A Mobility Study of Neolithic People from Roquemissou in Southern France using Strontium Isotopes

By

Jeffrey Coffin

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Arts
in
Public Issues Anthropology

Waterloo, Ontario, Canada, 2020

Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This thesis examines the patterns of changing $^{87}Sr/^{86}Sr$ isotope ratios across the growth bands of 17 third molars belonging to people buried at the site of Roquemissou in Southern France. These ratios reflect the isotopic composition of the landscape that these people inhabited during the ages of 8 to 13 when these molars developed in the maxilla. The landscape of the Massif Central - where the site is located - is quite variable in its strontium isotopic ratios, and the ratios within these teeth reflect that variation. The isotope ratios in the teeth of these individuals suggest that they come from across the Massif Central region, with only a small number matching the expected range of ratios at the site. There is some variation across the layers of enamel to suggest that a number of individuals moved around the landscape, but there are also several individuals with very stable ratios over time which indicates that they were sedentary. These data suggest that the people who lived at this time period (roughly 5000 years ago) may have adopted different subsistence strategies and migration patterns ranging from seasonal mobility to sedentism. Despite living across the Massif Central and practicing different lifeways, these people were all buried at the site of Roquemissou. This is not unusual for Late Neolithic cultures in the region and suggests that the people buried at Roquemissou shared a common cultural affiliation, despite living all across the landscape of Southern France.

Acknowledgements

I enrolled in this master's of public issues in anthropology at the University of Waterloo in early 2018, and I am very thankful to the Department of Anthropology for accepting my application. My experience in this program has been incredibly positive, and it has bolstered my growth both academically and emotionally. I would like to thank my supervisor, Dr. Alexis E. Dolphin for being primarily responsible for my success in this regard. Her dedication to helping me achieve my academic goals was apparent from our first meeting, and since then she has made it a top priority to offer expert guidance, thoughtful feedback, and considerate support at every step of my progress in this program. She helped me shape my ideas into an accomplishable thesis project and helped me get access to the tools necessary to complete this work. It was only through her connection to Dr. Mary Jackes that I was able to work with these prehistoric human remains, and her connection with Chris Yakymchuk and the Earth Sciences Department that I was able to access the complicated technical instruments through which I could perform the isotopic analysis.

My committee members, Dr. Alexis Dolphin, Dr. Mary Jackes, and Dr. Chris Yakymchuk have all been very involved in my research and writing, and I am grateful for all of their support. Dr. Chris Yakymchuk gave so much of his time to ensure that I had the best results possible and could understand them, and I appreciate this help immensely. Dr. Mary Jackes also offered constant support and knowledge about the site and the human remains, and I could not have finished this thesis without her insights.

I also owe a lot to Dr. Mary Jackes, Dr. Thomas Perrin, Dr. Philippe Gruat, and Aline Pelletier for giving me permission to work with these human remains. It is only through the contributions of everyone on Dr. Perrin's and Dr. Gruat's excavation teams, and the staff at the Espace Archéologique Départemental de Montrozier that I am able to do this research, and I am grateful to everyone responsible for unearthing, studying, and curating these materials with such care for so many years. Dr. Thomas Perrin also offered me a lot of support and guidance throughout this process, and I am thankful for his willingness to make time for me and respond to my questions.

I would like to thank the entire Earth Sciences Department as well, for allowing me to use their labs and LA-ICP-MS instrument. Dr. Chris Yakymchuk and his lab coordinator Carson made me feel very welcome in the lab and helped me to understand a lot about the complex instruments it houses.

Dr. Malte Willmes and Dr. Ian Moffat provided valuable information about the distribution of strontium isotopes across France, and I am very thankful that they were willing to share their research with me.

I want to thank the entire Department of Anthropology at the University of Waterloo for guiding my success in this program, especially my professors Dr. Adrienne Lo, Dr. Jennifer Liu, and Dr. Alexis Dolphin. The friendly and helpful contributions from all of the faculty and administration made this experience much easier. I would also like to thank the family of Iris Yuzdepski for their continuing support for the program. The Iris Yuzdepski scholarship greatly helped me to support myself financially over the last year and a half.

It was through this program that I was able to work on the Barqa Landscape project over the summer. While this had little to do with my thesis research, it was a valuable learning experience that gave me the opportunity to excavate and study human skeletal remains in the field. It also gave me the opportunity to travel to Jordan and experience the culture and history of this beautiful country. My thanks to director Dr. Russell Adams, my supervisor Dr. Alexis Dolphin, and the entire project team for giving me this unforgettable experience.

The rest of my graduate cohort, Chiara Williamson, Elizabeth Rayner, Martha Tildesley, Ben Scher, Kate Elliot, and Panchala Weerasinghe was one of the best parts about this program. Every one of them has been a supportive friend and academic colleague throughout the program, and they are all responsible for making this experience so positive for me. I wish them all professional and academic success and look forward to maintaining our friendship even after we all graduate.

My family and friends have also offered me invaluable support and advice throughout this period of my life, and I am incredibly lucky to have so many good people in my life.

Lastly, I wish to thank the individuals interred at the site of Roquemissou themselves, because without them this project would not be possible. It was a privilege to study such a fascinating group of people, and I am honoured to contribute to our knowledge of the lives of these people.

Contents

Author’s Declaration ii

Abstract iii

Acknowledgements iv

List of Figures vii

Chapter 1: Anthropology and the Public 1
  1.1 What is Public Issues Anthropology? 1
  1.2 Isotopic Analysis and Mobility 2
  1.3 Choosing Between Destructive Methods 4
  1.4 Presenting Anthropology to the Public 6
  1.5 Intent for Publication 6

Chapter 2: Mobility of People Buried at Roquemissou 8
  2.1 Introduction 8
  2.2 Methods 14
    2.2.1 Sample Preparation 14
    2.2.2 Laser Ablation – Multi-Collector – Inductively Coupled Plasma – Mass Spectrometry (LA-MC-ICP-MS) 14
    2.2.3 Data Reduction 16
    2.2.4 Analysis of Diagenesis 17
    2.2.5 Representing the Data 19
  2.3 Results 19
    2.3.1 Establishing a Local Range of ^{87}Sr/^{86}Sr Ratios 22
    2.3.2 Individual L1 25
    2.3.3 Individual L2 27
    2.3.4 Individual L5 28
    2.3.5 Individual L8 29
    2.3.6 Individual L9 30
    2.3.7 Individual R2 32
    2.3.8 Individual R4 33
    2.3.9 Individual R5 35
    2.3.10 Individual R7 36
    2.3.11 Bovid Tooth 37
  2.4 Discussion 38
  2.5 Conclusion 42

References 44

Appendix A 48

List of Figures

Figure 1: Map of France with the location of Roquemissou highlighted (Perrin et al. 2018: 328)……………………………………………………………………………..…………………9

Figure 2: Sample L5 with a line indicating the location of laser sampling…………………..…….15

Figure 3: Map of the distribution of biologically available ratios of ^{87}Sr/^{86}Sr across France with Roquemissou indicated with a white star (Willmes et al. 2018: 84)………………………..…....23

Figure 4: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual L1 ± 2 SE. Local range indicated by green box…………………………..…...…..25

Figure 5: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual L2 ± 2 SE. Local range indicated by green box……………………………...……27

Figure 6: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual L5 ± 2 SE. Local range indicated by green box……………………………...……28

Figure 7: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual L8 ± 2 SE. Local range indicated by green box……………………………..…….29

Figure 8: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual L9 ± 2 SE. Local range indicated by green box…………………………...………30

Figure 9: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R2 ± 2 SE. Local range indicated by green box……………………………….……..32

Figure 10: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R4 ± 2 SE. Local range indicated by green box…………………………………..….33

Figure 11: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R5 ± 2 SE. Local range indicated by green box………………………...……..…..35

Figure 12: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R7 ± 2 SE. Local range indicated by green box……………………...……..……..36

Figure 13: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for the bovine tooth ± 2 SE. Local range 0.7076-0.7121 not depicted……………………………….37

Figure 14: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individuals R2 and R7 ± 2 SE. Local range indicated by green box…………………………….39

Figure 15: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individuals L2, L5, R4, R5, and the *Bos* sample ± 2 SE. Local range indicated by green box….40

Figure 16: Average $^{87}Sr/^{86}Sr$ ratios over approximate number of days of enamel growth for individuals L1, L8, and L9 ± 2 SE. Local range indicated by green box………………………..41

List of Tables

Table 1: Results of radiocarbon analysis from the interosseous crests of 2 fibulae from the main shelter analyzed at the Beta Analytic lab in Miami (USA) (Perrin 2017: 115)……..…10

Table 2: Laser Ablation and MC-ICP-MS operating conditions……………………………..…16

Table 3: Results of LA-ICP-MS analysis for each tooth by points averaging approximate enamel growth over 3-4 months created with the Iolite program (Paton et al. 2011)…………...……….20

Chapter 1: Anthropology and the Public

1.1 What is Public Issues Anthropology?

This master's program is focused on public issues in anthropology; highlighting the fact that anthropological research does not exist in a bubble, but rather impacts human beings in the greater public. Therefore, conducting research and presenting its results affects individuals and the larger public. This thesis examines the mobility patterns of prehistoric people from Southern France by analyzing the ratios of different strontium isotopes in their dental enamel. The objective of this first chapter is to identify the different groups of people *who* are affected by this research and explain *how* they may be impacted. The various stakeholders involved in this research were always considered throughout the process and steps taken during the research were intended to provide as much valuable information while causing as little harm as possible. This is also true for the plans to present this information to the public.

The samples for this research came from the Neolithic burial shelters at the archaeological site of Roquemissou in Southern France. The groups of people affected by the study of this material include the researchers who excavated, curate, and study this material, the local populations of the Aveyron Department and Southern France, and the deceased Roquemissou individuals themselves. Minimally destructive sample preparation and analytical techniques were chosen to limit damage to the remains of these individuals themselves and allow future research to continue with these remains. This research relates to the heritage of the land and the people who live there, and by making information about the history of the landscape of Southern France more accessible I also hope to help the local communities learn about their heritage and be able to use this information to aid the further development of tourism in this region.

1.2 Isotopic Analysis and Mobility

Isotopic analyses of human remains comparing strontium isotopes to study human mobility have been common in anthropological research since 1985 (Bentley 2006; Ericson 1985; Price et al. 1994). Strontium isotopes are often used in studies of the mobility of living things because the ratio of $^{87}Sr/^{86}Sr$ in the environment is determined by the local geochemistry and can vary greatly between different environments and geological regions across the landscape. ^{86}Sr occurs in greater quantities in silica rich igneous rocks with high calcium content, and ^{87}Sr in older rocks with higher rubidium, and because strontium suffers little fractionation, these isotopes are weathered out of the bedrock and travel through the environment in quantities very similar to those of the parent rock (Bentley 2006). The local $^{87}Sr/^{86}Sr$ in soil and plants is a product of how much of each isotope has entered the local groundwater and river systems due to weathering from the local geology, as well as how much has been carried from other geological sources by melting glaciers, rivers, rainwater, and ocean spray (Bentley 2006). Animals and humans also absorb $^{87}Sr/^{86}Sr$ at the direct local ratio in the plants they eat, and the amount stored in their bones and tooth enamel (as a substitute for calcium) represents an average of the range of $^{87}Sr/^{86}Sr$ represented by all of the sources of strontium in their diet over a specific period of time (Montgomery 2010). This variation of $^{87}Sr/^{86}Sr$ ratios in human bone and enamel based on the ratios in locally exploited food sources allows researchers to identify where prehistoric people lived by making comparisons between the strontium signatures in their bone and enamel with the local geochemistry and biologically available $^{87}Sr/^{86}Sr$ ratios.

There are several methods for analyzing the elemental and isotopic composition of skeletal material. The most common technology applied to mobility studies using strontium isotopes is mass spectrometry because it provides accurate results on a multitude of isotopic and elemental data while remaining more accessible and less expensive than x-ray instruments (Horstwood et al. 2008). The method used in this type of research can be combined with two major means of sample introduction: bulk sampling and laser ablation. Bulk sampling methods have been most commonly employed in this type of study (Ericson 1985; Price et al. 1994). Bulk methods involve grinding the sample into a powder or dissolving it in acid and analyzing the resulting material. This method of sample preparation destroys the physical structure of the sample but offers highly accurate results of the elemental composition of the material that can be rounded to four decimal places (Copeland et al. 2010). This method typically compares the $^{87}Sr/^{86}Sr$ ratio in dental enamel – which forms during childhood and preserves the ratio that was present at the time – with the ratio in bone – which goes through remodelling constantly and thus reflects a strontium signature that was incorporated during the last 7 – 10 years prior to death (Price et al. 1994). This method is often used for identifying the origins of an individual, and if they moved to a new environment.

In contrast, laser ablation is a sampling technique that has gained popularity within the last two decades. This method involves ablating the surface of the material with a laser, producing microscopic particles that the mass spectrometer then analyzes. This method allows for microspatial analyses of the variation of isotope concentrations throughout different regions of the sample but is less precise than bulk sampling methods (Copeland et al. 2010). This method can also be used to compare dental enamel with bone to identify movement between childhood and adulthood. However, because of the microspatial capabilities of the laser this method has been applied to studying multiple points across different layers of dental enamel – which grow successively at a fixed rate – to identify changes in the $^{87}Sr/^{86}Sr$ ratio over the years that the individual's teeth were developing (Bentley et al. 2008). This allows researchers to identify seasonal patterns of movement across the landscape that would not be noticeable if the material was homogenized in a powder or solution.

1.3 Choosing Between Destructive Methods

Bioarchaeology and archaeology are inherently destructive processes. The process of excavation removes parts of the original context from artefacts and human remains, and many methods of analysis involve damaging these materials and remains further for specific purposes. Isotopic and trace element analyses of human remains using mass spectrometry is always a partially destructive process, and therefore it is important for researchers to consider the costs and benefits of the research to those stakeholders invested in the remains. While not every anthropological organization or group of stakeholders agrees on an ethical guideline for the treatment of human remains, Walker (2000) suggests that the major groups such as the American Anthropological Association, Canadian Association for Physical Anthropology, the United Nations Educational, Scientific and Cultural Organization, and many others agree on three basic principals: 1) treating remains with respect; 2) allowing descendants to control what is done with their ancestors' remains; and 3) preserving material from unnecessary destruction or damage. Walker (2000) highlights that research on human remains should not take place simply for the sake of knowing about the past but asserts that research on human remains provides valuable information on our shared human heritage and identity, which can be used to help people now and in the future. In this way, the knowledge gained from studying human remains is framed as an ethical imperative – studying human remains and preserving them for future study benefits all of society. This is often how destructive methods such as isotopic analyses are described and justified. For example, Turner & Andrushko (2011) argue that the benefits of destructive isotopic analyses outweigh the negative implications of destroying the skeletal sample because they can provide incredibly valuable information on human mobility, diet, and other aspects of social organization that could not otherwise be identified.

