The 'Shep-herd' relationship in Classical and Hellenistic Thessaly, Greece: Investigating husbandry practices using carbon, oxygen, and strontium isotopes from sheep and goat tooth enamel

by

Katherine G. Bishop

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Anthropology
University of Alberta

Abstract

I investigate pastoral archaeology in Greece, and specifically the Hellenistic contexts at Kastro Kallithea and Pharsalos. Current research on ancient pastoralism in Thessaly, Greece is divided over the presence, prevalence, and degree of specialized shepherding or seasonally mobile management (transhumance), a discussion referred to as the agropastoral debate. I present the first isotope-based contribution to this discussion. I sequentially sample sheep and goat third molars (M_3) recovered from Building 10 at Kastro Kallithea and the Arsenopoulos and Alexopoulos Plots at Pharsalos, and isotopically analyze the resulting enamel segments to reconstruct aspects of diet ($\delta^{13}C$), seasonality ($\delta^{18}O$), and geolocation ($^{87}Sr/^{86}Sr$). I integrate this stable isotope analysis with archaeological, ethnographic, and literary data to examine various husbandry styles used in Thessaly.

Through this research I have found evidence of sedentary, seasonally mobile, and other specialized forms of pastoralism, including the first recorded cases of transhumant animal management in Thessaly from the Hellenistic period. Each management style would have had corresponding impacts on ancient economy, sociopolitical livelihood, land use, and human-animal relationships. I show how the stable isotope values of animal teeth can be used as a tool for studying the spatiotemporal distribution of shepherding and, when used in conjunction with contextualizing research, ultimately allow us to study animal management styles in the Mediterranean. My research lays the foundation for future studies of animal management in Thessaly, starts to map out the extent of transhumance in the region, and contributes a nuanced voice to the long-standing debate on the use and extent of ancient Greek pastoralism. Ultimately this research presents a glimpse into shepherding livelihoods and connects the modern and deep pasts in Thessaly.

Preface

This thesis is an original work by Katherine G. Bishop. All views, interpretations, or conclusions have been made in consultation with various researchers, but the accuracy of research is the responsibility of the author.

Components of this research project required and received ethics approval from the University of Alberta Research Ethics Board under Pro00094918 (approved October 8, 2019). All work was done with expressed permissions of the local communities in Thessaly via formal approval through the Hellenic Ministry of Culture and Sports (#28, approved August 1, 2016).

This work belongs to the communities in Thessaly and future work should prioritize community involvement, outreach, and open dialogue with descendant groups.

Acknowledgements

From start to finish this research has been a result of support from communities, organizations, friends, and family; I will forever be grateful for your contributions and support.

Without the support of Thessalian communities, including those in Pharsala, Narthaki, and Kallithea, I would never have been able to access and work with their history. Without the Hellenic Ministry of Culture and Sports, Ephorate of Antiquities in Larissa, and project directors Margriet Haagsma (Kastro Kallithea) and Sophia Karapanou (Kastro Kallithea, Pharsalos) I would never have been permitted to transport and destructively analyze the teeth. Much of this support is due to the groundwork of community relations, financial investment, teams of excavation or research staff, and tireless field seasons of the Kastro Kallithea Archaeological Project, its members, the University of Alberta, and affiliate researchers. For all the work that has been done to make this project possible. Thank you.

This research came out of the discussions and ideas of numerous colleagues, including my supervisors, Sandra and Margriet, and committee member Rob, as well as others who have worked with KKAP or at the UofA over the years. Thank you Margriet, for your patience as I learned the history and language, and for your willingness to have me join the crew each summer. Your passion for this project started many years ago (thank you Reinder, Michael, and others) and I hope that I have done it justice. To Sandra, who worked with me throughout the pandemic and put up with my never-ending side projects, thanks for taking the time to look at my conference poster all those years ago; I am grateful to CAPA 2014 for starting us on this journey. To various discussions with Rob, Kisha, and Frances about animals, landscapes, and history. And to Pam, who kept me grounded outside of my area of research. Forensics was the spark that steered me into academia in the first place, and you afforded me the opportunity for it to come full circle. Thank you to *all* the researchers who have provided feedback, ideas, or direction over the years.

Many institutions and organizations helped to ensure that this project would succeed. Financial support has been extensive and has afforded me the chance to analyze more teeth, conduct outreach, and focus on community initiatives outside of the standard doctoral program. The list is extensive in part because of the importance of this research. Thank you to the Killam Foundation, the Social Sciences and Research Council of Canada, numerous departments and faculties at the University of Alberta, and the Canadian and American Biological Anthropology Societies. Thanks also to the administrative staff in the Anthropology Department, who supported, fielded questions, and helped with life whenever I needed it, either in person or remotely; you are part of why I was able to succeed in this program and all of my extra-curriculars. Programs through FGSR made me a better teacher and researcher, and because of you I became the ‘goat girl’. Thank you for creating multiple lifelines.

My role with GoatWorks helped me broaden my perspective on husbandry, opened many doors for outreach, and continued my love affair with goats. Thank you to Jeannette, Dan, and your 450+ kids for trusting me and letting me learn from you. To Joy and Niki for supporting many of my initiatives and working as an awesome team. I am grateful of the OPDP team, the City of Edmonton, and sustainability scholars for giving me those opportunities.

The past few years have brought about genuine friendships and support networks that I know are responsible for me finishing this program and continuing to survive the Covid-19 pandemic. To my first and only work wife, Victoria, and the eventual GWG shenanigans with Jennifer. I am excited to continue this journey together with you. My TBT group with Karyne and Jen was necessary leading up to and during the 'new normal'. To the individual support and foodie outings with Kevin or Jill, and the coffee catch ups with Alex or Charity. To the life support of Emily, Sam, Stella, and my soul sister Dharsy, you have been in this with me together for the long haul. To the others who were along this journey with me, who helped support or make me stronger, thank you.

Susan and Murray, you always said you would support me no matter what I did, no matter where my adventures took me, so long as I was happy doing it. Thank you for that endless far-reaching love. To the rest of my family, new, old, and never forgotten, the random emails, phone calls, or 'my face hurts from laughing' moments helped get me through all of this; and yes, it is finally 'soon'. And I am excited for what that means next.

To Andrew, who eventually followed me out here, thank you for your love, patience, and support, even when it meant you had to look at bones, live through months of -40°C, hear me complain, or suffer through our mental health issues. You always knew what to do, even when I could not. I will never be able to express how much you have done and continue to do for me.

There is a Greek word to describe doing something with soul, creativity, or love, or when you put something of yourself into what you are doing: μεράκι. I can honestly say that this phase of my life, and everything related to this project, has been done with μεράκι.

Table of Contents

ABSTRACT ..... **II**

PREFACE ..... **III**

ACKNOWLEDGEMENTS ..... **IV**

TABLE OF CONTENTS ..... **VI**

LIST OF FIGURES ..... **XIII**

LIST OF TABLES ..... **XVII**

LIST OF APPENDICES ..... **XIX**

CHAPTER 1: INTRODUCTION **1**

1.1 Research Problem **1**

1.2 Approaching the Problem **2**

1.3 Questions and Objectives **3**

1.4 Significance **4**

1.4.1 Regional Dataset 4

1.4.2 Historical and Community Understanding 4

1.5 Organization of Dissertation **4**

CHAPTER 2: THE AGROPASTORAL DEBATE **6**

2.1. Modern Animal Management in the Region **6**

2.1.1 Modern Animal Uses 6

2.1.2 Animal Economy 7

2.1.3 Modern Transhumance 8

2.2. Animal Use in Antiquity **11**

2.2.1 Terminal Products (Meat, Blood, and Hide) 11

2.2.2 Byproducts (Milk, Hair, and Manure) 12

2.2.3 Power and Land Processing 14

2.3. Animal Management in Antiquity **15**
2.3.1 Ethnoarchaeological Evidence 16
2.3.2 Literary Evidence 17
2.3.3 Archaeological Evidence 21

2.4. The Agropastoral Debate **21**
2.4.1 Agropastoral Model 22
2.4.2 Transhumance Model 22
2.4.3 Mixed Models 23

2.5. Summary **25**

CHAPTER 3: SITE ANALYSIS: HISTORY AND CONTEXT **26**

3.1. Thessalian Landscapes **26**
3.1.1 Geological Landscapes 27
3.1.2 Climatic Landscapes 28
3.1.3 Ecological Landscapes 29

3.2. Historical Background **31**
3.2.1 Pre-Classical Thessaly 31
3.2.2 Classical Thessaly 33
3.2.2 Hellenistic Thessaly 38

3.3 Pharsalos (Φάρσαλος) **43**
3.3.1. Location and Landscape 43
3.3.2. Pharsalian History 45
3.3.3. Archaeology of Pharsalos 45
3.3.4. Alexopoulos Plot 49
3.3.4. Arsenopoulos Plot 51

3.4. Kastro Kallithea (Kişlar) (Peuma/Peumata) (Πεὺμα) **54**
3.4.1. Location and Landscape 54
3.4.2. Kallithea/Peumata History 55
3.4.3. Archaeology of Kastro Kallithea 58
3.4.4. Building 10 61

3.5 Other Sites of Interest **66**

3.6 Summary **67**

CHAPTER 4: SHEEP AND GOAT DENTAL DEVELOPMENT **68**

4.1. Analyzing Bones vs. Teeth **68**
4.1.1 Assemblage Analysis 68

4.1.2 Individual Analysis 69

4.2. Ovicaprid Tooth Selection **70**
4.2.1 Permanent vs. Deciduous Teeth 70
4.2.2 Selecting a Molar 71
4.2.3 Sheep vs. Goat 73

4.3. Tooth Development: Amelogenesis **73**

4.4. Dental Development and Life History **75**
4.4.1 Species Variation 77
4.4.2 Breed Variation 77
4.4.3 Sex 80
4.4.4 Castration 80
4.4.5 Nutrition 81
4.4.6 Stress 83

4.5. Sequential Enamel Sampling **84**
4.5.1 Sampling Location (lobe and surface) 84
4.5.2 Sample Amount (segment size) 85
4.5.3 Checking Samples (Mature Enamel) 85

4.6. Method Limitations **86**

4.7. Summary **87**

CHAPTER 5: STABLE ISOTOPE BACKGROUND **88**

5.1. Stable Isotope Analysis **88**
5.1.1 Atomic/Isotope Basics 88
5.1.2 From Atoms to Enamel 90
5.1.3 Applications of Stable Isotope Research 92

5.2. Stable Carbon ($\delta^{13}C$) Isotopes in Living Systems **93**
5.2.1 Carbon isotopes in flora 93
5.2.2 Carbon isotopes in fauna 95
5.2.3 Available Local Carbon in Thessaly 95

5.3. Stable Oxygen ($\delta^{18}O$) Isotopes in Environmental Systems **97**
5.3.1 Oxygen isotopes in the environment 97
5.3.2 Oxygen isoscapes in Thessaly 99
5.3.2 Relevant Trends in Oxygen Isotope Fluctuation 101

5.4. Strontium ($^{87}Sr/^{86}Sr$) Isoscapes in Thessaly **102**
5.4.1 Strontium isotopes in biospheres 102
5.4.2 Strontium isoscape in Thessaly 103

5.5. Stable isotope analysis of Thessalian archaeological material **108**
5.5.1 Kastro Kallithea 108
5.5.2 Pharsalos 109
5.5.3 Chloe 109
5.5.4 Halos 110
5.5.5 New Halos 110
5.5.6 Other studies in Greece 111

5.6. Summary **114**

CHAPTER 6: MATERIALS AND METHODS **115**

6.1 Site and Sample Selection **115**
6.1.1 Research Area 115
6.1.2 Site Selection 116
6.1.3 Ovicaprid Sample Selection 117
6.1.4 Environmental Sampling 122

6.2 Sample Preparation **125**
6.2.1 Sheep and Goat Teeth 126
6.2.2 Environmental Sample Preparation 128

6.3 Carbonate ($\delta^{13}C$ and $\delta^{18}O$) Analysis **130**

6.4 Strontium Analysis **130**
6.4.1 Method Selection 130
6.4.2 Strontium Isotope Analysis of Tooth Enamel 131
6.4.3 Strontium Isotope Analysis of Plant and Soil Samples 132

6.5 Sample Pretreatment Pilot Study **132**
6.5.1 Background and Rationale 133
6.5.2 Method 136
6.5.3 Results 136
6.5.4 Interpretation 140
6.5.5 Conclusion 142

6.6 Summary **142**

CHAPTER 7: RESULTS **143**

7.1 Regional Isotope Sample Estimates **143**
7.1.1 Southeast Thessaly 143
7.1.2 Melitaia 145
7.1.3 Mount Óthrys 146
7.1.4 Anavra 147

7.1.5 Kastro Kallithea 148
7.1.6 Pharsalos 150
7.1.7 Summary of Regional Strontium Isotope Values 151

7.2 Ovicaprids (Sheep and Goats) **151**
7.2.1 L01 152
7.2.2 SG03 154
7.2.3 SG06 156
7.2.4 SG08 158
7.2.5 SG11 160
7.2.6 SG16 162
7.2.7 SG21 164
7.2.8 SG23 166
7.2.9 SG30 168
7.2.10 SG33 170
7.2.11 SG38 172
7.2.12 SG39 174
7.2.13 SG40 176
7.2.14 SG42 178

7.3 Analytical Error **180**
7.3.1 Carbon and Oxygen 180
7.3.2 Strontium 180

7.4 Summary **180**

CHAPTER 8: MANAGEMENT STYLES **181**

8.1 Interpreting Trends in the Stable Isotope Data **181**
8.1.1 Strontium Data 181
8.1.2 Stable Oxygen Isotope Data 187
8.1.3 Stable Carbon Isotope Data 192
8.1.4 Summary of Interpretation Methods 196

8.2 Local Management **197**
8.2.1 Local Free-Grazing 197
8.2.2 Supplemental Grazing 198

8.3 Non-Local Management **198**
8.3.1 Highland Management 199
8.3.2 Annual Movement 201
8.3.3 Constant Movement 201

8.4 Mixed-Mobile Management **202**
8.4.1 Local Highland Movement 202

8.4.2 Lowland Movement Between Sources 204

8.4 Other Specialized Management **206**
8.4.1 Changing Local Fodder or Water Source at Kastro Kallithea 207
8.4.2 Changing Local Fodder or Water Source at Pharsalos 208

8.5 Limitations **210**
8.5.2 Compounding Data Patterns 210
8.5.2 Approach Moving Forward 211

8.6 Summary **212**

CHAPTER 9: SHEPHERDING POLITICS **214**

9.1 Land Politics **214**

9.2 Land Ownership **216**
9.2.1 Kastro Kallithea 217
9.2.2 Sedentary Husbandry 218

9.3 *Polis* Grazing Rights **220**
9.3.1 Kastro Kallithea 222
9.3.2 Pharsalos 223
9.3.3 Privileged Herding 225

9.4 Non-Local Grazing Rights **225**
9.4.1 Grazing around Mount Óthrys 227
9.4.2 Movement within Mount Narthakion 229
9.4.3 Movement for Coastal Resources 229
9.4.4 Expanding Shepherding Territories 230
9.4.5 Hired Shepherds 232

9.5 Supplementing with Fodder **233**

9.6 Limitations **234**

9.7 Summary **235**

CHAPTER 10: HUMAN-OVICAPRID RELATIONSHIPS **237**

10.1 The Economic Value of Keeping Ovicaprids **237**
10.1.1 Domestic or Household Use 238
10.1.2 Market Value 239
10.1.3 Thessalian Wealth and the Golden Fleece 241

10.2 Social Aspects of Keeping Animals **242**

10.2.1 Social Prestige......242
10.2.2 Social Favour......244

10.3 The Politics of Keeping Animals......245
10.3.1 Political Prestige......245
10.3.2 Military Benefits......246
10.3.3 Withholding Goods and Services......246

10.4 Site-Specific Management Trends......247
10.4.1 Kastro Kallithea......247
10.4.2 Pharsalos......249

10.5 Summary......251

CHAPTER 11: CONCLUSIONS AND FUTURE RESEARCH...... 252

11.1 Re-Addressing the Agropastoral Debate......252
11.1.1 What Management Styles Did They Use?......252
11.1.2 How Did They Shepherd?......253
11.1.3 Why Did They Keep Animals?......253

11.2 Research Significance......254
11.2.1 Agropastoral Debate......254
11.2.2 Community History......255
11.2.3 Research Datasets......255

11.3 Future Directions......256
11.3.1 Method and Approach......256
11.3.2 Further Pastoralism and Subsistence Studies......257
11.3.3 Landscape Archaeology......257

11.4 Closing Remarks......257

REFERENCES CITED...... 259

APPENDICES...... 285

List of Figures

Figure 2.1 Map of Greece showing areas discussed in text, Sarakatsani migration routes (dotted black lines), habitation areas in Epirus (white stars = winter; black stars = summer), and mountains (black triangles; (1) Óthrys, (2) Helikon, (3) Cithaeron, and (4) Pelion). Base map is from D-Maps (2020). ..9

Figure 2.2 Images of a Sarakatsani summer village in Phocis, Greece, including (A) a house (*konakia*), and (B) settlement structure. Images taken by Kouremenos (1985, front cover, p.11, respectively) during the 1980s. 10

Figure 2.3 Images of a Sarakatsani village in Thessaly, Greece, including (A) a house (*konakia*) and (B) settlement structure. Images taken by Margriet Haagsma in Thessaly in 1989. 10

Figure 2.4 Hellenistic dairy processing vessel found in the destruction level of a house at Pharsalos. Image from Municipality of Pharsala (2015, p.86) and discussed in Karapanou (2000). 13

Figure 2.5 **Left:** *Lekythos* vessel from Classical Athens depicting women weaving using a weighted loom. Image from Sofroniew (2011). **Right**: A reconstructed loom with loom weight artefacts from Kastro Kallithea. Image from Haagsma *et al.* (2019a, p.62) 13

Figure 2.6 Stone foundation found near a modern Sarakatsani winter community area in eastern Thessaly. Foundation is speculated to have belonged to a non-modern pastoral group. Image taken by Margriet Haagsma in 1989. 17

Figure 2.7 Pastoral scene on a silver dish from the late Hellenistic period. The seated figure is believed to represent Greek poet Theocritus. Image from Levi (1993, p.112). 20

Figure 2.8 Ceramic from the Middle Minoan I (2000-1800 BCE) site of Palaikastro illustrating a shepherd and approximately 140 sheep. Image discussed in Branigan (1970, pp.70-71). Image from www.aristotleguide.wordpress.com. 20

Figure 3.9 Topographic map of Thessaly. Modern Thessaly border outlined in white. Sites demarcated by A: Pharsalos, and B: Kastro Kallithea. From ESRI Imagery (2020). 27

Figure 3.10 Map of ancient 'Thessaly', highlighting the tetrads, perioikoi, and some cities discussed in text (modified from Aston, 2017, p.85). Kastro Kallithea location added for reference. 32

Figure 3.11 Map of Achaia Phthiotis, including important settlements and forts dating to the Hellenistic period. .40

Figure 3.12 Aerial view of Pharsala with major points discussed in text outlined. Base map from Google (2020), with 3D function enabled. 44

Figure 3.13 Sketch of archaeological structures at Pharsalos depicting public areas (red squares) and domestic structures (blue squares) discussed in Table 3.7. 47

Figure 3.14 Outline of the Alexopoulos Plot structures depicting the Hellenistic era rooms and the Classical era units. Care of Sophia Karapanou. Removed for publication. 50

Figure 3.15 Outline of the Hellenistic era Arsenopoulos Plot structure based on a sketch from Sophia Karapanou. Removed for publication. 53

Figure 3.16 Aerial view of Kastro Kallithea with major points discussed in text outlined. Base map from Google (2020), with 3D function enabled. 55

Figure 3.17 Map of Kastro Kallithea (centre), including a sketch of the acropolis (top left; green) and housing block (right; purple), and reconstructed images of the public area (bottom, blue). Visual image is of B10. Contexts and references in Table 3.11 59

Figure 3.18 Kastro Kallithea Building 10 phase 1 based on excavations at the end of the 2013 field season (Haagsma *et al.*, 2015b; 2019a, p.53). The room contexts are broken down and listed below based on Haagsma *et al.* (2019a, pp.49-59) and personal discussion with Margriet Haagsma. 62

Figure 3.19 Kastro Kallithea Building 10 phase 2 based on excavations at the end of the 2013 field season (Haagsma *et al.*, 2015b; 2019a, p.60). The room contexts are broken down and listed below based on Haagsma *et al.* (2019a, pp.59-61) and personal discussion with Margriet Haagsma. 63

Figure 4.20 Remains of a modern adult sheep, including the teeth of the right maxilla and left mandible, from the second premolar (P2) to the third molar (M3). 71

Figure 4.21 Archaeological goat mandible (SG23) indicating directions discussed in text. 72

Figure 4.22 Generalized overview of amelogenesis using a goat right M_3 (SG08). 74

Figure 4.23 Molar formation (blue), enamel mineralization (purple), and eruption (green) patterns for sheep and goat mandibular third molars, as discussed in text according to specified sources 78

Figure 4.24 Comparison of healthy and unhealthy sheep M_3. 83

Figure 4.25 Left Sheep M_3 (SG12) with 1.5 mm incremental segments indicated on the mesial side of the anterior lobe perpendicular to the growth axis. 85
Figure 5.26 Isotope variation in plant tissue $\delta^{13}C$ changes according to growing conditions (e.g., proximity to the coast, root depth, elevation, and seasonality). 94
Figure 5.27 Factors influencing water $\delta^{18}O$ in the hydrosphere, including rain and evaporation processes according to the effects of continentality, seasonality, altitude, temperature, and rainfall (diagram from Pederzani and Britton, 2019, p.79). 98
Figure 5.28 Spatial distribution of $\delta^{18}O$ in Thessaly according to precipitation (A) and spring water/groundwater (B). Adapted from Dotsika *et al.* (2010, p.147). 99
Figure 5.29 Visual depiction of a seasonal oxygen isotope signal ($\delta^{18}O$) in sequentially sampled M_3 enamel bioapatite. Seasons are indicated on the right. Adapted from Balasse *et al.* (2003, p.208). 101
Figure 5.30 Geological map of study area. Maps are adapted from the Institute of Geology and Subsurface Research in Greece. Combines the Domokos, Pharsalos, and Anavra sheets; scale: 1:50,000. 104
Figure 5.31 Map of the Aegean region showing separate geological regions or isotopic zones (according to Nafplioti 2011, p.1562). The associated strontium isotope ranges for zones in my research area are Pindos (0.70808-0.70869), Parnassos (0.70808-0.70869), Sub-Pelagonian (0.70808-0.70869), Pelagonian (0.70853-0.70931), and Vardar (0.70926-0.71187). 106
Figure 5.32 Predicted geological map of the study area. Estimated $^{87}Sr/^{86}Sr$ ranges are based on surface geology (1:1M), sediment age estimates, and materials sampled from other studies conducted in the area. 108
Figure 6.33 Goat mandible (SG23) **(Left)** Full mandible; **(right)** removed right third molar (RM_3), showing the direction of growth from the occlusal surface of the cusp, or youngest part of the tooth, to the roots, or oldest part of the tooth (recall Chapter 4). 118
Figure 6.34 Building 10 sampling locations. Blue squares are ovicaprid samples (Section 6.1.3; Table 6.20) and red circles are small-bodied fauna samples (Section 6.1.4; Table 6.21). Image adapted from Haagsma *et al.* (2015b). See next page for context summary. 120
Figure 6.35 Arsenopoulos Plot sampling locations. Image removed for publication; instead it has been replaced with the summary listed above. 121
Figure 6.36 Alexopoulos Plot sampling locations. Image removed for publication; instead it has been replaced with the summary listed above. 121
Figure 6.37 Geological map of the study areas. Sample collection sites are outlined. This geological map is adapted from maps created by the Institute of Geology and Subsurface Research in Greece (scale 1:50,000) (Pharsalos, Anavra, and Domokos Sheets) and D-Maps (2020). 123
Figure 6.38 Anterior lobe separation for sample SG03. **Left**: Isomet 1-1180 low speed precision cutter with LM_3 clamped for processing. **Right**: LM_3 post-cutting, showing the anterior lobe removed from the main tooth. 127
Figure 6.39 Custom microsampling system created for this study. A Proxxon Micromet drill stand is equipped with a Proxxon Machine (micro) vise with self-stick non-slip surface grip pads. A Dremel precision rotary tool equipped with a diamond cut wheel (0.15 mm thickness) is clamped onto the drill stand. System serves as a Dremel-equipped miter saw (Bishop *et al.*, 2020). 127
Figure 6.40 Archaeological goat M_3 (SG12) with sequentially sampled enamel segments cut from the removed anterior lobe. 127
Figure 6.41 Sequential $\delta^{13}C$ values measured from SG12 molar enamel at different points along the mesial lobe from the crown-root junction (CRJ) (mm) according to treatment type. Refer to Table 6.4. 139
Figure 6.42 Sequential $\delta^{18}O$ values measured from SG12 molar enamel at different points along the mesial lobe from the crown-root junction (CRJ) (mm) according to treatment type. Refer to Table 6.4. 139
Figure 7.43 Geological map of sample locations and regions discussed in text. Estimated $^{87}Sr/^{86}Sr$ ranges are based on surface geology (1:1M), bedrock age estimates, and materials sampled from different sites in the area (Table 7.24, Appendix 7.8). 144
Figure 7.44 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from L01 molar enamel at different points along the mesial lobe from the crown root juncture (CRJ) (mm). The local strontium isotope range for Anavra is shown as a grey block. Refer to Table 7.30. 153
Figure 7.45 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG03 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.31. 155

Figure 7.46 Sequential $\delta^{13}C$ and $\delta^{18}O$ values measured from SG06 molar enamel at different points along the mesial lobe from the CRJ (mm). Refer to Table 7.32. 157
Figure 7.47 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG08 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.33. 159
Figure 7.48 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG11 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.34. 161
Figure 7.49 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG16 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.35. 163
Figure 7.50 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG21 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.36 165
Figure 7.51 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG23 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.37. 167
Figure 7.52 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG30 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.38. 169
Figure 7.53 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG33 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.39. 171
Figure 7.54 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG38 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.40. 173
Figure 7.55 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG39 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.41. 175
Figure 7.56 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG40 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.42. 177
Figure 7.57 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG42 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.43. 179
Figure 8.58 Sequential $^{87}Sr/^{86}Sr$ values from ovicaprids at Kastro Kallithea. The grey block represents the local isozone and all individuals inside the grey zone are considered local whereas those outside are considered non-local. 182
Figure 8.59 Sequential $^{87}Sr/^{86}Sr$ values from ovicaprids at Pharsalos. The grey block represents the local isozone and all individuals inside the grey zone are considered local whereas those outside are considered non-local. 183
Figure 8.60 Recorded $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from L01 enamel. 187
Figure 8.61 Types of intra-tooth $\delta^{18}O$ patterns from published studies as discussed in text. Adapted from A: Balasse *et al.* (2003, p.208), B: Britton *et al.* (2009, p.1169), C: Makarewicz and Pederzani (2017, p.9), and D: Chazin *et al.* (2019, p.63). 188
Figure 8.62 Types of intra-tooth $\delta^{13}C$ patterns from published studies as discussed in text. $\delta^{13}C$ (red) plotted with the corresponding $\delta^{18}O$ values. Adapted from A: Vaiglova *et al.* (2020, p.42), B: Isaakidou *et al.* (2019, p.51); C: Chazin *et al.* (2019, p.61), and D: Martín *et al.* (2021, p.99). 192
Figure 8.63 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG08 (green) and SG21 (purple) enamel. The grey block represents the local Kastro Kallithea $^{87}Sr/^{86}Sr$ range. 197
Figure 8.64 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG11 (orange), SG23 (green), and SG33 (purple) enamel. The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range. 200

Figure 8.65 A(Left): Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG39 (green) and SG42 (yellow). The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range. B(Right): SG33 (purple) is added for comparison to SG39 and SG42 203
Figure 8.66 Sequential $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG30 (brown) enamel. The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range. Green lines show potential periods of movement between grazing regions as discussed in text. 205
Figure 8.67 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG03 (orange) and SG16 (teal) enamel. The grey block represents the local Kastro Kallithea $^{87}Sr/^{86}Sr$ range. 207
Figure 8.68 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG38 (blue) and SG40 (purple). The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range. 209
Figure 8.69 Comparison of $\delta^{13}C_{carbonate}$ (Δ) and $\delta^{18}O_{carbonate}$ (O) values measured from SG06 enamel. 211
Figure 9.70 **Left**: Honorary decree [*IG* IX. ii, 234] recovered from Pharsalos (ca. late 3rd c. BCE) detailing beneficiaries who were granted citizenship and land on the Rizi Plateau. Interpretation and image from Decourt (1995, no. 50). **Right**: Map of the area. 3D Map from Google Earth 216
Figure 9.71 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for SG08 (green) and SG21 (purple) molar enamel at different points along the mesial lobe from the CRJ (mm). The Kastro Kallithea local strontium isotope range is shown as a grey block. 217
Figure 9.72 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from SG03 (green) and SG16 (gold) molar enamel at different points along the mesial lobe from the CRJ (mm). The Kastro Kallithea local strontium isotope range is shown as a grey block. 222
Figure 9.73 *Karayul* artesian spring on the eastern side of the north slope of Kallithea. A local shepherd had stopped to rest with his herd of over 50 sheep, goats, and herding dogs. Photo taken in May 2017. .223
Figure 9.74 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from SG38 (purple) and SG40 (blue) molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range is shown (grey block). 224
Figure 9.75 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from SG11 (orange), SG23 (blue), SG33 (purple), SG39 (green), and SG42 (yellow) molar enamel at different points along the mesial lobe from the CRJ (mm). The local Pharsalos strontium isotope range is shown as a grey block. 227
Figure 9.76 Isozone map for Mount Óthrys, including major cities discussed in text. Refer to Figure 7.43 for more information. Shoreline, altitudes, and locations from Reinders (2003, p.18) and Reinders and Prummel (1998, p.90). 228

List of Tables

Table 2.1 Sheep and goat farming systems practised in modern Greece, with varying levels of performance. 7
Table 2.2 Summary of proposed animal management strategies in use in ancient Greece. 15
Table 2.3 Sarakatsani land utilization in Epirus expressed in percentages. 24
Table 3.4 Timeline of important dates for 'Thessaly' history during the Classical (c. 480-323 BCE) period (from sources discussed in text). 34
Table 3.5 Timeline of important dates for Thessaly during the Hellenistic (323-30 BCE) period (from sources discussed in text). 39
Table 3.6 A timeline of control or allegiance for Thessaly and Pharsalos during antiquity. Adapted from various sources discussed in text. 46
Table 3.7 A summary of archaeological structures excavated by the 15th Ephorate in Larissa, including public and domestic buildings. Coordinates with Fig. 3.13. 47
Table 3.8 Faunal remains analyzed from the Alexopoulos plot at Pharsalos. Reported as number of identifiable specimens (NISP) and percentage of total identifiable fauna (%) and total domestic fauna (%) (Bishop, 2017). 50
Table 3.9 Faunal remains analyzed from the Arsenopoulos plot at Pharsalos. Reported as number of identifiable specimens (NISP) and percentage of total identifiable fauna (%) and total domestic fauna (%) (Bishop, 2018). 53
Table 3.10 A timeline of control or allegiance for Thessaly and likely over Kastro Kallithea during its history. Adapted from various sources discussed in text. 57
Table 3.11 Summary of archaeological structures excavated by the 15th Ephorate in Larissa, including public and domestic buildings. Table coordinates with Figure 3.17. 60
Table 3.12 Faunal remains analyzed from Building 10 at Kastro Kallithea. Reported as number of identifiable specimens (NISP) and percentage of total identifiable fauna (%) and total domestic fauna (%) (MacKinnon, 2016) 65
Table 4.13 Tooth Eruption Ages in Sheep 71
Table 4.14 Summary of the impacts of different life factors on ovicaprid dental development 76
Table 5.15 A sample of representative vegetation $\delta^{13}C$ values for Thessaly. 96
Table 5.16 Oxygen isotope values measured on spring water in Thessaly during the dry and cool season in 2018 (Dotsika *et al.*, 2018, p.238). 100
Table 5.17 Strontium isotope values recorded from snail shell samples in Thessaly by Panagiotopoulou *et al.* (2018). 107
Table 5.18 Summary of relevant findings from archaeological isotope research in Thessaly. References and studies discussed in text. 109
Table 5.19 Summary of relevant findings from archaeological isotope research in Greece. References and studies discussed in text. 112
Table 6.20 All ovicaprid samples chosen for stable isotope analysis. See Appendices 6.4-6.6 for specific sample context. 120
Table 6.21 Environmental samples collected to stablish a local baseline $^{87}Sr/^{86}Sr$. 124
Table 6.22 Measured mass (mg) before and after different pretreatment methods for SG12. Mass loss is the difference in mass based on the starting mass (%). 137
Table 6.23 Carbon and oxygen isotope values recorded from sequentially sampled mandibular molar (M_3) enamel of SG12 according to treatment type. The difference (Δ) is recorded for $\delta^{13}C_{no\text{-}treatment}$ and $\delta^{13}C_{chemical}$ and $\delta^{18}O_{no\text{-}treatent}$ and $\delta^{18}O_{chemical}$ See Fig. 6.41 and 6.42. 138
Table 7.24 Strontium isotope ranges for the region based on samples and bedrock age estimates (Fig. 7.1). Calculations shown in Appendix 7.1 (mean ± 2 SD). 144
Table 7.25 Strontium isotope values recorded from samples of soil (D) and plant (P) collected from around Melitaia. 145
Table 7.26 Strontium isotope values recorded from samples of soil (D) and plant (P) collected from around Mount Óthrys. 146
Table 7.27 Strontium isotope samples and estimated range (mean ± 2SD) from a modern lamb molar (L01) from Anavra. 147

Table 7.28 Isotope values and estimated range (mean ± 2SD) from small-bodied mammal samples (R) collected from Kastro Kallithea....148
Table 7.29 Isotope values and estimated range (mean ± 2SD) from small-bodied mammal samples (R) collected from Pharsalos....150
Table 7.30 Carbon, oxygen, and strontium isotope values of sequentially sampled mandibular molar (m_1) enamel of a modern Anavra lamb (L01). See Figure 7.44....152
Table 7.31 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG03. See Figure 7.45. 154
Table 7.32 Carbon and oxygen isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG06. See Figure 7.46. 156
Table 7.33 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG08. See Figure 7.47. 158
Table 7.34 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG11. See Figure 7.48. 160
Table 7.35 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG16. See Figure 7.49. 162
Table 7.36 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG21. See Figure 7.50. 164
Table 7.37 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG23. See Figure 7.51. 166
Table 7.38 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG30. See Figure 7.52. 168
Table 7.39 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG33. See Figure 7.53. 170
Table 7.40 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG38. See Figure 7.54. 172
Table 7.41 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG39. See Figure 7.55. 174
Table 7.42 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG40. See Figure 7.56. 176
Table 7.43 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG42. See Figure 7.57. 178
Table 8.44 Summary data and interpretations for each specimen according to its strontium isotope values ($^{87}Sr/^{86}Sr$). Local or non-local distinction based on the isozone, and the sedentary or mobile management distinction based on the intra-individual variation ($\Delta^{87}Sr/^{86}Sr$). 185
Table 8.45 Summary data and interpretations for archaeological specimens according to the stable oxygen isotope values ($\delta^{18}O$). Includes the seasonal or non-seasonal and the dampened or exaggerated distinction based on the intra-individual variation ($\Delta^{18}O$). 191
Table 8.46 Summary data and interpretations for archaeological specimens according to the stable carbon isotope values ($\delta^{13}C$). Includes the seasonal or non-seasonal distinction and the dietary variation based on the intra-individual variation ($\Delta^{13}C$). 194
Table 9.47 Modelling for the number of animals that can be managed on the Rizi Plateau land allotment [*IG* IX, 2 234] according to management strategies 219
Table 10.48 Archaeological samples categorized according to modern and ethnohistoric animal management strategies based on trends in recorded stable isotope data and proposed scenarios. Animals that could be part of multiple strategies are noted (*)....238
Table 10.49 Summary of different management styles according to site....247

List of Appendices

Appendix 2.1 Summary of key authors in the so-called agropastoral debate (discussed in text) 285
Appendix 3.2 General Chronology for Greece (Adapted from Bintliff 2012, p.6)..288
Appendix 3.3 Archaeobotanical remains recovered from Thessalian sites (adapted from Megaloudi, 2006)..........289
Appendix 6.4 Building 10 samples removed for analysis...291
Appendix 6.5 Arsenopoulos Plot samples removed for analysis. 292
Appendix 6.6 Alexopoulos Plot samples removed for analysis...293
Appendix 6.7 Carbon and oxygen isotope values recorded from sequentially sampled mandibular molar (M_3) enamel of SG12 according to treatment type. The difference (Δ) is recorded for $\delta^{13}C_{no\text{-}treatment-chemical}$ and $\delta^{18}O_{no\text{-}treatment-chemical}$..294
Appendix 7.8 Calculated $^{87}Sr/^{86}Sr$ ranges based on samples in Thessaly. Lower to upper limit (mean +/- 2 SD) ranges coordinate with Figure 7.43. 296
Appendix 7.9 Known and measured $\delta^{13}C$ and $\delta^{18}O$ values for NBS-19 recorded at the Stable Isotope Laboratory (SIL) concurrently with samples included in the current study. Measurement accuracy is recorded to two standard deviations (2SD). 297
Appendix 7.10 Known and measured $^{87}Sr/^{86}Sr$ ratios for SRM 987 recorded at the Stable Isotope Laboratory concurrently with samples included in the current study. Measurement accuracy is recorded to two standard deviations (2SD). 298
Appendix 8.11 Summary of standard deviations from isotope studies discussed in text...299
Appendix 8.12 Summary of stable isotope signature patterns by proposed explanation and study..........................300

CHAPTER 1: Introduction

While travelling through the Thessalian countryside in recent years, I saw shepherds with small flocks of black and brown sheep, large herds of white, grey, and black mottled goats, and mixed herds with hundreds of animals dotting the landscape. I have worked in communities where men have chosen to herd small groups of animals after their retirement from crop farming. And I have seen a collective of herds flow into the hills managed by a family of shepherds who descend from historic Sarakatsani lineages. I have also seen the expansive crop networks of barley, wheat, and fodder corn, which are the lifeline of many communities. The last 100 years have seen a drastic change in Thessalian economy, shifting from traditional pastoral systems to one devoted to the cash crop industry (Davies, 1941, p.155). This economic shift had corresponding impacts on the people and landscapes. Some of the last traditional pastoral communities, including the Sarakatsani and the Vlachs (Sovlachs), have taken up permanent housing and now make up a substantial percentage of the region's agriculturalists (Reinders, 1994, 1996; Reinders and Prummel, 1988; Wagman, 2016, p.7).

Prior to the major economic shift, ethnographic work by Hoeg (1926) Sanders (1962), Campbell (1964), Herzfeld (1985), and Kouremenos (1985) detailed aspects of traditional pastoralist culture; however, little is known about the history of traditional pastoralism into antiquity or the time depth of their presence in the region. When did transhumant pastoralism become a focal point of the economy in Thessaly, and what was the driving force for this shift? How did daily life in antiquity compare to the pastoral culture documented by the last modern herding groups? For many of the people who now live as farmers in Thessaly, a part of their identity is tied to ancient pastoralism.

1.1 Research Problem

Current research on pastoralism in antiquity is divided over the presence, prevalence, and effects of specialized management or seasonal livestock movement (transhumance) in Thessaly, referred to as the 'agropastoral debate.' Researchers like Halstead (1996) and Hodkinson (1988) argue that agropastoralism was the predominant form of economy in Thessaly until historically recent times; agriculture was the focal source of revenue, and small numbers of sheep, goats, pigs, horses, or cattle were raised locally for household use. If animals did move through the landscape, it was only across very short distances (Hodkinson 1988, pp.53-54). A growing body of evidence suggests that larger herds of animals were kept in the Classical and Hellenistic eras during a period of considerable economic and political change (Chandezon, 2003, 2020; Forbes, 1995; Reinders, 1996). Notions of individual wealth became centred on large herd sizes and wool- and dairy-based economies surged (Howe, 2008). Local pastures were insufficient to support increasing herd sizes, forcing shepherds and animals to move great distances and employ different forms of specialized pastoralism (Reinders, 1996; Skydsgaard, 1988).

Examining pastoralism in ancient Greece provides distinctive challenges because most research approaches require tangible evidence of habitation or landscape use, which are limited because of continuous pastoral mobility and poor site preservation (Chang, 1994; Chang and Koster 1986; Forbes 1994, 1995, 2013; Halstead 1996; Hodkinson 1988; Reinders 1994, 1996). Literary evidence is often centred on elite voices and their elite audiences and rarely discusses the daily livelihood of shepherds or their herds (Halstead, 2014). Ethnographic observations of modern herds provide a starting point of comparison for herd size, land usage, and economic output (Chang, 1993; Chang and Tourtellotte, 1993; Halstead, 2009, 2014), but the corresponding economic, social, and political considerations related to managing animals are specific to the time period. Despite these limitations it is increasingly important to document evidence of specialized pastoralism in antiquity. This history is important for the descendants of pastoral communities and has corresponding interactions with other aspects of identity, economy, and culture in Mediterranean antiquity.

1.2 Approaching the Problem

In this dissertation I re-examine the agropastoral debate using a novel approach that has proven effective when applied in other temporal and geographic settings. I examine social interactions between humans, animals, and landscapes according to ethnographic, epigraphic, literary, archaeobotanical, archaeological, and zooarchaeological evidence in Greece. I focus my analysis on southeast Thessaly and specifically discuss the Classical and Hellenistic sites of Pharsalos and Kastro Kallithea. These archaeological contexts yield evidence of increased urbanization, economic development, and animal use during the Hellenistic period (Reinders, 1994, 1996). The domestic contexts of Building 10 (Kastro Kallithea) and the Arsenopoulos and Alexopoulos Plots (Pharsalos) provide exceptional case studies for analyzing animal management practices during a period of significant economic and political change (ca. 217-197 BCE) (Haagsma *et al.*, 2019a; Karapanou, 1996, 2008). I use isotopic analyses of sheep and goat teeth recovered from these sites, as stable isotope analysis of animal tooth enamel has been used to document trends in animal diet and movement in other Mediterranean contexts (e.g. Isaakidou *et al.*, 2019; Trentacoste *et al.*, 2020; Vaiglova *et a.*, 2018). I use similar methodologies to reconstruct seasonal movement and discuss possible animal management strategies across Thessaly. Isotopic data are interpreted according to my research on modern and ancient social interactions between animals, shepherds, and the Thessalian landscape. Ultimately my results provide a better understanding of animal use in antiquity and contribute to our understanding of the lived history of modern and ancient Mediterranean pastoralists.

1.3 Questions and Objectives

The goals of my research are to (1) examine what pastoralism entailed in southeast Thessaly during the Classical and Hellenistic period, and (2) to contemplate the economic, social, and political consequences of managing animals in different ways during this time. Although the volume of sheep and goat skeletal remains and wool- or dairy-processing equipment at Kastro Kallithea (Haagsma *et al.*, 2019a; MacKinnon, 2016) and Pharsalos (Bishop, 2018; Karapanou 1996, 2008; Municipality of Farsala, 2015) suggests that ovicaprid management was important at both sites, no research has examined where, how, or why animals were kept in Thessaly.

Analysis of sequentially sampled enamel from sheep and goats recovered from archaeological contexts has the potential to generate new knowledge regarding animal diet (stable carbon isotopes), seasonality (stable oxygen isotopes), and movement between regions (strontium isotopes). Combining all forms of data can be used as a tool for discussing intra- and inter-individual variation in animal management and increasing our understanding of pastoralism in Thessaly. By considering the assemblage according to site (Kastro Kallithea or Pharsalos) and animal type (sheep or goat), my research is subdivided into the following three research questions:

1. WHAT were shepherds doing with the animals, including seasonal changes in feeding or movement, during the Classical or Hellenistic periods?
2. HOW were shepherds able to feed, move, or maintain their animals in Thessaly during the Hellenistic period? and,

3. WHY were animals shepherded in different ways, and how did these different ways of herding affect daily life?

1.4 Significance

1.4.1 Regional Dataset

Directed stable isotope analyses of animal management and mobility have gained popularity in recent decades, including in Greek contexts (e.g., Isaakidou *et al.*, 2019; Vaiglova *et al.*, 2018). Stable isotope analysis of migration or movement in Thessaly requires modern ecological sampling or local archaeological baseline data, which are limited (e.g., Panagiotopoulou *et al.*, 2018; Sparkes, 2017). My research will contribute to these background data and provide comparisons for future analyses.

1.4.2 Historical and Community Understanding

Evidence of movement between known regions strengthens arguments on economic partnerships (i.e., trade resources), land access (e.g., shared grazing rights), and human settlement strategies, all of which contribute to the growing understanding of life during antiquity. Reconstructing subsistence and mobility of animals recovered from the Arsenopoulos or Alexopoulos Plots or at Building 10 also increases our understanding of the previous tenants and uses of these buildings. Public presentations on archaeological work done at both of these sites and wider educational outreach continue to garner interest from local community members and descendant populations and increasing our awareness of life at these sites will have a lasting impact on regional histories.

1.5 Organization of Dissertation

This thesis presents a summary of the work done to achieve my research goals. As part of the background research, I re-examine the agropastoral debate and summarize much of the ethnographic, archaeological, and literary data on pastoralism in Greece (Chapter 2). In Chapter 3 I explore the historical and archaeological backgrounds specific to Thessaly and the sites of Kastro Kallithea and Pharsalos. My research relies on the faunal material collected from these sites, and in Chapter 4 I present why sheep and goat teeth were selected for my sampling strategy. Chapter 5 presents a brief summary of the principles of stable isotope analysis and in it I focus on how stable carbon, oxygen, and strontium isotope values can contribute to an understanding of the diet, season, and location of consumption for sheep and goats in Thessaly.

The culmination of background research leads to my materials and methods section (Chapter 6) and a brief summary record of results (Chapter 7). As a means for discussing the data trends, I organize the following chapters into questions about pastoralism, which address each of the research objectives: what did shepherds do with their animals (Chapter 8); how could they manage them in certain areas (Chapter 9); and why would they have kept or raised animals during antiquity (Chapter 10)? The economic, social, and political aspects of shepherding are used to re-examine the agropastoral debate and ultimately address my research goals in the conclusion (Chapter 11).

CHAPTER 2: The Agropastoral Debate

Pastoral farming is a dynamic aspect of Greece's economy, and herds of sheep and goats have modified the foraged landscape for thousands of years (Foxhall, 2006; Hadjigeorgiou *et al.*, 1999; Sossidou *et al.*, 2013). Today farmers manage one or two animals on their home property, smaller groups on local pasturage, or large herds using specialized forms of pastoralism, often including mountain grazing. Pastoral strategies are dictated by negotiations involving availability and division of labour, accessible land for grazing, economic factors, sociopolitical contexts, and climatic conditions (Campbell, 1964; Howe, 2008; Kavadias, 1965). Although we can witness these processes in Greece today, scholarly work in various periods of Greece's past is divided over the nature of animal management as well as its importance in domestic economies (Appendix 2.1). This "agropastoral debate" questions whether specialized pastoralism was practised at all, and if so, whether it included seasonal mobile management (transhumance) (Forbes, 1995). This chapter provides an overview of that debate and describes the current evidence for animal management in antiquity, with special attention given to the region of Thessaly, and the sites Kastro Kallithea and Pharsalos. In it I describe sheep and goat management in Greece today (2.1), discuss how animals were used in Classical and Hellenistic periods (2.2.), present evidence of animal management in antiquity (2.3), and examine this evidence in relation to the agropastoral debate (2.4).

2.1. Modern Animal Management in the Region

2.1.1 Modern Animal Uses

Animals have important roles in human lives as they contribute to our diets (dairy, meat, eggs), create tangible goods (wool, hide, feathers), provide a working service (draught labour, transportation, pest management, fertilizers), act as companions (pets, service), and serve as spiritual and cultural connections (religious deities, spirit animals) depending on the people and place. In traditional Greek communities today, sheep and goats predominantly have the role of dietary (dairy, meat) and textile (wool, hair) contributors. Lambs are also believed to serve a form of religious symbolism, as Easter lambs and lambs slaughtered and consumed at Mary's day of ascension (August 15th) have a strong social and cultural importance for many Greeks (Skiftou, 2005). Sheep and goats also contribute their manure to the farms and areas that they

Table 2.1 Sheep and goat farming systems practised in modern Greece, with varying levels of performance.

Farming System	Performance[1]	Feeding Strategy	Flock Size
Home Fed	High	Large quantities of grains and byproducts; limited foraging	Small < 10 animals
Intensive (lowland, local)	High to good	Grazed locally and fed supplements (50:50) daily	Small-Medium 10-80 animals
Extensive (with or without transhumance)	Good to not satisfactory	Year-long grazing (March – July)	Large 80-600 animals

graze on, although synthetic fertilizers are also commonly used today (Forbes, 2013). With sheep and goats serving different roles in the Greek economy, shepherds and farmers employ various management strategies accordingly (Table 2.1).

2.1.2 Animal Economy

According to Hadjigeorgiou *et al.* (1999) and Sossidou *et al.* (2013) there are hundreds of thousands of sheep and goat farming units in Greece, with over nine million sheep and five million goats managed across all units in 2010 (Hadjigeorgeiou 2011, p.31). These animals are used for milk and meat, and each farming unit includes an average of 84 sheep or 99 goats (Hadjigeorgiou *et al.*, 1999). Table 2.1, which was adapted from Hadjigeorgiou *et al*. (1999, p.18), lists the three different management styles in place around Greece today. Of all of the sheep and goats managed in Greece, 16.51% of sheep and 12.02% of goats were managed in Thessaly (Hadjigeorgeiou *et al.*, 1999, p.19), with the majority of extensive management taking place in mountainous or semi-mountainous regions (Hadjigeorgiou, 2011, pp.31-32). The farming style, performance level,[1] and flock size will vary according to the desired output and available resources. For example, intensive local farming requires limited staff and pasture to manage few animals locally; their quality of milk yield or reproduced offspring will be high, but they are produced in lower quantities. Alternatively, an extensive system that has a lot of staff and access to land will have large flocks; the quality of product may be low, but it is produced in a large quantity.

In areas with mountainous terrain or less favourable arable land (considered marginal landscapes) the extensive management style is more prevalent (Hadjigeorgiou *et al.*, 1999). In

[1] Assessed on the quality of byproduct, offspring, or meat produced.

1991, Greek land was designated as being arable and fallow land (30%), grazing land (40%), forest land (20%), areas under water (2%), or built and other areas (8%), which varied depending on the region (Hadjigeorgiou, 2011, p.32). With this available terrain, mild climate, and accessible streams and rivers, mobile animal management has been supported across the country for at least the past hundred years (Hadjigeorgeiou, 2011; Kavvadias, 1965; Kouremenos, 1985). Many modern mobile shepherds employ a specialized management strategy, called transhumance, wherein they graze their animals in mountainous regions during the summer months and move to lowland communities during the winter.

2.1.3 Modern Transhumance

Although the term 'transhumance' is debated (e.g., Chaniotis, 1999, p.191), I refer to it as the seasonal movement of herds, including short- and long-distance movement to the highlands in summer and lowland areas in winter. Davies (1941) separates transhumant practices according to ecology, climate, and economy. In the Mediterranean, summer lowland pastures become hot and dried out, whereas the upland pastures provide cool and moist relief for the herds; in winter, the uplands often become inhospitable because of freezing temperatures and snow, whereas the lowland crops and pastures revive under temperate rainy winter conditions (Davies, 1941). Some traditional transhumant communities only move with portions of their herds. Davies (1941, pp.162-163) discusses Greek farmers who owned large herds but were unable to support all of the animals on the local crop-land or pasture. Farmers paid shepherds to care for a portion of the herd and moved them to rented pastures in nearby areas during the summer months. The other portion of the herd was kept locally and had sufficient local pasture for grazing. Alternatively, Campbell (1964) observed Sarakatsani herders in Epirus (Fig. 2.1) that owned their animals and moved seasonally as family-based units under a family head (*Tselingas)*. Most of the family units grazed together at their permanent residence during the summer months (Fig. 2.1, black stars). Full family units then migrated to different winter grazing grounds that were rented from the villagers of each respective region, often 80 km away (Fig. 2.1, white stars). Households were arranged according to patrilineal affiliations and grazing rights were usually based on similar familial arrangements (Campbell, 1964).

Large communities of Sarakatsani and Vlach herders practise transhumance throughout the Mediterranean (Campbell, 1964; Kouremenos, 1985; Sanders, 1962). Figure 2.1 (dotted black

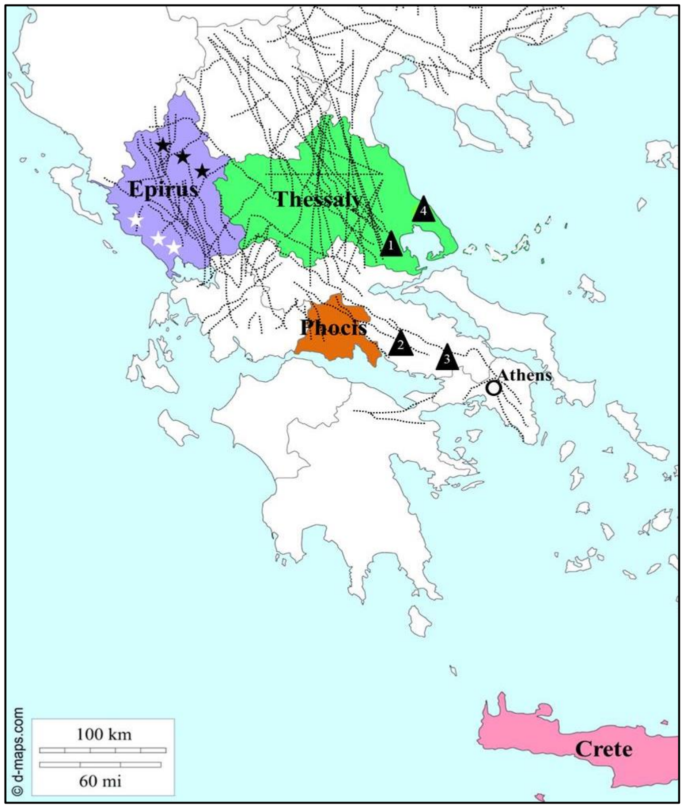

Figure 2.1 Map of Greece showing areas discussed in text, Sarakatsani migration routes (dotted black lines)[2], habitation areas in Epirus (white stars = winter; black stars = summer)[3], and mountains (black triangles; (1) Óthrys, (2) Helikon, (3) Cithaeron, and (4) Pelion). Base map is from D-Maps (2020).

lines) outlines Sarakatsani migration patterns recorded in the 1950s that cross every region of Greece (Kouremenos, 1985, p.3). Many of the migration routes cross and include major cities, which was likely a purposeful action in order to sell their products. Entire families could move between temporary summer housing and permanent winter villages with flocks of up to 500 animals per extended family herd. Temporary structures, like the *konakia* (Fig. 2.2), were made from locally available resources at summer sites (Kouremenos 1985, p.15). Kouremenos (1985) documented architecture (Fig. 2.2a) and settlement structure (Fig. 2.2b) of the Sarakatsani summer villages in the early 1980s in Phocis (Fig. 2.1). Figure 2.3 illustrates identical structures (Fig. 2.3a) and similar settlement patterns (Fig. 2.3b) belonging to the Sarakatsani herders observed by Margriet Haagsma in eastern Thessaly in 1989. Although much of the ethnographic

[2] outlined according to Kouremenos (1985, pp.2-3).
[3] according to Campbell (1964, p.365).

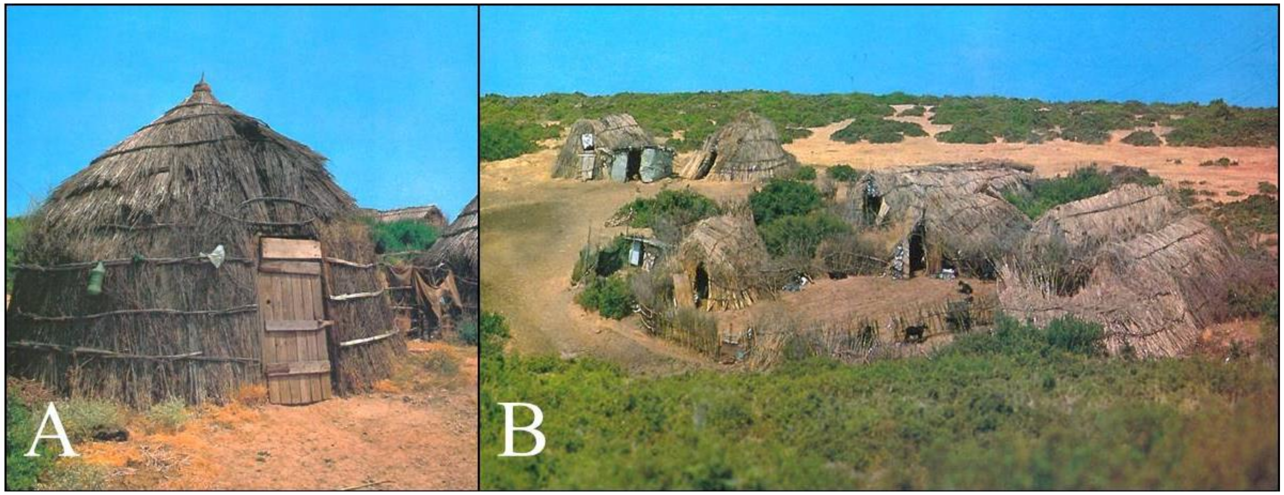

Figure 2.2 Images of a Sarakatsani summer village in Phocis, Greece, including (A) a house (*konakia*), and (B) settlement structure. Images taken by Kouremenos (1985, front cover, p.11, respectively) during the 1980s.

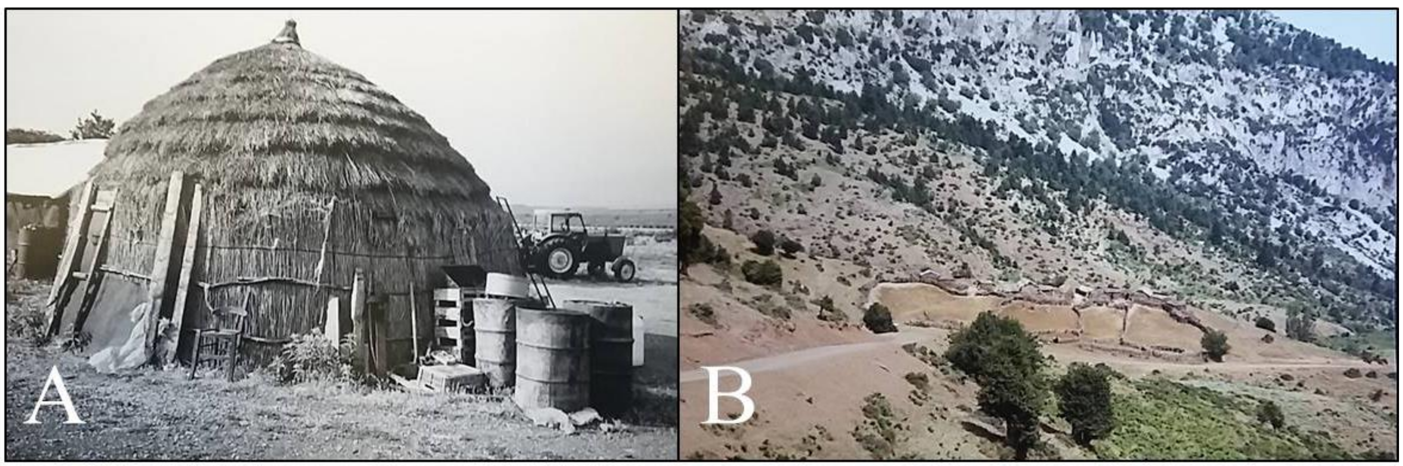

Figure 2.3 Images of a Sarakatsani village in Thessaly, Greece, including (A) a house (*konakia*) and (B) settlement structure. Images taken by Margriet Haagsma in Thessaly in 1989.

literature is based on Sarakatsani herders in the last 40 to 100 years, modern Sarakatsani descendants still work in Thessaly today. They explain that their approach to management is similar to their ancestors, with hundreds of sheep and goats grazing in the highlands and marginal landscapes at various points throughout the year. Beyond the recent past, we are unsure when this specialized management style came into use, and if so, for what purpose.

2.2. Animal Use in Antiquity

Ancient sources state that animals were considered important primarily for their meat resources (Alcock, 2006; Dalby, 2003). Foxhall and Forbes (1982) argue that the ancient Greek diet consisted of cereals, cultivars, and animal products. Roughly 70% of the daily food energy requirement is believed to have come from cereals (Foxhall and Forbes, 1982), including 5% to 10% coming from protein-rich pulses (Halstead, 1981), which has caused many to question the role of animals in ancient diets (e.g. Chaniotis, 1995, p.52). Other studies highlight the importance of meat in religion (Jameson, 1988; Rosivach, 1994) or discuss the vital roles of animals' byproducts or land processing abilities in daily life (Howe, 2014; White, 1970). This suggests that there may have been a stronger emphasis on animal use in antiquity than dietary requirements would suggest.

2.2.1 Terminal Products[4] (Meat, Blood, and Hide)

Jameson (1988, p.87) argues that wild animals caught as game were for regular subsistence, whereas domesticated animals were only consumed in the context of ritual sacrifice. Faunal assemblages from the Thessalian sites of Kastro Kallithea (MacKinnon, 2016) and Pharsalos (Bishop, 2018), indicate that wild game only accounted for roughly 10% to 15% of recovered fauna at either Hellenistic context (see Chapter 3). Faunal remains yielded evidence of butchery and burning and animals appear to have been processed for consumption at both sites (MacKinnon, 2016). This is in agreement with arguments that wild game was rarely consumed and domesticated fauna were sacrificed often (e.g., Jameson, 1988, Rosivach, 1994).

Rosivach (1994) examines public sacrifice in Classical Athens to better understand ideologies concerning sacrifice and meat requirements. His analysis quantified the relative number of animals required for sacrifice during set times in the year (e.g., see below, Section

[4] Used here to refer to animal products that are the result of the animal's death.

2.3.2, Table 2.3). Using public inscriptions and calendars from different social units (*demes* and *genos*) he was able to identify the required number of animals that had to be sacrificed on a monthly basis. In a given year *demes* required 33 to 43 animals for sacrifice, with the *genos* requiring an additional 13 animals to be killed in its half-year calendar. The species used include domestic sheep, goat, swine, and cattle, with sheep and goat among the most common animal required for sacrifice. Most sacrifice involved bloodletting or burning small portions of the animal for tribute to specified gods, whereas the rest of the animal would be consumed by or sold to the participants (Ekroth, 2014, 2017). Instead of being important for subsistence, animal meat and blood were often considered of cultural importance in Athenian social circles (Jameson, 1988; Naiden, 2017). Alternatively, Classical Athenian authors wrote about the unrefined extravagance of Thessalians, which included the notion that Thessalians ate too much meat (Pownall, 2009). Although these perceptions were likely exaggerations made by outsiders, Thessaly required terminal products for banqueting, sacrifice, and regular diet in antiquity.

2.2.2 Byproducts (Milk, Hair, and Manure)

Harnessing animal byproducts was an economic adaptation to domestication, as animals could sustainably provide products like milk, wool, or manure without being killed (Sherratt, 1981). Goats were important for milk production and especially for producing cheese (Isager and Skydsgaard, 1992, p.91). Straining vessel fragments have been located at Kastro Kallithea[5] and Pharsalos (Fig. 2.4) that are in keeping with descriptions of cheese processing from Aristotle [*Hist. Anim.* 521b, ff] (Ross, 1964) and Hesiod [*Works and Days*, 590] (West, 1988, p.54).

Sheep were also important wool producers and could be sheared annually prior to the summer season (Kron, 2014, p.116). Wool was used for textile production and provided the textile needs for the household. Chaniotis (2005, p.96) indicates that annual wool requirements for a household in Hellenistic Crete did not exceed two to three kilograms per person for clothing, with elites requiring larger quantities of wool for specialized textiles. According to Halstead (1981) these household wool requirements could be met by four to five sheep.

A minimum of six loom weights were likely used to complete a household loom in antiquity (Haagsma, 2010). Lawall (2014, p.171) references vase paintings to postulate that 'professional' or economic-driven loom systems may have used up to 65 to 70 loom weights, although issues of

[5] The remains of this specific vessel are contested, as they could either represent a cheese strainer or a colander.

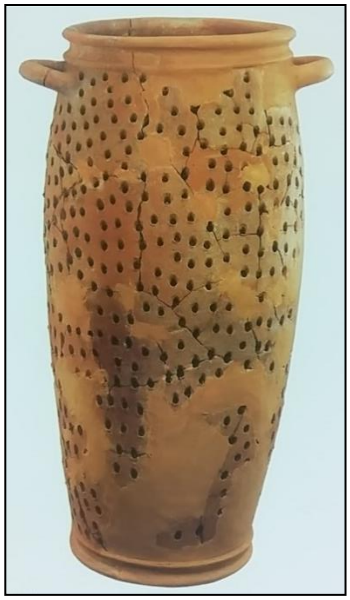

Figure 2.4 Hellenistic dairy processing vessel found in the destruction level of a house at Pharsalos. Image from Municipality of Pharsala (2015, p.86) and discussed in Karapanou (2000).

Figure 2.5 **Left:** *Lekythos* vessel from Classical Athens depicting women weaving using a weighted loom. Image from Sofroniew (2011).
Right: A reconstructed loom with loom weight artefacts from Kastro Kallithea. Image from Haagsma *et al.* (2019a, p.62)

identifying abundance, loom size, and system purpose are problematic. Domestic contexts that yield excessive amounts of loom weights may suggest a specialized economy beyond the means of the household, including the Cretan examples from single dwellings at Eleutherna (n=345) or Knossos (n=656) (Chaniotis 2005, p.96). As an alternative, the domestic structures at Halos (Thessaly) yielded scatters of five to 14 loom weights in most households (Haagsma, 2010, pp.207-208). Excavation at Building 10 at the nearby site of Kastro Kallithea yielded at least 230 loom weights (Haagsma *et al.*, 2019a) (Fig. 2.5, right). The abundance of wool-processing equipment at Building 10 supports extensive textile production beyond household means (Haagsma *et al.* 2015, 2019a), and may be more consistent with the economic-driven systems discussed by Lawall (2014).

Sheep and goat manure, either in the form of fecal matter or litter soaked in urine, was also a requirement for healthy agriculture (Kron, 2014, p.113). Due to their digestive physiology, sheep and goats naturally spread their manure evenly across a field as they graze (Hall, 2019). Columella [*De Re Rustica,* I.I.23-310] (Ash, 1941) discusses manure in detail and indicates that animal management and agricultural practices were so interrelated during antiquity that landowners (and their hired help) needed to be well-versed in both practices (White, 1970, p.275).

2.2.3 Power and Land Processing

Large stock animals, such as oxen, were important tools for agriculture and mobility. Animals would provide traction and could be attached to ploughs to help till the land (Sherratt, 1981). Varro [*Rustica.* I.20.4] (White, 1970, p.273) indicates that farmers would use donkeys, cows, or mules to help process the land. Mules and donkeys were also useful as pack animals during travel (White 1970, p.299). Although sheep and goats are capable of maintaining crop stubble or other vegetation (Bishop *et al.*, 2020; Hall, 2019), and do migrate as part of grazing, this is not commonly discussed in reference to ancient power or land processing.

Traditionally, horses would also be included in this section, as horses are large stock animals used in modern contexts for land processing or as pack animals. Horses in Greek antiquity were not often used for these purposes, but were instead important for hunting, warfare (e.g. infantry, cavalry), and sporting events (e.g. Olympics) (Aston and Kerr, 2018; Hyland, 2003; Willekes, 2018). Equids are among the most commonly referenced animals in ancient Greek iconography,

Table 2.2 Summary of proposed animal management strategies in use in ancient Greece.[6]

<table>
<tr><th>Farming System</th><th>Focus</th><th>Feeding Strategy</th><th>Flock Size</th><th>Conditions for Successful Management</th></tr>
<tr><td>Localized Herding and Mixed-Farming</td><td>Agriculture (cereals) with limited animal-based domestic economy</td><td>Summer grazing (local) Winter stall fed (homestead)</td><td>Small</td><td rowspan="2">Locally available fodder (stubble) and water sources</td></tr>
<tr><td>Semi-local agropastoral</td><td>Animal-based and agricultural economy mostly equal</td><td>Seasonal pasturage (locally)</td><td>Small-Medium</td></tr>
<tr><td>Long- or Short-Distance Specialized Pastoralism</td><td>Primary: animal-based economy; secondary focus at permanent residence</td><td>Summer pasturage (non-local); Winter grazing (local)</td><td>Large</td><td rowspan="2">Non-local grazing rights (permissions), room for grazing, and passable boundaries; access to local markets</td></tr>
<tr><td>Nomadic Specialized Pastoralism</td><td>Animal-based economy only (at markets)</td><td>Non-local grazing</td><td>Large</td></tr>
</table>

including prominent displays on ancient artwork, ceramic vessels, statues, figurines, and coins, and they are frequently mentioned in ancient literary sources (e.g., Homer *Iliad, Odyssey*; Plutarch *Alexander*; Xenophon *Hellenica, On Horsemanship*) (Willekes, 2016). Ancient Greek horses were an expensive commodity, with an animal's price and prestige associated with breeding location and management style (Thomas, 2014). The best horses reportedly came from Thessaly, however there is limited information about what their management style entailed or why they were favoured (Isager and Skydsgaard, 1992; Thomas, 2014; Willekes, 2019). Overall, domestic animals had different roles in society, and were likely used in different ways, each with their own associated management style.

2.3. Animal Management in Antiquity

Variations in animal management strategies correlate with dynamic and flexible relationships between animals, humans, and their landscapes (Biagetti and Howe, 2017; Frachetti, 2008). Similar to the three types of farming strategy in place today (Table 2.1), ethnohistoric data suggests that four different types of animal husbandry strategies were likely used in Greece during antiquity (Table 2.2) (Hadjigeorgiou, 2011; Reinders, 1994, 1996; Romano, 2013).

[6] adapted from Chang (1992, p.83), Chang (1993, p.695), and Romano (2013, p.158).

The 'localized herding and a mixed-farming' system was similar to the 'home fed' system in place today, and focused on cereal cultivation, with pastoralism as a secondary form of the domestic economy. In this scenario, animals would usually be kept and grazed not far from the village and typically stall-fed in winter. The size of the flock was based on stall, grain, or grazing capacity. The 'semi-local agropastoral' model, similar to the 'intensive farming' system, was a form of restricted mobile economy, which involved taking flocks to summer pastures in close proximity to both winter pastures and the main habitation site. With the ability to graze in different areas, shepherds could maintain larger flocks, but also rely on agricultural economy throughout the year. 'Long-distance specialized pastoralism' was similar to the 'extensive farming system' in place today. Both 'long-distance specialized pastoralism' and the 'nomadic specialized pastoral' model involved movement of large herds to non-local grazing areas. Unlike 'long-distance specialized pastoralism', nomadic shepherds were constantly moving, and relied solely on their animal-based economy. It is important to note that in many of these scenarios, shepherds would often be hired by landowners to manage their animals and agricultural lands, and a mixture of multiple variants of animal management was likely in use at the same time (Howe, 2008). Researchers use multiple means of analysis in order to decipher which strategies were in place, including when, where, and for what purpose.

2.3.1 Ethnoarchaeological Evidence

When Reinder Reinders surveyed the area surrounding the Óthrys mountain range (Fig. 2.1) in the 1980s, he was certain that the landscape used by the modern shepherds was similarly used in the past (Reinders, 1992, 1994; Reinders and Prummel 1998). Researchers often look at ethnographic sources as a point of departure in their assessment of animal management in antiquity (Chang, 1994; Forbes, 2013; Halstead, 2014). Carrer (2015), Cherry (1988), and Halstead (2009) use the ethnographic approach to examine social patterns and experiences of modern herders to understand site decisions, record evidence of material culture at each site, and apply all findings to archaeological contexts. This form of study, called ethnoarchaeology, involves detailing environmental surveys, ethnographic studies (e.g. mobility strategies and length of site occupation), and archaeological studies of factors effecting site location, site contents, and site visibility (Chang, 1993; Chang and Tourtellotte 1993; Ripoll, 2003).

Figure 2.6 Stone foundation found near a modern Sarakatsani winter community area in eastern Thessaly. Foundation is speculated to have belonged to a non-modern pastoral group. Image taken by Margriet Haagsma in 1989.

There are limitations to this approach, as the sociopolitical circumstances that allowed the development of modern large-scale nomadic stock farming and the ecological conditions that permitted large-scale mixed farming strategies differed from conditions seen in antiquity (Hadjigeorgeiou, 2011; Halstead, 1987b, 1996). Additionally, archaeological evidence of shepherding sites is limited, and any shepherding-related evidence is fairly subjective. As an example, Figure 2.6 may illustrate the remains of a *konakia* similar to those depicted in Figure 2.2a and 2.3a; however, due to a lack of dateable context at the 'site', it is difficult to associate a temporal period or people to this structure. Instead, researchers focus on multiple lines of evidence and combine ethnographic observations (Chang, 1994; Halstead, 2014), ancient literary sources (Howe, 2008; Skydsgaard, 1988) and the study of faunal and other material remains (Halstead, 1981, 1984) to better understand animal management in antiquity.

2.3.2 Literary Evidence

Reinders and Prummel (1998) present an argument based on mythological and historical sources that associate long term pastoralist traditions with southeast Thessaly. Ancient mythology likely grew out of local traditions and often weaves facts (real locations, people, or context) with imaginative or embellished stories (Dowden and Livingstone, 2011). Myth is often passed down and can become part of 'history', although it is best used as a vehicle for historical analysis (Griffiths, 2011, pp.194, 199). One such example can be found in Callimachus' Hellenistic poem *Hymn to Demeter* [VI, 86]. Here Erysichthon's mother gives excuses for why her son cannot attend a banquet or wedding, which include the fact that "he is counting his flocks on Óthrys" (Hopkinson, 1984, pp.68-69, 146). This example can be used to reflect on two significant details from the time period, (1) that there is an association between the Óthrys Mountains and pastoralist traditions; and (2) that Erysichthon was only going to supervise or count his flocks, not actually shepherd them. This poem supports the notion that shepherds were often hired to care for herds when they were considerable distances from home, and that the owners could often visit or monitor their property, as necessary.

Another example comes from the myth of Cerambus (Kerambos), who is mentioned in the late sources of Antoninus Liberalis' *Metamorphoses* (Celoria, 1992) and the *Metamorphoses* of Ovid (Goold and Miller, 2014). In Ovid [*Metamorphoses* VII, 351-356] (Goold and Miller, 2014), Cerambus is strongly associated with the Óthrys Region. The myth of Cerambus is the earliest written evidence associating the Óthrys with shepherding. In Antoninus Liberalis [*Metamorphoses* XXII, 252] (Celoria, 1992, p.79) we learn that Cerambus is a shepherd of many flocks, and that he herds them himself in the Óthrys Mountains. This poem also introduces the notion of seasonal mobile management when Pan, the god of shepherding and flocks, advises Cerambus to leave the mountains and head for the plains during winter [Antoninus Liberalis, *Metamorphoses,* XXII, 254-255] (Celoria, 1992). Although Cerambus did not listen to Pan's advice, with the result that his flocks became frozen in the snow, we can learn from the poem that Mount Óthrys was associated with summer grazing and that winter grazing took place in the surrounding plains.[7] As has been said, the written evidence of these myths is late and come from poetry written during the Classical and Hellenistic periods. Yet, the myths themselves derive from a long term oral tradition. They are not direct accounts of shepherds in the area, but myths often convey general 'timeless' understandings, such as the ways in which landscapes are used and transversed (Griffiths, 2011). Myths often include aetiological truths, meaning that they explain why things are the way they are (Dowden and Livingston, 2011). In this case, poets wrote about shepherds and how shepherding became associated with this area. If the myths of Erysichthon and Cerambus are any indication of long-term pastoral practices, we can surmise that the Óthrys was associated with pastoralism and also with mobile, or specialized, forms of shepherding.

[7] The Almiros and Sourpi plains are commonly used for winter grazing as part of modern transhumant shepherding around the Óthrys Mountains (see Reinders 1992, 1994).

Similar to the mentions in *Metamorphoses*, other literary sources indirectly discuss flock and agricultural management during the Archaic and Classical periods (Austin and Vidal-Naquet 1977, p.286). In *Theogony* [19] Hesiod explains that he was a shepherd who cared for a flock of sheep beneath Mount Helikon (Fig. 2.1, mountain 2) (Powell, 2017, p.33). The muses refer to Hesiod [*Theogony,* 22] as a "rough shepherd" (Powell, 2017, p.34) or one who "camps in the wild" (West, 1988, p.3), depending on the translation. Hesiod wrote so-called pastoral poetry, and both of these descriptions could imply that Hesiod's knowledge of shepherding was based on nomadic pastoralism rather than local herding. Alternatively, in *Works and Days* [788] Hesiod mentioned building a "sheep-pen" for local use (West 1988, p.60). He also discussed how their thick winter fleece will protect sheep from the north wind [*Works and Days,* 438-440], likely in reference to the ability for sheep to withstand harsh outdoor winter conditions while in these pens (Powell, 2017, p.131). Both Hesiod [*Works and Days]* and Antoninus Liberalis [*Metamorphoses*] discuss the management of flocks in the winter, with varying degrees of success depending on the location (Celoria, 1992; Powell, 2017). Sheep and goats are capable of withstanding considerable cold winters so long as they have their thick coats and can stay relatively dry (Hall, 2019). Taken in conjunction, these texts support and illustrate the presence of multiple means of management and hint at specialized pastoralism (Table 2.2) occurring in Greece during antiquity.

Shepherding is commonly mentioned in ancient texts in reference to military or religious connotations. As an example, Homer's *Iliad* (e.g., [*Il.* 5.565-67]) and *Odyssey* (e.g., [*Od*., 18.66-70]) use the expression "shepherd of men" (ποιμένα λαῶν) to describe a military captain as a shepherd of his flock of soldiers (Aubert, 2009, p.145). The tone of shepherding references changes in literature produced after the Hellenistic period, especially with Theocritus' work and the advent of bucolic poetry. Theocritus [*Idyll 5*] (see Section 2.5.2) presents a romanticized view of shepherding when he discusses the light conversation between two shepherds about the desired foods of their animals (Levi, 1993). Figure 2.7 shows a silver dish from the Hellenistic period that is believed to illustrate Theocritus fondly watching over his goats. Shepherds are portrayed differently in the late Classical and early Hellenistic periods than they were during previous periods (e.g., Homer). It is possible that this change relates to more widespread use of shepherding or simply an increase in romanticization of the conditions of shepherding life.

Figure 2.7 Pastoral scene on a silver dish from the late Hellenistic period. The seated figure is believed to represent Greek poet Theocritus. Image from Levi (1993, p.112).

Figure 2.8 Ceramic from the Middle Minoan I (2000-1800 BCE) site of Palaikastro illustrating a shepherd and approximately 140 sheep. Image discussed in Branigan (1970, pp.70-71). Image from www.aristotleguide.wordpress.com.

Sophocles not only mentions shepherding in his Athenian tragedies, but he also details an instance of transhumance. Foxhall (2006, p.274) translates the part of Sophocles' *Oedipus Tyrannus* [1121-40] where two shepherds are discussing their shared history:

> I am sure he knows well of the time we dwelled in the region of Cithaeron for six month periods, from spring to Arktouros he with two flocks, and I, his comrade, with one. And then for the winter I used to drive my flock to my own fold, and he took his to the fold of Laius.

Both shepherds were mobile with their herds and spent six months near a shared summer pasture in the mountain region of Cithaeron (Fig. 2.1, mountain 3) before returning to their lowland winter villages for the remainder of the year. The shepherd recounting this history reportedly winters in the lowlands neighbouring Cithaeron, while his comrade returns to the ancient Thebes[8], between Cithaeron and Athens (Jebb, 1893). This Athenian tragedy was first performed

[8] In Greek mythology, King Laius, or Laios of Thebes, was in the ancient town of Thebes and it is likely his fold wintered in proximity to the area (Jebb, 1893).

around 429 BCE (Foxhall, 2006). If specialized shepherding was well known to the Athenians by the Classical period, it is probable that these practices were also occurring in Thessaly during the Classical and/or Hellenistic periods.

2.3.3 Archaeological Evidence

Long term archaeological evidence supports claims that early estates had larger assemblages of animals, sometimes numbering in the hundreds. As an example, a bowl (Fig. 2.8) recovered from the Middle Minoan I Period (2000-1800 BCE) site of Palaikastro in (Crete, Fig. 2.1) illustrates a shepherd and flock of approximately 140 animals. This herd size closely matches other estimates (e.g. Rosivach 1994) and is believed to represent a considerable accumulation of wealth in livestock (Branigan, 1970). Mycenaean (1600-1100 BCE) tablets recovered from Knossos, Crete detail that between 80,000 and 100,000 sheep were required by the palace every year, either for meat, wool, or palatial herds (Killen, 1964, p.5), and often in support of expansive wool and textile-based industries in Crete during Mycenaean times (Killen, 1964, p.14). The ceramic vessel illustrated in Figure 2.8 predates the tablets recovered from Knossos, however both suggest that herds of considerable size were present in Crete during ancient times. Herds of this magnitude would have required considerable land for pasture and specialized management strategies accordingly. Similar practices may have been required in Thessaly during antiquity.

