰
	Petzenkirchen	-9.7‰
	Podersdorf	-9.1‰
	Villacher Alpe	-11.1‰
	Klagenfurt Flugplatz	-10.5‰
	Graz Universitat	-9.9‰
Belarus	Brest	-9.6‰
	Minsk	-10.7‰
Cyprus	Halefka	-5.4‰
	Nicosia	-4.6‰
Denmark	Taastrup	-10.1‰
Egypt	Sidi Barrani	-3.3‰
	Marsa-Matruh	-3.6‰
	Alexandria	-3.5‰
	Rafah	-3.5‰
	El-Arish	-3.2‰
	Cairo	-2.9‰
Estonia	Tartu	-10.9‰
	Vilsandi	-9.8‰
Finland	Rovaniemi	-14.0‰
	Espoo	-11.7‰
	Kuopio	-13.8‰
France	Brest Plouzane	-4.8‰
	Orleans la Source	-6.1‰
	Thonon les Bains	-9.3‰
	Cestas-Pierroton	-5.7‰

	Draix	-7.9‰
	Dax	-4.8‰
	Campistrous	-6.8‰
	Montpellier	-4.0‰
	Avignon	-5.4‰
	Carpentras	-4.7‰
	Gardanne	-4.5‰
	Malaussene	-5.4‰
	Ponte Leccia	-6.6‰
	Toulousse	-6.4‰
	Le Mas*	-6.3‰
	Villars*	-6.2‰
	Orgnac*	-6.6‰
Germany	Cuxhaven	-6.9‰
	Bad Salzuflen	-7.8‰
	Braunschweig	-7.2‰
	Berlin	-7.9‰
	Emmerich	-7.1‰
	Leipzig	-8.6‰
	Koblenz	-7.0‰
	Wasserkuppe Rhoen	-9.5‰
	Trier	-7.2‰
	Würzburg	-8.1‰
	Hof-Hohensaas	-8.8‰
	Karlsruhe	-7.9‰
	Stuttgart (Cannstatt)	-8.1‰
	Regensburg	-9.3‰
	Neuheberg	-10.2‰
	Feldberg-Schwarz.	-9.4‰
	Weil am Rhein	-8.3‰
	Konstanz	-9.8‰
	Hohenpeissenberg	-11.6‰
	Garmisch-P.kirch.	-11.1‰
Greece	Thessaloniki	-6.0‰
	Alexandropolis	-6.3‰
	Heraklion	-5.2‰
	Patras	-5.0‰
	Rhodes	-4.6‰
	Athens	-5.3‰
Israel	Beer Sheva	-5.0‰
	Bet Dagan	-4.3‰

	Har Kna’an	-6.3‰
Italy	Tiber River	-7.3‰
Jordan	Amman	-5.4‰
	Irbid	-5.9‰
Latvia	Riga	-9.5‰
Lebanon	‘Aramtá	-6.8‰
	Bekaa	-6.7‰
	Beirut	-4.6‰
	Bhamdoun	-7.4‰
	Tripoli	-6.0‰
	Tyr	-5.5‰
	Yohmor	-5.2‰
Monaco	Monaco	-3.2‰
Morocco	Bab Bou Idir	-7.3‰
	Rabat-Cnesten	-4.2‰
	Fes Sais	-4.2‰
	Beni Mellal	-5.1‰
Poland	Krakow	-9.7‰
Portugal	Faro	-4.0‰
	Porto	-4.2‰
Romania	Ramnicu Valcea	-8.0‰
Russia	Moscow	-11.6‰
	Murmansk	-12.8‰
	St. Petersburg	-11.4‰
Slovenia	Ljubljana	-8.7‰
	Portoroz	-6.4‰
	Kozina	-7.2‰
Spain	Valencia	-4.4‰
	Zaragoza	-5.9‰
	Barcelona	-4.6‰
	Leon	-8.0‰
	Murcia	-4.4‰

	Madrid	-6.4‰
	Seville	-4.3‰
	Barcelona	-4.1‰
	Valladolid	-7.2‰
Switzerland	Guttannen	-12.4‰
	Meiringen	-11.3‰
	Locarno	-8.7‰
Syria	Palmyra	-3.3‰
	Damascus	-6.4‰
	Idleb	-6.6‰
	Raqqa	-6.3‰
Tunisia	Tunis (Carthage)	-3.7‰
	Le Kef	-6.4‰
	Sfax	-3.6‰
	Nefta	-1.0‰
Turkey	Edirne	-7.3‰
	Izmir	-4.8‰
	Adana	-4.6‰
	Diyarbakir	-6.0‰
	Ankara	-7.5‰
	Erzurum	-7.8‰

*values derived from Labhun (2014).