Therefore, when choosing between bulk sampling or laser ablation methods of isotopic analysis it is important to choose the method that will cause the least amount of damage while still providing the most valuable information. I chose laser ablation over bulk sampling, so instead of destroying part of the enamel I cut it to create thin sections on slides. Dolphin et al. (2016) highlight how this preserves most of the structure of the tooth for future histological studies, as well as other trace element and isotopic studies that may wish to focus on any other section of the enamel. This preservation of remains for future study is another important reason for limiting destruction of human remains, because other researchers are also stakeholders with vested interests in the samples being studied (Walker 2000). There are no identified descendant communities for the individuals buried at Roquemissou because these 5000 year old remains are so ancient. However, the local French archaeological and historical communities are highly invested stakeholders that also want as little damage to come to these remains as possible. Therefore, laser ablation, the least destructive method of isotopic analysis available to me, was the correct choice. It allowed me to preserve the majority of the teeth, and their physical structure. The slides can be used for further isotope and trace element analyses, and more material can be removed from the teeth if necessary. The cross sections can also be studied for patterns of abnormal growth that could indicate periods of dietary stress. My research not only contributes to the literature about Neolithic France, but the methods I used to conduct it allow future research to take place using these samples.

1.4 Presenting Anthropology to the Public

Other factors that involve stakeholders and the public include how the information is presented, and whether this helps or hurts the people involved. This research will contribute to the current understanding of the lifeways of people in Southern France during the Neolithic period. It will add to our understanding of the settlement and movement patterns of these people, which can contribute to the larger understanding of the evolution of these practices in the region. This addresses the heritage of the local people, who are not necessarily descendants of such ancient people, but who share the same landscape and history. This research will be part of the exhibit on the site of Roquemissou at the museum in Montrozier, the Espace Archéologique Départemental de Montrozier. While this research will also be published in an academic journal in English, this exhibit allows the local people to learn about and engage with the prehistoric heritage of their landscape in a much more accessible way. This highly popular museum will allow French adults and children to access this information easily. The museum is also a popular tourist destination, thus knowledge about this region and its heritage will be spread to people from around the world, and in doing so it will aid the museum and the local population who benefit from tourism.

1.5 Intent for Publication

I intend to publish this research in the *International Journal of Osteoarchaeology*. This is a well-respected, peer-reviewed journal that focuses on studies of human and animal bones from archaeological contexts. This includes isotopic studies that attempt to reconstruct the lifeways of prehistoric people (International Journal of Osteoarcheology 2019). My research fits well with the journal's themes as it focuses on using strontium isotopes in the dental enamel of people from Neolithic Southern France to identify their seasonal movement patterns. The *International Journal of Osteoarchaeology* will provide a valuable medium that will allow me to contribute this research to the body of research on strontium isotope studies and Neolithic Southern France.

Chapter 2: Mobility of People Buried at Roquemissou

2.1 Introduction

The site of Roquemissou is located in the Aveyron department of Southern France, in the township of Montrozier, shown on the map in Figure 1. It is positioned on the edge of the Aveyron river at the foot of a 15-20m high wall of Bajocian oolithic limestone that hangs over and shelters the site in the areas where it has not collapsed (Perrin et al. 2018). This large overhang, which shelters the site by up to 4-5 meters in some areas, has preserved its stratigraphy for millennia and protected it from washing into the Aveyron. Roquemissou was initially discovered in 1978 and, in the following decade, ten excavations led by Gaston-Bernard Arnal uncovered a stratigraphic history ranging from the Upper Paleolithic to the Early Neolithic (Arnal 1991). A small 3.5m by 1.5m rock shelter in the cliff above the village site that contained a comingled assortment of prehistoric human remains was also excavated. Arnal (1991) and his team estimated a minimum of thirty individuals were interred in this ossuary during the Late Neolithic and Chalcolithic. Excavations of a second burial shelter near the site also took place at some point between the 80s and 90s, but the museum that houses the remains in Montrozier, the current excavation team, and the original excavation teams do not have any documentation, published or otherwise, on the details of this excavation (Jackes 2017: 95). The excavated remains from both shelters were stored at the Espace Archéologique Départemental de Montrozier, where they underwent little to no analyses until recently.

Figure 1: Map of France with the location of Roquemissou highlighted (Perrin et al. 2018: 328).

Excavations at the site began again in 2012 under the direction of Dr. Thomas Perrin, with renewed interest in exploring the Neolithic cultures at the site (Perrin et al. 2018). Dr. Perrin and his team have defined a clear stratigraphic sequence at the site with radiocarbon dates stretching from 11,300 cal. BC to 2300 cal. BC (Perrin et al. 2018). One of the major foci of the project has been on the Neolithic – the transition and interaction between multiple occupations during the Mesolithic and Early Neolithic, as well as the large village that existed at the site during the middle of the 3rd millennium BC in the Late Neolithic. This Late Neolithic layer was associated with the human remains from the burial shelters, so the team was also interested in analyzing the remains that were in storage. In 2016 examination of the material held at the Espace Archéologique Départemental de Montrozier began under the direction of Dr. Mary Jackes and Dr. David Lubell. Analyses of these skeletal materials proved difficult due to the lack of proper documentation and labelling from the original excavations, as well as the loss and damage of many of the original labels during a previous study's attempt to organize the material in the 1990s (Jackes 2017: 95). Despite these setbacks, researchers have been able to glean a great deal of information from these skeletons, particularly from the teeth, which were excavated very carefully and retained more of their original documentation and labels. The minimum number of individuals is currently estimated to be 45, with at least 18 individuals under the age of 10 (Jackes 2018: 75). Radiocarbon dates have also been recorded from two of the fibulae in the collection, these dates are represented in Table 1. These dates fit within the early ranges of the Late Neolithic village layer at the site (Perrin 2018: 101).

Laboratory ID	Raw Date	Cal. BC 2σ
Beta-459916	4410 ± 30	2917 – 3308
Beta-459917	4520 ± 30	3101 – 3356

Table 1: Results of radiocarbon analysis from the interosseous crests of 2 fibulae from the main shelter analyzed at the Beta Analytic lab in Miami (USA) (Perrin 2017: 115).

In the Late Neolithic, there was a major shift from the wide-reaching Chasseén culture to a vast number of regionally specific ceramic cultures. In the area around Roquemissou there are over a dozen recorded ceramic cultures during the Neolithic, many of which exhibit very little influence from other cultures (Cauliez 2016: 193). This is often associated with a transition from the small, single family settlements across the landscape of the Middle Neolithic to larger organizations of people with a shared cultural background or possible tribe-like affiliation (Vander Linden 2006). The Late Neolithic at Roquemissou is split into two phases, one dated to 2600-2500 BC which is mostly dominated by the Treilles culture, and the second dated to 2300 BC which contains more Campaniforme pyrénéen material, or what is called the Bell Beaker culture in English (Cauliez 2016: 201). The Bell Beaker culture was a ceramic tradition that spread across a large portion of Europe, but instead of representing an influx of new people wherever it is found, there are many examples of this ceramic style being partially adopted by local indigenous populations who maintained many of their original traditions as well (Vander Linden 2006). For this reason, and because of the persistence of some older styles alongside it throughout the Late Neolithic layer of Roquemissou, the presence of Bell Beaker material at the site is considered an adoption of this style by the local people of Treilles origins (Cauliez 2016: 202). The Treilles culture is found at sites dating from 3500-2200 BC throughout the Grands Causses, a region of limestone plateaus and valleys in the Southern Massif Central (Herrscher et al. 2013). Agriculture and animal herding practices outweighed hunting and fishing as the main means of subsistence for these people, with an emphasis on herding (Herrscher et al. 2013; Vander Linden 2006). The burial practices of these and other Late Neolithic people in this region also see a shift associated with a trend towards social cohesion among larger groups of people with a shared culture. The use of megalithic tombs and cave burials of the Middle Neolithic Chasseén culture shift from individual elite burials to larger communal burials of people of the same culture who could come from a single, large village, or all across this culture’s shared territory (Beyneix 2007; Herrscher et al. 2013; Vander Linden 2006). Roquemissou is located within the traditional Treilles cultural range, and the group burials dated to this time period appear to be representative of the Treilles burial practices. The site of the Grotte I des Treilles, which is roughly 100 km South of Roquemissou in the township of Saint-Jean-et-Saint-Paul, contains a large burial ossuary with a minimum of 149 individuals associated with the Treilles culture (Herrscher et al. 2013). There have been DNA (Lacan et al. 2011), and isotopic analyses of Treilles burials using ^{15}N and ^{13}C to examine diet (Herrscher et al. 2013), but to my knowledge there are no current studies of mobility using strontium isotopes for any Treilles ossuaries of Southern France.

The Late Neolithic was a period of considerable variation and specialization across and within different cultures. It was a period of increased sedentism and emphasis on farming in some places, and structured mobility in cultures which specialized in herding animals to different grazing areas across the landscape with the seasons (Bouby et al. 2019; Geddes 1983). The mobility and origins of the people interred in the rock shelters of Roquemissou are unknown, and there is archaeological evidence to suggest both long term residence of the Late Neolithic village layer, and burial practices integrating people from across a large territory that includes many semi-mobile herders. The objective of this thesis is to identify whether these burials represent people who lived near the site or people from across the landscape, through strontium isotope analysis. Isotopic analysis of strontium to identify residence usually involves comparing the strontium in an individual's bones with that of their enamel to differentiate between the isotopic signature of the landscape inhabited at the end of the individual's life with that of the earliest years of their life (Price et al. 1994). This is difficult to apply at Roquemissou because the comingled nature of the remains makes it impossible to associate the teeth and bones of specific individuals. The method applied in this research examines changing strontium ratios in just enamel, which has the added benefit of microspatial analysis of patterns of mobility over time. Enamel grows in layers that radiate out from the dentinoenamel junction and begin to form successively at a rate of 4 microns per day, with the earliest layers starting at the dentin horn, and the latest layers near the cervix (Hillson 1996). While the process of mineralization does not follow this time frame as precisely, permanent incorporation of strontium into the enamel matrix still happens chronologically from the first layers to be formed until the final ones, and changes in the $^{87}Sr/^{86}Sr$ ratio in the enamel from cusp to cervix represent chronologically different levels of $^{87}Sr/^{86}Sr$ absorption from different landscapes inhabited by the individual over the course of the development of the tooth's enamel (Meiggs 2007). Several studies have examined this pattern in animal (Bentley & Kinpper 2005; Gerling et al. 2017), human (Bentley et al. 2008) and other hominin (Richards et al. 2008) tooth enamel, and have identified patterns of shifting ^{87}Sr/^{86}Sr ratios in and out of local ranges suggesting patterns of seasonal movement across the landscape. The method of examining changing strontium ratios across the growth bands of enamel in humans and animals has been suggested as a way of examining the presence of transhumant practices (Meiggs 2007), and several studies have applied this to Neolithic populations to identify the presence of transhumance or sedentism in France (Goude et al. 2012), Germany (Bentley & Knipper 2005; Bentley et al. 2008) and Switzerland (Gerling et al. 2017). The samples for this project consist of 17 human third molars from both burial shelters, which would be compared with the expected local range based on geological data and faunal samples. Third molar enamel develop between the ages of 8 and 13 (AlQahtani 2010), so the strontium in the enamel should represent the residence and mobility patterns of these individuals during early adolescence. A *Bos* first molar excavated from the Late Neolithic layer of the site was also examined, with the intention of looking for patterns of seasonal mobility associated with transhumant pasturing as an explanation for any similar patterns in the human enamel. First molars in cattle develop for 6 months, the first two thirds of which happens *in utero* (Hillson 1996). The variability or homogeneity of the strontium ratios in these individuals will provide greater understanding as to whether these Late Neolithic people were mostly sedentary residents of the site or were composed of a broader cultural group of wide-ranging individuals who were interred together at this site.

2.2 Methods

2.2.1 Sample Preparation

The enamel of third molars was chosen for analysis because it develops later in life than for other teeth and takes longer to develop, providing a useful gauge of individuals' strontium intake from roughly the ages of 8 to 13 years old (AlQahtani et al. 2010). Seventeen loose third molars were selected from the Roquemissou sample by Mary Jackes, and their positive identification as third molars was verified by Dr. Mary Jackes, Dr. Alexis Dolphin, and myself based on morphological characteristics. The teeth were then photographed using a Nikon D5300 with a Nikon Macro lens. They were then embedded in EpoFix resin (Struers) and cut longitudinally into 2 mm thin sections using a Buehler Isomet slow-speed saw. Three faunal teeth were also chosen for use in this study, one caprine, one bovine, and one fox. These were also embedded in resin and sectioned. The 20 samples were mounted on 9 petrographic slides using Crystalbond adhesive.

2.2.2 Laser Ablation – Multi-Collector – Inductively Coupled Plasma – Mass Spectrometry (LA-MC-ICP-MS)

Laser ablation of the teeth was carried out using an Analyte G2 Excimer laser (Photon-machines, Bozeman, MT, USA). Analytical methods are similar to those reported in Meijer et al. (2019). The teeth were placed on a stage with the enamel surface in view of the laser, alongside several National Institute of Standards and Technology (NIST) and in-house standards. First, the instrument's high-magnification camera was used to target points to be lasered on the standards, as well as plot lines along the exposed inner surface of the dental enamel of the Roquemissou samples. These lines were plotted approximately 100 microns away from the dentinoenamel junction (DEJ), starting at the earliest enamel formed just above the dentine horn, running parallel to the DEJ, towards the root and across the multiple growth bands, until ending at the latest enamel formed (See example in Figure 2).

Figure 2: Sample L5 with a line indicating the location of laser sampling.

To remove external contamination the samples were pre-ablated with the laser at 20 Hz, with a fluence of 4 J/cm^2 in a 150 micron diameter spot that ran down the pre-selected line at 200 microns per second. For analysis of the ^{87}Sr/^{86}Sr ratios, the enamel was ablated at 20 Hz with a fluence of 4.5 J/cm^2 and a 110 micron diameter spot moving at a rate of 20 microns per second. Data were collected on a Nu Plasma II Multi-collector Inductively Coupled Plasma Mass Spectrometer (Nu Instruments, Wrexham, UK). The instrument was tuned to minimize oxide production even at the expense of sensitivity in order to minimize the generation of polyatomic ions that could interfere with the ^{87}Sr and reduce accuracy (e.g. Willmes et al. 2016a). Raw data were reduced using the Sr isotope data reduction scheme in the Iolite software package (v. 3.6; Paton et al. 2011), which corrects for instrumental mass fractionation, ^{87}Rb interference on ^{87}Sr, and ^{86}CaAr interference on ^{86}Sr.