Faunal assemblages can also yield information about site occupancy, herd size, animal availability, and to some extent animal use. Chapter 4 details how faunal analysis is capable of identifying certain species, element fragments, and taphonomic indicators (cutting, burning), which are used to indicate animals used for terminal products or byproducts. In this way faunal evidence can also be used to assess culling strategies and different management strategies (e.g., Payne, 1973). In sites where multiple strategies were likely in use, or the site was continuously occupied, assemblage analysis becomes limiting and more subjective (e.g., Greenfield and Arnold, 2008) (see Chapter 4, Section 4.1).

2.4. The Agropastoral Debate

Evidence of pastoral styles or processes is subjective and specific to certain contexts. As a result, researchers are divided over what forms of animal management took place, when, and for what purpose (Appendix 2.1).

2.4.1 Agropastoral Model

The agropastoral model argues that (1) records indicate that farmers had smaller flocks of two to eight animals[9], which by no means required seasonal movement to obtain larger pasturage; (2) if there were instances of larger herds their pasturage would have caused large-scale deforestation and erosion, which are claimed to be unsupported by the archaeobotanical record; (3) movement of animals was undesirable because it took necessary manure resources from the fields; and (4) faunal mortality profiles do not support transhumance (see Appendix 2.1 for proponents of this model; e.g., Hadjigeorgeiou, 2011; Halstead, 1996; Hodkinson, 1988).

One of the earliest and most important thinkers in this debate is Paul Halstead. Halstead (1981, 1984, 1987ab, 1996, 2006) has provided many reasons why specialized management like transhumance likely would not have been practised until after the Roman period. In particular, he argues that mobile herding took animals away from arable farming where their manure was important (Halstead 1987a), seasonal grazing would have required severe deforestation in summer and winter grazing areas (Halstead 1987b, 1996), and there was no significant demand for a byproduct-based economy (Halstead 1987b, 1989). Halstead is the primary advocate for the agropastoral model. This model is largely founded on economics and landscape use, and Halstead (1996, p.20) argues that a household herding and local garden economy would have been more than sufficient for small populations in regions such as Thessaly.

2.4.2 Transhumance Model

Alternatively, proponents of the transhumance model argue that larger herds were prevalent during antiquity. Increased flock sizes required more forage space than could be met by local landscapes, which prompted shepherds to move with their herds. Larger herds may have resulted from (1) textile and dairy economies requiring large herds of sheep and goats to meet byproduct demands; (2) increased demand for animals for sacrifice or other market sales as part of fairs or major events like the Pythian Games; or, (3) a rising importance of 'wealth in flocks' as it relates to pastoral politics (see Appendix 2.1 for proponents of this view; e.g., Chang, 1993, 1994; McHugh, 2017; Skydsgaard, 1988).

Reinders (1994, 1996) is a key advocate for the 'transhumant model' in Thessaly. Reinders and Prummel (1998) argue that Thessaly's increased urbanization in antiquity created market

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[9] Flock size based on Alcock *et al.* (1994) and Halstead (1981).

conditions suitable for supporting specialized pastoralism regionally. This form of animal husbandry would have required larger herds and supported movement throughout the region, which they believed had more than sufficient landscape resources to support it. Reinders and Prummel (1998) have spent decades analyzing the archaeology of parts of Thessaly and witnessed that the Óthrys Mountains are suitable for summer pasturing in recent times and argue that this landscape was also used as such in the past. This suitability suggests that transhumant pastoralism likely occurred during the Classical and Hellenistic periods in Thessaly.

Modern transhumant communities indicate that their strategies are based on economic gain as well as notions of culture and identity (Cherry, 1988). One of the strongest critiques of the agropastoral debate is that it fails to consider social and cultural aspects of animal management in antiquity (Forbes, 1995). Halstead (1987b, 1996) argues that transhumance was not possible because there was no economic market to support a byproduct economy. However, animals were likely kept and managed for reasons beyond those that are purely economic[10] or subsistence based. Transhumance is not just the relationship between shepherd, animal, and landscape, but also the interrelations with other shepherds, landowners, culture, and industry (Howe, 2014). Humans were the reason pastoral economy increased and were the driving force behind a rise in shepherding culture. An owner who has large flocks of healthy animals is seen as having 'wealth in flocks'[11] even though they were likely a drain on economic resources (Howe, 2008). Campbell (1964) observed modern Sarakatsani placing emphasis on quality and quantity of flocks, and even connected these values to a shepherd's social reputation. Howe (2003, p.136) argues that the same correlation was made during Hellenistic times. Pastoral culture in the Hellenistic period was driven by "pastoral politics", which in turn impacted grazing land claims and economic warfare (Howe, 2008). Proponents of the transhumance model use many lines of evidence to support it. One of its key strengths is its consideration of the social and cultural forms of pastoral identity.

2.4.3 Mixed Models

The final component of the agropastoral debate is the argument that successful Hellenistic economies required agropastoralism *and* transhumance (see Appendix 2.1 for proponents of this

[10] Campbell (1964) indicates that modern transhumance was not always financially stable.

[11] 'Rich in herds' or 'Rich in flocks' from Homeric epics [*Iliad* 2.106, 605, 705; 9.154, 296; 14.490; 16.417] [*Odyssey* 11.257; 15.226] and discussed by Howe (2014, p.141).

Table 2.3 Sarakatsani land utilization in Epirus expressed in percentages.[12]

Land Type	Amount of land used for grazing (%)
Cultivated areas (including arable land and orchards)	2.2
Previously cultivated land, now barren	3.1
Open pastureland	25.7
Forest or bush pasture	26.1
Forests	36.7
Roads, ditches, village sites, barren land, etc.	6.3

view; e.g. Forbes 1995, 1998; Howe, 2008, 2011; Papanastasis *et al.*, 2010). Halstead (1981, 1987b) argues that certain environments are better suited for mixed farming models, whereas others are ideal for permanent pasture. The range of animals kept at any one time (Tables 2.1, 2.2) reflects a balance between available fodder and the specific requirements for byproducts (Halstead 1981, p.322). Based on his analyses, Halstead (1981, 1984, 1987b, 1996, 2006) feels that economies that required more animals than the local ecology could support would have caused severe deforestation for the creation of new pasture. Such landscape alteration led to disturbances in growing capacities and overall erosion. Based on Oba *et al.* (2010), agronomy is disturbed more by the *absence* of grazing than by continuous or over- grazing practices. Hall (2019) also reports that selective grazing practices are capable of regenerating native growth and improving natural ecosystems. This would suggest that sedentary communities would require animals to graze their lands for at least some portion of the year, or once within a three year period (Hall, 2019). Regions that focused on agriculture, such as Thessaly, required local animal management for at least parts of the year. Although this supports the concept of small- scale agriculture and local animal management, it also supports large-scale transhumance; large herds that cannot be maintained locally year-round can be kept seasonally to graze on agricultural crop stubble (McHugh, 2017).

Modern shepherds in Greece also preferentially graze their animals on marginal landscapes for a portion of the year to ensure a balance between agriculture and pastoralism (Hadjigeorgiou *et al.*, 1999). Table 2.3 outlines the land utilized by Sarakatsani herders between 1956 and 1957 (Campbell 1964). Halstead (1996) was concerned that transhumance would have required open

[12] Adapted from Campbell (1964, Appendix II) and based on the Ministry of Agriculture (1956-1957).

pasture or cultivated areas for herds to graze on. Based on the Sarakatsani land use, Halstead's (1987a) 'expected' grazing land-type only accounts for 31% of the total land used. Ecologically, transhumance could have been practised in antiquity in similar ways as in modern times.

Halstead (1984, 1987b) has also argued that transhumance would have required deforestation, and since there is no evidence of severe deforestation during antiquity, there was no transhumance. However a number of authors have shown that shepherds could graze their animals in marginalized areas (Table 2.3) (e.g., Hall, 2019; Hughes, 1996; McHugh, 2017). This means that deforestation is neither evidence for, nor evidence against transhumance. Hughes (1996, pp.77-79) examines the effects of overgrazing on deforestation and erosion and concludes that foraging animals alone are not responsible for destroying mature forests, which are more impacted by anthropogenic forces related to the timber industry, clearing for agriculture, and urbanization.

2.5. Summary

Today, much of the land in Greece is well suited for large-scale agropastoralism, including crop farming, local herding, and long-distance animal management (Hadjigeorgiou *et al.*, 1999; Sossidou *et al.*, 2013). It is likely that a similar mixed approach was used in the past, with various pastoral strategies in place simultaneously (Cardete, 2019; Hodkinson, 1988; Howe 2003, 2008, 2011, 2014; Papanastasis *et al.*, 2010; Skydsgaard, 1988). Similar to modern farmers who keep few animals for household use, manage small agricultural plots, and have stock in larger mobile pastoral herds (Table 2.1), ancient communities likely employed various strategies to ensure all of their agricultural and pastoral needs were met (Table 2.2). This chapter provides the necessary context for discussing how or why animals may have been managed in antiquity. One of the limitations of the agropastoral debate is that the sociopolitical circumstances that allowed the development of modern large-scale nomadic stock farming and the ecological conditions that permitted large-scale mixed farming strategies differed from conditions seen in antiquity (Halstead, 1987, 1996; Hadjigeorgeiou, 2011). As I will show in the next chapter, the social, political, and economic context of Thessaly during the Hellenistic period may have been well-suited to foster a rise in mixed agropastoral economy during this time.

CHAPTER 3: Site Analysis: History and Context

Today, southern Thessaly is known for its production of agricultural goods (wheat, barley, rye, feed corn, chickpeas, lentils, nuts, and grapes) and arable pasture for livestock (sheep, goats, cattle, horses, pigs, and poultry) (Hadjigeorgiou *et al.*, 1999; Wagman, 2016). It is also home to marginal landscapes at high elevations, including the Óthrys Mountains, which are frequented by nomadic shepherds (Kavvadias, 1965; Reinders, 1994, 1996). In antiquity, the lower plains of Thessaly were well-known for their large population of cereal farmers due to soil fertility and access to fresh water. There is also speculation that the marginal landscapes on the Óthrys Mountains were also frequented by shepherds in antiquity (e.g., Reinders, 1994, 1996). As Chapter 2 discussed, the presence of specialized pastoralists in Thessaly is contested (Halstead, 1981, 1984, 2006). This chapter discusses the landscape and history of Thessaly, including the sociopolitical circumstances that *may* have allowed for the development of specialized animal management strategies in the past (see Appendix 3.2 for a generalized timeline). I first provide an overview of the Thessalian landscape (3.1), and then explore the history of the area of southeast Thessaly (3.2), examine the site context, history, and archaeology of Pharsalos (3.3), Kastro Kallithea (3.4), and other sites of interest in this analysis (3.5). This chapter serves as the historical and archaeological background for southeast Thessaly during the Classical (c. 480-323 BCE) and Hellenistic (323-30 BCE) periods, which provides the contextual background for the data interpretations in my project.

3.1. Thessalian Landscapes

To understand the social, political, and economic history of Thessaly, it is important to first provide an overview of the landscapes of this region today and in the past. Much of the culture and history of Thessaly stems from aspects of its geography, climate, and ecology (Aston, 2017; Westlake, 1935). Haagsma *et al.* (2019b) argue that changes in the physical landscape and settlement patterning during the Classical and Hellenistic period directly related to group identity and community changes during those times. Today Thessaly is outlined by provincial boundaries (Fig. 3.9, white line), but ancient "Thessaly" was demarcated by features of the visible landscape, and these boundaries often changed depending on the era. Graninger (2010) explains that early Archaic Thessaly included the two plains on either side of the Karadag Ridge. Mili (2015, p.2) explains that for most of the Classical and Hellenistic periods, "Thessaly" was the

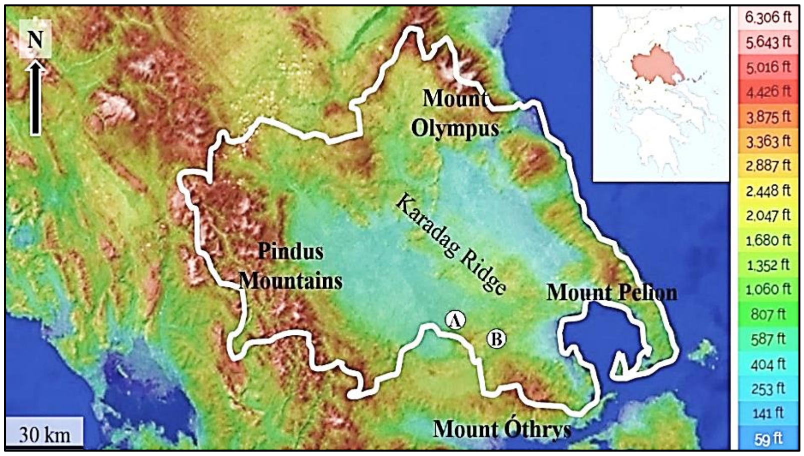

Figure 3.9 Topographic map of Thessaly. Modern Thessaly border outlined in white. Sites demarcated by A: Pharsalos, and B: Kastro Kallithea. From ESRI Imagery (2020).

region between Mount Olympus (north), Mount Pelion (east), Mount Óthrys (south), and the Pindus Mountains (west) (Fig. 3.9). Although Thessaly was considered a distinctive region as early as the 6th c. BCE, there were different political bodies controlling various regions throughout time, often related to geological strongholds or access to resources.

3.1.1 Geological Landscapes

Thessaly is considered to have the highest seismic activity in Greece, which not only influenced its geology over many millions of years, but also impacted settlement history (Higgins and Higgins, 1996; Wagman, 2016). As an example, a major earthquake was likely responsible for the destruction and site abandonment of the southeast coastal settlement of New Halos ca. 265 BCE (Reinders, 1996; Reinders *et al.*, 2016). Although Xenophon [*Hell.* 6.1.9] (Marchant and Bowersock 1925) commented on how exceedingly flat Thessaly was in his time, Figure 3.1 clearly shows elevated regions visible throughout Thessaly today. Xenophon was likely referring to the two main plains that are separated by the Karadag ridge, including those at the site of Pharsalos (Fig. 3.9 A). Descriptions of the Thessalian landscape are common themes in literary sources, and often depict land use patterns or the visible landscape. Examples include accounts of fertile lands in military accounts from the Classical period (e.g., [Thucydides, 1.2.3]) or areas rich in grain from accounts of the Hellenistic period (e.g., [Xenophon, *Hell.* 6.1.11]). Researchers have also used depictions of the geological landscape (e.g., the presence of mountains, streams, or plains) from ancient literary sources to map out the sites of military campaigns (e.g., Morton, 2017) or identify ancient settlements (e.g., Stählin, 1967).

3.1.2 Climatic Landscapes

Researchers also take clues from ancient literary sources and combine them with hydrogeology in Thessaly today (Bottema, 1988; Hughes and Thirgood, 1982; van Andel *et al.*, 1990). Summer droughts, watershed destruction, and deforestation result in intermittent flow and increased siltation, and contribute to many rivers running dry seasonally (Hughes and Thirgood, 1982, p.68). Erosion modifies climate because soils are unable to retain consistent water resources, which impacts water availability in climatic systems. Bottema (1988) uses pollen records from lakes in Thessaly to show that the region became more open, woodlands became drier, and erosion increased after the Neolithic period. Such changes to landscape would have resulted in marked alterations in climate (Hughes, 2014, p.251 n.73). Similarly, Hughes and Thirgood (1982) and van Andel *et al.* (1990) speculate that the Archaic and Classical eras saw widespread efforts to drain lakes and marshes for arable land for agriculture, which may have impacted rivers and streams in Thessaly. Theophrastus was a Hellenistic Greek philosopher who discussed climate and geology in antiquity. He specifically discusses the area around Larissa in Thessaly:

> … where formerly, when there was much standing water and the plain was a lake, the air was thicker and the country warmer; but now that the water has been drained away and prevented from collecting, the country has become colder and freezing more common [Theophrastus, *Hist. pl.* 5.14.2-3].

Authors argue that Theophrastus' discussion of ancient climate either relates to factual observation (Hughes, 2014), or to the belief that Thessaly was the location of an ancient Sea (Mili 2015)[13]. If Theophrastus' depiction was factual, regional climates in Thessaly were warmer and more humid prior to the Archaic period (Hughes, 2014). Alternatively, Papanastasis *et al.* (2010, p.124) indicate that climate has changed little from the Late Neolithic to modern times.

Today Greek climate is considered mostly Mediterranean, although its unique geography creates different microclimates regionally (van Andel *et al.,* 1990). Much of Thessaly's microclimates are due to the unique hydrogeology of the region, which includes highly productive aquifers (groundwater catchments) in the plains and portions of the mountains. These groundwater resources are essential for irrigation, in that they afford plants consistent access to water and help with drainage during heavy rainfall. In many areas the bedrock does not store groundwater (is non-aquiferous), and contributes to surficial water pooling. In some locations

[13] Mili (2015, p.42, fn.130) based on interpretations from Herodotus [*Hist.,* 7.129].

these non-aquiferous rocky areas have formed artesian springs, including the *Karayul* artesian spring near Kastro Kallithea (Haagsma *et al.*, 2019a, p.18). Having access to this unique hydrogeology in Thessaly has been a benefit to farmers and herders in modern times, and it likely contributed to the productivity of agriculture and pastoralism in the past. The *Karayul* spring is still accessible to herders around Kastro Kallithea today (Haagsma *et al.*, 2019a, p.18). Access to hydrogeological resources would have also been an important consideration when establishing settlements (e.g., Haagsma *et al.*, 2019a, p.42), or for mobile shepherds.

3.1.3 Ecological Landscapes

Climate, geology, and anthropogenic forces all impact what grows and proliferates in any given region. Today Greece is known for cultivating olive trees, cotton, pulses, vines, and tobacco (Pezaros, 2004), with southern Thessaly being a key supplier of grape, olive, and barley crops (Municipality of Farsala, 2015). During the Hellenistic period Thessaly was also known as a supplier of wheat and other grains [SEG, 34, 558, 1. 4-12] (Helly, 2001, p.251). Prior to human intervention, ancient Greek ecology is assumed to have included dense forest cover (Bottema, 1988). Deforestation effects were escalated with the rise in agricultural economy (after 7,000 BCE) and species that replaced the oaks, elms, and coniferous species were well-suited to human needs (Bottema, 1979; Rackham, 1982). Modern Thessaly contains many non-native species and few areas retain their proposed 'ancient ecology', visibly only along the steep cliffs and areas mostly inaccessible to anthropogenic forces or grazing animals (Hughes, 2014; Rackham, 1982, p.182; 1996). The natural foliage that still exists is largely dominated by evergreen trees that are reduced to shrubs (*macchia*; e.g. prickly/kermes oak, strawberry-tree, junipers), undershrub (e.g. *pournaria*), steppe grasses, and other annual herbaceous plants (Rackham 1982, pp.183-188; 1996, pp.18-22; Woldring 2003, pp.155-156).

Woldring (2003a, 2003b) analyzed Mount Óthrys (Fig. 3.9) ecology (modern and pre-modern human) as a means for better understanding the natural regional ecology. According to his research, species of deciduous oak began to decline during the Holocene and a noticeable reduction in these species was specifically visible by 1,000 BCE (Woldring, 2003b, p.165). At the same time there was a rise in shrubs, fruit/nut-bearing trees (e.g. olive, chestnut), and cultivars (e.g. barley, wheat) (consistent with Bottema, 1979). Woldring (2003a, p.159) sees these secondary groups as evidence of anthropogenic deforestation for agriculture and animal browsing as part of pastoralism. Similarly, Halstead (1984, 1996) explains that the loss of forests in the Bronze Age and Early Iron Age Greece would have caused large-scale soil erosion and environmental degradation, which are issues still prevalent today. Alternatively, Rackham (1982, p.195) argues that such erosion was not a result of human activity alone, and instead suggests that it began naturally during the last glaciation of Northern Europe. Woldring (2003a, p.159; 2003b, p.173) suggests that processes such as erosion and water flow may have also contributed to ecological changes over time, specifically through seed dispersal to different ecological zones on Mount Óthrys.

Pollen studies from lake cores can also be used to indicate how an area's ecology has changed over time. Bottema (1988) examined a soil core from southeast Thessaly (near ancient Halos, see Fig. 3.10) and recorded a pollen profile for the region. The profile shows evidence of changing vegetation in the highland regions between 5,000 and 3,000 years ago, with the replacement of forest with shrubland (Bottema 1988, p.223). Bottema (1988, p.222) argues that a rise in flowering weed pollen (e.g., from *Asphodelus* or *Plantago lanceolata*-type plants) indicates the presence of sheep and goat herds grazing in mountainous terrain. Bottema (1979) analyzed pollen from cores sampled on two areas of Thessaly: Lake Xinias (near Hellenistic settlement Xyniai) and a lakebed northwest of ancient Demetrias (Fig. 3.2). Bottema (1979) reports that pollen from agriculture dominated the lake core record in these regions up until the Hellenistic period. After roughly 200 BCE the extent of cultivation declined and natural vegetation (presumably shrubland) appears to invade the area (Bottema, 1979, p.12).

Ancient sources often discuss the exceptional growing conditions available in Thessaly, which likely supported a strong agricultural market for wheat, legumes, and vineyard crops. Evidence from bronze coins (dating to 400-367 BCE) and an inscription (dating to 197-185 BCE) recovered from the archaeological site of Skotoussa (Fig. 3.10) suggests that the region was home to certain types of vine-based crops, likely grapes (Missailidiou-Despotidou, 1993, p.197), as well as dedicated pasture areas for grazing. Megaloudi (2006) examined archaeobotanical evidence from the Neolithic to Classical periods at six archaeological sites around Thessaly to assess which plant species were present and in what relative abundance (Appendix 3.3). Remains were preserved through charring (by deliberate or accidental exposure to fire), waterlogging, mineralization, desiccation, metal-oxide preservation, imprinting (e.g., in pottery), or in coprolites (Megaloudi, 2006). The data in Appendix 3.3 support claims that cereals and legumes were important components of the agricultural economy in periods preceding the Classical and Hellenistic. Legumes would satisfy protein nutritional requirements for humans who did not consume much meat (Dalby, 1996), and many of the species in Appendix 3.3 are also considered nutritious fodder for animals (e.g., broomcorn millet, bitter vetch, and oats) (Hall, 2019; White, 1970).

When considering the modern Greek ecological landscapes, prominent agricultural practices produce both arable crops and livestock pasturage, with the emphasis placed on agriculture or pastoralism in different decades. For example, there was a 35:65 split before 1980 and a 70:30 split in 2000, respectively (Pezaros, 2004, p.10). Ultimately Thessaly is home to a landscape well suited for human occupation and especially profitable for farmers and pastoralists today and in the past.

3.2. Historical Background

This section provides a brief overview of the history of Thessaly. While written records exist for Thessaly as far back as the Mycenaean period (Karachalios and Noula, 2014; Westlake, 1935), I will focus here on events occurring during the Classical and Hellenistic periods. I do not intend to cover all aspects of this history, but instead provide the foundation for discussing increased urbanization, growing population, and concepts of shared identity in the region of Thessaly. Political conflict, rising urbanization, and economic networks intensify in the Classical era, and foster much of the cultural identity and practices that develop during the Hellenistic period. Much of this history is founded in epigraphic and other literary evidence largely based on military efforts and warfare. Tables 3.4 and 3.5 and Appendix 3.2 outline many of the key historical points, demarcations, and impacts discussed in this section.

3.2.1 Pre-Classical Thessaly

Throughout much of the 1st millennium BCE, Thessaly was thought to be part of an oligarchic society ruled by the support of powerful families (Graninger, 2010; Wade-Gery, 1924). According to Aristotle [*Fragmenta*, 497R, 498], the legend states that it was during the 6th c. BCE that ancient ruler Aleuas the Red first separated the Thessalian plains into four regions or tetrads, Pelasgiotis, Hestiaeotis, Phthiotis, and Thessaliotis, which were collectively known as tetradic Thessaly (Fig. 3.10) (Bouchon and Helly, 2015, p.233; Graninger, 2010, p.307). During this time tetradic Thessaly was thought to be ruled by three powerful families: Aleuads

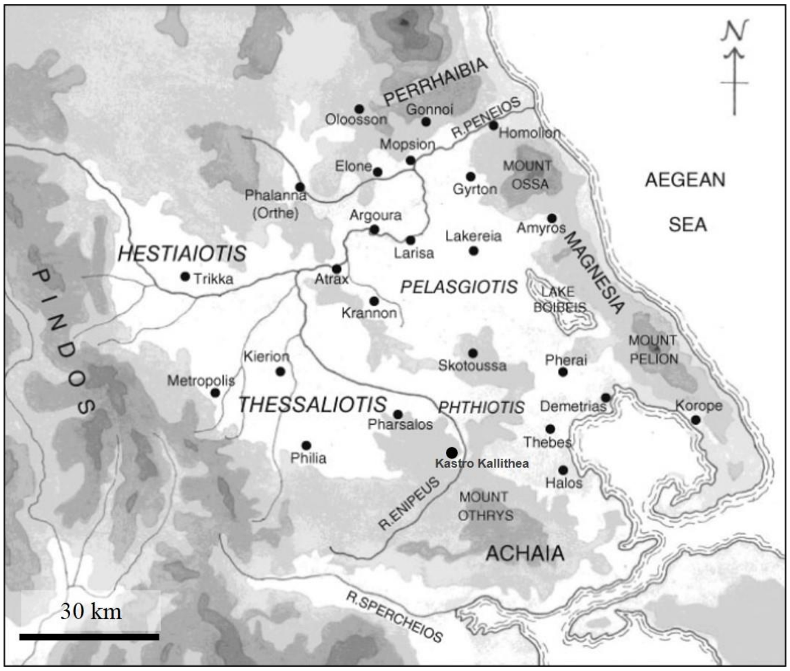

Figure 3.10 Map of ancient 'Thessaly', highlighting the tetrads, perioikoi, and some cities discussed in text (modified from Aston, 2017, p.85). Kastro Kallithea location added for reference.

of Larissa, Echekratids of Pharsalos, and the Skopads of Krannon (Graninger, 2010; Westlake, 1935, p.30). Within each tetrad were communities, or *kleroi*, who participated in civil wars between cities and tetrads (Wade-Gery, 1924, p.58), and *penestai*, the slave class that was responsible for agricultural maintenance and could also be called upon for military service alongside their 'owners' if necessary (Graninger, 2010, p.308; Graninger, 2011, p.12, f.n. 15; Westlake, 1935, p.22).

Neighbouring the Thessalians were the mountain communities of Perrhaebia (north), Magnesia (east) and Achaia Phthiotis (southeast), referred to as *perioikoi* (Graninger, 2010, p.308) (Fig. 3.10). Prior to the 6th c. the *perioikoi* are believed to have been loosely organized as autonomous states with "small-holdings of free peasantry" (Westlake, 1935, p.23). Over the course of the 6th c. and at least by the beginning of the 5th c., likely as a result of increased military involvement (possibly initiated during the First Sacred War, ca. 590 BCE: Robertson, 1978; Westlake, 1935), *perioikoi* became responsible for paying tribute (see Xenophon [*Hell*. 6.1.18]; Marchant and Bowersock, 1925). In the time of Jason of Pherae, the *perioikoi* were also expected to contribute to the military efforts of the *Tagos* (Graninger, 2010, p.308). Bouchon and

Helly (2015, p.231) refer to this political organization as the 'Thessalian Confederacy', which was ruled by the *Tagos*. The Thessalian Confederacy was a considerable Greek force with its own unique cultural traditions, languages, and religion (Graninger, 2010; Helly, 2001; Mili, 2015). The shared *ethnos* or identity at this time was considered to be distinct from the 'Greek' social identity, with some believing Thessalians to be more like Macedonians than Athenians (Helly, 2001; Graninger, 2010, 2011; Westlake, 1935, p.22).

Tetradic Thessaly had numerous treaties with Athens during this time (Bouchon and Helly, 2015, p.232), but during the 480 BCE Persian invasion of Thessaly (the unofficial start of the Classical era in Thessaly; Table 3.4), the Aleuads of Larissa aided Xerxes' Persian forces [Herodotus, *Hist.*, 7.172-4], showing a division within Thessaly. After Persian forces were defeated and receded from Thessaly, an alliance was forged between Athens and Thessaly in 462 BCE (Westlake, 1935, p.31), and by the time of the Peloponnesian War (431-404 BCE), Thessaly was reportedly fully unified in its support of Athens [Thucydides, 2.22.2-3, 4.78.2-3] (Robertson, 1976, p.104).

3.2.2 Classical Thessaly

Ancient authors who refer to Thessaly during the Classical period explain how blessed (μάκαιρα) Thessaly is compared to other political bodies, including Sparta or Athens [Pindar, *Pythian* 10, 1-2 & 18] (Aston, 2012, p.248; Mili, 2015, p.259). According to Bacchylides [*Ode* 14b, 6], Thessaly's fertile land was important for sheep-, cattle-, and horse-nurturing. According to Theocritus [*Idyll*, 16, 34-39], Thessalian oligarchs, including the Aleuads of Larissa and the Skopads and Kreondai of Krannon, were so wealthy that they had slaves, tens of thousands of sheep and cattle, and attentive shepherds that would manage the herds in the fields. These claims originate from poets or commissions that are Thessalian, which may artistically overstate Thessaly's affluence. Non-Thessalian authors also report on Thessalian wealth (e.g., Sokrates, as described by Plato [*Kriton*, 53d-e]; Euripides' *Andromache*) and especially Pharsalian lavishness (e.g., [Theopompos, *Philippika*, *FGrH*, 115 F 49]), but do so negatively and in terms of over-indulgence or greed (Aston, 2012; Mili, 2015; Stamatopoulou, 2007; Westlake, 1935). Because of the potential for ancient artistic representation to overstate some aspects of daily life and society, the history discussed here is gleaned from text, epigraphy, and archaeological remains based around major military campaigns related to Thessaly.

Table 3.4 Timeline of important dates for 'Thessaly' history during the Classical (c. 480-323 BCE) period (from sources discussed in text).

Date (BCE)	Major Event	Context and/or Impact
c. 480	Persians invade Thessaly	***Start of Classical era in Thessaly;*** Greco-Persian War (499-449 BCE): Persians (with Aleuads) vs. Athens (with Thessaly)
~454	Pharsalos attacked	Athens and allies attack but do not capture the city
449-448	2nd Sacred War[14]	During 1st Peloponnesian War (460-445): Athens vs. Sparta
431-404	Peloponnesian War	Delian League (Athens with Thessaly) vs. Peloponnesian League (Sparta); Athenian Plague (430-426)
395	Larissa sacks Pharsalos	As part of Thessalian Civil War (~400-346) between Pharsalos, Larissa (with Macedonia), and Pherae (with Sparta)[15]
375	Jason of Pherae becomes *Tagos*	Mobilized military across Thessaly, gaining control over major cities (Pharsalos is under Spartan garrison by this time)
370	Jason of Pherae is killed	Polydorus first takes control; he is assassinated by Polyphron, who is then assassinated by Alexander of Pherae
369	Alexander of Pherae is *Tagos*	Conflict between Aleuadae, Macedonians, and Boeotians for control of Thessaly; internal conflict between tetrads and *perioikoi*
364	1st Battle of Cynoscephalae	Alexander of Pherae vs. Pelopidas (Thebans), Athenian, Macedonian, and other Thessalian supporters; Pharsalos aligned with Thebans
361	Athens Treaty	Between Athens and Thessaly against Alexander of Pherae
358	Alexander of Pherae is killed	Political unrest between the Aleuads in Larissa and his successors in Pherae; Macedonian influence already spreading
356-346	3rd Sacred War	Macedonia (with Thessaly), Thebans, Phocis (with Athens) fight for control of sanctuary of Apollo at Delphi; Theban forces enter Thessaly; Philip II defeats Phocians in battle of Crocus field (near Kallithea) (ca.352)
346	Macedonian King Philip II controls Thessaly (as *archon*)	Creates Classical Thessalian League, which leads to new cultural traditions and political strife between old and new powers. Pharsalos is likely given control over the port at Halos (whose acropolis is destroyed).
336	Philip II Assassinated	Son Alexander III (Alexander the Great) becomes King of Macedon and *archon* of the Thessalian League
323	Alexander III Dies	***End of Classical era.***

[14] The first occurs ~590 BCE at the port of Delphi.
[15] Some argue the conflict goes until Jason becomes *Tagos*, but there is still conflict between the *poleis*, especially with the Aleuadae during his and Alexander's reigns (Graninger, 2011).

Skopads and Kreondai of Krannon, were so wealthy that they had slaves, tens of thousands of sheep and cattle, and attentive shepherds that would manage the herds in the fields. These claims originate from poets or commissions that are Thessalian, which may artistically overstate Thessaly's affluence. Non-Thessalian authors also report on Thessalian wealth (e.g., Sokrates, as described by Plato [*Kriton*, 53d-e]; Euripides' *Andromache*) and especially Pharsalian lavishness (e.g., [Theopompos, *Philippika*, *FGrH*, 115 F 49]), but do so negatively and in terms of over-indulgence or greed (Aston, 2012; Mili, 2015; Stamatopoulou, 2007; Westlake, 1935). Because of the potential for ancient artistic representation to overstate some aspects of daily life and society, the history discussed here is gleaned from text, epigraphy, and archaeological remains based around major military campaigns related to Thessaly.

By the end of the Archaic period Thessaly had powerful nobles and individual cities, but less of a unified *koinon*. Throughout the 5th c. BCE, major Thessalian cities begin to form with nobles living in houses in urban centres (Westlake, 1935, pp.34-35). While living in urban centres of *poleis*, aristocrats maintained the ownership and authority over their rural estates, which were still run and managed by *penestai* (Westlake, 1935, p.35). *Poleis*[16] regulated their own political affairs and many became exceedingly powerful. Increased mobility, agricultural intensification, and power prompted growing populations with mixed backgrounds, and increased demand for timber, grain, and other resources at city centres (Chandezon, 2011; Oliver, 2007; Westlake, 1935). Publicly-funded spaces were paid for by the taxes of *polis* citizens, who were afforded rights and privileges (e.g. owning land, participating in cults and festivals) while maintaining other civic duties (e.g. military requirements) (Chandezon, 2011; Marek, 1984). Military campaigns were prominent over the course of the Classical era, with different portions of Thessaly coming under the control of various rulers, tyrants, and kings.

After the Peloponnesian War (431-404 BCE), a Thessalian family in Pherae gained prominence, which effectively split the power of the Aleuadae family; multiple *Tagi*, including an Aleuad in Larissa and Lycophron in Pherae, vied for power in tetradic Thessaly (Sprawski, 1999). Soon after, Xenophon [*Hell.*, 6.1.19] reports on Lycophron's successor, and details Jason of Pherae's rise in power and eventual crowning as the sole *Tagos* of Thessaly by 375 BCE (Sprawski, 1999). By becoming *Tagos*, Jason was able to form a Thessalian army of 6,000

[16] City states; singular: *polis.*

horsemen and over 10,000 hoplites, and tribute support from the *perioikoi* and *penestai* [Xenophon, *Hell.,* 6.1.19]. With Jason as *Tagos*, Xenophon describes Thessaly as a collective state, or *koinon* of cities, which includes a leading military force and a collection of *poleis*. By 374 BCE Jason controlled all of Thessaly except Pharsalos (reportedly controlled by Spartan[17] appointed Polydamas) [Xenophon, *Hell.*, 6.1.5]. After extensive negotiations, Jason gained military control over all of the Thessalian League, and according to Xenophon's *Hellenica* could call upon the *Thessaloi* for military aid [6.1.19], financial backing [6.1.12], or sacrificial tribute [6.4.29] as needed (Sprawski, 1999).

Jason gained continental notoriety during his campaign to gain control over the Pythian Games in honour of the Delphian Apollo in 370 BCE [Xenophon, *Hell.*, 6.4.29] (Brownson, 1918). In his attempt to show power and prestige of his leadership and rule over Thessaly, he requested a sacrificial tribute from his people that amounted to over 1,000 cattle and over 10,000 sheep, goats, and pigs [Xenophon, *Hel*, 6.4.29] (Howe, 2008). Although Jason was assassinated prior to marching with this extravagant offering, his request for such a large surplus of animals at this time suggested that Thessaly was a thriving agricultural and pastoral state (Howe, 2008, 2011). Over 30 years had passed since the large-scale devastation of the Peloponnesian War, and it was likely that *penestai* had the opportunity to develop their communities, work the land, and establish a wealth of their own resources, including herds of domesticated animals.

Within a year of Jason of Pherae's assassination in 370 BCE, he was reportedly succeeded by a brother, Polydorus, who was assassinated and succeeded by another brother, Polyphron, who was then assassinated and succeeded by Jason's son, Alexander [Xenophon, *Hell.*, 6.4.34] (Brownson, 1918). Alexander's leadership was reportedly marked by cruelty and an insatiable hunger for power. Although he tried to rule as *Tagos,* many *poleis* attempted to stop his tyranny by enlisting the support of the Macedonians and Thebans (Graninger, 2010, p.369). King Alexander II of Macedon was welcomed into Larissa by the Aleuadae family and soon set up a garrison at Larissa and Krannon (Fig. 3.10). The Aleuads also sought support from the Thebans, who eventually won the support of Macedonian King Alexander II in 364 BCE and remained a Thessalian ally well after Alexander's murder in 358 BCE [Xenophon, *Hell.*, 6.4.35] (Brownson, 1918). Afterwards, Thessalian forces fought alongside their Theban allies during the Third

[17] Remains of the Spartan (Theban) garrison at Pharsala from 395 BCE (Stamatopoulou, 2007, p.221).

Sacred War (356-346 BCE) (Graninger, 2010, p.312). A funeral stele from Pharsalos documents the burial of a Theban during this time, and it is possible that he died during the war (Decourt, 1995, p.106, no.88).

After the third sacred war (346 BCE), Macedonian King Philip II gained control of Thessaly[18] [Demosthenes, 19.321] and established the Thessalian League, or Classical Thessalian League (Bouchon and Helly, 2015), which emphasized the original *tetrad* system as *tetrarchies* each composed of 10 major *poleis* [Demosthenes, 9.26]. In establishing Thessaly as a League, Philip was attempting to control the powerful *poleis*, unite those that supported Macedonian rule, and effectively end 50 years of Thessalian civil war [Diodorus, 10, 67; 16, 37.3; 16, 38.1] (Graninger, 2010, p.314). Around this time the *penestai* system also seems to have been abolished[19,20]. Estate owners still had workers, but people had the ability to pay for their freedom and work through the social hierarchy. Many *penestai* were also awarded rights and resources, and participated in *polis* affairs similarly to their nobleman (Westlake, 1935, p.36). Regional identity was based more on citizenship and *polis* rather than the kin-based relationships that managed communities prior to the Archaic era. Rights also included participation in different cults, and we see the rise in evidence of local and household cult accessible to various classes (Mili, 2015; Wagman, 2016). Under Philip II there was also new leadership on the (national) Amphictyonic Council at Delphi [Demosthenes, 19, 327], including Pharsalians in major roles as Commissioner [CID, II.21.72; CID, II.74, I.65], *Hieromnemon*[21] [CID, II.34, I.27; CID, II, 32, 42], and treasurer [CID, II.74, I.42] (Decourt, 1995, pp.161-163).

By providing citizenship and other rights, Thessalian League citizens could participate in new cultural traditions, pay taxes toward League affairs, and support Macedonian exploits as needed [Demosthenes 1, 21; 6, 23]. Philip II also rewarded *poleis* who supported Macedonian efforts during the war. As an example, and for their cavalry support, Pharsalos is also believed to have been awarded control over the port at Halos (Fig. 3.4) ([Demosthenes, 11, 1]; [Strabo, 9.5.8]; Decourt *et al.*, 2004, p.703), which was effectively destroyed at the end of the war by

[18] Aston (2012, p.267) argues for this earlier, ca. 352 BCE, but others suggest it occurred at the end of the Third Sacred War (e.g., Bouchon and Helly, 2015; Mili, 2005, p.299).
[19] Although those against Philip II were reportedly captured during the war and sold as slaves (e.g., [Demosthenes, 12, 5; 19, 327]; Vince and Vince, 1926).
[20] This may have occurred as early as Alexander of Pherae's reign (Westlake, 1935, p.144).
[21] Official magistrate or secretary of the council; this is one of the highest positions on the council.

Macedonian general Parmenion (ca. 346 BCE). While Pharsalos controlled major travel routes in Achaia Phthiotis, it was likely that additional settlements, posts, or vantage points were similarly established nearby in an effort to entrench Macedonian control (e.g., Kastro Kallithea/Peuma: Chykerda *et al.*, 2014, pp.20-21; Lee *et al.*, 2006, p.155; Tziafalias *et al.*, 2006b, p.227). Under this control Pharsalians and other Thessalians participated in military efforts under Philip II's successor Alexander III (Alexander the Great) (e.g., [Arrian. Alex. Anab. 3. 11] (Stamatopoulou, 2007, p.224). Prior to Alexander's death in 323 BCE, settlements like Pharsalos reportedly experienced an increase in prosperity, underwent fortification expansion, had the honour of providing dedications locally and at the sanctuary of Apollo at Delphi, and were featured prominently on dedications abroad (Stamatopoulou, 2007, pp.223-225).

3.2.2 Hellenistic Thessaly

With Alexander the Great's death in 323 BCE, the Lamian War began in Thessaly between the Aetolian League and Macedonia (under Antipater) for control over Thessaly. Often referred to as the Hellenic War, this battle marked the beginning of the Hellenistic era in Thessaly (Table 3.5). Many Thessalians came to the aid of Aetolian forces, including those who opposed Macedonian tyranny [Diodorus, 18.17] (Graninger, 2010, p.317). Although the war only lasted one year, and Macedon maintained control over Thessaly, many cities were heavily damaged or completely sacked (e.g., Krannon, Pharsalos (Fig. 3.11)) (Adams, 2010, p.210). In the years that followed, cities focused on rebuilding their settlements, armies, and finances.

After Antipater's death in 319 BCE, Macedon had numerous generals compete for the title of *archon* over Thessaly and other Macedonian regions (Adams, 2010, p.212; Graninger, 2010, p.318). Cassander, Antipater's son, assumed the position of *archon* of Thessaly ca. 315 BCE, winning favour over the Thessalian people through financial backing of the military and affinal relations by marriage to an elite Thessalian woman (Graninger, 2010, p.318). Polybius [4.76] comments that the Thessalians quickly re-submitted to Macedonian rule, but this was likely due to Thessaly's own lack of funds and depleted resources at the end of the Lamian War (Graninger, 2010, p.318). This amicable arrangement afforded Cassander the opportunity to (re)build garrisons at strategic places through Thessaly for Macedonian business [Diodorus, 20.110.2; 20.111.1; 20.28.3] (Graninger, 2010, p.318) (Fig. 3.11).

Table 3.5 Timeline of important dates for Thessaly during the Hellenistic (323-30 BCE) period (from sources discussed in text).

Date (BCE)	Major Event	Context and/or Impact
323-322	***Alexander III Dies*** Lamian/Hellenic War	***Start of Hellenistic Period***; Aetolian League (with Thessaly) vs. Macedon; Macedonia sacks Pharsalos (aligned with Aetolia)
317-277	Various Macedonians rule over Thessaly (usually as *archon*)	Leadership over Thessalian League includes Cassander (317- 297), Alexander V and Antipater II (297-294), Demetrios Poliorketes (294-288), Lysimachus (288-281), and Ptolemy Ceraunus (281-277) Halos restored to its citizens (from Pharsalos) ca. 302; Demetrias becomes capital city of Macedonia (in Thessaly) ca. 294
277-239[22]	Macedonian Antigonus (II) Gonatas is *hegemon*	Thessalians absent from Amphictyonic council, under Macedonian rule; Pharsalos briefly joins Aetolian League in 266
265	Earthquake	New Halos destroyed and abandoned; damage possible at other sites
239	Death of Antigonus (II) Gonatas	Demetrius II is Macedonian king; Aetolians gain control of parts of Thessaly, moving into Achaia Phthiotis throughout this decade.
229	Death of Demetrius II	Antigonus (III) Doson is Macedonian king; Aetolians aggressively claim cities, including parts of Thessaliotis and Achaea Phthiotis
222/21	Antigonus (III) Doson dies	Philip V becomes Macedonian king
220-217	Social War	Between Achaeans, Aetolians, Macedonians (Philip V): Phthiotic Thebes sacked (217); Pharsalos hit hard; increased settlement post-war
214-205	1st Macedonian war	Rome (with Aetolia, Sparta) vs. Macedonia
200-197	2nd Macedonian War	Rome (and allies) vs. Macedonia; Pharsalos destroyed (197) during 2nd Battle of Cynoscephalae: Rome (Flamininus) vs. Macedonia (Philip V)
196	Flamininus (Roman) creates Thessalian *koinon*	New cultural traditions, mass migration, settlement, and Thessalians are proclaimed "free" at the Isthmian Games
192-189	Syrian-Aetolian War	Aetolian forces vs. Rome; Aetolian League dismantled; Pharsalos garrisoned by Macedonians in 192, surrendered to Romans in 191
172-168	Third Macedonian War	Rome vs. Macedonia; Rome wins and Macedonia monarchy ends
146	Battle of Corinth	Rome vs. Corinth; Achaean League is dismantled
48	Battle of Pharsalus	Roman rivals: Caesar vs. Pompeius; start of the Roman Empire
30	Mark Antony, Cleopatra VII die	***Universal end of Hellenistic period***

[22] Some argue that his reign is between 277-274 and 272-239 (e.g., Haagsma et al. 2019b, pp.277-278)/

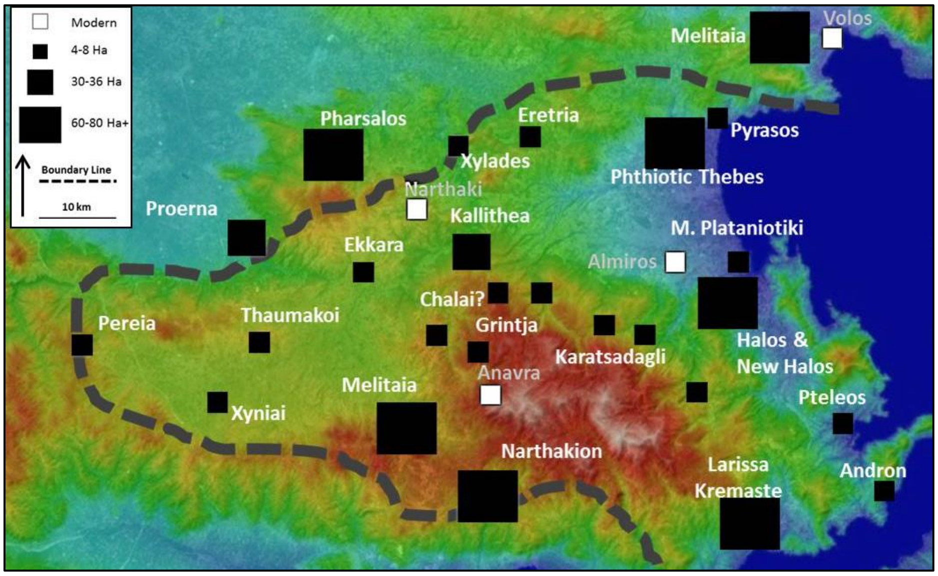

Figure 3.11 Map of Achaia Phthiotis, including important settlements and forts dating to the Hellenistic period.[23,24]

As part of Demetrius Poliorketes' race for the throne, he was said to have 'liberated' Achaia Phthiotis and advanced throughout Thessaly in an attempt to defeat Cassander [Diodorus, 20, 110-111] (Haagsma *et al.*, 2019b, p.277). Although Demetrius Poliorketes would not assume the role of Macedonian King until 294 BCE, he followed a similar approach to win over the Thessalians: he returned the rights of the port city of Halos to its people (ca. 302 BCE), he established a new Macedonian capital in Thessaly at the site of Demetrias (ca. 294 BCE) (Graninger, 2010, p.319), and he was likely responsible for the renovation and improvement of multiple fortifications in Achaia Phthiotis (Fig. 3.11) (Chykerda *et al.*, 2014, pp.20-21). The term 'liberated' is used here loosely, as Achaia Phthiotans would have still been under Macedonian rule, and as such been responsible for paying taxes[25] [Demosthenes, 1, 22] and supporting local military efforts [Demosthenes 19, 260] (Graninger, 2010, p.315).

[23] Map is adapted from Haagsma (2010, p.261), Haagsma *et al.* (2019b, p. 295), Reinders *et al.* (2016, p. 45), and Tziafalias *et al.* (2006a, p. 94).

[24] Pharsalos is included but it would have been considered part of Phthiotis. Similarly, Demetrias and Volos are included despite being part of Magnesia. There is some discrepancy over the placement of Ekkara (see Haagsma *et al.*, 2019b, pp.295-296 and Reinders *et al.*, 2016, p.45). I have gone with the easternmost placement as I believe it more closely relates to the association with the Achaia Phthiotis minting collective.

[25] Thessalians have often provided supplies to their 'allies', which was likely a form of taxation. Examples include grain to Thebes (ca. 377 BCE) [Xenophon, *Hell.,* 5.4.56] (Garnsey *et al.*, 1984, p.35) and grain to Rome (ca. 150 BCE) [Livy, 32, 37, 2] (Garnsey *et al.*, pp. 38-39). Macedon may have also made similar requests of Achaia Phthiotis during their 'liberation'.

A benefit of being under Macedonian rule would have been the military support [Plutarch, *Demetrius*, 40. 1-2] (Graninger, 2010, p.319) and infrastructure established by *archons* during this time (Chykerda *et al.*, 2014; Lee *et al.*, 2006). This security and social networking may have been welcomed after decades of social war in Thessaly, and regions like Achaia Phthiotis appear to have thrived under their new settlement structure. Regional minting (Reinders *et al.*, 2016), attempted border expansion (Ager, 1996, pp.101-103; Decourt, 1995, pp.68-70), evidence of prominent individuals abroad (Decourt, 1995, pp.161-163), and major dedications at sanctuaries (e.g., [IG, IX.2.237, 239, 247] (Mili, 2015, pp.305-324)) imply a sense of social cohesion and prosperity among *poleis*.

Despite apparent cohesion at the *polis* level, the succession of Macedonian Antigonus (II) Gonatas as *hegemon* (ca. 277 BCE) led to Thessaly's absence from the Amphictyonic Council at Delphi (Mili, 2015, pp.246-247; Scholten, 2000, p.46) and issues with cohesion at the *perioikic* level (Haagsma *et al.*, 2019b, pp.285-287). Both of these factors are likely due to rising tensions between Macedon and Aetolia who fought for power and ownership of Thessaly throughout the 3rd c. BCE. After the death of each successive Macedonian king, Aetolian forces gained more control of Thessaly: they gained access to the southwest region of Achaia Phthiotis (e.g., Melitaia) after the death of Antigonus (II) Gonatas (ca. 239 BCE); they obtained favour with more of Achaia Phthiotis (e.g., Kastro Kallithea) and parts of Thessaliotis (e.g., Pharsalos) after the death of Demetrius (II) (ca. 229 BCE); and Aetolia had control of most of Achaia Phthiotis (e.g., Phthiotic Thebes) shortly after the death of Antigonus (III) Doson (ca. 222/221 BCE) (Scholten, 2000, pp.164-199).

By the time Macedonian King Philip (V) assumed the throne (ca. 222/221 BCE), Achaia Phthiotis, which was likely partially or completely under Aetolian control by that time, was brought into the so-called Social War between the Aetolians and Macedonians. During this conflict, garrisons at Larissa, Demetrias, and Pharsalos were heavily hit and by the end of the war in 217 BCE, Phthiotic Thebes was destroyed by the Macedonians ([Polybius 5.9.44]; Graninger, 2010, p.321; Stamatopoulou, 2007, p.226). After Philip V's success, he established formalized decrees in major cities to promote resettlement, increased economy, and unity at the *ethnos* level (Bouchon and Helly, 2015, p.240). He focused these decrees in major cities that had been heavily damaged, including Larissa [IG, 9, 2, 517], Phalanna [IG, 9, 2, 1228], and Dyme (Habicht, 2006, p.71; Stamatopoulou, 2007, p.226). His decree at Pharsalos [IG, 9, 2, 234] granted 176 individuals citizenship and gave them the land and rights to own and work the fields (Decourt, 1995, pp.61-63, no.50; Habicht, 2006, pp.68-69). Thessalians also returned to major roles on the Amphictyonic Council at Delphi (e.g., [BCH45 (1921), IV, 39-40] (Decourt, 1995, pp.161-163)), suggesting that Philip's attempts to boost the economy were successful. Large domestic structures also appear during this time at the sites of Pharsalos (e.g., Arsenopoulos Plot – Section 3.3.4), Halos (see Haagsma, 2010), and Kastro Kallithea (e.g., Building 10 – Section 3.4.3), suggesting surplus wealth in the regional economy.

While Achaia Phthiotis appears to have prospered under the rule of Philip V, numerous anti-Macedonian allies would attempt to 'free' Thessalians from Philip's reign at the turn of the 2nd c.. As part of the Second Macedonian War, Roman general Flamininus and allies fought against Macedonian armies across Achaia Phthiotis [Livy, 32.14] (Scholten, 2000, pp.198-200). The peak battle of this war took place near Macedonian-controlled Pharsalos in 197 BCE, which saw the destruction of the city and damage to nearby settlements [Livy 32.10] [Diodorus 28.11] (Ager, 1996, pp.192-194). Flamininus would emerge victorious and end over a century of Macedonian rule over Thessaly. Once again, Achaia Phthiotis was 'liberated', and the political and social re-organization of tetradic and perioikic Thessaly had major consequences for its inhabitants and their domestic economies.

Graninger (2011) examines state religion, politics, and economy after the Second Macedonian War and during the formation of the new Thessalian Confederacy (ca. 196-140 BCE). The new Confederacy was considered a federal league or *koinon*, which included both the traditional Thessalian tetrads and perioikoi. This period saw increased territorialisation and emphasized a unified Thessalian political or cultural identity. Community populations fluctuated and some cities were abandoned in accordance with the changing political regime. People immigrated into the area or moved from one microregion to another and aspects of local and foreign religion were incorporated into each local doctrine (Oliver, 2007, p.88). Based on funeral stele from Pharsalos dating to the 2nd c. BCE, individuals from Phocis, Laconia, Aetolia (Pleuron), and other non-Thessalian locations were moving into the region at this time (Decourt, 1995, pp.113, 115-117). Graninger (2011) examines epigraphic remains of Thessalian calendars and finds that new regional festivals were created while older cults were either maintained or elaborated as the Thessalian *koinon* transformed identity in the region. Increased mobility within Thessaly also promoted active trade networks, supported by a new monetary system and craftbased economy (Haagsma *et al.*, 2019b). Oliver (2007, p.94) indicates evidence of craftsmen who migrated from Athens to Thessaly for new opportunities.

People were also enticed into the region to help rebuild economies that were in debt after the wars (Chaniotis, 2011). As part of this, men were granted economic or land-based *proxeniai* (Marek, 1984, p.150), and encouraged to work the crops that were often destroyed by military efforts (Chaniotis, 2011; Foxhall, 1993, pp.138-142). On multiple occasions after the inauguration of the Thessalian *koinon*, its citizens were required to provide grain to Roman forces in the form of required regular shipments (*sitodeia*) (Westlake, 1935, p.6). If *poleis* failed to ship grain, they would face exorbitant fines (Garnsey *et al.*, 1984, p.43). Warfare continued throughout the 2nd c. between Rome and Aetolia (192-189 BCE), Rome and Macedon (172-168 BCE), and Rome and Achaea (~146 BCE), which likely depleted Roman resources. By re-establishing Thessaly as a 'surplus producer' of agricultural resources at the turn of the 2nd c., Rome inadvertently guaranteed their soldiers continuous supplies.

By the later half of the 2nd c. BCE, many of the major settlements in Greece fell out of use in favour of small-scale rural agrarian villages, likely as a result of constant Roman taxation and warfare (Chaniotis, 2011; Rizakis, 2013). Settlements in Achaia Phthiotis may have similarly been abandoned ca. 140 BCE. In 48 BCE a major Roman battle took place on the plains near Pharsalos, but little else is known about southeast Thessaly during this time (Karachalios and Noula, 2014). Funeral *stelai* from Pharsalos suggest that the site was in use throughout the Roman period (Decourt, 1995, pp.117-124), however epigraphic evidence of prominent individuals from sites like Pharsalos or Peuma (Kastro Kallithea) stop around 140 BCE (Decourt, 1995, pp.161-163). For many this timeframe marks the end of the Hellenistic era in this part of Thessaly (Haagsma *et al.*, 2019b).

3.3 Pharsalos[26] (Φάρσαλος)

3.3.1. Location and Landscape

Pharsalos is the archaeological city located under modern day Pharsala (Fig. 3.12). The territory of ancient Pharsalos is estimated to have encompassed 100 to 200 km^2 with fluctuations according to time period and territorial claims (Wagman, 2016, p.4). The south is bounded by the

[26] Often written as Pharsalus in some translated texts, or as Farsalos or Farsala in English translations.

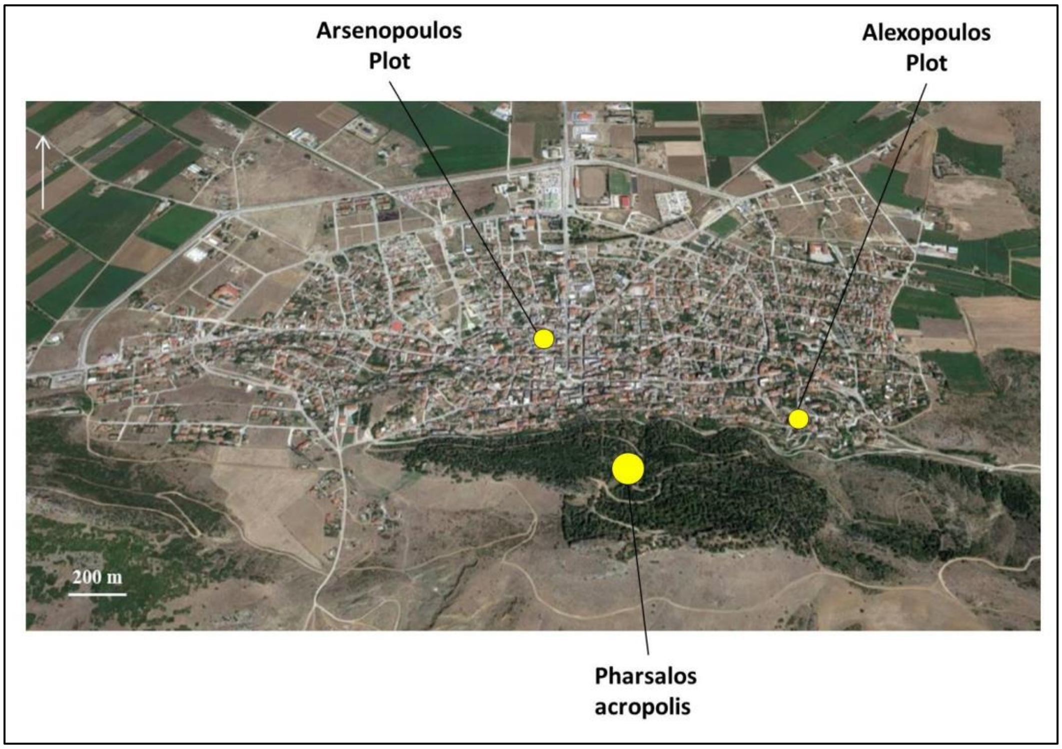

Figure 3.12 Aerial view of Pharsala with major points discussed in text outlined. Base map from Google (2020), with 3D function enabled.

Narthakion Mountains, the north by the long hills of Revenia, and east by the minor chain of Ziragiotis Mountains (Wagman, 2016). The city had a major spring, named the Apidanos, which fed into the Enipeus River. Pharsala is on the border of the valley of the River Enipeus, which would have provided adequate water for the people, crops, and animals. The region itself is well suited for drainage due to its low hills and gentle inclines. Modern Pharsala is known for its arable landscape, temperate climate, and sufficient rainfall, which support an agropastoral economy today (Municipality of Farsala, 2015).

Ancient Pharsalians were known to produce and train the best horses [Arrian, Anabasis of Alexander, XI, 163] (Decourt *et al.*, 2004, p.394), a sentiment still proudly expressed by Pharsalians today (Municipality of Pharsala, 2015; personal observation). Not only was Alexander the Great's horse Bucephalus reportedly from Pharsalos, but evidence of horses on coinage (Psoma, 2009; Stamatopoulou, 2007) and a dedication of an equestrian figure of Achilles at Delphi at the end of the third Sacred War (Westlake, 1935, p.187) also add to this stereotype. The plains area to the north is flat and dry and could easily have been used for horse management and soldier training in antiquity. If this area was reserved for horses and cavalry training, and other greenspaces were in use for agricultural needs, marginal areas would be required to manage animals for byproduct use. Alternatively, a trade network or appeal to the *perioikoi* for taxes in the form of animals may have been a system in place.

3.3.2. Pharsalian History

Ancient Pharsalos has also been referred to as the Mycenaean site of Phthia, which was the supposed home of Homeric hero Achilles (Bouchon and Helly, 2015, p.248; Karachalios and Noula, 2014; Municipality of Pharsala, 2015). As discussed in Section 3.2 (Tables 3.4, 3.5) Pharsalos is well known throughout Classical and Hellenistic antiquity for its role in major military campaigns and as the site of major battles. It was also the homeland of individuals with roles on the Amphictyonic Council at Delphi, athletes who were successful at the Pythian and Olympic Games, and affluent men who were granted *proxeniai* abroad (Decourt, 1995; Stamatopoulou, 2007). Pharsalos was one of the largest cities in Thessaly during antiquity and was the largest in tetradic Phthiotis at the onset of the Classical era (Graninger, 2010, p.316). The original city walls date to roughly the 6^{th} c. BCE (Wagman 2016, p.96), although Pharsalian coins were not minted until at least 480 BCE (Psoma, 2009, p.15). Similar to the rest of Thessaly, Pharsalos was ruled by an oligarchy, which was the *Echekratidae* family in the early 5^{th} c. BCE (Stamatopoulou, 2007). Table 3.6 presents an overview of the timeline of control or allegiance for ancient Pharsalos in antiquity. Depending on who Pharsalians were aligned with or controlled by, they underwent multiple stages of destruction and rebuilding (Stamatopoulou, 2013). Although the area has undergone considerable change in the past 2,000 years, it is still home to the modern city today, which bears the similar name of Pharsala.

3.3.3. Archaeology of Pharsalos

Limited archaeological work has been done in the city, with most investigations occurring before 1950 or as a result of recent salvage or rescue excavations (Stamatopoulou, 2007). Stählin began researching the area in the early 1900s in an effort to study the topography of Pharsala, searching for possible evidence of the ancient town of Pharsalos (Palaiopharsalos), which literary resources indicated was the site of the famous Roman Battle of Pharsalos in 48 BCE (Stählin, 1967). Other historians followed Stählin's evidence and believed they had discovered the ancient site of the great battle (Béquignon, 1932). In the process of their exploration, numerous other settlements

Table 3.6 A timeline of control or allegiance for Thessaly and Pharsalos during antiquity. Adapted from various sources discussed in text.

Date (BCE)	(the rest of) Thessaly	Pharsalos
Before 6th c.	Tetradic Thessaly (neutral)	Phthiotis (independent)
~590	Thessalian oligarchy: Aleuadae	Aleuadae
Early 5th c.	Some Persian rule (~480), mixed Thessalian oligarchy	Echekratidae
457	Mixed Thessalian oligarchy	Echekratidae exiled; uncertain
~404-396	Mixed; mostly mixed Thessalian oligarchy	Spartan (Theban) garrison
394	Mixed; mostly mixed Thessalian oligarchy	Aleuadae regain control
394-374	Mixed: Spartan, Aleuadae, Jason no later than 375 BCE	Spartan garrison (Polydamas as Theban *proxenos*)
374-370	Jason of Pherae (*tagos*)	Jason of Pherae
369-364	Thessalian, with some Macedonian and Theban	Theban support
363-347	Thessalian, with some Macedonian, Theban	Theban and Macedonian
346-323	Macedonian (Thessalian League)	Macedonian
323-322	In support of Athens and Aetolia	Sacked
322-302	Macedonian (Thessalian League)	Macedonian
302-239	Macedonian, as the Hellenistic Thessalian League	Macedonian
239-229	Macedonian, Aetolian moving east	Macedonian
229-217	Macedonian, more Aetolian moving north	Aetolian
217-197	Variable: Macedonian, Aetolian	Macedonian; Destroyed in 197
196	Roman: Hellenistic Thessalian League	Unknown[27]
191-146	Variable	Aetolian, Macedonian, Roman
146-5th c. CE	Roman	Roman

[27] Some have argued that Pharsalos became Roman-controlled after it was destroyed; Stamatopoulou (2007, p.227) indicates that there were no Pharsalian *strategoi* listed in Koinon manifesto in 196 or after the battle in 169, suggesting that they were not incorporated until later.

Table 3.7 A summary of archaeological structures excavated by the 15th Ephorate in Larissa, including public and domestic buildings. Coordinates with Fig. 3.13.

ID	Plot Name	Context and major findings	Reference
1	Argyris	Large Hellenistic house; multiple rooms	*A. Deltion* (1980) pp.288-291
2	Tsoumani	Large Hellenistic house; coins from Pharsalos, Larissa, and with Antigonus Gonatas; protrusion stones	*A. Deltion* (1988) pp.271-274
3	Anagnostopoulos	Hellenistic house; figurines and local Hellenistic pottery	*A. Deltion* (1994) pp.335-37
4	K.Bakali-Pan. Lioupi	Large Hellenistic house with archaic contexts below; atrium, mosaic, plumbing, some archaic contexts (epigraphy)	*A. Deltion* (1996) pp.373-374
5	Polyzos	Large house (Classical and Hellenistic contexts); many rooms; possible child's burial from the Bronze or Iron Age	*A. Deltion* (1999) p.423
6	Gounari (Katsouni)	Burned Hellenistic house; ceramic tiles, plaster walls	Karapanou (1996) p.377
7	Alexopoulos	House (Classical and Hellenistic phases); burned; courtyard, sanctuary (protrusion stones), pithoi, ceramics	Karapanou (1996) pp.376-377
8	Haempi	Hellenistic house, burned; Pithos, ceramics, and roof tiles; underground plumbing; after burning used for Roman burials	*A. Deltion* (1996) pp.377-378
9	Arsenopoulos	Large Hellenistic house (late 3rd to mid-2nd c. BCE); many rooms, *andron*, mosaics, plaster, courtyard, sanctuary	Karapanou (2008) pp.706-707
A	*Agora*	Public, centre of town, site of inscriptions	Stamatopoulos (2013), p.46
A	*Stoa(s)*	Potential remnants from two Hellenistic era stoas (public area)	Stamatopoulos (2007), p.224
B	*Gymnasion* or sanctuary	A public building, perhaps a *gymnasion* or sanctuary because of size, location, and construction	Stamatopoulos (2013), p.46
C	Sanctuary of Zeus Thaulios?	Inscriptions to this god have been found that date to the 4th c. BCE [PAE (1907), 151-53]	Decourt (1995) no. 62; Stamatopoulos, (2007), p.220

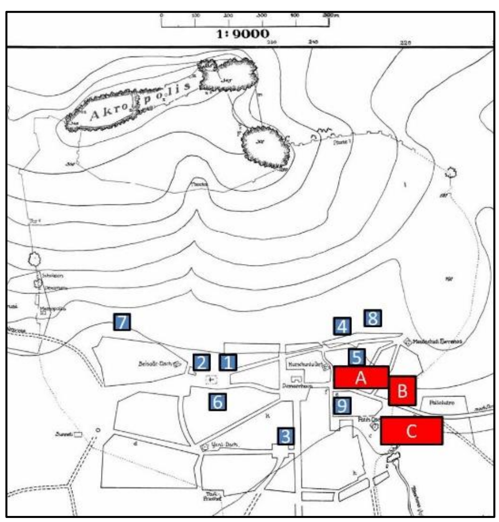

Figure 3.13 Sketch of archaeological structures at Pharsalos depicting public areas (red squares) and domestic structures (blue squares) discussed in Table 3.7.[28]

[28] Adapted from Stählin (1967, p.138), Stamatopoulou (2007, p.224), and references listed in Table 3.6. South is up.

were found scattered across the landscape. Stamatopoulou (2013) discusses recent excavations and corresponding research taking place in Thessaly from antiquity, including Pharsalos and Kastro Kallithea.

Sophia Karapanou and the 15th Ephorate in Larissa have been working on the Hellenistic portion of Pharsalos for almost 30 years (e.g., Karapanou, 1996, 2000, 2008). Over 48 plots have been excavated during salvage work, including parts of a road system (Karapanou, 2008, pp.56-59, 543-547, 551-556; Stamatopoulou 2013, p.46). Figure 3.13 and the associated Table 3.7 outline major domestic and public structures analyzed from Pharsalos. Many of the Hellenistic homesteads were built on previous Classical buildings, which was a common practice in Thessaly during periods of continuous site abandonment and re-occupation (Mulliez, 2010). Buildings have remnants of water pipes and cisterns, likely connecting to springs from the Enipeus River. Pharsalos was a larger city, complete with public buildings, a *stoa* (Fig. 3.13 A) that suggests a contest and training centre for youth, and a gymnasium or sanctuary for the public (Stamatopoulou, 2013).

In addition to domestic structures and public architecture, Pharsalos has an acropolis at a defensible elevation (Fig. 3.12, 3.13). The acropolis was likely fortified in the early 5th c. BCE, although a visible stratigraphy on the acropolis walls indicate that it was modified throughout time (Stamatopoulou, 2007). Perhaps the acropolis was established during the Persian War, and likely contributed to Pharsalos' successful defence against Athens mid-5th c. BCE. Due to constant sacking, destruction, or changes in garrison control (see Table 3.4), additions, improvements, and reconstruction to the acropolis walls were likely throughout the Classical and Hellenistic periods. Prior to the 5th c. there is little archaeological evidence of larger settlement occupation, and few mentions of Pharsalians engaging with Hellenic activities (e.g., military campaigns, Olympiads) (Stamatopoulou, 2007). After the Persian War, Pharsalos began minting distinct coins, suggesting more settlement-specific city occupation. The acropolis walls date to the Byzantine period, but older remains suggest that the acropolis encompassed a similar 500 m by 60 m space during the 5th and 4th c. BCE (Stählin, 1967, pp.139-140)[29]. (e.g., military campaigns, Olympiads) (Stamatopoulou, 2007).

[29] For comparison, the Acropolis in Athens measures 110 m by 250 m (Mili, 2015, p.102, fn. 13).

Known cults at Pharsalos are based on inscriptions and physical remains and belong to Zeus Thaulios, Demeter, Hermes, Apollo, Artemis, Aphrodite, Thetis, the Nymphs, and Hestia (Mili, 2015, pp.305-324; Stamatopoulou, 2013). Athena also appears frequently on Pharsalian coinage (Psoma, 2009; Stamatopoulou, 2013). A number of important inscriptions and dedications to Zeus Soter, Artemis, and Asclepius appear during the 3rd and 2nd c., which are often associated with household cult and safety (Decourt, 1995, no. 59-61, 66, 70, 71; Mili, 1995, pp.305-324). Additional protrusion stones recovered from numerous households (Table 3.4) have been connected to regional cult worship throughout Achaia Phthiotis (Haagsma *et al.*, 2012, p.248; 2019a, pp.68-69; 2019b, pp.289). Two of the domestic structures listed in Table 3.6 are the focus of my analysis, including the structures from the Alexopoulos Plot (Section 3.3.4) and the Arsenopoulos Plot (Section 3.3.5).

3.3.4. Alexopoulos Plot

The Alexopoulou plot was excavated in 1992 and contains the remains of a Hellenistic house with 5 rooms and another adjacent 2 units (Fig. 3.12, 3.13 #7). There is evidence of Classical occupation or occupations, including portions of the area that were re-built because of a fire and those with new architectural features (Karapanou, 1996). Other remains found in this plot included pottery, terra cotta figurines, a kettle, and loom weights. A stone block with protrusions potentially used as altars for sacrifice was found in this context and may signify household cult. Considering how this structure compares to others in Pharsalos (Table 3.7), the dwelling at the Alexopoulos plot is representative of a more modest household (Karapanou, 1996).

Chronology

The Hellenistic portion of this site has been designated based on ceramic remains; however a more specific temporal period has not been delimited at this time (Karapanou, *personal communication*; Karapanou, 1996). The dwelling at the Alexopoulos plot is close to the structure at the Katsouni plot (Fig. 3.7 #6), and both show evidence of burn destruction, potentially during a similar episode (A. Deltion, 1996, pp.336-337). During the Social War (220-217 BCE) (Table 3.5) Pharsalos was sacked and heavily damaged by Macedonian armies. When the garrisoned acropolis was sacked during the war it is possible that nearby domestic structures were similarly destroyed. If this were the case, the Alexopoulos plot structure would have been rebuilt in the

Table 3.8 Faunal remains analyzed from the Alexopoulos plot at Pharsalos[30]. Reported as number of identifiable specimens (NISP) and percentage of total identifiable fauna (%) and total domestic fauna (%) (Bishop, 2017).

Type of Remains	NISP	Percent (%) of Identifiable Fauna	Percent (%) of Domestic Fauna
Sheep/Goat	188	43.2	51.2
Pig	19	4.4	5.2
Equid	25	5.7	6.8
Cattle	75	17.2	20.4
Dog	55	12.6	15.0
Domestic fowl	5	1.1	1.4
Deer	43	9.9	
Hare	5	1.1	
Tortoise	20	4.6	
Total	**435**		

Figure 3.14 Outline of the Alexopoulos Plot structures depicting the Hellenistic era rooms and the Classical era units. Care of Sophia Karapanou. Removed for publication.[31]

[30] Due to heavy fragmentation and probable over-representation of remains, molluscs (including marine bivalves and sea/land gastropods) have been omitted from the total NISP counts (n=157). The flooring of this dwelling also included shell (Karapanou, 1996), therefore including fragments of shell may represent architectural supplies rather than consumed goods.

[31] This image has been provided for the defense only. I do not have permission to publish it in any form, so it was removed for the final publication.

period after 217 BCE, which coincides with a time when other settlements in southeast Thessaly experienced growth, prosperity, and resettlement of people.

Fauna

Based on the analysis of faunal materials in 2017, roughly 1661 mammal bone fragments were recovered from this locale. Of those fragments, 410 (25%) of the remains were identifiable to a specific taxon, and 346 of these were from domestic animals. Table 3.8 provides an overview of identifiable specimens. Domestic faunal remains dominate the assemblage at the Alexopoulos Plot, with sheep and goat representing the most common taxa.

Of the large fauna (e.g., cattle, equid) the most common elements came from the appendages, including bones of the feet (carpals, astragali, phalanges) and the distal ends of long bones. Remains of these bones are consistent with utilizing a portion of the animal rather than elements of the entire animal. Sheep and goat bones were represented by various elements from the full animal (mandibles, ribs, appendages), with a mix of adult and non-adult individuals. Based on the few identifiable specimens, there were more sheep than goats. Sheep and goats were often prepared whole for events (e.g., religious offering or celebratory event), which may explain the remains at the Alexopoulos plot. Evidence of cutting and burning on fragments of many of the faunal elements also support the theory that these fauna were the remains of consumption activity. One of the cervid (likely red deer) proximal phalanges had drill marks consistent with cultural modification seen at other sites (e.g., displays at the Diachronic Museum of Larissa).

3.3.4. Arsenopoulos Plot

The Arsenopoulos Plot was excavated in 1994-1996 and contains the remains of a wealthy Hellenistic house (Fig. 3.15) (Karapanou, 2008). This building had large dimensions, mosaic floors, an *andron*[32], a coin hoard, and provisions for drainage and water supply (Karapanou, 2008; Stamatopoulou, 2013). Most houses were not large enough to accommodate a space dedicated to hosting symposia (*andron*), and it suggests that this home was associated with individuals of higher economic standing (Karapanou, *personal communication)*. The Tsoumani

[32] A room used for entertaining male guests/symposia, which usually holds several couches, serving tables and sometimes lavish artwork.

Plot (Table 3.7, Figure 3.13 #2) also contained a Hellenistic dwelling of considerable wealth (A. Deltion, 1988 pp.271-274).

The dwelling at the Arsenopoulos Plot contained three areas of open space (αίθρια), 12 rooms, and six other spaces, including a large eating area with a hearth, two mosaic floors (geometric motif), plaster walls (blue, red, and white), and a shrine in the courtyard (Fig. 3.15) (Karapanou, 2008). Small deposits of votive offerings and figurines were recovered from the shrine, suggesting that cult activity was practised inside this home. The statues included two marble Aphrodite and one clay Ennodia-Hecate (Karapanou, 2008). Ennodia-Hecate is part of local Thessalian cult, and may relate to safety in marriage and/or motherhood (Mili, 2015, pp.147, 155-156). It is possible that the protrusion stones found at the Alexopoulos Plot, contexts at Kastro Kallithea, and other areas of Achaia Phthiotis relate to offerings for Ennodia-Hecate (Haagsma *et al.*, 2015a, p.248).

Chronology

This dwelling dates predominantly to the Hellenistic period, specifically to the late 3rd to mid-2nd c. BCE (Karapanou, *personal communication*). This period of occupation is consistent with the resurgence of resettlement in Pharsalos and other areas in Thessaly after the Social War (ca. 217 BCE). The inclusion of local Thessalian cult (e.g., Ennodia-Hecate) may coincide with the occupants' ties to previous Thessalian *ethnos* (see Mili, 2015, p.150) during a time of 'new *polis*' formation.

Fauna

Based on the analysis of faunal materials between 2016 and 2018, roughly 4676 mammal bone fragments were recovered from this site. Of those fragments, 2064 (44%) of the remains were identifiable to a specific taxon, and 1823 of these were categorized as domestic fauna. Table 3.9 provides an overview of identifiable specimens. Domestic fauna dominate the assemblage at the Arsenopoulos Plot dwelling, although a large portion of the identifiable specimens are represented by wild fauna (12%).

A considerable amount of faunal remains was recovered from the Arsenopoulos Plot. Fragments of pig, sheep/goat, and red deer included elements from all parts of the animal, whereas larger fauna (e.g., horse, cattle) were mostly represented by fragments of the long bones. The cattle bones that represented elements from all over the body were from an individual or

Table 3.9 Faunal remains analyzed from the Arsenopoulos plot at Pharsalos[33]. Reported as number of identifiable specimens (NISP) and percentage of total identifiable fauna (%) and total domestic fauna (%) (Bishop, 2018).

Type of Remains	NISP	Percent (%) of Identifiable Fauna	Percent (%) of Domestic Fauna
Sheep/Goat	1108	53.6	60.8
Pig	268	13.0	14.7
Equid	80	3.9	4.4
Cattle	215	10.4	11.8
Dog	117	5.7	6.4
Domestic fowl	35	1.7	1.9
Deer	155	7.5	
Boar	5	0.2	
Bear	1	<0.1	
Wolf	5	0.2	
Hare	19	0.9	
Tortoise	56	2.7	
Rodent	5	0.2	
Total	**2069**		

Figure 3.15 Outline of the Hellenistic era Arsenopoulos Plot structure based on a sketch from Sophia Karapanou. Removed for publication.

[33] Due to heavy fragmentation and probable over-representation of remains, molluscs (including marine bivalves and sea/land gastropods) have been omitted from the total NISP counts (n=40)

individuals that were not fully matured (e.g., calf). Adult cattle bones were only represented by portions of the limbs (e.g., shank cuts of meat). Of the adult remains that could be sexed, most of the sheep remains were from females, whereas the goat, cow, and pig bones were more evenly split between male and female individuals. Of the ovicaprids that could be further identified, there were more sheep than goats present. Many faunal remains in this assemblage show evidence of cutting, burning, and gnawing, and were recovered from many rooms throughout the home. A number of sheep/goat remains also show evidence of intentional modification, including drilling or plaster coating.

Hunted game is noticeable in this assemblage. As with the Alexopoulos plot, there is a significant amount of deer present in numbers comparable to the less common domesticated animals. A small portion of the assemblage is from unique wild game, represented by long bones (wolf, boar), teeth (boar), and part of the pectoral girdle (bear). Wild game of this sort involved hunting, a high-status activity, and these predatory taxa may reflect the Arsenopoulos Plot owner's affluence (Bishop, 2018).

3.4. Kastro Kallithea (Kişlar) (Peuma/Peumata) (Πεὺμα)

3.4.1. Location and Landscape

Kastro Kallithea is the fortification situated at an altitude of 618 m overlooking the modern town of Kallithea. It is one of the hills along the western border of the plain of Almiros in the ancient region of Achaia Phthiotis (Fig. 3.16) (Tziafalias *et al.,* 2006a). Formerly the settlement of Kişlar, the site was first surveyed in the early 1900s by Friedrich Stählin (Stählin, 1967), and over time the site became associated with the ancient *polis* of Peuma (e.g., Tziafalias *et al.*, 2009; Haagsma *et al.*, 2019ab), although this designation has been debated (Tziafalias *et al.*, 2006a, pp.92-93). Kişlar, which is Turkish for "winters" or "a place to winter", was known as an important site for shepherds and their mobile sheep or goat herds during the winter portion of their transhumant circuit (Haagsma *et al.*, 2019a). The village was renamed Kallithea in the 1970s, which roughly translates to "beautiful view" (*kali thea*), with the site coined Kastro Kallithea, or the castle at Kallithea (Tziafalias *et al.*, 2006a). The modern town is home to a small farming collective and the acropolis is still used today by shepherds as part of their grazing rounds.