Laser Ablation Operating Parameters	
Laser Ablation Instrument	Analyte G2 Excimer
Pre-Ablation	
Scan Type	Line
Beam Width	150 µm
Transition Rate	200 µm/s
Frequency	20 Hz
Fluence	4 J/cm^2
Ablation for Analysis	
Scan Type	Line
Beam Width	110 µm
Transition Rate	20 µm/s
Frequency	20 Hz
Fluence	4.5 J/cm^2
Carrier Gases	
He	1.1 L/min
Ar	1.0 L/min
MC-ICP-MS Operating Parameters	
MC-ICP-MS	Nu Plasma II
RF Power	1300
Cool Gas Flow Rate	1.3 L/min
Aux Gas Flow Rate	0.93 L/min
Interface Cones	Regular Ni cones for dry plasma condition
Mass Resolution	Low
Lens Settings	Optimized for minimal oxide production measured prior to Sr isotope analyses on NIST610 and monitoring ^{232}Th and ^{16}O^{232}Th
Collector Assignment/Isotopes Measured	H8-^{88}Sr
	H7-^{87}Sr, ^{87}Rb
	H6-^{86}Sr, ^{40}Ar^{46}Ca, ^{40}Ar^{16}O^{31}P, ^{40}Ca^{16}O^{31}P
	H4-^{85}Rb
	H2-^{84}Sr, ^{40}Ar^{44}Ca
	Ax-^{82}Kr, ^{40}Ar^{42}Ca

Table 2: Laser Ablation and MC-ICP-MS Operating Conditions.

2.2.3 Data Reduction

The tooth values were compared to several in-house standards including modern shark, racoon, groundhog, horse, and walrus enamel. These standards were independently analyzed using Thermal Ionization Mass Spectrometry (TIMS) to evaluate the accuracy of the ^{87}Sr/^{86}Sr ratios measured with LA-MC-ICP-MS. Analyses were conducted with a Thermo Scientific Triton TIMS at the Environmental Isotopes Lab at the University of Waterloo. Microscopic amounts of enamel from the three faunal samples, as well as one of the human samples (L7) were also analyzed using TIMS to compare to the LA-ICP-MC-MS ratios. The ratios of the faunal samples were similar, only varying slightly at the fourth decimal place. However, the ratios for human tooth L7, with a very low concentration of Sr (~20 ppm), differed from 0.7144 to 0.7122, which is significant. We speculate that this is due to interference of polyatomic ions (e.g. $^{40}Ca^{31}P^{16}O$ or $^{40}Ar^{31}P^{16}O$) on ^{87}Sr (e.g. Horstwood et al. 2008), which is more prevalent for low signals on Sr.

The sample originally consisted of 17 human third molars and 3 faunal teeth, but several of the human teeth were excluded from further analysis due to potential problems with background interference. Samples L3, L6, L7, L10, R1, and R6 were removed for their low ratios of $^{84}Sr/^{86}Sr$ (<0.051) that are different from natural ratios (~0.056), which suggests polyatomic interference that could not be corrected for of interference from ^{84}Kr and ^{86}Kr. The ratios of $^{84}Sr/^{86}Sr$ should remain within the range of 0.051-0.056 in enamel, and ratios outside of this range could suggest interference from ^{84}Kr and ^{86}Kr (Copeland et al. 2010). Samples L4 and R3 were also removed due to very low ^{88}Sr signal strength during their analysis and for the potential for non-resolvable polyatomic interference. Low signal strength is problematic because it allows for greater possible contamination by ArPO and CaPO on mass 87. There are corrections that can be made during data analysis to eliminate or mitigate these interferences, but for the purpose of this thesis the more problematic samples were removed to maximize the confidence with which these results could be presented. From this point on, discussion of the sample refers only to the 9 human and 3 faunal remains that are within this range of reliability.

2.2.4 Analysis of Diagenesis

The samples were also analyzed for concentrations of trace elements using three 50 micron spots near the beginning, middle, and end of each line at 5 Hz with a fluence of 4.5 J/cm^2 for 40 seconds (following 3 blasts of the same spot at 65 microns for pre-ablation), and the results analyzed in an Agilent Technologies 8800 ICP-MS Triple Quad (Agilent Technologies, Santa Clara, USA). The elements and appropriate isotopes analyzed were ^{31}P, ^{43}Ca, ^{44}Ca, ^{66}Zn, ^{67}Zn, ^{68}Zn, ^{88}Sr, ^{137}Ba, ^{138}Ba, ^{232}Th, and ^{238}U. NIST612 was used for standardization and ^{43}Ca was used as the internal standard. Data were reduced using Iolite v 3.6 (Paton et al. 2011) using the trace element internal standardization data reduction scheme. The Ca/P ratio was normalized to that of the Durango apatite. These results are presented in the Table in appendix A.

Trace elements were examined to identify possible diagenetic changes to the enamel chemistry. Ca/P ratios for each spot remained within the recommended range of 1.8-2.7 (Kohn et al. 1999; Szostek et al. 2012), suggesting that the enamel was unaltered by diagenesis. Th and U are both elements that enter the enamel almost entirely through diagenesis, and their presence in higher quantities in enamel suggests contamination. At each of the spots analyzed on these teeth, Th concentrations were mostly around 0.01 ppm or below, with only two outliers reaching unusual levels of 0.03 ppm and 0.04 ppm (c.f. Willmes et al. 2016b). Uranium concentrations were also in the expectedly low ranges, mostly around 0.01 ppm and below, with only a few outliers reaching as high as 0.05 ppm. For both elements the teeth that were included in this study fall within expected ranges of unaltered material and do not suggest significant diagenetic contamination (Kohn et al. 1999; Willmes et al. 2016b).

Sr concentrations were also measured, as unusual quantities of Sr has also been suggested as an indicator of diagenesis (Kohn et al. 1999; Willmes et al. 2016b). The average Sr concentrations in these teeth are lower than normal, and while the included samples fall within the expected range of 50 – 500 ppm (Willmes et al. 2016b), most are under 100 ppm. While these low concentrations of Sr do not suggest diagenetic contamination of these teeth, it does reduce the precision of ^{87}Sr/^{86}Sr ratios and makes them more susceptible to polyatomic interference, which can hinder accuracy as discussed above.

2.2.5 Representing the Data

To visualize the changes in strontium over time the raw data was segmented into blocks of approximately 18-24 seconds of laser scanning using the Iolite data processing program. Because human enamel grows at approximately 4 microns per day, and the laser ran at a speed of 20 microns per second, each second should represent roughly 5 days of enamel growth, so these 18-24 second blocks represent the average of roughly 90-120 days (or 3-4 months) of enamel growth (e.g. R2 – Point 1 is an average of 20 seconds of laser scanning time. 20 x 5 = 100 days of enamel growth approximately). In cattle, the enamel of the first molars develops over the course of roughly 6 months and mineralizes in roughly the same chronological pattern from cusp to cervix (Gerling et al. 2017; Hillson 1996). The approximate number of days of enamel growth for each point of the *Bos* tooth was estimated by dividing the average development time of bovid enamel (6 months) with the number of points (21). These are all rough estimations to help visualize the progression of time, and their accuracy may vary.

2.3 Results

The results of the LA-MC-ICP-MS analysis of the human and *Bos* teeth are represented in Table 3. This includes the ratio of ^{87}Sr/^{86}Sr and 2 standard errors, as well as the signal strength (^{88}Sr V) and ratio of ^{84}Sr/^{86}Sr, which were used to preclude various interferences. Each point represents an average of these values over a number of growth bands, and the approximate number of days these bands took to grow is represented as well. The caprine and fox teeth were not sectioned into multiple points using the Iolite program, and their ^{87}Sr/^{86}Sr ratios were recorded as an average of the total line analyzed by the laser. These numbers are 0.7121 and 0.7076 for the caprine and fox respectively.

Sample	**Signal Strength (^{88}Sr V)**	**^{84}Sr/^{86}Sr**	**^{87}Sr/^{86}Sr**	**2 SE**	**Approximate Days of Enamel Development**
R2					
Point 1	0.2658	0.0521	0.7114	0.0012	100
Point 2	0.2433	0.054	0.7116	0.0015	195
Point 3	0.2346	0.0537	0.7118	0.0014	310
Point 4	0.2301	0.0563	0.7109	0.0015	410
Point 5	0.2272	0.0522	0.7116	0.0016	505
Point 6	0.2063	0.0567	0.7123	0.0016	610
Point 7	0.1942	0.0567	0.7119	0.0015	710
R4					
Point 1	0.0990	0.0502	0.7170	0.0032	100
Point 2	0.1012	0.0531	0.7153	0.0032	205
Point 3	0.0997	0.0580	0.7175	0.0034	300
Point 4	0.1052	0.0549	0.7168	0.0030	400
Point 5	0.1085	0.0521	0.7183	0.0028	500
Point 6	0.1118	0.0565	0.7205	0.0028	600
Point 7	0.1119	0.0551	0.7188	0.0028	705
Point 8	0.1285	0.0559	0.7189	0.0025	800
Point 9	0.1486	0.0519	0.7186	0.0031	860
R5					
Point 1	0.4814	0.0563	0.7176	0.0006	120
Point 2	0.4121	0.0556	0.7179	0.0008	230
Point 3	0.4032	0.0556	0.7187	0.0008	330
Point 4	0.4031	0.0566	0.7180	0.0008	440
Point 5	0.4432	0.0572	0.7183	0.0008	555
Point 6	0.4369	0.0564	0.7186	0.0008	645
Point 7	0.4219	0.0553	0.7183	0.0009	740
Point 8	0.4113	0.0556	0.7188	0.0008	860
Point 9	0.3419	0.0568	0.7187	0.0010	970
Point 10	0.3010	0.0552	0.7190	0.0012	1065
Point 11	0.3835	0.0559	0.7182	0.0008	1155
R7					
Point 1	0.1420	0.0568	0.7125	0.0023	110
Point 2	0.1719	0.0539	0.7124	0.0018	225
Point 3	0.1891	0.0509	0.7121	0.0017	335
Point 4	0.1945	0.0504	0.7109	0.0018	435
Point 5	0.1977	0.0579	0.7116	0.0016	555
Point 6	0.1697	0.0581	0.7105	0.0017	665
Point 7	0.1659	0.0561	0.7123	0.0024	775
Point 8	0.2477	0.0501	0.7113	0.0014	890
Point 9	0.3137	0.0473	0.7117	0.0011	1005
Point 10	0.2885	0.0508	0.7114	0.0012	1110
Point 11	0.2251	0.0516	0.7132	0.0021	1160
L1					
Point 1	0.1631	0.0560	0.7152	0.0019	120
Point 2	0.1466	0.0540	0.7139	0.0020	235

Sample	Signal Strength (^{88}Sr V)	^{84}Sr/^{86}Sr	^{87}Sr/^{86}Sr	2 SE	Approximate Days of Enamel Development
Point 3	0.1662	0.0544	0.7115	0.0022	330
Point 4	0.1812	0.0573	0.7088	0.0018	435
Point 5	0.2120	0.0570	0.7086	0.0017	555
Point 6	0.2207	0.0585	0.7114	0.0014	675
Point 7	0.1699	0.0557	0.7149	0.0079	780
Point 8	0.1864	0.0566	0.7098	0.0018	895
Point 9	0.2216	0.0575	0.7100	0.0016	1015
Point 10	0.2164	0.0542	0.7093	0.0014	1140
L2					
Point 1	0.1264	0.0563	0.7170	0.0026	110
Point 2	0.1264	0.0515	0.7183	0.0025	230
Point 3	0.1482	0.0524	0.7160	0.0019	350
Point 4	0.1385	0.0566	0.7161	0.0023	460
Point 5	0.1259	0.0523	0.7176	0.0022	595
Point 6	0.1001	0.0569	0.7188	0.0029	715
Point 7	0.1174	0.0562	0.7177	0.0030	830
Point 8	0.1160	0.0539	0.7176	0.0027	950
Point 9	0.0920	0.0504	0.7189	0.0037	1055
Point 10	0.1027	0.0571	0.7144	0.0042	1105
L5					
Point 1	0.2210	0.0543	0.7148	0.0013	110
Point 2	0.2249	0.0554	0.7152	0.0014	215
Point 3	0.2083	0.0587	0.7137	0.0015	320
Point 4	0.1750	0.0578	0.7152	0.0018	435
Point 5	0.1725	0.0558	0.7161	0.0021	530
Point 6	0.1929	0.0573	0.7140	0.0016	635
Point 7	0.2243	0.0568	0.7137	0.0015	745
Point 8	0.1983	0.0556	0.7143	0.0016	865
Point 9	0.2659	0.0566	0.7144	0.0012	965
Point 10	0.2422	0.0562	0.7141	0.0020	1015
L8					
Point 1	0.1688	0.0554	0.7099	0.0017	110
Point 2	0.1534	0.0538	0.7104	0.0020	225
Point 3	0.1583	0.0533	0.7123	0.0016	345
Point 4	0.1490	0.0561	0.7121	0.0019	460
Point 5	0.1506	0.0534	0.7128	0.0022	570
Point 6	0.1420	0.0557	0.7138	0.0020	675
Point 7	0.1548	0.0535	0.7131	0.0027	750
L9					
Point 1	0.9218	0.0552	0.7080	0.0004	105
Point 2	0.9474	0.0552	0.7079	0.0004	220
Point 3	0.9519	0.0547	0.7083	0.0003	320
Point 4	0.9588	0.0547	0.7079	0.0004	430
Point 5	0.9251	0.0545	0.7080	0.0004	535
Point 6	1.0084	0.0550	0.7078	0.0004	635
Point 7	0.9468	0.0546	0.7079	0.0004	740
Point 8	0.9166	0.0547	0.7079	0.0004	845
Point 9	0.9427	0.0550	0.7075	0.0004	955
Point 10	1.111	0.0547	0.7072	0.0004	1055
Bos					
Point 1	1.2834	0.0556	0.7207	0.0003	8

Sample	Signal Strength (^{88}Sr V)	^{84}Sr/^{86}Sr	^{87}Sr/^{86}Sr	2 SE	Approximate Days of Enamel Development
Point 2	1.1692	0.0553	0.7200	0.0003	17
Point 3	1.0343	0.0546	0.7195	0.0003	25
Point 4	0.9828	0.0550	0.7193	0.0003	34
Point 5	0.9572	0.0552	0.7192	0.0004	42
Point 6	0.9570	0.0554	0.7189	0.0004	50
Point 7	0.9453	0.0551	0.7187	0.0004	59
Point 8	0.9380	0.0559	0.7188	0.0004	67
Point 9	0.9333	0.0554	0.7185	0.0004	75
Point 10	0.8308	0.0558	0.7183	0.0004	84
Point 11	0.8055	0.0557	0.7182	0.0004	92
Point 12	0.9230	0.0564	0.7182	0.0004	101
Point 13	0.9132	0.0554	0.7183	0.0004	109
Point 14	0.9476	0.0559	0.7188	0.0004	118
Point 15	0.8987	0.0545	0.7183	0.0004	126
Point 16	0.8555	0.0560	0.7184	0.0004	135
Point 17	0.8356	0.0554	0.7187	0.0005	143
Point 18	0.8477	0.0565	0.7185	0.0004	152
Point 19	0.8768	0.0534	0.7193	0.0016	160
Point 20	0.9022	0.0570	0.7189	0.0004	169
Point 21	0.9048	0.0570	0.7195	0.0006	177

Table 3: Results of LA-ICP-MS analysis for each tooth by points averaging approximate enamel growth over 3-4 months created with the Iolite program (Paton et al 2011).