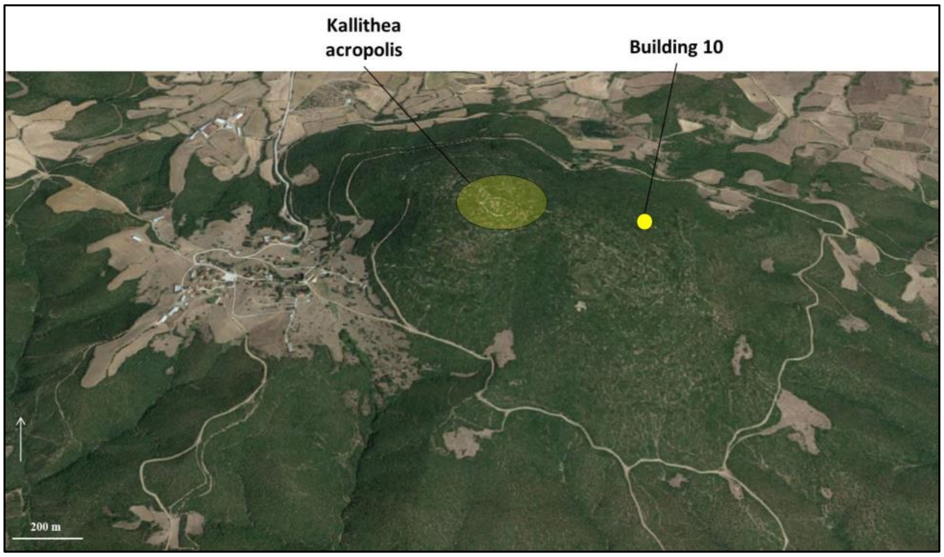

Figure 3.16 Aerial view of Kastro Kallithea with major points discussed in text outlined. Base map from Google (2020), with 3D function enabled.

3.4.2. Kallithea/Peumata History

In contrast with Pharsalos, which featured prominently in ancient literary or epigraphic sources, Peuma was less well recorded during antiquity. Ancient authors like Demosthenes (Classical period), Polybius (Hellenistic period), and Strabo (early Roman period) never mention a fortification in this area despite their description of the topography and settlements in the region (Haagsma *et al.*, 2019, p.32). Despite this lack of written evidence, Kastro Kallithea is believed to be the ancient site of Peuma. The designation began with Stählin's (1967) interpretation during initial survey work and has been corroborated by other researchers (e.g., Decourt, 1995, p.87; Helly, 2001, p.244), epigraphic support of the relative position (e.g., SEG XVIII.238), and a single coin discovered during the surface survey (Chykerda *et al.*, 2014, p.20). The initial use of the site likely dates to the late Classical period and did not include domestic structures or evidence of habitation. The walled citadel and acropolis site was likely a small outpost operated by civilians or soldiers (Haagsma *et al.*, 2019a). Based on this timeline, it is possible that Pharsalos controlled the citadel and used the site as a means for monitoring the port at Halos (Lee *et al.*, 2006, p.155). Pharsalos was granted access to the ports in 346 BCE by Macedonian King Philip II for their support during his campaign [Demosthenes, 11, 1] (Vince and Vince, 1926). Kastro Kallithea is uniquely positioned midway between the two sites and has a more defensible position and vantage point of the coast than Pharsalos.

The larger portion of Kastro Kallithea, including the domestic blocks, *agora*, and defensive wall, likely dates to the late 4th and early 3rd c. BCE (Chykerda *et al.*, 2014; Tziafalias *et al.*, 2006a). This is based on similar structures constructed in Achaia Phthiotis around the same time, including New Halos (recently removed from Pharsalian power and instated as an independent *polis* by Demetrios in 302 BCE) and Phthiotic Thebes (Chykerda *et al.*, 2014). Based on Peuma's involvement in a joint minting endeavor with both of these sites (Reinders *et al.*, 2016), the similarities in site structure and wall construction (Chykerda 2010), and the political environment at the beginning of the 3rd c. (Tziafalias *et al.*, 2006ab), the development of Kastro Kallithea as a settlement likely began at the onset of the 3rd c. BCE under the direction of Demetrios Poliorketes of Macedonia. Table 3.10 outlines the likely timeline of rule over Peuma. Kastro Kallithea would have remained under Macedonian legislation for the next 70 years. This is based on evidence of men from Peuma appearing at the Macedonian capital Demetrios early to mid-3rd c. BCE (Decourt, 1995, pp.161-63) and coins recovered from Kastro Kallithea that include Macedonian King Antigonus Gonatas (*Hegemon* of the Thessalian confederacy between 277 and 239 BCE) (Haagsma *et al.*, 2019b, pp.277-278).

Once Peuma was formally established as an independent settlement, it appears to have flourished. It was part of a collective of Achaia Phthiotis settlements that began minting their own bronze coins with the AX/XA monogram. Prior to the mid-4th c. Melitaia and Halos were the only minting sites in Achaia Phthiotis, but after 302 BCE New Halos, Phthiotic Thebes, Peuma, Ekkara, and Larissa Kremaste began producing bronze coins with the similar monogram (Reinders *et al.*, 2016). A collective monogram may signify shared social and economic networks, populations, and public interests.

There is varied discourse about when Aetolian forces entered Thessaly and how far they reached into Achaia Phthiotis (e.g., Graninger, 2010; Scholten, 2000). There are reports of Aetolian advancement into the region during periods of new Macedonian Leadership, including after the deaths of Antigonus (II) Gonatas (ca. 239 BCE), Demetrius II (ca. 229 BCE), and Antigonus (III) Doson (ca. 222/221 BCE) (Table 3.5). During this period it is likely that Aetolian forces gained influence over the region of Achaia Phthiotis that included Kastro Kallithea between 230 and 220 BCE (Scholten, 2000). Throughout their almost 100 years of regulation under Macedonian leadership, Peuma and other Phthiotic Achaian *poleis* were absent from the

Table 3.10 A timeline of control or allegiance for Thessaly and likely over Kastro Kallithea during its history. Adapted from various sources discussed in text. Refer to Table 3.3 for corresponding Pharsalian data.

Date (BCE)	(the rest of) Thessaly	Kastro Kallithea
346-323	Macedonian (Thessalian League)	Regulated by Pharsalos (Macedonian)
323-322	In support of Athens and Aetolia	Regulated by Pharsalos (Athens?)
322-302	Macedonian (Thessalian League)	Regulated by Pharsalos (Macedonian)
302-229	Macedonian, as the Hellenistic Thessalian League, some Aetolian advances	Emphasis on Achaia Phthiotis (AX Minting: 302-265, 260-230 BCE)
229-217	Macedonian, more Aetolian moving north	Aetolian supporters in area
217-197	Variable: Macedonian, Aetolian	Macedonian
196	Roman: "Thessalian *Koinon*"[34], variable	Thessalian Koinon (Independent/Roman)
191-146	Variable: Roman, Macedonian, Aetolian	Thessalian Koinon (Independent/Roman) and Aetolian (ca. 191) forces likely throughout this period[35]

Amphictyonic Council; no epigraphic evidence mentions individuals from these settlements. During the 230-220 BCE period, at least two Peumatian names appear at Delphi [BCH 45 (1921), IV, 39-40; BCH 45 (1921), V, 25)] (Decourt *et al.*, 2004, pp.715-716). Both proxeny decrees explain that the men were *Theorodokoi*, and granted rights at Delphi for their roles as hosts during the games at Delphi (Decourt *et al.*, 2004, pp.715-716). In order for Peumatians to be recognized as helping the Amphictyonic Council, it is likely that they were under Aetolian Legislation rather than Macedonian support. Aetolians had increasingly built up the Amphictyonic Council as a political unit by mid-3rd c. BCE (Scholten, 2000, p.95). Another epigraphic support of Aetolian rule over Peuma is an inscription in Larissa [IG IX. 2, 519] that honours a Larissan for services rendered to Peuma during unspecified troubles ca. 229-228 BCE (Decourt, 1995, no. 131). Decourt (1995, pp.145-147) speculates that this decree relates to Aetolian penetration into Peuma, and Scholten (2000, pp.168-169) argues that a date of 229-228

[34] Referred to by recent authors as the Hellenistic Thessalian League (Bouchon and Helly, 2015).
[35] A mix of Thessalian *koinon,* Aetolian and Roman coins was found at Building 10, Building 5 (small temple), and Building 1 (*stoa*) that date to this period.

BCE is likely, supporting the inclusion of Peumatians at the Amphictyonic Council by 220 BCE. An additional Peumatian name was recorded at Delphi between 220 and 210 BCE (Decourt, 1995, pp.161-163), suggesting that Aetolian rule continued up until Macedonian King Philip V regained control of Achaia Phthiotis at the end of the Social War in 217 BCE.

As part of regaining control over the region, Philip V enacted post-war decrees for citizenship across Thessaly. As part of his rebuilding efforts, movement and emigration occurred into major settlements, which likely coincided with the establishment of Building 10 and other domestic structures at Kastro Kallithea (Haagsma *et al.*, 2019a). Building 10 remained in use until the Second Macedonian War when Flamininus defeated Philip V in 197 BCE. Under new Roman influence, Building 10 was restructured into its second phase and occupied until ~140 BCE (Haagsma *et al.*, 2019a).

3.4.3. Archaeology of Kastro Kallithea

Recent archaeological analyses at Kastro Kallithea have been ongoing since 2004, including an initial surface assessment (Surtees 2012; Surtees *et al.*, 2014; Tziafalias *et al.* 2006ab), excavations of the *agora* and other public buildings (1 through 4) (Haagsma *et al.*, 2011; Lee *et al.*, 2006; Tziafalias *et al.*, 2006a), analysis and excavation of a sanctuary and associated public buildings (Building 5 and 6, respectively) (Haagsma *et al.*, 2011, 2015a), analysis of the fortifications and other defensive structures (Chykerda 2010; Chykerda *et al.*, 2014; Lee *et al.*2006; Tziafalias *et al*. 2006a, 2009), and an intensive analysis of the domestic structure referred to as Building 10 (Haagsma *et al.*, 2015a, 2019ab). All excavations have been possible because of collaboration with the Ephorate of Antiquities in Larissa and the Municipality of Pharsala and neighbouring regions. Figure 3.17 and Table 3.11 provide a visual representation and overview of the different buildings analyzed at this site to date.

The acropolis is fortified with a small temple and was constructed during the Classical period (Fig. 3.16, 3.17) (Chykerda 2010; Tziafalias *et al.* 2006a). During the Hellenistic period an urban centre was constructed, including houses, streets, an agora and other public buildings, and a second small temple; the settlement appears well-planned and houses are laid out according to a regular grid plan (Tziafalias *et al.* 2006, 2009). The settlement is estimated to have covered an area of 30-36 ha and included a population of roughly 1,000 people at its maximum (Haagsma *et al.* 2011, 2015a, 2019a; Tziafalias *et al.* 2006). The Kastro refers to the

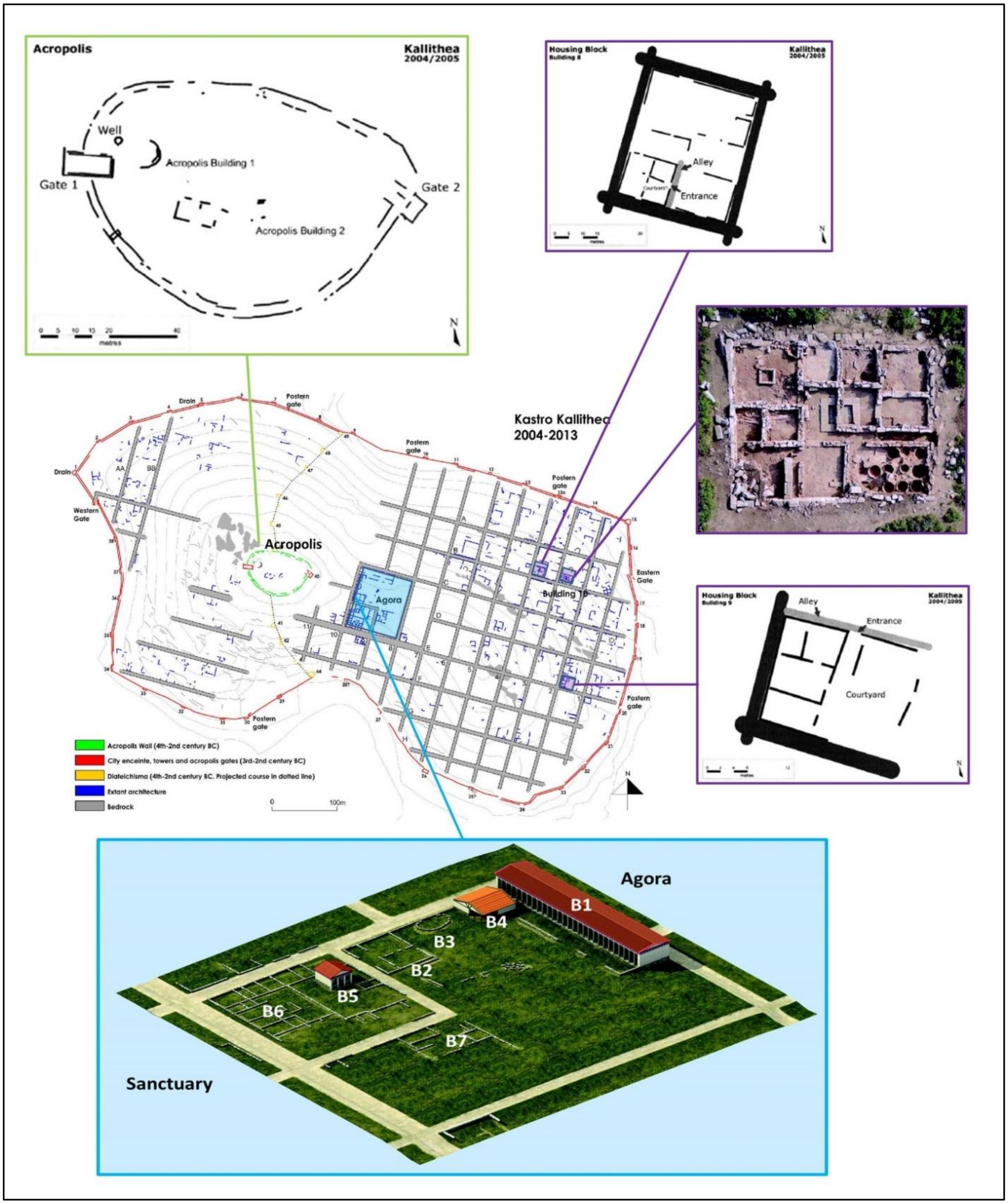

Figure 3.17 Map of Kastro Kallithea (centre), including a sketch of the acropolis (top left; green) and housing block (right; purple), and reconstructed images of the public area (bottom, blue). Visual image is of B10. Contexts and references in Table 3.11.

Table 3.11 Summary of archaeological structures excavated by the 15th Ephorate in Larissa, including public and domestic buildings. Table coordinates with Figure 3.17.

ID	Function	Context and major findings	Reference
B1	Stoa	Second building stage: includes slotted base for stele (public decrees?); columns and elongated building; contained offering bowl with cattle bones	Haagsma *et al.*, 2012, p.246; Tziafalias *et al.*, 2006a, pp.117-118
B2	Political Gathering?	Second building stage: likely related to the stoa, served a public function, with a cistern nearby; violently destroyed	Haagsma *et al.*, 2011, p.199; Tziafalias *et al.*, 2006a, pp.117-118
B3	Agora: Unknown	Second building stage (same as B4); tholos-like building, public, destroyed by fire	Haagsma *et al.*, 2011, p.200; Tziafalias *et al.*, 2006a, pp.117-118
B4	Agora: Unknown	Second building stage (same as B3); public building; coin from late 4th c.	Lee *et al.*, 2006, p.148; Tziafalias *et al.*, 2006a, pp.117-118
B5	Small temple	Altar, rooms, protrusion stones; destruction layer and fire (late 3rd/early 2nd c.); lots of drinking vessels; includes a Roman coin	Haagsma *et al.*, 2011, p.203; 2019a, p.65; Tziafalias *et al.*, 2006a, pp.117-118
B6	Public: Unknown	Likely associated with the temple, this public building may have been used for feasting; it includes a cistern; similar destruction layer (as B5)	Haagsma *et al.*, 2011, p.203; Tziafalias *et al.*, 2006a, pp.117-118
B7	Public: Unknown	Includes multiple rooms and is associated with a public space	Haagsma *et al.*, 2019a, p.48
B8	House	Small house (17m x 15m)	Haagsma *et al.*, 2019a, p 49
B9	House	Small house	Haagsma *et al.*, 2019a, p.49
B10	House	Wealthy large home with two phases (217-197, 197-c.140 BCE); Includes considerable amounts of pottery, 69 coins, loom items, animal bones, evidence of worship (protrusion stones, snake pot), and lavish goods.	Haagsma *et al.*, 2012, 2019a
Acropolis	Acropolis	Likely Classical in date, includes a small sanctuary (AB1)	Chykerda 2010; Tziafalias *et al.*, 2006a

extensive fortifications around the settlement, which includes defensive walls, two major gates, three additional lesser gates, and 49 towers (Chykerda 2010; Chykerda *et al.*, 2014; Lee *et al.*, 2006). The general architecture and overall positioning of the fortification afforded Kastro Kallithea vantage over the landscape between the southern Óthrys Mountain ranges and northern Narthacium Mountain, which leads to other major Thessalian settlements, including Pharsalos to the northwest, Phthiotic Thebes to the northeast, and Halos/New Halos to the east (Fig. 3.11) (Chykerda 2010; Chykerda *et al.* 2012, 2014).

The acropolis and oval circuit wall date to the late Classical period, whereas the *enceinte*, or external fortification that circles the entire site, dates to the late 4th or early 3rd c. BCE (Fig. 3.17) (Chykerda *et al.*, 2014; Tziafalias *et al.*, 2006a). Public buildings 1 and 2 of the *agora*, the sanctuary buildings (B5 and B6), and some of the domestic structures and roads were likely built during this second development phase (late 4th/early 3rd c. BCE). This period of civic and domestic structure development likely corresponds to an influx of residents and increasing defensible strategies at the *polis* level (Chykerda *et al.*, 2014; Tziafalias *et al.*, 2006a, 2009). Public buildings 3 and 4, and domestic structures including Building 10 were part of a third phase of development, likely occurring at the end of the 3rd and early 2nd c. BCE (Tziafalias *et al.*, 2006a; Haagsma *et al.*, 2015a). It is possible that the public development occurred earlier, potentially as a result of rebuild after the earthquake in 265 BCE.[36] Architecture, ceramic motifs, and coins found at various buildings throughout Kastro Kallithea were all used to chronologically identify stages of development and use (Haagsma *et al.*, 2015b, 2019a).

3.4.4. Building 10

Building 10 represents a domestic context and archaeological analyses of this dwelling took place between 2007 and 2013 (Haagsma *et al.* 2015a). Analysis of Building 10 commenced in 2017 with a permanent exhibition on display at the Museum in Pharsala (Haagsma *et al.*, 2019a). There are multiple stages of occupation at Building 10, representing two phases of likely Hellenistic occupation (Fig. 3.18, 3.19). Domestic structures are established because of their layout, organization within the grid block, and the artefact assemblages located on and within them (Surtees 2012, pp.126-128, 227-230; Surtees *et al*., 2014, p.438). As an example, tableware artefacts distributed within a certain space can be interpreted as formal dining within the structure whereas charred or other burnt remains and numerous ecofacts (animal bone, plant matter) could imply food preparation areas (Surtees *et al.*, 2014). Based on artifact presence and layout, Building 10 had at least 10 rooms, including a courtyard, storage room (with storage vessels (*pithoi*) *in situ*), a bath room (with perfume bottles (*unguentaria*)), and a room with a considerable supply of textile-producing items (e.g. over 230 loom weights) (Haagsma *et al.* 2015a, 2019a). Similar to the domestic houses at Pharsalos, Building 10 also contained cultic items, including a burned snake pot with the remains of a juvenile sheep or goat, and protrusion stones similar to those recovered at Pharsalos (Haagsma *et al.*, 2019a).

[36] This is speculation. An earthquake destroyed the settlement at New Halos in 265 BCE and based on proximity Kastro Kallithea was also likely impacted; see Chykerda 2010, p.69 for possible earthquake damage to fortification.

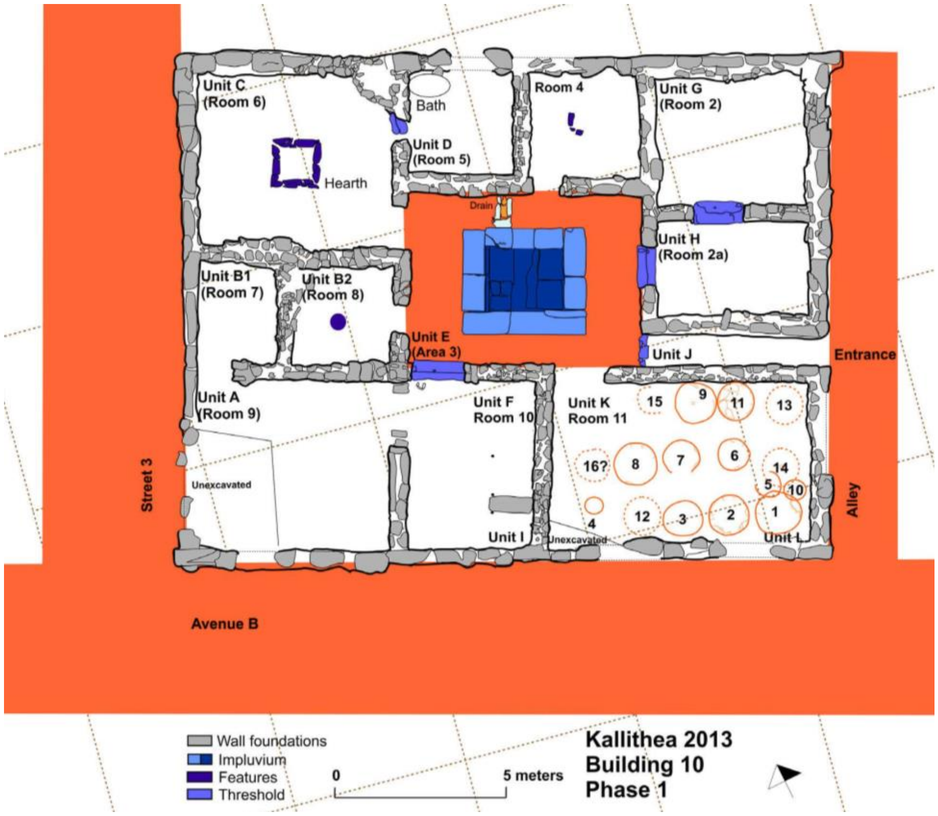

Figure 3.18 Kastro Kallithea Building 10 phase 1 based on excavations at the end of the 2013 field season (Haagsma *et al.*, 2015b; 2019a, p.53). The room contexts are broken down and listed below based on Haagsma *et al.* (2019a, pp.49-59) and personal discussion with Margriet Haagsma.

Unit	Room or Area	Function	Findings	Reference
A	9	-	Unexcavated (erosion)	-
B1	7	-	-	-
B2	8	-	-	-
C	6	Kitchen/Prep	Hearth, burning, snakepot, cauldron	pp.55-57, 68
D	5	Bathroom	Tub, *unguentaria*	pp.52, 54-57
E	3	Courtyard	Rainwater drain (open roof style)	pp.52-53
F	10	-	Grinding stones	p.55
G	2	Social room?	*Andron*, Aphrodite statue	pp.57-59, 69
H	2a	Front hall	Connects to room with *andron*	pp.57-59
I	10	-	(Wooden) stairs and post hole	p.55
J	-	Entrance corridor	0.9 m wide	pp.51-52
K	11	Storage	14 pithoi (combined capacity estimated at 14,202 L)	pp.53-54
L				
-	4	-	-	-

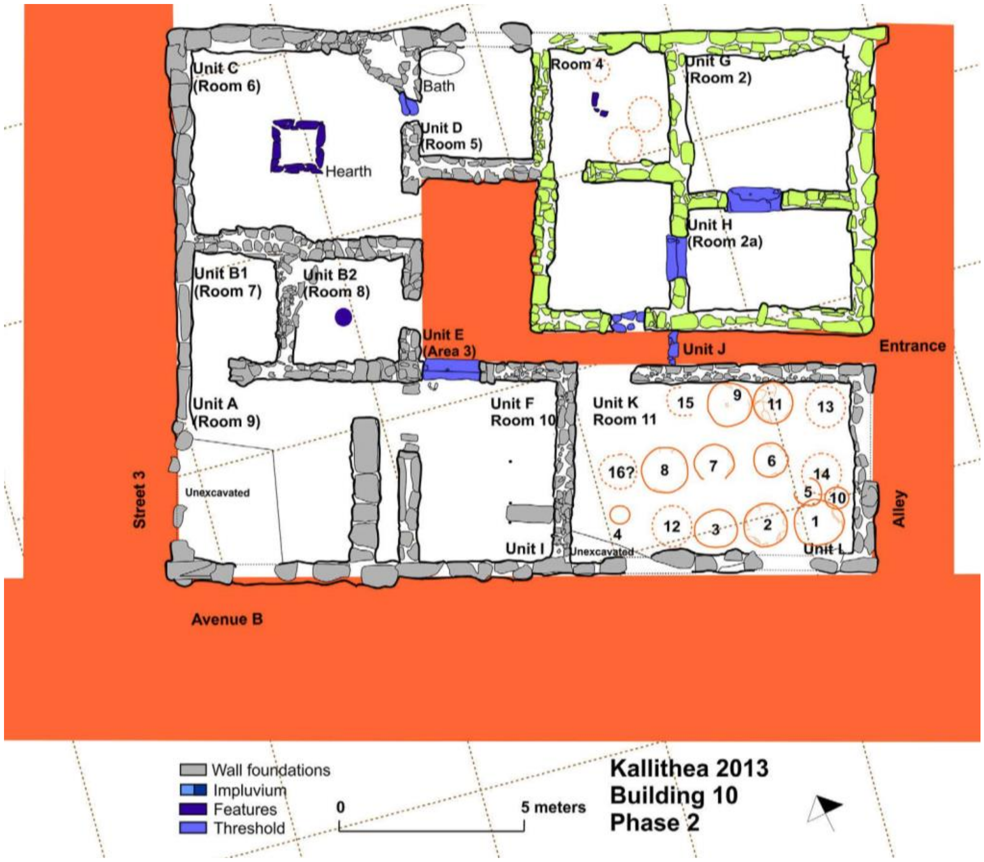

Figure 3.19 Kastro Kallithea Building 10 phase 2 based on excavations at the end of the 2013 field season (Haagsma *et al.*, 2015b; 2019a, p.60). The room contexts are broken down and listed below based on Haagsma *et al.* (2019a, pp.59-61) and personal discussion with Margriet Haagsma.

Unit	Room or Area	House	Function	Findings	Reference
A	9	N/A	-	Debris from other rooms	p.59
B1	7	2	Habitation		p.59
B2	8	2	Cooking	Fireplace	pp.59, 61
C	6	2	-		p.59
D	5	2	Bathroom	Tub	p.61
E	3	1	Habitation	Drain filled; new room	p.60
F	10	N/A	-	Debris from other rooms	pp.59-60
G	2	1	Weaving?	Loomweights	p.60
H	2a	1	Weaving?	Loomweights	p.60
I	10	N/A	-	Debris from other rooms	pp.59-60
J	-	N/A	Alley	-	-
K	11	N/A	-	Debris from other rooms	pp.59-60
L	11	N/A	-	Debris from other rooms	pp.59-60
-	4		Cooking	Fireplace, cooking pottery, *pithoi* storage	pp.60-61

Chronology

Two occupations for the settlement include Phase 1 (Fig 3.18), likely occupied between 217 and 197 BCE, and Phase 2 (Fig. 3.19), which was presumably occupied after 197 BCE until site abandonment around 140 BCE (Haagsma *et al.* 2011, 2015a, 2019a). Depending on the phase, different rooms were in use, had a likely function, and included specific findings (see tables associated with Fig. 3.18, 3.19). The first phase of Building 10 represented a large and expensive household with many rooms, two storeys, local and non-local material remains, and a socializing room complete with an *andron* (Haagsma *et al.*, 2019a, p.38). The second phase of Building 10 likely represented two smaller and more modest dwellings (Haagsma *et al.*, 2019a, p.38). Based on the number of roof tiles present in Unit A (Room 9), it was likely that Building 10 was destroyed when the roof collapsed ca. 197 BCE (Haagsma *et al.*, 2019, p.59). The public sanctuary and adjacent building at the *agora* (Building 5 and 6) also contain a layer of destruction dating to this time period, and it is possible that parts of Kastro Kallithea were destroyed during the same campaign that saw the sacking of Pharsalos ca. 197 BCE (Haagsma *et al.*, 2019, p.59.

Fauna

Zooarchaeological analyses of Building 10 were conducted by MacKinnon (2016) and Bishop (2016) (Table 3.12). Recovered faunal remains indicate that the same fauna located at Pharsalos were also prevalent at Kastro Kallithea with minor differences. Kastro Kallithea has the remains of donkeys/asses (listed as equid), other rodents (porcupine; listed as other wild mammals) and considerably more tortoise. These wild species were likely more prevalent on Kallithea's hillside because of available cover in the oak undergrowth. Based on the analysis of faunal materials in 2010 and 2012, roughly 1680 remains were identifiable to specific taxa. Of these remains 1311 (78%) were from domestic animals. Table 3.12 provides an overview of identifiable specimens. A large portion of the assemblage at Building 10 comprises wild fauna, however sheep and goat remains clearly dominate. The presence of fish at Building 10 may be due to the proximity to the coast, or due to excavation methods that favoured the collection of microfauna. The higher prevalence of wild boar at Building 10 compared to Pharsalos may be due to herds of boar roaming the lower mountain range in this region, which are seen even today.

Based on MacKinnon (2016) the assemblage at Building 10 contains elements from all parts of the animal and includes a mixture of young and old cattle, sheep/goat, and pig. There does not

Table 3.12 Faunal remains analyzed from Building 10 at Kastro Kallithea[37]. Reported as number of identifiable specimens (NISP) and percentage of total identifiable fauna (%) and total domestic fauna (%) (MacKinnon, 2016)[38]

Type of Remains	NISP	Percent (%) of Identifiable Fauna	Percent (%) of Domestic Fauna
Sheep/Goat	924	55.0	70.5
Pig	212	12.6	16.2
Equid	12	0.7	0.9
Cattle	49	2.9	3.7
Dog	83	4.9	6.3
Domestic fowl	31	1.8	2.4
Deer	112	6.7	
Hare	32	1.9	
Wild Boar	14	0.8	
Other Wild Mammals	31	1.9	
Tortoise	122	7.3	
Wild Birds	48	2.9	
Fish	10	0.6	
Total	**1680**		

appear to be a trend for preferred cuts of meat, and full bodies were prepared (burned, cut) and disposed of at Building 10. Female sheep and goat remains outnumber males 2:1, which may reflect females being kept into maturity for their use in dairy- or wool-based husbandry. Of the sheep/goats that could be further identified, there were more sheep than goats present (MacKinnon, 2016). Similar to assemblages at Pharsalos (Bishop 2018) and New Halos (Reinders and Prummel, 1998), there is a high frequency of *astragaloi* at Building 10 including those that have cultural modifications in the form of drilled holes or cut marks (MacKinnon, 2016, p.5).

MacKinnon (2016) also notes that there is no significant difference in the amount of domestic faunal material between Phase 1 and Phase 2. Compared to six houses at New Halos (Reinders and Prummel, 1998) or the two dwellings at Pharsalos (Table 3.10, 3.11), pig is much more prevalent at Building 10 and the Arsenopoulos Plot, whereas cattle is more common in the

[37] Due to heavy fragmentation and probable over-representation of remains, molluscs (including marine bivalves and sea/land gastropods) have been omitted from the total NISP counts.
[38] This data also appears in the formal publication Bishop *et al.* (2020).

dwellings at New Halos and the Alexopoulos Plot. Sheep and goat are the most frequent fauna recovered at any site in this area, suggesting their importance in Thessalian subsistence, but the evidence for differences in cattle or pig consumption between sites may relate to social or other implications.

3.5 Other Sites of Interest

Based on transportation pathways, shared histories, and other associations (e.g., Achaia Phthiotis minting collective; Reinders *et al*., 2016), there are numerous sites that are important when discussing findings from Pharsalos and Kastro Kallithea. Both sites were occupied during periods of volatile military campaigns and resettlements from the Macedonians, Aetolians, and Romans, and likely involved the movement of different religions, backgrounds, and skills. Having a better understanding of the underlying history for this site will lay the foundation for interpreting pastoralism and animal use in the past.

Achaia Phthiotis was home to numerous contemporary walled cities, isolated towers, and forts during antiquity. Figure 3.11 indicates many of the sites first mapped out by Stählin (1967) and later updated according to surveys and analyses (e.g., Haagsma *et al.*, 2019b; Reinders 1994, 1996; Reinders *et al.*, 2016). The topography of the region may reveal how different sites were positioned or why they were established during different periods of antiquity, but they also indicate how different social or trade networks may have formed. The topography creates multiple sight lines and vantage points for military efforts (Chykerda *et al.*, 2014), which may have been advantageous for military leaders (e.g., Dimitrios Poliorketes, ca. 302 BCE) or smaller *poleis* within Achaia Phthiotis (e.g., the AX minting collective; Reinders *et al.*, 2016).

Coins recovered from Kastro Kallithea point to different economic networks in which Kastro Kallithea and its potential trade partners participated. Coins from the early Hellenistic period (4th c. BCE) show Kastro Kallithea collaborating or trading within Achaia Phthiotis (Ekkara, Halos), Thessaly (Atrax, Larissa, Pharsalos, Pherae, Phalanna, and Skotoussa), and with further areas (Skiathos[39], Pella[40], and Elis[41]) (Haagsma *et al.*, 2019a, p.65). Other coins corroborate Kastro Kallithea's relationships with larger governing bodies, including those from Achaia Phthiotis (Phthiotic Thebes, Peuma), Thessaly (Melitaia, Thessalian League), and those

[39] Destroyed by Philip V in 200 BCE.
[40] Macedonia.
[41] Peloponnese.

minted under Antigonos Gonatas, Philip V, the Magnesian Koinon, the Aetolian League. These coins all originate from relatively local areas, which Haagsma *et al.* (2019a, p.65) suggest supports a relatively local export of Kallithea-based goods. Alternatively, remains of exotic goods recovered from Building 10 support a more widespread scope of imported goods (Haagsma *et al.*, 2019a, p.66).

Each settlement would have also been able to control the resources (agricultural and pastoral) available in each region. The importance of expanding upon these resources has been well-documented by the need for judging panels to settle land claims (e.g., epigraphic evidence translated by Ager, 1996) during antiquity. A number of different claims from the 3rd c. were ruled on that included Peuma and their neighbours (Melitaia and Chalai in one and Pereia and Phylladon in the other) [SEG XVIII.238] (Ager, 1996, pp.101-103). Although Peuma was unsuccessful in their attempt to expand land boundaries in both cases, the fact that they went through arbitration with western settlements may signify negative relations between neighbouring governing bodies.

3.6 Summary

This chapter gave a broad overview of the landscape in modern Thessaly and provided evidence and speculation about what the environment was like in antiquity. The geography, climate, and geology make Thessaly an area suitable for profitable agriculture and pasturage. What followed was an outline of the history for Thessaly that showed how the landscape and population changed, largely as a result of militaristic conquest. Many of these changes led to an influx of different people, cultures, and new ways that land were to be used in the area. The section that followed presented the archaeological history for the area including specific contexts at Pharsalos and Kastro Kallithea. The materials collected for my analysis are from all three of these contexts and represent sheep and goats used by their inhabitants. The stable isotope values of these teeth will be used to infer management styles and correlate the human-animal relationships to broader concepts of identity, society, and environment during antiquity.

CHAPTER 4: Sheep and Goat Dental Development

The purpose of my study is to establish how animals were managed in Thessaly during the Classical and Hellenistic periods and examine how management in antiquity relates to shepherding practices today. I focus on sheep and goat management as ovicaprids were the most common fauna recovered at Kastro Kallithea and Pharsalos (see Chapter 3) and ovicaprid husbandry plays an important role in the Greek economy today (see Chapter 2). In recent years researchers have outlined the utility of dental remains to study ovicaprid management (e.g., Ibáñez *et al.*, 2020; Isaakidou *et al.*, 2019; Trentacoste *et al.*, 2020). In my study I have chosen to sample sheep and goat third mandibular molars and analyze the enamel from the mesial surface of the anterior lobe of these teeth. This chapter provides the background for why I have chosen this specific sampling strategy to study ovicaprid management in Thessaly by outlining (4.1) why I choose teeth over bone samples; (4.2) how and why I choose specific teeth; (4.3) how those teeth form; (4.4) how dental formation can be impacted by life history; (4.5) how sampling area impacts what sequential samples represent; and (4.6) potential limitations of this approach. Ultimately this chapter sets the foundation for how I interpret animal management strategies from sheep and goat molar enamel.

4.1. Analyzing Bones vs. Teeth

4.1.1 Assemblage Analysis

Faunal remains provide an exceptional source of information, with species identification, element type, and taphonomic indicators often being used to infer aspects of human diet. Demographic information gleaned from domestic fauna can also be used to examine animal management strategies. As an example, Payne (1973) recorded the age at death and sex of fauna recovered from Aşvan Kale (Turkey) and created models for inferring various strategies for managing animals. Based on the mortality profiles Payne (1973) established three culling strategies that correlated to pastoralism that emphasized meat, milk, or wool production. Under a meat culling model, the skeletal assemblage will mostly contain sub-adult remains, as most animals would be killed at an age when they reach their best fat yield. In a dairy culling model, the assemblage will contain mostly younger male skeletons with female skeletal remains representative of post-lactation ages (4-7 years). Under the wool culling model, the assemblage will be composed of skeletal remains of older animals of mixed sex (8+ years) (Payne, 1973). Payne's (1973) kill off models have been used by a number of researchers interested in animal-based economies (e.g., Collins and Halstead, 1999; Halstead, 1981, 1987; Rosavich, 1994). However, Chang and Koster (1986) argue against mortality profile use because the models do not distinguish mixed subsistence strategies.

Harvest profiles are another useful approach to studying animal management using faunal assemblages, as these profiles can be used to indicate whether a site was in use for all seasons of the year. The logic of harvest profiles is based on the presence or absence of animals of certain ages. If animals are born in spring, and skeletal remains of newborn animals are recovered, the site was occupied in the spring (Arnold and Greenfield, 2006). If animals of all ages are recovered from an assemblage, the site was continuously occupied and animals were used for various purposes (Greenfield and Arnold, 2008). Harvest profiles from Kastro Kallithea indicate that Building 10 was occupied year-round, and MacKinnon (2016) suggests that farmers and herders likely practised a mixed agricultural and pastoral scheme to maximize a variety of resources (recall Chapter 3). Halstead (1987) argues that year-round occupation of a site suggests that specialized management strategies, such as transhumance, did not occur. Chang and Koster (1986) argue that full assemblage analyses are unable to indicate a specific exploitation strategy, especially when there are multiple strategies occurring simultaneously. Chapter 2 outlined different ways animals are managed in Greece today; if multiple strategies were in use in the past, there are limitations to analyzing a full assemblage.

4.1.2 Individual Analysis

Instead of analyzing characteristics of the overall assemblage, which provide information at the population level, some approaches afford researchers a glimpse into animal management at the individual level. For example, macroscopic evidence of skeletal pathologies can be correlated to how the animal was treated or used during life. A healed wound may indicate that an animal was cared for and protected during the healing period (e.g., MacKinnon, 2010; Udrescu and Van Neer, 2005), whereas bones with heavy entheseal markers may indicate that the animal was used for draught labour that involved repetitive strain (e.g. Galindo-Pellicena *et al.*, 2017; Salmi and Niinimaki, 2016). A highly detailed individual-level analysis can be achieved when entire animals are intentionally buried in an assemblage. In these cases, zooarchaeologists can record age, sex, pathology, and mortuary practice together, and correlate this information to the animal's life history or role in society (e.g. Fern, 2007; Losey *et al.*, 2011).

Instead of using macroscopic analysis of skeletal elements, the biochemical composition of bones and teeth can be recorded and used to interpret aspects of an ovicaprid's life history. Stable isotope analysis is discussed in more detail in Chapter 5, but the basic principle is that growing bones and teeth incorporate atoms from materials in an animal's environment (e.g., food, water, air). Bone continuously remodels throughout an animal's life, with elements often representing multiple years' worth of growth depending on the animal and skeletal element. As a result, stable isotope analysis of bone yields dietary information that is also time averaged. In contrast, dental enamel develops in a chronological pattern and does not remodel after development has finished. Depending on the animal, tooth type, and portion of the tooth, incremental enamel samples can represent a very specific period of life. Stable isotope analysis of sequential enamel samples thus can recover dietary information from consecutive periods of an animal's life. Understanding how ovicaprid teeth develop and what factors influence maturation are essential to understanding what period of time each incremental sample represents.

4.2. Ovicaprid Tooth Selection

4.2.1 Permanent vs. Deciduous Teeth

Domesticated ovicaprids have a dental formula of $\frac{0:0:3:3}{3:1:3:3}$ (Fig. 4.20). Table 4.13 summarizes the rough estimates of dental eruption timing in modern and unimproved/wild sheep and goats published by Silver (1969). Figure 4.20 illustrates maxillary dentition in an adult sheep. The estimates in Table 4.13 are used as the foundation for eruption timing in many other studies (e.g. Bullock and Rackham, 1982; Deniz and Payne, 1982; Greenfield and Arnold, 2008). Deciduous teeth predominantly reflect the growth period starting during gestation and continuing through the first few months of life. Although teeth begin erupting prior to their completion, deciduous teeth would be completely mineralized long before the eruption of permanent dentition (Hillson, 2005; Silver, 1969). Deciduous teeth correspond to a growth and development period of three to six months, whereas permanent teeth can reflect one to two years of growth and development. In particular, permanent third molars take roughly two years to develop and are the largest teeth in

Table 4.13 Tooth Eruption Ages in Sheep[42]

Tooth (maxillary: mandibular)		Deciduous Teeth	Permanent Teeth	
			Modern Improved Breed	Semi-wild sheep
Incisors	Central (0:1)	Birth - 1 week	12-18 mo.	18 mo.
	Middle (0:1)	Birth - 1 week	18-24 mo.	30 mo.
	Lateral (0:1)	Birth - 2 weeks	27-36 mo.	42 mo.
Canines	(0:1)	Birth to 3 weeks	33-48 mo.	50 mo.
Premolars[43]	1	Usually Absent	Usually Absent	Usually Absent
	2 (1:1)	Absent	21-24 mo.	30 mo.
	3 (1:1)	Absent	21-24 mo.	30 mo.
	4 (1:1)	Absent	21-24 mo.	40 mo.
Molars	1 (1:1)	Birth - 6 weeks	5 mo. (upper) 3 mo. (lower)	6 mo.
	2 (1:1)	Birth - 6 weeks	9-12 mo.	18 mo.
	3 (1:1)	Birth - 6 weeks	18-24 mo.	3-4 years

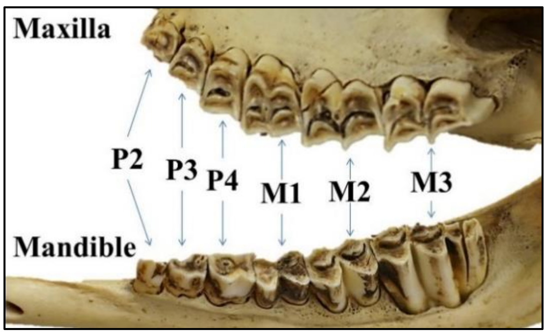

Figure 4.20 Remains of a modern adult sheep, including the teeth of the right maxilla and left mandible, from the second premolar (P2) to the third molar (M3).

the ovicaprid mouth. Larger teeth provide more enamel for sampling and correspond to a longer span of time that can be recorded from each sample. As a result, molar teeth are most often used for stable isotope analysis (e.g., Balasse 2002, 2003; Balasse *et al.*, 2009, 2012a, 2012b, 2013, 2017; Buchan *et al.*, 2015; Henton *et al.*, 2010; Isaakidou *et al.,* 2019; Trentacoste *et al.*, 2020; Valenzuela-Lamas *et al.* 2018; Zazzo *et al.*, 2005, 2010, 2012).

4.2.2 Selecting a Molar

The faunal assemblages at Kastro Kallithea and Pharsalos are heavily fragmented and include mostly disarticulated teeth with some mandibular fragments. There are more disarticulated

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[42] Adapted from Silver (1969, p.297) and Payne (1973, p.297).

[43] Deciduous premolars are often referred to as deciduous molars (e.g. deciduous $m_1 = P_2$), although some authors do this interchangeably (e.g. Payne 1973, p.297).

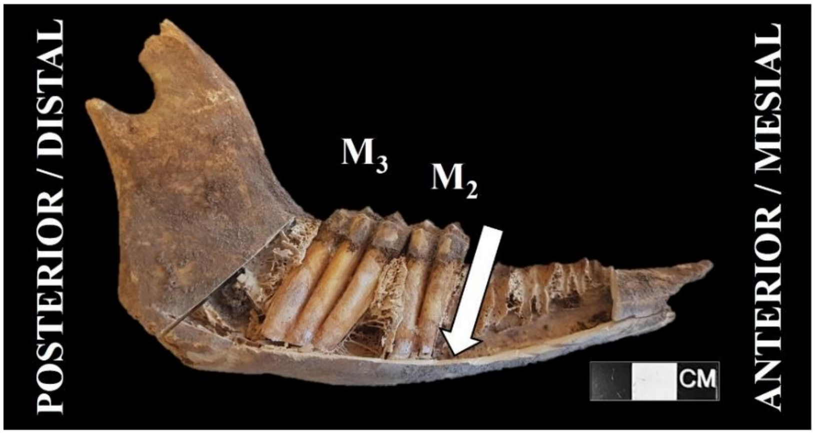

Figure 4.21 Archaeological goat mandible (SG23) indicating directions discussed in text. Right mandible with cortical bone removed to expose the second (M_2) and third (M_3) molars *in situ*. The white arrow shows the direction of molar growth, from the occlusal surface of the cusp, or earliest forming part of the tooth, to the crown-root juncture, or latest forming part of the tooth. Anterior is toward the front of the mouth and mesial refers to the aspect of the tooth that faces the midline of the dental arcade. Posterior is toward the back of the mouth and distal refers to the aspect of the tooth that is furthest from the midline. Buccal is the side of the tooth facing the cheek, and is the opposite of lingual, the side of the tooth facing the tongue (not pictured here).

mandibular molars than maxillary molars in this assemblage. Due to their morphology and growth patterning (see Fig. 4.20), position identification of loose teeth (e.g. M_2 vs. M_3) is more easily done for mandibular teeth than for maxillary teeth. Although some stable isotope studies have analyzed maxillary molars (e.g., Balasse *et al.*, 2013; Trayler and Kohn, 2017), most studies rely on mandibular molars because of their abundance and ease of analysis (e.g., Balasse *et al.*, 2009; Reade *et al.*, 2015; Valenzuela-Lamas *et al.*, 2018). Of the studies that sample disarticulated mandibular molars, few studies have chosen M_1 (e.g., Passey and Cerling, 2002; Perry *et al.*, 2008), and the rest have sampled M_2 (e.g., Balasse *et al.*, 2012a, 2012b; Buchan *et al.*, 2015; Henton *et al.*, 2010; Humphrey *et al.*, 2008) or M_3 (e.g., Evans *et al.*, 2019; Tornero *et al.,* 2013; Valenzuela-Lamas *et al.*, 2018). In a disarticulated assemblage M_3 are more easily identifiable because they contain three horizontal cusps compared to the two horizontal cusps on M_1 or M_2 (Fig. 4.21) (Deniz and Payne, 1982; Weinreb and Sharav 1964). Being able to confidently identify disarticulated molar type is paramount because each develops, matures, and erupts across different stages of life and therefore represents different snapshots in time (Luyt and Sealy, 2018).

4.2.3 Sheep vs. Goat

It is also necessary to indicate whether a disarticulated tooth was from a domestic sheep (*Ovis aries*) or a domestic goat (*Capra hircus*). Grine *et al.* (1986) established a method for differentiating sheep and goats by thin-sectioning teeth and microscopically examining differences in enamel ultrastructure. His analysis was limited to specific teeth and he found that ultrastructure could be altered by anthropogenic forces (e.g., foddering practices). ZooMS is a newer procedure that has gained popularity for its ability to differentiate these species according to protein structure (Buckley *et al.*, 2010). ZooMS distinguishes sheep from goat remains using a small sample of collagen to identify a single peptide. Unlike DNA analysis, which is expensive, takes time, and is plagued by contamination issues, ZooMS is cheap, quick, and not easily influenced by contaminants (Buckley *et al.*, 2010).

Although ZooMS is an important tool for faunal analysis, the shape of the M_3 is one of the best non-destructive ways to differentiate sheep from goat. Researchers have established morphological criteria to macroscopically differentiate sheep and goat M_3. In particular, Halstead *et al.* (2002, p.548) use six reference points (e.g., shape, angle, point direction) on the occlusal surface of the M_3 to distinguish sheep from goat. Balasse and Ambrose (2005, p.695) use two additional points of reference (e.g., shape, curvature direction) on the mesial surface of the M_3 to distinguish sheep from goat. When used in conjunction, all eight criteria can be used to reliably identify M_3 as being from a sheep or a goat (Balasse and Ambrose, 2005; Halstead *et al.*, 2002).

4.3. Tooth Development: Amelogenesis

Veterinary sciences (Suga, 1979; 1982) and laboratory studies (Passey and Cerling, 2002; Reade *et al.,* 2015; Zazzo *et al.,* 2012) indicate that tooth enamel formation (amelogenesis) occurs directionally from the apex of the tooth crown to its cervix (Fig. 4.21). Tooth enamel is composed of a mineral portion called calcium phosphate hydroxyapatite, commonly referred to as bioapatite (Hillson, 2005). Enamel development is a multi-stage process that starts with the deposition of enamel matrix crystals, followed by multiple stages of maturation and mineralization to create a hard lattice structure (Suga, 1979; 1982). Amelogenesis was first studied in continuously forming rodent incisors, which provided a means for studying rates of growth (Hillson, 2005; Suga, 1979). In contrast, sheep and goat teeth develop, grow, and mineralize at varying rates and stop growing at specific stages (Hillson, 2005; Suga 1979; 1982;

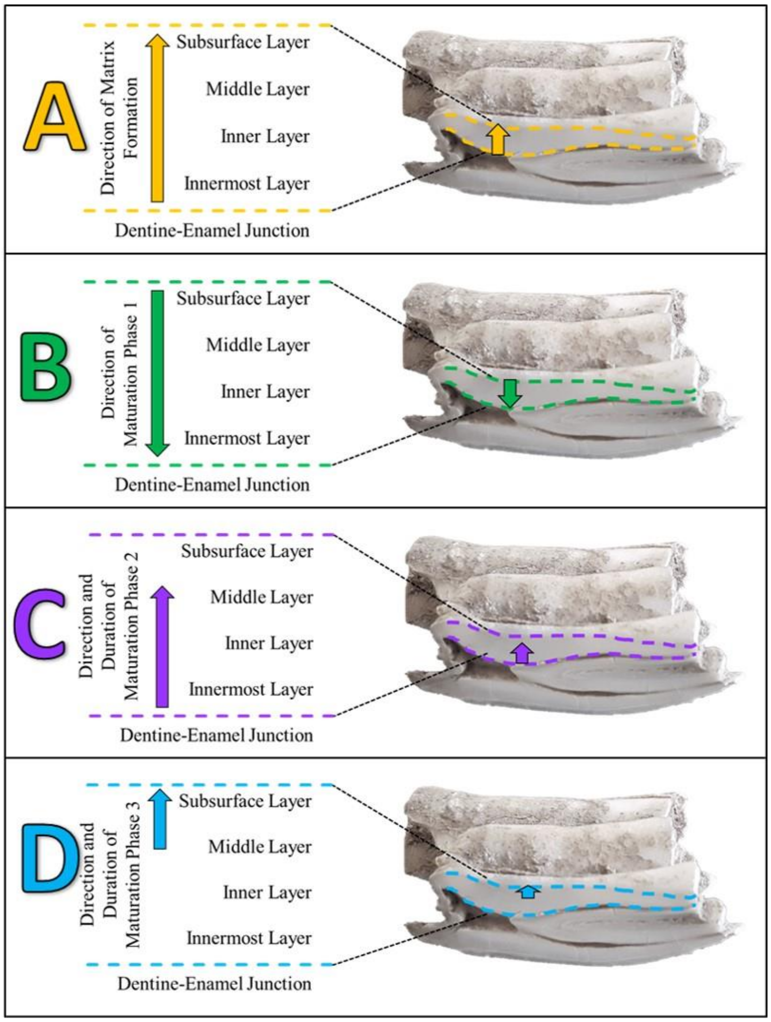

Figure 4.22 Generalized overview of amelogenesis using a goat right M_3 (SG08). Amelogenesis stage, meaning, and corresponding events from Suga (1982, p.1536) are discussed in the text (Section 4.3) and relate to the image shown. This cross-section was obtained by removing the mesial portion of the anterior lobe to expose the distal portion of the lobe. The buccal enamel segment is outlined from the dentine-enamel junction to the surface layer.

Weinreb and Sharav, 1964; Zazzo *et al.,* 2005) (Fig. 4.22). Suga's (1982) analysis of amelogenesis has been adapted to stable isotope analyses (e.g., Balasse, 2002; 2003; Balasse and Ambrose, 2005; Henton *et al.,* 2010; Reade *et al.,* 2015; Zazzo *et al.,* 2005; 2010; 2012). Stable isotope researchers study amelogenesis to find out how long an enamel segment of a given length takes to completely form. This time period corresponds to a portion of an animal's life. Examining sheep and goat-specific amelogenesis can indicate what period of the animal's life relates to what enamel segment of each tooth.

Figure 4.22 shows an overview of amelogenesis using a tooth sampled from Kastro Kallithea (SG08) combined with Suga's (1982) interpretation. There are four main stages of amelogenesis: one stage of matrix formation (Fig. 4.22A) and three stages of enamel maturation (Fig. 4.22B-D). The innermost layer represents the area of enamel directly above dentine at the dentine-enamel junction (or DEJ). Enamel matrix formation starts with initial secretion of the matrix. In this step the innermost layer (10 μm) is immediately fully mineralized and the rest of the matrix is partially mineralized as it is laid down by ameloblastic cells from the innermost layer towards the enamel surface (Fig. 4.22A). At this stage, the innermost layer is the most heavily mineralized portion of the enamel. During the three following stages of maturation, further mineralization creates completely mature crystals of enamel. This process does not create a marked change in the width of enamel, only in the concentration or rates of mineralization in various zones of the enamel. The first of these substages is marked by an increase in mineralization spreading from the surface to the interior portion of the enamel (Fig. 4.22B). At this stage, the subsurface layer (5 μm) is the most heavily mineralized portion of the enamel, with decreasing mineralization inwards to the DEJ. The second maturation stage involves the progression of mineralization from the innermost layer toward the surface layer (Fig. 4.22C). This stage causes all middle and inner layers to have a consistent level of mineralization. The third maturation stage is abrupt and most of the mineralization happens at this stage (Fig. 4.22D).

Suga (1982) was unable to identify the exact timing of each stage of amelogenesis. Similarly, Zazzo *et al. (*2005) noted that mineralization occurred over different periods of time, which made it difficult to sample segments of enamel along the developmental layers. Instead, researchers analyze horizontal bands of enamel to record an average period of time, although in these studies amelogenesis timing is shown to be dependent on a number of internal factors (e.g. tooth selection, sampling location) and external factors (e.g. breed, sex, life history) (e.g., Reade *et al.,* 2015; Tornero *et al.*, 2013; Zazzo *et al.*, 2012).

4.4. Dental Development and Life History

Ovicaprid skeletal maturation and dental development patterns are influenced by various factors of life history, including species, breed, sex, castration, nutrition, weaning, and breeding time (Table 4.14). With some extrapolation, many of these factors also likely impact amelogenesis and therefore the time represented by each enamel subsample.

Table 4.14 Summary of the impacts of different life factors on ovicaprid dental development

Impacting Factor	**Impact on Dental Development**	**Source**
Species	No difference in enamel formation	Hillson 2005; Millard 2006; Suga 1982
	Significant difference in sequence and timing (M_3 erupts sooner in sheep)	Amorosi 1989; Balasse and Ambrose 2005; Balasse *et al.*, 2013; Halstead *et al.* 2002; Jones 2006; Noddle 1974; Payne 1973; Silver 1969; Vigal and Machordom 1985
Breed Type	Sheep eruption sequence is the same (except some wild vs. domesticates), eruption timings differ	Aitken and Meyer 1982; Amorosi 1989; Arrowsmith et al. 1974; Hemming 1969; Ho *et al.* 1989; Jones 2006; McGregor 2011; Moran and O'Connor 1994; Payne 1973; Upex and Dobney 2012; Wiener and Purser 1957; Worley *et al.* 2016
Improved Breed?	Improved breeds erupt ~ 6 months sooner than unimproved breeds (sheep or goat)	Jones 2006; Noddle 1974; Payne 1973; Silver 1969; Weinreb and Sharav 1964; Zazzo *et al.* 2010; Zeder and Lapham 2010
Sex	No significant difference in eruption	Moran and O'Connor 1994; Popkin *et al.* 2012; Vigal and Machordom 1985; Worley *et al.* 2016
	Male goats erupt 3 months before females	Deniz and Payne 1982; Hillson 2005; Ho *et al.* 1989; Jones 2006
	Female sheep erupt 1-3 months before males	Clutton-Brock *et al.,* 1990
Castration	Inconsistent impact of castration	Moran and O'Connor 1994
	Castrated sheep erupt before males	Clutton-Brock *et al.,* 1990; Hatting 1983, in Clutton-Brock *et al.,* 1990; Noddle 1974
	Marginal impacts on ovicaprid eruption	Amorosi 1989; Davis 2000; Noddle 1974; Popkin *et al.* 2012; Worley *et al.* 2016
Nutrition	No impact on sheep	Field *et al.* 1990; Worley *et al.* 2016
	Significant impact on sheep. The more marked the nutritional difference, the more significant the differences in eruption	Amorosi 1989; Arrowsmith *et al.*, 1974; Every *et al.* 1998; Gunn 1964a, 1964b, 1965, 1967a, 1967b, 1968; Upex and Dobney 2012
	Significant impact on goat (similar as above)	Deniz and Payne 1982
Season of Birth	Impacts tooth formation indirectly based on seasonal factors that they are exposed to	Jones 2006; Upex and Dobney 2012
Stress	Stress impacts dental development, which correlates to instances of enamel hypoplasia	Kierdorf *et al.* 2012; Upex and Dobney 2012

4.4.1 Species Variation

Sheep (*Ovis*) and goat (*Capra*) are two distinct genera that experience different dental formation and eruption timings. Trayler and Kohn (2017) demonstrate that ungulate species have different rates of matrix formation and maturation. In their analysis, a month of enamel formation yielded fully mineralized enamel in sheep and goat, but enamel that was not fully mineralized in horse or bison (Trayler and Kohn, 2017). According to their study, the only remarkable difference between sheep and goat amelogenesis occurs during the first maturation stage (Fig. 4.22B) (Trayler and Kohn, 2017). During this period goats have a more heavily mineralized subsurface layer, whereas sheep have a more heavily mineralized middle layer (Suga, 1982).

Sheep and goat life histories also differ in ways that have been shown to impact skeletal growth and development (Table 4.14) (e.g. Amorosi, 1989; Hillson, 2005; Jones, 2006; Noddle, 1974; Payne, 1973; Silver, 1969; Vigal and Machordom, 1985; Zeder, 2006; Zeder and Lapham, 2010; Zeder and Pilaar, 2010). Under some of these circumstances, amelogenesis timing is impacted, both in terms of duration and onset. As an example, ovicaprid dental aging techniques are often considered representative of steadfast parameters for all sheep and goats throughout time (Greenfield and Arnold, 2008). Figure 4.23 summarizes the results of 17 studies that report ovicaprid M_3 formation, mineralization, and eruption timing. Some of these studies identified eruption times according to their own sample study, while others adapted the results of another study to their specific context. Because there are differences in life factors and environmental conditions (Table 4.14), each study recorded different eruption ages (Fig. 4.23). This is one of the major caveats for season of birth studies (e.g., Balasse *et al.*, 2012ab; Henton *et al.*, 2010; Tornero *et al.*, 2013; see Chapter 5). Understanding how sheep and goat bodies mature is paramount for identifying how amelogenesis is impacted during development, and ultimately what time period enamel segments represent.

4.4.2 Breed Variation

As indicated in Table 4.13, many studies report differences in eruption timing and duration according to whether the animal was wild or 'improved'. Breed improvement refers to genetic modification of breeds through domestication and breed selection (Aitken and Meyer, 1982; Arrowsmith *et al.,* 1974). Improvement often selects for increased rates of growth and development, as animals that develop faster are more profitable for the herder (Gunn, 1968). Sheep dental eruption timing differs between breeds because of their different rates of maturation

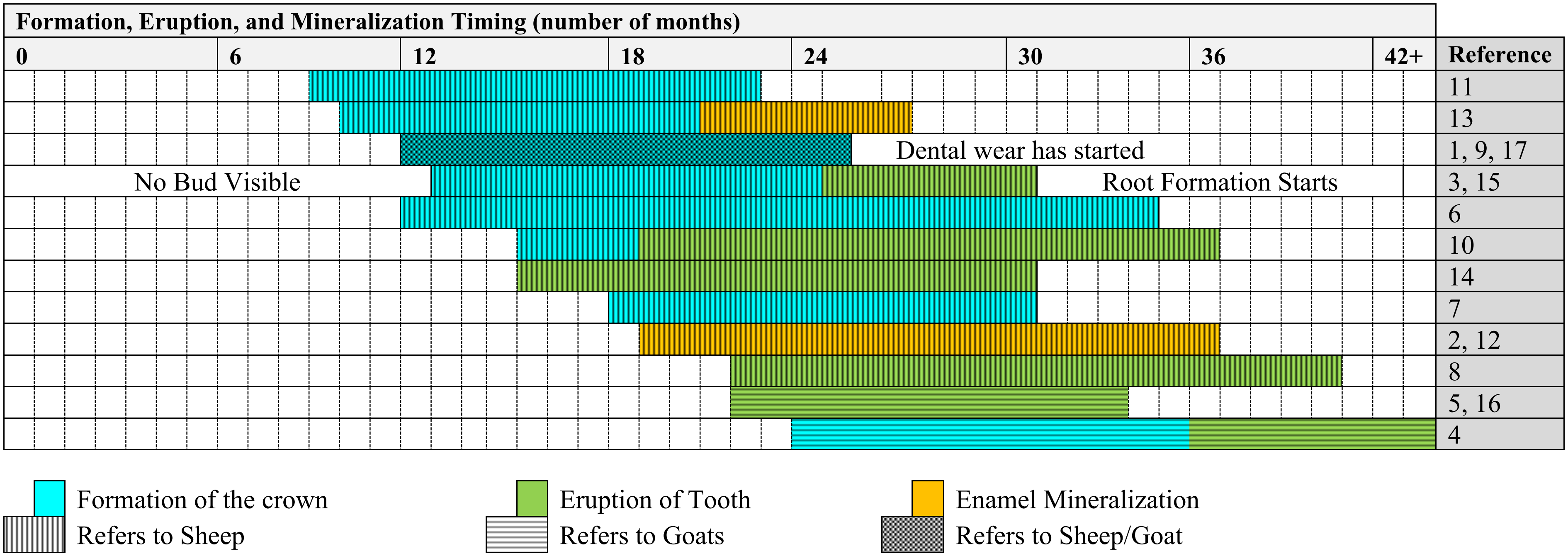

Figure 4.23 Molar formation (blue), enamel mineralization (purple), and eruption (green) patterns for sheep and goat mandibular third molars, as discussed in text according to specified sources

References discussed in figure

1. Balasse 2002
2. Balasse 2003
3. Balasse *et al.,* 2013
4. Bullock and Rackham 1985
5. Deniz and Payne 1982
6. Frick and O'Neil 1996
7. Halstead 1985 *[44]
8. Hemming 1969
9. Hillson 2005
10. Jones 2006
11. Milhaud and Nézit 1991, in Zazzo et al., 2010
12. Reade *et al.,* 2015
13. Tornero *et al.,* 2013
14. Upex and Dobney 2012
15. Weinreb and Sharav 1964
16. Vigal and Machordom 1985
17. Zeder 2006

*[44] Cow values are used as a sheep proxy.

(Aitken and Meyer, 1982; Arrowsmith *et al.,* 1974; Wiener and Purser, 1957) (Fig. 4.23). Worley *et al.* (2016, p.863) suggest that tooth enamel morphology and thickness may also be impacted by where each breed lives and eats. For example, Deniz and Payne (1982) reports that three slightly different breeds of Angora goat had significantly different molar eruption times, which were attributed to poorer nutrition according to grazing location.

If eruption timing is altered because of genetic predisposition and environmental conditions, it is possible that amelogenesis is similarly altered. Studies often rely on controlled reference data sets to indicate how each breed *should* develop and mature. Many studies have relied on modern Orkney sheep breeds for estimating enamel formation timing within ancient assemblages (e.g., Balasse and Tresset, 2007; Balasse *et al.,* 2009; Mainland *et al.,* 2016). According to Aitken and Meyer (1982), Jones (2006), Zazzo *et al.* (2010), and Zeder and Lapham (2010), some improved sheep breeds have dental eruption occurring roughly six months prior to unimproved breeds (Table 4.13). If this is the case, improved sheep breeds are not suitable for proxies of ancient breeds. One way that studies have attempted to gain access to 'unimproved' modern proxies is by focusing on collections of wild or feral animals. Zeder (2006, p.87) argues that by studying wild goat breeds, researchers can examine animals that are considered "closer to their natural state" before domestication genetically modified them.

Bullock and Rackham's (1982) study of feral goats (Fig. 4.23) found that third molars started forming at the beginning of the second year of life, began erupting a year later, and were fully erupted by four years of age. The third molar took over two years to become fully formed. Rates of growth and development for these animals provide a more appropriate comparative sample of ovicaprid breeds in Greece from antiquity. Sheep and goat remains at Kastro Kallithea and Pharsalos are of mostly domesticated animals (recall Chapter 3), which likely represent unimproved breeds (MacKinnon, 2010; White, 1970). Amelogenesis likely occurred sooner than wild breeds but over a similar duration. The breeds of Neolithic sheep from Romania studied by Balasse *et al.* (2013, 2015) had M_3 that developed over a 1.5 to 2 year span. If the unimproved breeds examined by Balasse *et al.* (2003) are genetically similar to my samples, sheep and goats in Hellenistic Greece likely had M_3 erupt between 2 and 4 years of life, and M_3 enamel will reflect 1.5 to 2 years of development.

4.4.3 Sex

Some studies indicate no significant difference in dental eruption between male and female sheep or goats (Moran and O'Connor 1994; Vigal and Machordom 1985; Worley *et al.,* 2016) (Table 4.14). Other studies have shown that male and female dental eruption is different with increasing disparity as an animal matures (Deniz and Payne, 1982; Ho *et al.,* 1989). Male M_3 erupt sooner than female M_3 by almost three months in some studies (Jones 2006). Alternatively, the Clutton-Brock *et al.* (1990) study of age-progressive dentition in sheep found that female molar teeth erupt months in advance of male molars. Female skeletal maturation has also been recorded as occurring earlier than in males, with most skeletal elements fusing many months sooner in females (Popkin *et al.,* 2012). Sex-based skeletal development discrepancies are likely caused by genetic differences according to breed.

I have been unable to identify studies that have analyzed rates of amelogenesis or enamel thickness according to sex in sheep or goats. Compared to females, males require more calories because of their larger body size and therefore must consume more food. It is possible that males have a genetic predisposition for thicker enamel to account for this increased intake of food (Every *et al.,* 1998). Just as goats have a thicker enamel than sheep to account for their increased intake of rougher or grittier foods (Grine *et al.,* 1986), it is possible that males also have thicker enamel. Zazzo *et al.* (2012) measured longer periods of amelogenesis in teeth that had thicker enamel. Similarly, animals with thicker enamel will have longer periods of amelogenesis compared to breeds that have thinner enamel (Trayler and Kohn, 2017). If males have thicker enamel than females, they may undergo more time-averaged periods of amelogenesis, but more work needs to be done at this time to confirm a sex-based difference.

One of the limitations of working with disarticulated teeth or partial elements is that I am unable to assign a sex to any of the individual ovicaprid M_3 sampled from Kastro Kallithea or Pharsalos based on gross morphology. DNA analysis can indicate if the remains belong to a male or female, but this form of analysis is destructive and costly. As a result, all remains were sampled without a sex allocation.

4.4.4 Castration

Another potential sex-based influence on amelogenesis is castration. Kron (2014) notes that castration was practised prior to the Late Hellenistic period. According to Ekroth (2014a, p.169) ancient Greek pastoralists castrated sheep and goats, as the meat of castrated animals (wethers) had “more fat and a less offensive taste or smell.” Wethers are also easier to control (Dýrmundsson, 1973) and produce better qualities of wool (Ekroth, 2014a). Certain cults also required sacrifice of castrated animals, and wethers were likely raised with the rest of the flock for this purpose (Ekroth 2014b; Rosivach, 1994). There is contradictory evidence regarding the effects of castration on skeletal development (Table 4.14) (Moran and O’Connor, 1994). Multiple studies have examined the impact of castration on cheek teeth eruption and have come to different conclusions: (1) wether cheek teeth erupt early (Clutton-Brock *et al.,* 1990), (2) there is no impact on eruption (Worley *et al.,* 2016), or (3) wether M_3 eruption is marginally delayed compared to uncastrated males (Davis, 2000).

Davis (2000) analyzed dental eruption and wear and epiphyseal fusion of 30 unimproved Shetland wethers and 12 unimproved Shetland rams. His study indicated that castration delayed permanent teeth eruption by three months at most (wether M_3 erupt at 26 months; uncastrated M_3 erupt at 23 months) (Davis 2000, p378). Both values are similar to the estimate of eruption of M_3 in sheep recorded in Silver (1969) (Fig. 4.23), but this difference may be specific to the breed analyzed. Deniz and Payne (1982) studied three different breeds of Angora (improved) goats and observed no delays in dental eruption due to castration. If castration impacts M_3 development, it appears to only affect the age at which teeth begin to form and then later erupt (Moran and O’Connor, 1994). At this time, no conclusions can be made about whether castration impacts the rates of amelogenesis, and no evidence has suggested this. As with sex, castration status cannot be determined from my sample of disarticulated teeth.

4.4.5 Nutrition

Skeletal maturation and growth require a diet with adequate supplies of energy and nutrients. The most adequate nutrition lambs and kids receive is directly from their mother’s milk (Upex and Dobney, 2012). Pastoral communities that require dairy for their own nutrition and revenue will wean animals shortly after birth (White, 1970), a practice that likely affects animal skeletal maturation and growth. Gudmundsson (1993) examined the quantity and quality of forage for developing Icelandic sheep and concluded that growth and development are intrinsically linked to adequate nutrition during key developmental periods. Arrowsmith *et al. (*1974) and Field *et al.*

*(*1990) report that low-plane diet[45] directly stunted bone growth. M_3 develop over a 1.5 to 2 year period and experience varied rates of development according to seasonal nutrition intake (Gunn, 1967a, 1967b). Worley *et al. (*2016) found no difference in M_3 eruption times when sheep are raised on low-plane pasturage or on high-plane pasturage. Tooth eruption was altered when diet was drastically changed during development. In particular, changing from a low-plane to high-plane diet or a high-plane to low-plane diet impeded bone fusion and tooth eruption (Worley *et al.,* 2016). Arrowsmith *et al. (*1974) also found that sheep fed with better quality nutrition had significant permanent tooth eruption acceleration (approximately 30 days) compared to non-supplemented sheep. This may be directly related to accelerated rates of amelogenesis when adequate nutrition is available.

In Gunn's (1964a, 1964b, 1965, 1976a, 1976b, 1968) six year study, three different groups of Cheviot Hill sheep were monitored for growth and development on three unique diets in the first year of life. Diets included a high-plane diet meant to increase bulk weight, a mid-plane diet meant to keep a consistent weight, and a low-plane diet meant to mimic traditional winter feeding and reduce bulk weight (Gunn, 1964a). After one year all three groups began grazing on the same traditional diet and were treated similarly for the remainder of their life (Gunn, 1964b). Sheep fed high-plane fodder during the first year of growth had permanently increased skeletal size compared to the same breed that were fed low-plane, or even mid-plane, diet (Gunn, 1965). There was also a considerable correlation between diet and eruption, with high-plane nutrition attributed to early incisor eruption and low-plane nutrition correlated to delayed incisor eruption (Gunn, 1967b). This study did not examine the impacts of nutrition on molar eruption, but nutrition clearly impacted other aspects of development and likely also altered tooth development.

Season of birth could also impact tooth development. Traditionally, sheep born in the winter are exposed to high quality nutrition from their mother's milk, and a shorter period of lower quality winter reserves. M_3 begin forming after the first year of life and likely will not be impacted by the effects of weaning, but seasonal impacts on food availability may affect the rates

[45] Technical term used in animal feeding. According to Field *et al.* (1990, p.1616) a high-plane diet is 76% Total Digestible Units (TDN) and 12.3% crude protein, and a low-plane diet consists of 70.6% TDN and 16.1% crude protein. Essentially a low-plane diet is less digestible but has more protein when compared to a high-plane diet. Worley *et al.* (2016, p.865) states that their high-plane pasturage had improved grassland undersown with barley and perennial ryegrass with clover mix; their low-plane pasturage was on poorly drained native grassland.

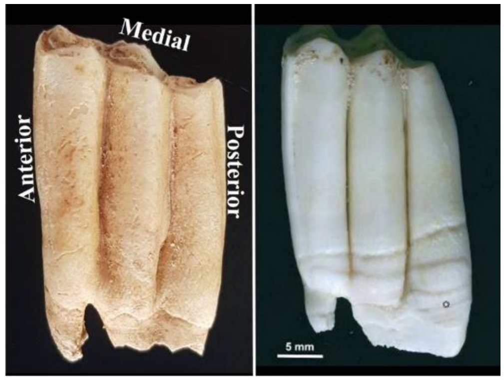

Figure 4.24 Comparison of healthy and unhealthy sheep M_3.
Left: A healthy left M_3 of a sheep from Kastro Kallithea (SG12). Labels indicate lobe positioning.
Right: Left M_3 of a sheep from the Orkney Islands (Kierdorf *et al.*, 2012). Tooth has evidence of multiple episodes of enamel hypoplasia near the root juncture and across all three lobes. Image from Kierdorf e*t al.*, 2012, p.495.

of amelogenesis if there are periods of significant food shortage (Frick and O'Neil, 1996; Gunn, 1964a). Similarly, transhumance involves movement to different food sources throughout the year and can involve changes in dietary quality. If the summer highlands have a low-plane diet compared to the winter lowlands, there could be impacts on M_3 development.

4.4.6 Stress

Some previously mentioned factors can cause physiological stress in animals. Extreme changes in diet, diseases, or other stressful episodes impact animal bodies and can alter growth and development. Upex and Dobney (2012) and Kierdorf *et al. (*2012) examine enamel hypoplasia in sheep and goat breeds that have undergone stressful episodes. Enamel hypoplasia occurs during periods of stress while the tooth is forming and denotes impaired secretion during amelogenesis (Fig. 4.24). Without proper secretion, the tooth forms improperly and this impaired secretion causes visible stress lines (Kierdorf *et al.,* 2012; Upex and Dobney, 2012). Kierdorf *et al. (*2012) also recorded irregular intervals for growth during stressful episodes, with amelogenesis taking longer under more extreme stress.

Another life factor that can cause stress for mother ovicaprids is birthing and lactation (Upex and Dobney, 2012). Similar to nutritional stresses in other studies, birthing and lactation can contribute to a prolonged period of amelogenesis and increased risk of hypoplastic defects like the ones indicated in Figure 4.24. In the Upex and Dobney (2012) study, ewes had their first lamb by 25 months of age, which falls within developmental period for M_3. If amelogenesis is prolonged because of birthing and weaning, ewe M_3 are at a greater risk of developing hypoplastic defects or taking longer to develop compared to male M_3. Because there is no evidence that the ovicaprids at Kastro Kallithea or Pharsalos experienced enamel hypoplasia, its potential effects on tooth formation are not further discussed in the dissertation.

4.5. Sequential Enamel Sampling

Ultimately it is likely that it took roughly two years for the M_3 of Kastro Kallithea and Pharsalos ovicaprids to fully develop. Over the course of those two years, sections of the M_3 formed, mineralized, and matured at different rates. Zazzo *et al.* (2012) found that varying enamel thickness on different portions of the tooth impacts amelogenesis timing, with thinner portions representing a shorter period of growth and thicker enamel representing a longer period of growth. As an example, a 1 mm band of thin enamel may correlate to a 1-month period of growth, whereas a 1 mm band of thick enamel may correlate to a 2 month period of growth that overlaps with other segments. Enamel thickness changes depending on the tooth surface or lobe; therefore the segment chosen for analysis dictates the period of time associated with the sequential measurement.

4.5.1 Sampling Location (lobe and surface)

Each ovicaprid M_3 includes three lobes that grow concurrently and are distinguished as anterior, medial, and posterior (Fig. 4.24). Kierdorf *et al.* (2012, p.492) explain that the enamel on a sheep's M_3 posterior lobe takes longer to form than that on the rest of the tooth. Figure 4.24 (right) illustrates the difference in enamel growth across the three lobes as shown by the path of the hypoplastic defect. If amelogenesis occurred at the same rate across all three lobes, you would expect to see a hypoplastic defect that was straight and parallel to the crown-root junction. Instead you see a defect forming at a sharp diagonal angle on the posterior lobe, and a shallower angle on the anterior lobe. One possible cause for this is that the buccal enamel on the posterior lobe is thicker than on the anterior lobe (Kierdorf *et al.*, 2012; Zazzo *et al.*, 2012).

Lobe surface also dictates how thick enamel is. There are four surfaces on an ovicaprid M_3: mesial (towards front midline), buccal (cheek), distal (towards back of mouth), and lingual (towards tongue) (Fig. 4.24). Zazzo *et al.* (2012) examined intra-individual variation in enamel thickness according to mesial, buccal, and lingual surfaces. They found that the mesial portion of

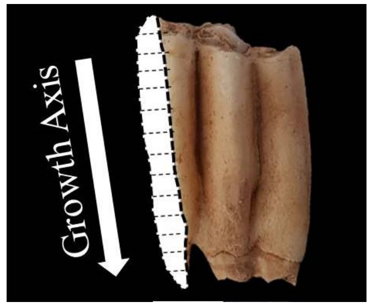

Figure 4.25 Left Sheep M_3 (SG12) with 1.5 mm incremental segments indicated on the mesial side of the anterior lobe perpendicular to the growth axis.

M_3 contained the thinnest portion of the inner enamel (Zazzo *et al.,* 2012), whereas the buccal surface contained the thickest enamel (Humphrey *et al.,* 2008). Considering lobe type and surface area, the mesial surface of the anterior lobe has the thinnest enamel (Zazzo *et al.*, 2012), whereas the buccal surface of the posterior lobe has the thickest enamel (Humphrey *et al.*, 2008; Kierdorf *et al.*, 2012).

4.5.2 Sample Amount (segment size)

Zazzo *et al.* (2010) recorded tooth growth rates in modern sheep using stable isotope analysis of dietary changes. As part of their study, sheep were fed a diet of C_3 plants followed by an isotopically distinct C_4 plant diet. Zazzo *et al.* (2010) was able to record the time it took for different body tissues (bones, teeth) or excrement (feces, exhaled CO_2) to isotopically record the new diet, which was correlated to rates of growth and dietary routing. Zazzo *et al.* (2010, p.3575) estimate that ovicaprid M_3 enamel generally grows at a rate of 115±10 μm/day, although in their study they recognize that enamel thickness and various life factors already discussed here will impact the rate of growth. Other studies have shown that the buccal side of enamel will record roughly 18 months of diet in 30 to 35 mm of enamel, with each 2 mm sample representing roughly two months of diet (Balasse *et al.,* 2013; 2017; Tornero *et al.*, 2013). It is expected that a similar sampling strategy using enamel on the mesial surface will sample slightly shorter time segments, with each ~1.5 mm band of enamel equating to roughly 1 to 1.5 months of diet during life (Zazzo *et al.*, 2010; 2012) (Fig. 4.25).

4.5.3 Checking Samples (Mature Enamel)

Recall that teeth grow incrementally along the growth axis, from the occlusal surface of the cusp towards the crown-root juncture (Fig. 4.25). Enamel that completes development erupts over the alveolar crypt, exposing the occlusal surface of the crown and completed portions of each lobe to the oral environment. Depending on the tooth's stage of development, unexposed portions of its enamel may not be fully mineralized. During analysis, if teeth are removed from the alveolar bone for sampling, an M_3 may include incompletely mineralized enamel. Enamel that has finished the maturation phases of amelogenesis has less porosity than teeth that are still mineralizing and maturing (Wang and Cerling, 1994). Porosity is an important consideration when sampling archaeological teeth as lower porosity reduces the opportunity for diagenesis and alteration of the biochemical structure of enamel in the burial environment (Wang and Cerling, 1994). Figure 4.24 (left) illustrates a M_3 that has fully mineralized enamel, as indicated by the consistent surface texture and colouring from the apex of the crown to the crown-root juncture. To reduce the chance for diagenetic alteration in my samples, only fully mineralized M_3 enamel was analyzed.

4.6. Method Limitations

Zooarchaeologists often face limitations when studying sheep and goat remains because of their similar skeletal structure, physiology, and growth patterns (Boessneck, 1969). Many of the studies discussed have created or utilized comparative reference collections that are species and breed-specific (Table 4.14). It is often difficult to find unimproved breeds for archaeological comparisons, so reference collections must be used with considerable judgement (Silver, 1969, p.300). There are no current reference studies that have analyzed dental development or skeletal maturation in sheep or goats from modern or ancient Greece, and other information related to the animals, including breed, sex, or quality of nutrition, are unavailable. There is limited information available about animal life cycles for Hellenistic Thessaly and what is known is based on White's (1970) summary of ancient Roman texts.

As a result, there are also limitations in matching the exact sequence of enamel sample to a specific time period in the animal's life (Zazzo *et al.*, 2005). Table 4.14 identifies factors that influence dental eruption and may also impact amelogenesis. My research does not rely on identifying an exact month of the animal's life. The relative period of one to two months is assigned to 1.5 mm enamel subsamples to give a broad indication of what period the sampled tissue *should* correlate to. One of the benefits of sampling mesial lobe enamel is that there is less opportunity for time averaging compared to buccal enamel. In analyzing strontium, oxygen, and carbon in conjunction within the *same* samples, I can identify patterns in diet and mobility across these relative time periods. Many of the life cycle parameters discussed within this analysis are currently only responsible for a delay in mineralization of one to three months, which may not significantly impact interpretations of the results. Despite any potential variation, crowns form over a period of at least one year, meaning that I will be able to record any seasonal changes in diet and mobility over that period.

4.7. Summary

This chapter presented an overview of my rationale for sample selection. After review of the available information, I concluded that 1.5 mm bands of mesial surface enamel from the anterior lobe of the third molar should develop over the course of roughly one to two months of life. Sequential samples of enamel can be isotopically analyzed to interpret dietary patterns across multiple months in a one to two year period. I also discussed how ovicaprid life factors may impact amelogenesis, which could influence how stable isotope values are interpreted.

CHAPTER 5: Stable Isotope Background

The primary aim of my study is to analyze modern and ancient shepherding practices, including what sheep and goats eat, where and how they move across a landscape, and how seasons and terrains impact management. This information has corresponding implications for ecology, economy, and community histories. Recording modern management practices can easily be accomplished through ethnographic observation and discussions with shepherds today (e.g., Hall, 2019). Examining animal management in antiquity is not as straightforward. Chapter 2 provided a background on agropastoralism in Thessaly during antiquity, including evidence from literary sources, material culture, and ecofacts. Although this modern evidence is invaluable for contextualizing our understanding of the past, it cannot be used to infer what specific shepherds were doing in different communities. This chapter introduces stable isotope analysis, a method that is capable of recording diet, mobility, and seasonal management in individual animals. I can take individual stable isotope values and use these to infer shepherding practices at the community and regional levels. Chapter 4 summarized sheep and goat dental development and indicated the utility of using sequentially sampled enamel segments to study animal life history. This chapter provides the theoretical background to explain how stable isotope analysis works and what it means to isotopically analyze body tissues like enamel (5.1). I briefly summarize how stable isotope analysis has been used to study animal management and review the isotopic landscapes in Thessaly specific to stable carbon (5.2), oxygen (5.3), and strontium (5.4) isotopes. In the final section (5.5) I summarize the isotope data collected from archaeological materials in Thessaly and surrounding areas to date. Previous data and interpretations are a necessary starting point for understanding my own data. In discussing the potential isoscapes in Thessaly, I provide the foundation for how I can use these methods to achieve my research goals.

5.1. Stable Isotope Analysis

5.1.1 Atomic/Isotope Basics

An atom of an element is defined by its number of protons, which determines its chemical properties. Isotopes of each element vary according to their number of neutrons. Although neutrons have no charge and so do not alter the atom's chemical properties, they do have mass, so each isotope will vary in mass according to the number of neutrons it has.

Carbon

Carbon's lighter isotope (^{12}C) has six neutrons and weighs less than the heavier isotope with seven neutrons (^{13}C) (Hoefs, 2009). The isotopic composition of a sample measures the ratio of different isotopes (e.g., $^{13}C/^{12}C$) that are present. In light elements such as carbon, the lighter isotopes are the most common and the heavier isotopes occur in minimal proportions (Schwarcz, 2000). In these isotopic systems, stable isotope abundances are expressed as differences (δ) per mil (‰) relative to the shared international standard recognized by the National Bureau of Standards **(1)**:

$$\delta = \left(\frac{R(sample) - R(standard)}{R\ (standard)}\right) \times 1000 \qquad \textbf{(1)}$$

The standard for $\delta^{13}C$ is Vienna Peedee Belemnite (VPDB), which is ^{13}C-enriched relative to most biological material (Hoefs, 2009). As a result, the $\delta^{13}C$ values of most organic substances are negative (O'Leary, 1981).

In my study I measure stable carbon isotope values to analyze animal diet. The $\delta^{13}C$ values of ovicaprid plant diets will vary according to the types of plant eaten, the portion that is consumed, and the growing conditions for each source (Ehleringer and Rundel, 1989; O'Leary 1981). Section 5.2 presents a summary of the expected stable carbon isotope variation in Thessaly and discusses what this means for $\delta^{13}C$ values measured on ovicaprid dental enamel.

Oxygen

Like carbon, oxygen is also considered a light element and stable content is expressed as $\delta^{18}O$ according to the process outlined above **(1)** using ^{18}O and ^{16}O (Ambrose and Norr, 1993; Schwarcz, 2000). There are different standards used to express $\delta^{18}O$, with the preferred standard varying according to what is being measured. As an example, drinking water $\delta^{18}O_{VSMOW}$ is reported using Vienna Standard Mean Oceanic Water (VSMOW), whereas carbonate $\delta^{18}O_{VPDB}$ values are often reported on the VPDB scale using the same standard as carbon (Pederzani and Britton, 2019). In this project I measure carbonate $\delta^{18}O_{VPDB}$ values, which will be referred to as $\delta^{18}O$ unless otherwise stated.

I use stable oxygen isotope values to reconstruct hydroscapes and their corresponding impact on seasonality and mobility. The $\delta^{18}O$ values of the food and water ovicaprids consume will mostly vary according to the season and location that they graze in (Daux *et al.*, 2005; Sponheimer and Lee-Thorp, 1999). Section 5.3 presents a summary of the oxygen isoscape in Thessaly and discusses expected trends in $\delta^{18}O$ data.

Strontium

Unlike carbon and oxygen, strontium is a heavier element. Strontium naturally occurs as three non-radiogenic stable isotopes, ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), and ^{88}Sr (~82.53%), and one radiogenic isotope, ^{87}Sr (~7.04%) (Bentley, 2006b). The natural abundances of the two isotopes of interest to this project (^{87}Sr and ^{86}Sr) are closer to each other than are the abundances of ^{13}C and ^{12}C or ^{18}O and ^{16}O and because of this $^{87}Sr/^{86}Sr$ values are expressed as simple proportions (Bentley, 2006a, 2006b). Isotopic variation of strontium ($^{87}Sr/^{86}Sr$) is used to trace geographical origin and movement of organisms. ^{87}Sr is produced by the decay of ^{87}Rb, with a half-life of 48.8 billion years, and ^{87}Sr itself does not undergo radioactive decay (Bentley, 2006b). Bedrocks include varying amounts of rubidium and strontium and have varying $^{87}Sr/^{86}Sr$ values that reflect their age and composition.

I use variation in $^{87}Sr/^{86}Sr$ to study movement between different geological regions. In section 5.4 I discuss the strontium isoscape of Thessaly and establish how I will use this isoscape data and ovicaprid enamel strontium isotope values in my study.

5.1.2 From Atoms to Enamel

In this project, $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values are measured on tooth mineral. Tooth mineral is composed of hydroxyapatite (or bioapatite: $[Ca_{10}(PO_4)_6(CO_3)_4(OH)_2]$), which is formed using atoms taken up from the environment (through breathing, eating, or drinking) during dental development. This short section describes the sources of enamel carbon, oxygen, and strontium atoms; details of isotopic patterning are discussed in the following sections.

Carbon

As an animal consumes and digests food, carbon from its diet passes into the blood plasma as dissolved CO_2 (Kellner and Schoeninger, 2007). Some of this carbon is integrated into bioapatite when it is precipitated from the blood plasma during dental formation and used as a building block for tooth formation and mineralization (Fernandes *et al.,* 2012, pp.297-298). Carbon atoms from the energy portion of the diet (carbohydrates, lipids, and proteins not used for protein synthesis) are represented in this enamel carbonate (Ambrose and Knorr, 1993; Kellner and Schoeninger, 2007, p.1112). Stable carbon isotope analysis of enamel carbonate can thus provide information on an organism's overall diet.

Oxygen

Oxygen isotope ratios can be measured from carbonate $(CO_3)^{-2}$ or phosphate $(PO_4)^{-3}$ ions of enamel bioapatite (Sjögren and Price, 2013). Carbonate $\delta^{18}O$ is used most often because smaller sample sizes are required for analysis and preparation is easier (Sjögren and Price, 2013, p.693). My analysis will also focus on $\delta^{18}O$ measured from enamel carbonate. Oxygen is incorporated into tooth enamel in a similar way to carbon. Oxygen atoms from water and food are incorporated into an animal's blood plasma and hydroxyapatite containing these atoms is precipitated from the blood plasma during enamel formation and mineralization (Daux *et al.,* 2005). The carbonate $\delta^{18}O$ value of tooth enamel bioapatite will therefore reflect the sources of meteoric water consumed directly (as drinking water) or indirectly (as food) during enamel formation. Minor physiological changes will also cause $\delta^{18}O$ differences between animals. As an example, animals that pant to cool themselves exhale $H_2{}^{16}O$ molecules more than sweating animals, who cool themselves through ^{18}O-enriched sweat, and as a result panting animals would have a higher $\delta^{18}O$ value (Sponheimer and Lee-Thorp, 1999).

Strontium

Strontium is a naturally occurring element in the biosphere because of its ability to substitute for calcium. Although strontium is not part of the unit formula of enamel bioapatite ($[Ca_{10}(PO_4)_6(CO_3)_4(OH)_2]$), it will become incorporated into enamel as a trace mineral (ranging from 50 to 500 ppm) (Bentley, 2006b; Ericson, 1985). Due to their similar ionic charges and masses, strontium (Sr^{2+}) often substitutes for calcium (Ca^{2+}) in minerals, including enamel phosphate (Bentley 2006b; Lewis *et al*., 2014; Smith, 1998). These substitutions are subject to biopurification: because vertebrate digestive systems discriminate against Sr^{2+}, strontium concentration relative to calcium (Sr/Ca) decreases with increasing trophic level (Burton and Wright, 1995). Sheep and goats take up strontium from their diet and this strontium enters the blood plasma. Strontium is then incorporated into the bioapatite that precipitates from the plasma and is used during enamel formation and mineralization (Ericson, 1985). Unlike carbon and oxygen, there is little fractionation in $^{87}Sr/^{86}Sr$ values from source (bedrock, ground water) through food webs (plants) and into dental tissues of herbivores (Flockhart *et al.,* 2015). Enamel strontium isotope ratios that differ from the value range typical of locally bioavailable strontium can be used as a tool for inferring geological origin or systematic movement across a landscape (e.g., Arnold *et al.,* 2013; Bentley and Knipper, 2005; Bentley, 2006a; Ericson, 1985).

5.1.3 Applications of Stable Isotope Research

The feasibility of studying stable isotopes from animal bone was first established in the late 1970s and involved basic dietary reconstructions using bulk bone collagen samples (e.g., Chisholm *et al.*, 1983; DeNiro and Epstein 1978; van der Merwe and Vogel, 1978; Vogel and van der Merwe 1977). Dietary isotope values from animal bone were initially used as examples of available diet and nutritional ecosystems as part of human studies (e.g., Chisholm *et al.*, 1982; Katzenberg, 1989; Schwarcz and Schoeninger, 1991). By the late 1990s, animal ecologists started using stable isotope analysis in lab and field experiments; isotope changes in living tissues (e.g., hair, feathers, blood, feces) were coordinated with observable changes in location and diet (e.g., Giannes *et al.*, 1997, 1998; Hobson, 1999). Soon thereafter, archaeologists began applying these modern animal-directed approaches to research questions of animal activities in the past. Instead of working with living tissues, archaeological studies soon included enamel from archaeological teeth (e.g., Dejmal *et al.*, 2014; Makarewicz, 2017; Szpak *et al.*, 2019; Yi *et al.*, 2018; see Makarewicz and Sealy, 2015 for review).

Teeth are a unique sample material, as their mineralization process creates an age-specific fingerprint of diet (Frick and O'Neil, 1996; Kohn *et al.*, 1996). A chronological record of dietary and environmental inputs during the period of tooth formation and mineralization is established based on variation in stable isotope values over a row of consecutive teeth (Balasse *et al.,* 2003; Kohn *et al.,* 1996; Tomczyk *et al.,* 2016) or within a single tooth (Balasse *et al.,* 2002; Frick and O'Neil, 1996; Mainland *et al.* 2016). Sequential samples from teeth have been used to analyze detailed time-scale studies of migration (Balasse *et al.* 2002; Britton e*t al.* 2009; Henton *et al.* 2012), birth seasonality (Balasse and Tresset 2007; Blaise & Balasse 2011; Tornero *et al.* 2013) and other animal management practices (Balasse *et al.* 2012a, 2013, 2015; Buchan *et al.* 2015).

The isotopic patterning of an element in any given circumstance depends on what is naturally occurring in the biosphere, and the processes acting on the land surface, atmosphere, hydrosphere, or ecosystem. These isotopic landscapes, or isoscapes, were initially established and used by modern ecologists studying animal migrations (e.g., Bowen, 2010; Bowen and West, 2008; Hobson *et al.* 2010). Archaeologists also adapted this approach by recording baseline isotope values from local modern environmental samples (e.g., plants, soils, or water) or archaeological samples from known contexts (e.g., non-mobile small-bodied fauna, archaeobotanical remains) (e.g., Dotsika *et al.*, 2010, 2019; Panagiotopoulou *et al.*, 2018; Price *et al.*, 2014). Using these samples as a range of probable local isotope values, archaeologists could study animals that were local to the isoscape (within the range) or non-local (outside of the range). As an example, Isaakidou *et al.* (2019) created an isoscape for Crete using isotope values from modern plants and previous data from snail shells (i.e., small-bodied, relatively non-mobile fauna). As part of the larger isoscape there were isotopically different zones, or isozones, that could be used to discuss movement between areas within the Crete isoscape. In the following sections I discuss isotope variability specific to the Thessalian isoscape to establish the possible isozones around Kastro Kallithea and Pharsalos.

5.2. Stable Carbon ($\delta^{13}C$) Isotopes in Living Systems

5.2.1 Carbon isotopes in flora

Stable carbon isotope ratios of plant tissues are dependent on the $\delta^{13}C$ value of available carbon (atmospheric CO_2, dissolved inorganic carbon in water) and the isotope fractionation events that occur during carbon fixation, including diffusion, dissolution, and hydration of CO_2, and the fixation reactions themselves (O'Leary, 1981). Three primary pathways of carbon fixation in plants (C_3, C_4, and CAM) vary in their use of CO_2, which results in different plant tissue $\delta^{13}C$ values. Most cultivars (e.g., wheat, fruits, vegetables) use the C_3 photosynthetic pathway and are referred to as C_3 plants. C_3 plants catalyze CO_2 during the day and the enzyme that regulates this process discriminates strongly against ^{13}C, giving C_3 plants a ^{13}C-depleted carbon isotope ratio ($\delta^{13}C$: -35‰ to -20‰) (Ehleringer and Rundel, 1989; O'Leary 1981). Some wild plants, mostly warm-climate grasses, as well as a few cultivars (e.g., millet, maize, sugarcane) use the C_4 photosynthetic pathway and are referred to as C_4 plants. C_4 plants catalyze CO_2 during the night and the enzyme that regulates this process does not heavily discriminate against ^{13}C, giving C_4 plants a comparatively ^{13}C-enriched isotope ratio ($\delta^{13}C$: -14‰ to -9‰) (Ehleringer and Rundel, 1989; O'Leary, 1981). Most succulents use the crassulacean acid metabolism (CAM) photosynthetic pathway and are referred to as CAM plants. CAM plants grow in harsh environments and use both photosynthetic processes as needed. CAM plant $\delta^{13}C$ values are highly variable (O'Leary, 1981) and will not be discussed in detail here because they are not relevant to the moderate climate in Thessaly.

In addition to plant type (C_3, C_4, CAM), plant tissue $\delta^{13}C$ values will vary due to the growing conditions (coastal vs. inland; open vs. canopy; altitude), season, type of plant (deep

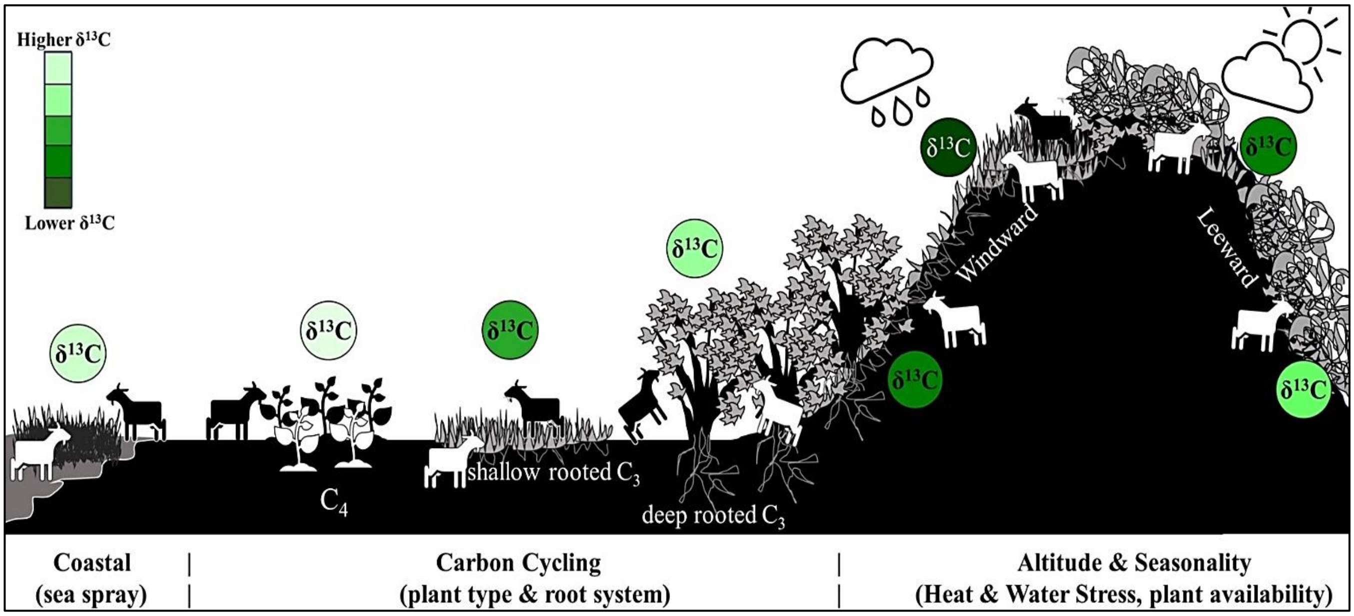

Figure 5.26 Isotope variation in plant tissue $\delta^{13}C$ changes according to growing conditions (e.g., proximity to the coast, root depth, elevation, and seasonality).

rooted tree vs. shallow rooted grass) and the portion of the plant in question (roots vs. leaves) (Fig. 5.26) (Ehleringer and Rundel, 1989; Froehle *et al.*, 2012; O'Leary 1981). As an example, aquatic plant $\delta^{13}C$ values depend on the photosynthetic pathway and the carbon substrate taken up (dissolved carbon dioxide or bicarbonate). Because of the more abundant dissolved inorganic carbonate in marine environments, plants growing in marine environments discriminate less against ^{13}C and as a result show ^{13}C-enrichment relative to land plants (Froehle *et al.*, 2012). Another example is the fact that C_3 plants grown in open conditions will have higher $\delta^{13}C$ values than those grown under a heavy canopy. This principle also impacts the $\delta^{13}C$ variation observed in leaves, stems, and shoots, as different portions of the plant have greater access to direct sunlight (Farquhar *et al.*, 1989; Smedley *et al.*, 1991). Heaton (1999, p.640) also explains that vegetation type and positioning within the canopy matters. Tall trees that compose the canopy itself will have $\delta^{13}C$ values that are roughly 3 to 4‰ higher than the shorter trees and leaves on longer branches can also have values up to 4‰ higher than short-branched vegetation. These examples show that multiple factors can impact plant tissue $\delta^{13}C$ values simultaneously. I elaborate more on examples if they are relevant to my thesis.

5.2.2 Carbon isotopes in fauna

The stable carbon isotope ratios of faunal body tissues like the dentine and enamel of teeth depend on the $\delta^{13}C$ values of ingested dietary items and on dietary routing, the patterned variation of carbon contributions from different dietary macronutrients (carbohydrates, protein, lipids) during tissue formation and remodelling (Ambrose and Knorr, 1993; DeNiro and Epstein, 1978; Fernandes *et al.,* 2012). The composition and physiology of a tissue influences how carbon isotopes will be taken up from the environment during its formation, which in turn will impact the $\delta^{13}C$ values of different tissues (Lai *et al.,* 2007).

In herbivores, the $\delta^{13}C$ values of dental enamel will reflect the plants consumed during tooth formation. Because of isotopic fractionation during energy metabolism, the relationship between diet and enamel $\delta^{13}C$ is not a simple 1:1 ratio (Farquhar *et al.*, 1989; Fernandes *et al.,* 2012). Digestive physiology will also impact the uptake of carbon and overall energy metabolism (Kellner and Schoeninger, 2007). Sheep and goats are ruminants, so energy from digested carbon comes from fermentation rather than direct consumption; ^{13}C-depleted methane gas is excreted during rumination, which leads to a relatively high $\delta^{13}C$ value for dental enamel compared to the $\delta^{13}C$ value of the diet (Kellner and Schoeninger, 2007, p1123). Controlled feeding experiments indicate that the $\delta^{13}C$ value of enamel will be elevated above that of dietary energy by up to +12‰ in ruminants (Lai *et al.* 2007). For example, if a plant has a $\delta^{13}C$ value of -26‰, a ruminant consuming it will have a dental enamel $\delta^{13}C$ value of -17‰ to -14‰ depending on how much they eat and for what period. Cerling (2009, p.460) explains that the $\delta^{13}C$ values for enamel from a pure C_3 diet can range from about -20‰ to -8‰ depending on the environment and associated growing conditions. In southern Greece, Vaiglova *et al.* (2020) found that the local range for C_3 diet was between -12‰ and -9‰ and anything higher than -9‰ indicated some C_4 admixture into the diet. As animals consume different foods between meals or over the course of multiple days, the $\delta^{13}C$ values of their dental enamel will represent an average of the diet consumed during that formation period.

5.2.3 Available Local Carbon in Thessaly

To record trends in stable carbon isotope values of ovicaprid dental enamel in Thessaly, I must first establish what flora grew in the region. Wild Greek flora are dominated by C_3 plants in most locales (Collins and Jones, 1986; Koukoura, 2007) and prior to the introduction of maize to Greece in the Ottoman era, millet was the only known C_4 domesticate (Andrews, 1993; Nitcsh *et*

Table 5.15 A sample of representative vegetation $\delta^{13}C$ values for Thessaly.[46]

Common Name	Scientific Name	$\delta^{13}C$ (‰, VPDB)
Kermes Oak	*Quercus* sp. (n=6)	-27.0 ± 0.25
Wheat	*Triticum dicoccum* (n=2)	-22.6, -23.9
Rye	*Secale cereal*	-22.8
Oat	*Avena sativa*	-27.2
Chickpea	*Cicer arietinum L.*	-23.8
Linen	*Linum* sp.	-26.4
Grass pea	*Lathyrus sativus L.*	-23.2
Lentil	*Lens culinaris*	-23.3
Mung bean	*Vigna radiate*	-19.3
Green bean	*Phaseolus vulgaris*	-24.4
Moss	Bryophyta (n=2)	-8.6, -10.6

al., 2017; Valamoti, 2016). Millet has been found in areas near Kastro Kallithea during ancient times (Megaloudi, 2006; Petroutsa and Manolis, 2010), so should be considered a potential item in local animals' diets. The influences illustrated in Figure 5.26 can also cause differences in dietary $\delta^{13}C$ in the Thessalian biosphere.

C_3 Plants

C_3 plants have a recorded $\delta^{13}C$ value range of -35‰ to -20‰, varying by species, plant part and growing conditions. Dotsika *et al.* (2019, pp.12-13) measured stable carbon isotope values of some modern plants in Thessaly, including those specific to my study region (Table 5.15). These modern values cannot be directly compared to archaeological $\delta^{13}C$ values. Because of industrialization and introduction of ^{13}C-depleted anthropogenic carbon dioxide (fossil fuels), modern values need to be corrected by +1.4‰ relative to archaeological values (Long *et al.*, 2005). The values in Table 5.15 have been adjusted to serve as direct comparisons for available flora in antiquity.

C_4 Plants

Millet is the only C_4 cultivar known to have grown in Thessaly during antiquity. Nitsch *et al.* (2017, p.54) report that the $\delta^{13}C$ values of millet from their Late Bronze Age Site in northern Greece range between -10.8‰ and -10.3‰. Wild C_4 plants occur in Greece today, but are a

[46] Values are based on modern samples from Dotsika *et al.* (2019, pp. 12-13), which have been adjusted (+1.4‰) for archaeological comparison (see text for explanation).

minority focused in certain arid ecosystems (Pyankov *et al.*, 2010, pp.291-292). They include some wild grasses (e.g., *Hyparrhenia hirta*) (Price *et al.,* 2017, p.117) and a number of other plants, including several in the Chenopodiaceae subfamily (Pyankov *et al.*, 2010, p.292). Many of these plants are halophytes (e.g., saltbush), which grow in saline coastal environments. Sheep and goat herds that were grazing in coastal areas may have had access to these wild C_4 plant sources, like the Neolithic herds studied by Vaiglova *et al.* (2018) for northern Greece. Mosses recovered from the northeast coast of Thessaly (sites at Pydna and Agathoupoli) also thrive in humid or coastal environments, and Dotsika *et al.* (2019, p.13) found their $\delta^{13}C$ values to range between -10‰ and -8‰ (Table 5.15). Mosses are unique organisms that have $\delta^{13}C$ values similar to C_4 plants (Dotsika *et al.*, 2019). Akeret and Jaacomet (1997, p.237) have observed sheep and goats consuming mosses and it is possible that they also consumed them in the past.

5.3. Stable Oxygen ($\delta^{18}O$) Isotopes in Environmental Systems

5.3.1 Oxygen isotopes in the environment

Stable oxygen isotope ($\delta^{18}O$) values of enamel are based on those of body water (Sponheimer and Lee-Thorp, 1999). Ovicaprids living in humid environments obtain most of their water directly from their diet, and their tissue stable isotope values are determined by geography, climate, seasonality, and meteoric water sources (Daux *et al.*, 2005; Sponheimer and Lee-Thorp, 1999). The stable oxygen isotope content of meteoric water sources ($\delta^{18}O_w$) varies regionally according to precipitation patterns, elevation, and relative humidity; fractionation generally decreases $\delta^{18}O_w$ values with distance from coasts and increasing altitudes because of seawater evaporation and condensation effects (Dotsika *et al.*, 2010; Kohn *et al.* 1996) (Fig. 5.27). Because of their mass differences, it takes less kinetic energy to evaporate molecules containing ^{16}O than those containing ^{18}O, and molecules containing ^{18}O will condense before those containing ^{16}O (Sjögren and Price, 2013). As a result, seasonal temperature changes also impact local $\delta^{18}O_w$ as evaporation during warm summer months tends to increase $\delta^{18}O_w$ values while cold winter climates lead to comparatively low $\delta^{18}O_w$ values (Fricke and O'Neil, 1996). In locations with deep water reservoirs, or aquifers, groundwater is not exposed to surface evaporation and condensation, and $\delta^{18}O_w$ values do not often change seasonally (Darling, 2004, p.748). The $\delta^{18}O_w$ of an aquifer also varies depending on location and what source feeds into it (e.g., mountain runoff, lake water) (Fig. 5.27) (Darling, 2004, pp.757-758).

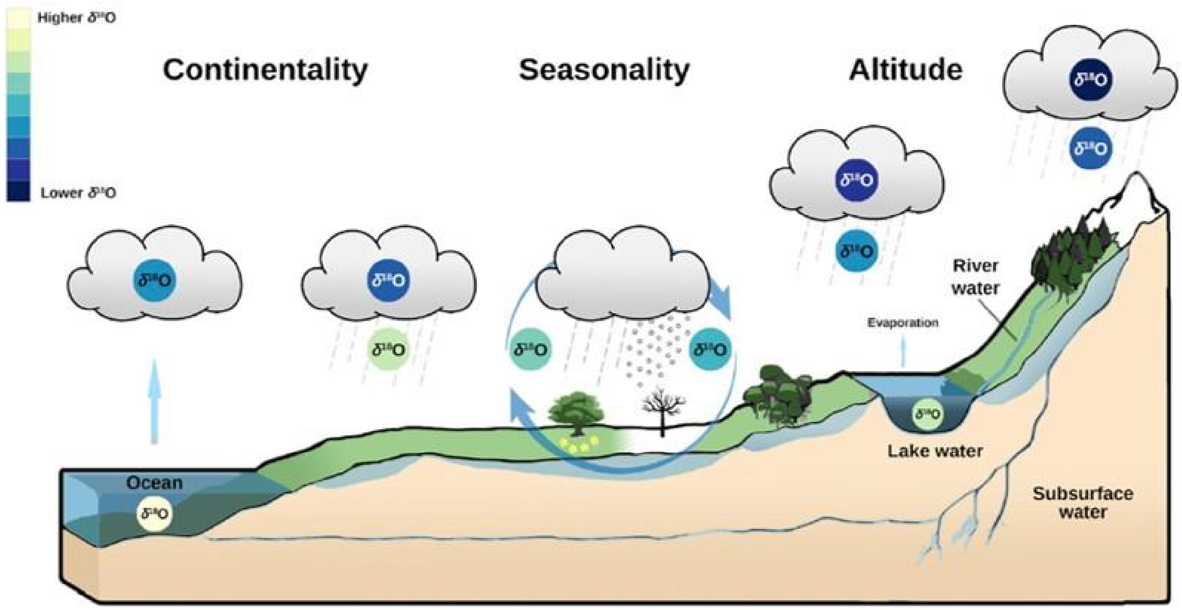

Figure 5.27 Factors influencing water $\delta^{18}O$ in the hydrosphere, including rain and evaporation processes according to the effects of continentality, seasonality, altitude, temperature, and rainfall (diagram from Pederzani and Britton, 2019, p.79).

As an example of how stable oxygen isotope values vary because of temperature and rainfall, Darling (2004) measured averaged $\delta^{18}O_w$ in different coastal sites of the Mediterranean during a 20- to 30-year period. Gibraltar (Spain) had a moderate climate and little precipitation (up to 100 mm during rainy months), which yielded a narrow seasonal fluctuation of average oxygen isotope values ($\delta^{18}O$: -3‰ to +2‰). In contrast, Antalya (Turkey) had more variable temperatures and more precipitation (up to 230 mm during the rainy months), which resulted in a wider seasonal fluctuation in average stable oxygen isotope values ($\delta^{18}O$: -4‰ to +4‰). Several other factors also impact water $\delta^{18}O$ values in any given hydrosphere (Figure 5.27).

Animals that obtain most of their water from their food will have $\delta^{18}O$ values dependent on meteoric water sources *and* these foods. Plants grown using groundwaters and surface soil waters will have $\delta^{18}O$ values that reflect rainfall and the effects of condensation and evaporation, whereas plants with deep root systems will have $\delta^{18}O$ values that reflect aquifers (Darling, 2004). As a result, grass-grazing herbivores have diets that are depleted in ^{18}O relative to herbivores that browse on tree leaf fodder (Sponheimer and Lee-Thorp, 1999, pp.724-726). Additionally, the roots and stems of plants reflect the $\delta^{18}O$ value of meteoric water, but leaf water will be comparably enriched in ^{18}O due to preferential evapotranspiration of the lighter isotope in the

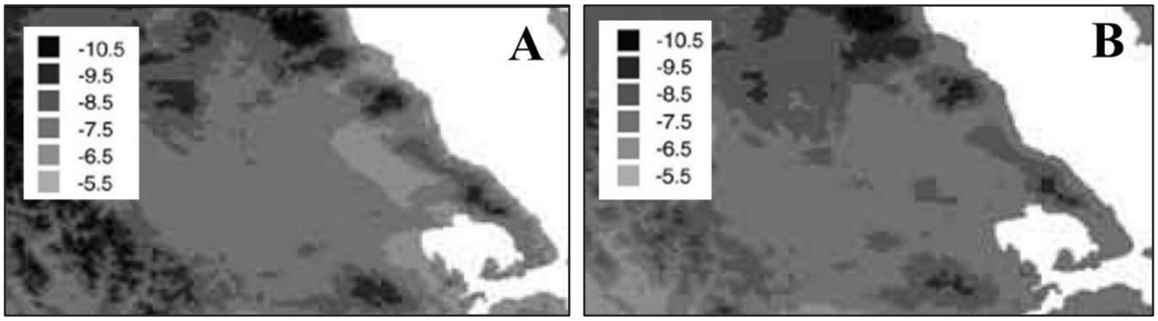

Figure 5.28 Spatial distribution of $\delta^{18}O$ in Thessaly according to precipitation (A) and spring water/groundwater (B). Adapted from Dotsika *et al.* (2010, p.147).

leaf (Sponheimer and Lee-Thorp, 1999, p.723). This can create $\delta^{18}O$ differences between the plant water consumed by herbivores that focus on roots and stems and the plant water consumed by animals that focus on leaves (Pederzani and Britton, 2019).

5.3.2 Oxygen isoscapes in Thessaly

The strong relationship between temperature, altitude, and other environmental influences on $\delta^{18}O$ are consistent enough to allow for predictive mapping of yearly averages. According to geographic, seasonal, and hydraulic factors, the range of modern meteoric water $\delta^{18}O$ in Greece fluctuates between -19.6‰ and +0.4‰ (Dotsika *et al.* 2010). Figure 5.28 illustrates the spatial distribution of $\delta^{18}O_{precipitation}$ (A) and $\delta^{18}O_{groundwater}$ (B) in Thessaly based predictive modeling and survey data of precipitation, spring, borehole, well, river, lake, and sea water (Dotsika *et al.*, 2010, p.147). In southeast Thessaly values vary between the eastern coast near Halos ($\delta^{18}O_{precipitation}$: -5.5‰, $\delta^{18}O_{groundwater}$: -6.5‰), the western plain near Pharsala ($\delta^{18}O_{precipitation}$ and $\delta^{18}O_{groundwater}$: -7.5‰), and the southern Óthrys Mountains ($\delta^{18}O_{precipitation}$: -10.5‰, $\delta^{18}O_{groundwater}$: -8.5 to -9.5‰) (Dotsika *et al.*, 2010, p.147). Based on weather data collected since the 1960s, the weighted monthly seasonal $\delta^{18}O$ values recorded at Thessaloniki (northern Thessaly) varied between a minimum value of -11‰ in the winter and a maximum value of -2.5‰ in the summer (Argiriou and Lykoudis, 2006, p.491). Other areas of Thessaly will vary in meteoric precipitation values according to geography, including altitude and distance from the coast (e.g., Bowen and Wilkinson, 2002; Darlin, 2004; Poage and Chamberlain, 2001). As an example, it is estimated that $\delta^{18}O$ will decrease by -0.25‰ per 100m increase in elevation in Thessaly (Dotsika *et al.*, 2010, p.145).

Table 5.16 Oxygen isotope values measured on spring water in Thessaly during the dry and cool season in 2018 (Dotsika *et al.*, 2018, p.238).

Source	Source Type	Location	Measured $\delta^{18}O$ (‰, VSMOW)
Kanalia	Spring	Karditsa	-8.3
Neo Monastiri	Spring	Karditsa	-8.2
Zografia	Spring	Karditsa	-7.7
Apostoli	Spring	Trikala	-8.0
Kotroni	Spring	Trikala	-8.3
Pyli	Spring	Trikala	-7.8

Dotsika *et al.* (2018) measured the $\delta^{18}O$ values of spring water sources throughout Greece during the dry (< 200 ppm) and cool (<25°C) season. Springs in western Thessaly are listed in Table 5.16, and their values range between -7.7‰ and -8.3‰. Karditsa and Trikala are located near the western border of Thessaly and their hydrology is impacted by the Pindus mountain range; springs that are fed by windward precipitation would have higher $\delta^{18}O$ near lower elevations than those on leeward sides at higher elevations. Based on altitude and proximity to the coast, the $\delta^{18}O$ values of available water sources in my study region (southeast Thessaly) are likely to be higher compared to the values recorded by Dotsika *et al.* (2018). As an example, Sparkes (2017) studied the carbon and oxygen isotope values from bulk human enamel samples (n=50) from a Hellenistic population at New Halos (see Section 5.5.5). The enamel $\delta^{18}O_{VSMOW}$ range for this population was between 23.1‰ and 27.4‰ and the $\delta^{18}O_{drinking\ water}$ range that would have produced these values was reconstructed to be between -11.94‰ and -5.04‰; when non-local individuals were removed, the local range of $\delta^{18}O_{drinking\ water}$ was likely between -8.5‰ and -5.5‰ (Sparkes, 2017, pp.136-138). These values are consistent with the spatial estimates outlined in Figure 5.28.

The values listed in Table 5.16 represent $\delta^{18}O_{drinking\ water}$ relative to the standard VSMOW (Vienna Standard Mean Ocean Water). The values that I will measure as part of my study are $\delta^{18}O_{carbonate}$ values, which will be expressed using the VPDB standard. There is an equation for converting $\delta^{18}O_{VPDB}$ to $\delta^{18}O_{VSMOW}$ that allows direct comparison of these values (**2**) (Chenery *et al.*, 2012). A second equation allows for the conversion of $\delta^{18}O_{VPDB}$ to an estimated $\delta^{18}O_{ingested\ water}$ value (**3**) (Henton *et al.,* 2010, p.435). This conversion equation is specific to domestic

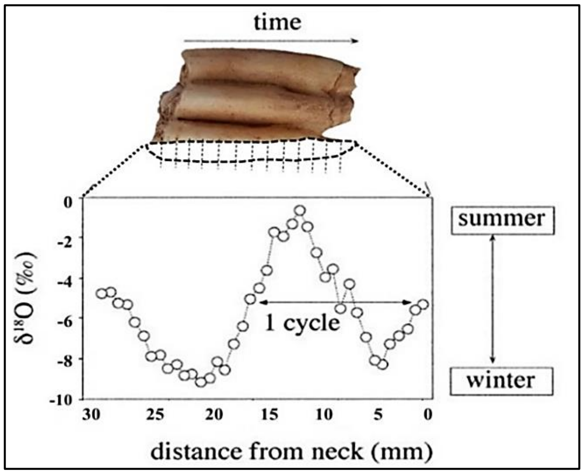

Figure 5.29 Visual depiction of a seasonal oxygen isotope signal ($\delta^{18}O$) in sequentially sampled M_3 enamel bioapatite. Seasons are indicated on the right. Adapted from Balasse *et al.* (2003, p.208).

sheep. As discussed below, these equations can be useful in showing movement between significant hydroscapes or directly comparing data from other studies (e.g., Sparkes, 2017).

$$\delta^{18}O_{VSMOW} = \delta^{18}O_{VPDB} \times 1.03086 + 30.86 \quad \textbf{(2)}$$

$$\delta^{18}O_{ingested\ water} = ((\delta^{18}O_{VPDB} \times 0.98) - 35.71) / 1.48 \quad \textbf{(3)}$$

5.3.2 Relevant Trends in Oxygen Isotope Fluctuation

Stable oxygen isotope analysis is often conducted on sequentially sampled enamel bioapatite because of the information it provides on seasonal trends in diet (Balasse *et al.*, 2002; Pederzani and Britton, 2019). Meteoric water $\delta^{18}O$ values fluctuate according to season, sometimes by up to 9‰ (Argiriou and Lykoudis, 2006). Figure 5.29 illustrates a seasonal oxygen isotope signal detected in sequential molar enamel samples on a sheep tooth. In this graphic the highest $\delta^{18}O$ value correlates to the peak of the summer (~ 12 mm along the crown), and the lowest $\delta^{18}O$ value correlates to the dead of winter (at ~22 mm and 5 mm along the crown) (Darling, 2004).

The variation of enamel $\delta^{18}O$ values in a tooth (the difference between maximum and minimum values, $\Delta^{18}O$) can also reveal movement between different hydroscapes (Pederzani and Britton, 2019). Sinusoidal peaks that appear more exaggerated (higher $\Delta^{18}O$) than expected or more dampened (low $\Delta^{18}O$) given local conditions can reflect the compounded effects of diet, seasonality, and movement on enamel $\delta^{18}O$. As an example, movement from a coastal location to an inland one, or from a lower to a higher elevation, will expose an animal to lower plant and drinking water $\delta^{18}O$ values relative to the original coastal or lowland location. If this movement occurs during a season in which local water and plant $\delta^{18}O$ is dropping (for example, moving inland or upland in the fall), the usual declining stable oxygen isotope trend associated with the fall will appear exaggerated and the $\Delta^{18}O$ will be high. Alternatively, keeping an animal in highland areas (lower local $\delta^{18}O$) during the warm and dry months and moving it to lowland areas (higher local $\delta^{18}O$) during the wet winter months will create a cancellation effect, with seasonal depletion or enrichment in $\Delta^{18}O$ counterbalanced by regional effects, and the yearly sinusoidal signal will appear dampened (low $\Delta^{18}O$).

5.4. Strontium ($^{87}Sr/^{86}Sr$) Isoscapes in Thessaly

5.4.1 Strontium isotopes in biospheres

Strontium naturally occurs in the environment because of weathering soil particles (Bentley, 2006b). Older bedrocks with large rubidium concentrations will have higher $^{87}Sr/^{86}Sr$ values (e.g., 0.740) compared to younger bedrock with small rubidium concentrations that will have much lower $^{87}Sr/^{86}Sr$ values (e.g., 0.7037) (Ericson, 1985, pp.505-506). Unmodified bedrocks of marine origin such as limestone reflect the seawater $^{87}Sr/^{86}Sr$ value at their time of formation (Burke *et al.,* 1982). Strontium isotope values in soils reflect known geochemical signatures that are specific to regional sediment (Bentley, 2006b), ground water sources (Burke, *et al.* 1982), or bedrock identity. Bedrock strontium signatures ($^{87}Sr/^{86}Sr$) do not necessarily directly equate to sediment strontium signatures because different rock types weather and release strontium at different rates (Ericson, 1985). If a region has a single bedrock source, soil $^{87}Sr/^{86}Sr$ will reflect that source and be homogeneous throughout the area. If there are multiple bedrock sources in a small area, or if the area is affected by higher winds (leading to more input of windblown dust), varied altitude (leading to downhill movement of sediments), and alluvial deposits (which may show different $^{87}Sr/^{86}Sr$ values reflecting their point of origin), soil $^{87}Sr/^{86}Sr$ can vary considerably between sites in close proximity (Bataille and Bowen, 2012, p.42; Bowen and West, 2008, p.84; Price *et al.*, 2002, p.20). Thus, although bedrock types and ages provide a general idea of soil $^{87}Sr/^{86}Sr$ values in an area, they do not predict them exactly.

From the soil, strontium moves into plants. Plants incorporate strontium into their root systems from the soil solution (Gupta *et al.*, 2008). The ultimate source of this bioavailable strontium varies depending on what is available in the soil and water at their root level (Bentley, 2006b). Plants with deeper root systems (e.g., trees) will have strontium isotope values that reflect bedrock sources, whereas plants with surface roots (e.g., grass) will incorporate strontium from surface soil and surface water sources. Plants that grow in coastal environments will incorporate strontium from seawater via sea spray, and in some settings precipitation is a significant strontium source (Bentley, 2006b).

From the plants, strontium moves into heterotrophs. Strontium passes from soil to plants to heterotrophs without $^{87}Sr/^{86}Sr$ fractionation, with the result that organisms within a region will share similar $^{87}Sr/^{86}Sr$ ratios (Bentley, 2006a, 2006b). This averaging effect means that plants tend to average out the individual $^{87}Sr/^{86}Sr$ values of soils and animals further average out individual $^{87}Sr/^{86}Sr$ values of plants, which leads to an overall decrease in variance from soils to plants to animals (Bentley, 2006b, pp.150, 155). This means that ovicaprids consuming plants within the same strontium isozone will therefore have the same range of $^{87}Sr/^{86}Sr$ values.

5.4.2 Strontium isoscape in Thessaly

Predicting the local $^{87}Sr/^{86}Sr$ isozone is often done through the culmination of data sources. Researchers often start by studying geological maps, as the composition and age of underlying bedrock can be used to infer probable $^{87}Sr/^{86}Sr$ values for a region (Burke *et al.*, 1982; Ericson, 1985). Next, the $^{87}Sr/^{86}Sr$ of local water and soil samples are tested to shed light on surface sediment $^{87}Sr/^{86}Sr$ and possible regional impacts of erosion, flooding, or irrigation on bedrock $^{87}Sr/^{86}Sr$ (e.g., Nafplioti, 2011; Voerkelius *et al.*, 2010). Finally, local plant and small heterotroph samples (e.g., snail shell, rodent teeth) are analyzed for $^{87}Sr/^{86}Sr$ to create a range of bioavailable $^{87}Sr/^{86}Sr$ for the isozone, which complements the geological map, water, and soil-based interpretations (e.g., Panagiotopoulou *et al.*, 2018). Heterotrophs that are non-mobile and local to an area are expected to consume plants grown in local sediments and have $^{87}Sr/^{86}Sr$ reflective of the local isozone.

Geological Map of Southeast Thessaly

The Institute of Geology and Subsurface Research in Greece has conducted survey of Greece, and my study region in southeast Thessaly is spread across the Domokos, Pharsalos, and Anavra maps (Fig. 5.30). I have stitched together all three sheets to study the geology around Pharsala, Kastro Kallithea, and surrounding regions. The maps include the relative sediment age of each geological zone, which can be used to predict strontium isotope patterning. For example, the

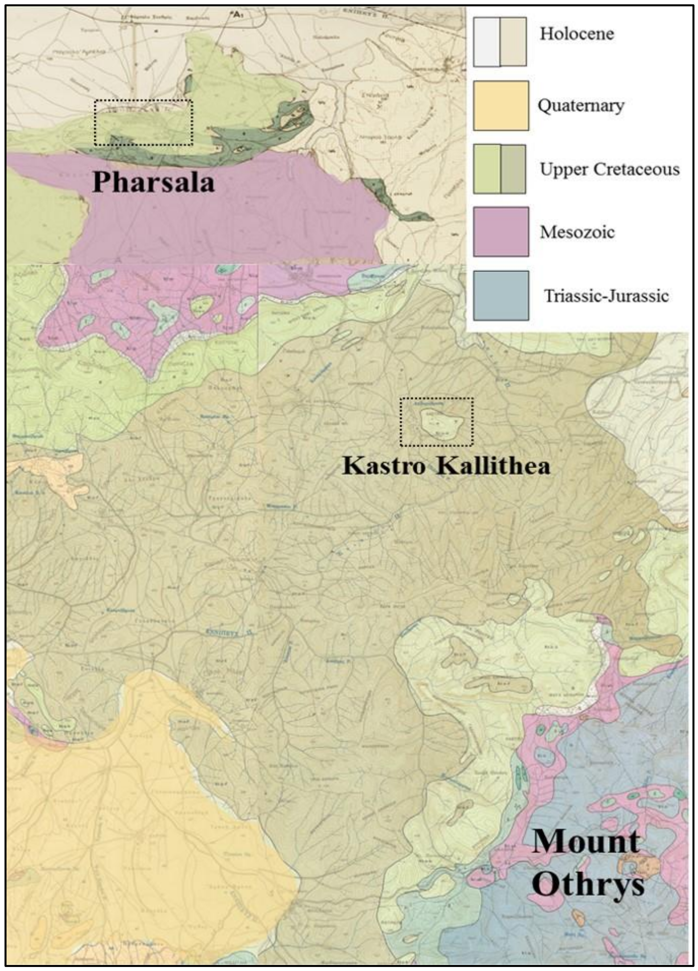

Figure 5.30 Geological map of study area. Maps are adapted from the Institute of Geology and Subsurface Research in Greece. Combines the Domokos, Pharsalos, and Anavra sheets; scale: 1:50,000.

sediment in parts of Mount Óthrys (labelled as Triassic-Jurassic) are older and are expected to have higher $^{87}Sr/^{86}Sr$ than those around Kastro Kallithea (labelled as Upper Cretaceous). Consulting geological maps and sediment ages is a good first step to understanding the geological variability in the area. It was the initial stage for other researchers who went on to conduct additional site-specific sample analysis to record the broad (Nafplioti, 2011; Voerkelius *et al.*, 2010) and more specific local (Panagiotopoulou *et al.*, 2018) strontium isoscape.

Mineral Water Estimates in Europe

After consulting local geological maps, Voerkelius *et al.* (2010) developed a predictive map for estimating local bioavailable $^{87}Sr/^{86}Sr$ values using the strontium isotope values of modern mineral water sources across Europe. Mineral water originates in mineral springs or groundwater, which accumulates strontium during dissolution and reprecipitation from minerals (Voerkelius *et al.*, 2010, p.934). Since plants take up strontium from the groundwater, a predictive model that uses ground water samples is a good guideline for refining regional isozones. Based on over 650 bottled water samples combined with predictive modelling based on geological maps of different regions, they were able to generate a set of estimated $^{87}Sr/^{86}Sr$ values for regions of different geological age across the continent (Voerkelius *et al.*, 2010, p.936). Testing the model using measured foodstuff $^{87}Sr/^{86}Sr$ confirmed that these estimates work well as initial predictors of bioavailable $^{87}Sr/^{86}Sr$ values. Whelton *et al.* (2018, p.771) measured $^{87}Sr/^{86}Sr$ values from faunal teeth and used the predictive modelling system of Voerkelius *et al.* (2010) as a guide for their analysis. Here I follow a similar approach to establish initial estimates for local $^{87}Sr/^{86}Sr$ ranges in Thessaly. The age-based estimates from Voerkelius *et al.* (2010) were correlated to the geological maps showing sediment types and ages in Thessaly (Fig. 5.30), which predicted that each area had the following ranges:

- Holocene: 0.70701-0.70900
- Quaternary: 0.70901-0.71100
- Upper Cretaceous: 0.70701-0.70900
- Mesozoic: 0.70701-0.70900
- Triassic-Jurassic: 0.70901-0.71100

These estimates are broad predictions and likely do not capture the local strontium isotope variation present in southeast Thessaly.

Broad Regional Estimates of Aegean/Greek $^{87}Sr/^{86}Sr$ Values

Nafplioti (2011) conducted the first study of regional bioavailable strontium $^{87}Sr/^{86}Sr$ variation specific to the Aegean. This study used 67 samples (archaeological and modern animal enamel, bone, and modern snail shells) from 21 Aegean sites combined with information from geological maps to establish general isotopic zones for the Aegean. These zones are illustrated in Figure 5.31; the figure capture includes the estimated $^{87}Sr/^{86}Sr$ value ranges for each zone. Most of Thessaly, including Kastro Kallithea and Pharsalos, lies within the Sub-Pelagonian zone. Although none of the samples (black circles) analyzed in Nafplioti's (2011) study were taken from Thessaly, the fact that Thessaly lies within this zone can be used as a starting point. It

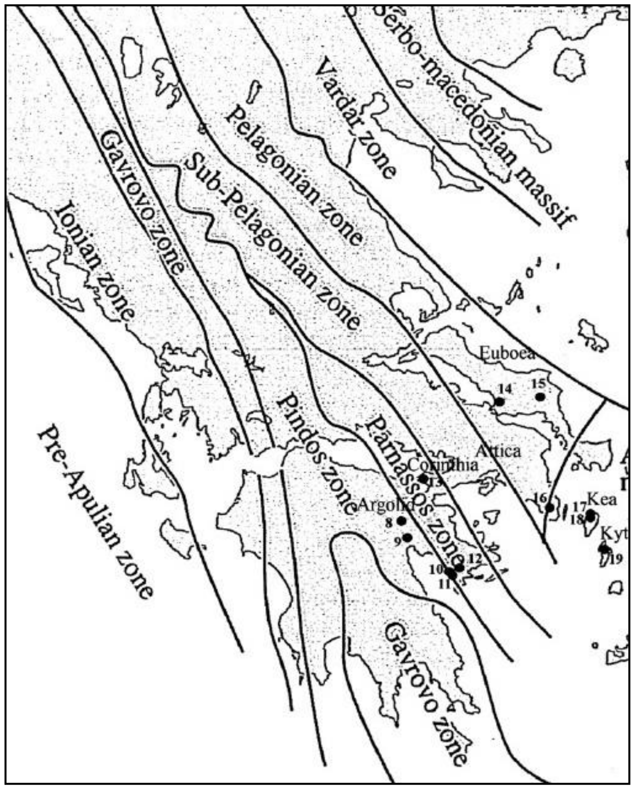

Figure 5.31 Map of the Aegean region showing separate geological regions or isotopic zones (according to Nafplioti 2011, p.1562). The associated strontium isotope ranges for zones in my research area are Pindos (0.70808-0.70869), Parnassos (0.70808-0.70869), Sub-Pelagonian (0.70808-0.70869), Pelagonian (0.70853-0.70931), and Vardar (0.70926-0.71187).

suggests that $^{87}Sr/^{86}Sr$ values around Kastro Kallithea and Pharsalos should generally fall in the 0.70808-0.70869 range. Although this range is narrower and fits within the predictive estimate for Kastro Kallithea discussed above (Voerkelius *et al.,* 2010), not all ranges overlap with the general Sub-Pelagonian zone estimate. Additional sampling is required to capture the local strontium isotope variation present in southeast Thessaly.

Modern Thessaly Snail Shell Values

Although the regional geology and water and surface sediment samples provide a good initial indication of the expected bioavailable $^{87}Sr/^{86}Sr$ values, plant and small heterotroph samples are precise and accurate measurements of biological available strontium (Sillen *et al.,* 1998, p.2466). Snail shell samples can provide a good indication of bioavailable strontium $^{87}Sr/^{86}Sr$, as shell mineral incorporates strontium directly from the snail's plant-based diet. Panagiotopoulou

Table 5.17 Strontium isotope values recorded from snail shell samples in Thessaly by Panagiotopoulou *et al.* (2018).

Site	Sample ID	$^{87}Sr/^{86}Sr$ value
Pharsala	FS03s	0.7084
	FS04s	0.7082
	FS11s	0.7088
Chloe	CH03s	0.7088
	CH09s	0.7089
	CH11s	0.7103
	CH12s	0.7095
Halos	HL01s	0.7078
	HL04s	0.7080
	HL14s	0.7088
	HL18s	0.7079

et al. (2018) collected modern snail shell samples from three different areas of southeast Thessaly to begin to establish regional variation in strontium across Thessaly (Table 5.17). Three snail shells were sampled from lowland areas north of the settlement at Pharsala and likely represent the modern $^{87}Sr/^{86}Sr$ range of bioavailable strontium for the archaeological site at Pharsalos. Four snail shells were sampled from three different geological zones in the region around Chloe (Fig. 5.32). Both samples collected from elevated areas (CH11s, CH12s) yielded higher $^{87}Sr/^{86}Sr$ values. Four samples were taken from around the archaeological site of Halos (Fig. 5.32). This site is situated along the coast, where bioavailable strontium isotope values may be influenced by modern seawater (0.7092). Interestingly, none of the Halos samples appear to be influenced by seawater and three of the samples (HL01s, HL04s, HL18s) fall outside of Nafplioti's (2011) estimate for the Pelagonian or Sub-Pelagonian zones (Fig. 5.31), which Halos overlaps. This illustrates the differences possible when moving from bedrock values to values of soils and then the organisms living on them.

Strontium Isoscape Summary

In summary, baseline strontium can vary in Thessaly according to sediment age (Voerkelius *et al.*, 2010), distance from the coast (Nafplioti, 2011), and elevation (Panagiotopoulou *et al.*, 2018). Although none of the current studies have examined the areas around Kastro Kallithea or the Óthrys Mountains, I can use these published data and estimated ranges as a predictive model

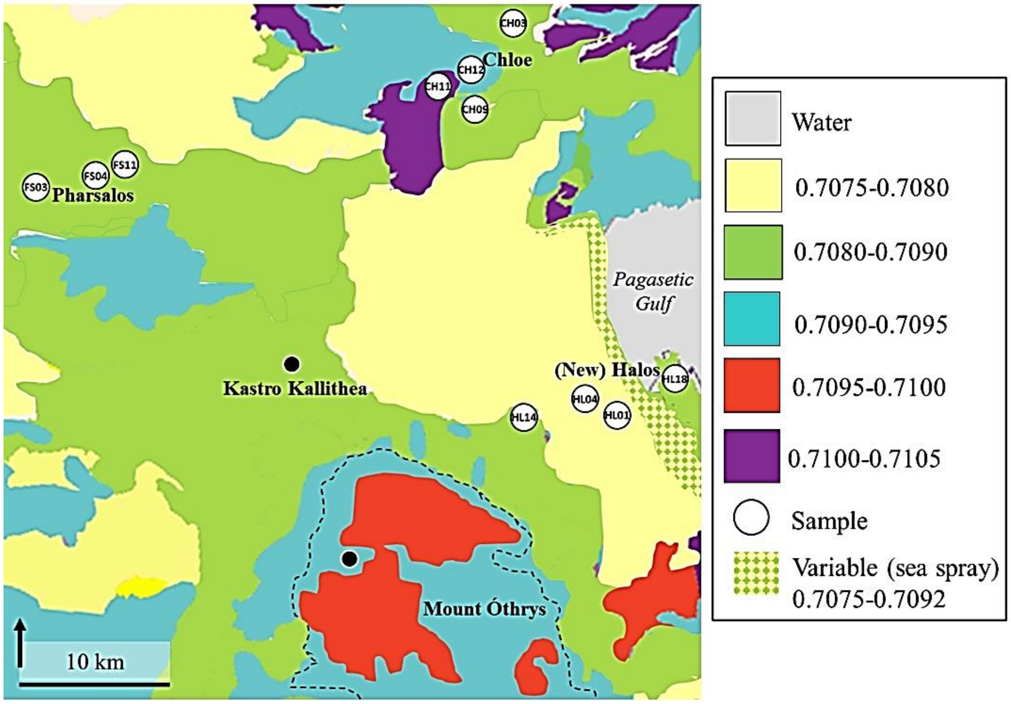

Figure 5.32 Predicted geological map of the study area. Estimated $^{87}Sr/^{86}Sr$ ranges are based on surface geology (1:1M), sediment age estimates, and materials sampled from other studies conducted in the area.

for the local isoscape in southeast Thessaly (Fig. 5.32). This map will be discussed more in Chapter 7 with the integration of sample data analyzed as part of my current study.

5.5. Stable isotope analysis of Thessalian archaeological material

There have been a few isotope analyses of archaeological materials in Thessaly to date. I use this section to briefly summarize that research and collate relevant comparisons for the data generated in the current study (Table 5.18).

5.5.1 Kastro Kallithea

Aiken (2019) examined pig diet and management by measuring collagen stable carbon and nitrogen isotope values from 30 Hellenistic era pig bones at Kastro Kallithea. For comparison she also determined the collagen $\delta^{13}C$ and $\delta^{15}N$ values of six sheep and goat bones, including three mandibles whose teeth were also sampled as part of my study (SG06, SG11, SG23). Isotope ranges and relevant data are listed in Table 5.18. In her study, Aiken (2019, p.121) concluded that pigs and ovicaprids both consumed mostly C_3 resources as part of a free-range foraging diet.

Table 5.18 Summary of relevant findings from archaeological isotope research in Thessaly. References and studies discussed in text.

Site	Applicable Findings
Kastro Kallithea	Pig $\delta^{13}C$: -21.3 to -18.5‰ and $\delta^{15}N$: 1.4 to 7.7‰ Ovicaprid $\delta^{13}C$: -20.9 to -17.8‰ and $\delta^{15}N$: 4.4 to 6.9‰
	SG06 collagen: $\delta^{13}C$: -20.3‰ and $\delta^{15}N$: 6.4‰ SG11 collagen: $\delta^{13}C$: -20.2‰ and $\delta^{15}N$: 6.3‰ SG23 collagen: $\delta^{13}C$: -20.1‰ and $\delta^{15}N$: 5.1‰
Pharsalos	Local Environmental Range: 0.7078-0.7090 Local Human values: 0.7080-0.7090 (n=6) Non-Local Human values: 0.7090-0.7094 (n=7)
Chloe	Local Environmental Range: 0.7086-0.7102 Human values: 0.7089-0.7092 (n=10)
Halos: Voulikaliva, Kephalosi	Local Environmental Range: 0.7078-0.7092 Human values: 0.7079-0.7092 (n=13)
	Herbivore collagen $\delta^{13}C$: -20.1 to -17.5‰ and $\delta^{15}N$: 2.6 to 8.3‰ Possible evidence of C_4 consumption by humans and fauna
New Halos	Local Human Range: 0.70808-0.70927
	Ovicaprid $^{87}Sr/^{86}Sr$: 0.71123
	Mostly C_3 sources; possible evidence of C_4 consumption

5.5.2 Pharsalos

Panagiotopoulou *et al.* (2018) investigated human population movements and mortuary patterns in southeast Thessaly in the Early Iron Age, including analysis of two separate burial grounds around Pharsala. Using $^{87}Sr/^{86}Sr$ values of molar dentine and enamel, Panagiotopoulou *et al.* (2018) examined mobility and the impact an individual's movement into a region had on their mortuary preferences. Their study also included a set of environmental samples (water and snail shells) analyzed to establish the $^{87}Sr/^{86}Sr$ values of local bioavailable strontium, which was the first of its kind in Thessaly. The results of the environmental analysis are discussed above. The humans buried around Pharsala were categorized as being either locally born (0.7080-0.7090) or of a non-local origin (0.7090-0.7094) according to the baseline of environmentally available strontium established from the environmental samples (Table 5.18).

5.5.3 Chloe

Iron Age people buried at Chloe were also included in the mobility and mortuary investigation by Panagiotopoulou *et al.* (2018). Chloe is one of the burial grounds of the ancient site of Pherae, and most of its mortuary traditions were found to be similar to those at Pharsala. The teeth of individuals buried at Chloe had $^{87}Sr/^{86}Sr$ values ranging between 0.7089 and 0.7094, with all individuals considered to fit within the local range (0.7086-0.7102) established by environmental samples. Panagiotopoulou *et al.* (2018, p.16) argue that this local population were all descended from the same community and followed the same traditional customs.

5.5.4 Halos

Panagiotopoulou *et al.* (2018) also analyzed individuals from the Voulikaliva cemetery at the site of Halos. The teeth of individuals buried here had a $^{87}Sr/^{86}Sr$ range between 0.7078 and 0.7092, with at least two broad groups identified. One group fits well within the range expected for a coastal town, as their $^{87}Sr/^{86}Sr$ values coincide with a range defined by modern seawater and the local limestone bedrock (0.7089 to 0.7092). The second group likely lived on, or consumed a diet derived from, the area slightly inland of the settlement whose bedrock was dominated by sedimentary rocks with slightly lower $^{87}Sr/^{86}Sr$ values.

In an earlier study, Panagiotopoulou *et al.* (2016) measured $\delta^{13}C$ and $\delta^{15}N$ values of herbivore (ovicaprid, equine, cattle) collagen samples recovered from Voulikaliva and the nearby site of Kephalosi (Table 5.18). These animal values were determined as part of an analysis of human diet and available local resources. Some of the herbivores had unusually high $\delta^{15}N$ values, which were explained as examples of animals nursing or grazing in a manured area. Some human samples from the Voulikaliva cemetery show collagen $\delta^{13}C$ values above -18‰, which Panagiotopoulou *et al.* (2016, p.218) argue indicates some C_4 plant (millet) consumption. One cow also yielded a $\delta^{13}C$ value within this range, which may coincide with supplemental millet foddering, salt marsh grazing (e.g., halophytes), or access to mosses.

5.5.5 New Halos

Sparkes (2017) analyzed the isotopic profiles of individuals recovered from a Hellenistic cemetery at New Halos (Fig. 5.32). Her study included human and faunal samples, which were analyzed for carbon, nitrogen, oxygen, and strontium isotope values. Based on the stable carbon and nitrogen isotope values, individuals at New Halos had access to non-homogenous resources. Although the human $\delta^{13}C$ values indicate a diet dominated by C_3 plant sources (grains, olive oil, wine), two individuals likely consumed some C_4 plants (e.g., millet) (Sparkes, 2017, p.195). New Halos was inhabited during the same period that parts of Pharsalos and Kastro Kallithea were occupied, so the dietary interpretations made by Sparkes (2017) are likely relevant to human diets at my sites.

Mobility was also assessed using oxygen and strontium isotope analysis of human enamel. The local range of $^{87}Sr/^{86}Sr$ at New Halos was determined to be between 0.70808 and 0.70927 based on local geology and internal patterning of the human $^{87}Sr/^{86}Sr$ values, a range that is consistent with the local range established by Panagiotopoulou *et al.* (2018). The entire set of human values (including outliers) ranged between 0.7075 and 0.7110 (Sparkes, 2017, pp.142, 144). Strontium isotope analysis revealed individuals who had immigrated to the region during different stages of life, and Sparkes (2017) demonstrated by comparing $^{87}Sr/^{86}Sr$ to dietary isotopes that non-locals had different diets once they moved to New Halos. This may signify regional affinities for different foods, changing consumption patterns, or changing food access once the individual moved into the region. A $^{87}Sr/^{86}Sr$ value was obtained for one ovicaprid sample (0.71123), which was not consistent with the local geology or any of the human values (Sparkes, 2017, p.180). This ovicaprid likely came to be at New Halos because of mobile pastoralism or trade from other regions.

5.5.6 Other studies in Greece

Other researchers have used stable isotope analysis of archaeological remains to explore aspects of diet in Greece in the past. In the sections below I briefly summarize the broad findings that are relevant to my research and that will provide a contextual backdrop for interpreting the faunal data recorded as part of my study (Table 5.19).

Northern Greece (Macedonia)

Various studies have examined human diet in Northern Greece between the Neolithic and Byzantine periods. Although studies focus on carbon and nitrogen isotope data from human bones, most also report some data for available fauna in the area. Triantaphyllou (2015) included the stable carbon and nitrogen isotope analysis of Neolithic and Bronze Age fauna from the western Macedonian site of Xeropigado Koiladas; they showed that sheep (-18.3 ± 0.7‰) and cattle (-16.9 ± 1.7‰) had higher $\delta^{13}C$ values than those of pigs (-20.4 ± 0.4‰) and wild deer (-21.7 ± 0.4‰). Triantaphyllou (2015) argue that the ^{13}C-enrichment of sheep and cattle diet was due to preferential access to C_4 plants (millet or certain wild grasses) for domestic herbivores. Vaiglova *et al.* (2018, p.19) also found higher $\delta^{13}C$ values for their Neolithic cattle from

Table 5.19 Summary of relevant findings from archaeological isotope research in Greece. References and studies discussed in text.

Site	Applicable Findings
Northern Greece (Macedonia)	Diet is predominantly C_3 plants with possible evidence of millet (C_4) or halophyte consumption
Central Greece	Diet is purely of C_3 plants
Peloponnese	Diet is purely of C_3 plants
	Sheep $\delta^{13}C$: -13.7 to -9.0‰; $\delta^{18}O$: -5.3 to 1.2‰ Goat $\delta^{13}C$: -13.3 to -11.4‰; $\delta^{18}O$: -4.0 to 2.2‰
	Evidence of animals with seasonal and monotonous diets
Crete	Diet is purely of C_3 plant sources
	Sheep $\delta^{13}C$: -12.9 to -9.5‰; $\delta^{18}O$: -4.0 to -0.6‰ Goat $\delta^{13}C$: -12.1 to -10.3‰; $\delta^{18}O$: -5.2 to 2.1‰
	Evidence of animals with seasonal, opposing seasonal, and monotonous diets

Makriyalos than from other fauna, but in contrast argue that the animals had diets that were ^{13}C-enriched relative to other domesticated herbivores because of grazing in coastal wetland pasture with wild C_4 plants (halophytes). Nitsch *et al.* (2017) measured stable carbon and nitrogen isotope values for various plant and animal remains recovered at the Bronze Age sites of Archontiko and Thessaloniki Toumba and established that while C_3 plants dominated animal diets, C_4 and halophytic plants were also available and used as animal fodder in northern Greece. Combining the results of the three studies we see that although there were some instances of access to C_4 plants, all animal diets recorded in northern Greece appeared to have been composed of predominantly C_3 plant sources.

Central Greece

In contrast to these results, Papathanasiou *et al.* (2013, p.2932) and Vika *et al.* (2009) found a narrow range of $\delta^{13}C$ values consistent with C_3 resource consumption from human and animal samples in central Greece. Papathanasiou *et al.* (2013) examined fauna from the Early Iron Age site of Agios Dimitrios and Vika *et al.* (2009) analyzed Classical era fauna from the site of Thebes. Their results suggest that millet was not a common source of food for humans and animals in Central Greece during the Early Iron Age or Classical eras. Since millet is found in botanical assemblages from the Neolithic era onwards (see Megaloudi, 2007), it is likely that for both Agios Dimitrios and Thebes, the local economic preference was not to consume millet or use it as a fodder source.

Peloponnese

Vaiglova *et al.* (2014, 2020) measured stable carbon and nitrogen isotope values for archaeological samples of plant and animals from the Neolithic site of Kouphovouno in the Peloponnese. In their 2014 analysis, herbivore collagen $\delta^{13}C$ values mostly clustered into C_3 plant-based dietary patterns, with no apparent differences in management. Their 2020 analysis included carbon and oxygen isotope values measured on sequential tooth enamel segments from ovicaprids, which found some ovicaprids with seasonal differences in diet and others with a dampened or monotonous diet (Vaiglova *et al.*, 2020, p.12). Animals categorized as having a seasonal dietary signal were explained as consuming fresh vegetation (grazing) year-round, with enamel values reflecting seasonal fluctuations in moisture and temperature (Vaiglova *et al.*, 2020, p.13). Alternatively, monotonous $\delta^{13}C$ values were attributed to animals being fed harvested resources (i.e., grain or crop stubble) year-round (Vaiglova *et al.*, 2020, p.14). The range of recorded sheep and goat carbon and oxygen isotope values from that study are listed in Table 5.19 (Vaiglova *et al.*, 2020, p.12).

Crete

Isaakidou *et al.* (2019) investigated sheep and goat herding in the Mycenaean (Late Bronze Age) polity of Knossos in Crete using the same approach that I use for my current study in Thessaly. Plant samples and geological age estimates were used to established local bioavailable strontium $^{87}Sr/^{86}Sr$ values on Crete ranging from 0.7089 to 0.7094, oxygen isotope data were used to infer seasonal patterns in diet, and carbon isotope data were used to interpret the vegetation component of the diet. Based on the nine individuals analyzed, oxygen isotope values always yielded a seasonal sinusoidal trend. Strontium isotope data suggested animals might be grazed locally and non locally at varied locales throughout the year(s) recorded by the enamel. Their study presents the first sequential analysis of isotopes recorded from ovicaprid molar enamel in Greece, and the findings were applied to questions concerning animal husbandry from Mycenean Crete. Because of the similarity in research, the specific results and interpretations from Isaakidou *et al.* (2019) are invaluable to the interpretation and discussion of my own data.

5.6. Summary

This chapter has presented the theoretical background for stable isotope analysis. It provided the foundation for how I can reconstruct aspects of ovicaprid diet using stable isotope analysis of carbon, oxygen, and strontium isotopes in conjunction. I can establish locally available isotope values based on modern trends in geology, climate, and ecology. I can use the studies outlined in this chapter as a baseline of comparison for any recorded values as part of my own study. According to the recorded trends in ovicaprid dental enamel I can interpret what animals were eating ($\delta^{13}C$), where ($^{87}Sr/^{86}Sr$), and during what season ($\delta^{18}O$).

CHAPTER 6: Materials and Methods

In my study I analyzed faunal materials recovered from one domestic dwelling at Kastro Kallithea (Building 10) and two domestic contexts from the site at Pharsalos (Alexopoulos and Arsenopoulos plots). Chapter 3 presented an overview of the known archaeological history of all three contexts and reported that sheep and goats were the most common domestic animals recovered. To provide insights on how animals were managed in antiquity, I selected sheep and goat third molars (M_3) from all three contexts. Enamel from the teeth were sequentially sampled and the resulting enamel subsections were analysed to produce data reflecting the animals' diet ($\delta^{13}C$), seasonality ($\delta^{18}O$), and mobility ($^{87}Sr/^{86}Sr$). These data provide insight into animal management, including instances of seasonal mobility or sedentary habitation. This chapter presents an overview of the methods used for my analysis, including (6.1) how and why samples were selected; (6.2) how samples were prepared for analysis; (6.3) carbonate isotope analysis; and (6.4) strontium isotope analysis. In section 6.5 I summarize issues with sample pretreatment and present a pilot study that was created after initial data publication (Bishop *et al.*, 2020). This chapter also sets the foundation for how all data are interpreted.

6.1 Site and Sample Selection

6.1.1 Research Area

When Reinder Reinders surveyed the Óthrys mountain range, Almiros-Sourpi plains, and areas surrounding the Pagasetic Gulf in the 1980s, he was certain that the landscape used by modern shepherds was used in a similar way in antiquity (Reinders and Prummel, 1998). The shepherds working in this region will tell you that they descend from ancient shepherds who knew how to use the mountain and plain regions to manage their animals (e.g. Campbell, 1964; Hoeg, 1925; Kavadias, 1965; Perucho, 2017). In chapters 2 and 3 I outline the literary and archaeological evidence that supports this history. Local ecology is well-suited for ovicaprid grazing, the streams and other water sources allow large herds to be sustained, and the semi-mountainous and lowland terrains accommodate seasonal movement to different pasturelands. If the southeast portion of Thessaly is suitable for large-scale animal management today, it is reasonable to believe that material remains recovered from sites in this region are a good model to indicate how animals were managed during Hellenistic times.

6.1.2 Site Selection

Kastro Kallithea and Pharsalos were chosen for sample collection because they both contain sufficient faunal assemblages available for my analysis (Chapter 3), archaeological investigation had already established major aspects of site history (Chapter 3), and material evidence suggested that both locations were involved in an animal-based economy (Chapters 2 and 3).

Kastro Kallithea – Building 10

Excavations, urban survey, and analysis have been ongoing at Kastro Kallithea since 2004 (Haagsma *et al.*, 2011, 2015a, 2015b, 2019; Surtees *et al.*, 2014; Tziafalias *et al.*, 2006, 2009), although the first topographical survey of the area was carried out in the first quarter of the 20th c. (Stählin, 1967). The two major occupation stages of the settlement include Phase 1, dating to the end of the fourth until the later 3rd c. BCE, and Phase 2, dating to the second century BCE (Haagsma *et al.,* 2011, 2015a, 2015b). Recent analyses focused on the domestic structure named Building 10, which has evidence of occupation during both phases and a different associated architectural configuration and use during each phase (Haagsma *et al.* 2011, 2015a, 2015b, 2019) (recall Fig. 3.18, 3.19; Fig. 6.34). Large assemblages of faunal material have been collected from both phases of occupation, with the majority of remains dating to the second phase. Building 10 represents a moderate to elaborate two-storey dwelling with evidence of food storage, weaving, religious worship, and food consumption. Faunal materials recovered from contexts in Building 10 (recall Table 3.12) originated from primary deposits during the first phase of occupation that likely resulted from food consumption, storage, or preparation, which are good resources for me to better understand animal management at Kastro Kallithea.

Pharsalos – Arsenopoulos Plot

The Arsenopoulos Plot was uncovered as part of rescue excavations in Pharsala during the 1990s (Karapanou, 2008), and includes a large Hellenistic building with over 12 rooms (recall Fig. 3.15; Fig. 6.35) (Karapanou, 2008). Based on recovered materials and architecture, the Arsenopoulos Plot consisted of a large and prestigious household dating to the late 3rd to mid-2nd c. BCE (Karapanou, *personal communication* 2018). Among the prestigious material remains were high value coin hoards, exotic goods, a shrine with marble, clay, and stone statues, and other religious items (Karapanou, 2008). One courtyard is attached to a large room with a hearth assumed to have been used for food consumption, with another potential kitchen directly adjacent to it. Faunal materials recovered from contexts at the Arsenopoulos Plot (recall Table 3.9) originated from primary deposits during the Hellenistic phase of occupation that likely resulted from food consumption, storage, or preparation. Materials sampled from this assemblage will serve as an example of animals consumed at or managed for an elaborate domestic context at the site of Pharsalos.

Pharsalos – Alexopoulos Plot

The Alexopoulos Plot was uncovered as part of rescue excavations in Pharsala during the 1990s and contains the remains of a private Hellenistic-era home (Karapanou, 1996) (recall Fig. 3.14; Fig. 6.36) (Karapanou, 1996). A block with six round stone protrusions was recovered from the sanctuary, which has similarities to enigmatic remains recovered at Kastro Kallithea, including four that were located in or near the courtyard of Building 10 (Karapanou, 1996; Haagsma *et al.*, 2019). It is believed that these items represent a form of regional household cult (Haagsma and Karapanou, *forthcoming*). Other more standard household items were also recovered from this homestead, including broken vases, *pithoi*, amphorae, plates, and figurines, among other things. Based on the recovered material goods and observable architecture, the Alexopoulos Plot likely contained a household of moderate means.

Another section of the Alexopoulos Plot contains two adjacent rooms of an earlier (Classical period) context (Units A and B), possibly indicating multiple use and reuses of this dwelling over time (Karapanou, 1996). Faunal materials collected from contexts at the Alexopoulos Plot (Table 3.8) originated from a primary deposit during the first (Classical) period of occupation and deposits from the second (Hellenistic) phase of occupation that likely resulted from food consumption, storage, or preparation. Remains sampled from these contexts will provide additional examples of animals consumed at or managed for domestic contexts in Pharsalos.

6.1.3 Ovicaprid Sample Selection

Sheep and goats (ovicaprids) are the model animal to use in my study, as ovicaprids were the most likely animal to have been managed in southeast Thessaly during the Hellenistic period. My position is based on (1) the breadth of ovicaprid remains recovered from the selected study sites, (2) the assortment of material remains related to ovicaprid by-product production also found at these sites (e.g. loom weights, weight moulds, spindle whorls, spools, cheese strainers), and (3) personal observation and ethnographic evidence indicating the prevalence of sheep and

Figure 6.33 Goat mandible (SG23)
(Left) Full mandible; **(right)** removed right third molar (RM$_3$), showing the direction of growth from the occlusal surface of the cusp, or youngest part of the tooth, to the roots, or oldest part of the tooth (recall Chapter 4).

goat herders in Thessaly today. For these reasons, I sampled sheep and goat teeth for stable isotope analysis.

I reviewed all faunal materials recovered from Building 10, the Arsenopoulos Plot, and the Alexopoulos Plot during the 2016, 2017, and 2018 field seasons (Chapter 3). The assemblages included sufficient sheep and goat dental materials from secured contexts (Appendices 6.4-6.6). Context security was based on intact archaeological layers that were not contaminated by soils or materials from other temporal contexts. They relate to primary deposits reflecting periods of consumption or food preparation (e.g., discarded as refuse at or below the floor layer), and/or food storage (e.g., found around or within *pithoi*). Archaeological dating of all contexts is based on ceramic typology, coin chronology, and radiocarbon dates (Kastro Kallithea only). I also confirmed context security of each sampled tooth with a site director: Margriet Haagsma (Building 10) or Sophia Karapanou (Alexopoulos Plot, Arsenopoulos Plot).

The third mandibular molar (M$_3$) (Fig. 6.33, right) was selected as the preferred tooth for stable isotope analysis for two reasons. First, sheep and goat M$_3$ are easily identifiable from other disarticulated teeth (M$^{1-3}$, M$_{1-2}$). If I only sample M$_3$, which I can attribute to a single individual, I can prevent sampling the same individual multiple times, which would lead to data overrepresentation. Second, by sampling M$_3$, I can easily compare my findings to those of other published studies, many of which also chose to sample M$_3$ (e.g. Balasse *et al.*, 2017; Tornero *et al.*, 2016a; Zazzo *et al.*, 2012).