Further discussion of these results will occur in the following sections.

2.3.1 Establishing a Local Range of ^{87}Sr/^{86}Sr Ratios

The region of the Southern Massif Central is very geologically diverse, and therefore has a very wide range of biologically available ^{87}Sr/^{86}Sr ratios. Maps of the strontium distribution in the region using plant, soil, and rock samples – such as the one in Figure 3 – identify a wide array of ^{87}Sr/^{86}Sr ratios ranging from below 0.705 to above 0.721 (Willmes et al. 2018). These maps are valuable to the interpretation of ^{87}Sr/^{86}Sr ratio data because they provide contextual information for the distribution of biologically available strontium across the landscape. Roquemissou itself is situated in the Aveyron valley adjacent to a large outcrop of limestone, which is part of the large formation of Jurassic limestone that forms the bedrock in this valley and throughout the Grands Causses to the East (Goude et al. 2012; Willmes et al. 2018).

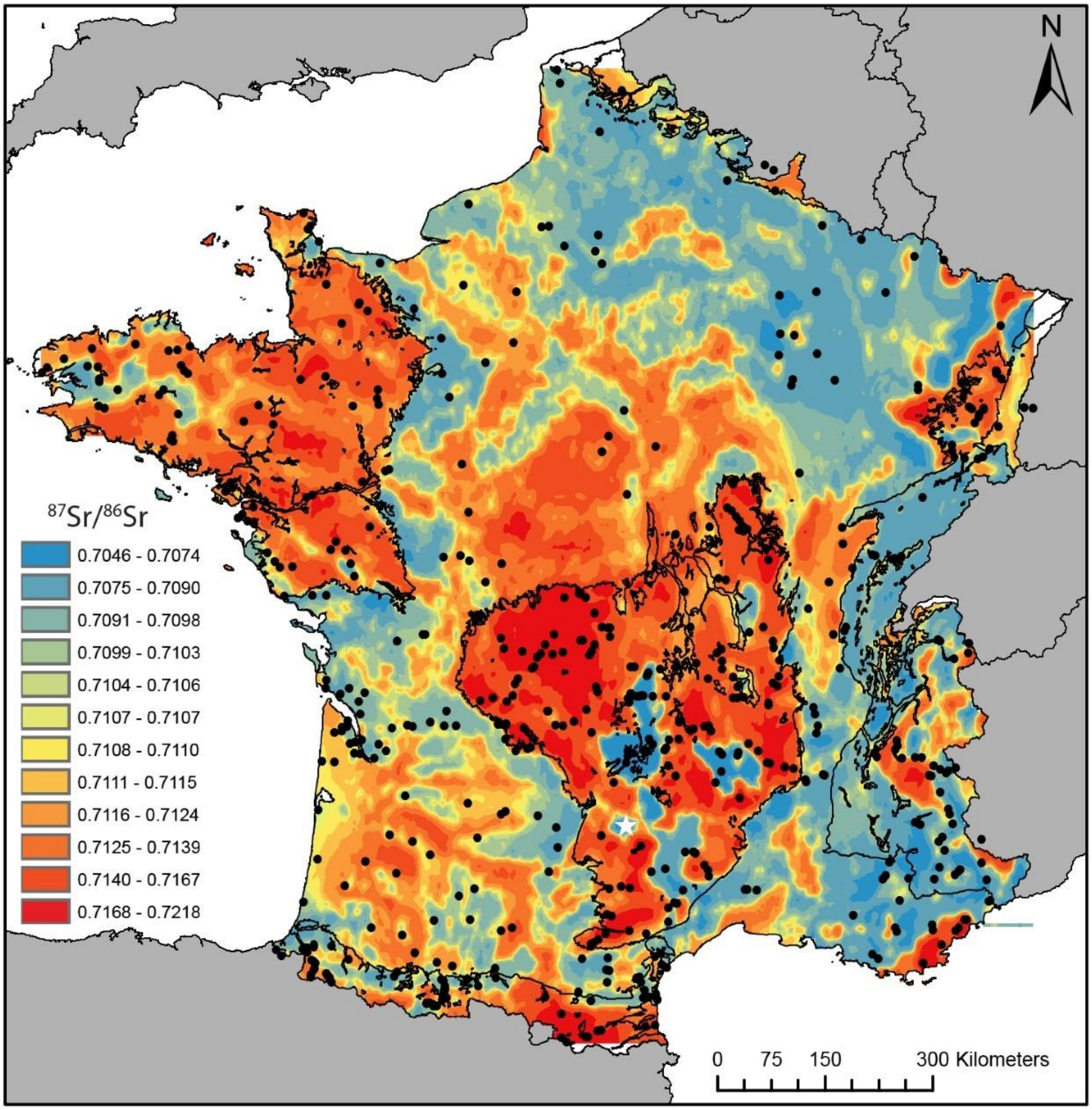

Figure 3: Map of the distribution of biologically available ratios of ^{87}Sr/^{86}Sr across France with Roquemissou indicated with a white star (Willmes et al. 2018: 84).

Limestone typically has ^{87}Sr/^{86}Sr ratios on the lower end of the spectrum, and this valley has expectedly low biologically available strontium ratios according to analyses of local soil samples, including a soil sample collected from roughly 750 m away from the site of Roquemissou that had a ^{87}Sr/^{86}Sr ratio of 0.7093 (Moffat 2013). This roughly 35 km wide pocket of low biologically available strontium within which the site is located is surrounded by highlands with much higher ratios, which exceed 0.711 and even 0.7168 in some places (Willmes et al. 2018). The local range is therefore difficult to determine purely based on maps of biologically available strontium, because if the inhabitants of the site hunted or foraged food even 10 km from the site it would greatly increase their average $^{87}Sr/^{86}Sr$ ratios. The faunal samples were analyzed to address this issue and help identify what the local range might be. The fox enamel has an average $^{87}Sr/^{86}Sr$ ratio of 0.7076, the caprine of 0.7121, and the bovid of 0.7196. The ratio in the fox fits the expected range for this region based on the geology and other soil samples, so it likely lived locally, within the valley. The caprine ratio is somewhat higher than expected in the immediate region of the site, and likely lived further outside of the Aveyron valley. If this animal were consumed for food then it would increase the overall average $^{87}Sr/^{86}Sr$ ratios in the inhabitants of Roquemissou, and it suggests that their hunting and foraging range could expand into regions with this slightly higher $^{87}Sr/^{86}Sr$ ratio. The bovid has a very high strontium ratio that is clearly not local to the site, though could come from the highlands roughly 10 km to the South. The final decision on the expected local range for the site is that it should fall between the ratios of the fox and caprine, between 0.7076 and 0.7121. This range includes the expected range based on geological and soil samples, while allowing for a slightly larger range of mobility that includes some of the surrounding highlands that may also have been sources of food. This estimation of local range is a rough approximation of the expected dietary strontium intake for people who lived at the site and sourced their food locally but could be improved in the future with the analysis of more samples.

2.3.2 Individual L1

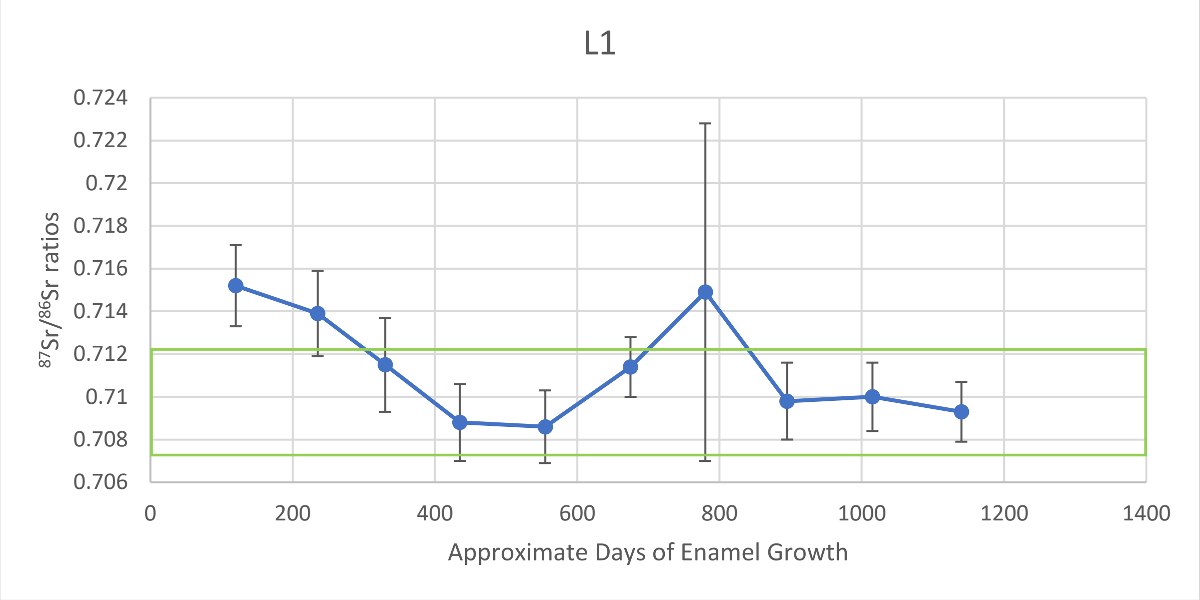

Figure 4: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual L1 ± 2 SE. Local range indicated by green box.

The first point (which represents roughly the first 120 days, or 3-4 months of enamel growth) starts at 0.715 and gradually descends to under 0.709 by point number 4 (which is roughly 435 days from the beginning of the first month recorded by point 1). Point 5 remains under 0.709 and within the expected local range (represented by the green box) and point 6 begins to rise again to close to the upper limit of the local range at 0.7114. Unfortunately, point 7 contains 5 extreme outliers (the largest one above 3) that were included in the average of this point when it was created in the Iolite program, so it has large margins of error, is likely much higher than it should be, and can be disregarded for this current analysis. Point 8 drops back down to just below 0.710, where the range remains constant for the final 2 points. The standard error for most of the points is roughly 0.002 in each direction, so while the error bars of the second and even third points overlap with those of the first, the lowest two points 4 and 5 are completely outside this range, suggesting that this is a statistically significant change. The error bars of point 6 overlap with those of the lower points 4 and 5, as well as 8, 9, and 10, and because point 7 is unusable it cannot be stated with confidence that this second rising pattern represents a real change in the $^{87}Sr/^{86}Sr$ ratios.

The first point represents roughly 120 days of enamel growth starting approximately around age 8, and suggests that this individual lived in a region of much higher local $^{87}Sr/^{86}Sr$ ratios than Roquemissou during this time. The next three points indicate a significant drop in the local $^{87}Sr/^{86}Sr$ ratios, over the course of roughly 315 days. By point 4 the ratio is well within the local range of Roquemissou, where the ratio remains for the duration of enamel growth represented by point 5, or roughly the following 120 days. Then for the following point 6, the $^{87}Sr/^{86}Sr$ ratio increases to 0.7114, which is still within the expected local range, but much closer to the upper edge. This could indicate that this individual had moved to the periphery of the local Roquemissou area, or it could suggest that L1 spent part of this period of approximately 120 days at Roquemissou starting a gradual move to a landscape with a higher local $^{87}Sr/^{86}Sr$ range, possibly even the one inhabited during the period of time represented by point 1. This possible movement back to a region with much higher $^{87}Sr/^{86}Sr$ ratios for point 6 is still within the margins of error for the other points well within the local range of Roquemissou, and because point 7 is unusable due to its extreme outliers it cannot be used to confirm what the local $^{87}Sr/^{86}Sr$ ratios were during the following period of approximately 105 days of enamel growth. Finally, points 8, 9, and 10 are all back comfortably within the local range of Roquemissou, close to 0.710. The margins of error for these three points are all within the limits of the local range, so this individual almost certainly spent these roughly 360 days of the early teenage years in the local area of the site.

2.3.3 Individual L2

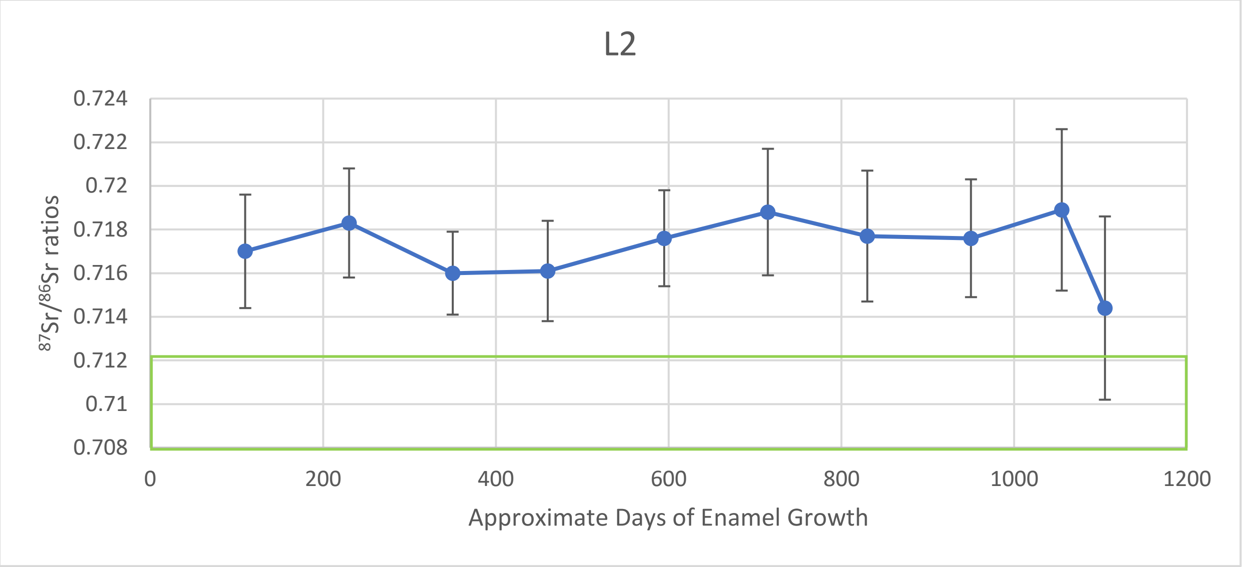

Figure 5: Average $^{87}Sr/^{86}Sr$ ratios over approximate number of days of enamel growth for individual L2 ± 2 SE. Local range indicated by green box.