Although there is some disagreement over the exact start and end ages, it is agreed that ovicaprid third molars form, erupt, and fully mineralize over a maximum period of two years (Bullock and Rackham, 1985; Payne, 1987; Silver, 1969). Chapter 4 presents an overview of the growth pattern for ovicaprid M_3 and indicates that the rate of growth will vary in time according to breed, diet, seasonality, and enamel thickness (e.g., Passey and Cerling, 2002; Suga, 1982; Zazzo *et al.* 2005, 2010, 2012). For my analysis I chose to sample the mesial side of the anterior lobe of M_3, as it represents the thinnest portion of ovicaprid molar enamel (and thus the optimal time resolution). Based on the estimations made by Zazzo *et al.* (2005, 2010), and the results provided by Balasse *et al.* (2013, 2017) and Tornero *et al.* (2013), roughly 1.5 to 2.0 mm bands of perpendicular mesial side ovicaprid M_3 enamel equate to roughly one month of diet during life (recall Chapter 4). Figure 6.33 (right) illustrates an archaeological goat M_3 with the direction of enamel development from earliest forming (top/occlusal) to latest forming (bottom/apical) portions of the lobe. Although M_3 develop over a period of two years, tooth wear reduces the amount of observable enamel by removing it from the occlusal aspect of the crown. As an example, biochemical analysis of the M_3 depicted in Figure 6.33 only documents a period of approximately 12 to 18 months of life based on the remaining crown height (26.0 mm).

Kastro Kallithea – Building 10

Project zooarchaeologist Michael MacKinnon finished his complete analysis and inventory of the early and later phases of Building 10 in 2015 (MacKinnon, 2016). I reviewed his reports and all previously analyzed material between 2016 and 2018 to assess the quantity and quality of dental remains; I also took note of the elements and taxa present within the assemblage at Building 10 (see Chapter 3) (Bishop, 2016). Appendix 6.4 lists all teeth initially taken from the Kastro Kallithea faunal assemblage to be assessed for suitability for stable isotope analysis (41 ovicaprid teeth). Based on preservation, the amount of the crown that remained, and discussions with director Margriet Haagsma about context security, seven sheep and goat teeth from Building 10 were selected for further analysis. These represent seven unique individuals (Table 6.20; Fig. 6.34). Six individuals were fully analyzed for carbon, oxygen, and strontium stable isotope data. Due to financial constraints, one individual was only tested for carbon and oxygen stable isotope data. All unused teeth will be returned to the Kastro Kallithea Archaeological Project for permanent storage during the next available field season.

Table 6.20 All ovicaprid samples chosen for stable isotope analysis. See Appendices 6.4-6.6 for specific sample context.

Sample ID	Context	Taxa	Tooth	Isotope Analyzed
SG03	Building 10	Sheep	LM_3	Carbon, Oxygen, Strontium
SG06	Building 10	Sheep	LM_3	Carbon, Oxygen
SG08	Building 10	Goat	RM_3	Carbon, Oxygen, Strontium
SG11	Building 10	Sheep	LM_3	Carbon, Oxygen, Strontium
SG16	Building 10	Goat	RM_3	Carbon, Oxygen, Strontium
SG21	Building 10	Sheep	LM_3	Carbon, Oxygen, Strontium
SG23	Building 10	Goat	RM_3	Carbon, Oxygen, Strontium
SG30	Alexopoulos	Sheep	LM_3	Carbon, Oxygen, Strontium
SG33	Alexopoulos	Sheep	LM_3	Carbon, Oxygen, Strontium
SG38	Arsenopoulos	Sheep	RM_3	Carbon, Oxygen, Strontium
SG39	Arsenopoulos	Goat	LM_3	Carbon, Oxygen, Strontium
SG40	Arsenopoulos	Sheep	RM_3	Carbon, Oxygen, Strontium
SG42	Arsenopoulos	Sheep	RM_3	Carbon, Oxygen, Strontium

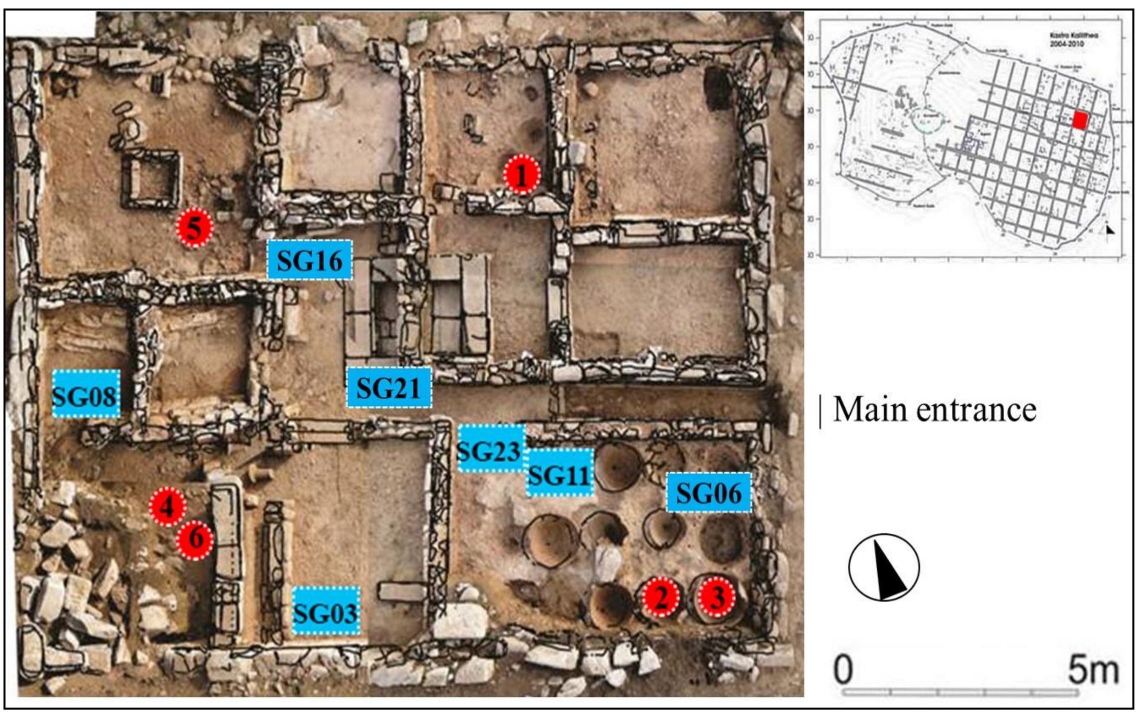

Figure 6.34 Building 10 sampling locations.
Blue squares are ovicaprid samples (Section 6.1.3; Table 6.20) and red circles are small-bodied fauna samples (Section 6.1.4; Table 6.21). Image adapted from Haagsma *et al.* (2015b). See below for context summary.

Kastro Kallithea Sample Context Summary:

SG03: Sub-floor off storage room (food storage, consumption, or refuse)

SG06: Sub-floor in storage room (food storage or refuse)

SG08: Sub-floor adjacent to kitchen (food preparation, storage, consumption, or refuse)

SG11: Food storage room (food storage, preparation, or refuse)

SG16: Sub-floor in courtyard (food consumption or refuse)

SG21: Sub-floor in courtyard (food consumption or refuse)

SG23: Food storage room (food storage, preparation, or refuse)

Figure 6.35 Arsenopoulos Plot sampling locations.
Image removed for publication; instead it has been replaced with the summary listed below.

Arsenopoulos Plot Sample Context Summary:

SG38: Courtyard of small shrine (offering, consumption, or refuse).

SG39: Long room at back of house (food storage, consumption, or refuse)

SG40: Long room at back of house (food storage, consumption, or refuse)

SG42: Hallway off of courtyard (consumption or refuse)

Figure 6.36 Alexopoulos Plot sampling locations.
Image removed for publication; instead it has been replaced with the summary listed below.

Alexopoulos Plot Sample Context Summary:

SG30: Classical Phase, below midden (likely consumption or refuse)

SG33:Hellenistic Phase (consumption, preparation, or refuse)

Pharsalos – Arsenopoulos and Alexopoulos Plots

I conducted a basic inventory of the faunal assemblage from the Arsenopoulos and Alexopoulos plots between 2016 and 2018. I followed the same approach as MacKinnon (2012, 2016) to identify and record all data. A brief overview of materials was conducted in 2016, with most study taking place in 2018. During the 2017 field season, students from the University of Alberta, as part of the Kastro Kallithea Archaeological Project, also studied materials from the Arsenopoulos Plot under my supervision. Assessment of Pharsalos materials included identifying taxon, element, section, side, age, and sex, where available, and recording all data in Excel spreadsheets (Bishop, 2017, 2018). As per MacKinnon (2016), identifications to the most precise taxon possible were made with the aid of several reference texts (e.g., Hillson, 1996, 2005; Schmid, 1972) and reference photos. As part of this inventory, any ovicaprid dental remains (disarticulated teeth, mandibles, or maxillae) were flagged for me to assess in greater detail (36 dental samples from Arsenopoulos, Appendix 6.5; eight samples from Alexopoulos, Appendix 6.6). In 2018 site director Sophia Karapanou indicated which of these samples were from secure contexts. Based on her recommendation, as well as preservation and crown height, four ovicaprid teeth from the Arsenopoulos Plot and two ovicaprid teeth from the Alexopoulos Plot were sampled for stable isotope analysis; they represent six unique individuals (Table 6.20; Fig. 6.35, 6.36). All unused teeth will be returned to Sophia Karapanou at the Diachronic Museum in Larissa for storage with the other Pharsalos materials.

6.1.4 Environmental Sampling

I collected local environmental (plant, soil, and dental) samples with the goal of establishing local strontium isotope ranges for Kastro Kallithea and Pharsalos. As reviewed in Chapter 5, current available strontium isotope data from Thessaly indicate that the region is isotopically diverse (Nafplioti, 2011; Panagiotopoulou *et al.*, 2018; Sparkes, 2017; Voerkelius *et al.*, 2010). It is difficult to predict bioavailable $^{87}Sr/^{86}Sr$ ratios in the vegetation local to the study area because the region is geologically complex (Fig. 6.37). To provide an indication of local baseline $^{87}Sr/^{86}Sr$ ratios for Kastro Kallithea and Pharsalos, I analyzed archaeological remains of small-bodied (non-mobile) mammals from both sites. I also included previously published isotope data for Pharsalos (Panagiotopoulou *et al.*, 2018) to create a local $^{87}Sr/^{86}Sr$ range. Dental enamel from a modern local (Anavra) sheep and modern plant and soil samples were also tested to give a

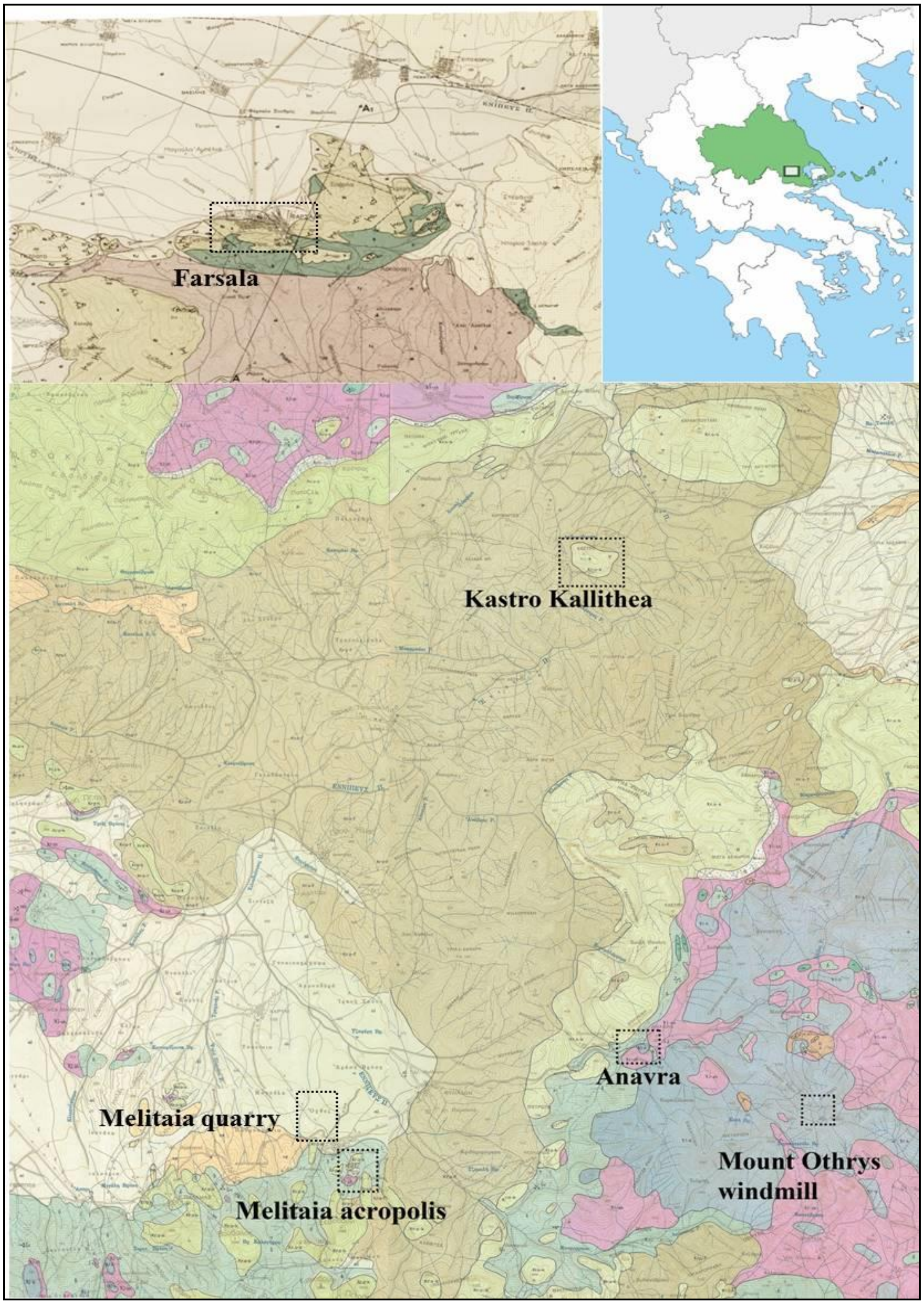

Figure 6.37 Geological map of the study areas. Sample collection sites are outlined. This geological map is adapted from maps created by the Institute of Geology and Subsurface Research in Greece (scale 1:50,000) (Pharsalos, Anavra, and Domokos Sheets) and D-Maps (2020).

Table 6.21 Environmental samples collected to stablish a local baseline $^{87}Sr/^{86}Sr$.

Sample ID	Sample Type	Location	Collection Notes/Context
D01	Soil	Melitaia acropolis	From animal burrow
D02	Soil	Mount Óthrys	Under windmill site
D03	Soil	Melitaia Quarry	On road shoulder
P01	Wild Pear Leaves	Mount Óthrys	Near windmill site
P02	Kermes Oak Leaves	Melitaia acropolis	From acropolis
L01	3-month old Lamb Molar (m_1)	Anavra	Wintered in Anavra, summered in the mountains
R01	Mouse teeth	Building 10	Fig. 6.5; from a *pithos*
R02	Mouse teeth	Building 10	Fig. 6.5; from a *pithos*
R03	Mouse teeth	Building 10	Fig. 6.5; from a *pithos*
R04	Rat (maxillary incisor)	Building 10	Figure 6.5
R05	Shrew (mandibular molar)	Building 10	Figure 6.5
R06	Mouse (maxillary incisor)	Building 10	Figure 6.5
R07	Hare mandible	Arsenopoulos	Figure 6.6
R08	Shrew incisor	Arsenopoulos	Figure 6.6

preliminary idea of values in higher elevations and from sites with known shepherd use (Mount Óthrys, Melitaia) (Table 6.21; Fig. 6.37).

Soil Samples

During the 2015 field season modern soil samples were collected from geologically distinct areas often frequented by modern shepherds (Table 6.21, Fig. 6.37). Samples were collected from what appeared to be undisturbed areas. Samples were collected by Sandra Garvie-Lok and Margriet Haagsma in 2015 and frozen samples were exported to Canada for analysis in 2017. All unused modern materials will remain frozen in the University of Alberta lab until proper disposal can take place.

Plant Samples

Modern leaf samples were collected from plants often consumed by modern sheep and goat herds (Table 6.21, Fig. 6.37). Wild pear (*Pyrus* sp.) and kermes oak (*Quercus coccifera*) trees both have extensive root systems that stretch into the earth and are less likely to be impacted by disturbed topsoil. Sandra Garvie-Lok and Margriet Haagsma collected both samples in 2015 and frozen samples were exported to Canada for analysis in 2017. All unused modern materials will remain frozen in the University of Alberta lab until proper disposal can take place.

Kastro Kallithea Small Fauna Tooth Samples

Six archaeological tooth samples from small-bodied fauna were collected from the Building 10 assemblage to provide a baseline of locally available strontium isotope ratios at Kastro Kallithea. Three samples were recovered from inside large storage vessels (*pithoi*) and three were recovered from mixed refuse as part of secure layers in Building 10 (Table 6.21, Fig. 6.34). All sampled fauna were likely deposited shortly after site abandonment. Materials were collected from flotation samples during excavation and were washed multiple times through this process.

Pharsalos Small Fauna Tooth Samples

Two archaeological tooth samples from small-bodied fauna were collected from the Arsenopoulos Plot assemblage to provide a baseline of locally available strontium isotope ratios at Pharsalos. Both were recovered from mixed refuse as part of secure layers (Table 6.21; Fig. 6.35). Materials were collected as part of regular excavation and washed prior to analysis. No small faunal remains were collected from the Alexopoulos Plot.

Modern Anavra Lamb

One modern lamb head was acquired from an Anavra butcher in June 2015 (Figure 6.37). The three-month-old lamb was sourced from a shepherd whose flock of sheep was traditionally raised in Anavra in the winter months (October to April) and the Óthrys Mountain highlands in the summer months (April to October). The head was processed by Sandra Garvie-Lok in 2015 (see Section 6.2.2) and Bishop in 2016, and frozen prior to being transported to Canada for analysis in 2017. The deciduous first molar (m_1) was selected for stable isotope analysis to provide an example of stable isotope values resulting from modern ovicaprid management in the area (Table 6.21). All unused modern materials will remain frozen in the University of Alberta lab until proper disposal can take place.

6.2 Sample Preparation

All samples were transported from Thessaly to the laboratory at the University of Alberta in Edmonton for macroscopic analysis and sample preparation. All samples were photographed and documented to record identifying characteristics, including taxa (as per Halstead *et al.* (2002) and Balasse and Ambrose (2005)) and age at death (as per Payne (1987)).

6.2.1 Sheep and Goat Teeth

Establishing a Sequential Sampling Method

The common approach of drilling sequential bands of powdered enamel from the tooth (e.g., Balasse, 2002; Balasse *et al.* 2002; Chase *et al.*, 2014; Isaakidou *et al.*, 2019) was found to be unworkable in our laboratory. I attempted this method and drilled sequential bands of powdered enamel using spare teeth.[47] Low humidity conditions led to unacceptable scattering of the enamel powder. Numerous attempts to limit static were unsuccessful. Colleagues who also attempted these methods in other University of Alberta laboratory settings experienced similar sample loss (Martinez De La Torre *et al.*, 2016). As an alternative, lobe segments were removed from the tooth (Fig. 6.38), and a custom microsampling system (Fig. 6.39) was used to sample sequential enamel bands as solid slices (Figure 6.40). Once samples were cut into sequential sections, they could be powdered in a covered mortar and pestle. This approach was still impacted by static, but powdered enamel was contained to the mortar instead of dissipating throughout the laboratory. All test runs of this approach prevented considerable sample loss. The following three steps were taken to prepare samples for stable isotope analysis. My approach ensured that samples were cleaned and sequentially sampled without compromising on sample loss.

1: Sample Preparation

Articulated teeth were extracted from mandibular samples where necessary. The lateral portion of the mandibular body was cut using a Dremel tool fitted with a diamond cutting wheel (0.15mm thickness), removing the bone to expose, but not damage, the articulated teeth (Fig. 6.33, left). Molars were cleaned by rinsing under distilled water, abraded using a Dremel tool fitted with a diamond abrasive grinding bit to remove all remaining adhering debris, and then re-rinsed under distilled water.

2: Anterior Lobe Removal

The anterior lobe was removed longitudinally using an Isomet 1-1180 low speed precision cutter cooled with distilled water (Figure 6.38). Lobe samples were abraded to remove dentine up to

[47] Modern ungulate teeth of no historical or contextual importance

Figure 6.38 Anterior lobe separation for sample SG03.
Left: Isomet 1-1180 low speed precision cutter with LM_3 clamped for processing.
Right: LM_3 post-cutting, showing the anterior lobe removed from the main tooth.

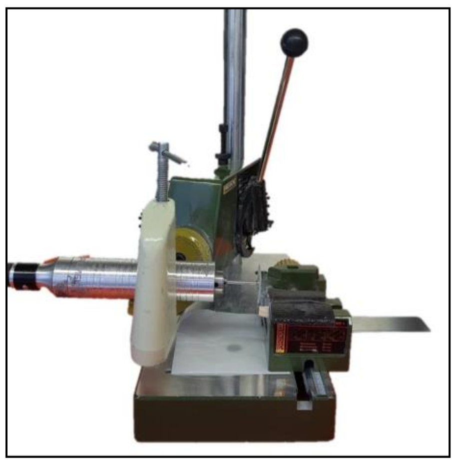

Figure 6.39 Custom microsampling system created for this study.
A Proxxon Micromet drill stand is equipped with a Proxxon Machine (micro) vise with self-stick non-slip surface grip pads. A Dremel precision rotary tool equipped with a diamond cut wheel (0.15 mm thickness) is clamped onto the drill stand. System serves as a Dremel-equipped miter saw (Bishop *et al.*, 2020).

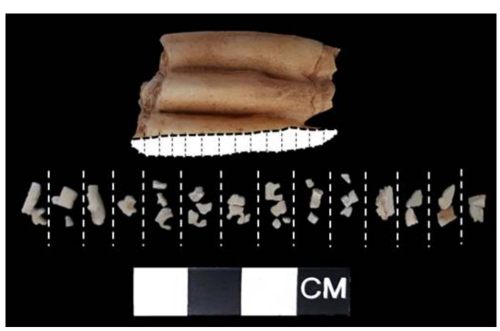

Figure 6.40 Archaeological goat M_3 (SG12) with sequentially sampled enamel segments cut from the removed anterior lobe.

the dentine-enamel junction using the Dremel tool with diamond-abrasive grinding bit attachment. The prepared lobes were then wiped clean with dry sterile wipes. All tools were cleaned with alcohol between uses.

3: Sequential Enamel Sampling
Teeth were secured at the root surface using a small vise positioned under a diamond cutting disc (0.15 mm thickness) fitted to a Dremel tool (Fig. 6.39). This Dremel tool was stabilized in another vise and pressed down to make each cut. Every cut was measured using a sliding caliper to ensure each sample was ~1.5 mm thick (Fig. 6.40). After each cut the microsampled enamel band was collected in a sterile labelled micro centrifuge vial and recorded according to the distance from the crown-root juncture (CRJ). Cutting implements were cleaned with alcohol between each use. Following cutting, each enamel sample was ground to a powder using an agate mortar and pestle. Enamel samples of approximately 5-20 mg were transported to the Saskatchewan Isotope Laboratory for stable isotope ratio analysis. For a discussion of the issue of sample pretreatment, please see Section 6.5.

6.2.2 Environmental Sample Preparation

Small-Bodied Fauna Tooth Samples
Due to the small size of the remains, most samples consist of multiple teeth from a single individual, and no attempt was made to separate enamel from dentine during processing. Dentine is often preferentially avoided for strontium analysis because dentine microstructure is more permeable to external contaminants than enamel. If small-bodied faunal dentine absorbed strontium from the surrounding soil, recorded $^{87}Sr/^{86}Sr$ will still reflect local baseline values. Teeth were extracted from their jaws when necessary and lightly brushed to remove adhering debris. Whole teeth were ground to a powder using an agate mortar and pestle and samples of approximately 5-20 mg of enamel were transported to the Stable Isotope Laboratory at the University of Saskatchewan (Saskatchewan Isotope Laboratory) for stable isotope ratio analysis. Methods used in that laboratory for strontium isotope analysis are detailed in Section 6.4.

Leaf Samples
Leaves were sampled according to established preferences at the Saskatchewan Isotope Laboratory. Each leaf sample contained several branches with leaves and stems still attached. I

chose a large branch, separated all leaves from their stems, and bagged the accumulated leaves in a sterile bag according to each sample. Approximately 5 g of whole leaf sample were transported to the Saskatchewan Isotope Laboratory for strontium isotope analysis. Once at the Saskatchewan Isotope Laboratory, leaf samples were digested for bulk strontium isotope analysis according to established methods (Sandra Timsic, *personal communication*). Ultraclean acid and savillexes were used throughout the sample preparation and column chemistry process. Whole leaves were dissolved in a PTFE beaker using concentrated HNO_3 with lid on hotplate at 100°C for a few days. Samples were dried down and had 6M HCl added to reflux overnight at the same temperature and then dried; this step was repeated once more. The sample then had diluted HCl added to prepare it for cation chromatography as part of strontium isotope analysis.

Soil Samples

Approximately 5 g of each soil sample was separated into a small sterile glass vial and transported to the Saskatchewan Isotope Laboratory for strontium isotope analysis. Once at the Saskatchewan Isotope Laboratory, soil samples were digested for bulk strontium isotope analysis according to established methods (Sandra Timsic, *personal communication*). Soil samples were weighed and processed using HNO_3 and HF. Samples were roasted in an oven at 130°C for around 72 hours. Samples were then cooled and placed on a hotplate to reduce the volume by half. Approximately 1-2 mL HNO_3 was added repeatedly and dried gently to eliminate all fluoride from the sample. Approximately 10 mL of 6M HCl was added and refluxed overnight prior to being dried. The sample was then converted into chloride to prepare it for cation chromatography as part of the strontium isotope analysis.

Modern Lamb Sample

When the lamb head was initially collected, it was manually defleshed and skeletal materials were boiled three times, soft tissue scraped off, soaked in bleach, and allowed to dry. Remains were sealed and stored for a year. Because of mould growth remains were cleaned two more times in 2016. In each cleaning visible mould was removed, the remains were washed with diluted bleach, and the bones were air dried for five days. The remains were then sealed and frozen until laboratory analysis. The tooth was then sampled according to the same procedure used for archaeological sheep and goat teeth (see section 6.2.1).

6.3 Carbonate ($\delta^{13}C$ and $\delta^{18}O$) Analysis

Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope values were determined from the bioapatite portion of all rodent bulk enamel samples and all sequential ovicaprid enamel samples in accordance with Saskatchewan Isotope Laboratory procedures (Sandra Timsic, *personal communication*). Powdered enamel samples were roasted in a vacuum oven at 200°C for 1 hour to remove water and volatile organic contaminants. Carbon and oxygen stable isotope values were obtained using a Finnigan Kiel-IV carbonate preparation device directly coupled to the dual inlet of a Finnigan MAT 253 isotope ratio mass spectrometer. Powdered carbonate (20-50 μg) was reacted at 70°C with 3 drops of anhydrous phosphoric acid for 420 seconds. The evolved CO_2 was then cryogenically purified and passed to the mass spectrometer for analysis. Isotope ratios are corrected for acid fractionation and ^{17}O contribution using the Craig correction (Craig, 1957). Every sample is analyzed eight times and then the average value is taken and reported. If the standard deviation for a sample is higher than the rest of the samples in that run, additional analyses are conducted (available sample permitting) to obtain consistent results (Sandra Timsic, *personal communication*). Acceptable results were reported to me as corrected $\delta^{13}C$ and $\delta^{18}O$ values in per mil (‰) notation relative to the Vienna Pee Dee Belemnite (VPDB) scale. Data were directly calibrated against the international standard NBS-19, which has the following values: $\delta^{13}C$ = 1.95‰ VPDB and $\delta^{18}O$ = -2.20‰ VPDB. The $\delta^{13}C$ and $\delta^{18}O$ values recorded for each run of NBS-19 (n=32) are included in Appendix 7.9.

6.4 Strontium Analysis

6.4.1 Method Selection

There is some debate over how to measure strontium isotope values. Thermal Ionization Mass Spectrometry (TIMS) is considered the foremost established method used for $^{87}Sr/^{86}Sr$ analysis of archaeological materials, which produces precise results but with costly preparation measures (e.g., Balasse *et al.*, 2002; Bentley and Knipper, 2005; Grimstead *et al.*, 2016; Willmes, 2015). Laser-Ablation Inductively-Couple-Plasma Mass Spectrometry (LA-ICP-MS) is an alternative analytical technique that offers comparably shorter sample run times, lower analytical costs, and smaller amounts of material required for testing (Lewis *et al.*, 2014). A surge of studies advocated in favour of LA-ICP-MS between 2008 and 2010 (e.g., Copeland *et al.* 2008, 2010; Horstwood *et al.*, 2008; Nowell and Horstwood, 2009; Richards *et al.*, 2008, 2009; Vanhaecke *et* *al.*, 2009). After 2010, though, few studies mention its use as the literature appeared saturated with studies reporting precision issues. In most instances, laser ablation caused isobaric interference by incorporating foreign entities into the sample (Lewis *et al.*, 2014). As a result of this contamination, $^{87}Sr/^{86}Sr$ ratios recorded using LA-ICP-MS varied considerably from those recorded using TIMS.

More recent publications (e.g., Grimstead *et al.* 2016; Knudson *et al.* 2016; Le Roux *et al.* 2014; Lewis *et al.* 2017; Martinez De La Torre *et al.* 2016; Pozebon *et al.* 2014; Willmes *et al.* 2016) revisit this debate with expanded methods in an effort to once again test the precision and accuracy of LA-ICP-MS compared to TIMS. As an example, Willmes *et al.* (2016) used a new form of laser ablation (LA-MC-ICP-MS) in their analysis. Strontium isotope values were recorded from the same sample using LA-MC-ICP-MS and TIMS with a 300 ppm difference recorded between the two. Although this is considerably better than values recorded during initial laser ablation studies, 300 ppm is the difference between 0.7108 and 0.7111. In Thessaly, this $^{87}Sr/^{86}Sr$ variation could be interpreted as an animal foraging along the coast rather than a more accurate mountainous terrain. Studies that advocated for LA-ICP-MS involved isotopically distinct areas that only required precision coefficients of ±0.01 (e.g. Copeland *et al.* 2008, 2010). After critically reviewing these studies, and considering the precision constraints, I determined that the TIMS method is more suitable for documenting $^{87}Sr/^{86}Sr$ in my study region. Although LA-MC-ICP-MS provides a cost-effective form of analysis, the data obtained from this method are not as precise, often only recordable to the third of fourth decimal place. Alternatively, the TIMS method is capable of recording data to the sixth decimal place, which affords me a more precise understanding of strontium differences in the area.

6.4.2 Strontium Isotope Analysis of Tooth Enamel

Strontium isotope values were determined for all rodent samples and alternating ovicaprid sequential enamel bands (in other words, sampling every 3.0 mm along the anterior lobe) in accordance with Saskatchewan Isotope Laboratory procedures (Sandra Timsic, *personal communication*). Samples were dissolved in ultrapure 2.0 M HNO_3 and a few drops of H_2O_2, then dried, centrifuged, and processed through cation chromatography. The released Sr was purified from Ca and other minor and trace elements by cation conventional exchange chromatography. Purified Sr was loaded onto single Ta filaments with a phosphoric acid Ta-gel mixture to increase ionization efficiency. Isotopic measurements of Sr were performed by thermal ionization mass spectrometry (TIMS) using a Thermo-Elemental Triton instrument using a static multi-collection measurement routine, and correction for instrumental mass fractionation to an $^{88}Sr/^{86}Sr$ of 8.375209 using an exponential mass fractionation law. Isobaric interference of ^{87}Rb on ^{87}Sr was monitored using ^{85}Rb. Samples that produced isobaric interference were rerun if prepared sample was still available (Sandra Timsic, *personal communication*). Acceptable results were processed by the Saskatchewan Isotope Lab and reported to me as corrected $^{87}Sr/^{86}Sr$ ratios. Reproducibility of $^{87}Sr/^{86}Sr$ analyses was better than ±15 ppm (0.0015) (2σ) based on numerous runs of SRM 987 performed throughout the course of this work yielding $^{87}Sr/^{86}Sr$ of 0.710273. The $^{87}Sr/^{86}Sr$ ratios recorded for each run of SRM 987 (n=7) are included in Appendix 7.10.

6.4.3 Strontium Isotope Analysis of Plant and Soil Samples

After the pretreatment described above in section 6.2.2, leaf and soil samples were run through cation chromatography to purify released strontium from calcium and other minor and trace elements. Purified strontium was loaded onto single tantalum filaments with a phosphoric acid tantalum-gel mixture to increase ionization efficiency. Isotopic measurements of strontium were performed by thermal ionization mass spectrometry using a Thermo-Elemental Triton instrument using a static multi-collection measurement routine, and correction for instrumental mass fractionation to an $^{88}Sr/^{86}Sr$ of 8.375209 using an exponential mass fractionation law. Isobaric interference of ^{87}Rb on ^{87}Sr was monitored using ^{85}Rb. Acceptable results were processed by the Saskatchewan Isotope Lab and reported to me as corrected $^{87}Sr/^{86}Sr$ ratios. Reproducibility of $^{87}Sr/^{86}Sr$ analyses was better than ±15 ppm (0.0015) (2σ) based on numerous runs of SRM 987 performed throughout the course of this work yielding $^{87}Sr/^{86}Sr$ of 0.710259. The $^{87}Sr/^{86}Sr$ ratios recorded for each run of SRM 987 (n=1) are included in Appendix 7.10.

6.5 Sample Pretreatment Pilot Study

For reasons fully laid out below, it was decided that enamel samples would not be acid pretreated. After conducting all analyses and presenting preliminary data (Bishop *et al.*, 2020), a reviewer expressed concern about our lack of enamel acid pretreatment prior to isotopic analysis. Acid pretreatment is considered essential for bone because of its high organic content and porosity (McMillan *et al.*, 2019; Snoeck and Pellegrini, 2015) and similar methods were initially used to prepare enamel samples out of precaution (e.g., Balasse *et al.*, 2002, 2003; Towers *et al.*, 2011), with subsequent studies following these methods verbatim (e.g., Chase *et al.*, 2014; Mainland *et al.*, 2016). As part of recent studies researchers have advocated for standardized methods of carbonate analysis of bones and teeth (Demény *et al.* 2019; McMillan *et al.*, 2019), with some also evaluating the need for enamel bicarbonate pretreatment (Skippington *et al.*, 2019). Initially our decision to omit pretreatment was based primarily on concerns of excessive sample loss and recrystallization during chemical pretreatment, which are problems that have been noted in other studies (e.g., Pellegrini and Snoeck, 2016; Skippington *et al.*, 2019; Snoeck and Pellegrini, 2015). Section 6.5.1 presents a summary of chemical pretreatment studies, including how processes impact enamel sample size, contamination, and recorded isotope values. As a result of this background research, I created a pilot study to assess how chemical pretreatment impacted my samples. The following sections summarize the methodological approach (6.5.2), findings (6.5.3), interpretation (6.5.4), and conclusion (6.5.5) about chemically pretreating samples as part of my study.

6.5.1 Background and Rationale

The study published by Balasse *et al.* (2002) serves as a foundational approach for recording stable isotope ratios from sequential bands of ovicaprid enamel. As part of their study, they outlined a methodological framework and tested various protocols for enamel pretreatment as part of bioapatite extraction. Their approach followed similar methods used for bone pretreatment (see Garvie-Lok *et al.* (2004) for a good summary), which include soaking powdered sample in acetic acid to liberate exogenous contaminants that adhere to archaeological bone during diagenesis. Enamel has a higher density and lower porosity than bone, and the absolute necessity of chemical pretreatment is less clear. Initial studies, including Balasse *et al.* (2002), pretreated enamel out of precaution. As a result of varying concentrations and soak times, pretreatment resulted in sample loss of 88% (1M, 24 hrs), 95% (0.2 M, 6 hrs), and 40% (0.1 M, 4 hrs). The third pretreatment method (0.1 M for 4 hours) resulted in the least amount of sample mass loss, and that protocol was adapted as the pretreatment standard for future studies (e.g. Balasse *et al.*, 2003, 2013, 2017; Chase *et al.*, 2014; Grimstead *et al.*, 2016; Tornero *et al.*, 2013, 2016ab; Zazzo *et al.*, 2010, 2012).

Snoeck and Pellegrini (2015) use elemental analysis to assess the efficacy of various chemical pretreatment methods, including investigating how enamel sample structure is impacted by a four-hour soak in 1 M acetic acid. In their analysis, samples soaked in buffered acetic acid resulted in 29% to 65% mass loss, decreased carbonate content, and increased structural crystallinity (Snoeck and Pellegrini, 2015, p.401). Under these circumstances, the acid dissolved endogenous (natural) and exogenous (contaminated) carbonate, with varying quantities of both recrystalizing into the final sample substrate. Although this step reduced contaminants in bone and tooth dentine, it is still unclear whether the loss of sample mass is worth the reduction of natural and contaminated carbonate in enamel samples.

Exogenous carbonate can influence the isotope ratios recorded from a sample, but a fluctuation in the endogenous carbonate can also change isotope values. Pellegrini and Snoeck (2016) examine how chemical pretreatment with acetic acid influences the stable carbon and oxygen isotope values analyzed from modern and archaeological enamel. Modern samples should not be impacted by exogenous carbonate, as they have not undergone diagenesis, and the resulting stable carbon and oxygen isotope values recorded from these samples should not vary due to chemical pretreatment. In five modern enamel samples $\Delta^{13}C$ ($\delta^{13}C_{treated}$ - $\delta^{13}C_{untreated}$) varied between -0.7‰ and +0.4‰ and $\Delta^{18}O$ ($\delta^{18}O_{treated}$ - $\delta^{18}O_{untreated}$) varied between +0.2‰ and +1.7‰, whereas in two archaeological enamel samples the $\Delta^{13}C$ varied between -0.7‰ and -0.2‰ and $\Delta^{18}O$ varied between +0.9‰ and +1.7‰. Similar variation was noted by Pellegrini *et al.* (2011, p.74), wherein eight samples of the laboratory enamel standard had $\Delta^{18}O$ variation between +0.2‰ and +0.5‰. The variation in values recorded by Pellegrini and Snoeck (2016) and Pellegrini *et al.* (2011) correspond with the structural variation recorded by Snoeck and Pellegrini (2015), which were all due to the acetic acid pretreatment and impact it had on endogenous and exogenous carbonate composition. Endogenous carbonate was lost because of acetic acid pretreatment.

Skippington *et al.* (2019) also assessed how chemical treatment influenced sample crystallinity, carbonate content over time, and the resulting isotope signatures. They aimed to establish the best acetic acid concentration and soak time to remove exogenous carbonate before structural (endogenous) carbonate was impacted. After 15 minutes of soaking in a buffered (0.1 M) acetic acid treatment, the carbonate composition was varied and the resulting $\delta^{13}C$ and $\delta^{18}O$ values for modern and archaeological samples had changed (Skippington *et al.*, 2019, p.764). Measured variation was high enough that it could be interpreted as a difference in feeding ecology (carbon) or relative humidity (oxygen), with longer soaking treatment attributed to greater variation (Skippington *et al.*., 2019, pp.764, 766). Based on Skippington *et al.* (2019), Snoeck and Pellegrini (2015), and Pellegrini and Snoeck (2016), any chemically pretreated sample would result in varied carbonate structure and carbon and oxygen isotope values. Although the intention is to remove contaminated carbonate, chemical treatment also inadvertently removes endogenous sample matter. I question whether it is more important to chemically remove exogenous carbonate at the risk of also modifying the endogenous carbonate. I spoke about this issue with Sandra Timsic (Stable Isotope Laboratory Manager) at the University of Saskatchewan and she explained that their laboratory protocol preferentially omits chemical pretreatment because it inadvertently modifies the natural state of each sample.

As a way of preventing this, Chenery *et al*. (2012) assessed how chemical pretreatment impacted their archaeological samples. Their goal was to determine whether they could omit the acetic acid soak altogether. They mechanically cleaned and powdered samples, soaked half of each with 0.1 M acetic acid for two hours, and analyzed treated and untreated carbonate samples for $\delta^{13}C$ and $\delta^{18}O$. Ten samples were selected to represent different burial environments and periods. Samples were run multiple times, and the mean $\delta^{13}C_{treated}$ - $\delta^{13}C_{untreated}$ and $\delta^{18}O_{treated}$ - $\delta^{18}O_{untreated}$ was measured for every sample, with the recorded spread of $\Delta^{13}C$ between -0.18‰ and +1.29‰ and $\Delta^{18}O$ between -1.11‰ and +0.26‰. For most of the samples, the offset difference was within the range of reproducibility (i.e., two standard deviation, 2σ) for each sample (Chenery *et al.*, 2012, p.311). Because of this small variation, Chenery *et al.* (2012) chose to not carry out chemical pretreatment on their remaining samples.

Other similar stable isotope studies (e.g., Evans *et al.*, 2019; Madgwick *et al.*, 2019; Sparkes, 2017) have opted to omit chemical pretreatment and only abrade the outermost (surface) layer of enamel in order to sufficiently remove any contaminants and maintain sample integrity. As a means for assessing how chemical pretreatment would impact samples from my deposition environment, I conducted a pilot study (similar to Chenery *et al.* 2012) that measured the $\Delta^{13}C$ and $\Delta^{18}O$ offset for chemically and non-pretreated archaeological samples at Kastro Kallithea and Pharsalos. I was specifically interested in recording any potential consistency in the offset and assessing how chemical pretreatment influenced the observable trends in data.

6.5.2 Method

Sampling Strategy

I chose to sample an ovicaprid tooth from Kastro Kallithea that had similar burial context to other sampled remains. I chose SG12 (left, third mandibular molar; LM_3) for the pretreatment study as it was recovered from special feature α of Unit K2, which corresponds to the same provenience as SG11 and SG23 (Table 6.20; Fig. 6.34; Appendix 6.4).

Sample Preparation

I conducted all pretreatment methods on the mesial surface of the anterior lobe of the same molar (see section 6.1.4 for sampling rationale). SG12 LM_3 was prepared, separated, and sequentially sampled according to the methods presented in Section 6.2.1. Following cutting (see Fig. 6.40), each sequential band sample was ground to a powder using an agate mortar and pestle. All samples were separated into two halves and weighed (Table 6.22). Each microsample half was vialed and labelled according to: (1) No Pretreatment or (2) Chemical Pretreatment.

Protocol: No Pretreatment

Powdered samples vialed for "no treatment" required no further alteration.

Protocol: Chemical Pretreatment

All samples assigned for chemical pretreatment were treated according to well-established methods that used a consistent acid concentration and soaking time (e.g., Balasse *et al.* 2002, 2003; Demény *et al.* 2019; Makarewicz, 2017; Zazzo *et al.* 2010). Each sample was pretreated with 0.1 M acetic acid (CH_3COOH) (40µL per 1.0 mg of enamel) for 4 hours. Samples were treated at room temperature, rinsed with double-distilled water and centrifuged five times, and freeze-dried for 48 hours to remove all moisture.

Stable Isotope Analysis

All samples were packaged and reweighed (Table 6.22) prior to being transported to the Saskatchewan Isotope Laboratory for stable isotope ratio analysis. See Section 6.3 for the protocol for carbonate isotope ratio analysis. Samples were rerun where available.

6.5.3 Results

A summary of the stable isotope results are listed in Table 6.23 (full results in Appendix 6.7) and visually illustrated by Figures 6.41 and 6.42. I measured the difference (Δ) of $\delta^{13}C_{no\text{-}treatment}$ and

Table 6.22 Measured mass (mg) before and after different pretreatment methods for SG12. Mass loss is the difference in mass based on the starting mass (%).

Sample Location (mm from CRJ)	Untreated				Chemically Treated			
	Sample Mass (mg)			Mass Loss	Sample Mass (mg)			Mass Loss
	Before	After[48]	Difference		Before	After	Difference	
20.0	12.7	12.6	-0.1	-0.8%	22.8	19.0	-3.8	-16.7%
18.5	19.6	18.8	-0.8	-4.1%	18.9	14.4	-4.5	-23.8%
17.0	8.9	8.8	-0.1	-1.1%	25.2	22.4	-2.8	-11.1%
15.5	8.9	9.1	0.2	+2.2%	14.2	11.3	-2.9	-20.4%
14.0	6.3	6.0	-0.3	-4.8%	11.6	9.6	-2.0	-17.2%
12.5	9.2	8.9	-0.3	-3.3%	17.0	9.8	-7.2	-42.4%
11.0	7.6	7.2	-0.4	-5.3%	12.7	10.8	-1.9	-15.0%
9.5	12.2	12.3	0.1	+0.8%	19.7	17.2	-2.5	-12.7%
8.0	5.1	5.6	0.5	+9.8%	15.4	12.7	-2.7	-17.5%
6.5	4.0	4.4	0.4	+10.0%	8.8	6.5	-2.3	-26.1%
5.0	31.3	31.2	-0.1	-0.3%	42.6	33.4	-9.2	-21.6%
3.5	8.9	8.8	-0.1	-1.1%	21.0	17.1	-3.9	-18.6%
2.0	12.0	12.6	0.6	+5.0%	39.8	34.3	-5.5	-13.8%
0.5	7.0	7.4	0.4	+5.7%	10.6	2.3	-8.3	-78.3%

[48] Shows difference in mass measurement variation across days/times (due to calibration, repackaging, etc.). In some cases this led to an artificial increase in sample mass(+).

Table 6.23 Carbon and oxygen isotope values recorded from sequentially sampled mandibular molar (M_3) enamel of SG12 according to treatment type.
The difference (Δ) is recorded for $\delta^{13}C_{no\text{-}treatment}$ and $\delta^{13}C_{chemical}$ and $\delta^{18}O_{no\text{-}treatent}$ and $\delta^{18}O_{chemical}$ See Fig. 6.41 and 6.42.

Sample Location (mm from CRJ)	No Pretreatment (No-Treatment)		Acetic Acid Pretreatment (Chemical)		$\Delta^{13}C$	$\Delta^{18}O$
	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$		
20.0	-9.32	-3.65	-10.27	-1.36	-0.94	2.29
18.5	-9.11	-3.63	-10.06	-2.13	-0.94	1.50
17.0	-9.32	-4.46	-10.61	-2.33	-1.29	2.13
15.5	-9.16	-4.71	-10.16	-2.33	-1.00	2.37
14.0	-9.63	-5.13	-10.62	-2.66	-0.99	2.48
12.5	-10.09	-5.04	-10.76	-3.25	-0.67	1.79
11.0	-10.18	-5.49	-11.33	-3.78	-1.15	1.71
9.5	-10.39	-6.26	-11.76	-4.34	-1.38	1.92
8.0	-10.76	-6.24	-12.35	-4.61	-1.59	1.63
6.5	-11.38	-5.97	-12.66	-4.71	-1.28	1.26
5.0	-11.07	-6.22	-11.70	-5.20	-0.63	1.02
3.5	-10.50	-5.92	-12.08	-4.04	-1.58	1.87
2.0	-10.75	-5.43	-11.61	-4.62	-0.86	0.80
0.5	-10.67	-4.86	-11.49	-2.65	-0.83	2.21

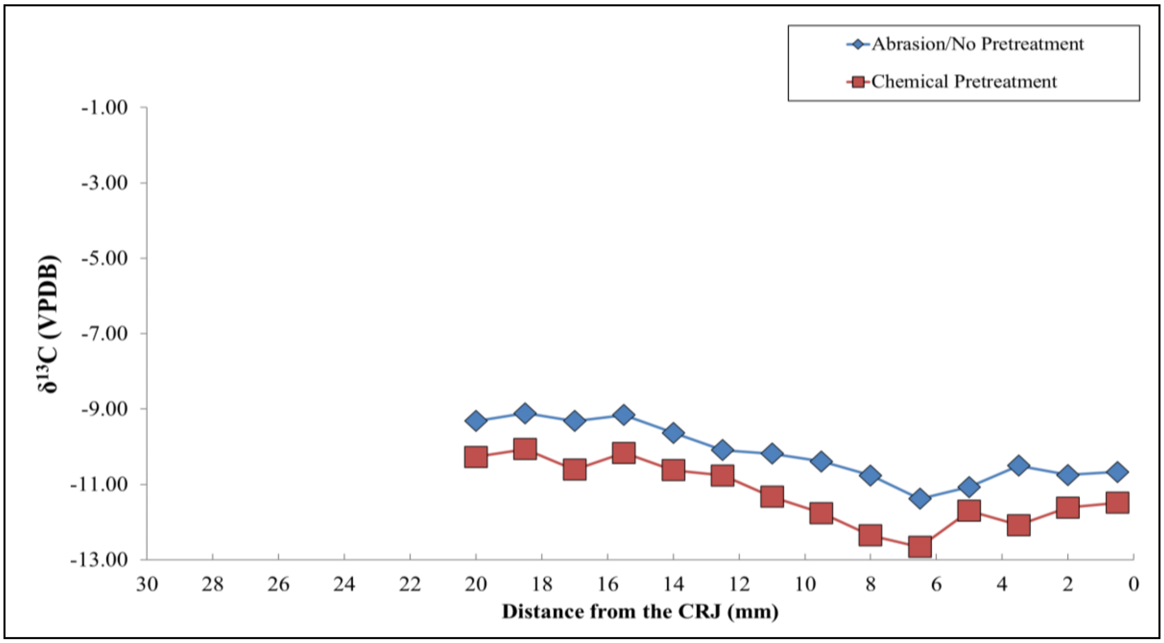

Figure 6.41 Sequential $\delta^{13}C$ values measured from SG12 molar enamel at different points along the mesial lobe from the crown-root junction (CRJ) (mm) according to treatment type. Refer to Table 6.4.

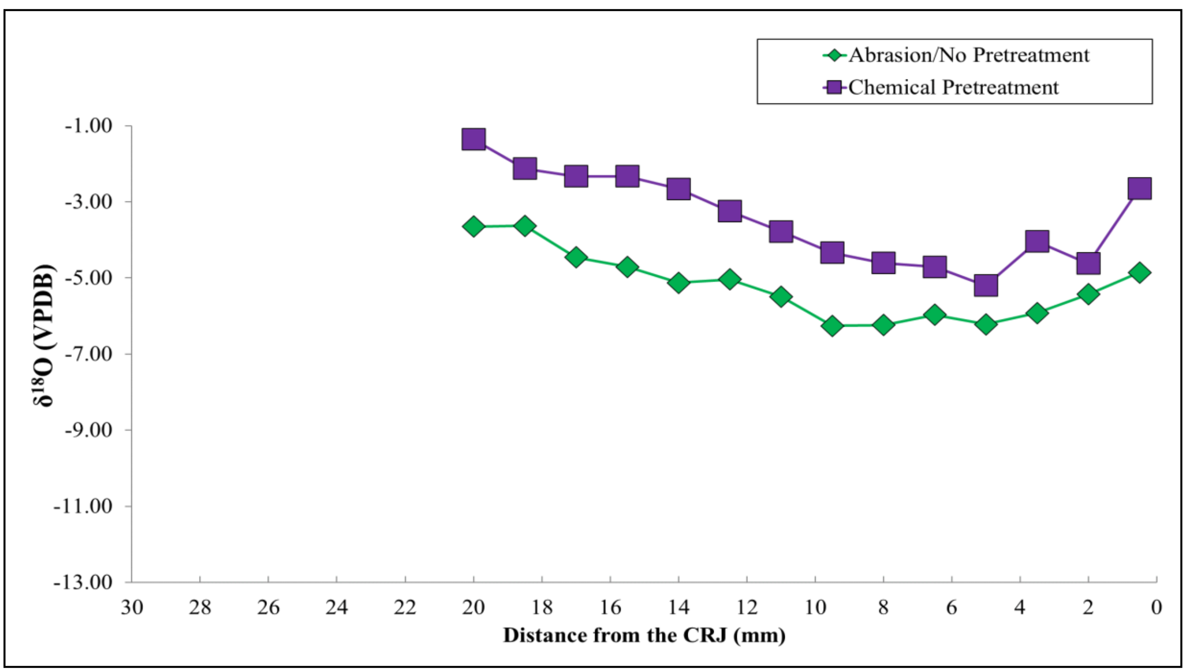

Figure 6.42 Sequential $\delta^{18}O$ values measured from SG12 molar enamel at different points along the mesial lobe from the crown-root junction (CRJ) (mm) according to treatment type. Refer to Table 6.4.

$\delta^{13}C_{chemical}$ and $\delta^{18}O_{no\text{-}reatment}$ and $\delta^{18}O_{chemical}$ to obtain the offset values for each microsample. I compared recorded isotope values from abraded and chemically pretreated microsamples to establish whether the trends in data were similar, and if so, if there was a measurable offset. I compared these offsets to other studies and determined whether any anomalous data trends were the result of sample size, methodological error, or other potential causes. Ultimately, I assess whether the data trends vary when samples were pretreated or not chemically pretreated. A major reason for choosing not to pretreat samples was the risk of sample loss. Mass loss results are listed in Table 6.22 and include the mass loss percent (difference/initial mass) for untreated and chemically treated samples.

6.5.4 Interpretation

Isotope Values and Patterning

I compared the differences in carbon and oxygen isotope ratios and found no major concerns in data trends. I also examined isotope differences in relation to starting sample mass, sample mass loss, and rerun variation (1σ) to gauge possible reasons for offset and/or trends in data. I found no correlation. The shape and proportion of each curve was consistent regardless of treatment method. There is a consistent measurable offset for $\Delta\ \delta^{13}C_{no\text{-}reatment\text{-}chemical}$ (~1‰) and a similar consistent measurable offset for $\Delta\ \delta^{18}O_{no\text{-}treatmnt\text{-}chemical}$ (~2‰). Chemical pretreatment of samples resulted in lower $\delta^{13}C$ values and higher $\delta^{18}O$ values compared to samples that were not pretreated. Although there is a visible offset, there is no major impact on the patterns of variation in the isotope data. Figures 6.41 and 6.42 illustrate the measured isotope values, and there appear to be smoother trends in data for non-chemically treated samples. In particular, the $\delta^{18}O_{chemical}$ measured between 5.0 and 0.5 mm (Fig. 6.42, purple squares) was more disjointed along the trend, whereas the $\delta^{18}O_{abraded}$ yielded a smoother transition in isotope change in the same area of the tooth.

Similar direction and magnitude of offsets between acid-treated and untreated samples were found in other archaeological studies (e.g., Chenery *et al.*, 2012, p.312; Skippington *et al.*, 2019, pp.766-768) as well as in studies of fresh bone (Garvie-Lok *et al.* 2004, p.770). As discussed above, fresh bone should not be contaminated with exogenous carbonate, and any post-treatment offset is due to removal of endogenous carbonate (Garvie-Lok *et al.*, 2004). In my study there is likely removal of endogenous and exogenous carbonate, but the patterning appears the same; the same interpretations can be made from both pretreated and non-treated carbonate. For example, regardless of pretreatment, the following interpretations can be made about SG12, a sheep LM_3:

- **Carbon**: The carbon isotope signature is variable over the period measured and appears consistent with the seasonal oxygen isotope trend. The seasonal trend shows a diet that is enriched in ^{13}C during the summer months (20.0 mm) relative to the winter months (6.5 mm). The carbon isotope variation ($\Delta^{13}C$) between extreme values is 2.27‰ (non-treated) or 2.60‰ (chemically treated).
- **Oxygen**: The oxygen isotope signature is consistent with a seasonal (sinusoidal) signal. The first summer likely occurs around 20.0 mm and the second around 0.5 mm. There is a 2.60‰ (non-treated) and 3.84‰ (chemically treated) difference in oxygen isotope variation ($\Delta^{18}O$) between summer and winter months.

Stable isotope ratios were more extreme (larger offset) in the chemically pretreated samples compared to non-treated samples, but the trends in data were the same. This means that I will need to be cautious when directly comparing my sample values to chemically pretreated archaeological sample values. However, the patterns in non-treated studies (like mine) can be directly compared to patterns in chemically pretreated studies without any major concern, as shown above.

Sample Mass Loss

A major reason for choosing not to acid pretreat samples was the concerns over sample loss. Based on mass measurements taken before treatment and after repackaging (Table 6.22), chemical pretreatment caused an average of 23.9% sample mass loss (%/mg). Although repackaging could have caused an average of 0.9% sample mass loss, acid pretreatment was still capable of losing almost a quarter of the sample. In my study, each sample needed to be separated out for carbonate and strontium isotope analysis, which required at least 0.5 mg for carbonate and no less than 5 mg of sample for strontium analysis. The sequential sampling measures discussed above (cutting and grinding) often created samples that were already at risk of being too small (i.e. weighed ~5-6 mg). If chemical pretreatment had occurred after cutting and grinding, and an additional 24% of mass was lost, I would have been unable to run the samples.

6.5.5 Conclusion

Ultimately, I argue that the omission of the chemical pretreatment step was not a serious problem for my results. Pretreatment did not alter how data were interpreted and by not pre-treating samples, I can easily compare my results to recent research in the area (e.g. Sparkes, 2017). The data offsets are similar to other published studies (e.g., Garvie-Lok *et al.*, 2004; Skippington *et al.*, 2019), including those that used the small amount of variation as a condition for not pre-treating sample material (e.g., Chenery *et al.*, 2012, p.310). By omitting chemical pretreatment, I was able to reduce sample mass loss by an average of 23.9% while avoiding inadvertently modifying the natural state of each sample. Based on these findings, I feel comfortable presenting data obtained from materials that were not chemically pretreated.

6.6 Summary

This chapter presents an overview of the methods chosen for my analysis, as well as the rationale and procedures followed for sample selection, preparation, and processing. Efforts were taken to ensure that each ovicaprid and rodent sample represents a unique individual and that all samples were obtained from secured contexts. Although not all collected samples could be processed, I am confident that the data obtained is representative of a well-rounded sample of different management styles at the three contexts. All methodologies were selected to prevent sample loss and ensure sampling accuracy. The pretreatment pilot study served as a control measure to determine how pretreatment impacted the recorded stable isotope values. The established offset or variable values have not impeded my ability to analyze data trends in this study or compare data to other research. Methodologies for carbon, oxygen, and strontium isotope analysis were also chosen to ensure that my data trends are easily comparable to other studies. I have also set the foundation for how data are interpreted in Chapter 7.

CHAPTER 7: Results

This chapter presents all findings for my project, which have been separated into three sections. The first section presents the environmental samples and locally available strontium isotope values broken down according to area (7.1). I include an overview of the data recorded from modern soil and plant samples, archaeological small-bodied mammal dental samples, and modern Anavra lamb samples to summarize the regional variations in stable isotope values recorded in other studies (Chapter 5). Ultimately, I use this section to establish local and non-local isotope ranges. The second section presents the stable carbon, oxygen, and strontium isotope data recorded in modern and archaeological sheep and goat dental samples from Anavra, Kastro Kallithea, and Pharsalos (7.2). I have included an overview of the number of samples taken for each tooth. In Section 7.3 I discuss testing errors from the study. Although the chapter will conclude with a brief summary of findings, later chapters will discuss trends in the data and the overall interpretations.

7.1 Regional Isotope Sample Estimates

7.1.1 Southeast Thessaly

This section summarizes the data for naturally occurring strontium isotope values in southeast Thessaly. It is organized according to sample location and includes materials sampled as part of this study, samples from Panagiotopoulou *et al.* (2018), an isotope range calculated by Sparkes (2017, p.144), and combined calculated ranges where available (recall Chapter 5). Table 7.24 lists the samples used to establish each range, and Appendix 7.8 presents the calculations for upper and lower limits (mean ± 2SD) of each range where available. I integrate these range values with surface geology[49] and bedrock age estimates (recall Chapter 5, Section 5.5) to create a rough estimate of regionally available strontium isotope values. Figure 7.43 has been modified from the predictive geological map illustrated in Figure 5.32 to include the samples tested as part my project.

[49] Maps are from EDGI and represent the lithology age according to European data harvested from national INSPIRE WFS for geologic units.

Table 7.24 Strontium isotope ranges for the region based on samples and bedrock age estimates (Fig. 7.1). Calculations shown in Appendix 7.1 (mean ± 2 SD).

Area	Sample ID	Calculated Range
Melitaia	P02	0.7084
Mount Óthrys	P01	0.7094
Anavra	L01-L09	0.7081 – 0.7086
Kastro Kallithea	R01-R06	0.7082 – 0.7090
Pharsalos	R07, R08, FS03s, F04s, FS11s	0.7081 – 0.7090
Chloe	CH03, CH09	0.7087 – 0.7090
	CH11	0.7103
	CH12	0.7095
Halos	HL01, HL04	0.7076 – 0.7082
	HL14, HL18	0.7087 – 0.7090
New Halos	36 Human Samples	0.7081 – 0.7093

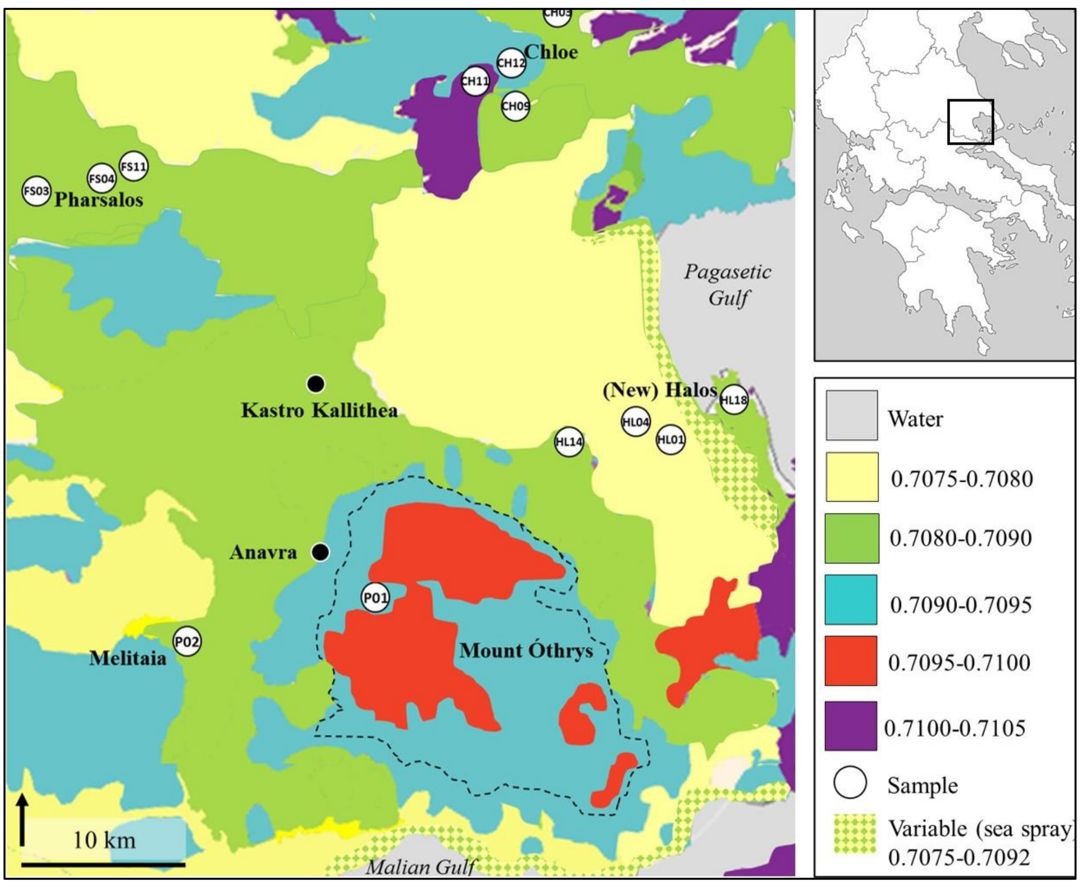

Figure 7.43 Geological map of sample locations and regions discussed in text. Estimated $^{87}Sr/^{86}Sr$ ranges are based on surface geology (1:1M), bedrock age estimates, and materials sampled from different sites in the area (Table 7.24, Appendix 7.8).

Table 7.25 Strontium isotope values recorded from samples of soil (D) and plant (P) collected from around Melitaia.

Sample	$^{87}Sr/^{86}Sr$	Error
D01	0.714171	± 0.000010
D03	0.706575	± 0.000008
P02	0.708441	± 0.000008

7.1.2 Melitaia

Soil (D01) and plant (P02) samples were collected from the Melitaia acropolis, and an additional soil (D03) sample was collected near the acropolis on the roadside leading to a local quarry (Fig 7.43; Table 7.25).

P02: P02 was sampled from a Kermes Oak, which is a large tree with a deep root system. Roots that stretch further into the ground reduce the amount of potential contamination caused by surface level erosion or modern influences and this plant sample should reflect local bedrock strontium on the acropolis. According to soil age estimates and the bedrock geology in the region around Melitaia, strontium isotope values from P02 are a good indication of the available geological strontium on the acropolis.

D01/D03: In contrast to the plant sample, soil samples D01 and D03 are inconsistent with expectations based on the local geology and even the Kermes oak grown in the region (P02). D01 has values well outside the range for anything in the immediate region, whereas D03 has values lower than anything in the immediate region. Surface soils may include contaminants, especially modern fertilizers and foreign soils introduced by human activities like construction (e.g., road development), and ultimately may not reflect the naturally occurring local strontium values present in the Hellenistic period. Although attempts were made to avoid anthropogenic contamination, it is clear from the mismatch between the local geology and the strontium isotope values measured on both soil samples that this was unsuccessful. Due to presumed issues with contamination, these soil samples will not be used to discuss regional strontium variation.

Summary: Based on the plant sample, local bioavailable strontium $^{87}Sr/^{86}Sr$ at Melitaia was around 0.7084, consistent with expectations based on the local surface geology. Based on that geology, a range of bioavailable strontium isotope values of about 0.7080 to 0.7090 is expected. Nearby regions to the west should offer both lower (0.7075 to 0.7080) and higher (0.7090 to 0.7095) bioavailable strontium isotope values (see Figure 7.43).

Table 7.26 Strontium isotope values recorded from samples of soil (D) and plant (P) collected from around Mount Óthrys.

Sample	^{87}Sr / ^{86}Sr	Error
D02	0.719988	± 0.000004
P01	0.709384	± 0.000004

7.1.3 Mount Óthrys

Mount Óthrys has numerous peaks and plateaus that vary in age depending on altitude. Samples of soil (D02) and plant (P01) were collected near a windmill site at a low to moderate elevation (Fig 7.43; Table 7.26).

P01: P01 was sampled from a Wild Pear tree, which has an extensive deep root system that stretches further into the ground and reduces potential surface level contamination. This sample should reflect local bedrock strontium on Mount Óthrys. According to soil age estimates and the bedrock geology for this low to moderate elevation of Mount Óthrys (0.7090 to 0.7095), strontium isotope values from P01 are a good indication of bioavailable strontium $^{87}Sr/^{86}Sr$ for this area.

D02: Soil sample D02 is inconsistent with expectations for the local geology for any region of Mount Óthrys. The values are also higher than anything in the immediate region. Similar to D01 and D03, surface soils may include contaminants that alter the strontium isotope values. Despite attempts to avoid anthropogenic contamination, D02 likely includes foreign soils introduced by human activities like construction (e.g., windmill, road development), and ultimately may not reflect naturally occurring local strontium isotope values present in the Hellenistic period. Similar to D01 and D03, the value recorded from D02 was not included in the Mount Óthrys strontium range.

Summary: Based on the plant sample, local bioavailable strontium $^{87}Sr/^{86}Sr$ at this low to moderate elevation of Mount Óthrys is around 0.7094. A wider range of bioavailable strontium isotope values ranging as high as 0.7105 and as low as 0.7090, is expected depending on location and altitude (see Figure 7.43).

Table 7.27 Strontium isotope samples and estimated range (mean ± 2SD) from a modern lamb molar (L01) from Anavra.

Sample	^{87}Sr / ^{86}Sr	Error	Estimated Range (Mean ± 2 SD)
L01	0.708400	± 0.000006	0.7081-0.7086
	0.708385	± 0.000007	
	0.708407	± 0.000007	
	0.708466	± 0.000007	
	0.708149	± 0.000008	

7.1.4 Anavra

Sequential molar enamel samples (L01) were collected from a modern lamb that lived in Anavra *in utero* and during the first three months of its life. The range of values recorded from L01 are presented in Table 7.27. A more thorough discussion of this series of isotope values is presented in section 7.2.1.

L01: The strontium isotope values of the L01 enamel segments are consistent with the expected range for the area directly around Anavra based on its geology (Fig. 7.43). Although there is some variation in the isotope values, suggesting movement after birth and prior to death (discussed below), information provided when the lamb was procured indicates that the animal remained in the Anavra region. Thus the values of the enamel segments represent various spots in this isoscape and are likely are a good indication of bioavailable strontium $^{87}Sr/^{86}Sr$ values for the area.

Summary: Based on the five enamel samples, the local strontium isotope range at Anavra is at least between 0.7081 and 0.7086, the range defined by the mean of the five values ± 2SD. The Anavra area shares a similar geological age with Kastro Kallithea and Pharsalos, so we would expect similar strontium isotope values. However, the geology of the area immediately uphill predicts higher $^{87}Sr/^{86}Sr$ values. Because of this, the bioavailable strontium isotope range in the wider Anavra region is expected to be wider, with a higher upper limit.

Table 7.28 Isotope values and estimated range (mean ± 2SD) from small-bodied mammal samples (R) collected from Kastro Kallithea.

Sample	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	Error	Estimated Range (Mean ± 2 SD)
R01	-9.81	-6.73	0.708664	± 0.000010	0.7082-0.7090
R02	-8.75	-7.96	0.708702	± 0.000004	
R03	-8.87	-7.50	0.708771	± 0.000011	
R04	-8.21	-9.14	0.708367	± 0.000008	
R05	N/A*	N/A*	0.708421	± 0.000010	
R06	-9.72	-7.57	0.708868	± 0.000007	

* Sample failed to produce lab-acceptable isotope values and there were insufficient materials for a retest

7.1.5 Kastro Kallithea

Teeth from individual mice (R01-R03, R06), rat (R04), and a shrew (R05) were collected from secure Hellenistic contexts at Building 10 of Kastro Kallithea to establish the local strontium isotope range for the area (Table 7.28).

Carbon and Oxygen: The stable carbon isotope values of R01 through R06 indicate a range of available food sources, presumably from agricultural goods grown in the region (in the case of rat R04 potential foods also include insects and various refuse around the site). The $\delta^{13}C$ values are consistent with a diet focused on C_3 plant resources (recall from Chapter 5 that the $\delta^{13}C$ range for a C_3 consumer can be between -20‰ and -8‰). The values are also similar to those of the Pharsalian small-bodied mammals (below). The mouse and rat $\delta^{18}O$ values should reflect the animals' diet and drinking water but are specific to small-bodied mammals, so are not directly comparable to the ovicaprid data and will not be used to discuss them.

Strontium: The range of strontium isotope values calculated from all small-bodied mammals was consistent with expected values for the area around Kastro Kallithea based on its geology (Fig. 7.43). There are small differences between individual rodents, which may be related to species physiology or food access. For example, the lowest $^{87}Sr/^{86}Sr$ value was found for R04 and the highest was found for R06. Both individuals were recovered from the same area in Building 10. R04 (rat) represents a rodent that is predominantly omnivorous and may have consumed waste from a variety of human foods as well as insects, whereas R06 (mouse) represents a rodent that mostly eats seeds, grains, and other harvested vegetation. Their different

$^{87}Sr/^{86}Sr$ values may reflect the different microregions that food sources were grown or collected from over the course of different seasons and years.

Summary: Based on all six small-bodied mammal samples, the $^{87}Sr/^{86}Sr$ values of local bioavailable strontium at Kastro Kallithea should be at least between 0.7082 and 0.7090 (Table 7.24). This range is consistent with expectations based on local geology (see Figure 7.43). Further sampling may help to confirm and refine this range.

Table 7.29 Isotope values and estimated range (mean ± 2SD) from small-bodied mammal samples (R) collected from Pharsalos.

Sample	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	Error	Estimated Range (Mean ± 2 SD)
R07	-10.79	-5.66	0.708676	± 0.000008	0.7084 – 0.7088
R08	-11.79	-7.11	0.708526	± 0.000006	

7.1.6 Pharsalos

Teeth from individual shrew (R07) and hare (R08) samples were collected from secure Hellenistic deposits of the Arsenopoulos Plot of Pharsalos to add to the information on the local strontium isotope range for the area (Table 7.29).

Carbon and Oxygen: The stable carbon isotope values are consistent with small-bodied mammal values from Kastro Kallithea. R07 and R08 appear to have consumed C_3 plant sources. Their $\delta^{18}O$ values are similar to those of the other small-bodied mammals at Kastro Kallithea. As with the Kallithea samples, these $\delta^{18}O$ values are species specific and will not be used to discuss the ovicaprid oxygen isotope data.

Strontium: The recorded strontium isotope values of both small-bodied mammals was consistent with the expected range for the area around Pharsalos based on its geology. They are also consistent with the results reported by Panagiotopoulou *et al.* (2018). By combining the values of R07 and R08 with the values from local samples published by Panagiotopoulou *et al.* (2018), I was able to establish a range of local bioavailable strontium $^{87}Sr/^{86}Sr$ values (Table 7.24; Appendix 7.8). Table 7.29 only lists the estimated range according to the samples in my study.

Summary: Based on small-bodied mammal samples and published snail shell data, the local strontium isotope range at Pharsalos is at least between 0.7081 and 0.7090 (Table 7.24). Further research may help refine this range in the future.

7.1.7 Summary of Regional Strontium Isotope Values

Samples from Melitaia, Anavra, Kastro Kallithea, and Pharsalos all share a similar strontium isotope range between 0.7080 and 0.7090, which likely extends into other regions of southeast Thessaly (Fig. 7.43). Complex geological maps for the region (recall Chapter 5) suggested that there could have been microregional variation between these sites; however this is not what the current data suggest. Based on the sample from Mount Óthrys and published strontium isotope data from Chloe (Panagiotopoulou *et al.*, 2018), there are clear strontium isotope demarcations between zones of different elevations.

Similarly, snail shell data from Halos (Panagiotopoulou *et al.*, 2018) suggest that the Almiros and Sourpi plains have lower strontium isotope values than areas of higher elevation. Sparkes (2017) determined that the local human $^{87}Sr/^{86}Sr$ range for New Halos was between 0.7081 and 0.7093. This range is higher than expected based on the local geology alone, likely due to the effects of sea spray. Although geological maps would not indicate the effects of sea spray, proximity to the coast likely influences the available strontium, with food sources in this area impacted by modern seawater ($^{87}Sr/^{86}Sr$: 0.7092) (Bentley, 2006b) (Fig. 7.24). Although the plains between Halos and Kastro Kallithea likely have lower bioavailable strontium (0.7075 – 0.7080), animals grazing directly on the coast may have elevated strontium isotope values reflecting the sea spray effect.

More samples from different areas and altitudes will eventually help to create a better strontium isotopic picture of Thessaly. Currently the isoscape data are sufficient to discuss local, non-local, and mobility-based trends in ovicaprid samples. Additionally, I can complement these data by using the stable carbon and oxygen isotope values recorded by each individual. Although an animal may not be moving outside of a discernible isoscape, dietary trends can be used to indicate different management practices.

7.2 Ovicaprids (Sheep and Goats)

This section summarizes the data recorded from ovicaprid samples. Each section includes the measured carbon, oxygen, and strontium isotope values, a graphic illustration of the data, and a brief summary of potential interpretations of the data.

Table 7.30 Carbon, oxygen, and strontium isotope values of sequentially sampled mandibular molar (m_1) enamel of a modern Anavra lamb (L01). See Figure 7.44.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
L01	15.0	-11.79	-7.11	0.708400	± 0.000006
L02	13.5	-11.61	-6.16	-	-
L03	12.0	-11.48	-5.84	0.708385	± 0.000007
L04	10.5	-10.73	-5.47	-	-
L05	9.0	-10.46	-5.75	0.708407	± 0.000007
L06	7.5	-9.35	-5.50	-	-
L07	6.0	-7.70	-5.17	0.708466	± 0.000007
L08	4.5	-7.76	-5.05	-	-
L09	3.0	-9.21	-5.61	0.708149	± 0.000008

7.2.1 L01

The Anavra lamb (L01) was three months of age at death in June, and the m_1 spans roughly five months worth of diet. The data for L01 are listed in Table 7.30 and Figure 7.44. The sequentially sampled enamel segments likely represent the development period between December and April (as per Míšek, 1999). Reading Figure 7.44 from right to left, the earliest period is around 15.0 mm and the latest period is around 3.0 mm. The dietary values recorded in the enamel samples are from the Anavra region during this period (Fig. 7.43).

Carbon: The carbon isotope signature is consistent with a diet of C_3 plant sources although the primary diet source varies considerably ($\Delta^{13}C$: 4.09‰) during gestation, birth (~7.5 mm), and weaning.

Oxygen: The molar tooth first started forming in December, when atmospheric oxygen is depleted in ^{18}O relative to summer humidity. By early spring, the atmospheric values steadily increase in $\delta^{18}O$ values. The brief decrease in $\delta^{18}O$ values at the 7.5 mm mark and at 3.0 mm may be related to birth, weaning, or water intake changes for the mother.

Strontium: The lamb was in Anavra for the duration of growth and development *in utero* and prior to slaughter. The $^{87}Sr/^{86}Sr$ values represent the locally bioavailable values for Anavra. The shift in $^{87}Sr/^{86}Sr$ values recorded after three months (6.0 mm) correlate with local movement within Anavra. Local strontium isotope values appear to decrease as one moves west from Anavra (Fig. 7.43). Overall strontium variation ($\Delta^{87}Sr/^{86}Sr$) is 0.000317.

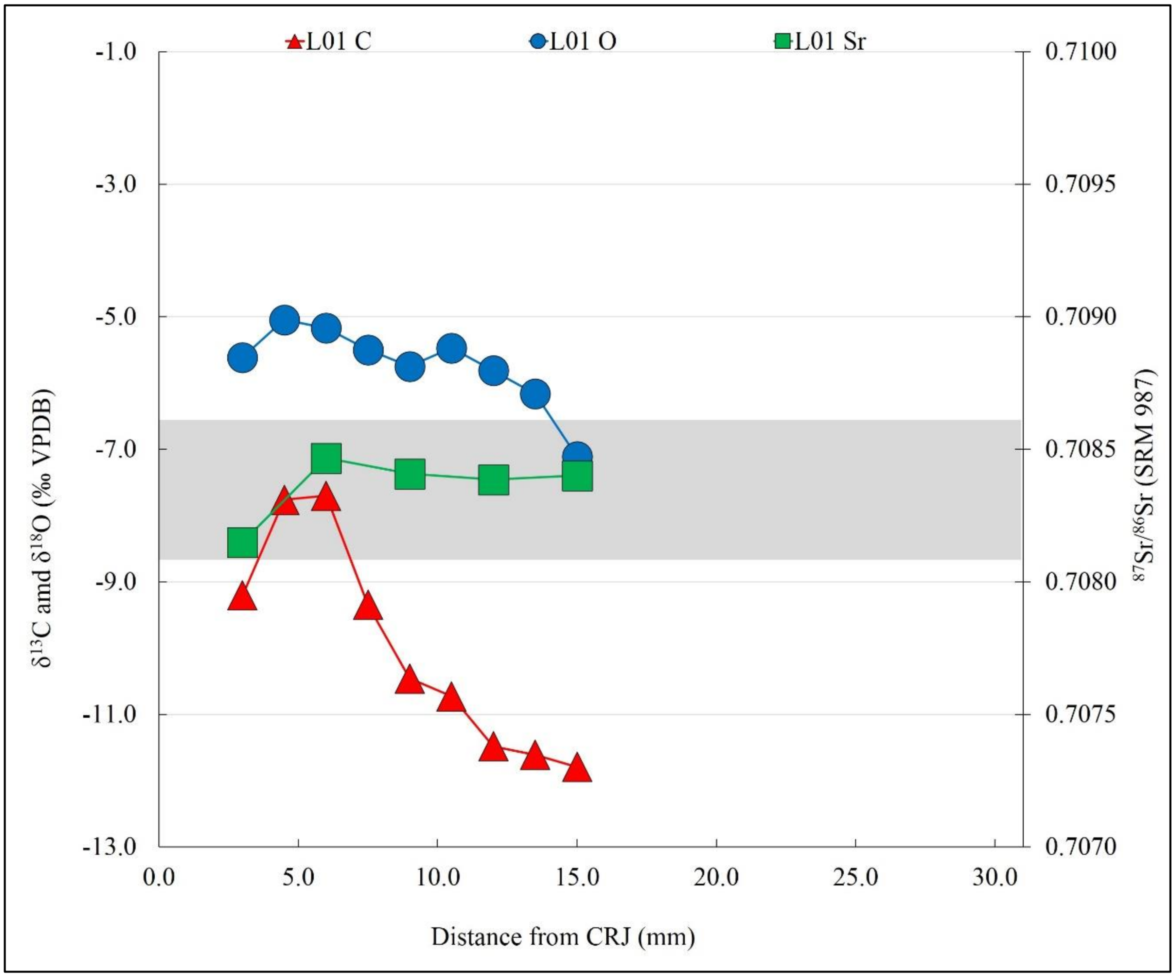

Figure 7.44 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from L01 molar enamel at different points along the mesial lobe from the crown root juncture (CRJ) (mm). The local strontium isotope range for Anavra is shown as a grey block. Refer to Table 7.30.

Table 7.31 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG03. See Figure 7.45.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S1	12.0	-10.03	-3.74	0.708753	± 0.000006
S2	10.5	-9.95	-4.07	-	-
S3	9.0	-10.48	-3.69	0.708704	± 0.000011
S4	7.5	-10.08	-4.36	-	-
S5	6.0	-10.00	-3.45	0.708691	± 0.000005
S6	4.5	-9.83	-4.18	-	-
S7	3.0	-9.52	-4.38	0.708741	± 0.000015
S8	1.5	-9.62	-2.99	-	-
S9	0.0	-9.65	-4.73	0.708774	± 0.000010

7.2.2 SG03

The data for SG03, a sheep LM_3 from Kastro Kallithea, span roughly eight months worth of diet and are listed in Table 7.31 and Figure 7.45.