This individual had very low overall quantities of strontium, causing much greater variation and greater analytical uncertainties. Because of these large margins of error which, for almost every point, overlap with the neighbouring points, none of the patterns in this line can be accepted as real variation. It is safer to assume that this individual lived entirely within the local range of ~0.717 for roughly the ages of 8-11, or three years of enamel growth represented by this graph.

Despite the limitations of the data, a lack of shifting $^{87}Sr/^{86}Sr$ ratios over time can offer a great deal of information about this individual. L2 likely did not live at Roquemissou during the entirety of the approximately three years of adolescence that the enamel of this tooth took to grow, or if this individual did the diet was composed largely of food sourced from away from the site. Only the final point, number 10, has even its margins of error overlap with the local range of Roquemissou, but these are particularly large margins of error and the point could just as easily be higher and closer to the previous points. This individual likely lived in a region with higher local $^{87}Sr/^{86}Sr$ ratios from the ages of roughly 8-11, in the range of 0.717. These are particularly high for overall local ranges according to the map of $^{87}Sr/^{86}Sr$ distribution by Willmes et al. (2018) represented in Figure 3, and likely restricts this person to a small number of constrained regions of the Massif Central – the closest of which being in the hills roughly 10km to the South of Roquemissou.

2.3.4 Individual L5

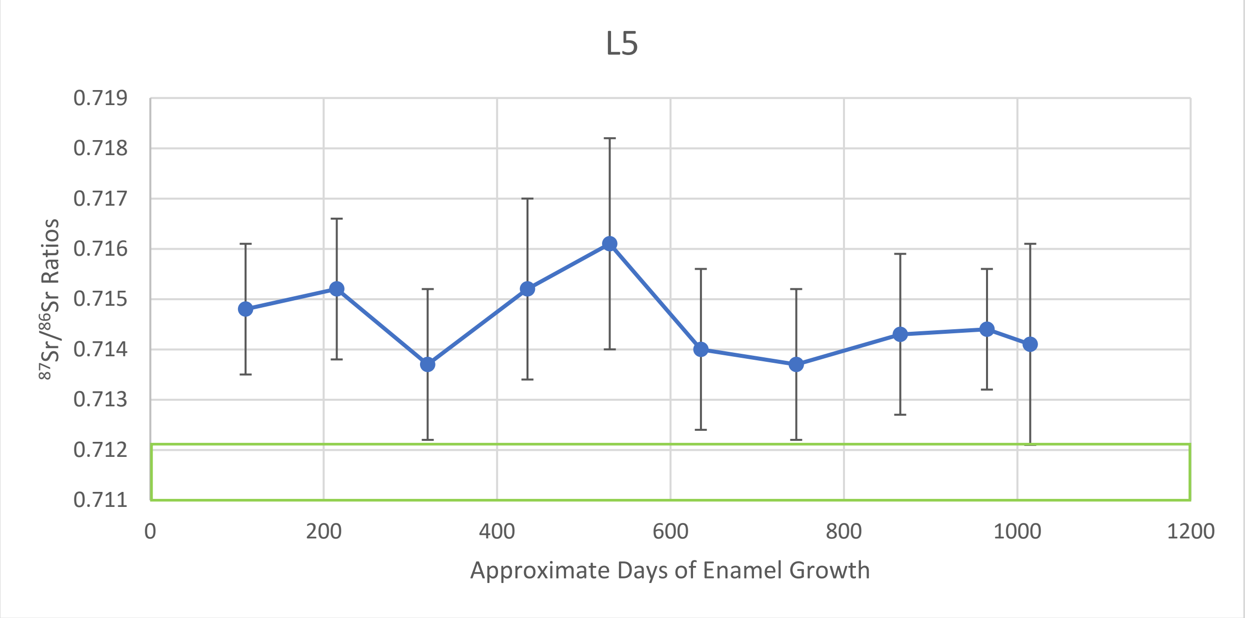

Figure 6: Average $^{87}Sr/^{86}Sr$ ratios over approximate number of days of enamel growth for individual L5 ± 2 SE. Local range indicated by green box.

This individual also has larger error bars caused by smaller quantities of overall strontium. While some of the very different points like point 3 at 0.7137 and point 5 at 0.7161 are outside of one another's margins of error, the error bars overlap and a middle point between 0.714 and 0.715 could still intersect with all of the error bars.

This individual was also likely a non-local who lived and sourced food outside of the local range of Roquemissou during the approximately 2.8 years of enamel growth starting around age 8 represented in this graph. L5 probably lived in a region with a local range of 0.714-0.715, and likely did not leave this region.

2.3.5 Individual L8

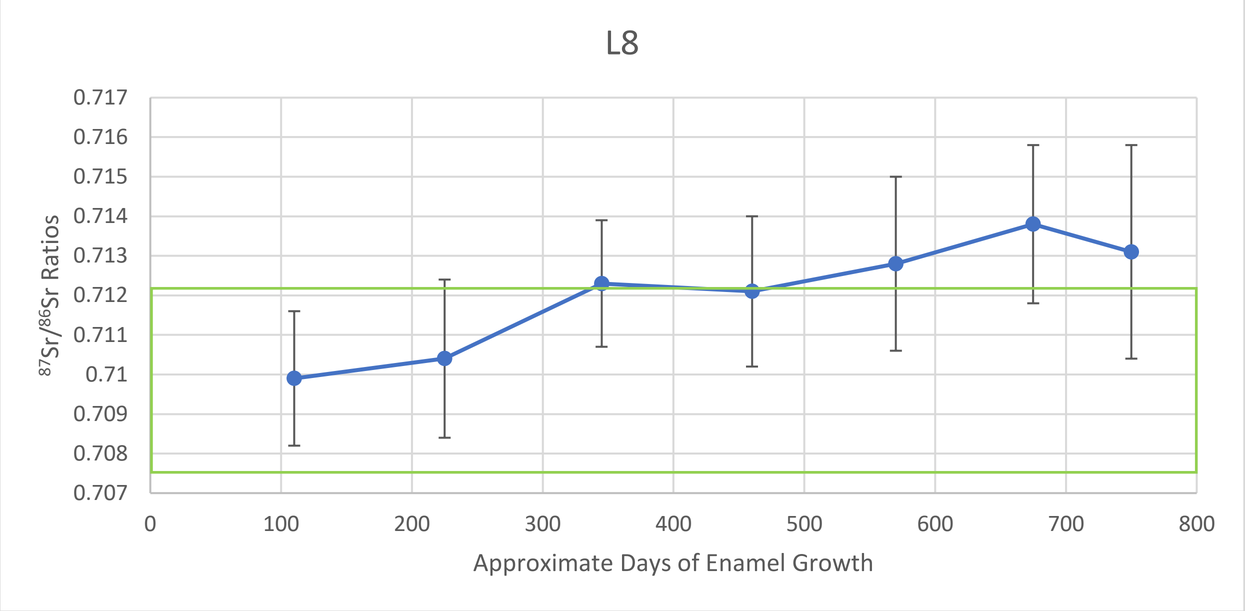

Figure 7: Average $^{87}Sr/^{86}Sr$ ratios over approximate number of days of enamel growth for individual L8 ± 2 SE. Local range indicated by green box.

This individual also had larger error bars due to low concentrations of strontium, but some of the variation between these points is still large enough to represent statistically significant variation. Point 1 starts well within the local range of Roquemissou at 0.7099. There is a steady increase in the following 5 points to 0.7104, 0.7123, 0.7121, 0.7128, and finally 0.7138. Point 6 is the highest point, and its margins of error do not overlap with those of the first and lowest point, meaning that this pattern of climbing $^{87}Sr/^{86}Sr$ ratios over the approximate 1.8 years of enamel growth represented by the first 6 points in this graph represents real change. The final point 7 does drop down a small amount to 0.7131, but it has the largest margins of error which overlap the entirety of those of the previous point, so it does not suggest real change with any confidence.

This individual likely lived in the local range of Roquemissou during the first roughly 110 days, starting at the age of 8, that are represented by this graph. Over the following 565 days the $^{87}Sr/^{86}Sr$ ratios in the enamel increased because L8 was moving across the landscape to regions of increasingly higher local strontium ranges, and by the approximate age of 10 likely lived outside of the local range of Roquemissou, in a region with local $^{87}Sr/^{86}Sr$ ratios closer to 0.714. Whether or not this gradual increase over time was temporary or permanent (at least until the eventual burial back at Roquemissou) is unclear as this shift to non-local residence occurs at the end of the enamel growth, which is still relatively early in this individual's life. What is clear is that this was not seasonal movement to and from Roquemissou, but the gradual movement away from the region over the course of almost two years.

2.3.6 Individual L9

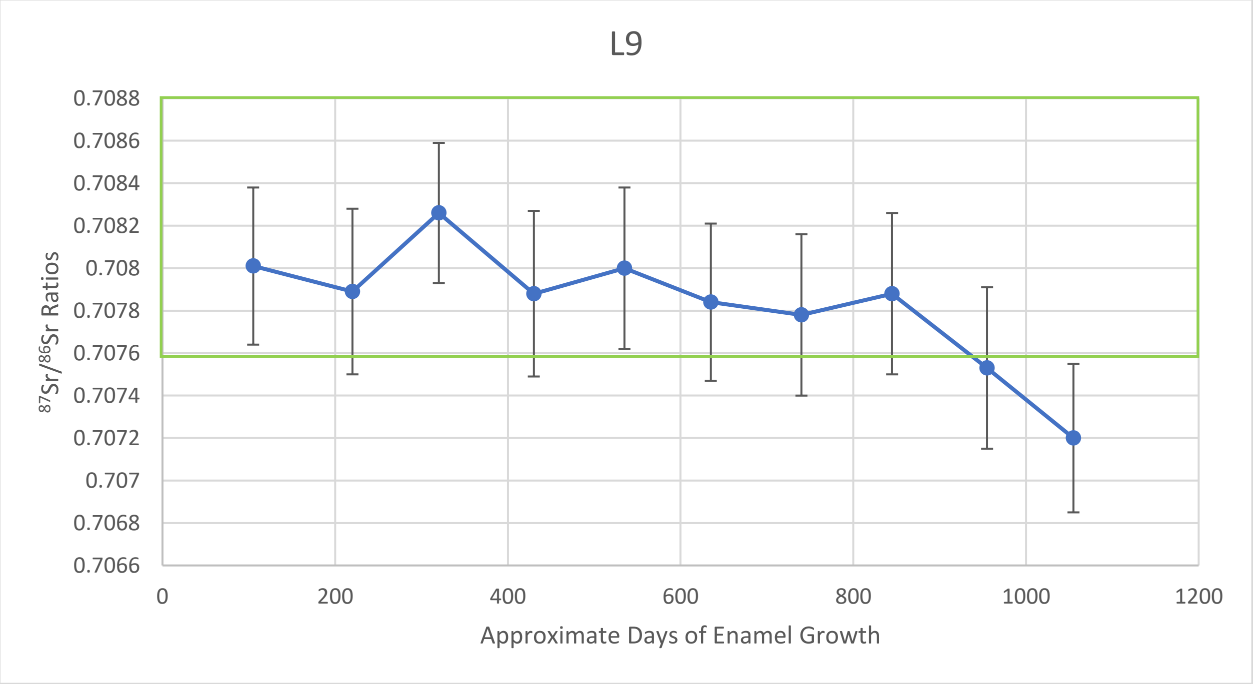

Figure 8: Average $^{87}Sr/^{86}Sr$ ratios over approximate number of days of enamel growth for individual L9 ± 2 SE. Local range indicated by green box.

This individual has higher quantities of overall strontium than most of the others, so the error bars for the points on this graph are comparatively much smaller, allowing for a more detailed analysis of the patterns. This individual also exhibits significantly less change in $^{87}Sr/^{86}Sr$ ratios over time than all of the others. Point 1 is at 0.70801, and it and its error bars are within the local range of Roquemissou. The following 7 points, representing roughly 740 days, all have strontium ratios within the local range of Roquemissou, between 0.7083 and 0.7078. The following points 9 and 10 show a decline in their $^{87}Sr/^{86}Sr$ ratios to 0.7075 and 0.7072, both below the local range of Roquemissou. The margins of error for point 10 are also outside of the local range of Roquemissou, and do not overlap with all of the error bars of the previous points, suggesting that this trend represents real change.

This individual was likely a local in the region of Roquemissou for most of this period of third molar enamel development, which represents roughly ages 8-11. The first 2.3 years of this time was spent within the local range of the site, with very little fluctuation of $^{87}Sr/^{86}Sr$ ratios, suggesting that this person lived a sedentary lifestyle at that time. The $^{87}Sr/^{86}Sr$ ratios in the dental enamel that developed over the following approximately 210 days of life suggest that this person gradually moved away from Roquemissou to a region with lower local strontium ratios. This is unusual because the region of Roquemissou has some of the lowest local $^{87}Sr/^{86}Sr$ ratios in the region of the Massif Central according to the map by Willmes et al. (2018), and this region is mostly surrounded by areas of higher $^{87}Sr/^{86}Sr$ ratios. Moffat (2013) identified a soil sample from roughly 5 km West of the site that produced a lower ratio of 0.708, but this is still within the expected local range of Roquemissou, much closer to the ratios of the first several points. There are regions of lower $^{87}Sr/^{86}Sr$ ratios to the Northeast, though the map of the $^{87}Sr/^{86}Sr$ distribution across the landscape between these points remains poorly defined.

2.3.7 Individual R2

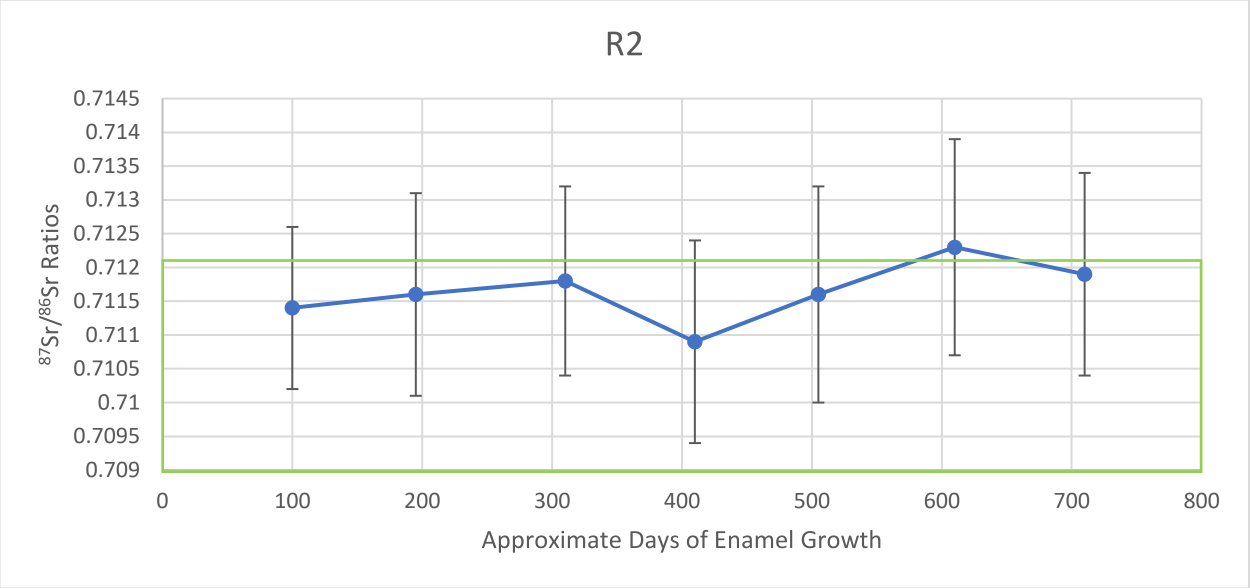

Figure 9: Average $^{87}Sr/^{86}Sr$ ratios over approximate number of days of enamel growth for individual R2 ± 2 SE. Local range indicated by green box.

This individual also has higher quantities of overall strontium than most of the samples, but comparatively little variation between each point. The greatest variation between points in this individual is 0.0014 between the lowest point 4 (0.7109) and the highest point 6 (0.7123), which is very homogenous for these samples and the highly variable local strontium ranges in this region. Because of the very minor scale of the variation between these points, the margin of error for each point overlaps with every other point, suggesting that these minor changes are not significant, and this individual likely had a constant $^{87}Sr/^{86}Sr$ input of around 0.7117.

Due to the very minimal variation in $^{87}Sr/^{86}Sr$ ratios over the almost 2 years represented by this graph, it is likely that this individual was sedentary during these years from roughly age 8-10. The average $^{87}Sr/^{86}Sr$ ratio in the enamel over this time was roughly 0.71164, which is within the local range of Roquemissou, though at the higher end of this range. This individual likely lived within the local range of Roquemissou for the entirety of this two year period of life, but likely near a source of slightly higher $^{87}Sr/^{86}Sr$ ratios, or else R2 lived closer to the site itself and routinely exploited a food source with higher ^{87}Sr/^{86}Sr ratios, but did not personally travel around the landscape to access this food source. The margin of error for all points extends outside the local range, so it is possible that this person lived outside of the local range as well.

2.3.8 Individual R4

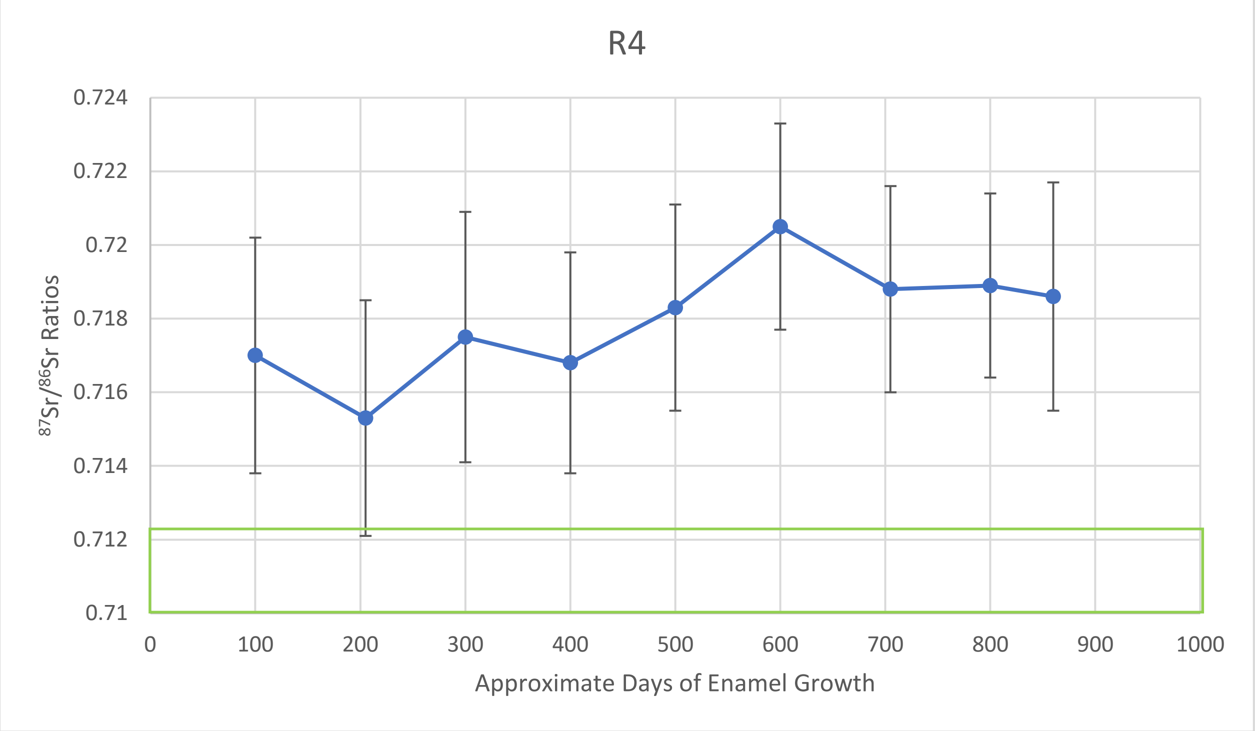

Figure 10 Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R4 ± 2 SE. Local range indicated by green box.

This individual had lower concentrations of overall strontium, so the margins of error were quite large. There does appear to be a pattern of rising ^{87}Sr/^{86}Sr ratios over time, as the lowest points 1, 2, and 4 (0.717, 0.7153, and 0.7168 respectively) are all outside of the range of standard error for the highest point 6 (0.7205). There is significant overlap of the margins of error of all points around the range of 0.718, but the difference between the highest and lowest points being greater than a single standard error does suggest that the possibility of real movement between the low early points and the higher later ones. The average ^{87}Sr/^{86}Sr ratio of the first four points is 0.71665, and the average of the last four is 0.7192, which could suggest a slight upward trend indicating a transition to a region with higher local strontium ratios from roughly age 8-10. This trend must be viewed with caution.

This individual likely lived mostly outside of the local range of Roquemissou, and inhabited a region with significantly higher local $^{87}Sr/^{86}Sr$ ratios from ages 8-10, or approximately 2.3 years of enamel development represented by this graph. The possible trend upwards suggests that this person migrated to a region with an even higher local strontium range over time, as the average of the first 4 points representing approximately 400 days of this individual's life is 0.71665 and the average of the last 4 points representing approximately 360 days is 0.7192. The large margins of error make this trend questionable, but if it does represent real migration then this was a gradual, but long-term shift in environments, since both periods represent roughly a full year of this individual's life, as opposed to moving across the landscape seasonally.

2.3.9 Individual R5

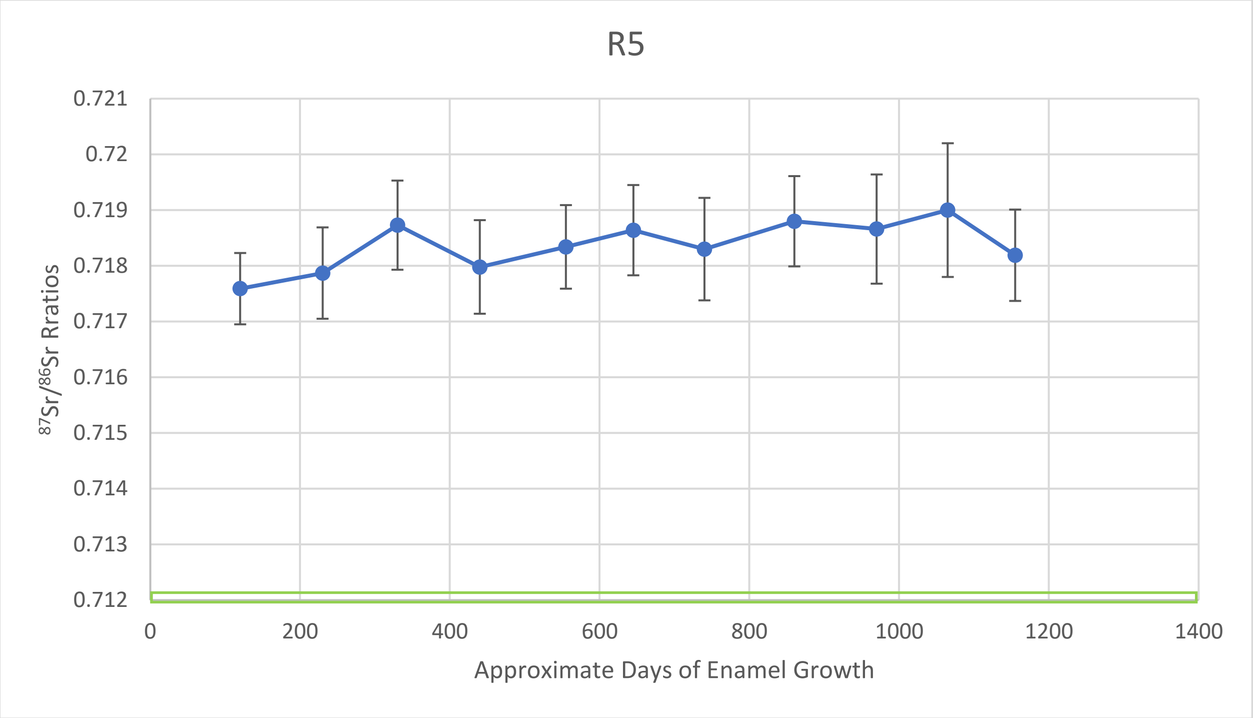

Figure 11: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R5 ± 2 SE. Local range indicated by green box.

This individual has higher quantities of overall strontium than many of the others, so the error bars are comparatively small. R5 also has very little variation, with a difference of 0.00141 between the lowest point 1 (0.71759) and highest point 10 (0.719). All of the points have overlapping error bars within the range of 0.718 and 0.7185, so it is likely this individual lived within a region with roughly this local range.

This individual likely lived in a region of much higher local ^{87}Sr/^{86}Sr ratio than Roquemissou for the approximate 3.16 years of enamel growth on this molar. R5 was likely sedentary during this period between the ages of roughly 8-11, as there are only minute changes over time in the ^{87}Sr/^{86}Sr ratios in the enamel, and most of these are insignificant. R5 likely inhabited a region with local ^{87}Sr/^{86}Sr ratios around 0.718 to 0.7185, which limits the possible regions they could have lived because there are few areas on the map in Figure 2 by Willmes et al. (2018) that have biologically available local ranges higher than 0.7168. The closest of these regions is approximately 10 km to the South of the site.

2.3.10 Individual R7

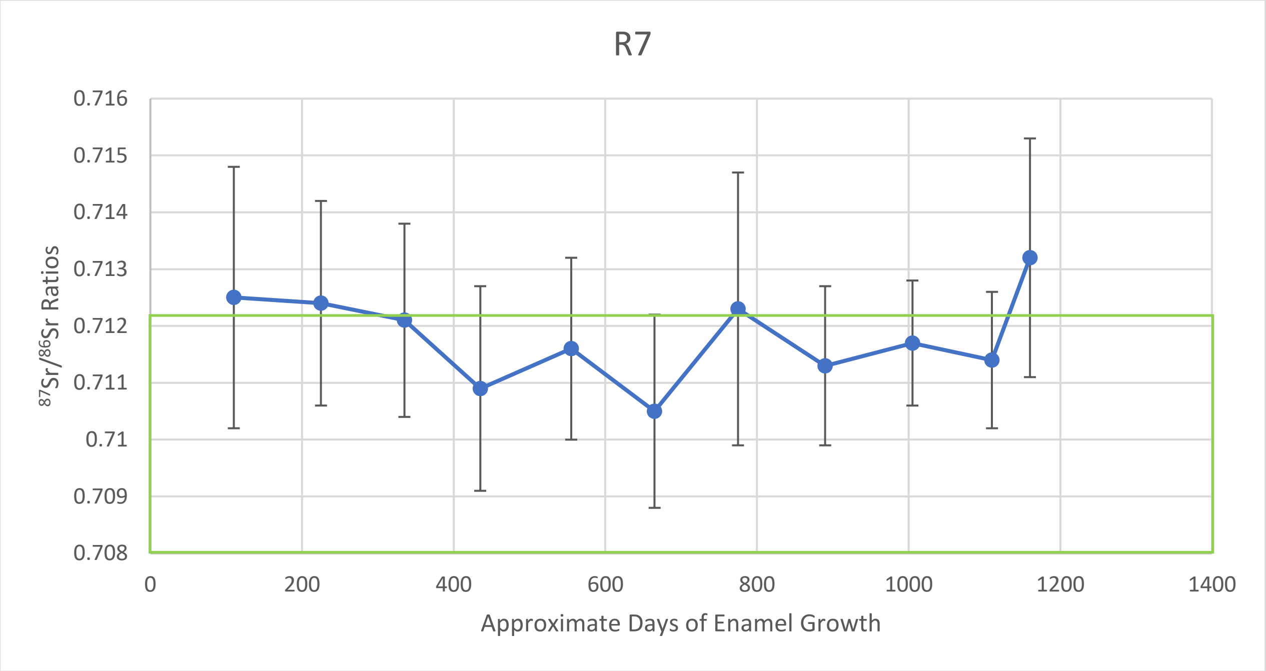

Figure 12: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individual R7 ± 2 SE. Local range indicated by green box.