Carbon: The carbon isotope signature is consistent with a diet of C_3 plant sources and does not change considerably over the time period of the tooth's formation ($\Delta^{13}C$: 0.96‰).

Oxygen: Although a full year is not represented by the enamel analysed, it is still clear that the oxygen isotope signature is not consistent with the sinusoidal curve expected for a seasonal signal. Instead the enamel appears to have less stable oxygen isotope variation ($\Delta^{18}O$: 1.74‰). This trend, and other trends noted in my data set will be discussed more in Chapter 8.

Strontium: The strontium isotope values do not vary considerably ($\Delta^{87}Sr/^{86}Sr$: 0.000083) over the eight months of diet recorded and are consistent with the local Kastro Kallithea range.

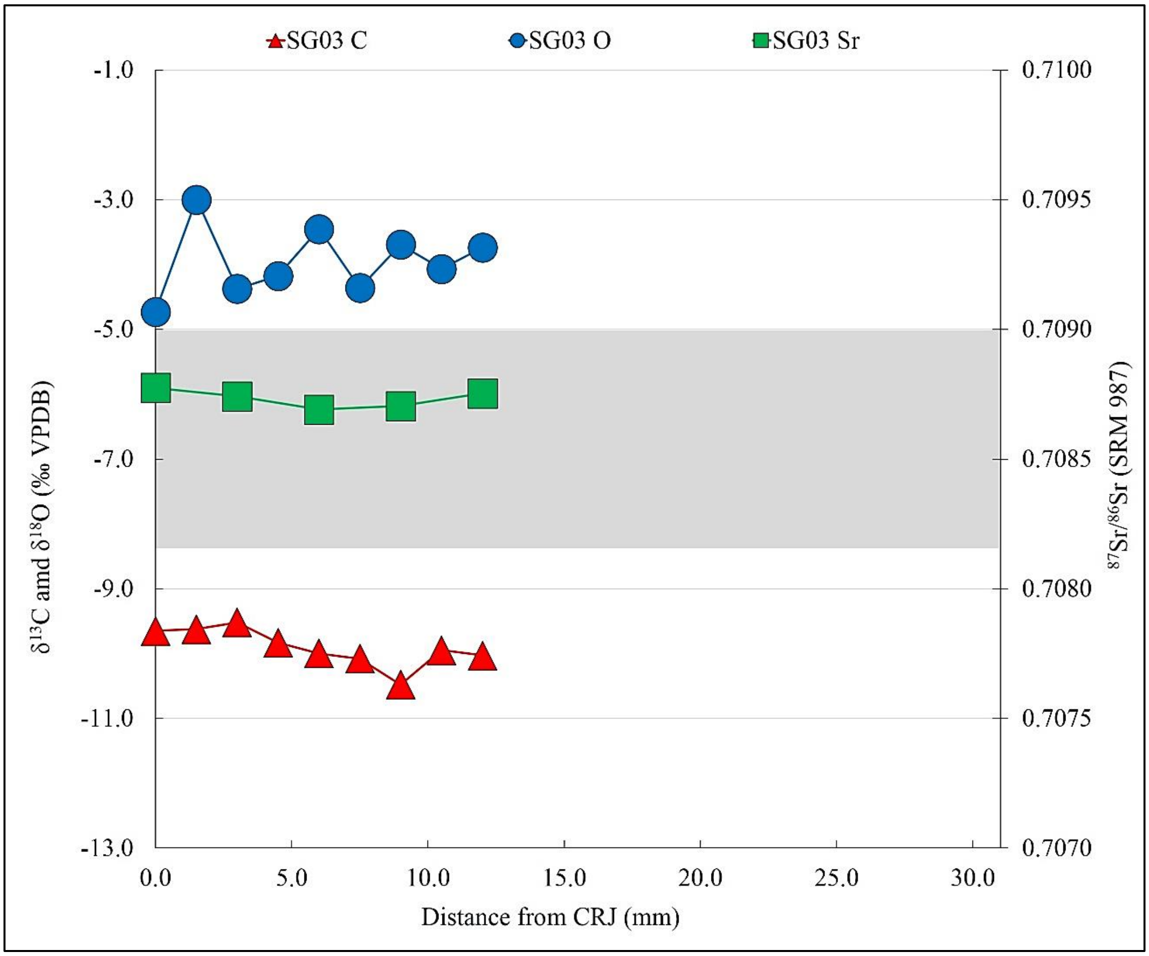

Figure 7.45 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG03 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.31.

Table 7.32 Carbon and oxygen isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG06. See Figure 7.46.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)
S10	19.0	-9.60	-4.45
S11	17.5	-9.37	-4.67
S12	16.0	-9.23	-3.23
S13	14.5	-9.13	-2.86
S14	13.0	-8.92	-2.23
S15	11.5	-9.01	-1.77
S16	10.0	-8.96	-2.57
S17	8.5	-9.45	-3.98
S18	7.0	-10.28	-3.95
S19	5.5	-10.55	-4.87
S20	4.0	-9.14	-5.21

7.2.3 SG06

The data for SG06, a sheep LM_3 from Kastro Kallithea, span roughly nine to 13 months worth of diet, and are listed in Table 7.32 and Figure 7.46. This sample was originally chosen for analysis but was not completed due to financial concerns; currently only carbon and oxygen isotope analysis has been completed.

Carbon: The carbon isotope signature is consistent with a diet of C_3 plant sources. The carbon isotope variation ($\Delta^{13}C$) is 1.63‰ and occurs between 8.5 mm and 4.0 mm, which may correlate with the onset of winter months.

Oxygen: The oxygen isotope signature appears as a sinusoidal (seasonal) curve. Summer likely correlates with the highest value at 13.0 mm, whereas winter likely correlates with the low values at the 19 – 17.5 mm and 5.5 – 4.0 mm marks. The variation between summer and winter months ($\Delta^{18}O$) is 3.44‰.

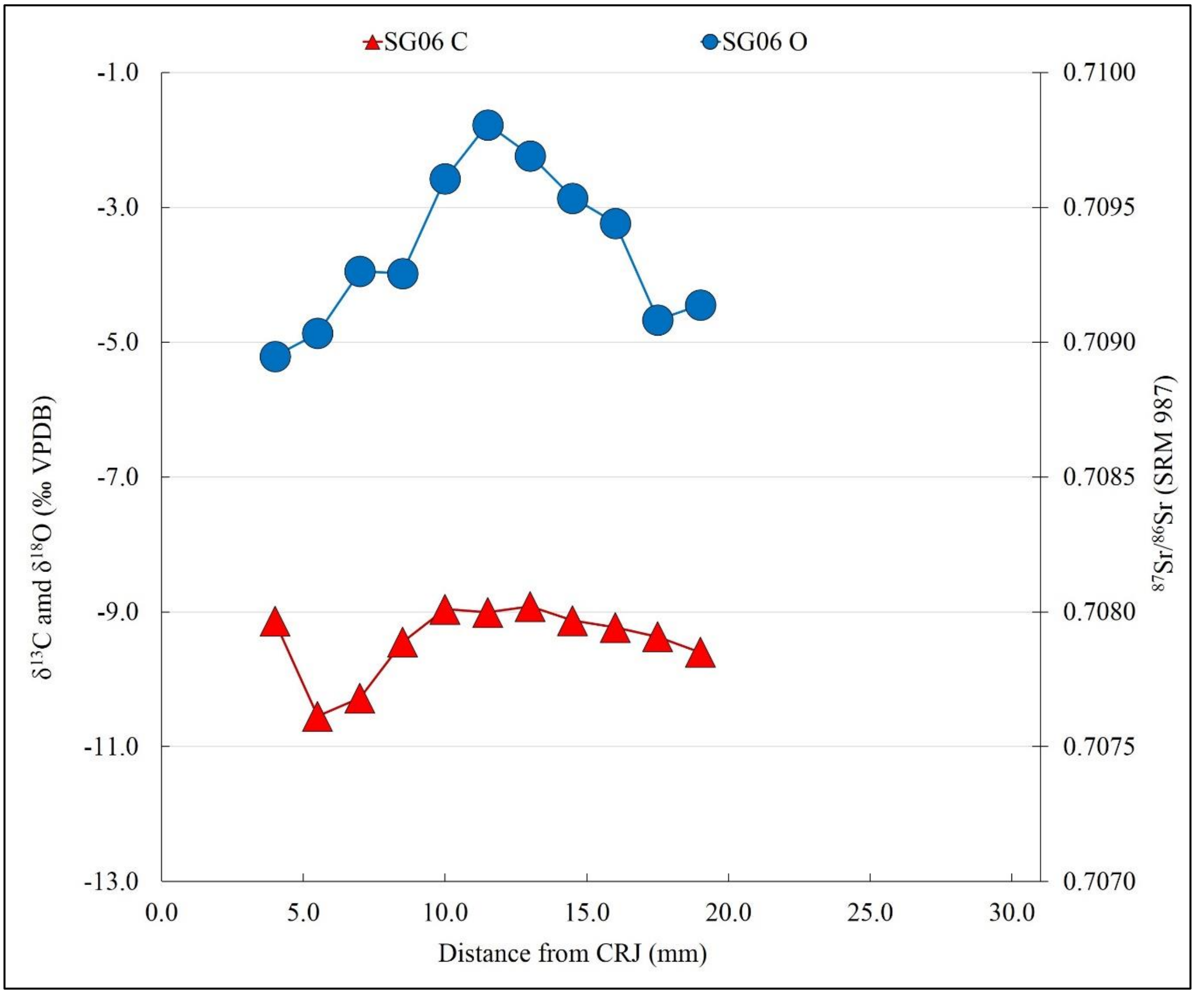

Figure 7.46 Sequential $\delta^{13}C$ and $\delta^{18}O$ values measured from SG06 molar enamel at different points along the mesial lobe from the CRJ (mm). Refer to Table 7.32.

Table 7.33 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG08. See Figure 7.47.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
G1	23.5	-10.98	-4.92	0.708340	± 0.000007
G2	22.0	-10.19	-5.67	-	-
G3	20.5	-10.12	-5.69	0.708366	± 0.000007
G4	19.0	-8.95	-5.88	-	-
G5	17.5	-9.30	-5.85	0.708311	± 0.000016
G6	16.0	-10.86	-5.04	-	-
G7	14.5	-10.21	-4.62	0.708319	± 0.000012
G8	13.0	-10.04	-4.38	-	-
G9	11.5	-10.10	-4.08	0.708367	± 0.000009
G10	10.0	-10.34	-3.95	-	-
G11	8.5	-9.69	-3.76	0.708307	± 0.000004
G12	7.0	-9.95	-3.03	-	-
G13	5.5	-10.56	-2.80	0.708302	± 0.000007
G14	4.0	-9.84	-3.29	-	-
G15	2.5	-9.41	-4.32	0.708266	± 0.000006

7.2.4 SG08

The data for SG08, a goat RM_3 from Kastro Kallithea, span roughly 14 months worth of diet and are listed in Table 7.33 and Figure 7.47.

Carbon: The carbon isotope signature is consistent with a diet of C_3 plant sources, and $\Delta^{13}C$ is 2.03‰. The highest $\delta^{13}C$ value occurs during the apparent winter months (19.0 – 17.5 mm).

Oxygen: The oxygen isotope signature appears as a sinusoidal (seasonal) curve (Fig. 7.47). Summer likely correlates with the period at 5.5 mm, whereas winter correlates with the period of 19 – 17.5 mm. Based on the length of the tooth there should be roughly 14 months of diet recorded, however the seasonal trends suggest that only 12 months are observed, from autumn (23.5 mm) to autumn (2.5 mm). The overall $\Delta^{18}O$ is 3.08‰.

Strontium: The strontium isotope values do not vary considerably over the 14 months ($\Delta^{87}Sr/^{86}Sr$: 0.000101) and are consistent with the Kastro Kallithea range.

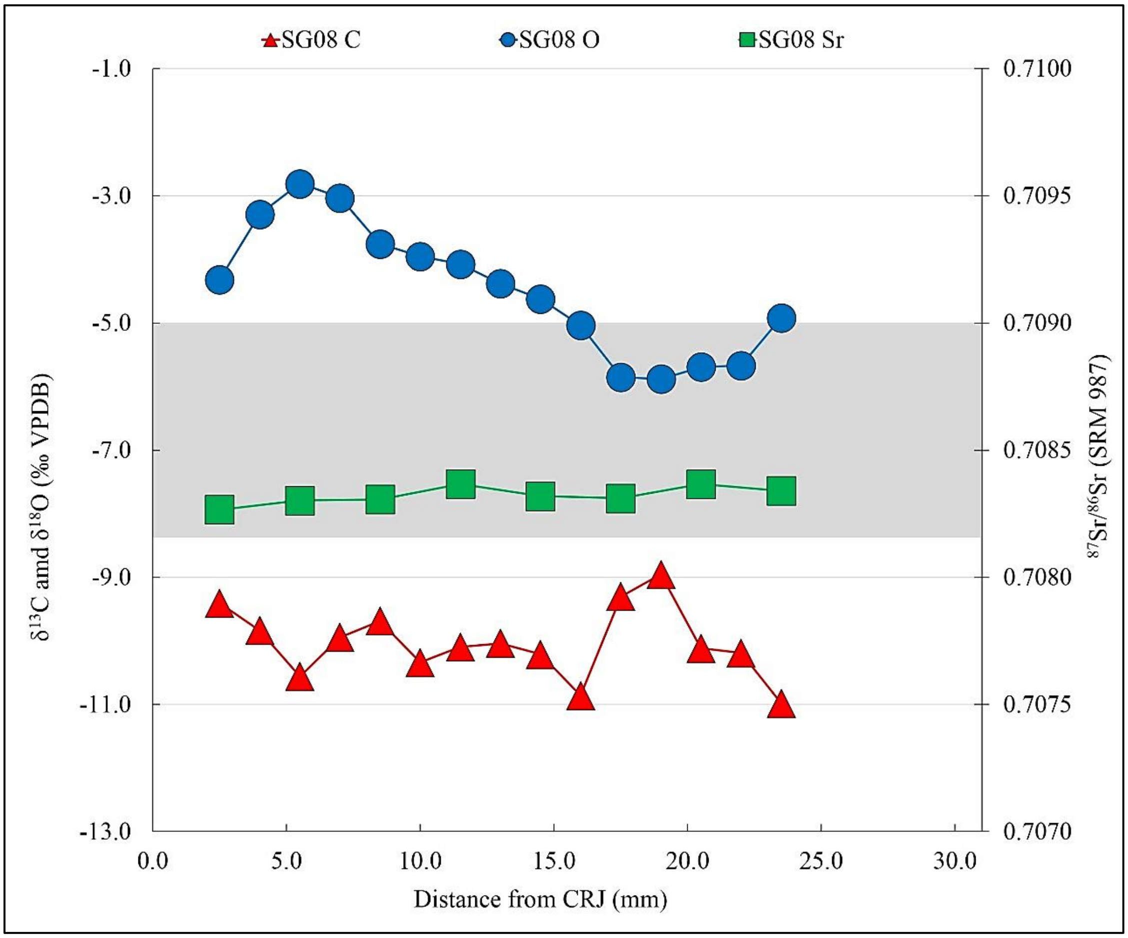

Figure 7.47 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG08 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.33.

Table 7.34 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG11. See Figure 7.48.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S31	30.0	-8.53	-4.04	0.709310	± 0.000007
S32	28.5	-8.59	-4.50	-	-
S33	27.0	-8.94	-4.67	0.709327	± 0.000007
S34	25.5	-9.58	-4.92	-	-
S35	24.0	-9.30	-5.03	0.709337	± 0.000011
S36	22.5	-9.18	-5.24	-	-
S37	21.0	-9.80	-5.45	0.709494	± 0.000010
S38	19.5	-9.66	-5.53	-	-
S39	18.0	-10.77	-5.51	0.709569	± 0.000006
S40	16.5	-10.72	-5.60	-	-
S41	15.0	-10.60	-5.92	0.709671	± 0.000007
S42	13.5	-11.08	-5.92	-	-
S43	12.0	-10.54	-5.72	0.709668	± 0.000008
S44	10.5	-10.48	-4.97	-	-
S45	9.0	-10.88	-4.69	0.709735	± 0.000003
S46	7.5	-11.30	-4.30	-	-
S47	6.0	-10.37	-4.29	0.709763	± 0.000003
S48	4.5	-10.21	-4.27	-	-
S49	3.0	-9.99	-4.56	0.709758	± 0.000005
S50	1.5	-9.31	-5.27	-	-
S51	0.0	-9.78	-6.00	0.709583	± 0.000005

7.2.5 SG11

The data for SG11, a sheep LM_3 from Kastro Kallithea, span roughly 20 months worth of diet, and are listed in Table 7.34 and Figure 7.48.

Carbon: The carbon isotope signature is consistent with a diet of C_3 plant sources, and $\Delta^{13}C$ is 2.77‰. The higher $\delta^{13}C$ values appear to correlate with the summer months of the first year (30.0 – 25.5 mm) and the fall months of the second year (1.5 mm) relative to the winter and spring months of the second year (between 13.5 mm and 7.5 mm).

Oxygen: The oxygen isotope signature appears as a sinusoidal (seasonal) curve for the second year (~16.5 – 0 mm), but as a gradual or more flattened curve during the first year (30.0 – 16.5 mm). The second summer likely correlates with the period of high $\delta^{18}O$ at 6.0 mm to

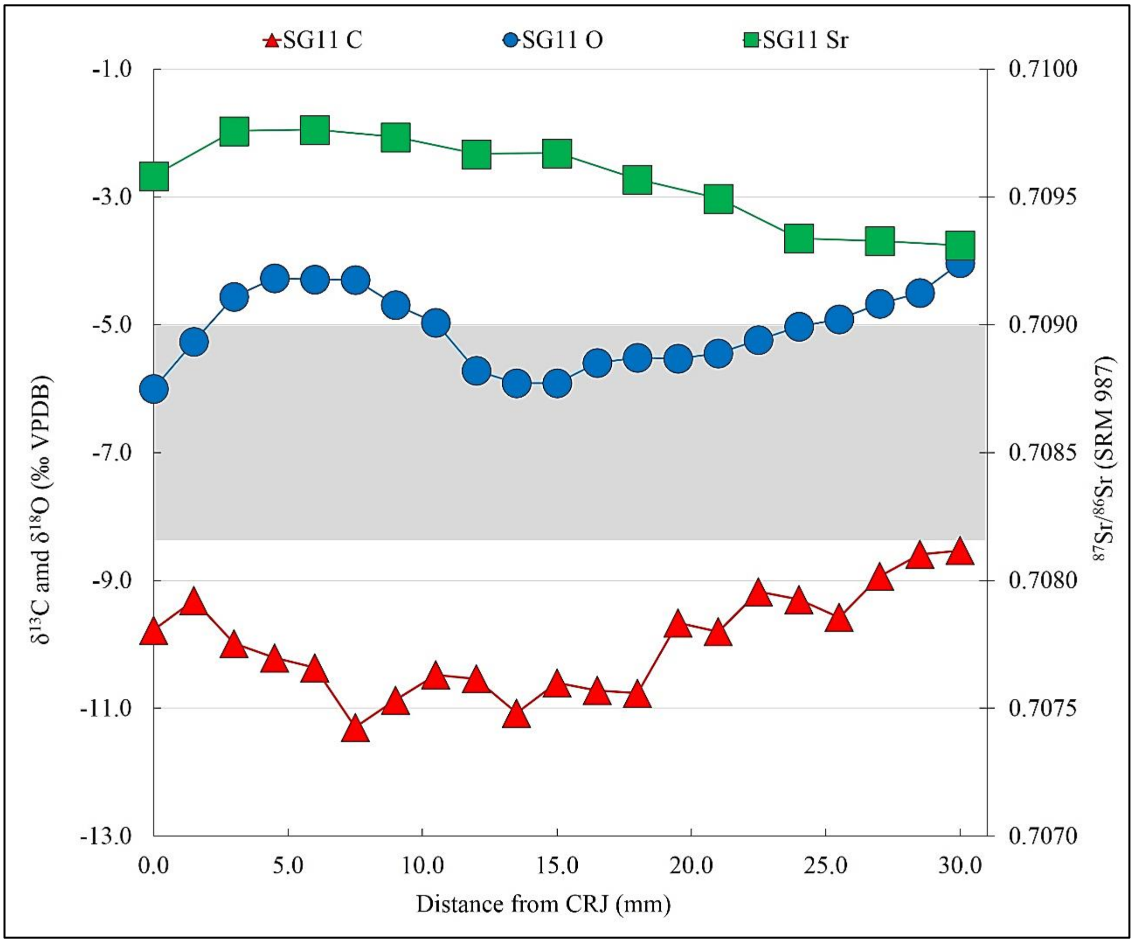

Figure 7.48 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG11 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.34.

4.5 mm, the first winter likely with the low values at the 15.0 mm to 13.5 mm marks, and the second winter likely with the 0 mm mark. The overall $\Delta^{18}O$ is 1.96‰.

Strontium: The strontium isotope values show variability across the measured period ($\Delta^{87}Sr/^{86}Sr$: 0.000453), rising gradually over much of its length. The $^{87}Sr/^{86}Sr$ range is higher than the local Kastro Kallithea range. Based on the estimates laid out in Figure 7.43 and Table 7.24, the values recorded in SG11 are similar to those estimated for the mid-to low altitude (year 1) and highlands (year 2) of Mount Óthrys.

Table 7.35 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG16. See Figure 7.49.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
G17	23.0	-7.59	-3.84	0.708635	± 0.000004
G18	21.5	-7.79	-2.16	-	-
G19	20.0	-7.58	-3.02	0.708730	± 0.000015
G20	18.5	-7.71	-2.95	-	-
G21	17.0	-7.78	-3.94	0.708728	± 0.000013
G22	15.5	-7.77	-3.85	-	-
G23	14.0	-8.12	-3.56	0.708697	± 0.000008
G24	12.5	-8.30	-2.84	-	-
G25	11.0	-8.37	-3.71	0.708666	± 0.000008
G26	9.5	-8.58	-3.89	-	-
G27	8.0	-9.22	-4.13	0.708544	± 0.000008
G28	6.5	-9.71	-2.51	-	-
G29	5.0	-10.96	-3.00	0.708635	± 0.000006
G30	3.5	-11.56	-3.90	-	-
G31	2.0	-10.16	-3.64	0.708636	± 0.000008
G32	0.5	-9.00	-4.01	-	-

7.2.6 SG16

The data for SG16, a goat RM_3, span roughly 15 months worth of diet, and are listed in Table 7.35 and Figure 7.49.

Carbon: The carbon isotope signature varies considerably over the 15 months ($\Delta^{13}C$: 3.98‰). The pattern during the first year may indicate a diet of C_3 and C_4 plant sources (23.0 – 9.5 mm) followed by a change in diet that was likely only of C_3 sources (9.5 – 0.5 mm).

Oxygen: The oxygen isotope signature is not consistent with a seasonal (sinusoidal) signal; instead, values fluctuate every few months. The overall $\Delta^{18}O$ is 1.97‰.

Strontium: The strontium isotope values do not vary considerably ($\Delta^{87}Sr/^{86}Sr$: 0.000186) over the measured period and the $^{87}Sr/^{86}Sr$ values are consistent with a local Kastro Kallithea range.

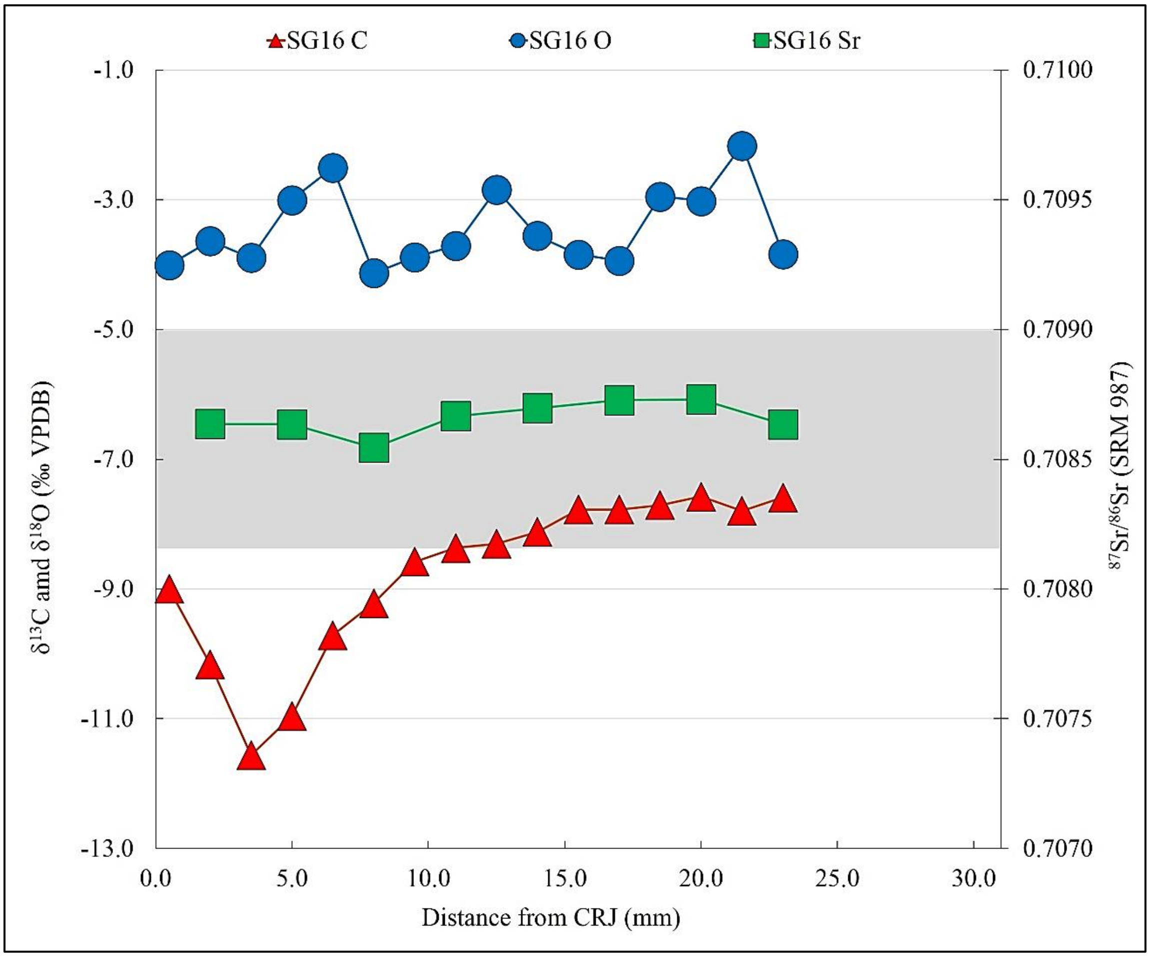

Figure 7.49 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG16 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.35.

Table 7.36 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG21. See Figure 7.50.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S52	26.0	-8.80	-3.00	0.708906	± 0.000003
S53	24.5	-8.57	-3.66	-	-
S54	23.0	-8.87	-3.90	0.708847	± 0.000004
S55	21.5	-9.21	-4.54	-	-
S56	20.0	-9.62	-5.23	0.708798	± 0.000012
S57	18.5	-10.34	-5.49	-	-
S58	17.0	-10.78	-5.68	0.708799	± 0.000004
S59	15.5	-10.35	-5.60	-	-
S60	14.0	-11.13	-5.23	0.708791	± 0.000010
S61	12.5	-10.46	-5.24	-	-
S62	11.0	-10.00	-5.39	0.708837	± 0.000003
S63	9.5	-9.11	-4.86	-	-
S64	8.0	-9.53	-4.21	0.708798	± 0.000004
S65	6.5	-8.69	-4.57	-	-
S66	5.0	-8.32	-5.67	0.708641	± 0.000018

7.2.7 SG21

The data for SG21, a sheep LM_3 from Kastro Kallithea, span roughly 14 months worth of diet, and are listed in Table 7.36 and Figure 7.50.

Carbon: The carbon isotope signature is mostly consistent with a diet of C_3 plant sources, although the diet may have also included C_4 plants sources during the first (26.0 – 23.0 mm) and last (6.5 – 5.0 mm) summers recorded. The overall $\Delta^{13}C$ is 2.81‰.

Oxygen: The oxygen isotope signature is consistent with a seasonal (sinusoidal) signal. The first summer occurs between 26.0 mm and 24.5 mm and the second around 8.0 mm. There is some variability in oxygen isotope values during the fall, winter, and spring months, but winter likely occurs around the 15.5 mm mark. The overall $\Delta^{18}O$ is 2.68‰.

Strontium: The strontium isotope values do not vary considerably ($\Delta^{87}Sr/^{86}Sr$: 0.000265) over the measured period and the $^{87}Sr/^{86}Sr$ values are consistent with a local Kastro Kallithea range.

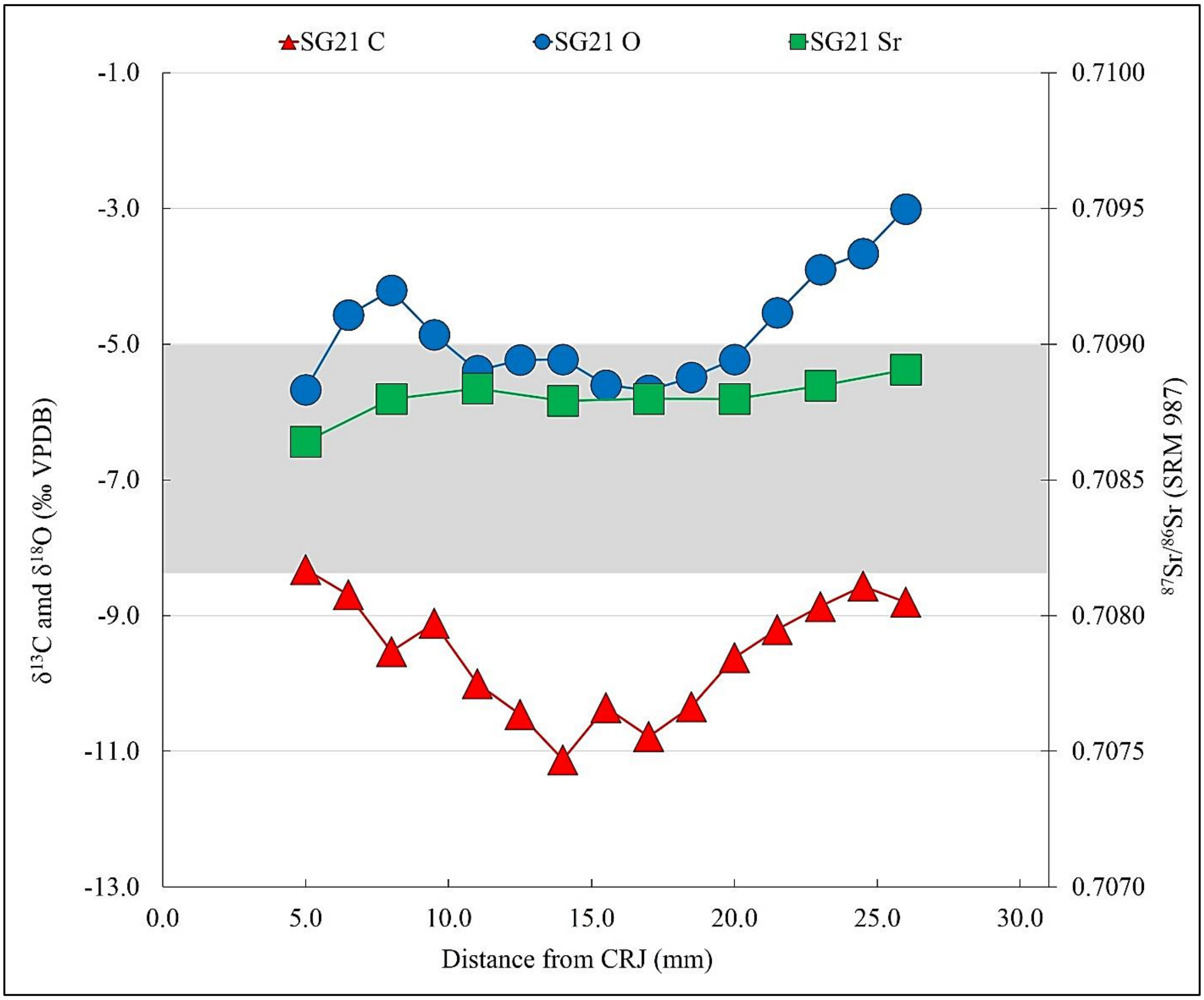

Figure 7.50 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG21 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.36

Table 7.37 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG23. See Figure 7.51.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
G33	20.0	-10.83	-4.74	0.709308	± 0.000006
G34	18.5	-11.57	-4.55	-	-
G35	17.0	-10.96	-5.58	0.709596	± 0.000006
G36	15.5	-10.88	-5.63	-	-
G37	14.0	-10.68	-6.67	0.709336	± 0.000007
G38	12.5	-10.16	-6.54	-	-
G39	11.0	-10.63	-6.79	0.709398	± 0.000008
G40	9.5	-11.36	-7.41	-	-
G41	8.0	-10.48	-6.69	0.709093	± 0.000014
G42	6.5	-10.92	-6.30	-	-
G43	5.0	-11.36	-5.18	0.709059	± 0.000011
G44	3.5	-11.45	-3.99	-	-
G45	2.0	-11.24	-3.85	0.709195	± 0.000019
G46	0.5	-9.14	-4.53	-	-

7.2.8 SG23

The data for SG23, a goat RM_3 from Kastro Kallithea, span roughly 13 months worth of diet, and are listed in Table 7.37 and Figure 7.51.

Carbon: The carbon isotope signature varies over the 13 months ($\Delta^{13}C$: 2.43‰) but is consistent with a diet of C_3 plant sources.

Oxygen: The oxygen isotope signature is consistent with a seasonal (sinusoidal) signal. The first summer occurs around 18.5 mm, the second summer around 3.5 mm to 2.0 mm, and the winter months occur around the 8.0 mm mark. The overall $\Delta^{18}O$ is 3.57‰.

Strontium: There is considerable fluctuation in strontium isotope values ($\Delta^{87}Sr/^{86}Sr$: 0.000538) over the course of the period measured. The $^{87}Sr/^{86}Sr$ range recorded in SG23's enamel is higher than local Kastro Kallithea values. Based on the estimates discussed in Figure 7.43 and Table 7.24, the highest $^{87}Sr/^{86}Sr$ values are consistent with the highlands of Mount Óthrys, whereas the lower $^{87}Sr/^{86}Sr$ values may correlate with lower altitudes in the mountains or an area along the coast (e.g., area affected by the sea spray).

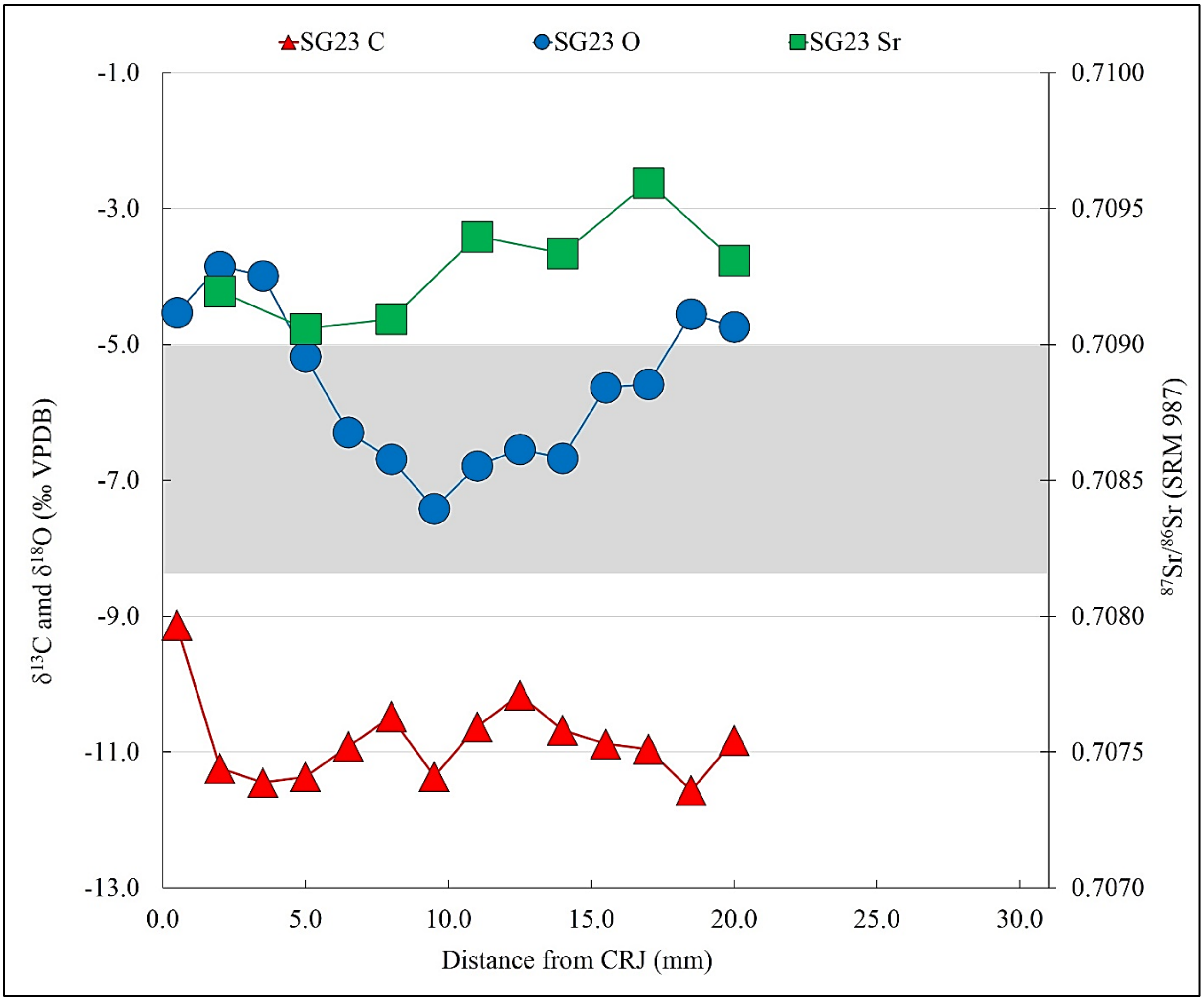

Figure 7.51 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG23 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Kastro Kallithea is shown as a grey block. Refer to Table 7.37.

Table 7.38 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG30. See Figure 7.52.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S71	25.0	-6.76	-3.16	0.708766	± 0.000005
S72	23.5	-7.39	-3.76	-	-
S73	22.0	-7.18	-3.52	0.708764	± 0.000004
S74	20.5	-8.44	-4.14	-	-
S75	19.0	-9.81	-4.75	0.708822	± 0.000003
S76	17.5	-8.60	-4.85	-	-
S77	16.0	-8.59	-4.76	0.708789	± 0.000015
S78	14.5	-10.15	-5.03	-	-
S79	13.0	-10.70	-5.90	0.708942	± 0.000011
S80	11.5	-10.51	-5.85	-	-
S81	10.0	-10.62	-5.20	0.708950	± 0.000003
S82	8.5	-10.26	-4.88	-	-
S83	7.0	-10.12	-4.49	0.708940	± 0.000003
S84	5.5	-8.67	-3.95	-	-
S85	4.0	-8.26	-2.08	0.708792	± 0.000003
S86	2.5	-7.56	-1.65	-	-
S87	1.0	-7.59	-3.50	0.708675	± 0.000004

7.2.9 SG30

The data for SG30, a sheep LM_3 from Pharsalos, span roughly 16 months worth of diet, and are listed in Table 7.38 and Figure 7.52.

Carbon: The carbon isotope signature appears to follow the seasonal (sinusoidal) oxygen pattern and varies considerably ($\Delta^{13}C$ is 3.94‰). The values are consistent with a diet of C_3 plant sources with additional C_4 plants in the diet possible during the first (25.0 – 20.5 mm) and last (5.5 – 1.0mm) summers recorded.

Oxygen: The oxygen isotope signature is consistent with a seasonal pattern. The first summer occurs around 25.0 mm, the second around 2.5 mm, and the winter months around 11.5 mm. The overall $\Delta^{18}O$ is 4.25‰.

Strontium: This sheep shows enamel $^{87}Sr/^{86}Sr$ values that agree with the estimated Pharsalos strontium isotope range. There is some variation in isotope values ($\Delta^{87}Sr/^{86}Sr$: 0.000275), with an increase in $^{87}Sr/^{86}Sr$ observed during the winter and spring months (16.0 – 4.0 mm).

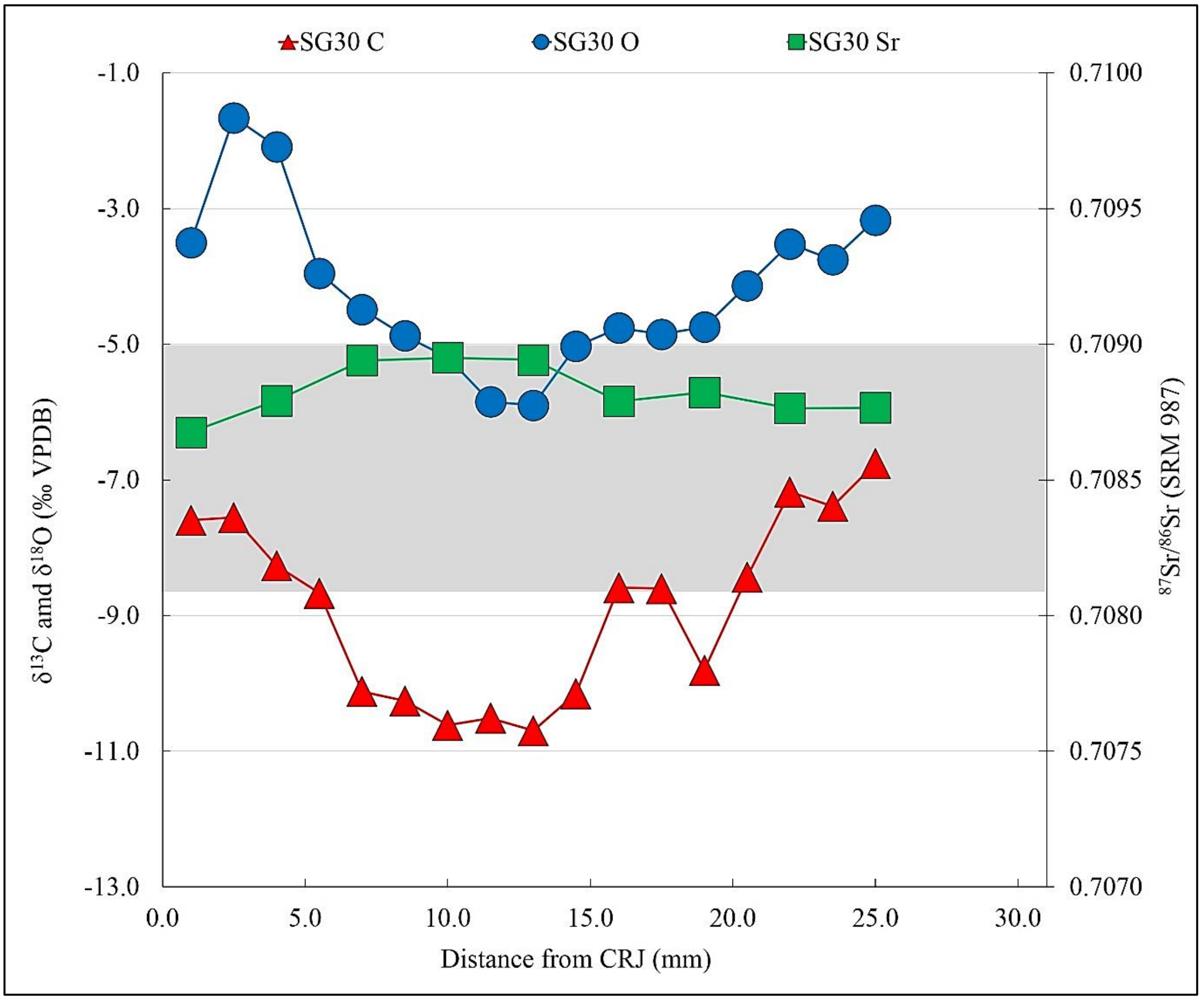

Figure 7.52 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG30 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.38.

Table 7.39 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG33. See Figure 7.53.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S88	21.0	-10.32	-3.95	0.709407	± 0.000003
S89	19.5	-9.36	-3.70	-	-
S90	18.0	-10.12	-3.97	0.709778	± 0.000011
S91	16.5	-9.78	-4.04	-	-
S92	15.0	-9.86	-4.77	0.709815	± 0.000003
S93	13.5	-9.36	-4.13	-	-
S94	12.0	-9.92	-4.14	0.709843	± 0.000004
S95	10.5	-10.68	-4.21	-	-
S96	9.0	-11.39	-4.14	0.709803	± 0.000006
S97	7.5	-9.45	-4.37	-	-
S98	6.0	-11.56	-3.65	0.709614	± 0.000009
S99	4.5	-11.54	-3.33	-	-
S100	3.0	-12.05	-2.88	0.709386	± 0.000003
S101	1.5	-11.79	-2.55	-	-
S102	0.0	-9.53	-2.51	0.709062	± 0.000004

7.2.10 SG33

The data recorded from SG33, a sheep LM_3 from Pharsalos, span roughly 14 months worth of diet, and are listed in Table 7.39 and Figure 7.53.

Carbon: The carbon isotope signature is variable over the period measured ($\Delta^{13}C$: 2.70‰) although the $\delta^{13}C$ values are consistent with a diet of C_3 plant sources.

Oxygen: The oxygen isotope signature is variable and shows no clear sinusoidal (seasonal) signal. The overall $\Delta^{18}O$ is 2.26‰.

Strontium: There is considerable variation in strontium isotope values ($\Delta^{87}Sr/^{86}Sr$: 0.000781), with values increasing during the first period (21.0 – 18.0 mm), remaining consistent for the next period (18.0 – 12.0 mm), and then decreasing for the third period (12.0 – 0.0 mm). Based on the estimates discussed in Figure 7.43 and Table 7.24, SG33's $^{87}Sr/^{86}Sr$ values are consistent with the highlands around Mount Óthrys. No strontium values are within the local estimated range for Pharsalos.

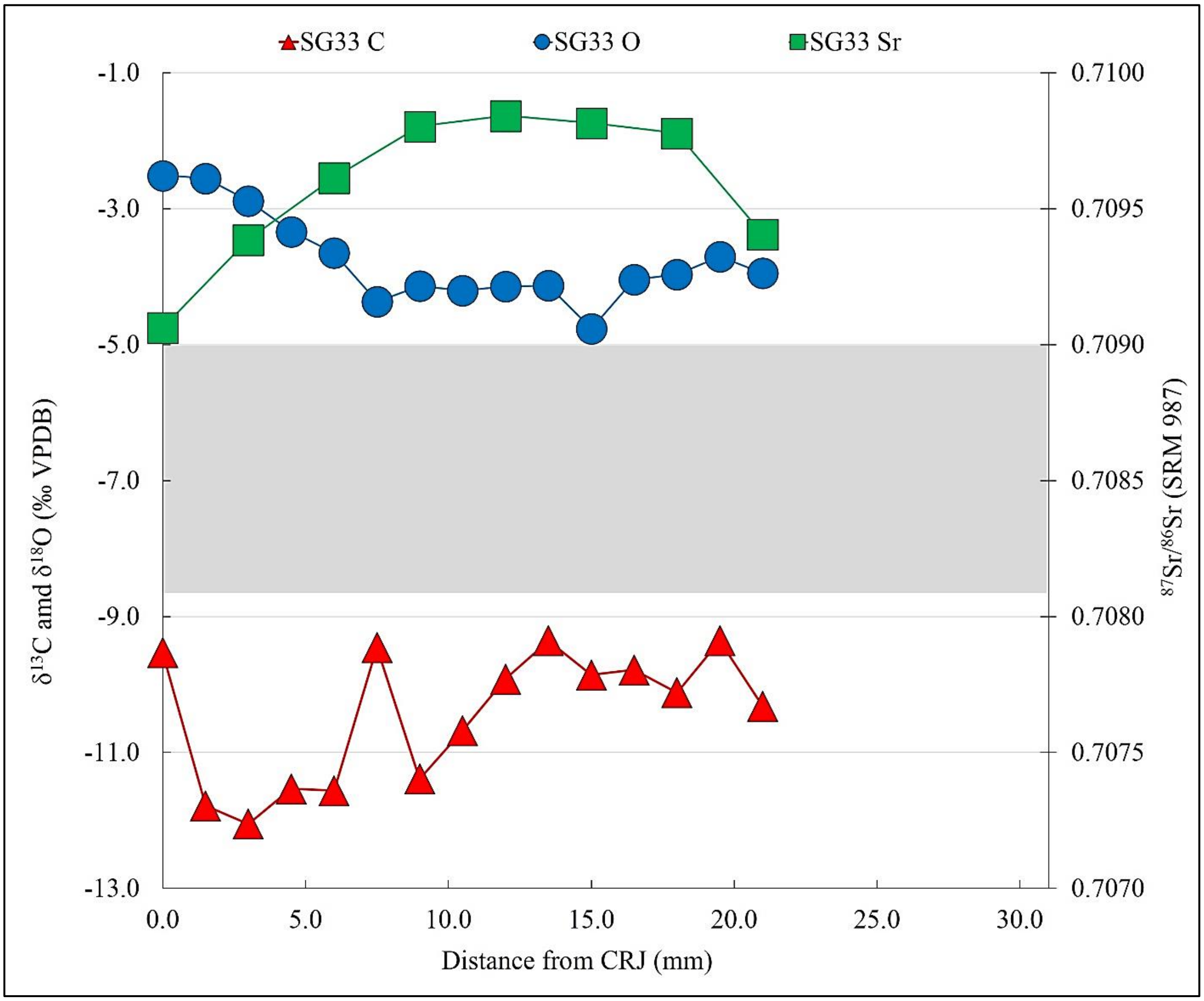

Figure 7.53 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG33 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.39.

Table 7.40 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG38. See Figure 7.54.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S124	21.0	-8.68	-4.70	0.708544	± 0.000004
S125	19.5	-8.90	-3.72	-	-
S126	18.0	-8.61	-3.36	0.708562	± 0.000004
S127	16.5	-8.08	-3.71	-	-
S128	15.0	-8.30	-4.37	0.708545	± 0.000009
S129	13.5	-8.64	-5.11	-	-
S130	12.0	-8.58	-5.27	0.708551	± 0.000007
S131	10.5	-8.56	-3.28	-	-
S132	9.0	-8.35	-2.67	0.708551	± 0.000020
S133	7.5	-8.65	-3.20	-	-
S134	6.0	-9.00	-4.65	0.708547	± 0.000003
S135	4.5	-10.03	-5.41	-	-
S136	3.0	-9.28	-6.21	0.708566	± 0.000003
S137	1.5	-10.76	-6.25	-	-
S138	0.0	-9.69	-6.21	0.708610	± 0.000003

7.2.11 SG38

The data for SG38, a sheep LM_3 from Pharsalos, span roughly 14 months worth of diet, and are listed in Table 7.40 and Figure 7.54.

Carbon: The stable carbon isotope values are consistent with a diet of C_3 with some additional C_4 plants in the diet during the first year (21.0 – 7.5 mm). The overall $\Delta^{13}C$ is 2.68‰.

Oxygen: The oxygen isotope signature is not consistent with a seasonal (sinusoidal) signal; instead, values vary considerably every few months. The overall $\Delta^{18}O$ is 3.58‰.

Strontium: Strontium isotope values remain consistent ($\Delta^{87}Sr/^{86}Sr$: 0.000066) throughout the period represented by the enamel and are consistent with local Pharsalos values.

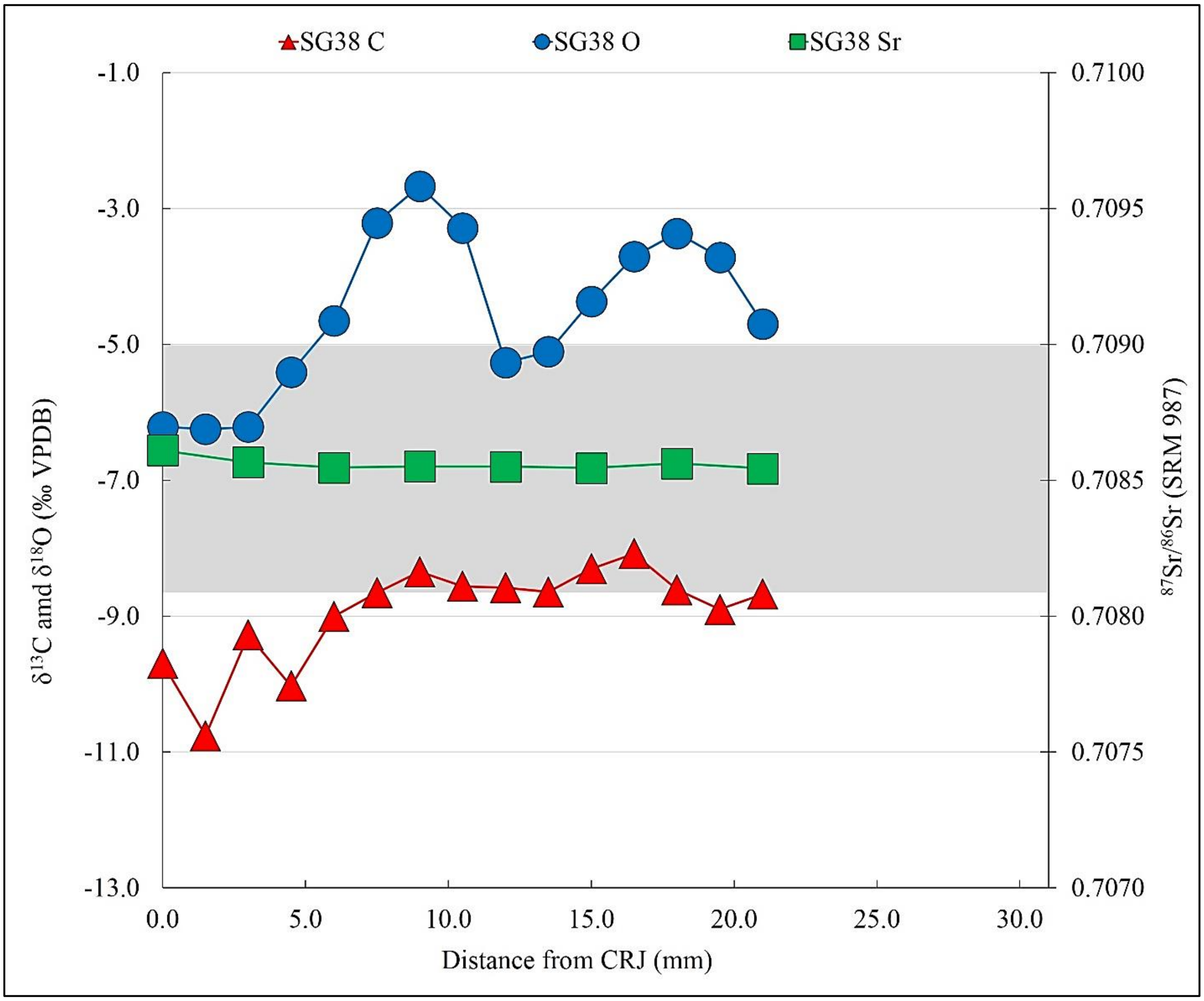

Figure 7.54 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG38 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.40.

Table 7.41 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG39. See Figure 7.55.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
G47	30.5	-10.35	-3.42	0.708981	± 0.000047
G48	29.0	-9.60	-2.55	-	-
G49	27.5	-9.24	-2.48	0.708913	± 0.000006
G50	26.0	-8.43	-2.91	-	-
G51	24.5	-7.98	-3.41	0.708978	± 0.000008
G52	23.0	-7.52	-3.14	-	-
G53	21.5	-7.60	-3.37	0.709051	± 0.000007
G54	20.0	-8.21	-3.33	-	-
G55	18.5	-8.07	-3.72	0.709043	± 0.000006
G56	17.0	-9.54	-3.92	-	-
G57	15.5	-9.18	-4.45	0.709102	± 0.000009
G58	14.0	-9.41	-4.60	-	-
G59	12.5	-8.66	-4.44	0.709085	± 0.000009
G60	11.0	-9.21	-4.37	-	-
G61	9.5	-10.26	-4.38	0.709013	± 0.000006
G62	8.0	-10.83	-4.69	-	-
G63	6.5	-10.73	-4.23	0.709035	± 0.000008
G64	5.0	-10.32	-3.85	-	-
G65	3.5	-9.64	-2.84	0.709056	± 0.000007

7.2.12 SG39

The data for SG39, a goat RM_3 from Pharsalos, span roughly 18 months worth of diet, and are listed in Table 7.41 and Figure 7.55.

Carbon: The stable carbon isotope values vary considerably ($\Delta^{13}C$ is 3.31‰) and are consistent with a diet of mostly C_3 plants with a period that includes some C_4 plants during the first year (27.5 – 18.5 mm).

Oxygen: The oxygen isotope signature follows a seasonal sinusoidal pattern but the pattern is not complete. Based on the length of the tooth there should be roughly 18 months of diet recorded; however the seasonal trends suggest that only 12 months are observed, from the first summer (29.0 – 27.5 mm) to the second summer period (3.5 mm). The overall $\Delta^{18}O$ is 2.21‰.

Strontium: The strontium isotope values do not vary considerably ($\Delta^{87}Sr/^{86}Sr$: 0.000190) over the period measured, however they are within and outside of the upper limit of the local

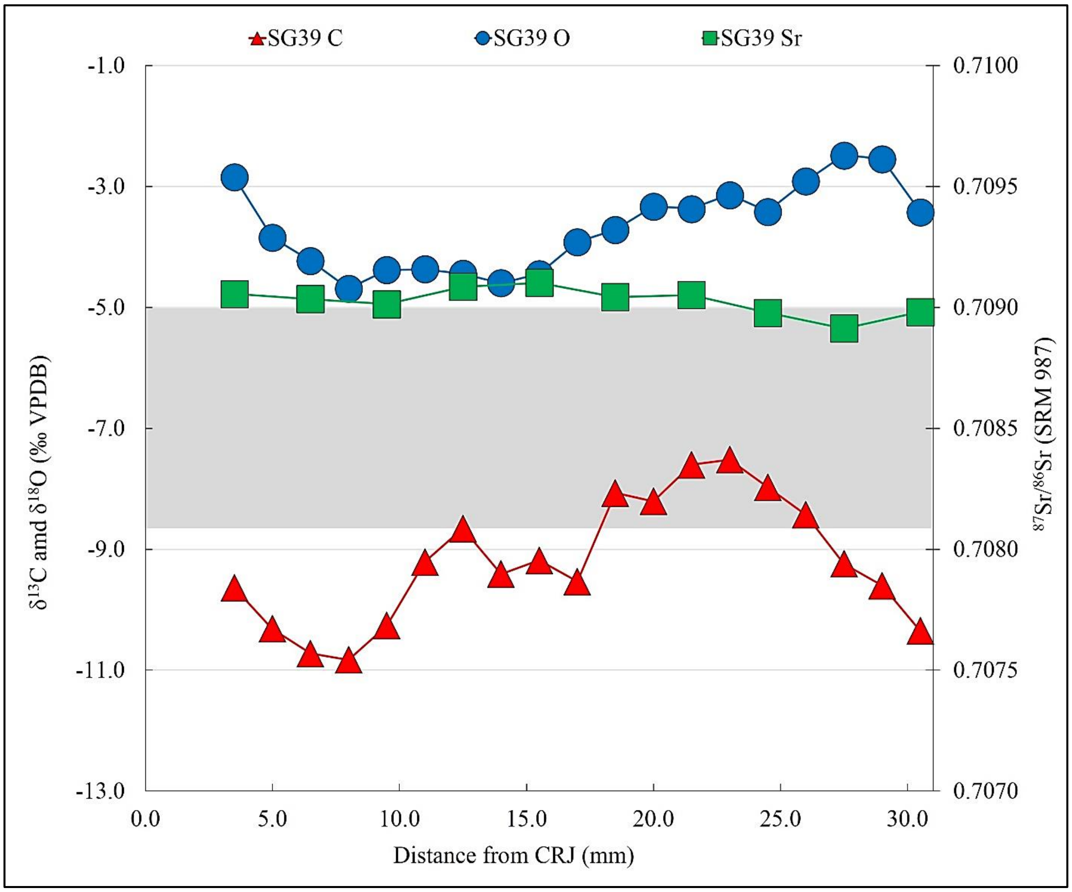

Figure 7.55 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG39 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.41.

Pharsalos range. The goat had $^{87}Sr/^{86}Sr$ values that fell within the reconstructed Pharsalos range during its first summer (30.5 – 21.5 mm), and then had non-local values for the rest of the time.

Table 7.42 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG40. See Figure 7.56.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S139	20.5	-9.10	-5.00	0.708660	± 0.000004
S140	19.0	-8.91	-4.58	-	-
S141	17.5	-8.75	-3.30	0.708761	± 0.000004
S142	16.0	-8.63	-3.58	-	-
S143	14.5	-8.81	-3.37	0.708841	± 0.000003
S144	13.0	-8.99	-2.69	-	-
S145	11.5	-10.13	-4.95	0.708636	± 0.000003
S146	10.0	-8.75	-5.54	-	-
S147	8.5	-8.58	-5.72	0.708655	± 0.000003
S148	7.0	-8.60	-5.31	-	-
S149	5.5	-8.89	-5.87	0.708649	± 0.000004
S150	4.0	-8.66	-5.82	-	-
S151	2.5	-9.00	-5.59	0.708640	± 0.000003

7.2.13 SG40

The data for SG40, a sheep LM_3 from Pharsalos, span roughly 12 months worth of diet, and are listed in Table 7.42 and Figure 7.56.

Carbon: The stable carbon isotope values are consistent with a diet of C_3 with some additional C_4 plants possible in the diet. The pattern is mostly consistent and the overall $\Delta^{13}C$ is 1.55‰.

Oxygen: The oxygen isotope signature is not consistent with a seasonal (sinusoidal) signal; instead, values varied every few months. The overall $\Delta^{18}O$ is 3.18‰.

Strontium: The strontium isotope values are mostly consistent ($\Delta^{87}Sr/^{86}Sr$: 0.000205) throughout the period measured and fit within the local Pharsalos range.

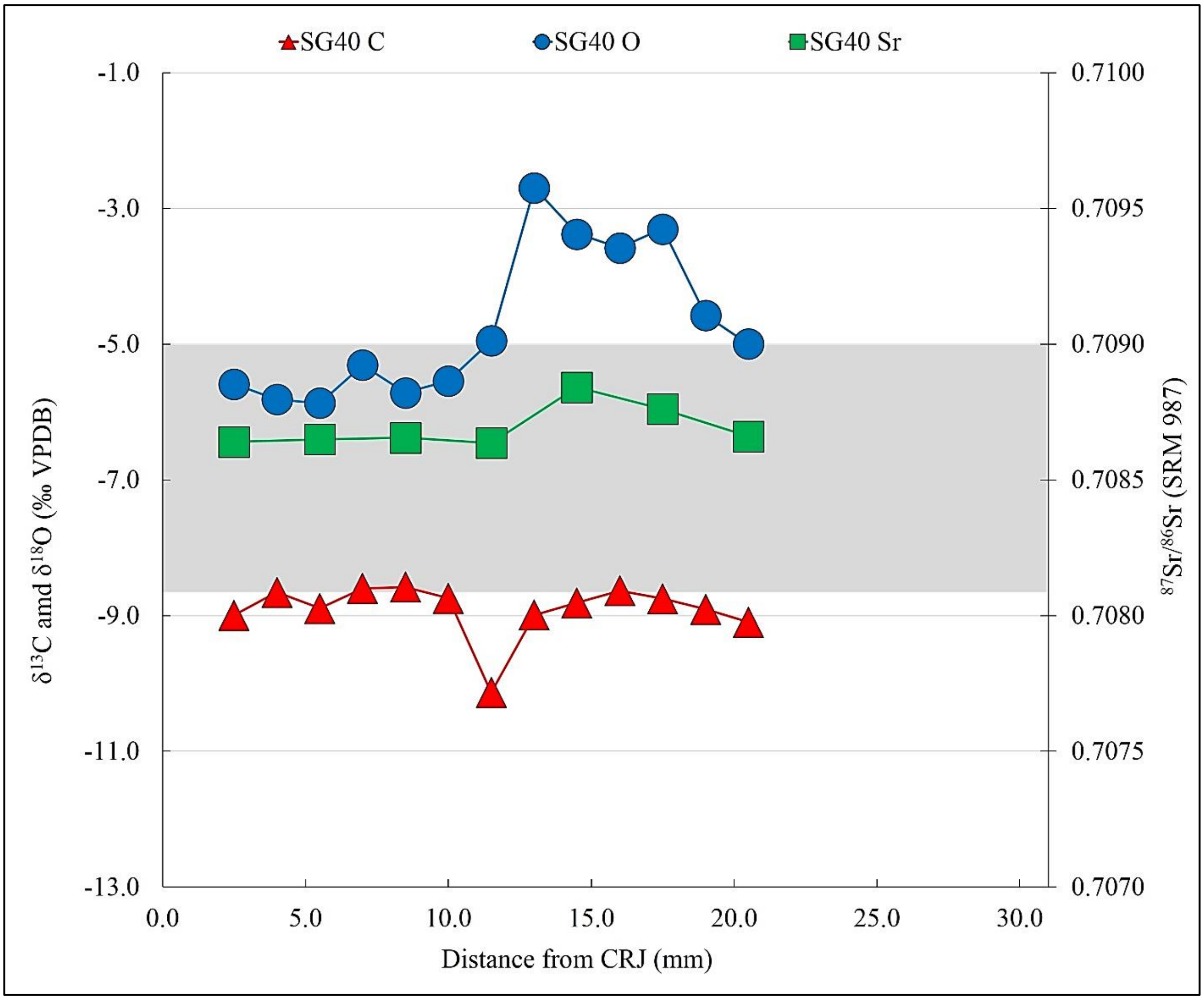

Figure 7.56 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG40 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.42.

Table 7.43 Carbon, oxygen, and strontium isotope values measured on sequentially sampled mandibular molar (M_3) enamel of SG42. See Figure 7.57.

Sample	Distance from CRJ (mm)	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	^{87}Sr / ^{86}Sr	2 SE
S153	28.0	-8.03	-2.73	0.708966	± 0.000009
S154	26.5	-7.68	-3.14	-	-
S155	25.0	-7.57	-3.16	0.708890	± 0.000003
S156	23.5	-7.29	-3.63	-	-
S157	22.0	-7.50	-3.90	0.708815	± 0.000004
S158	20.5	-7.81	-4.10	-	-
S159	19.0	-8.30	-4.14	0.708744	± 0.000004
S160	17.5	-8.21	-4.34	-	-
S161	16.0	-8.46	-4.64	0.708738	± 0.000003
S162	14.5	-9.53	-4.70	-	-
S163	13.0	-8.37	-4.97	0.708669	± 0.000016
S164	11.5	-10.32	-4.88	-	-
S165	10.0	-9.84	-4.16	0.708700	± 0.000004
S166	8.5	-10.27	-3.78	-	-
S167	7.0	-10.50	-3.49	0.708704	± 0.000004
S168	5.5	-10.05	-3.50	-	-
S169	4.0	-8.69	-2.55	0.708733	± 0.000004

7.2.14 SG42

The data for SG42, a sheep LM_3 from Pharsalos, span roughly 16 months worth of diet, and are listed in Table 7.43 and Figure 7.57.

Carbon: The stable carbon isotope values vary considerably ($\Delta^{13}C$ is 3.21‰) and are consistent with a diet of mostly C_3 plants with a period that includes some C_4 plants during the first year (28.0 – 14.2 mm).

Oxygen: The oxygen isotope signature follows a seasonal sinusoidal pattern but the pattern is not complete. Based on the length of the tooth there should be roughly 18 months of diet recorded, however the seasonal trends suggest that only 12 months are observed, from the first (28.0 mm) to the second (4.0 mm) summer. The overall $\Delta^{18}O$ is 2.42‰.

Strontium: The strontium isotope values are mostly consistent during the second year, although during the first year (28.0 – 20.5 mm) the values are within the upper limit of the local Pharsalos range. Overall strontium isotope variation ($\Delta^{87}Sr/^{86}Sr$) is 0.000297.

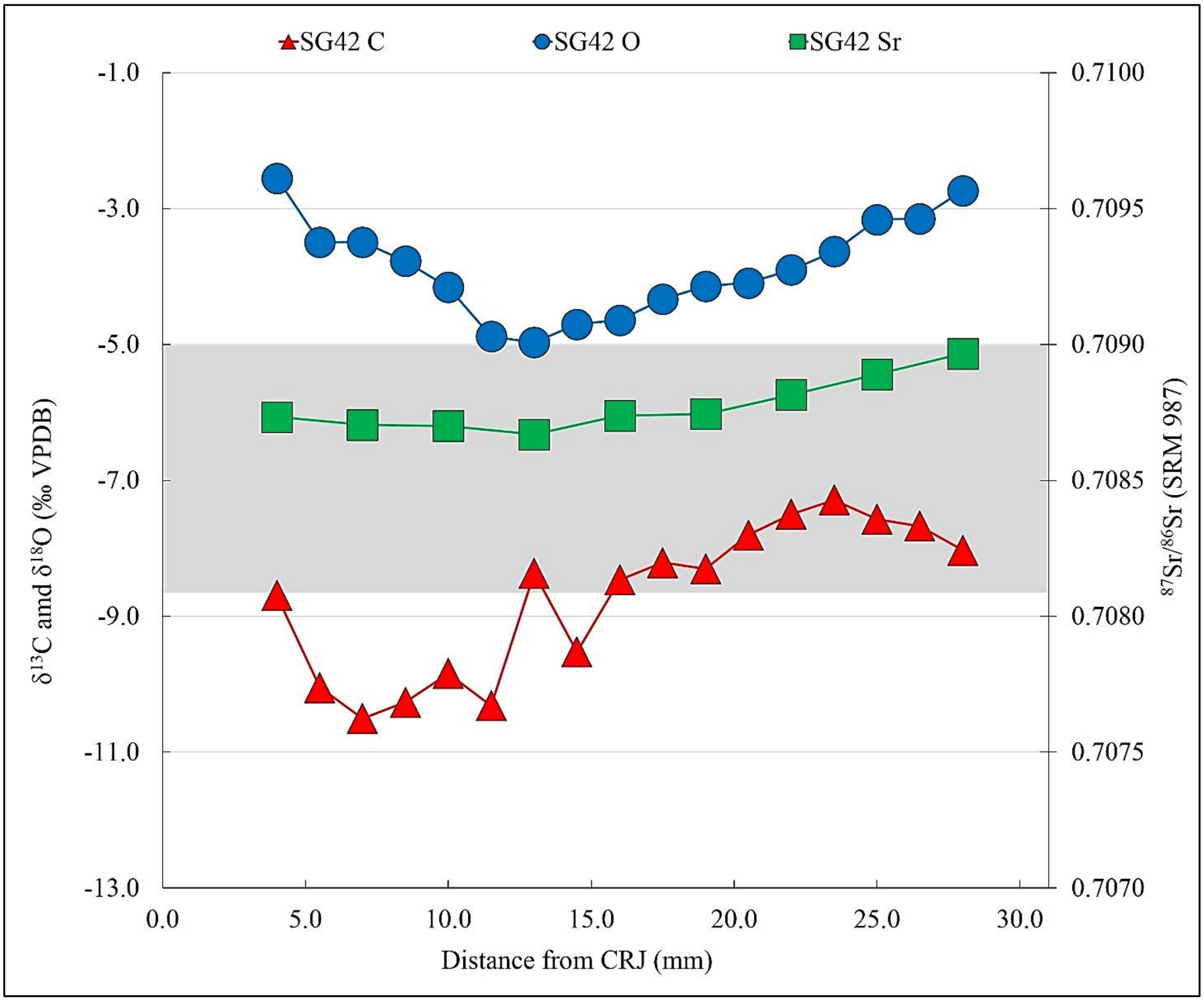

Figure 7.57 Sequential $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values measured from SG42 molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range for Pharsalos is shown as a grey block. Refer to Table 7.43.

7.3 Analytical Error

7.3.1 Carbon and Oxygen

The carbon and oxygen isotopes were repeated (run in duplicate or triplicate) for numerous samples, either to correct issues with the initial run or to ensure repeatability. Where this was done, the values presented in sections 7.1 and 7.2 are averaged values of multiple runs. Stable carbon and oxygen isotopic compositions were calibrated relative to the VPDB standard using NBS-19, which has the following values: $\delta^{13}C$ = 1.95‰ VPDB and $\delta^{18}O$ = -2.20‰ VPDB. Appendix 7.9 lists the measured carbon and oxygen isotope values for NBS-19 during each run of my samples (n=32). Precision ($u(R_w)$) was determined to be 0.05‰ for $\delta^{13}C$ and 0.10‰ for $\delta^{18}O$ on the basis of repeated measurements of calibration standards (following Szpak *et al.*, 2017).

7.3.2 Strontium

Standard error has been presented with each recorded sample. Strontium isotope compositions were calibrated relative to the SRM-987 standard, which had the following value for my study: $^{87}Sr/^{86}Sr$ = 0.710272 ± 0.000007 (2 SE). Using the same approach as Section 7.3.1, precision was determined to be 0.000029 for $^{87}Sr/^{86}Sr$. Appendix 7.10 lists the measured value for SRM-987 during each run of my samples (n=8).

7.4 Summary

This chapter included the data produced as part of my research, including preliminary interpretations. Stable isotope data for plants and small-bodied fauna were combined with predictive strontium isotope modelling using various studies in the region. Using the established strontium isoscape ranges, I was able to identify local and non-local strontium isotope signatures in the individual teeth. Oxygen isotope data was used to record seasonal trends in data or indicate instances where seasonality was not measured. Carbon isotope data indicated variation in C_3 plant sources in Thessaly with some additional C_4 plant sources depending on the time of year. This chapter presented the data the following discussions will be based on. In the next three chapters I use these results to discuss animal management in Thessaly in terms of *what* shepherds were doing with their animals (8), *how* they were able to move or manage them in unique ways (9), and *why* animals would have been kept in these ways during the Hellenistic period (10).

CHAPTER 8: Management Styles

This chapter presents themes related to animal management style according to the isotope results presented in Chapter 7. I first establish how I interpret trends in the strontium, oxygen, and carbon isotope data in terms of animal movement, seasonality, and diet (8.1). These trends are then used to propose groups of animals based on apparent husbandry types: local management (8.2), non-local management (8.3), mixed-mobile management (8.4), and other specialized management (8.5). Although these forms of management are separated based on inferred mobility patterns, they are also discussed according to reconstructed foddering or grazing techniques. In Section 8.6 I discuss limitations of using stable isotope data to assign a management style in this way, as well as ways in which these data provide tools for use in the future. Despite these limitations, the interpretations in this chapter establish the basis for discussing how (Chapter 9) and why (Chapter 10) animals at my study sites were managed in antiquity. A case study of this data has already been published (Bishop *et al.*, 2020); this included preliminary interpretations of four of the ovicaprids (SG03, SG08, SG11, and SG23) from Kastro Kallithea.

8.1 Interpreting Trends in the Stable Isotope Data

8.1.1 Strontium Data

I will use trends in strontium isotope data to categorize animals in two ways: (1) local or non-local grazing and (2) sedentary or mobile management. Local versus non-local grazing will be established by comparing each animal to reconstructed local $^{87}Sr/^{86}Sr$ ranges, while mobility will be inferred from internal strontium isotope variation ($\Delta^{87}Sr/^{86}Sr$) within each tooth.

<u>Local vs. Non-Local Grazing</u>

Locally managed animals have strontium isotope values that do not extend beyond the upper and lower limits of locally available strontium, which I refer to as an isozone (Stevens *et al.*, 2013; Trentacoste *et al.*, 2020). The reconstructed local $^{87}Sr/^{86}Sr$ isozone for Kastro Kallithea is 0.7082 to 0.7090 and the range for Pharsalos is 0.7081 to 0.7090 (recall Table 7.24). The two sites thus have the same local $^{87}Sr/^{86}Sr$ range based on the data available at this time. This was expected for many settlements located on similar geological substrates in this region and highlights a limitation of $^{87}Sr/^{86}Sr$ analysis for studying mobility in Thessaly. It is possible for animals that

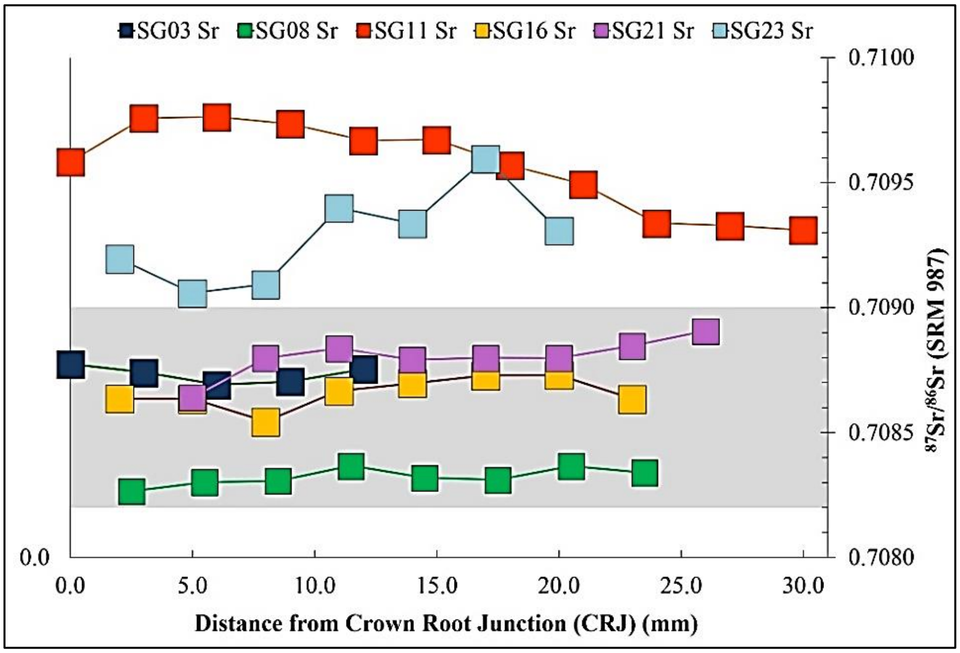

Figure 8.58 Sequential $^{87}Sr/^{86}Sr$ values from ovicaprids at Kastro Kallithea. The grey block represents the local isozone and all individuals inside the grey zone are considered local whereas those outside are considered non-local.

appear 'local' to a given site to have actually been managed in another isotopically similar area. While I acknowledge this uncertainty, for the purpose of this study I will consider an animal 'local' if its recorded $^{87}Sr/^{86}Sr$ falls within the confines of the established $^{87}Sr/^{86}Sr$ isozone.

At Kastro Kallithea four ovicaprids were raised locally (SG03, SG08, SG16, and SG21) and two were raised non-locally (SG11 and SG23) (Fig. 8.58). Both non-local animals were raised in an isozone that had higher $^{87}Sr/^{86}Sr$ values than the local Kastro Kallithea range. Similarly, four animals at Pharsalos were raised locally (SG30, SG38, SG40, and SG42), one was raised non-locally (SG33), and the final individual was mix-managed (SG39) (Fig. 8.59). SG39 was in a non-local area during the initial period of enamel formation and then grazing locally for the remaining period. Although the non-local animal (SG33) grazed in an area with $^{87}Sr/^{86}Sr$ values much higher than at Pharsalos, the mixed-local animal (SG39) grazed in an area with only slightly higher $^{87}Sr/^{86}Sr$ values. It was anticipated that all animals would be managed locally for local use, and I interpret the presence of non-local animals as indicators of mobility into the local region as part of specialized management, trade, and/or sale.

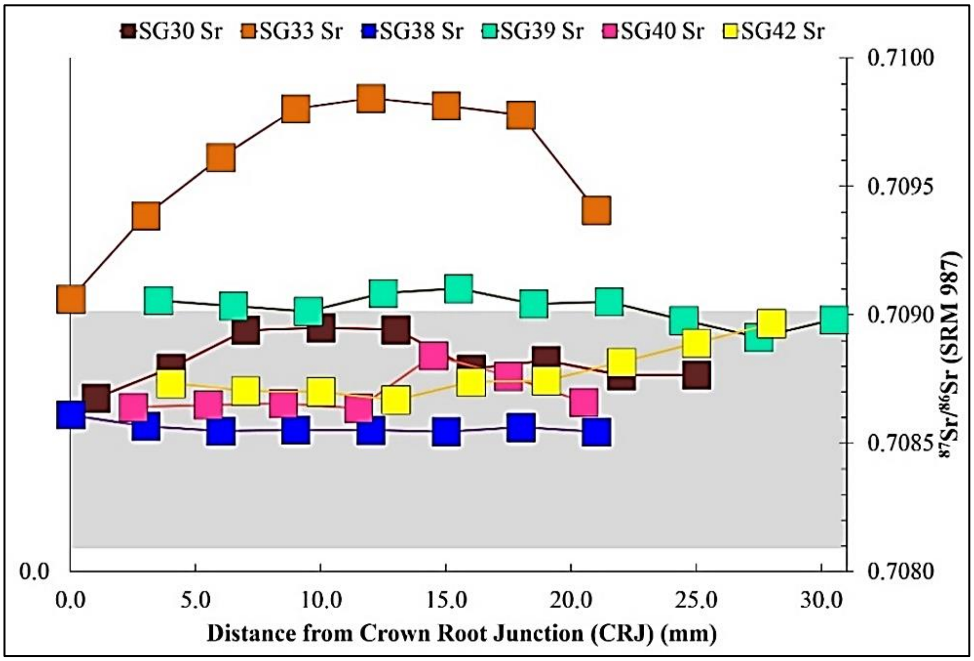

Figure 8.59 Sequential $^{87}Sr/^{86}Sr$ values from ovicaprids at Pharsalos. The grey block represents the local isozone and all individuals inside the grey zone are considered local whereas those outside are considered non-local.