This individual has low overall concentrations of strontium, and therefore large margins of error. The variation between most points is insignificant because they are within the margin of error of the points on either side of them. The average of all the points is 0.7118, and the margins of error for all of the points intersect this value, so this individual should be treated as though the points maintain this value over the entire graph.

An average strontium ratio of 0.7118 is just within the upper limit of the local range of Roquemissou. This person likely lived at the periphery of the site's range during this period of roughly age 8-11, either living closer to the border of an area of higher local strontium ratios, or eating more food sourced from these regions.

2.3.11 Bovid Tooth

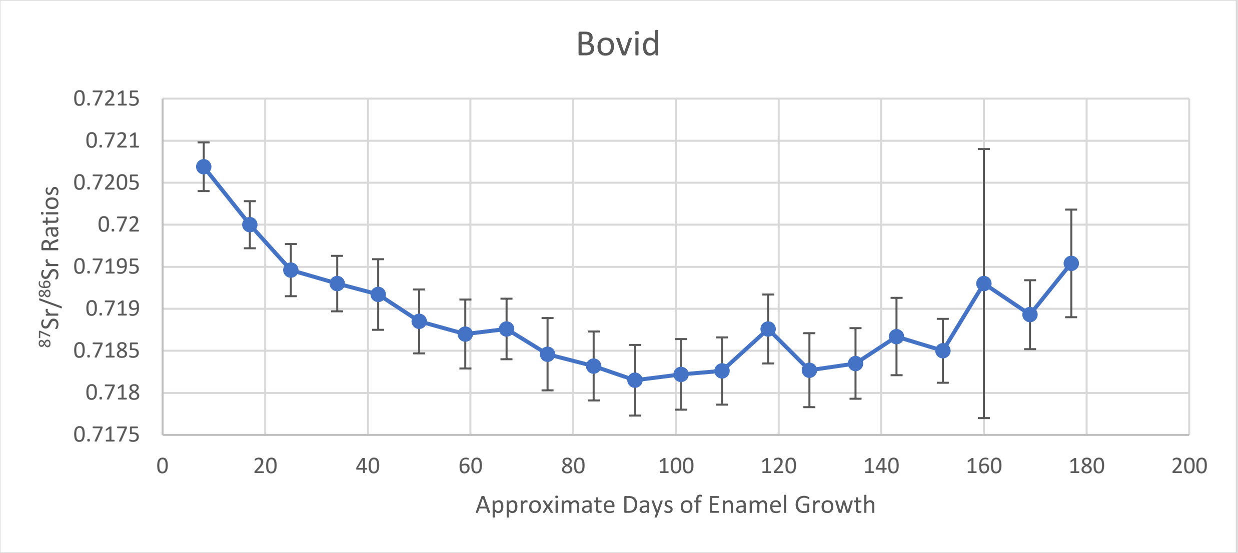

Figure 13: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for the bovine tooth ± 2 SE. Local range 0.7076-0.7121 not depicted.

This pattern exhibits a parabolic curve, starting high at point 1 (0.7207), and slowly dropping over approximately the next 92 days to the lowest point 11 (0.7182), before rising again over the next approximately 85 days to point 21 (0.7195). Aside from three outliers in points 8, 14, and 19, the points follow a parabolic pattern of increasing steepness over time at the ends.

This sample is a *Bos* M1. First molars in cattle develop much more quickly than human molars, and this developmental period takes roughly 6 months, most of which occurs *in utero* (Gerling et al. 2017; Hillson 1996). For the majority of this period of development the strontium ratios in its teeth therefore represent the landscape that its mother lived on while carrying it. The strontium ratios in this *Bos* tooth are well above the local range of Roquemissou, in regions of much higher strontium characteristic of some of the Massif Central's highest elevations. This bovid (and its mother) likely did not live at the site of Roquemissou at all during this period of its life. It did however migrate from a region with local strontium ratios above 0.72 down to a region with local ratios between 0.719 and 0.718, and then back up again to a region above 0.719 during this period of time representing roughly half to ¾ of a year. It likely lived in a region of much higher strontium ratios, which are typically in the highlands, but it did migrate from closer to the peak of these highlands to the periphery, and then further into them again. This pattern occurring over roughly half a year could indicate a seasonal pattern of mobility from this highland pasture in the spring and summer to a relatively more lowland pasture in the fall and winter.

2.4 Discussion

There is considerable variation in the patterns of the strontium ratios in the enamel of these individuals, indicating that the people buried in these shelters at Roquemissou represented both sedentary people, and people who migrated across the landscape of the Massif Central in many different ways. During this period of their lives, which roughly represents the ages between 8 and 13, only two of these individuals (R2 and R7) exhibit patterns that remain within the local range of Roquemissou. These individuals, represented in Figure 14, could be described as "locals" during their early adolescence, as they likely did not spend a significant amount of time outside of this region of lower strontium ratios. These individuals both may have been sedentary, as the variation in the ratios of R2 and R7 over time is minimal. The slightly larger variation in R7 may be due to their lower concentrations of overall strontium.

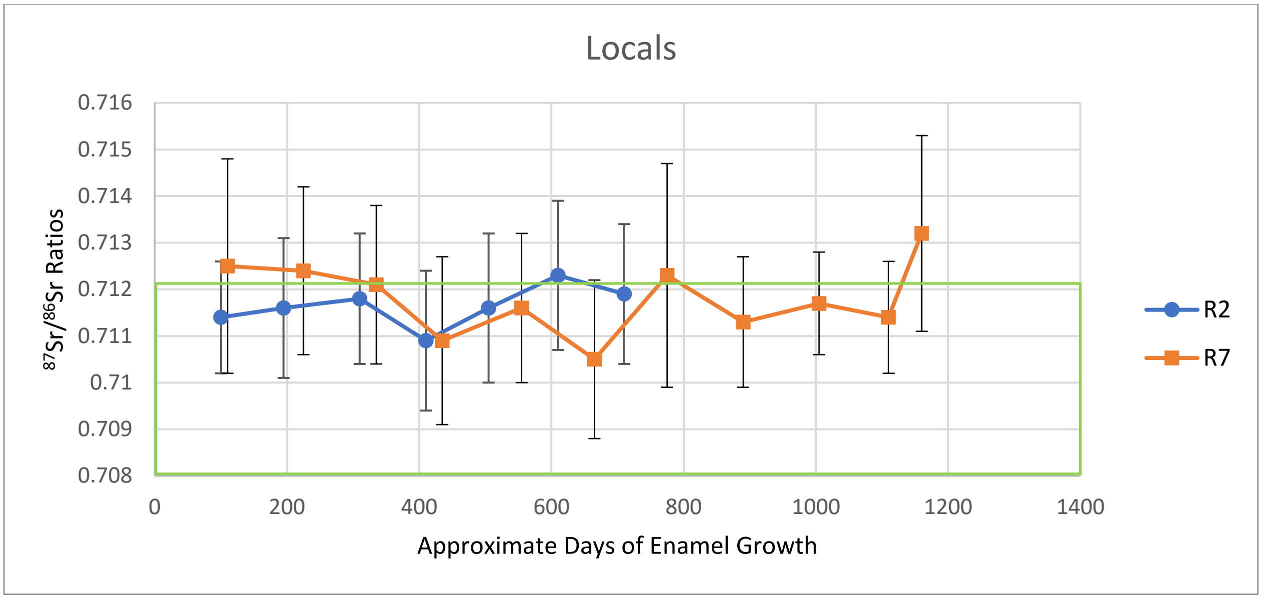

Figure 14: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individuals R2 and R7 ± 2 SE. Local range indicated by green box.

Four of these individuals (L2, L5, R4, and R5) do not have any points containing ^{87}Sr/^{86}Sr ratios within the local range of Roquemissou during this period of early adolescence, and as Figure 15 illustrates, likely lived at various different ranges found across the landscape of the Massif Central. Individuals L2, R4, and R5 all share similar strontium ratios, averaging between roughly 0.716 and 0.719. They also show little variation over time between points, though R4 and R5 exhibit a minor pattern of increasing strontium ratios from the beginning to the end of their enamel development. It is possible that these individuals all lived within the same area and represented the same group of semi-sedentary people. They also may have been related to, and in contact with the people of Roquemissou in some way, since these higher regions of strontium exist only 10 km away from the site. However, their dietary strontium intake is significantly higher than the local landscape of the site, meaning that they spent most of their time in a landscape with higher ratios, or at least sourced most of their food from there. Individual L5 does not fit within the same range as these others and has average strontium ratios between those of the Roquemissou individuals and the other non-locals.

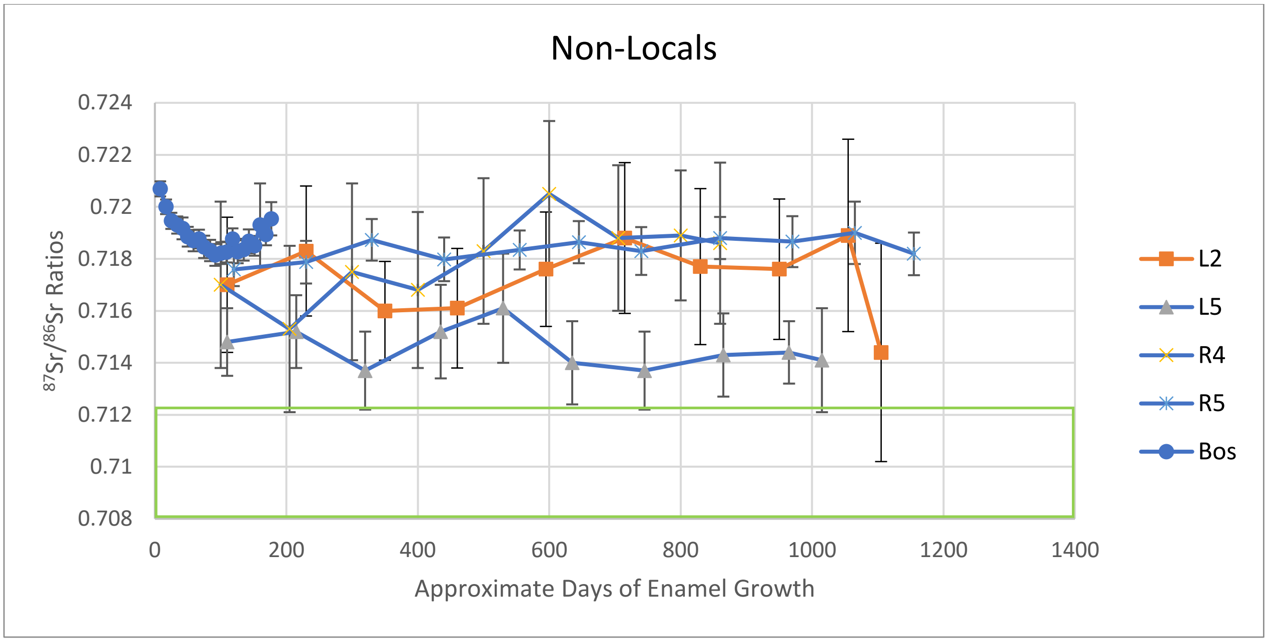

Figure 15: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individuals L2, L5, R4, R5, and the *Bos* sample ± 2 SE. Local range indicated by green box.

The bovid falls within the range represented by individuals L2, R4, and R5 for the majority of this roughly 6 month period of its life at the end of its foetal development and first few months after birth, however, at the beginning and the end of this period it (and its mother) lived outside this range in regions of even higher local strontium ratios. This pattern of travelling from a region of higher strontium ratios to within the same proposed local range as the Roquemissou individuals L2, R4, and R5, and then back to higher ratios again, could suggest the practice of transhumant animal domestication and pasturing at different fields across the landscape from one season to another. This practice has been suggested as the cause of shifting ^{87}Sr/^{86}Sr ratios across the enamel of cattle in a number of studies examining Neolithic sites in places such as France (Goude et al. 2011), Germany (Bentley & Knipper 2005), and Switzerland (Gerling et al. 2017), and farmers in Southern France today also use the highlands of the Massif Central to pasture their livestock seasonally. This single bovine tooth is not enough to suggest a significant pattern of transhumant animal domestication among the people of the highlands of the

Massif Central, but further study using other samples from Roquemissou and neighbouring contemporary sites could support this pattern.

The final 3 individuals (L1, L8, and L9), represented in Figure 16 exhibit widely different patterns between different points over time, despite all transitioning between the local and non-local range of Roquemissou over this period of their lives. L1 lives outside the local range of Roquemissou during the earliest stages of their enamel growth around age 8, but migrates to this region in under a year, possibly leaving to a region of high strontium and then returning again. This pattern reflects relatively short-term movements between different environments, possibly seasonally. Individual L8 in contrast begins this period of life within the local range of Roquemissou, and gradually moves to landscapes of increasingly higher strontium ratios over the course of a year and a half. Finally, L9 spends most of this time within the local range, with very minimal variations suggesting this individual was mostly sedentary, before migrating to landscapes with even lower strontium ratios. Therefore, while these three individuals make up the group of "visitors" who spend time within and outside of the local range during this period of their lives, they have little in common in the ways in which they migrate across the landscape.

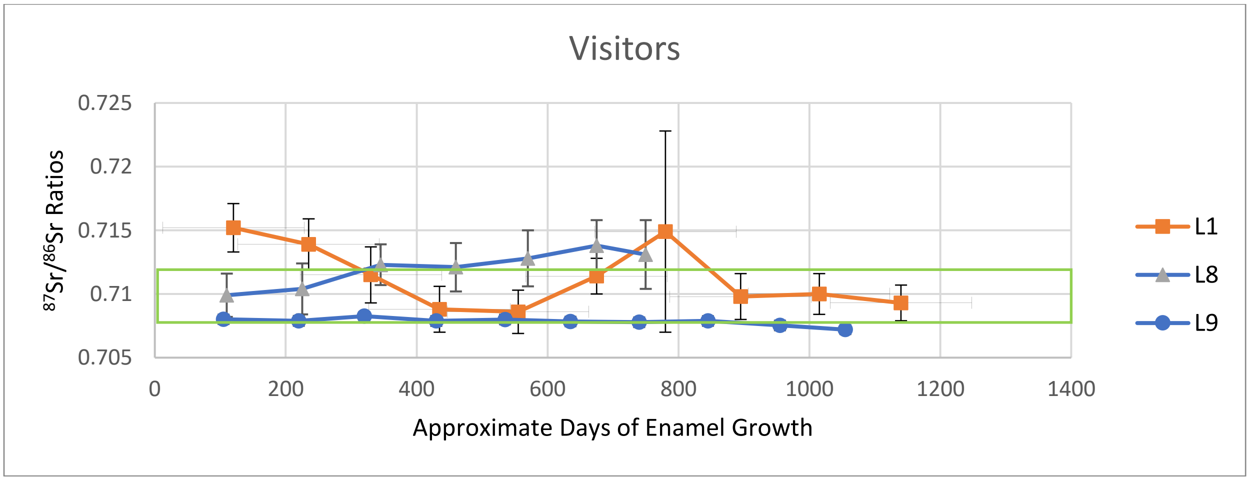

Figure 16: Average ^{87}Sr/^{86}Sr ratios over approximate number of days of enamel growth for individuals L1, L8, and L9 ± 2 SE. Local range indicated by green box.