Based on strontium isotope values alone, most of the animals in my study fit within the local range for the region, with all Kastro Kallithea-local animals fitting within the same isozone range as Pharsalos-local animals. Because of the common overall signature shared by many locales in Thessaly, I need to look for other potential indicators of mobility.

<u>Sedentary vs. Mobile Management</u>

Researchers traditionally categorize an animal as being mobile or sedentary (non-mobile) according to its local or non-local $^{87}Sr/^{86}Sr$ values as done above (e.g., Arnold *et al.*, 2016; Balasse *et al.*, 2002; Evans *et al.*, 2019). Another approach involves looking at inter-individual variation ($\Delta^{87}Sr/^{86}Sr$) as an indicator of mobility in different herds or animal types (e.g., Chase *et al.*, 2014). This method uses inter-individual $\Delta^{87}Sr/^{86}Sr$ as a tool to indicate animals that grazed near each other during set times in the year, potentially as part of similar migration patterns (Britton *et al.* 2009). Each ovicaprid in my study displays a different $^{87}Sr/^{86}Sr$ pattern or trend, which appears to show that all twelve individuals were managed in different ways as part of separate herds.

Yet another approach is to consider intra-individual $\Delta^{87}Sr/^{86}Sr$, which is the amplitude of variation between sequential enamel samples of a single individual. This is based on the logic that an animal with higher internal $\Delta^{87}Sr/^{86}Sr$ was more likely mobile throughout its life (see Appendix 8.11). If sedentary means that the herd is to be kept local for local purposes (e.g., milking and manuring), they are capable of moving and grazing within an area defined by half a day's journey (~ 5 km) (Cardete, 2019; Hall, 2019). Under this scenario, animal isotope values may reflect small-scale changes in strontium within a 5 km radius. Alternatively, mobile means that the herd moves regularly to different pastures beyond 5 km from the habitation site.

As an example, Lazzerini *et al.* (2021) sequentially sampled $^{87}Sr/^{86}Sr$ from the enamel of GPS-tracked goats to examine how $^{87}Sr/^{86}Sr$ varied during periods of short- and long-term mobility in Mongolia. One of the goats in their study moved around an $^{87}Sr/^{86}Sr$ isozone range of 0.71178 to 0.71645 (Δ: ~0.005) and had an inter-individual $\Delta^{87}Sr/^{86}Sr$ of 0.00185. Their study found that herds grazing in isozones with larger ranges generally had more intra-individual $\Delta^{87}Sr/^{86}Sr$. Similar results and intra-individual $\Delta^{87}Sr/^{86}Sr$ were also found in wild herd studies in Africa (Balasse *et al.*, 2002) and North America (Britton *et al.*, 2009). These case studies involve isozone $^{87}Sr/^{86}Sr$ ranges that are much wider than what I have determined for Thessaly, but their approaches have been adapted for archaeological contexts in the smaller $^{87}Sr/^{86}Sr$ range isozones of the Mediterranean.

Isaakidou *et al.* (2019) examine archaeological sheep and goat herd movement across Crete in isozones that are comparable to Thessaly (isozone range of 0.7089 to 0.7094; Δ: ~0.0005). They found that low intra-tooth $\Delta^{87}Sr/^{86}Sr$ (< 0.00012) in samples represented animals that were not ranging widely between regions, or more simply, animals that were 'local' to the study area (Isaakidou *et al.*, 2019, p.47). Larger intra-tooth $\Delta^{87}Sr/^{86}Sr$ (> 0.00048) was measured in one non-local individual, which was designated as an animal that had relocated, or moved, between isozone regions in the area. Trentacoste *et al.* (2020) followed a similar approach for archaeological sheep in central Italy. The isozone ranges for the sites were 0.7088 to 0.7103 (Δ: 0.0015) and the intra-individual $\Delta^{87}Sr/^{86}Sr$ was less than 0.0001 for all non-mobile sheep. One of their sheep had an intra-individual $\Delta^{87}Sr/^{86}Sr$ of 0.0003 recorded from the top, middle, and bottom portions of the dental enamel. Based on this variability, and in consideration of the local isozone, Trentacoste *et al.* (2020, p.11) hypothesize that this sheep may have been moving between local areas within a few kilometers of the site. In both Isaakidou *et al.* (2019) and

Table 8.44 Summary data and interpretations for each specimen according to its strontium isotope values ($^{87}Sr/^{86}Sr$).
Local or non-local distinction based on the isozone, and the sedentary or mobile management distinction based on the intra-individual variation ($\Delta^{87}Sr/^{86}Sr$).

Specimen ID	Local or Non-Local to the Isozone	Sedentary or Mobile Management	
		$\Delta\ ^{87}Sr/^{86}Sr$	Interpretation
L01	Local	0.000317	Somewhat Mobile
SG03	Local	0.000083	Sedentary
SG08	Local	0.000101	Sedentary
SG11	Non-local	0.000453	Mobile
SG16	Local	0.000186	Sedentary
SG21	Local	0.000265	Sedentary
SG23	Non-Local	0.000538	Mobile
SG30	Local	0.000275	Mostly Sedentary
SG33	Non-Local	0.000781	Mobile
SG38	Local	0.000066	Sedentary
SG39	Mixed	0.000190	Sedentary
SG40	Local	0.000205	Sedentary
SG42	Local	0.000297	Mostly Sedentary

Trentacoste *et al.* (2020), intra-individual $\Delta^{87}Sr/^{86}Sr$ greater than roughly 0.0003 was indicative of small-scale mobility within isozones that were comparable to the ones in my study (see also Appendix 8.11).

Many of these studies only include two or three sequential samples, which may not account for the total range of $\Delta^{87}Sr/^{86}Sr$ across the measured period. Lazzerini *et al.* (2021) conducted the first study to sequentially test precise segments of ovicaprid enamel (365 to 686 measurements were made on a single tooth using laser ablation) and compared them to expected $^{87}Sr/^{86}Sr$ patterning based on GPS-tracked mobility. Their impressive study demonstrated the applicability of this approach and showed that small- and large-scale movement within isozones can be detected from a period as small as two months. Although my analysis included far fewer sequential samples than Lazzerini *et al* (2021), by measuring $^{87}Sr/^{86}Sr$ from every 1.5 to 3 mm of enamel my study can also pick up on small-scale movement within the course of a year; I should be able to comment on an animals' mobility based on intra-individual $\Delta^{87}Sr/^{86}Sr$. Because of the success of the studies listed above, I similarly adopt this approach for my analysis. For this initial application in Thessaly I use the $\Delta^{87}Sr/^{86}Sr$ limits discussed by Isaakidou *et al.* (2019), Trentacoste *et al.* (2020), and the other studies listed in Appendix 8.11. This means that I will tentatively classify an ovicaprid in my study as sedentary or mobile based on its intra-individual $\Delta^{87}Sr/^{86}Sr$ being below or above 0.0003, respectively. This number may be refined as further work in Thessaly contributes local isoscape data, but for the purposes of my study I believe that it is a suitable estimate.

Table 8.44 lists the calculated intra-individual $\Delta^{87}Sr/^{86}Sr$ and proposed interpretation for each ovicaprid in my study. When compared to the local and non-local isozone designations from the previous section, all three non-local individuals (SG11, SG23, and SG33) have $\Delta^{87}Sr/^{86}Sr$ well over the 0.0003 threshold. Interestingly, the mixed isozone individual (SG39) has $\Delta^{87}Sr/^{86}Sr$ lower than the limit, which may indicate that the goat was sedentary but raised in a non-local or unique isozone. All four of the local Kastro Kallithea ovicaprids (SG03, SG08, SG16, and SG21) and two of the local Pharsalos ovicaprids (SG38, SG40) were also categorized as sedentary (< 0.0003) (Table 8.44). Two local Pharsalos animals (SG30, SG42) that were considered local were deemed mostly sedentary, as the $\Delta^{87}Sr/^{86}Sr$ was around the 0.0003 benchmark. Some studies, including Bogaard *et al.* (2014), noted small-scale mobility within the isozones from intra-individual $\Delta^{87}Sr/^{86}Sr$ as low as 0.00023, wherein the animal may have moved altitudinally within the same isozone from plains to terrace grazing. Animals that have been categorized as mostly sedentary (SG30 and SG42) may have grazed using a similar pattern.

Modern Example (L01)

The Anavra Lamb (L01) is a good example of how internal $\Delta^{87}Sr/^{86}Sr$ can be used to show small-scale horizontal and vertical movement in my study region (Table 8.44; Figure 8.60). As discussed in Section 7.1.4, L01 was managed in Anavra during gestation and after birth and free grazed in different sections of the same isozone during the last months of life. We were told that the shepherd practised traditional herding and the lamb grazed in areas around the village (lowland) and in the nearby hills overlooking the town (highland). This movement in the last few months before death was sufficient to produce $\Delta^{87}Sr/^{86}Sr$ of 0.000317, which is above the threshold I use to represent mobility. Archaeological ovicaprids in my study that have intra-individual $\Delta^{87}Sr/^{86}Sr$ around 0.0003 may have been managed around Pharsalos in ways similar to L01 was managed around Anavra. Larger $\Delta^{87}Sr/^{86}Sr$ seen in SG11, SG23, and SG33 likely meant that these animals were moving across great distances or even between different isozones across the landscape (Lazzerini *et al.* 2021; Valenzuela-Lamas *et al.*, 2016). Throughout my discussion

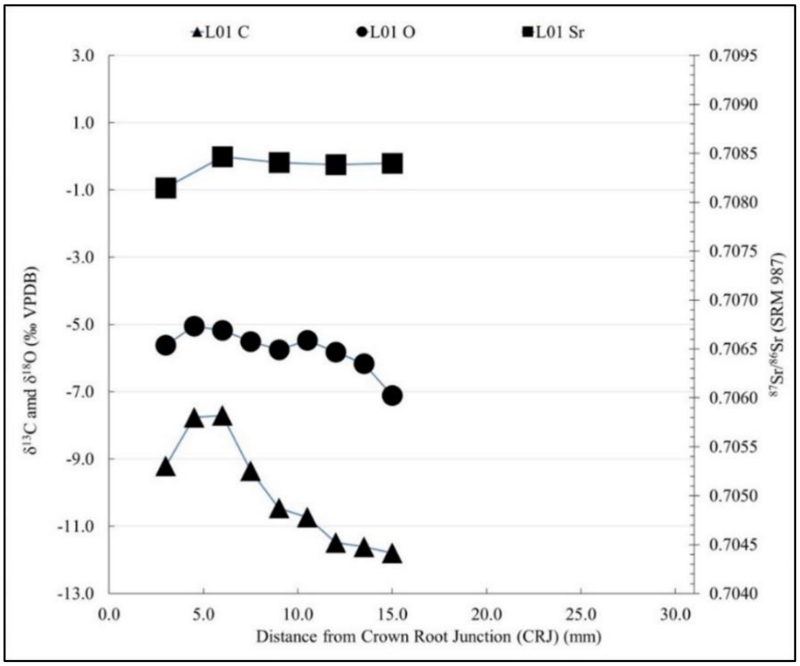

Figure 8.60 Recorded $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from L01 enamel.

I use strontium isotope values, isozone values, and $\Delta^{87}Sr/^{86}Sr$ ranges as means for discussing location- and mobility-based husbandry strategies in Thessaly.

8.1.2 Stable Oxygen Isotope Data

I will use trends in stable oxygen isotope data to discuss (1) seasonal water sourcing and (2) mobility patterns. Seasonality and water sourcing patterns will be interpreted according to the presence or absence of a sinusoidal curve, whereas mobility patterns will be inferred from the amplitude of the curve ($\Delta^{18}O$) compared to known seasonal reservoir variation in the area, either as a dampened, normal, or exaggerated signal.

Water Sourcing and Seasonality

In Chapter 5 I explained how enamel stable oxygen isotope values reflect that of body water, which in ovicaprids reflects the $\delta^{18}O$ of ingested local meteoric water from drinking water and within ingested plants (e.g., leaf water). Since the $\delta^{18}O$ of meteoric water is strongly influenced by seasonal climate, seasonality can often be interpreted from intra-individual $\delta^{18}O$ variation. When sequential $\delta^{18}O$ values are plotted, this seasonal fluctuation generates a sinusoidal curve (Fig. 8.61A). Animals that ingest meteoric water sources that are similarly impacted by climate

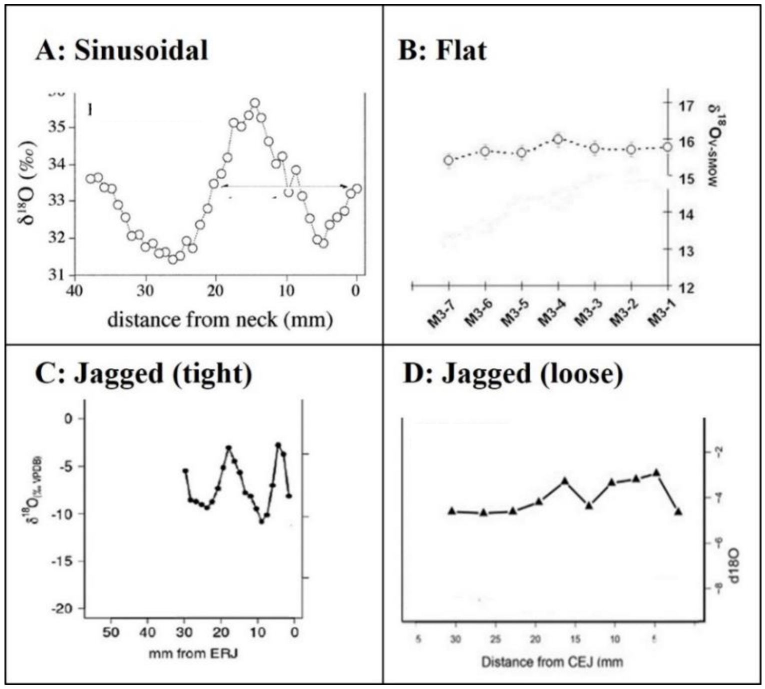

Figure 8.61 Types of intra-tooth $\delta^{18}O$ patterns from published studies as discussed in text. Adapted from A: Balasse *et al.* (2003, p.208), B: Britton *et al.* (2009, p.1169), C: Makarewicz and Pederzani (2017, p.9), and D: Chazin *et al.* (2019, p.63).

Will theoretically have a sinusoidal curve. I correlate $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ data according to seasonality if the serial $\delta^{18}O$ values form a sinusoidal pattern. In Thessaly, this means that the enamel $\delta^{18}O$ would be lowest during the cooler and wetter months (reaching a minimum around December) and highest during the hotter dry months (peaking around June) (Argiriou and Lykoudis, 2006, p.491).

Numerous studies have recorded examples of non-seasonal $\delta^{18}O$ signals that I can use as a guide for delineating atypical isotope trends (e.g., Bocherens *et al.*, 2001; Isaakidou *et al.*, 2019; Valenzuela-Lamas *et al.*, 2016) (Appendix 8.12; Fig. 8.61). If an animal consistently drinks water from different reservoirs or ingests plants grown in areas impacted by different growing conditions, its values will not generate a sinusoidal curve. As an example, Britton *et al.* (2009, p.1169) studied sequential enamel samples from wild caribou. One of their examples had a flattened oxygen isotope trend (Fig. 8.4B). They explain that this type of patterning may be due to extensive movement to areas that cause the animal to escape the climatic extremes that cause sinusoidal curving (Britton *et al.*, 2009, p.1168). As another example, Makarewicz and Pederzani (2017, p.9) explain that data trends that show multiple optimal maxima points per year (Fig.

8.61CD), which they refer to as 'false optimals', are often driven by differences in what animals consume or the type of water they ingest. They explain that determining which of these variation sources are responsible for differences is challenging, but that it tells a more complex story about movement and water sourcing than standard seasonality. When an animal moves to different food or water sources that are not consistently impacted by seasonality, or what Chazin *et al.* (2019, p.63) refer to as "isotopically-mixed" areas, its sequential enamel $\delta^{18}O$ values can generate a tightly jagged (Fig. 8.61C) or loosely jagged (Fig. 8.61D) pattern.

Ultimately these examples indicate that non-sinusoidal $\delta^{18}O$ patterning can be used to speculate on unique grazing patterns or water sourcing. I use these examples as a guide for identifying whether my sample individuals have a seasonal (sinusoidal) curve or a non-seasonal (varied water sourcing) curve. I further determine whether the curves are tightly jagged, loosely jagged, or flat (Fig. 8.61; Table 8.45) and use them to discuss potential movement to various water sources in the region. At Kastro Kallithea, five individuals (SG06, SG08, SG11, SG21, and SG23) have sinusoidal curve patterns and ingested food and water sources that were similarly impacted by seasonality. Two other ovicaprids (SG03 and SG16) have $\delta^{18}O$ patterning that fits the tight jagged pattern in Figure 8.61C, and both have similar profiles. At Pharsalos, three ovicaprids (SG30, SG39, and SG42) have sinusoidal curve patterns. Two additional individuals (SG38 and SG40) have loosely jagged profiles that are both like the one depicted in Figure 8.61D. The final individual (SG33) has a mostly flat $\delta^{18}O$ pattern like the one in Figure 8.61B.

Mobility Patterns

Researchers traditionally use sequential $\delta^{18}O$ values to determine seasonality and match other isotopic trends in the animal to the seasons, as done above (e.g., Balasse *et al.*, 2002; Chase *et al.* 2014). Another use of the sinusoidal curve involves looking at intra-individual variation and the amplitude of variation ($\Delta^{18}O$) between sequential enamel samples of a single individual (e.g., Tornero *et al.* 2016b; Vaiglova *et al.*, 2020). Part of this is based on climatic factors that, when combined with movement to different areas, either dampen or exaggerate the expected seasonal signal (Pederzani and Britton 2019, p.89). In some cases, this dampening can be so extreme that it creates a 'flat' signal (Fig. 8.61B) (Britton *et al.*, 2009). A benefit of this approach is that researchers can speculate about cases of probable altitudinal movement that may otherwise go undetected based on strontium isotope data alone (Pederzani and Britton, 2019, p.89).

As an example, Isaakidou *et al.* (2019) examined modern temperature and precipitation data in Crete depending on month, altitude, or distance from the coast. They correlated these climate patterns with $\delta^{18}O$ fluctuation to document how a seasonal curve would change at various places on Crete. For example, $\delta^{18}O$ values of precipitation are lower at higher altitudes by approximately 0.15-0.5‰ for every 100 m of elevation (Isaakidou *et al.*, 2019, p.43). A seasonal sinusoidal curve at a higher altitude would have lower $\Delta^{18}O$ because altitude not only reduces precipitation values but also reduces seasonal $\Delta^{18}O$ through other factors like evaporation and condensation. Similarly, if an animal moved from a higher altitude in the summer to a lower altitude in the winter, the dampening effects would be compounded, and the expected sinusoidal curve would appear flattened. In their analysis, Isaakidou *et al.* (2019, p.46) found that their archaeological sheep had less $\Delta^{18}O$ (2.2-2.8‰) compared to their goats ($\Delta^{18}O$: 3.2-4.5‰), which was attributed to greater vertical mobility in sheep compared to goats on Crete.

One of the limitations of examining $\Delta^{18}O$ is not knowing what the local 'normal' seasonal amplitude should be for ovicaprids in that region. Although we can study the modern $\Delta^{18}O$ in precipitation or expected meteoric water (e.g., Argiriou and Lykoudis, 2006, p.491), intra-individual $\Delta^{18}O$ in sequential enamel bicarbonate is expected to be much lower due to dietary and physiological factors that impact the conversion of ingested sources to body water $\delta^{18}O$ (e.g., seasonal averaging effect) (Pederzani and Britton, 2019). As a way around this, studies often discuss the inter-individual $\Delta^{18}O$ specific to their study population and research context (e.g., Britton *et al.*, 2009, p.1168; Chazin *et al.*, 2019, p.53). Isaakidou *et al.* (2019) discuss the difference in $\Delta^{18}O$ values between goats and sheep within their study population. Since the goats and sheep in my study were managed using different mobile/sedentary or local/non-local means, any inter-individual comparisons could be complicated by non-local isotope values.

Instead, I consider the $\Delta^{18}O$ in two individuals who were local, sedentary, and had true sinusoidal curves at Kastro Kallithea (SG08 and SG21) to be examples of the 'normal' seasonal $\Delta^{18}O$ benchmark (Table 8.44, 8.45). Under this premise, local sedentary individuals were exposed to the normal seasonal $\Delta^{18}O$ and can provide a benchmark for comparison of what is dampened or exaggerated. To create a more standardized range, I will consider the $\Delta^{18}O \pm 2\sigma$ (standard error) for each set of $\delta^{18}O$, which is a common approach for establishing baseline range $\Delta^{18}O$ for other isotopes like strontium (e.g., Price *et al.*, 2002). Based on this approach, the normal seasonal $\Delta^{18}O$ range at Kastro Kallithea is between 2.26‰ and 3.61‰, which I use as a

Table 8.45 Summary data and interpretations for archaeological specimens according to the stable oxygen isotope values ($\delta^{18}O$).
Includes the seasonal or non-seasonal and the dampened or exaggerated distinction based on the intra-individual variation ($\Delta^{18}O$). 'Normal' benchmark examples are indicated by a (*).

ID	Water Source (Seasonal or Non-Seasonal)		Variation from Seasonal Norms	
	Curve Pattern	Interpretation	$\Delta^{18}O$ (‰)	Interpretation
SG03	Jagged (tight)	Unique (non-seasonal) Sources	1.74	Dampened
SG06	Sinusoidal	Seasonally Impacted	3.44	Normal Seasonal
SG08	Sinusoidal	Seasonally Impacted	3.08*	Normal Seasonal
SG11	Sinusoidal	Seasonally Impacted	1.96	Dampened
SG16	Jagged (tight)	Unique (non-seasonal) Sources	1.97	Dampened
SG21	Sinusoidal	Seasonally Impacted	2.68*	Normal Seasonal
SG23	Sinusoidal	Seasonally Impacted	3.57	Normal Seasonal
SG30	Sinusoidal	Seasonally Impacted	4.25	Exaggerated
SG33	Flat	Unique (non-seasonal) Sources	2.26	Normal Seasonal
SG38	Jagged (loose)	Unique (non-seasonal) Sources	3.58	Normal Seasonal
SG39	Sinusoidal	Seasonally Impacted	2.21	Dampened?
SG40	Jagged (loose)	Unique (non-seasonal) Sources	3.18	Normal Seasonal
SG42	Sinusoidal	Seasonally Impacted	2.42	Normal Seasonal

loose guideline for interpretation. There are no individuals at Pharsalos that meet the local, sedentary, and seasonal parameters, so I have considered all Pharsalian ovicaprids using the Kastro Kallithea benchmark. I consider an animal to have a dampened oxygen isotope amplitude if its $\Delta^{18}O$ is below 2.26‰ and a potentially exaggerated amplitude if its $\Delta^{18}O$ is above 3.61‰ (Table 8.45).

In addition to the two normal ovicaprids (SG08, SG21), Kastro Kallithea has two other animals that have normal seasonal $\Delta^{18}O$ (SG06 and SG23), and three that may show dampened seasonal $\Delta^{18}O$ (SG03, SG11, and SG16). At Pharsalos four of the ovicaprids (SG33, SG38, SG40, and SG42) have normal seasonal $\Delta^{18}O$, one may show exaggerated $\Delta^{18}O$ (SG30), and the final animal (SG39) may show dampened seasonal patterning, although the $\Delta^{18}O$ is near the lower 'normal seasonal' limit. All interpretations made based on seasonal variation and $\Delta^{18}O$ are speculations in relation to the normal individuals, and I recognize that mobility patterns are best discussed in relation to the strontium isotope values. Using the $\Delta^{18}O$ calculated from intra-individual serial sampling provides an additional measure of analysis and helps me propose reasonable interpretations of the data as a whole.

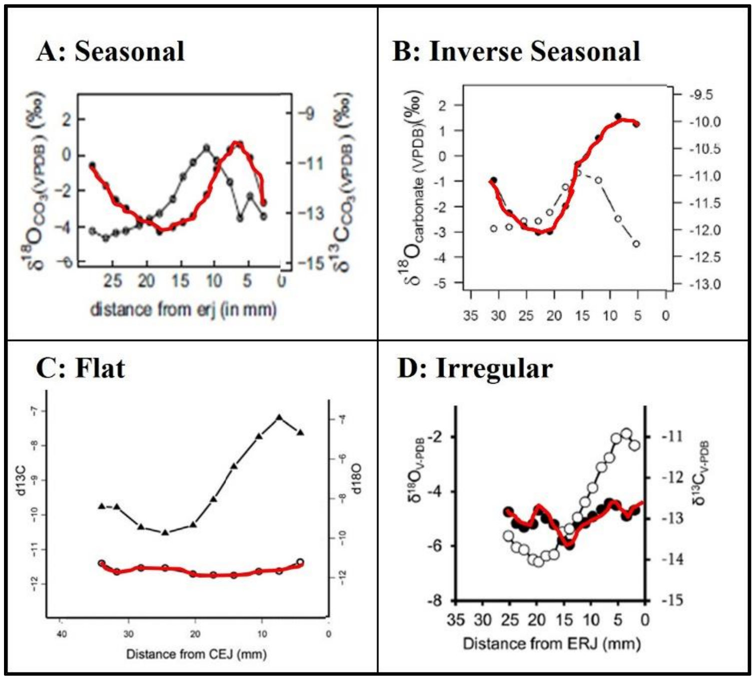

Figure 8.62 Types of intra-tooth $\delta^{13}C$ patterns from published studies as discussed in text. $\delta^{13}C$ (red) plotted with the corresponding $\delta^{18}O$ values. Adapted from A: Vaiglova *et al.* (2020, p.42), B: Isaakidou *et al.* (2019, p.51); C: Chazin *et al.* (2019, p.61), and D: Martín *et al.* (2021, p.99).

8.1.3 Stable Carbon Isotope Data

I will use trends in stable carbon isotope data to discuss dietary patterns. In particular, I interpret how the trends compare to the seasonal oxygen isotope curves and examine the intra-individual amplitude variation ($\Delta^{13}C$) or pattern shape to hypothesize potential deviations from normal seasonal grazing patterns.

Seasonal Diet

Stable carbon isotope values vary according to changes in diet, which in sheep and goats includes changes in plant type, portion, and growing season or location (recall Chapter 5; Appendix 8.12). As an example, over the course of a year, dietary $\delta^{13}C$ values can fluctuate 1‰ to 3‰ in ovicaprids consuming C_3 plants because of seasonal changes in growing conditions or plant availability (Balasse *et al.*, 2002, p.923; Chazin *et al.*, 2019, p.59). For example, sunlight, heat, and lower amounts of precipitation impact water availability during summer months, which seasonally favours ^{13}C during photosynthesis (Farquhar *et al.*, 1989). When sequential $\delta^{13}C$ values are plotted, this seasonal fluctuation generates a sinusoidal curve that coordinates with the seasonal stable oxygen isotope curve (Fig. 8.62A). I discuss seasonal variation in diet for all individuals in my study; I categorize it as ‘normal seasonal’ if its serial $\delta^{13}C$ values form a sinusoidal pattern that coordinates with the $\delta^{18}O$ sinusoidal pattern (Table 8.46). In Thessaly, this means that the $\delta^{13}C$ would be lowest during the darkest winter months and highest during the sunniest summer months (Vaiglova *et al.*, 2020).

Studies have also recorded examples of $\delta^{13}C$ signals that do not coordinate with the seasonal $\delta^{18}O$ values. In many of these scenarios, the stable carbon isotope patterning is the result of seasonal changes in regional fodder sources, and largely reflects shifts in C_3 or C_4 plant availability (e.g., Chakraborty *et al.,* 2018; Chase *et al.*, 2014; Janzen *et al.*, 2020). As most of the plants available for consumption in my study area are C_3 plants, there are other rationales that I use as a guide for interpreting atypical isotope trends in my ovicaprid data (e.g., Balasse *et al.* 2013; Mainland *et al.,* 2016; Trentacoste *et al*., 2020) (Fig. 8.62; Appendix 8.12). As an example, one of the sheep from Isaakidou *et al.* (2019, pp.51-52) showed a pattern of inversely correlated $\delta^{13}C$ and $\delta^{18}O$ sinusoidal signalling (Fig. 8.62B). They explain that the sheep was likely vertically translocated during wet summers and dry winters as found in some other studies (e.g., Chazin *et al.*, 2019, p.63; Tornero *et al.*, 2016). Under this scenario, the animal was moving to different altitudes, grazing on an area that still had seasonal variation in $\delta^{18}O$, but offered a variety of plant species and/or plant parts; the plant species available during the winter had higher typical $\delta^{13}C$ than those that were available during the summer. In other studies, the $\delta^{13}C$ pattern appears flattened (Fig. 8.62C) (e.g., Chase *et al.*, 2014; Chazin *et al.*, 2019; Isaakidou *et al.* 2019). Vaiglova *et al.* (2020, p.14) explain that this flattening may be the result of animals not being fed fresh local vegetation. If an animal consumed dried crop fodder harvested during a different season, the crop $\delta^{13}C$ will reflect the season that it grew in. For example, Makarewicz (2017) recorded high $\delta^{13}C$ in animals during winter months that suggested ingestion of plants collected during the summer months.

If an animal’s $\delta^{13}C$ is not seasonal, inversely seasonal, or flattened, it is considered irregular (Fig. 8.62D). Numerous studies have recorded irregular $\delta^{13}C$ patterning and speculated on different scenarios that could have resulted in each variation, including seasonally-varied foddering (e.g., Balasse *et al.*, 2003; Bocherens *et al.*, 2001; Mainland *et al.*, 2016; Trentacoste *et al.*, 2020), altitudinal changes in diet (e.g., Isaakidou *et al.*, 2019; Janzen *et al.*, 2020; Vaiglova *et al.*, 2020) or variation in C_3 and C_4 plant grazing (e.g., Chakraborty *et al.*, 2018; Chase *et al.*, 2014; Janzen *et al.*, 2020). The example shown in Figure 8.5D depicts a sheep with a jagged $\delta^{13}C$

Table 8.46 Summary data and interpretations for archaeological specimens according to the stable carbon isotope values ($\delta^{13}C$). Includes the seasonal or non-seasonal distinction and the dietary variation based on the intra-individual variation ($\Delta^{13}C$).

ID	Animal Type	Seasonal or Non-Seasonal		Variation from Seasonal Norms	
		Pattern	Interpretation	$\Delta^{13}C$ (‰)	Interpretation
L01	Lamb	Seasonal?	Seasonal Sources	4.09	Different Region/Sources
SG03	Sheep	Flat	Some Crop Foddering	0.96	Similar Region/Sources
SG06	Sheep	Irregular	Variable Sources	1.63	Similar Region/Sources
SG08	Goat	Irregular	Variable Sources	2.03	Similar Region/Sources
SG11	Sheep	Seasonal	Seasonal Sources	2.77	Similar Region/Sources
SG16	Goat	Irregular	Variable Sources	3.98	Different Region/Sources
SG21	Sheep	Seasonal	Seasonal Sources	2.81	Similar Region/Sources
SG23	Goat	Inverse Seasonal	Altitudinal Movement	2.43	Similar Region/Sources
SG30	Sheep	Seasonal	Seasonal Sources	3.94	Different Region/Sources
SG33	Sheep	Inverse Seasonal	Altitudinal Movement	2.70	Similar Region/Sources
SG38	Sheep	Irregular	Variable Sources	2.68	Similar Region/Sources
SG39	Goat	Seasonal	Seasonal Sources	3.31	Different Region/Sources
SG40	Sheep	Flat	Some Crop Foddering	1.55	Similar Region/Sources
SG42	Sheep	Seasonal	Seasonal Sources	3.21	Different Region/Sources

pattern. Martín *et al.* (2021, p.99) explain that this sheep was likely given a dietary supplement of leaf fodder during the winter months (higher $\delta^{13}C$) and grazed in an area that was under a thick forest canopy during the summer months (lower $\delta^{13}C$). Short-term variation in diets, either through grazing outside of the forest canopy, or consuming natural fodder in the winter, would have corresponded to a similar dampened variation in sheep $\delta^{13}C$ (Martín *et al.,* 2021, p.99).

Ultimately these examples show that $\delta^{13}C$ patterning can be used to infer unique fodder sources or grazing patterns. I use these examples to indicate if my samples have a seasonal or inversely seasonal (sinusoidal) curve in relation to the $\delta^{18}O$ pattern, or if it has a flattened or irregular pattern (Fig. 8.62; Table 8.46). I use these patterns to discuss fodder source and movement to different sources depending on season. At Kastro Kallithea, two individuals (SG11 and SG21) have a seasonal sinusoidal curve that correspond with the $\delta^{18}O$ pattern. One individual (SG03) has a flattened $\delta^{13}C$ pattern, and the remaining four (SG06, SG08, SG16, and SG23) have irregular patterning. At Pharsalos, three ovicaprids (SG30, SG39, and SG42) have sinusoidal curve patterns that correspond to the $\delta^{18}O$ pattern. The remaining individuals each have an inverse seasonal $\delta^{13}C$ pattern (SG33), a flattened $\delta^{13}C$ pattern (SG40), or an irregular $\delta^{13}C$ pattern (SG38) (Table 8.46).

Different Food Sources

Researchers traditionally use sequential $\delta^{13}C$ values to discuss subsistence change between areas dominated by C_3 or C_4 plants (e.g., Chakraborty *et al.*, 2018; Chase *et al.*, 2014; Janzen *et al.*, 2020). In regions where the foliage is predominantly C_3 plants, researchers collectively use $\delta^{13}C$ and $\delta^{18}O$ values to discuss seasonal or non-seasonal dietary variation as part of sedentary and mobile management, as done above (e.g., Balasse *et al.*, 2017; Mainland *et al.*, 2016; Tornero *et al.*, 2016b). In addition to the curve pattern, another indication of dietary change is the amplitude of variation ($\Delta^{13}C$) in each ovicaprid. If seasonal $\Delta^{13}C$ is expected to be between 1‰ and 3‰ (e.g., Balasse *et al.*, 2002, p.293; Chazin *et al.*, 2019, p.59), $\Delta^{13}C$ greater than 3‰ is likely due to changes in food source beyond seasonality.

As an example, Isaakidou *et al.* (2019) found that most of their ovicaprids had $\Delta^{13}C$ between 0.5‰ and 2.2‰, which they explained was an example of normal seasonal variation or consumption of plants within the same area or ecozone. One of their sheep had a $\Delta^{13}C$ of 3.2‰, which when considered in relation to the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values, was the result of seasonal altitudinal grazing between winter lowland and summer upland pastures. Similarly, the southern Greek sheep studied by Vaiglova *et al.* (2020, p.43) also had $\Delta^{13}C$ over 3.5‰ due to drastic changes in diet because of movement outside of the main region. Both studies also found that $\Delta^{13}C$ may be species-specific because of the natural tendency for sheep to graze and goats to browse, which can impact what foods it eats and in turn what its $\Delta^{13}C$ is. Isaakidou *et al.* (2019) and Vaiglova *et al.* (2020) both recorded the highest $\Delta^{13}C$ in their sheep compared to goat samples. Based on the values listed in Table 8.46, the animals in my study did not vary depending on taxa.

When considering the $\Delta^{13}C$ patterning in ovicaprids based on these examples, most of the ovicaprids in my study consumed isotopically similar food sources or foddered in similar regions over the course of the period measured. At Kastro Kallithea, six ovicaprids (SG03, SG06, SG08, SG11, SG21, and SG23) had $\Delta^{13}C$ less than 3‰ and likely consumed foods that were similarly impacted by seasonality or were within the same region. One goat (SG16) at Kastro Kallithea did not fit within the seasonal range and likely consumed foods from different regions or sources. At Pharsalos, three ovicaprids (SG33, SG38, and SG40) had $\Delta^{13}C$ less than 3‰, and likely consumed foods in similar regions or consumed foliage grown under similar seasonal impacts. The remaining three ovicaprids (SG30, SG39, and SG42) had $\Delta^{13}C$ above 3‰, which is likely due to the animals consuming different types of plants, parts of plants, or growing regions. The $\Delta^{13}C$ in all samples was not large enough to suggest that animals had C_4 plant diets, but instead is consistent with the $\Delta^{13}C$ seen in other studies in mainland Greece (Vaiglova *et al.*, 2020) or Crete (Isaakidou *et al.*, 2019). Using the $\Delta^{13}C$ calculated from intra-individual serial sampling provides an additional measure of analysis of diet and helps me contextualize the interpretations that I propose based on all data collectively.

Modern (L01) Example

The Anavra Lamb (L01) is an example of how stable carbon isotope values can be used to show seasonal changes in diet (Fig. 8.60). There are limitations when interpreting the values of an animal during the prenatal and nursing periods. As an example, one of the reasons why I did not discuss the $\delta^{18}O$ in detail for L01 is that there has been limited work discussing $\delta^{18}O$ in milk or during gestation, and none that have considered the implications for sheep. Instead, based on the shepherd's testimony, the animal's age at death and the known gestation period have been used to correlate seasons to the strontium and stable carbon isotope data (recall Section 7.1.4). The first few months of recorded life (9.0 – 15.0 mm) would have occurred in utero and likely reflect the ewe's diet; $\delta^{13}C$ values increase from winter (15.0 mm) to spring (9.0 mm) because of seasonal changes ($\Delta^{13}C$: 1.33‰). The amplitude of $\Delta^{13}C$ is much greater after birth (5.0 – 9.0 mm; $\Delta^{13}C$: 2.76‰), likely in part because the lamb consumed the ewe's milk during some of this period, which would result in trophic level elevation of about 1‰ during that time. Overall, L01 fits the model listed above, as the total $\Delta^{13}C$ is 4.09‰, which corresponds to a diet of different regions or sources (i.e., seasonal changes in diet for the ewe, nursing, and weaning onto local graze).

None of the ovicaprids in my study show the same isotope trends as L01 because the lamb's diet incorporates gestation, birth, and weaning. Although it is a good example to show how isotope values can be interpreted, it is not a suitable example for discussing adult ovicaprid samples that record two to four year's worth of adult life, and it will not be discussed further.

8.1.4 Summary of Interpretation Methods

Shepherds use flexible management strategies that often vary according to animal, herd size, temperament, weather patterns, terrain, or encounters (e.g., other animals, human activities). The purpose of my discussion is to explain what the stable isotope values can tell us about probable

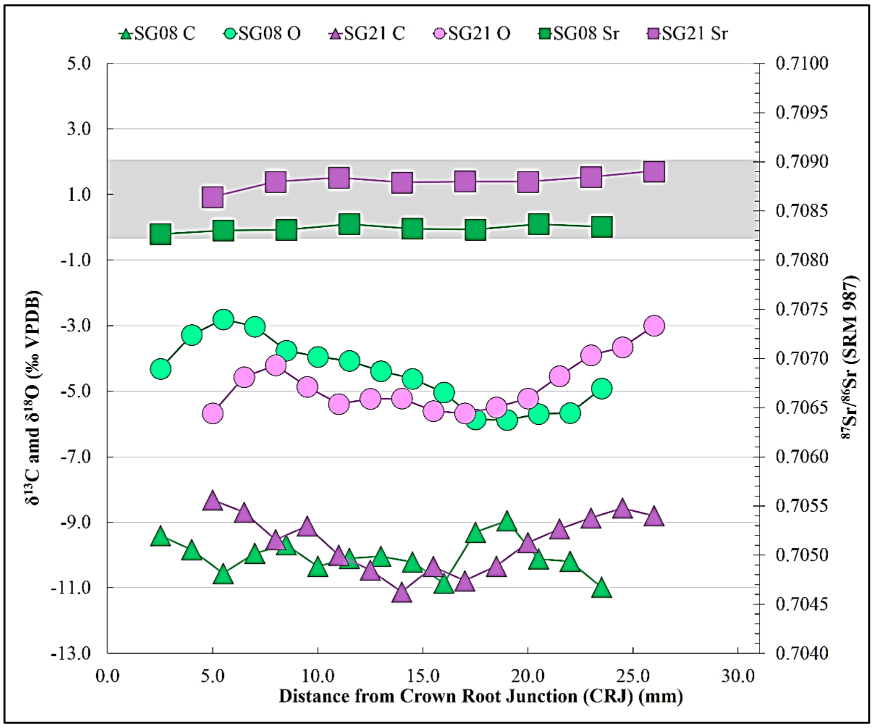

Figure 8.63 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG08 (green) and SG21 (purple) enamel. The grey block represents the local Kastro Kallithea $^{87}Sr/^{86}Sr$ range.

location and mobility patterns and to further speculate on possible scenarios leading to those behaviours. Based on how other studies have interpreted the $^{87}Sr/^{86}Sr$, $\delta^{18}O$, and $\delta^{13}C$, as discussed above, I consider what management styles were in use at Kastro Kallithea and Pharsalos during antiquity.

8.2 Local Management

According to strontium isotope data, one sheep (SG21) and goat (SG08) were sedentary and managed locally in the Kastro Kallithea isoscape (Table 8.44) following a seasonal (sinusoidal) pattern (Table 8.45). Although these two animals appear to have been kept isotopically local to the village, stable carbon isotope values suggest that each animal was managed differently.

8.2.1 Local Free-Grazing

A local Kastro Kallithea sheep (SG21) has seasonal stable carbon and oxygen isotope values (Fig. 8.63). Based on the variation in all three isotopes, SG21 was sedentary ($\Delta^{87}Sr/^{86}Sr$: 0.000265), had normal seasonal access to water ($\Delta^{18}O$: 2.68‰), and consumed foods that were consistent with the season and region ($\Delta^{13}C$: 2.81‰). Sheep are grazers and SG21 would have grazed on C_3 foliage in local pastures grown under seasonal influences. Instances of short-term $\delta^{13}C$ variation may be due to the animal grazing on different portions of the plant (e.g., roots, leaves, or stems), variation in the proportion of the species grazed, or fluctuation in precipitation during different growing periods (Isaakidou *et al.*, 2019, p.48). Overall, SG21 presents an example of an animal managed locally under isotopically 'normal' circumstances.

8.2.2 Supplemental Grazing

The local Kastro Kallithea goat (SG08) shows similar patterns to SG21 in that SG08 was isotopically local and sedentary ($\Delta^{87}Sr/^{86}Sr$: 0.000101) and had normal seasonal access to water ($\Delta^{18}O$: 3.08‰) (Fig. 8.63). Although SG08's stable carbon isotope data are within the range of seasonal variation ($\Delta^{13}C$: 2.03‰), the pattern appears irregular with the peak occurring at winter (19.0 mm) followed by a flattening between winter and summer (5.5 – 16.0 mm). Isaakidou *et al.* (2019, p.50) noted a similar pattern in their goats and argue that the irregular $\delta^{13}C$ variation and dampening of the expected seasonal variation in $\delta^{13}C$ may have been a result of a more restricted browsing diet that included monotonous local C_3 browse. If SG08 were managed locally throughout the year, it may not have had sufficient areas to pasture and required supplemental fodder during the winter months. If it were fed a supplemental source during this time, that fodder likely would have been grown during warmer and drier conditions, and this would have raised the $\delta^{13}C$ value of the winter diet. If this fodder were dried and did not contain sufficient water for the goat, the animal would have had to drink from a local water source, which would be consistent with the observed seasonal stable oxygen isotope signal.

Overall, SG08 and SG21 represent two examples of animals managed local to Kastro Kallithea. Although they were fed differently, potentially through free-grazing or with supplemental fodder, the patterns were what I expected if an animal was being managed locally for local use. Animals that have any deviation from these 'normal' patterns are indicative of a specialized form of husbandry.

8.3 Non-Local Management

Based on strontium isotope values, three ovicaprids were strictly non-local to the Kastro Kallithea (SG11 and SG23) or Pharsalos (SG33) isozones (Fig. 8.64). All three ovicaprids had unique stable carbon and oxygen isotope patterns and likely represent different management strategies.

8.3.1 Highland Management

One sheep from the Alexopoulos Plot (SG33) was non-local and mobile ($\Delta^{87}Sr/^{86}Sr$: 0.000781) throughout the measured period. The recorded oxygen isotope signature was non-seasonal and appears somewhat flattened ($\Delta^{18}O$: 2.26‰) suggesting that the animal had access to unique water sources that were not similarly impacted by season. The stable carbon isotope pattern most closely matches the inverse seasonal dietary pattern, which may be due to altitudinal movement in a non-local area ($\Delta^{13}C$: 2.81‰). SG33 had the highest $^{87}Sr/^{86}Sr$ values among all ovicaprids (Fig. 8.59), which is thought to correspond with highland regions in Thessaly (recall section 7.1). Although SG33 may have grazed in a non-local lowland area with higher $^{87}Sr/^{86}Sr$ values that has not yet been documented in Thessaly, movement between regions in the Óthrys Mountains may have also caused SG33's unique trends in carbon and oxygen isotope data.

According to the geological mapping (Fig. 7.43), Mount Óthrys is composed of three relative zones of bedrock geology. Based on the Anavra lamb, the lower western limits of Mount Óthrys have strontium ratios lower than 0.7090 (Zone 1). Moving towards the centre and rising in altitude, the values recorded from P01 suggests that the second area has strontium ratios between 0.7090 and 0.7095 (Zone 2). The third area is expected to have a higher $^{87}Sr/^{86}Sr$ ratio than the previous zones, between roughly 0.7095 and 0.7100 (Zone 3). The strontium isotope signature found for SG33 may indicate movement between Zone 2 in the hot summer season and Zone 3 in the cold winter season.

Although it may seem counter-intuitive to move to a higher region during the colder months, choosing to winter in an area sheltered from snowfall may ensure accessible (uncovered) pasture annually. Large mountains, like the Óthrys, are exposed to different precipitation patterns and quantities depending on the altitude, position, and season. For example, airborne moisture falls as rain on the windward side of mountains, which is often depleted in ^{18}O compared to the leeward side (Scholl *et al.*, 2007). Additionally, points of higher elevation receive precipitation that is depleted in ^{18}O compared to points of lower elevation (Pederzani and Britton, 2019). Potential scenarios to explain the flattened seasonal oxygen isotope trend may be that SG33 grazed at a higher altitude during the winter months and at a lower altitude during the summer months, or that it grazed on foliage grown on the leeward side of the highlands during the wet winter and spring months and the windward side of the mountains during the drier summer and autumn months.

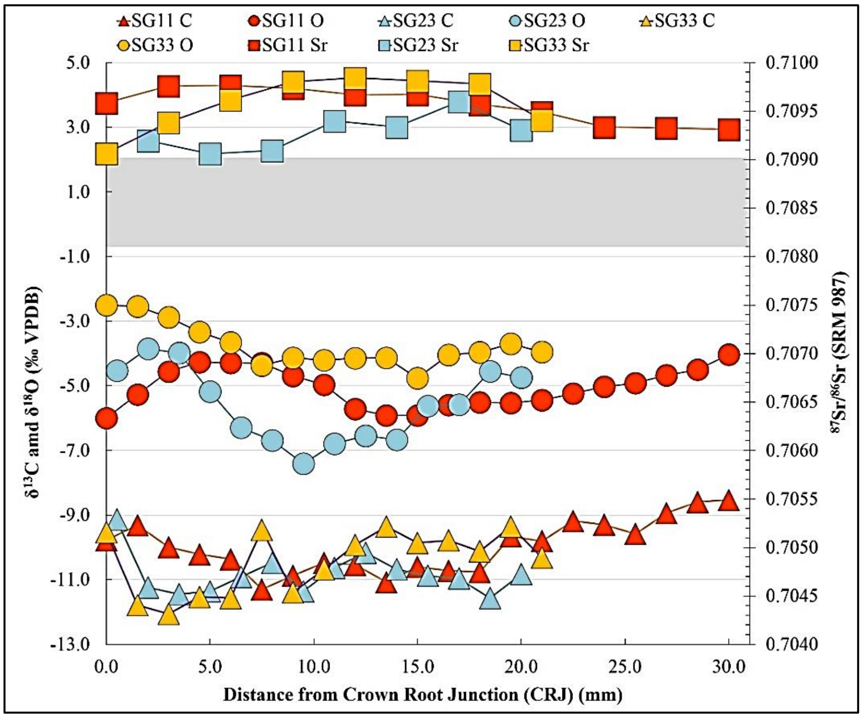

Figure 8.64 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG11 (orange), SG23 (green), and SG33 (purple) enamel. The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range.

The carbon isotope patterning may also support the scenario of altitudinal movement in Mount Óthrys. Woldring (2003, p.154) recorded different vegetation zones on Mount Óthrys which varied depending on altitude and precipitation. The windward side contains more deciduous oak forests, which encompass the area at altitudes between 600 and 1200 m. The leeward side includes pine species (up to 1000 m) and drought-resistant kermes oak shrubland (*pournaria*) (up to 1275 m). Non-photosynthetic portions of a plant are often enriched in ^{13}C compared to leafy portions (Farquhar and Lloyd, 1993), and consumption of shrubland would correlate to higher $\delta^{13}C$ values compared to those from a diet of browsing in areas with deciduous oaks.

When combined, the isotope signatures recorded for SG33 could be due to highland grazing on kermes oak and other pine species on the leeward side of the mountains during the cold and wet seasons, and lowland grazing of deciduous oak species on the windward side of the mountains during the hot and dry seasons. Shepherds would have been able to avoid colder wet snow in the lowlands of the windward side and had access to variable forms of browse each season. At the end of the period measured (0.0 mm) the strontium isotope ratio falls closer to the Pharsalos isoscape, potentially signifying that the sheep was moving closer to Pharsalos prior to slaughter.

8.3.2 Annual Movement

One sheep from Kastro Kallithea (SG11) was also non-local and mobile ($\Delta^{87}Sr/^{86}Sr$: 0.000453), although based on the changes in strontium isotope values this animal appeared to move from one region to another isotopically different region after roughly one year (~21.0 mm) (Fig. 8.64). The recorded oxygen isotope signature was seasonal and appears mostly flattened ($\Delta^{18}O$: 1.96‰) like the pattern in SG33. Unlike SG33, SG11's carbon isotope values are seasonal and likely indicate that the animal consumed foods in a similar region or from a similar source ($\Delta^{13}C$: 2.77‰) seasonally. A possible scenario that caused these three isotope patterns is that SG11 grazed in Zone 2 during the first year and moved to Zone 3 during the second year. Specifically, SG11 may have grazed in an area affected by seasonal evaporation and condensation (e.g., windward side of the mountain) during the second year (0.0 – 18.0 mm), and in an area exposed to oxygen dampening influences during the first year (18.0 – 29.5 mm), which may have caused the dampening effect on the oxygen isotope pattern. Because SG11 was consuming foods that followed a seasonal trend in data, the sheep was likely moving within each zone to graze on seasonally available sources.

8.3.3 Constant Movement

A third ovicaprid, SG23, may have also been managed in the Óthrys Mountains. Unlike SG11 and SG33, SG23's changing $^{87}Sr/^{86}Sr$ values may be the result of moving to a different geological area every three months (Fig. 8.64). SG23 is a goat from Kastro Kallithea that was non-local and mobile ($\Delta^{87}Sr/^{86}Sr$: 0.000538). The pattern of oxygen isotope values was considered normal and seasonal ($\Delta^{18}O$: 3.57‰), and the carbon isotope patterning was considered inverse seasonal but within a normal range ($\Delta^{13}C$: 2.43‰). The strontium isotope values from SG23 are higher than the Kastro Kallithea range and are within the range at Mount Óthrys. Using the same location estimates for SG11 and SG33, SG23 may have moved between mountain Zone 2 and 3 between summer and autumn (17.0 – 20.0mm), browsed in Zone 2 again during the autumn and early winter months (11.0 – 14.0 mm), moved to Zone 1 during the spring months (5.0 – 8.0 mm), and returned to Zone 2 for the spring and summer months (2.0 –

5.0 mm). Alternatively, the final area that SG23 may have moved to was more coastal (potentially south of Mount Óthrys; Fig. 7.43), as strontium isotope values in this enamel segment are similar to seawater sources in the area (0.7092). The fluctuation in carbon isotope values during the final months may also support this lowland grazing in an area with halophytes or other foods comparatively enriched in ^{13}C, although the $\Delta^{13}C$ is still within the normal seasonal range for C_3 plants.

Although SG23 had strontium isotope patterning to suggest movement in Mount Óthrys (similar to SG11 and SG33), and carbon isotope trends consistent with altitudinal movement (similar to SG33), the seasonal oxygen isotope signature was not dampened in SG23 ($\Delta^{18}O$: 3.57‰), which was expected for an animal moving between different altitudes. A possible scenario is that SG23 moved between areas of the mountain that were exposed to precipitation and the full effects of seasonality compared to the areas that SG11 or SG33 grazed in. Additionally, if SG23 moved from a lowland area (Zone 1) to an even lower coastal area during the second summer, the oxygen isotope values would be normal seasonal (undampened), which is what was recorded. Overall, I speculate that SG11, SG23, and SG33 present three examples of animals managed non-locally and in the mountains of Thessaly. Based on their strontium, oxygen, and carbon isotope patterning, each animal was managed differently.

8.4 Mixed-Mobile Management

Based on strontium isotope values and variations, three ovicaprids found at Pharsalos (SG30, SG39, and SG42) were not managed using traditional local *or* fully mobile (non-local) trends. Based on the patterns in isotope data, and in consideration of similar patterns in my other samples or from other published research, I speculate that these individuals are examples of animal management involving movement between different local regions.

8.4.1 Local Highland Movement

One goat (SG39) from the Arsenopoulos Plot had local and non-local strontium isotope values. Despite the mixed-location pattern, the animal was considered sedentary ($\Delta^{87}Sr/^{86}Sr$: 0.000190). A sheep (SG42) from the Arsenopoulos Plot had the opposite pattern, in that it was considered local but was potentially mobile ($\Delta^{87}Sr/^{86}Sr$: 0.000297). Both animals had similar seasonal oxygen and carbon isotope patterning to ovicaprids that were mobile in the mountains (i.e., SG33; Fig. 8.65B). Because of these trends in data, I discuss SG39 and SG42 together as I

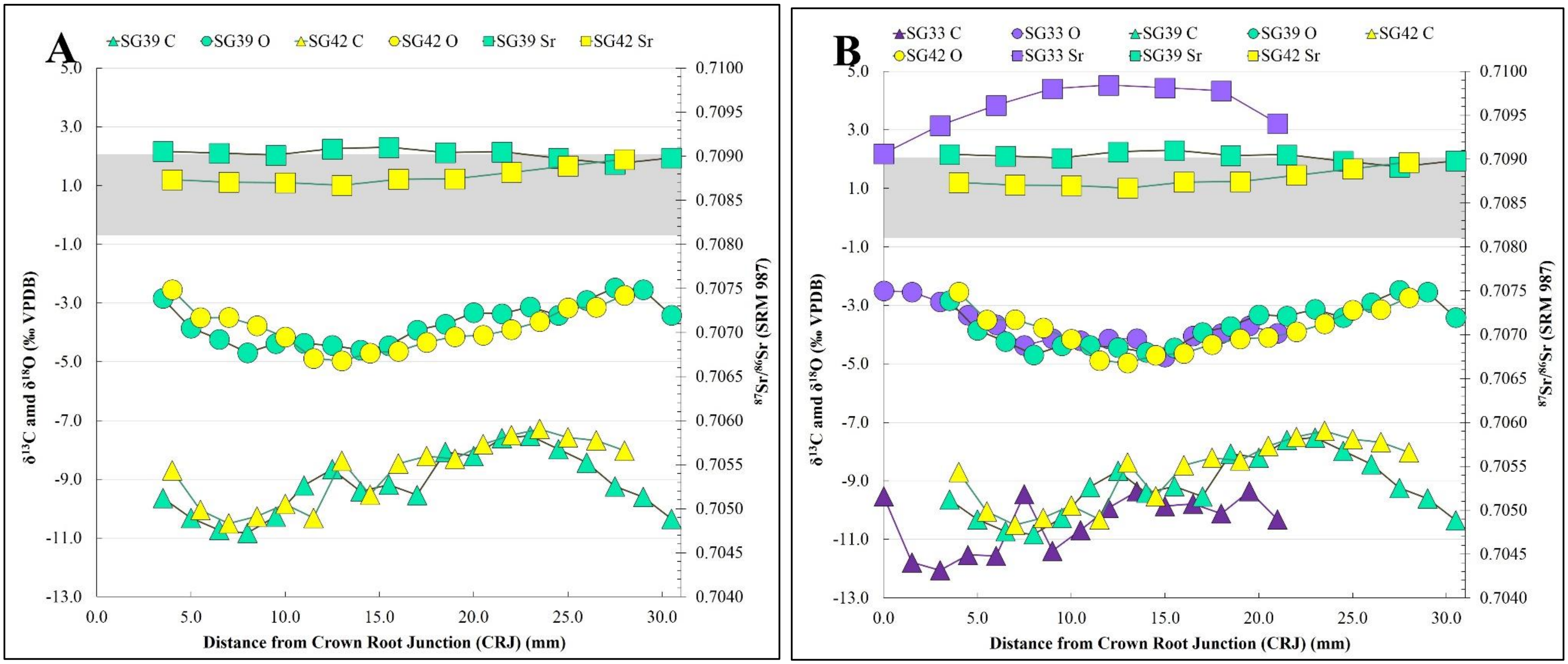

Figure 8.65 A(Left): Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG39 (green) and SG42 (yellow). The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range. B(Right): SG33 (purple) is added for comparison to SG39 and SG42.

believe that the isotope patterning is the result of similar management trends. More specifically, I speculate that SG39 and SG42 may be examples of ovicaprids that were grazed at different elevations in a nearby or local area.

Although SG39 and SG42 did not have strontium isotope values within the anticipated isoscape range for Mount Óthrys (e.g., SG11, SG23, or SG33), the oxygen and carbon isotope patterning is similar to animals anticipated to have altitudinal movement (e.g., SG33) (Fig. 8.65B). Both SG39 and SG42 have $\Delta^{18}O$ that is potentially dampened from the seasonal standard ($\Delta^{18}O$: 2.21‰ and 2.42‰, respectively), which is similar to the trend noted in the non-local and mobile SG33 ($\Delta^{18}O$: 2.26‰). In addition, SG39 and SG42 have $\Delta^{13}C$ that is higher than what would be expected by normal seasonal variation alone ($\Delta^{13}C$: 3.31‰ and 3.21‰, respectively). This trend was also found in one of the sheep on Crete ($\Delta^{13}C$: 3.2‰; $\Delta^{18}O$: 2.4‰), which Isaakidou *et al.* (2019, p.48) argued was the result of vertical mobility. Although SG39 and SG42 were mostly local to the Pharsalos isoscape, I believe that they were likely managed at higher altitudes than animals that were considered local and sedentary to the area (e.g., SG08, SG21).

8.4.2 Lowland Movement Between Sources

Another mixed-mobile example is the Classical era sheep from Pharsalos (SG30) (Fig. 8.66). SG30 was local and potentially mobile ($\Delta^{87}Sr/^{86}Sr$: 0.000275), had an exaggerated seasonal oxygen pattern ($\Delta^{18}O$: 4.25‰), and had a similarly large range of seasonal $\Delta^{13}C$ (3.94‰). None of the other ovicaprids in my study have similar isotope patterns to SG30. Isaakidou *et al.* (2019, p.48) speculate that these trends may be suggestive of lowland movement and consumption of shallow-rooted annual plants. Carbon isotope values from shallow-rooted plants vary more with seasonal precipitation and temperature compared to browsing on deep-rooted flora (i.e., bushes and trees), with higher $\Delta^{13}C$ evidenced by grazing in open pasture (no canopy cover) or saline environments (e.g., salt marshes) (Isaakidou *et al.*, 2019, p50). Both of these scenarios are possible for SG30.

If SG30 was grazing in a coastal area during the summer and autumn months and an inland area during the winter and spring months, its diet would be enriched in ^{18}O relative to foliage consumed inland during the spring and winter months, and the difference between the two extremes would be high. The coastal area of Halos included salt marshes with halophytic plants, which are enriched in ^{13}C relative to other C_3 plant sources and could also account for the high

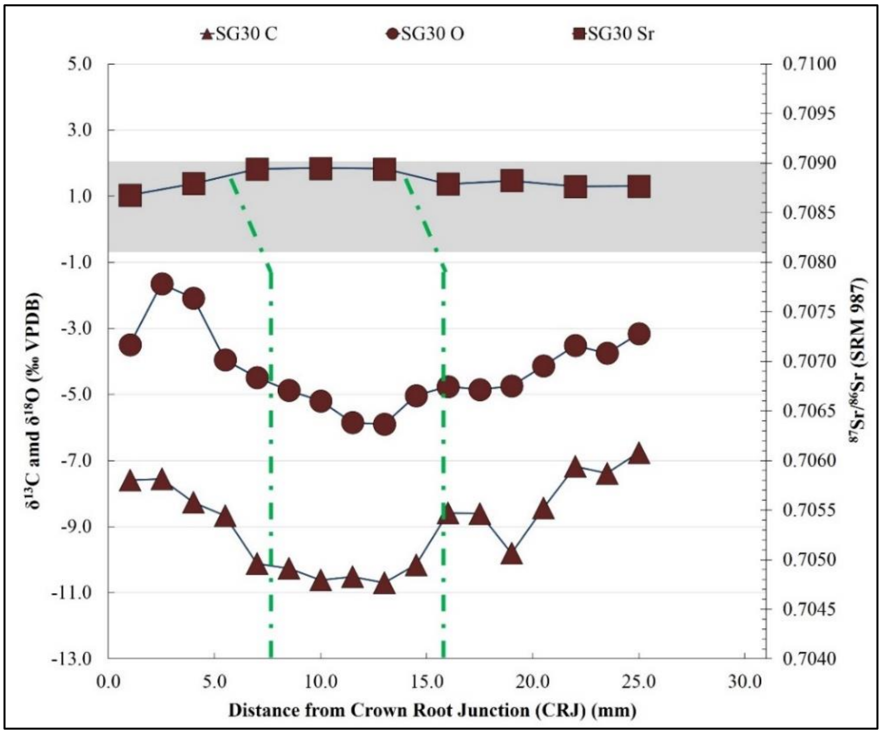

Figure 8.66 Sequential $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG30 (brown) enamel. The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range. Green lines show potential periods of movement between grazing regions as discussed in text.

$\Delta^{13}C$ (3.94‰). However, if SG30 consumed enough coastal resources to influence its carbon and oxygen isotope values, its strontium isotope values might be expected to be closer to the values for seawater (0.7092; recall Fig. 7.43), which is not the case, and this is a point against the coastal grazing scenario.

Instead of coastal grazing, SG30 may have grazed in open pastures as part of small-scale local movement. Foraging on shallow-rooted plants could have contributed to the higher $\Delta^{18}O$ and movement between microregions could account for the higher strontium isotope variation yet kept SG30 isotopically local. The $\Delta^{13}C$ may also be caused by SG30 consuming some C_4 plants during the warmer seasons. As an example, in the late autumn to early spring period (16.0– 7.0 mm), SG30 may have grazed on shallow-rooted C_3 plants (lower $\delta^{13}C$) in open winter pasture (lower $\delta^{18}O$) in one area of the isozone (higher $^{87}Sr/^{86}Sr$). During the late spring to early autumn periods (1.0 – 7.0 mm, 16.0 – 25.9 mm), SG30 may have grazed on ground cover including some C_4 plants (higher $\delta^{13}C$) in open summer pasture (higher $\delta^{18}O$) in another area of the isozone (lower $^{87}Sr/^{86}Sr$). Figure 8.66 includes green lines that delineate the proposed time periods according to the offset between carbon and oxygen isotope and strontium isotope values established in other studies (e.g., Lazzerini *et al.*, 2021; Zazzo *et al.*, 2010).

Isaakidou *et al.* (2019, pp.43-44) discuss evidence of sheep and goats grazing on C_4 plants (e.g., *Portulaca oleracea* – purslane, *Cynodon dactylon* – Bermudagrass; Bergmeier, 2008) that are specifically available on Crete between late spring until early autumn. Although it is unclear if either species were available in Thessaly during antiquity, consumption of C_4 plants during the late spring and early autumn would align with the timing of ^{13}C-enriched diet seen in SG30 (Fig. 8.66). I am not suggesting that SG30 grazed on Crete, but instead that a similar pattern of summer grazing in an open area that had wild or cultivated C_4 plants may have been the cause of SG30's carbon values and variation.

Vaiglova *et al.* (2018, p.20) found that a diet of local foliage corresponded with enamel $\delta^{13}C$ values between -12‰ and -10‰, whereas values between -9‰ and -3‰ instead corresponded with a diet of foods comparatively enriched in ^{13}C (e.g., halophytes, millet). Since SG30 does not have a coastal strontium isotope signature but does have numerous $\delta^{13}C$ values above 9‰, this sheep may have had access to millet, millet crop stubble, or wild C_4 plants (e.g., Bergmeier, 2008). Millet was a potential fodder crop in the Peloponnese as early as the Late Helladic (e.g., Weiberg *et al.*, 2019); however more work would be required to confirm its use at Pharsalos. Although these interpretations are speculative, I believe that SG30, SG39, and SG42 present three examples of animals that were managed using specialized practices. None of these individuals show evidence of being managed strictly local or non-local nor strictly mobile or sedentary. Instead, their shepherds likely employed a mixed-mobile management approach that involved local lowland and highland pastures.

8.4 Other Specialized Management

The remaining ovicaprids had non-seasonal oxygen isotope patterns that suggested the animals were managed using other unique approaches. Two ovicaprids at Kastro Kallithea (SG03 and SG16) and two at Pharsalos (SG38 and SG40) were isotopically local and non-mobile but had non-seasonal oxygen isotope trends. The specific trends observed in these animals differ depending on whether the animal was managed at Kastro Kallithea (Fig. 8.67) or around Pharsalos (Fig. 8.68). I discuss the unique management trends specific to each respective site.

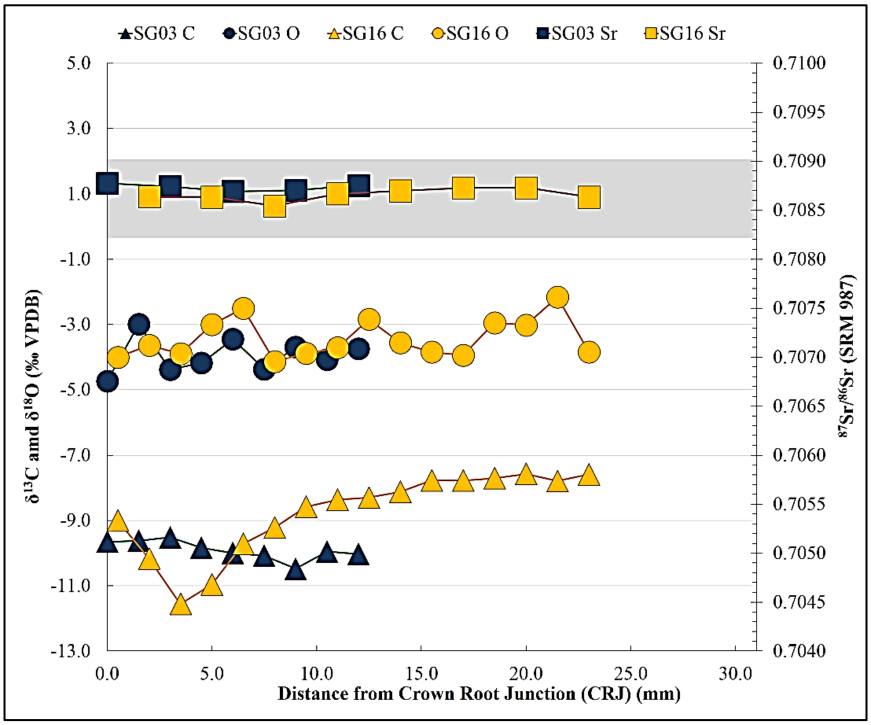

Figure 8.67 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG03 (orange) and SG16 (teal) enamel. The grey block represents the local Kastro Kallithea $^{87}Sr/^{86}Sr$ range.

8.4.1 Changing Local Fodder or Water Source at Kastro Kallithea

A sheep (SG03) and goat (SG16) from Kastro Kallithea were local and sedentary ($\Delta^{87}Sr/^{86}Sr$: 0.000083, 0.000186) and both had jagged non-seasonal oxygen isotope trends with dampened variation ($\Delta^{18}O$: 1.74‰, 1.97‰) (Fig. 8.67). Because an ovicaprid obtains most its water from food, these signatures may correlate to consumption of plants grown using different water sources seasonally. Animals grazing around Kastro Kallithea today have access to various streams and springs; the $\delta^{18}O$ values of these water sources would have been varied because of different rates of condensation, evaporation, and reservoir source. If an animal grazed in a different field every few months, it would have a consistent $^{87}Sr/^{86}Sr$ signature reflecting the same local geology, varied $\delta^{18}O$ values representing the various water sources used for plant growth, and $\delta^{13}C$ values depending on the plants consumed.

Although SG03 and SG16 had similar non-seasonal oxygen isotope patterning, the plants they were eating were considerably different. Based on the flattened $\Delta^{13}C$ (0.96‰), SG03 may have been crop fed (Isaakidou *et al.*, 2019; Vaiglova *et al.*, 2020) or consumed foliage grown using irrigation from wells, lakes, or artesian springs (e.g., Chazin *et al.*, 2019; Janzen *et al.*,

2020) that dampened any apparent seasonal carbon isotope signal. Many scenarios can create a dampening effect on carbon isotope seasonality in plants. For example, deep-rooted C_3 sources (e.g., bushes and trees) are not as impacted by seasonal changes in $\delta^{13}C$ as short-rooted grasses and may have caused the limited variation in SG03's $\delta^{13}C$. Similarly, plants that have been harvested and dried will have less water content and the animal will require supplemental hydration (e.g., drink from streams or rivers) (Hall, 2019). Combining the $\delta^{18}O$ from dried fodder sources and consumed water can also cause a dampening effect on sequential ovicaprid $\delta^{18}O$ values (e.g., Vaiglova *et al.*, 2020, p.43), which may be the cause of SG03's isotope patterning.

SG16 also showed signs of carbon isotope dampening (flattening) for the first year (9.5 – 23.0 mm; $\Delta^{13}C$: 1.00‰) followed by a more generic seasonal variation during the second year (0.5 – 8.0 mm; $\Delta^{13}C$: 2.34‰). The overall variation for SG16 ($\Delta^{13}C$: 3.98‰) is higher than the expected variation for seasonal influences alone and may be due to the goat browsing on ground cover including some C_4 plants for the first part of the year and then switching to an exclusive C_3 plant diet for the second part. As discussed above, C_4 plants like Bermudagrass or millet may have been available fodder sources during the summer months. Similar to SG03, the flattened $\Delta^{13}C$ for the first year may have been the result of foddering on dried C_4 grains and consuming water sources that were not seasonal. Based on the oxygen isotope patterning SG03 and SG16 were managed using water and fodder sources that were not seasonally impacted like other ovicaprids at Kastro Kallithea. Additionally, SG03 was fed predominantly C_3 sources whereas SG16 likely had some access to C_4 plants for at least the first year.

8.4.2 Changing Local Fodder or Water Source at Pharsalos

Two sheep from Pharsalos (SG38 and SG40) were also considered sedentary ($\Delta^{87}Sr/^{86}Sr$: 0.000083 and 0.000186), kept within the local isoscape, and registered non-seasonal oxygen isotope signatures (Fig. 8.68). Unlike the ovicaprids from Kastro Kallithea that had tight jagged oxygen isotope patterns, the Pharsalian sheep had a more loosely jagged trend with variation ($\Delta^{18}O$: 3.58‰ and 3.18‰) that was within the upper limit of the normal range.

If irregular and non-seasonal oxygen isotope trends are due to consumption of different fodder or water sources, larger variation within this pattern may relate to grazing in areas with drastically different water sources. For example, water reservoir depth impacts the rate of evaporation and condensation, which both impact the concentration of ^{18}O values in each source

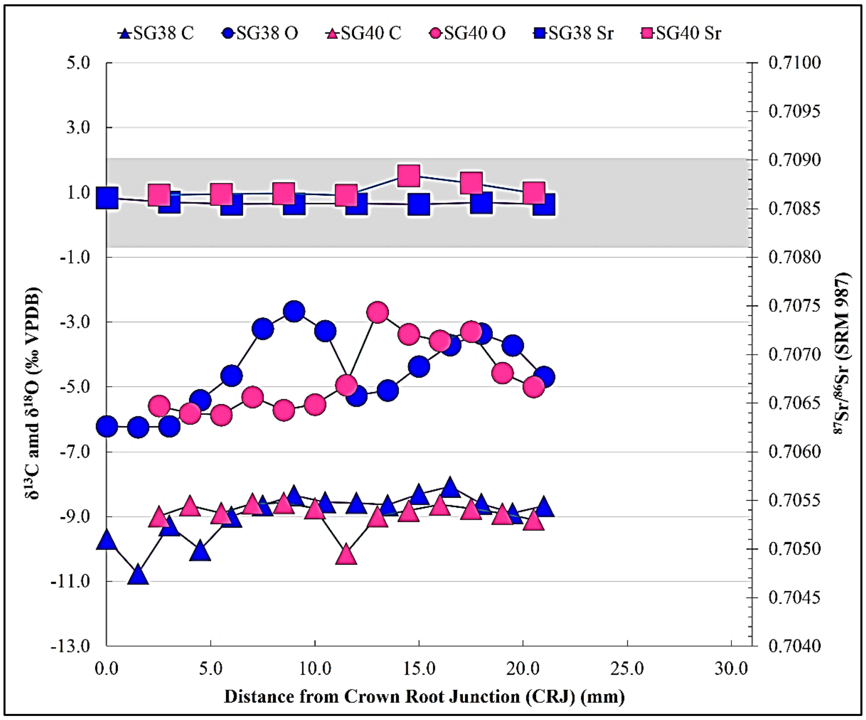

Figure 8.68 Comparison of $\delta^{13}C_{carbonate}$ (Δ), $\delta^{18}O_{carbonate}$ (O), and $^{87}Sr/^{86}Sr$ (□) values measured from SG38 (blue) and SG40 (purple). The grey block represents the local Pharsalos $^{87}Sr/^{86}Sr$ range.

(Pederzani and Britton, 2019; recall Chapter 5). As a result, Pharsalos' shallow streams stemming from the small Apidanos River would have been more impacted by seasonality (larger $\Delta^{18}O$) than the deep portions of the Enipeas River (smaller $\Delta^{18}O$). An animal that grazed near one source in the summer and moved to another source during the autumn would have a larger $\Delta^{18}O$ but a non-seasonal pattern like the loosely jagged trend in SG38 and SG40. Additionally, neither sheep had seasonal carbon isotope values, and although both were within the range of normal seasonal variation ($\Delta^{13}C$: 2.68‰, 1.55‰), the patterns appear flattened for most of the time recorded in both animals. Both SG38 and SG40 have $\delta^{13}C$ consistently around -9.0‰, which may mean that these animals were consuming mostly C_3 plants with limited additional C_4 sources (Vaiglova *et al.*, 2018).

Another possible scenario is that the animals were grazing under heavy forested canopy around the different rivers and streams during the spring through autumn months. Dense closed canopies can impact how plants uptake ^{13}C from the environment; these conditions would effectively offset any seasonal carbon isotope signal during the seasons when the canopy is the thickest (e.g., spring-summer) (e.g., Balasse *et al.*, 2012a, 2013; Martín *et al.*, 2021, p.99). Although the canopy effect also simultaneously produces lower ^{13}C values in leaf fodder, Balasse *et al.* (2012a, p.41) found that a consumption of branches and non-leafy portions of the trees grown in forest canopies can actually lead to a ^{13}C-enriched diet compared to leafy fodder grown outside of a forest canopy. The higher and flattened carbon isotope values in SG38 and SG40 may be due to this type of seasonal browsing. Overall, if these animals were kept locally to Pharsalos, as suggested by their strontium isotope data, they likely moved between different pastures, water sources, or potentially forest canopies as part of small-scale local management.

8.5 Limitations

Throughout this chapter I made speculations or inferences about possible management strategies used for each animal rather than concluding each scenario as a fact. There are limitations to interpreting isotope patterns and correlating those patterns to a specific management style. In this section I briefly discuss these limitations and provide cautionary approaches for future work.

8.5.2 Compounding Data Patterns

One of the limitations of analyzing isotope data from teeth, is that enamel development, maturation, and mineralization can vary depending on numerous aspects of life (recall Chapter 4). This means that the uptake of isotopes, and the resulting isotope data trends, can manifest differently in different segments of the tooth (e.g., Zazzo *et al.*, 2005, 2010), across multiple teeth (e.g., Balasse, 2002, 2003), or in different animals within the same herd (e.g., Henton *et al.*, 2012; Lazzerini *et al*., 2021). Although I have attempted to limit issues with intra-individual variation, through selecting M_3 from different individuals, some of the variation between animals may be due in part to differences in enamel development *and* management trend.

Additionally, stable isotope values can result from various factors and multiple causes can combine to create, exaggerate, or dampen the same trend (Appendix 8.12). For example, SG11 and SG33 had similar and almost overlapping dampened seasonal oxygen trends despite apparently consuming different resources and using different mobility strategies. Similarly, SG03/SG16 and SG38/SG40 had similar oxygen isotope patterning and variation despite different strontium isotope values and carbon isotope patterning. A third example comes from SG23 and SG30, who have similar oxygen isotope patterning despite not being in the same region, using the same form of mobility, or consuming the same foods seasonally.

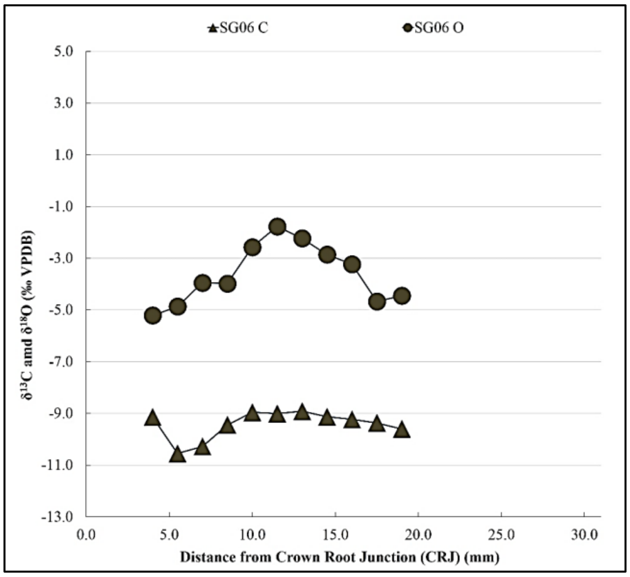

Figure 8.69 Comparison of $\delta^{13}C_{carbonate}$ (Δ) and $\delta^{18}O_{carbonate}$ (O) values measured from SG06 enamel.

Domesticated animals also have access to wild and cultivated food sources that can be harvested and stored for consumption during a different season or in a different location. If an animal were to be stall-fed for any portion of the year, and fed on harvested materials, it can alter the recorded seasonal, dietary, and/or geological trends, as discussed above (e.g., Chase *et al.*, 2014; Isaakidou *et al.*, 2019; Trentacoste *et al.*, 2020; Vaiglova *et al.*, 2020). Although I have addressed how foddering could influence stable carbon and oxygen isotope values, I have omitted foddering source as a potential cause of $\Delta^{87}Sr/^{86}Sr$ and 'perceived' changes in location. If fodder crops were imported into an area for ovicaprid consumption, the strontium isotope values would reflect the sediments of the growing area. Supplemental fodder for ovicaprids was not considered a normal practice (e.g., White, 1970), and I have not yet found evidence of animal fodder imported in from different regions in antiquity.

8.5.2 Approach Moving Forward

Throughout the course of my analysis, I found that the best way to limit issues with scenario interpretation was to combine multiple lines of evidence in the specific context of Thessaly. Part of this involved discussing scenarios in relation to all isotope values and explaining when certain scenarios were unlikely because of conflicting isotope patterns. Sheep SG06 presents a good example of why all three isotope patterns should be discussed in relation to each other.

This individual was only analyzed for carbon and oxygen isotope data (Fig. 8.69). Based on its sequential values, the animal consumed a water source that was normal and seasonal ($\Delta^{18}O$: 3.44‰) and a diet that was irregular and non-seasonal ($\Delta^{13}C$: 1.63‰). Without the strontium isotope data to provide context about mobility and location, the management strategy of this sheep could apply to many of the scenarios previously discussed. For example, if this animal was local and sedentary like SG08 and SG21, the animal may have eaten harvested grains or grazed on deep-rooted plants with a dampened seasonal signal (e.g., Isaakidou *et al.*, 2019, p.48), but not consumed water from varied sources like SG03 and SG16. Alternatively, if SG06 was non-local or mobile like SG23, the dietary patterning could be caused by movement to different areas in the winter that were exposed to seasonality (4.5 – 9.0 mm) and grazing on plants that are less impacted by the effects of seasonality at higher altitudes during the spring through autumn months (8.5 – 19.0 mm). The animal may have also grazed in an area that had dense forest canopy, which was a pattern suggested for SG38 and SG40. Without strontium isotope data to show potential movement patterns, it is difficult to interpret the carbon and oxygen data further.