2.5 Conclusion

The individuals interred in the burial shelters at Roquemissou apparently do not represent a single homogeneous population with the same lifeways and origins, but it must be emphasized that the analyzed teeth give us a picture of several years in the subadult lives of a few individuals from the Late Neolithic. The overall patterns of more than half of these individuals suggest mobility across the landscape, with only 4 individuals exhibiting patterns suggesting sedentism during early adolescence. This mobility, however, is gradual in most cases, and aside from L1, most individuals appear to remain stationary within, or slowly migrate through a region of a limited strontium range for more than a year. Few of the individuals buried at Roquemissou appear to be permanent residents of the site throughout this period of their lives, but more than half at least visited the region for some time. Three of the four other individuals whose strontium ratios remained outside of the local range during this entire period likely lived within a range of roughly 0.716 – 0.719, so it is possible that this represents the local range of another village site or region of semi-permanent habitation that shared some contact with Roquemissou. However, the strontium ratios in the enamel of these individuals do not suggest that they sourced any significant amount of their diet from near Roquemissou, so the contact between these people is only assumed due to their presence in the same burial shelter after death.

In relation to the excavated site of Roquemissou, these burials are characteristic of large communal Late Neolithic burials, specifically those of the Treilles and other related local cultures that are represented in the material culture at the site (Beyneix 2007; Cauliez 2016). This burial tradition is associated with increased social cohesion of a larger number of people with a similar culture and relatively prescribed territory (Beyneix 2007; Vander Linden 2006). This practice of burying the dead from a shared cultural background in the same tomb could explain the vast differences in locality and mobility suggested by the strontium ratios in the enamel of these individuals buried at Roquemissou. These graves represent multiple people from a shared culture (likely Treilles) spread across the Massif Central. There is evidence of semi-mobile animal herding as well as more sedentary settlement among Treilles people across the Massif Central (Herrscher et al. 2013), and these different practices would likely be represented in the strontium ratios of people interred at other Treilles burial sites similar to how they are at the site of Roquemissou. It would be beneficial to compare this with future research on the strontium ratios in the enamel of people interred at other Treilles ossuaries throughout the South of France, such as the Grotte I des Treilles.

References

AlQahtani, S.J., Hector, M.P., & Liversidge, H.M. 2010. Brief Communication: The London Atlas of Human Tooth Development and Eruption. *American Journal of Physical Anthropology*, 142, 481-490.

Arnal, G. 1991. Roquemissou, Gages-Montrozier (Aveyron). *Stratigraphie de l'Holocène, rapport de synthèse, inédit*.

Bentley, R. A. 2006. Strontium isotopes from the earth to the archaeological skeleton: a review. *Journal of archaeological method and theory*, 13(3), 135-187.

Bentley, R. A., & Knipper, C. 2005. Transhumance at the early Neolithic settlement at Vaihingen (Germany). *Antiquity*, 79(306), 1-3.

Bentley, R. A., Wahl, J., Price, T. D., & Atkinson, T. C. 2008. Isotopic signatures and hereditary traits: snapshot of a Neolithic community in Germany. *antiquity*, 82(316), 290-304.

Beyneix, A. 2007. Les comportements funéraires au Néolithique en France méridionale: une vue d'ensemble. *L'Anthropologie*, 111(1), 68-78.

Bouby, L., Durand, F., Rousselet, O., & Manen, C. 2019. Early farming economy in Mediterranean France: fruit and seed remains from the Early to Late Neolithic levels of the site of Taï (ca 5300–3500 cal bc). *Vegetation history and archaeobotany*, 28(1), 17-34.

Cauliez, J. 2016. Chapitre 20. Le site de Roquemissou et le groupe des Treilles dans l'Aveyron in Perrin, T. (ed.). *Roquemissou 2016 Rapport intermédiaire de fouille programmée 2014-2016.* pp. 193-204. Service Regional de l'Archeologie de Midi-Pyrenees, Toulouse.

Copeland, S. R., Sponheimer, M., Lee-Thorp, J. A., le Roux, P. J., de Ruiter, D. J., & Richards, M. P. 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*(7), 1437-1446.

Dolphin, A. E., Teeter, M. A., White, C. D., & Longstaffe, F. J. 2016. Limiting the impact of destructive analytical techniques through sequential microspatial sampling of the enamel from single teeth. *Journal of Archaeological Science: Reports*, 5, 537-541

Ericson, J. E. 1985. Strontium isotope characterization in the study of prehistoric human ecology. *Journal of human evolution*, 14(5), 503-514.

Geddes, D. 1983. Neolithic transhumance in the Mediterranean Pyrenees. *World Archaeology*, 15:1, 51-66, DOI: 10.1080/00438243.1983.9979884

Gerling, C., Doppler, T., Heyd, V., Knipper, C., Kuhn, T., Lehmann, M.F., Pike, A.W. and Schibler, J., 2017. High-resolution isotopic evidence of specialised cattle herding in the European Neolithic. *PloS one*, *12*(7), p.e0180164.

Goude, G., Castorina, F., Herrscher, E., Cabut, S., & Tafuri, M. A. 2012. First strontium isotope evidence of mobility in the Neolithic of Southern France. *European Journal of Archaeology*, *15*(3), 421-439.

Herrscher, E., Lheureux, J., Goude, G., Dabernat, H., & Duranthon, F. 2013. Les pratiques de subsistance de la population Néolithique final de la grotte I des Treilles (commune de Saint-Jean-et-Saint-Paul, Aveyron). *Préhistoires Méditerranéennes*, (4), 1-27.

Hillson, S. 1996. Dental Enamel. *Dental anthropology*. Cambridge University Press.

Horstwood, M. S. A., Evans, J. A., & Montgomery, J. 2008. Determination of Sr isotopes in calcium phosphates using laser ablation inductively coupled plasma mass spectrometry and their application to archaeological tooth enamel. *Geochimica et Cosmochimica Acta*, *72*(23), 5659-5674.

International Journal of Osteoarchaeology. 2019. “International Journal of Osteoarchaeology: Overview.” Accessed August 18, 2019. https://onlinelibrary.wiley.com/page/journal/10991212/homepage/productinformation.html.

Jackes, M. 2017. Chapitre 12. Roquemissou cave burials: preliminary assessment of the mandibles and first molars in Perrin, T. (ed.) *Roquemissou 2017 Premier rapport intermediaire de fouille programme 2017-2019.* pp. 95-102. Service Regional de l’Archeologie de Midi-Pyrenees, Toulouse.

Jackes, M. 2018. Chapitre 9. Report for 2018 on human remains from the Roquemissou burial shelters: further research on minimum numbers of young children at Roquemissou in Perrin, T. (ed.) *Roquemissou 2018 Rapport de fouille programmée 2017-2019.* pp. 75-98. Service Régional de l'archéologie d'Occitanie, Toulouse.

Kohn, M. J., Schoeninger, M. J., & Barker, W. W. 1999. Altered states: effects of diagenesis on fossil tooth chemistry. *Geochimica et cosmochimica acta*, 63(18), 2737-2747.

Lacan, M., Keyser, C., Ricaut, F., Brucato, N., Duranthon, F., Guilaine, J., Crubézy, E., & Ludes, B. 2011. Ancient DNA reveals male diffusion through the Neolithic Mediterranean route. *Proceedings of the National Academy of Sciences*, 108(24), 9788-9791.

Meiggs, D., C. 2007. Visualizing the seasonal round: a theoretical experiment with strontium isotope profiles in ovicaprine teeth. *Anthropozoologica*, 42(2), 107-128.

Meijer, J., Dolphin, A.E., Yakymchuk, C., & Gervers, M. 2019. Interpreting Medieval Mobility from Burials at the Rock-Hewn Church of St. Georges, Gurat (France): Insights from Strontium Isotope Analysis of Bones and Teeth. *International Journal of Osteoarchaeology*, 29, 574-583.

Moffat, I. 2013. Spatially resolved strontium isotope micro-analysis of lower and middle Palaeolithic fauna from archaeological sites in Israel and Southern France, PhD thesis, The Australian National University, 1127.

Montgomery, J. 2010. Passports from the past: Investigating human dispersals using strontium isotope analysis of tooth enamel. *Annals of human biology*, 37(3), 325-346.

Paton, C., Hellstrom, J., Paul, B., Woodhead, J., and Hergt, J. 2011. Iolite: Freeware for the visualization and processing of mass spectrometric data. *Journal of Analytical Atomic Spectrometry*, 26(12), 2508-2518.

Perrin, T. 2017. Chapitre 16. Les datations radiocarbone in Perrin, T. (ed.) *Roquemissou 2017 Premier rapport intermediaire de fouille programme 2017-2019.* pp. 115-118. Service Regional de l'Archeologie de Midi-Pyrenees, Toulouse.

Perrin, T. 2018. Chapitre 10. Les datations radiocarbone in Perrin, T. (ed.) *Roquemissou 2018 Rapport de fouille programmée 2017-2019.* pp. 99-103. Service Régional de l'archéologie d'Occitanie, Toulouse.

Perrin, T., Manen, C., Valdeyron, N., & Guilaine, J. 2018. Beyond the sea… The Neolithic transition in the southwest of France. Quaternary International, 470, 318-332.

Price, T. D., Johnson, C. M., Ezzo, J. A., Ericson, J., & Burton, J. H. 1994. Residential mobility in the prehistoric southwest United States: a preliminary study using strontium isotope analysis. *Journal of Archaeological Science*, *21*(3), 315-330.

Richards, M., Harvati, K., Grimes, V., Smith, C., Smith, T., Hublin, J.J., Karkanas, P. and Panagopoulou, E., 2008. Strontium isotope evidence of Neanderthal mobility at the site of Lakonis, Greece using laser-ablation PIMMS. *Journal of Archaeological Science*, *35*(5), pp.1251-1256.

Szostek, K., Stepańczak, B., Szczepanek, A., Kępa, M., Głąb, H., Jarosz, P., Włodarczak, P., Tunia, K., Pawlyta, J., Paluszkiewicz, C. & Tylko, G. 2011. Diagenetic signals from ancient human remains-bioarchaeological applications. *Mineralogia*, 42(2-3), 93-112.

Turner, B. L., & Andrushko, V. A. 2011. Partnerships, pitfalls, and ethical concerns in international bioarchaeology. *Social Bioarchaeology*, 44-67.

Vander Linden, M. 2006. For Whom the Bell Tolls: social hierarchy vs social integration in the Bell Beaker culture of southern France (third millennium BC). *Cambridge Archaeological Journal*, *16*(3), 317-332.

Walker, P. L. 2000. Bioarchaeological ethics: a historical perspective on the value of human remains. *Biological anthropology of the human skeleton*, 3-39.

Willmes, M., Glessner, J.J., Carleton, S.A., Gerrity, P.C., and Hobbs, J.A. 2016a. ^{87}Sr/^{86}Sr isotope ratio analysis by laser ablation MC-ICP-MS in scales, spines, and fin of rays as a nonlethal alternative to otoliths for reconstructing fish life in history. *Canadian Journal of Fisheries and Aquatic Sciences*, 73(12), 1852-1860.

Willmes, M., Kinsley, L., Moncel, M. H., Armstrong, R. A., Aubert, M., Eggins, S., & Grün, R. 2016b. Improvement of laser ablation in situ micro-analysis to identify diagenetic alteration and measure strontium isotope ratios in fossil human teeth. *Journal of Archaeological Science*, 70, 102-116.

Willmes, M., Bataille, C. P., James, H. F., Moffat, I., McMorrow, L., Kinsley, L., Armstrong, R., A., Eggins, s., & Grün, R. 2018. Mapping of bioavailable strontium isotope ratios in France for archaeological provenance studies. *Applied Geochemistry*, 90, 75-86.

Appendix A

This Table contains the trace element results analyzed by the Agilent Technologies 8800 ICP-MS Triple Quad (Agilent Technologies, Santa Clara, USA) for diagenesis.

Sample	Ca/P	Zn (ppm)	Sr (ppm)	Ba (ppm)	Th (ppm)	U (ppm)
R2						
Start	2.0	36.0	103.1	19.9	0.00	0.02
Mid	2.0	36.1	95.8	15.9	b.d.l.	b.d.l.
End	1.9	247.4	93.0	17.9	0.00	0.00
R4						
Start	2.0	50.2	50.2	1.7	0.00	0.00
Mid	1.9	41.8	59.1	1.7	0.04	0.04
End	2.0	81.4	83.8	2.8	0.01	0.03
R5						
Start	2.0	38.3	214.7	13.6	b.d.l.	0.00
Mid	2.0	32.4	220.9	12.2	0.00	0.01
End	1.9	72.7	233.8	8.3	b.d.l.	b.d.l.
R7						
Start	2.0	45.7	79.9	3.2	0.00	0.00
Mid	2.0	31.3	78.9	2.1	b.d.l.	0.00
End	2.3	106.2	93.4	67.7	0.00	0.02
L1						
Start	2.0	58.9	87.7	18.2	0.00	0.03
Mid	2.0	41.1	127.6	16.6	0.00	0.01
End	2.4	119.3	109.7	62.3	0.00	0.02
L2						
Start	2.0	76.1	86.5	7.6	0.00	0.01
Mid	2.0	55.4	97.5	3.3	0.00	0.00
End	2.3	155.9	70.8	16.8	0.02	0.02
L5						
Start	2.0	57.8	104.5	12.6	0.00	0.02
Mid	2.0	43.1	118.2	9.8	b.d.l.	0.01
End	2.3	118.2	144.5	51.3	b.d.l.	0.02
L8						
Start	1.9	43.7	46.5	6.4	0.00	0.01
Mid	2.0	43.4	45.3	6.4	0.01	0.01
End	1.9	130.1	41.1	2.6	0.00	0.01
L9						
Start	1.9	40.9	252.0	7.9	0.00	0.01
Mid	1.9	32.9	257.4	5.4	0.01	0.01
End	1.9	62.4	258.8	6.4	0.00	0.00