Similarly, carbon and oxygen isotope data are required to provide context to the strontium isotope data. Without all values considered collectively, I would not have been able to speculate on the specialized forms of animal management at Kastro Kallithea or Pharsalos. Additionally, I found that by incorporating interpretations and approaches from previous work in Crete (Isaakidou *et al.,* 2019) and southern Greece (Vaiglova *et al.*, 2020) I was able to contextualize much of the data and interpretations specific to Thessaly. As more research is done in this area, I will continue to incorporate studies that expand our understanding of the region and mobility, dietary, and seasonal trends related to animal management.

8.6 Summary

In this chapter I discuss seasonal variation in diet and mobility according to isotope data, contextual analysis of the area, and previous stable isotope research of animal management. According to the data from 12 different ovicaprids at Kastro Kallithea and Pharsalos, shepherds were managing animals (1) locally at different areas of the settlement, (2) a mixture of mobile and local depending on the season or location, and (3) non-local for the duration of the year. Grazing locations likely included areas around Kastro Kallithea, Pharsalos, the elevated areas around Mount Óthrys, and potentially other areas beyond these regions. Ovicaprids grazed and browsed on different plants depending on the season, altitude, and proximity to certain resources (e.g., rivers, forests). Some animals may have also been foddered seasonally using crop or crop waste materials. Modern shepherds in Greece exhibit various management styles according to the available land, economic focus, and resulting herd size. The presence of 12 ovicaprids that were managed in different ways in antiquity suggests that animals played valuable roles in the past. The following chapter addresses how animals could have been managed in different ways, and Chapter 10 examines the social, economic, and political reasons for why landowners would manage animals in different ways.

CHAPTER 9: Shepherding Politics

While working in Narthaki I observed various forms of pastoralism. I watched the Sarakatsani herders drive their large flocks into the mountains each day in the summer. I passed by houses with a handful of sheep grazing in fenced backyards. I also watched as older shepherds cared for herds of up to 50 animals on various patches of local public land. Although I am tempted to use these observations as a point of departure in my assessment of how different animals were managed in the past, I recognize that the sociopolitical circumstances that permit each shepherd to manage their animals are different from those in antiquity (Chang, 1997; Halstead, 1987, 1996; Hadjigeorgiou, 2011). In Chapter 8 I presented interpretations from the stable isotope analysis and speculated what shepherds may have been doing with their herds. In this chapter I examine how shepherds could have managed animals in the past, by considering the social and political aspects of pastoralism at Kastro Kallithea, Pharsalos, and surrounding areas during the Hellenistic period. By relating the management styles interpreted from my samples with epigraphic and literary evidence from the era, I discuss the 'shepherding politics' evident in the region. This incorporates the politics of how land was used, including the rights to graze on private land (9.2), public land (9.3), and lands outside of the *polis* (9.4). I also consider the implications for owners who fed their animals grain or other fodder sources instead of grazing them (9.5). Each of these considerations leads to a better understanding of how animals were managed in antiquity, as well as who may have owned the buildings at Kastro Kallithea and Pharsalos. This chapter focuses on the Hellenistic period and considers only those animals that I have all stable isotope data for. This means that I will not discuss SG30 (Classical era sheep) or SG06 (no strontium data).

9.1 Land Politics

Today the ability to own, lease, or use land for animal grazing is based on local and regional governing policies (Hadjigeorgiou *et al.*, 1999). Chandezon (2021, p.305) explains that Classical era land ownership, including agropastoral activities like livestock movement, was restricted to the *polis*, referred to as *politeia*. If pastoralists were permitted to graze outside of their private land, it had to be within the territory the city regulated or had access to. Hellenistic evidence of land politics, including pasture access and private land management, is based on epigraphic, literary, and archaeological sources. As an example, Hodkinson (1988, p.48) and Chandezon

(2003, pp.43-44) discuss literary evidence of a pasture tax that shepherds were required to pay if herds grazed on trespassed pasture near Attica. Howe (2011, pp.13) also discusses evidence of *horoi* (ὅροι) boundary stones at elevated spaces between farms in the countryside around Athens. These highly visible boundary markers were a form of 'No Trespassing Sign' in Classical and Hellenistic Attica (Howe, 2011). Stanton (1984, p.302) postulates that the *horoi* in Kaminia (south of Athens) mark the grazing boundary between two *demes*, which may have served as the boundary between free and taxable pasture areas. Although there is no evidence of *horoi* in Thessaly, there are instances of disputes over pasture grounds in highly coveted areas, often referred to as preferential pasture. An inscription [FD III, iv, 355(3)] from the 2nd c. BCE describes conflict over grazing on sacred land between Halos and Phthiotic Thebes. Sacred land could not be farmed, and grazing could only be granted by the community monitoring the sanctuary connected to the land (Papazarkadas, 2011, p.12). These examples highlight the significance of access to pasture, and the potential ramifications of grazing in areas where permissions were not granted.

Similarly, allocation of land for grazing and access to public pastures in and around settlements were also regulated by *poleis*. Decourt (1995) translates inscriptions that include the granting of *epinomia* at Pharsalos. *Epinomia* dictated grazing access, and could include land ownership, the rights to use land for grazing, or permissions to access public pasture. *Epinomia* was often part of a so-called proxeny decree and naming an individual a *proxenos* was an honour that came with gifts and privileges from the community. *Proxenoi* were usually wealthy men who had provided a community with favours, for example by sponsoring projects or repaying debts accrued during a war or disaster (Chaniotis, 2005).[50] Proxeny decrees were usually recorded in stone and set up in public spaces of the community bestowing this honour. Chandezon (2003, pp.351-358) describes 71 inscriptions of proxeny decrees that include grazing rights, with 40 inscriptions specifically concerning Thessaly.

In Chapter 3 I explained that southeast Thessaly was continuously involved in conflict during the 3rd c. BCE. After the Social War (c. 217 BCE), Macedonian King Philip V established formalized decrees in major cities to promote resettlement, fuel the economy, and foster unity at the *ethnos* level (e.g., [*IG* IX. ii, 234]) (Fig. 9.70). Occupation of Building 10, the Arsenopoulos

[50] Such men would be referred to as *euergetai.*

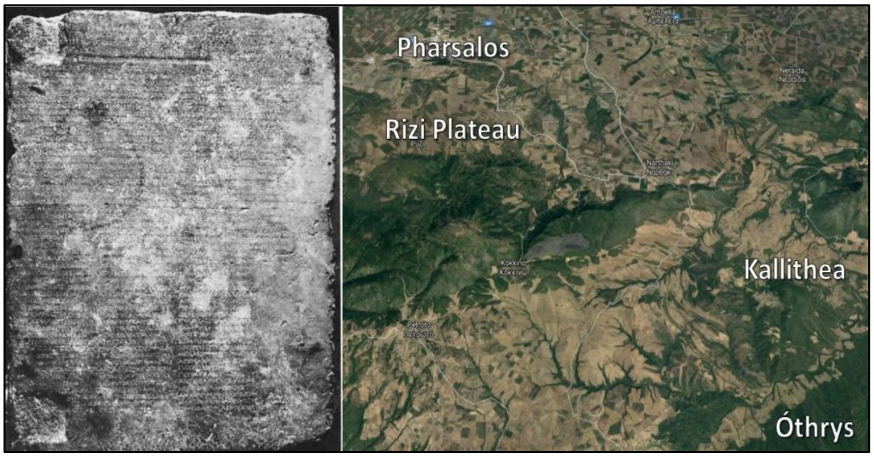

Figure 9.70 **Left**: Honorary decree [*IG* IX. ii, 234] recovered from Pharsalos (ca. late 3rd c. BCE) detailing beneficiaries who were granted citizenship and land on the Rizi Plateau. Interpretation and image from Decourt (1995, no. 50).
Right: Map of the area. 3D Map from Google Earth.

Plot, and the second phase of the Alexopoulos Plot all date to this period of increased settlement and economic growth (c. 217 – 197 BCE). There is clear evidence of animal exploitation and by-product processing at each of these contexts (recall Chapter 3). Since sheep and goats were important for meat, dairy, and wool in these areas, I argue that estate owners must have held specific land permissions to manage these animals. In some circumstances, landowners may have also held special permissions for moving herds to different regions in Thessaly. Evidence of pasture-related border disputes in the Óthrys Mountain area (c. 210 BCE) (Ager, 1996, pp.425-429, no. 156; Reinders and Prummel, 1998, p.94) also signify the importance of shepherding land politics during this time.

9.2 Land Ownership

Although there is no written evidence of formal land allotments at Kastro Kallithea, there are detailed inscriptions at Pharsalos. Figure 9.70 shows an image of a formalized decree [*IG* IX. ii, 234], which details 176 beneficiaries who aided Pharsalos at the end of the 3rd c. BCE. Philip V granted each adult citizenship and gave them 60 *plethra* (or roughly 6 ha) of arable land in the Rizi Plateau (Decourt, 1995, no. 50). Individuals establishing a home on this land would be able to farm the fields and manage a small number of animals locally year-round. Animals raised on this allotted land would have consumed foods grown on a consistent geological source. They would have obtained their water requirements largely from the crops or other vegetation

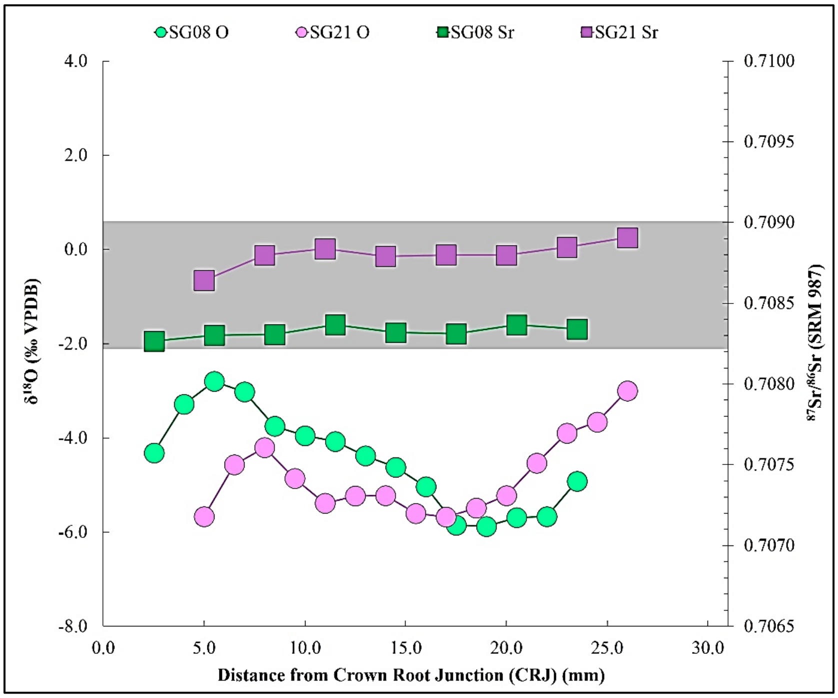

Figure 9.71 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for SG08 (green) and SG21 (purple) molar enamel at different points along the mesial lobe from the CRJ (mm). The Kastro Kallithea local strontium isotope range is shown as a grey block.

grown on the property, which would have been exposed to seasonal changes in humidity or growing conditions. These animals would have a local and sedentary strontium isotope signature and a seasonal oxygen isotope signature. Two animals at Kastro Kallithea (SG08, SG21) may represent this pattern of shepherding. (Fig. 9.71).

9.2.1 Kastro Kallithea

Based on their strontium signatures, goat SG08 and sheep SG21 from Building 10 both grazed in an area consistent with local geology over a two-year period. Their $^{87}Sr/^{86}Sr$ values show minor variation over this time, but not enough to suggest movement to another region. Sinusoidal variation in their $\delta^{18}O$ values suggests that both animals had access to consistent water sources whose $\delta^{18}O$ values varied seasonally. I believe that these animals were raised on similar plots of land year-round, potentially including a backyard plot or small privately-owned land allotments around Kallithea. Although both animals were within the local Kastro Kallithea isoscape, they grazed on separate plots. SG08 grazed in an area that had the lowest strontium isotope values found in my study; these fall within the local Kastro Kallithea range but are also consistent with the modern lamb from Anavra (L01). SG21 also has $^{87}Sr/^{86}Sr$ isotope values consistent with the local range, but distinct from SG08. Like Pharsalos and the Rizi Plateau, residents of Kallithea likely had plots of land outside and around the fortification that were owned and used to farm and raise animals. Animals managed on the same public pastures would be expected to have similar strontium isotope signatures, which is not the case. Instead, the owner of Building 10 either had access to separate land allotments for their animals or acquired at least one sheep or goat from someone who did.

9.2.2 Sedentary Husbandry

Based on the interpretation above, SG08 and SG21 both spent their time on a consistent geological source, which may indicate grazing on one or two plots of local land. The management style corresponds with backyard grazing or what Halstead (1996) refers to as 'household herding'. Landowners were mixed farmers, and the number of animals kept on the land was proportional to the scale of arable farming (Halstead, 1996, p.23) and the requirements for products like wool or dairy (Isager and Skydsgaard, 1992). Based on ethnographic estimates, a sheep can graze up to 0.1 ha in a winter term (Campbell, 1964). If goats are permitted to 'sustainably browse' an area (i.e., whereby the integrity of the crop is maintained or not damaged), one goat can consume up to 0.3 ha of land during the height of summer vegetation growth (Hall, 2019[51]). Both forms of management have different intentions and permit a different number of animals to be maintained. Using the Rizi Plateau land allotment as an example (Table 9.47), the landowner could have up to 6 ha of land for personal use. If that 6 ha of land were to be preferentially allotted for pasture only, it would be able to support 30 sheep year-round. If households preferentially managed their 6 ha of land for agriculture, there would be insufficient pasture for any animals, and they would rely on byproduct materials (wool, milk) from other sources. Under the mixed economy model, landowners could grow crops for a portion of the year, maintain few (up to 20) animals locally, have their excess (~ 40) animals graze non-locally, and have sufficient winter pasturage for all 60 sheep on fallowed crops.[52]

[51] Based on the notion that 450 goats can sustainably browse 10 ha of weeds in 1 week, and that there are 13 weeks during the summer months.

[52] There are mixed opinions on the use of crop fallowing, crop rotation, and allocating subsistence crops for foddering purposes (e.g., Hodkinson, 1988; Isager and Skydsgaard, 1992; Jameson, 1988; White, 1970). I have tried to simplify the estimates listed in Table 9.47 to accommodate instances where animals sustainably browsed on areas that were not currently being used for subsistence crops, which could include fallowed crops.

Table 9.47 Modelling for the number of animals that can be managed on the Rizi Plateau land allotment [*IG* IX, 2 234] according to management strategies

Management Strategy	Land Allotted	# Sheep Sustained	Amount of Land for Crops
Animals only (wool/dairy)	6 ha	30 year-round	0 ha
Agriculture only	6 ha	0	6 ha
Mixed Farming/ Mobile Management	6 ha	Summer: 20 Winter: 60	6 ha[53]

Researchers have estimated that households would manage small flocks of two to ten animals on their farm plots (Alcock *et al.* 1994, p.153 (n=2-8); Halstead, 1981 (n=5-10). If SG08 and SG21 were each part of a small household flock of ten animals, 3 ha could be used strictly for their pasture, with the other 3 ha being used for other animals or agriculture. Based on ethnographic (Halstead, 1981) and epigraphic (Haagsma, 2010) data on wool requirements, we can calculate the number of animals required by each household to produce sufficient wool per person each year and assess whether the small flock could produce a sufficient yield. Halstead (1981, p.328) estimates that sheep will provide 0.2-0.7 kg of wool per year. Individuals in Thessaly's Hellenistic communities would have required roughly 2-5 kg[54] of wool per year to create sufficient textiles for their own use (Haagsma 2010). This equates to roughly eight to ten sheep per person, per year, to provide sufficient wool textiles. Based on these calculations, the proposed small household flock of two to ten animals would have been insufficient for the wool requirements of a Hellenistic family[55] (Haagsma 2010, p.203). Alternatively, if families on the Rizi Plateau used a mixed farming/mobile management strategy, they would have had sufficient wool yield annually (Table 9.47).

It is also possible that the Rizi Plateau decree represents a unique and extravagant amount of land allotted to immigrants in the region. McHugh (2017, p.19) suggests that 20-50 *plethra* (2-5 ha) of land is a more modest and realistic estimate of how much land was owned by average individuals. If the typical landowner had 2-5 ha of land, their ability to outfit an entire family in

[53] Soils would also be manured, which is an important part of agriculture (e.g., [Theophrastus *Caus. Pl.* 3.9.5]).
[54] This estimate is broad to account for the 2-3 kg estimate from Chaniotis (2005) and Halstead (1981, p. 327) for warmer climate (e.g., southern regions), and up to 5 kg of wool required in colder climate (e.g., northern regions).
[55] Haagsma (2010, pp. 202-203) explains that a typical (i.e., five-person) family may only require two new garments each year however even this required at least 15 adult fully-fleeced sheep.

sheared wool would have to rely on a mixed farming strategy. In contrast, it has been suggested that wealthy farmsteads around Athens could have had as much as 200 to 300 *plethra* (20-30 Ha) of land (McHugh, 2017, p.19). Using the same figures used to generate the estimates listed in Table 9.1, a wealthy estate using a mixed model could have sustained up to 300 animals and sheared up to 210 kg of wool annually.

If SG08 and SG21 were kept strictly for household use, I question how the teeth of both ovicaprids ended up in the domestic structures within the *polis* walls. Building 10 was considered a more elite home within the city limits. It is reasonable to believe that its wealth stemmed from land holdings outside of the fortification, which could provide arable crops or pasture for livestock. Having dedicated land for animals to graze near Kastro Kallithea would have given the Building 10 owner access to milk, wool, and manure on a regular basis for processing or economic gain. An abundance of wool-processing equipment was found in Building 10 and large herds would have been required to provide sufficient materials regularly (Haagsma *et al.*, 2019a). SG08 and SG21 clearly grazed on different pasture blocks, which may be due to Building 10 owning or having access to separate pastures for sheep (SG21) and goats (SG08). Without significant movement to different regions, both animals would have required at least one hectare[56] of pasture annually, which could have been privately owned, leased, or considered public.

9.3 *Polis* Grazing Rights

Another possible form of local management is grazing in a variety of local pastures. If someone was granted *epinomia*, the individual or their estate could be permitted to graze in numerous public places associated with the *polis* (Isager and Skydsgaard, 1992). With public grazing access, animals could be kept near the domestic structure and graze at various public pastures in and around the settlement. Decourt (1995) translates an inscription reportedly from Larissa [*IG* IX. 2, 519] that depicts the honours a Larissan received for services rendered to Peuma during an unspecified conflict (Fig. 9.3). Decourt (1995, no. 131, pp.145-147) hypothesizes that this *epinomia* was granted because of support during military incursions in the late 3rd to early 2nd c. BCE. This example does not detail the honours given, but similar decrees have been recorded

[56]A goat can sustainably browse ~0.02 ha of land per week (Hall, 2019).

from Pharsalos (Decourt 1995, no. 53[57]) that do include the rights to graze. Decourt (1995, pp.68-70) translated the inscription from Pharsalos, and explains that the *proxenos* had the rights to acquire land, house, and vineyards, graze his animals like the other Pharsalians, and to register in the cult of his choice. According to other Hellenistic epigraphy, prestigious *epinomia* allotments could include pasturage for 220 large (e.g., cattle) and 1,000 small (e.g., sheep, goat) animals, which was granted to assure the recipient's continued friendship with the community [*SEG* xxvii, 63] (Hodkinson, 1988, p.62). Decourt (1995) outlines various communities in Thessaly that have recorded *epinomia* allotments, including mention of pasture beneficiaries at Pharsalos (no. 51, p.64; no. 53, pp.68-70), and evidence of a Peumatian being granted proxeny in Chaironea in Boeotia [*IG*, VII, 3287, 2] (Decourt, 1995, pp.161-163). Chandezon (2003, pp.285, 387) discusses proxeny decrees in Greece and notes that many were granted to individuals residing in neighbouring *poleis*.

Although public grazing zones were not outlined at Pharsalos, two stone inscriptions from neighbouring Skotoussa [*SEG* 43, 311] describe the geographic makeup of the city and provide details on the pastures granted as part of *epinomia.* The Skotoussa inscriptions (ca. 194/7 – 185 BCE) explain that pasture was permitted inside the city wall around defensive towers and between the outer and inner defensive walls (Chandezon, 2003, p.75, no. 16; Missailidou-Despotidou, 1993, pp.191, 212). Alternatively, public pasture permitted outside of the city walls included areas between the riverbank and fortification, around the sanctuary and citadel, and the area around the ancient cemetery (Missailidou-Despotidou, 1993, p.212). Pharsalos and Kallithea had similar architectural structures and habitation zones to Skotoussa (recall Chapter 3), and local grazing areas may have been like those designated by the inscription. Residents of either city may have also had *epinomia* rights to graze in these areas at neighbouring Skotoussa.[58]

I argue that SG03, SG16, SG38, and SG40 may be examples of animals permitted to graze on public pastures, potentially because of *epinomia* or other grazing rights. Two additional animals, SG39 and SG42, may have also grazed on public pastures at elevated areas local and non-local to Pharsalos, which would have required additional grazing permissions.

[57] Also referred to as [BCH 111(1987), p. 544].

[58] Although no proxeny decrees are currently available for *epinomia* at Skotoussa, Chandezon (2003) indicates that at least 40 decrees describe these privileges for individuals around Thessaly.

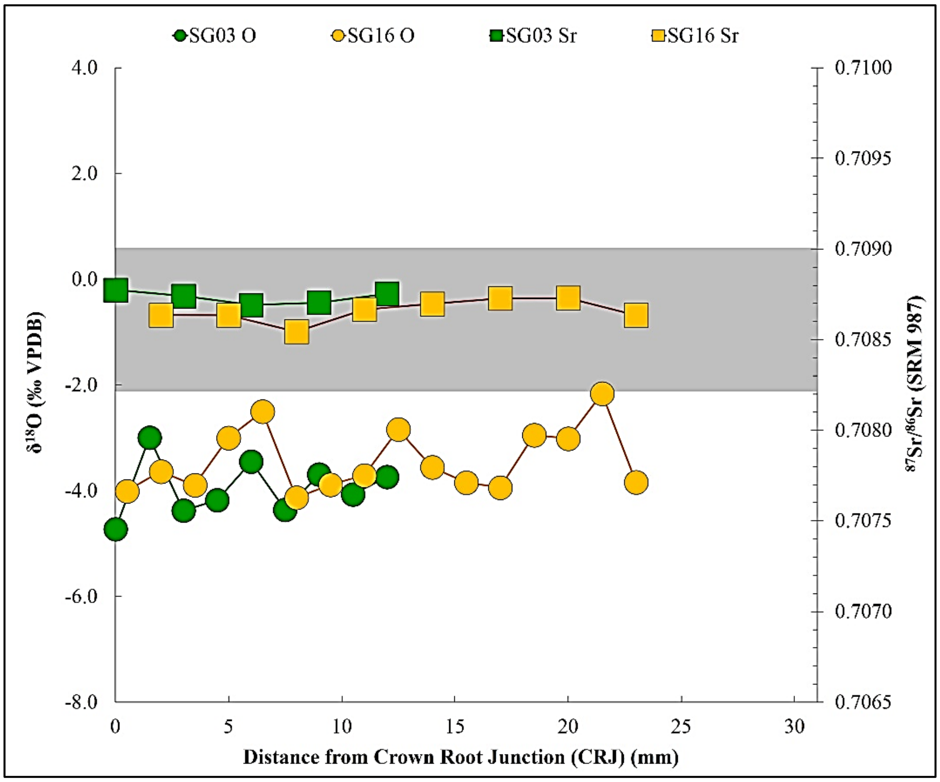

Figure 9.72 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from SG03 (green) and SG16 (gold) molar enamel at different points along the mesial lobe from the CRJ (mm). The Kastro Kallithea local strontium isotope range is shown as a grey block.

9.3.1 Kastro Kallithea

A sheep (SG03) and goat (SG16) from Building 10 grazed in an area whose $^{87}Sr/^{86}Sr$ signature was consistent with local geology over a two-year period (Fig. 9.72). It was argued in detail in Chapter 8 that the lack of seasonal oxygen isotope signal in both ovicaprids may have been caused by regular variation in water sources. If SG03 and SG16 had been kept on the same plot of land under sedentary management, they would have obtained their water (via plants and drinking water) from a single seasonally-impacted reservoir and would show sinusoidal $\delta^{18}O$ patterning. If the animals both consumed water from a single deep well system year-round, they would show a monotonous $\delta^{18}O$ signal that did not fluctuate seasonally. Neither of these patterns is seen; instead, the enamel $\delta^{18}O$ values of SG03 and SG16 vary regularly but in a non-seasonal pattern. This could be explained if these animals were raised on varied plots of land throughout the year with different water sources, which may have included lands allocated as part of *epinomia* or citizenship grazing access.

Figure 9.73 *Karayul* artesian spring on the eastern side of the north slope of Kallithea. A local shepherd had stopped to rest with his herd of over 50 sheep, goats, and herding dogs. Photo taken in May 2017.

The land allocated for public grazing at Skotoussa included areas with access to fresh drinking water. If grazing pastures around Kallithea included access to varied sources of water, including grazing around artesian springs, the animals would be expected to have variable but non-seasonal oxygen isotope signatures. For example, the *Karayul* artesian spring is an ancient water source on the eastern side of the north slope of Kallithea that is still visited by shepherds today (Haagsma *et al.*, 2019a, p.18) (Fig. 9.73). Grazing around this spring may have been an important feature of *epinomia* granted at Kallithea during the Hellenistic period. If animals were permitted to graze in the area around the spring, near a local stream, or on a nearby pasture on an irregular schedule, they would have the same strontium isotope values but varied oxygen values that were non-seasonal.

9.3.2 Pharsalos

The sheep from the Arsenopoulos Plot (SG38, SG40) both grazed in an area within the local Pharsalos $^{87}Sr/^{86}Sr$ range (Fig. 9.74). Like the sheep and goat from Kallithea, both SG38 and SG40 had non-seasonal oxygen isotope signatures, suggesting that they had varied water sources that were not influenced by seasonality in the traditional way. Pharsalos had access to two unique aquatic landscapes, the Enipeas and the Apidanos Rivers, which are tributaries of the wider Pineios River watershed (Municipality of Farsala, 2015, pp.17, 23, 27). In the north part of Pharsala, the Enipeas River flows east to west to create an important wetland habitat that includes raging non-passable portions, divergent narrow passages, and small pools of standing

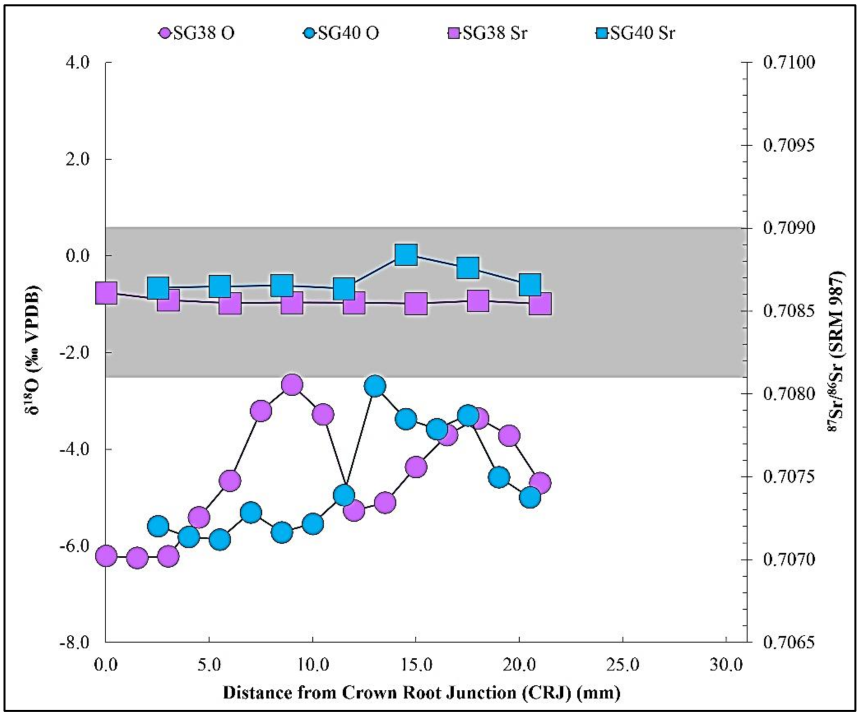

Figure 9.74 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from SG38 (purple) and SG40 (blue) molar enamel at different points along the mesial lobe from the CRJ (mm). The local strontium isotope range is shown (grey block).

marsh (Municipality of Farsala, 2015, pp.26-27). The Apidanos River system once flowed[59] west of Pharsala, running north to south, and serving Pharsalos with water directly [Herodotus, 7.129] (Municipality of Farsala, 2015, p.27). Foliage in these areas would grow using water from reservoirs with varying oxygen isotope signatures because of reservoir depth, evaporation and transpiration rates, and proximity to larger tributaries. In each season, an animal that grazed near a spring from the Apidanos River would have a different oxygen isotope signature than an animal that grazed on marshland formed from the Enipeas River.

The remnants of the Apidanos Spring were converted into a public area in Pharsala at the foothill of the acropolis, which is located roughly 100 m from the Arsenopoulos Plot. Animals SG38 and SG40 might have had the opportunity to graze near the Apidanos springs if their owner had permissions or access to graze their animals in public areas within the city centre; the animals may also have grazed on private land outside of the *polis* near the Enipeas River

[59] This river reportedly stopped flowing after an earthquake in 1954, but was once considered an important area for soldiers (e.g., Herodotus mentions that the huge army of Xerxes quenched their thirst here)

watershed. The variation in strontium isotope values for SG40 (at ~15.0 mm) may also relate to changing grazing location from within the *polis* walls to outside of the main city area. The inscription from Skotoussa detailed public grazing in and out of the main *polis* boundaries, which may be like the grazing allotments at Pharsalos, and the cause of the isotope signatures recorded for SG38 and SG40.

9.3.3 Privileged Herding

I argue above that four of the animals from Building 10 and the Arsenopoulos Plot (SG03, SG16, SG38, SG40) appear to have been managed local to the Kallithea and Pharsalos regions, with variable access to unique water sources, including shallow streams, deep well waters, or artesian springs. Based on the non-seasonal oxygen isotope signals, these animals would have consumed distinct water sources not influenced by seasonal patterns. For animals to be kept locally but with access to varied water sources, they would have needed to move and graze on different nearby plots, which would have included a mix of public and private land holdings. If SG03, SG16, SG38, and SG40 were managed locally in this way, I argue that the owners of Building 10 and the Arsenopoulos Plot had permissions to graze their animals on specialized pastures around each respective *polis*. Grazing rights may have been included in regular citizenship and would have afforded shepherds the space to graze more animals than a singular land allotment would support (Table 9.47). Although [*IG* VII, 3171] likely outlines an exceptional *epinomia* (to graze 220 large and 1,000 small animals in Phokis), the owners of Building 10 and the Arsenopoulos Plot may have had sufficient area to graze hundreds of sheep and goats regionally because of their access to privileged pastures dispersed throughout the broader locale.

9.4 Non-Local Grazing Rights

Herds that grazed outside of a community's local settlement area, either for additional pasture space or as part of movement between regions, required a legal arrangement from the other communities that owned the space. For example, epigraphic evidence [BCH 89, 1965, 665ff] details the legal arrangement that Myania and Hypnia[60] made for shared pasture (Howe, 2003, p.135). Not only would their respective shepherds use this grazing area while moving between summer and winter pasture sites, but there were also culling rules in place to ensure the health of

[60] Myania and Hypnia were two communities in western Lokris (northwest of Phocis)

all animals and prevent disease. Based on the legislation, only citizens from one of the two communities could use the pasture. Howe (2008, pp.87-88) translates a 2nd c. BCE inscription [*IG* IV^{2}1.75] from southwest Greece that describes a dispute over one such land use arrangement. The inscription describes a conflict between two local *ethne*[61] who both claimed access to a specific goat pasture. Although the *ethne* agreed that pasturage would be equally shared, the arrangement was short-lived and rising hostilities forced the *ethne* into arbitration under the regional government. Ultimately the government sided in favour of the original compromise, forced both *ethne* to share the pasture, and fined them for 'misconduct' (Howe 2008, p.88). If shepherds chose to graze on unregulated areas, Homer [*Il*, 9.404-5] reports that they ran the inherent risk of raids and animal theft (Howe, 2003, pp.135-136).

Similar issues also arose at sacred spaces when shepherds over-used land allocations (Chandezon, 2003; Chaniotis 1999, p.198; Skydsgaard 1988, p.74). An example involved the sanctuary of Apollo Koropaios in the ancient town of Koropi, Thessaly, which was often visited by shepherds and herds in the summer during their pastoral rounds (Chandezon, 2003, pp.94-96, no.19). The site is located east of modern Volos and is positioned in the lower mountain forest region of Mount Pelion. The sanctuary was severely degraded and at risk of further destruction by browsing animals. As a precaution, the sanctuary made a formalized decree in the late 2nd c. BCE that prohibited grazing on the sanctuary grounds. According to the inscription, any individuals caught grazing their animals or damaging the trees on the property would be fined and punished (Chandezon, 2003, p.94).

When arguments over land rights could not be resolved independently, communities relied on arbitrations to settle disputes (see for example Ager, 1995). Epigraphic evidence of such arbitrations suggests that there was increased competition over grazing rights in southeast Thessaly during the late Hellenistic period (Haagsma *et al.*, 2019b, pp.286-287). Arbitration records included disputes over pasturage in the Óthrys Mountains (e.g., [*IG*, IX, 2, 89]; Ager, 1996, no. 156), grazing access to the salt marshes in between Halos and Phthiotic Thebes (Reinders and Prummel, 1998, p.85), and grazing at sanctuaries in southern Thessaly (e.g., [FD, III, 4, 355], see Haagsma *et al.*, 2019b, p.286). Five animals from Pharsalos and Kallithea (SG11, SG23, SG33, SG39, and SG42) likely grazed in areas non-local to those sites (Fig. 9.75).

[61] Epidauros and Hermione; this conflict took place in northeast Peloponnese.

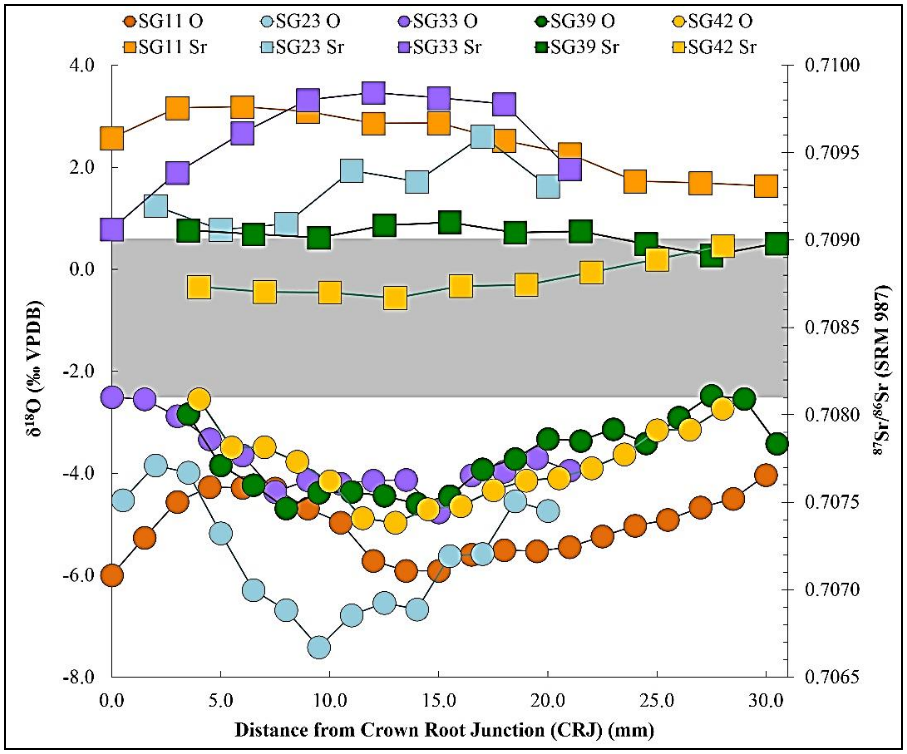

Figure 9.75 Sequential $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values measured from SG11 (orange), SG23 (blue), SG33 (purple), SG39 (green), and SG42 (yellow) molar enamel at different points along the mesial lobe from the CRJ (mm). The local Pharsalos strontium isotope range is shown as a grey block.

I argue that the owners of these animals would have required additional permissions, rights, or privileges to graze these animals in non-local areas. Permissions either came from ownership, independent *epinomia*, *polis* access, or other shared access between numerous communities. In some instances, I hypothesize that land arbitration may have been a direct result of pastoral networks.

9.4.1 Grazing around Mount Óthrys

Today pastoral networks in Thessaly extend into the marginal landscapes of the mountains, which include the Óthrys Mountains for shepherds around Kastro Kallithea and surrounding communities. A sheep (SG11) and goat (SG23) from Building 10 and a sheep (SG33) from the Arsenopoulos Plot all show signs of grazing in areas with considerable variation in strontium isotope values (Fig. 9.75). As detailed in Chapter 8, all three animals may have grazed in the Óthrys mountain range (Fig. 9.76) and varied their location depending on the season: (1) SG11

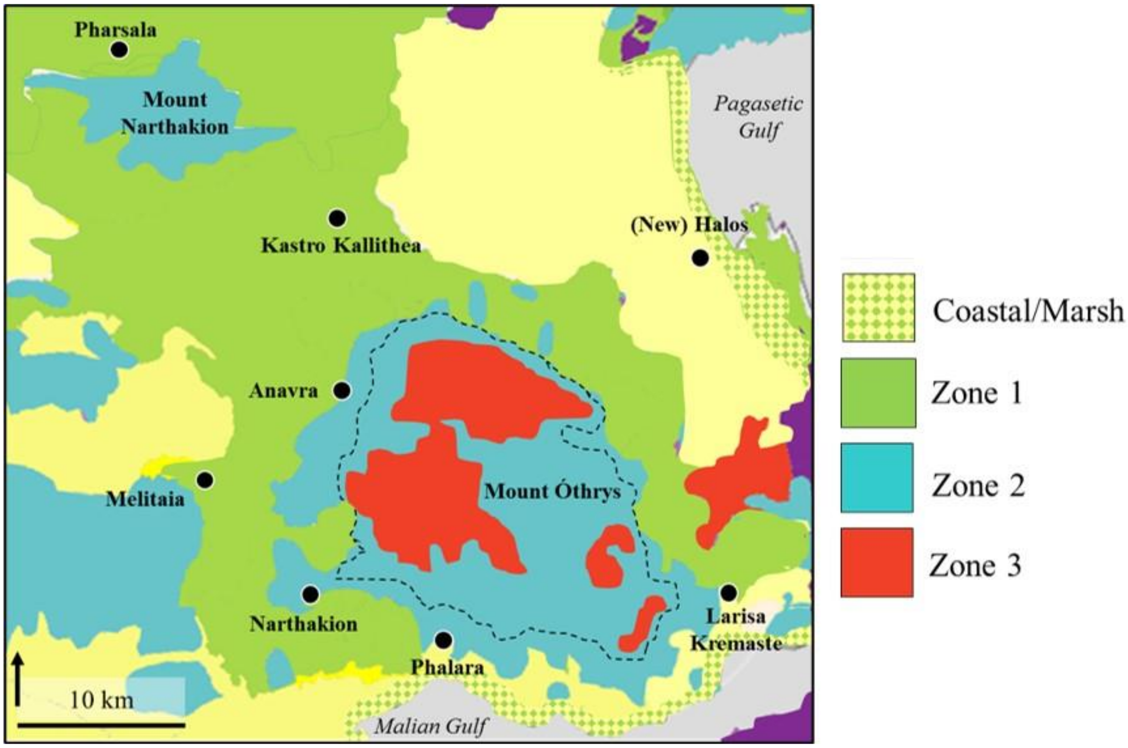

Figure 9.76 Isozone map for Mount Óthrys, including major cities discussed in text. Refer to Figure 7.43 for more information. Shoreline, altitudes, and locations from Reinders (2003, p.18) and Reinders and Prummel (1998, p.90).

grazed on the upper windward side of the mountains (Zone 2) during the first year and the lower leeward side of the mountains (Zone 3) during the second year, (2) SG33 grazed in the highland leeward side (Zone 3) during the winter months and the lowland windward areas (Zone 2) during the summer months, and (3) SG23 grazed in different altitudinal Zones (1-3) every few months. All three animals were managed in different ways, likely representing different herds that had specialized privileges and grazing access.

Each animal shows unique movement patterns that may have been driven by pasture access or weather systems. Arvanitopoulos (1912, p.307)[62] describes archaeological evidence of temporary winter houses at the sanctuary site of Zeus Akraios on the peak of "little Olympus" on Mount Pelion. This site was speculated to have been first occupied at the beginning of the 5th c. BCE with occupation extending (sporadically) through the late historic period. Similar shepherd encampments may have been in place along pastoral routes in Mount Óthrys (near

[62] Translated by Gino Canlas (2017).

Kastro Kallithea) or Mount Narthakion (near Pharsalos). Although Pan advises against winter grazing in the Óthrys Mountains because of the freezing and potentially snowy conditions [Antoninus Liberalis, *Metamorphoses*, XXII, 254-255], sanctuary sites would provide the necessary refuge for shepherds moving with their flocks. Large flocks are capable of withstanding cold and snowy conditions so long as food sources remain available (Hall, 2019). Sanctuaries were often places with abundant sources of browse that shepherds may have relied on while travelling. If sanctuary access were restricted, shepherds would have also required permissions or the rights to use theses areas or risk animals going hungry.

9.4.2 Movement within Mount Narthakion

Shepherds could also benefit from pasturing their animals at higher elevations locally. As discussed in Chapter 8, one sheep (SG42) and goat (SG39) from the Arsenopoulos Plot were managed using a mixed-mobile strategy that may have included grazing on local pastures at different altitudes in and around Pharsalos (Fig. 9.75). These animals were considered mostly sedentary, grazed within an isotopically local area, and moved to different altitudes depending on the season. The area south and east of the acropolis at Pharsala includes hills and varying altitudes leading to the Rizi Plateau and continuing to the Narthakion Mountain range. Based on the $^{87}Sr/^{86}Sr$ isoscape reconstruction for this area (Fig. 9.76), SG39 and SG42 may have grazed in this region because of permissions afforded to citizens of Pharsalos or as special *epinomia* allotments in the mountains around the city centre. Movement between these mountains and the city of Pharsalos would have afforded owners more animals to be kept within the same herd, but with the added requirement of grazing access or safe passage.

9.4.3 Movement for Coastal Resources

One goat (SG23) may have grazed along the coast prior to moving back into the Mountains for the summer season (Fig. 9.75). Reinders (2003, pp.16-17) identifies areas along the Pagasetic Coast where ancient salt marshes could be accessed and describes their importance for shepherds moving between regions (Reinders and Prummel, 1998, p.85). By the end of the wet spring season, these marshes would be saturated and easily accessed by shepherds moving between areas. Although Reinders (2003) specifically discusses the marshes near Halos, similar reservoirs likely formed along the Maliakos Coast, near the towns of Phalara or Larissa Kremaste (Fig. 9.76).

Salt is important for herd animals, especially in the summer months as it helps animals retain water when there are limited resources (Campbell, 1964) or to help them digest heavy summer fodder (Hall, 2019). Ancient shepherds were required to either acquire salt for their flocks, or to graze in saltier pasture ([Aristotle, *Historia Animalium*, 595b-593a]; Papazarkadas, 2011). Shepherds also required salt for making cheese, and acquiring it at markets or collecting it from natural sources was often an important part of pastoral mobility (Attema and de Neef, 2021). Salt could also be used to make animals appear fatter and healthier (due to swelling from water retention) when they are being sold at market or primed for sacrifice (Ekroth, 2014b; White, 1970). If SG23 was moved into an area of saltier pasture during the wet spring months, it is possible that their herd was moving towards towns with seasonal markets (e.g., Larissa Kremaste or Phalara). Under this scenario, shepherds would be able to sell salt-swollen lambs and kids or processed cheeses for a high price, collect necessary supplies or wares, and return to the mountain region for the remainder of the year. SG23 may have had access to different grazing areas because of its owner's involvement with markets or *epinomia* with the *poleis* of Phalara or Larissa Kremaste. Economic partnerships and market economy will be further discussed in the next chapter.

9.4.4 Expanding Shepherding Territories

Although Pharsalos is believed to have had control over the port of Halos until c. 302 BCE [Demosthenes, 11, 1], little is known about the lands controlled or regulated by Pharsalos or Kastro Kallithea during later periods. Less is known about which areas their citizens were permitted to freely access. Epigraphic evidence shows that Peuma attempted to expand its regional control into neighbouring southern borders earlier in the 3rd c. BCE, which some argue would have increased their hold on agricultural and pastoral accessibility (e.g., Haagsma *et al.*, 2019a). According to a marble stele from the temple of Apollo at Delphi, there were two formal land rulings that involved Peuma between 270 and 260 BCE [SEG XVIII, 238]. The first was towards Melitaia and Chalai and the second towards Pereia and Phylladon, and in both instances Peuma was ruled unsuccessful in its claim (Ager, 1996, pp.99-101).

Similar disputes between Melitaia and the *polis* of Narthakion[63] were reported to have gone back and forth for centuries during antiquity (Ager, 1996, pp.425-429, no.156). Their disputes

[63] Different from Mount Narthakion.

specifically involved access over marginal landscapes in nearby mountain regions that included the rights to wood and pasture resources (Reinders and Prummel, 1998, p.94) (Fig. 9.76). Arbitration often resulted in new boundary demarcations being installed to prevent future conflict, although the length of this dispute resulted in a change in ownership and boundary movement every few decades (Chandezon, 2003, p.334). It is possible that the Peumatian boundary disputes related to access to prime grazing real estate for transhumant shepherds or land granted to *proxenoi*, just like the Melitaia and Narthakion feud.

Alternatively, shared pasture between allies may have been part of political strengthening, like the shared pasture arrangement from Lokris [BCH 89, 1965, 665ff]. For example, Peuma may have had shared pastures with other members of Achaia Phthiotis along major trade routes. After 302 BCE Peuma was part of a shared minting collective (AX), which included the north, east, and southeast portions of Achaia Phthiotis (e.g., New Halos, Phthiotic Thebes, Ekkara, and Larissa Kremaste) (Reinders *et al.*, 2016). There may have been other shared political endeavours, including grazing areas or access to roads/paths between these regions. In contrast, Peumatians likely had less access to the south and southwest regions of Achaia Phthiotis based on the border disputes with Melitaia, Chalai, and Pereia. Shepherds were also known to graze on areas that were otherwise prohibited,[64] but often at their own risk.

A Peumatian was granted the rights to graze in areas delegated by Chaironea in Boeotia [*IG*, VII, 3287, 2], east of Delphi. How shepherds moved between these two regions is less clear. Forbes (1994, p.192, fn. 45) and Hodkinson (1988, p.36) discuss the possibility of 'dual nationals' or joint ownership of flocks between partners in different *poleis*. Under this scenario, animals may graze or live near one *polis* for part of the year, and freely move to another area for the second part of the year. The timeline for movement would depend on the communities, partners, and permissions (Forbes, 1994). Alternatively, Chandezon (2003, pp.285, 387) notes that over a quarter of the city-specified proxeny decrees were granted to individuals residing in neighbouring *poleis*. This may be the reason for variation in location for SG23, or movement between non-local and local areas for SG39; these individuals may have been part of a grazing collective in Achaia Phthiotis that permitted the movement of animals seasonally. Under the

[64] Chandezon (2003) discusses numerous instances where shepherds were brought in as witnesses during land disputes (e.g., no. 17 (p.80), no. 18 (p. 83)). During arbitrations shepherds would often detail their use of an area, regardless of whether they had permissions to access.

grazing collective, shepherds could participate in short-distance transhumance to regions less than 10 km away from a home area (Cardete, 2019). Shared grazing territory could also be based on areas with known markets and a grazing collective may similarly be based on regional economic networking.

9.4.5 Hired Shepherds

Estate owners also needed to consider who could manage their animals, especially when they owned herds in various parts of Thessaly at one time. If the resident of Building 10 owned all six ovicaprids, which all show different management practices, they likely belonged to six different herds. Backyard animals raised as part of a household or smaller herd that grazed close to agricultural fields could have been sufficiently managed by the members of the house or family (Gutzwiller, 2006, p.1; Halstead, 1996). Large herds that moved around the *polis* or beyond would have required hired shepherds to manage them. According to Theokritos [*Idyll* 16, 34ff] (Howe, 2003, p.134), shepherds would manage tens of thousands of sheep across the plains in central Thessaly[65] during the Hellenistic period. Although I recognize that literary sources often exaggerated examples to improve the imagery, I wonder if this example can be used to explain the work of hired shepherds.

Numerous authors discuss hiring shepherds, including slaves [Xenophon, *Mem.* 1.5.2]), freed men [Lysias, 20.11], and those of lower status [Aristotle, *Poet*. 2.6-7 (1448a)] (Hodkinson, 1988, p.51). Estates were also catalogued according to the animal herd, hired herdsmen, and guard dogs[66] (Isager and Skydsgaard, 1992, p.98, 100). The catalogue of Odysseus' wealth [Homer, *Od*yssey 14.99-104] includes his own herdsmen as well as additional, yet reliable, hired labour to look after his herds in different areas (Howe, 2014, p.143). Like modern shepherds who have regular staff and hired seasonal staff (Campbell, 1964; Hall, 2019), estate owners might hire or move their staff into shepherding roles, as necessary. Regardless of who was hired, Columella [I. 23-31] explains that the hired help needed to be well-versed in the details of the animals (White, 1970). The head shepherd (*magister pecoris*) might also be required to have some veterinary training or expertise [Varro *II*. 10. 10] (White, 1970, p.311).

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[65] Specifically Krannon, southwest of modern Larissa

[66] Reference of Eutemon's affairs detailed that his herd of goats and herdsmen were valued at 1300 drachmas [Iseus *Isae*. 6.33] (Howe, 2011, p. 11)

White (1970, p.352) explains that *epinomia* and citizenship privileges and rights extended to the hired members of the estate, which could also include small plots of land for themselves or enough animals for household use. Chaniotis (1999, p.190) discusses the potential for animals to be owned and managed on the estate by unfree persons [*I. Cret*. IV 75 B 7]. Modern shepherds stress the importance of including their own animals in with the owner's herd when they move to different pastures (e.g., Herzfeld, 1985), as hired shepherds are encouraged to protect and take good care of all animals. Modern Sarakatsani work together to manage larger herds as a collective rather than individual units (Campbell, 1964). It is possible that similar communities of shepherds were used in the past, wherein an estate owner hired numerous individuals to herd thousands of animals (e.g., Chang, 1997), just as Theokritos [*Idyll* 16, 34ff] depicts. If large herds are not from the same estate, they likely signify shared pasture, like the story depicted by Sophocles [*Oedipus rex*, 11132ff]. In this famous discussion, a Theban slave and a Corinthian hired shepherd share lowland pasture on their journey back to their respective estates (Hodkinson, 1988, p.51).

If shepherds were hired to manage non-local ovicaprids (SG11, SG23, SG33, SG39, and SG42), their owners could maintain their dwellings at Kastro Kallithea or Pharsalos and maintain local agricultural plots outside the *polis* walls. Animals might be frequently selected from these locations for consumption, which explains how the remains of each animal ended up at Building 10 or the plots at Pharsalos. Callimachus's Hymn to Demeter [IV, 86] depicts an estate owner (Erysichthon) "counting his flocks" in the non-local area of Mount Óthrys. Even though this reference is a poem, it may reflect some form of pastoral practices. Erysichthon may have done this to keep track of his 'property', take stock of how birthing seasons went, and possibly transport a few animals home for sacrifice.

9.5 Supplementing with Fodder

If animals did not graze directly on wild vegetation, estate owners were required to grow fodder crops or harvest other foliage.[67] Kron (2014, p.112) discusses improved nutrition for animals kept locally, which sometimes meant planting and harvesting species like alfalfa (e.g., Columella [*De re rustica*, 2.16-7], Pliny [*Natural History* 18.258-63], and Varro [*De re rustica* 1.31.5]).

[67] For example, Pomak pastoralists collected forked branches (tsátal) and put them in oak trees for their animals during winter fodder shortages in the Rhodope Mountains in Thrace, Greece (Ripoll, 2003, p. 294).

White (1970) details literary sources that discuss proper fodder sources for animals, including the importance of keeping fodder dry to avoid disease. Howe (2008, p.32) argues that only the exceptionally wealthy could afford to provide their animals with fodder and manpower resources rather than have them graze naturally on scrub, marginal landscapes, or designated pasture. It meant that land had to be devoted to pasture or animal fodder, rather than food production. Hesiod [*Works and Days*, 405, 436, 606] mentions that oxen and mules are the only animals who receive winter fodder, which must be collected as part of agricultural processing (Skydsgaard, 1988, p.76). Skydsgaard (1988, p.78) does not believe that ancient Greeks systematically grew fodder crops, although in some harsher winter seasons shepherds may have required it. Although Theokritos [*Idyll* 5, 126-140] mentions a lot of the plants that could be used as fodder for sheep and goats, which were likely included in the pastures or areas that animals preferred to graze on, it does not mean that these plants were specifically grown for fodder (Skydsgaard, 1988, p.82).

If an animal were fed dried fodder, it would require supplemental water sources. Isotopically, the animal would have strontium isotope values reflecting the location where the foliage was grown and the oxygen isotope values would reflect the household water source (e.g., a well or a nearby stream). The animal would appear to be local with a seasonal or muted oxygen isotope signal. It is possible that the ‘mixed local’ ovicaprids (SG39 and SG42) were fed fodder grown from nearby agricultural fields and had access to stream water. Based on oxygen isotope trends there appear to be no local individuals that consistently consumed deep well water year-round.

9.6 Limitations

There are limitations on interpreting how animals grazed, which include extrapolating where they were permitted to move and for what purpose. In Chapter 8 I discuss issues with interpreting specific reasons for isotope changes and stress that many of the scenarios are speculation. In this chapter I take many liberties with movement between specific locations because of the limited available strontium isotope data. Although I have focused my discussion on neighbouring mountain ranges with known shepherding movement (e.g., Mount Narthakion and Mount Óthrys), further samples from a wider range of areas, including mountains (e.g., Olympus, Pelion, and the Pindus Mountains), major settlement areas (e.g., Ekkara, Demetrias, Larissa Kremaste, Phthiotic Thebes; Fig. 3.4), and important sites (e.g., Delphi), would greatly expand our knowledge of the local isoscape and could improve interpretations. Additional samples from the areas at and around Pharsalos and Kastro Kallithea will also improve the recorded range and potentially help interpret other instances of small-scale movement or indicate animals that are grazing in truly non-local areas (e.g., SG39 and SG42).

In addition to these uncertainties, it is also possible that some of the teeth recovered at Kastro Kallithea and Pharsalos originated from a market purchase of animals that had been raised by shepherds no affiliated with the household. In this case, those animals may not actually have lived at or around Kastro Kallithea or Pharsalos. Based on the considerable wool-processing equipment recovered from Building 10, it is highly unlikely that the homeowner did not own at least some of the animals whose teeth are part of this study. In terms of our general understanding of husbandry in the region, this is not actually a major limitation. Although there is no way to know for certain whether specific animals were owned, rented, or purchased from acquaintances in the community, the group as a whole still reflects the animals available to the community at the time. Thus they are still appropriate for this discussion of how animal management would have occurred in various landscapes in the region.

9.7 Summary

Shepherding is both dictated by and potentially the cause of political aspects of history. By integrating stable isotope analysis of zooarchaeological materials with epigraphic evidence, we can better understand aspects of land use and animal management in the past. The residents of Building 10, the Arsenopoulos Plot, and the Alexopoulos Plot had houses within the city walls, and likely held citizenship and *polis* rights within each community. Based on epigraphy from Pharsalos, this included the rights to graze. Because of these shared rights, I expected to find ovicaprids in each of these contexts with local, non-mobile, and seasonal isotopic signatures. Citizenship and permissions to graze in public areas may lend itself to grazing around artesian springs and on different pastures throughout the year, but evidence of animals with unique local and non-seasonal signatures may indicate that the owners of Building 10 and the Arsenopoulos Plots had unique rights, or *epinomia* grazing rights, that afforded their herds special access to varied pastures. Interestingly, evidence of non-local and potentially transhumant animals in all three contexts indicates that owners had access to animals with varied mobile patterns, or they themselves had grazing rights in different areas of Greece. This may include special grazing in

Mount Óthrys, at major settlement sites in Achaia Phthiotis, or saltmarshes around the gulfs. Alternatively, ovicaprid remains found at these contexts may have been part of purchased sacrificial animals that other shepherds sold during set times in the year.

All six teeth studied from Building 10 were recovered from contexts that date to the first phase of occupation (217 – 197 BCE) and represent three different types of land-use trends. One tooth from the Alexopoulos plot (SG33) and all four teeth from the Arsenopoulos plot also likely date to the period between the Social War and the second Macedonian War (217 – 197 BCE). I argue that the presence of 11 animals managed using different land-use patterns concurrently within a 20-year period supports the idea that mixed management was important to Thessaly during the Hellenistic period. Not only were various forms of shepherding ongoing at these two sites, but evidence of land permissions and grazing rights in Pharsalos, Larissa, and Skotoussa suggest that this was a consistent trend in Hellenistic Thessaly (Chandezon, 2003). Reports of land disputes and other arbitration between different *poleis* may have also resulted from the need for pasture, and ultimately shepherding politics (Ager, 1996; Reinders and Prummel, 1998).

CHAPTER 10: Human-Ovicaprid Relationships

While visiting Pharsala in 2018, I was approached by a member of the community who was eager to mention Pharsalos' rich and deep history in horse breeding. I was familiar with Thessaly's reputation for horses, especially reports of Alexander the Great's horse (Bucephalus) originating from Pharsalos (e.g., Thomas, 2014, p.102), but to hear it explained as an almost passing greeting signified generations of pride in a history of animal management. Although animals are most often managed for what they produce, their role in human livelihood extends beyond tangible goods into the social, political, and economic realms (e.g., Losey *et al.*, 2011, 2018; MacKinnon, 2010; Salmi *et al.*, 2021). In previous chapters I discuss what shepherds were doing with their animals and how they may have been able to manage herds during the Hellenistic period. This final chapter discusses why someone would keep animals, either individually or as part of small or large herds. Forbes (1995) argues that instead of focusing on how animals were managed, a key aspect of the agropastoral debate, we should be looking beyond the how and considering the why. To do this, I consider the local economic (10.1), social (10.2), and political (10.3) agendas in southeast Thessaly during the Hellenistic period to examine why these 12 ovicaprids would have been managed at all. By focusing on the human-animal relationships specific to the Hellenistic context of Kastro Kallithea and Pharsalos (10.4), I explore how the region's pride over animal management may have started, and why it has lasted millennia.

10.1 The Economic Value of Keeping Ovicaprids

Domesticated animals afford humans a ready supply of secondary and terminal products, strength for movement and heavy labour, and agricultural processing through crop turnover and manuring (Sherratt, 1981). Managing one or two animals around the house can serve the daily needs of a small family, requires no additional land or fodder source, and can be accomplished using limited skills or care (Halstead, 2006). Larger herds require additional sources of land, fodder, and support, but offer substantial quantities of goods or services in return (Halstead, 1996). In Table 10.48 I integrate the stable isotope data of each ovicaprid with known farming systems (recall Tables 2.1 and 2.2) to estimate the type of feeding strategy, flock size, and economic output for the ovicaprids in my study. Each animal was managed in a different way, which likely corresponded to a unique purpose.

Table 10.48 Archaeological samples categorized according to modern and ethnohistoric animal management strategies[68] based on trends in recorded stable isotope data and proposed scenarios. Animals that could be part of multiple strategies are noted (*).

Management Strategy	Feeding Strategy	Flock Size	Economic Output	Samples
Household management	Graze on local private pasture only	Small (8-10 animals)	dairy, wool, garden fertilizer	SG08 SG21
Local management (different reservoirs or altitudinal changes in nearby pasture)	Grazing on local public and private owned pastures	Small-Medium (10-80 animals)	dairy, wool, fertilizer for household or small market economy	SG03 SG16 SG38 SG39* SG40 SG42*
Long-distance extensive management (with local component)	Seasonal movement to pasturage with some local occupation	Large (>80 animals)	large market economy, meat/sacrifice, seasonally: wool, lambs, milk, fertilizer	SG30 SG39* SG42*
Long-distance extensive management (entirely non-local); potential trade	Seasonal movement to different pasturage zones (mountains)	Large (>80 animals)	large market economy, meat/sacrifice, trade networks	SG11 SG33
Extensive and regular movement (transhumance) (entirely non-local); potential trade	Year-long grazing with no regular occupation	Large (>80 animals)	large market economy, meat/sacrifice, trade networks	SG23

10.1.1 Domestic or Household Use

One sheep (SG21) and goat (SG08) from Kastro Kallithea likely grazed on local pasture close to Building 10. When animals are kept near the home, they only produce a limited quantity of goods, and usually only for household use (Halstead, 2006). Wool is often removed once or twice annually, and the animal would not be required to stay by the property just for wool production (Campbell, 1964; White, 1970). Milk can be provided daily during the lambing or kidding season, which occurs once between winter and summer (Campbell, 1964). If the sheep or goat is kept in an enclosure bedded with hay or other dry matter, these materials will become

[68] With consideration of Table 2.1 (adapted from Hadjigeorgiou *et al.*, 1999, p.18) and Table 2.2 (adapted from Chang, 1992, p.83; Chang, 1993, p.695; Romano, 2013, p.158).

soaked with urine and feces (Hall, 2019). Manure is highly coveted for agricultural purposes (Forbes, 2013; Kron, 2014), and enclosure bedding can be removed frequently for use as fertilizer (Hall, 2019). SG08 and SG21 were adult animals that spent at least 15 to 18 months of their lives grazing close to Kastro Kallithea. Permanent occupation around the site was likely based on household needs or as part of the landowner's fertilizer strategy for agriculture; Columella argues that a good knowledge of fertilizer was a requirement of farming [*De Re Rustica*, I.I.23-310] (Ash, 1941).

10.1.2 Market Value

Other sheep and goats from Building 10 and the Arsenopoulos Plot were likely kept in larger herds capable of producing excess quantities of byproducts (Table 10.48). Chandezon (2021, p.290) argues that the rise in population and movement into city states during the Hellenistic period saw a rise of complex agropastoral practices, which ultimately led to an emergence of market economies. Oliver (2007, p.94) indicates evidence of craftsmen who migrated from Athens to Thessaly for new opportunities, and the allotment of lands on the Rizi Plateau [*IG* IX, 2.243] would have provided space and citizenship for families to participate in community markets. As a result, the economy diversified as families were engaged in producing and consuming a multitude of commodities, such as specialty funerary statues, ceramic wares and styles, textiles, and the trade of different breeds of animals (Chandezon, 2011; Oliver, 2007). The *agora* at Pharsalos may have been a site of public or private sale of goods (Decourt, 1995, no.52, pp.64-68). Similar public market spaces at Kastro Kallithea may have included parts of a sheepfold (Building 3), which could have been used in animal-based market sales (Haagsma *et al.*, 2011, p.200; Tziafalias *et al.*, 2006a, pp.117-118).

Animals were most often in demand for sacrifice, since meat and related goods (e.g., blood, hides) usually had their origins in cultic activity (Jameson, 1988; Howe, 2008, 2014). A large-scale market infrastructure is detailed for Athens, and it is reasonable to believe that similar but smaller-scale markets were also common outside of Attica. For example, a decree from Classical Eretria implies that governmentally regulated and organized events for both public and private markets were common outside of Athens [*IG* IX^{9} 189.26-41] (Howe, 2014, p.144). Markets would include animals from private sellers that could be sold to public members for use in sacrifice. Revenues from selling sanctuary-managed animals could also be used to financially support the sanctuary (e.g., Sanctuary of Athena Alea in Tegea [*IG* V^2 3.1-21]; Howe, 2003, 2008). A market at the Delian Sanctuary of Apollo also included the sale of wool, hair, and other secondary products [*ID* 503.23-24; *IG* II^3 1638.66; 1639.15-17; 1640.28] (Howe, 2014).

Most of the ovicaprids in my study represent adult sheep and goats that lived to at least four years of age. Older animals were not often consumed as part of important community-based sacrifice as their meat is tougher and less pristine than young lambs or yearlings (Ekroth, 2014b). It is unlikely that these ovicaprids were managed for direct consumption as part of public cult; however they may have been consumed as part of private feasting, private cult, or to ensure older animals did not go to waste after their death. Alternatively, females may have been managed locally to produce offspring that were sacrificed regularly during major holidays (Ekroth, 2014b; Rosivach, 1994).

Instead, local herds of sheep managed by the owners of Building 10 (SG03) or the Arsenopoulos Pot (SG38, SG40, SG42) were likely valued for their wool or dairy production. Demosthenes [47.53f] describes his flock of 50 'fine-fleeced sheep', which were considered valuable commodities at risk of being stolen because of their high market value (Howe, 2011, p.11). A flock of this size likely had value because it could produce up to 35 kg of wool annually (Halstead, 1981, p.328). The wool sheared from medium-sized flocks kept locally at Kastro Kallithea and Pharsalos could have been sold directly at local markets. The volume of textile production equipment recovered from Building 10, including 230 loom weights, 12 spindle whorls, six spools, and loom weight moulds (Haagsma *et al.*, 2019a), could reflect the estate owner managing their 'fine-fleeced flock' locally (e.g., SG03, SG21). Instead of selling the unprocessed wool, textiles produced at Building 10 likely garnered a higher price at market, either locally or as part of wide-spread community markets.

Numerous goats were also kept local to Kastro Kallithea (SG08, SG16) and Pharsalos (SG39). Goat hair is not traditionally used to make clothing textiles, though certain breeds (e.g., angora, cashmere) produce a soft undercoat of wool, which is capable of being worked into highly coveted garments (Hall, 2019; Ryder, 1993). Instead, the coarser nature of goat hair lends itself to rougher textiles (Ryder, 1993). Archaeological examples of goat hair products include carpet for stamped clay floors found in Turkey (Vogelsang-Eastwood, 1987) and curtains, blankets, and tents of goat hair that have been recovered in Jordan (Ryder, 1993). An estate that included a herd of goats and their herdsman was sold for a high price during the Classical period

[Isae. 6.33].[69] If hair-producing goats were kept local to the area, they may have been managed for their milk in addition to coarse textiles. Isager and Skydsgaard (1992, p.91) also emphasize the importance of goat-produced cheese products during antiquity. The extensive description of cheese processing from Aristotle [*Hist. Anim.* 521b, ff] (Ross, 1964) and Hesiod [*Works and Days*, 590] (West, 1988, p.54) may reflect the economic importance of goat cheese at markets. Remains of milk-processing vessels have also been recovered from domestic contexts at Pharsalos (Municipality of Pharsala, 2015) and potentially Building 10 (Haagsma *et al.*, 2019a) (recall Chapter 2; Fig. 2.4), which would have been necessary pieces of equipment for making soft or hard cheeses.

10.1.3 Thessalian Wealth and the Golden Fleece

Animal-based markets were also important for Pan-Hellenic games and associated public festivals (*panegyreis*) (Howe, 2014, p.147). As an example, Plutarch [*Moralia* 437a, 438a-b] explains that markets during the tournaments at Delphi often included a disproportionate ratio of animals to people, and Livy [33.32.1-3] describes how the Isthmian Games' location afforded citizens opportunities for sea-based trade of animal-derived goods (Halstead, 2014, p.147). These multi-regional fairs often occurred during the spring and autumn periods that corresponded with culling and shearing times, which Howe (2014, p.149) argues may align with the movement of transhumant herds. [70] Selling animals remotely or over great distances would have required a specific interest in goods or breeds. Just as Pharsalian horses became known as a reputable and highly coveted breed, international interest in Thessalian sheep or goat products may have been born out of myth and carried through word of mouth.

One especially well-known ovicaprid-related myth is that of the golden fleece. In this myth, Jason and the rest of the Argonauts traveled through perilous terrain to return the golden fleece[71] as part of earning his place as the King of Iolcus (Thessaly). Lordkipanidze (2001, pp.3-5) argues that the ram's significance may have stemmed from the fleece itself, as sheep skin or fleece could symbolize protection (e.g., in Anatolia the skin is used in rituals to prevent drought) or (royal) power [Varro, *On Agriculture*, II, 1, 6], or have an association with religious deities (e.g.,

[69] Isaeas was a Classical orator (420-340 BCE), who in this passage is discussing the estate of Euctemon.

[70] Pausanias [10.21.15] observed how religious festivals (e.g., Isis in southern Phocis) created seasonal market fairs that could easily be sustained by transhumant pastoralists in the region. Although his description dates to ~140 CE, similar trends in earlier periods are expected (Howe, 2003, p.142).

[71] Often depicted as a golden-wooled and winged ram.

Zeus Aktaios on Mount Pelion). If the golden fleece, and more broadly Thessalian wool, carried these associations, it is reasonable to suppose that the myth perpetuated the value of this commodity. In addition, depictions of this myth are also on the very item that facilitated the trade and exchange of 'golden fleece': coins (Haagsma 2010, p.214).

Producing sufficient goods to supply a business beyond local domestic economy requires constant movement or grazing in marginal landscapes. At least two sheep in my study were likely grazing permanently outside of the local area (SG11, SG33), with two others from Pharsalos (SG30, SG42) in non-local areas for at least a portion of the year. Goats were also grazing permanently away from Kastro Kallithea (SG23) or semi-permanently away from Pharsalos (SG39) during the time recorded. Any of these animals could have been managed as part of a large-scale economic venture. Remains of exotic and imported goods were recovered from Building 10 (Haagsma *et al.*, 2019a, p.66) and the Arsenopoulos Plot (Karapanou, *personal communication*), which may be tied to an international trade economy. If the owners of these houses also owned large herds in the mountains or had access to numerous wool supply herds, their wealth in fleece could account for the lavish homes they owned in each respective community. Wealth associated with flocks grazing in the Óthrys Mountains may also be depicted in the poem of Callimachus' Hymn to Demeter [VI, 86] (Hopkinson, 1984), and the myth involving Cerambus and Pan [Antoninus Liberalis, *Metamorphoses,* XXII, 254-255] (Celoria, 1992) (recall Chapter 2, Section 2.3.2).

10.2 Social Aspects of Keeping Animals

Richness in flocks and the push for an animal-based economy were likely borne out of social and political forces. Much as the stock market today can be influenced by hedge fund investors or political interference, Howe (2011, p.5) discusses the Hellenistic infrastructure that made an animal-based economy possible, including specialized markets, systems of landholding, investment by elites, and state involvement. By emphasizing the social importance or prestige associated with wealth in flocks, animal-based economies became more prevalent, and in turn promoted the practice of raising larger flocks or herds of animals.

10.2.1 Social Prestige

Homeric epics were among the first to mention the concept of 'richness in flocks', which Howe (2014, p.141) explains connected animals, exchangeable wealth, divine favour, and status, with emphasis placed on religiously significant domestic animals [*Iliad* 2.106, 605, 705; 9.154, 296; 14.490; 16.417] [*Odyssey* 11.257; 15.226]. Howe (2014, p.137) discusses concepts of 'acceptable' forms of wealth, which were gained directly from the land either as a result of agriculture (e.g., [Aristotle, *Politics* 1285b.12-21], [Cicero, *De Officiis* 1.151]) or through animal management (Howe, 2011), which Aristotle claimed as having produced the best return of investment [Aristotle, *History of Animals*, 522b20, 572b20, 572b10, 577a5-17, 596a10-24]. Despite authors who glamorized agriculture as a gateway to riches [Aristotle *Politica* 12557a-1258], Homer only referred to the concept of 'richness in crops' once in his works [*Iliad* 5.613] (Howe, 2011, 2014).

Although the literature would suggest a shift from agricultural to pastoral economy during the Classical and Hellenistic periods, Greek and Roman practices appear firmly centred on a mix of animal husbandry and arable/arboreal farming (e.g., Cherry, 1988; Foxhall, 1996; Halstead, 1996; Howe, 2011, 2014; White, 1970). Arable farming was still important for human subsistence and economic livelihood, but concepts of 'real wealth' or wealth-based status stemmed from disposable income in the form of grazing herds. In this way, animal herds became a tangible and visible form of marketable property (Howe, 2014, p.142). Much as the golden fleece became a symbol of power and protection, seeing large numbers of animals attributed to one owner may symbolize wealth and power in different communities.

Howe (2008, pp.1-5) uses Xenophon's [*Hell.* 6.4.29-30] depiction of Jason of Pherae to explain the mechanics of visual displays of wealth, which he refers to as pastoral politics. As Xenophon narrates, Jason, as a new officer of the Thessalian territories (c. 370 BCE), sought the role of Director of the Pythian Games in Delphi. Such a position would grant Jason control over much of southern Greece (Pownall, 2016). To garner this control, he chose to display his own prestige and power through animals. As the myth goes, Jason demanded that the people of Thessaly prepare a caravan of herdsmen and guards that would transport the procession of many animals for sacrifice, with no fewer than 1,000 cattle, including the finest bulls, and at least 10,000 sheep, goats, and swine [Xen. *Hell*. 6.4.29]. The procession was to travel from Thessaly to Delphi in 370 BCE for the feast in honor of Delphian Apollo and the Pythian Games that followed (Howe 2008, p.2). Not only was Jason assembling a massive amount of presumably *surplus* animals from his herdsmen, but he planned to take these animals on public display throughout central Greece. Jason's intent was to display surplus wealth as a direct connection to the gods and for the people of Greece. Although he was killed before these events transpired, news of his magnitude was expected to have travelled to other areas, perpetuating his power and prestige, and securing his position as director (Howe 2008, p.5).

With small plots of land being allocated to most members of society (e.g., immigrants and freedmen; [*IG*. IX. 2. 234. ll. 1-4]), multiple large herds may have become symbols of power, and a means for separating different socioeconomic classes in Thessaly. Xenophon, Aristotle [*Politica* 1258b.12-21], and Cicero [*De Officiis* 2.89] suggest that only elite members of society could convert their wealth into livestock (Howe, 2014, p.139). These elite writers and their elite educated audiences were perpetuating their own worth, prestige, and superiority in herds. Even the perpetuation of the golden fleece myth reinforces this connection between sheep (livestock) and power. Similarly, individuals who were gifted livestock or pasture may have been symbolically granted access (power) to elite status if they did not already hold it.

10.2.2 Social Favour

If this is the case, *epinomia* is a way that communities increased the wealth, prestige, and value economics for the already elite class. Donlan (1997) has argued that public displays of animal goods, especially in the form of gifting animals or *epinomia*, perpetuated what it meant to be elite and contributed to forms of complex status negotiations (Howe, 2014, p.143). The wealth-generation potential of animal production, and the social power of being bestowed animals or land, were sometimes complaints of ancient authors outside of Thessaly. For example, Athenian orator Demosthenes [19.265] complained when King Philip II of Macedon (ca. 4th c. BCE) rewarded several non-elite Athenian ambassadors with expensive animals (cattle, sheep, and horses) (Aston, 2012). These sources of wealth and opportunity let men become leaders of the *polis* when they were not previously elites (Howe, 2011, p.12) because locals "envied them, honoured them, and considered them true men" (Howe, 2008, p.45).

Social favour also extended into the religious sphere. Being granted *proxeniai* at Pharsalos (e.g., Decourt, 1995, no53, pp.68-70) could mean registering in the cult of one's choosing, which may have previously only been for elite members of society. If registering in a cult became a common practice, community members would have equal status; however, if elite members of society had surplus animals, or pristine sacrificial lambs (Ekroth, 2014ab), they would be able to distribute meat at feasts and visibly maintain their elite status while also continuing to hold favour with their gods.

10.3 The Politics of Keeping Animals

10.3.1 Political Prestige

Being granted *epinomia* extends beyond social relationships and contributes to political endeavours. Oliver (2011, p.359) discusses how *poleis* that wanted to increase their population were required to make themselves attractive to foreign and domestic individuals. If grazing rights, room to graze, and access to the market were given as part of certain citizenship rights, communities could ensure increased immigration. Communities with higher populations would thereby have surplus men available for military purposes. It is speculated that Philip V encouraged immigration to southeast Thessaly after the Social Wars for these purposes (Chandezon 2021, p.296). He was eager to restock military supplies, restart the economy, and maintain his own control over the region. Decourt (1995) and Chandezon (2003) discuss numerous instances of citizenship decrees, granting of *proxeniai*, and other public rights given in Thessaly during the Hellenistic period, which likely contributed to how the ovicaprids in my study were managed.

If communities sought to grant grazing rights and maintain control over highly coveted pastoral resources, disputes were likely common during the Hellenistic period. The epigraphic evidence of land disputes between Peuma and Melitaia/Chalai and Peuma and Pereia/Phylladon (Ager, 1996, pp.99-103) and between Narthakion and Melitaia (Ager, 1996, no. 32) during these times give further clarification. These inscriptions discuss boundary arbitrations around the Óthrys Mountain region, and both resulted in formalized boundary demarcations to prevent future conflict. At least three ovicaprids in my study (SG11, SG23, SG33) showed signs of grazing in these areas during later periods. Although pastorally driven land disputes were likely common in southeast Thessaly, only few documents of arbitrations at Delphi were recorded (Ager, 1996; Chandezon, 2003; Reinders and Prummel, 1998). It is possible that these boundary disputes related to access to prime grazing real estate and land granted as *proxeniai*, and relations between regions may have changed after the Social War to accommodate access.

10.3.2 Military Benefits

Shepherds and their animals also served various roles during military campaigns. During the Battle of the River Aous (c. 198 BCE) Livy [32.11.1-3] reports that a shepherd was brought to Flamininus to help the Romans in their military efforts against the Macedonians (Heinemann, 1935). The author reports that shepherds offered to guide Flamininus' men along the pastoral pathways in the hills and take them into an advantageous position against the enemy [Plutarch, *Flam*. 4.2-3] (Loeb Classical Library, 1921). Shepherds have unique experience navigating through a landscape that at first glance would otherwise seem difficult to access (Chang, 1992, 1993). Shepherds acting as scouts and guides during military campaigns proved effective for Flamininus at the battle in 198 BCE [Livy, 32.11.4-6], and were likely used in similar ways during other campaigns (e.g., [Polybius, 18.19.2.9]). Numerous ovicaprids in my study appear to have been managed in the mountains and their shepherds needed an intimate knowledge of the surrounding areas, potentially serving military roles during major conflicts in Thessaly.

Domestic herd animals were also physically used as part of warfare. Ovicaprids were used to trick the enemy into believing that armies were much larger than they were. As an example, Alexander the Great tied branches to sheep tails prior to herd movement to create a dust storm that resembled thousands of men moving in on the Persian army (Mayor, 2014, p.288). Alexander the Great also set up camp with his men mixed into larger ovicaprid herds or tied torches to sheep caravans to deceive military scouts into seeing the lights of a much larger military camp (Mayor, 2014, p.288). Although it is unclear how ovicaprids may have been used as part of warfare in Thessaly, it is likely that larger caravans of sheep and goats could have served a purpose for the various instances of war throughout the centuries.

10.3.3 Withholding Goods and Services

Warfare could include physical combat as well as military sabotage. Davies (2001, p.17) discusses a salt ban imposed onto Macedonians and their expanding territories during the Macedonian War (c. 167 BCE) (see Livy [45.29.11]). Salt is a requirement for animals (Hall, 2019) and cheese-making processes, and a ban on salt could seriously harm herding industries. A salt ban could have prevented movement of animals beyond their central communities, forced movement to different areas with known salt access (e.g., Halos' salt marshes), restricted shepherding 'scouts' that aided military endeavours, or directly harmed the cheese economy (Attema and de Neef, 2021).

Table 10.49 Summary of different management styles according to site.

Management Type	Kastro Kallithea	Pharsalos
Local, Backyard/Stall-fed, or mixed farming	SG21, SG08	*None*
Local, Multi-plot movement	SG03, SG16	SG38, SG39*, SG40, SG42*
Local and non-local mix	*None*	SG30, SG39, SG42
Entirely non-local mobile movement	SG11, SG23	SG33

Foxhall (1993, p.141) explains how supplies and harvested materials were often stored off-site for safe keeping avoiding complete destruction or plundering by attacking military. Shepherds caring for their flocks could serve as lookouts of these materials as well as scouting for any oncoming outsiders. Owners that hired shepherds to manage their wealth of livestock away from vulnerable communities may have also been preventing financial losses because of military raids. Ultimately shepherds and their herds served vital roles in the political history of Thessaly. Not only could animals have been kept for military purposes, but there were likely political advantages to caring for large herds remotely from the main villages during this time.

10.4 Site-Specific Management Trends

Residents of Kastro Kallithea (Peuma) and Pharsalos were part of different communities and networks and likely had different reasons for participating in local and non-local husbandry. In addition to the economic, social, and political reasons listed above, the owners of Building 10, the Arsenopoulos Plot, and the Alexopoulos Plot have specific contextual points worthy of discussion. In addition, based on the 12 ovicaprids I analyzed, there were clear differences in how animals were managed depending on site (Table 10.49).

10.4.1 Kastro Kallithea

Four of the Building 10 ovicaprids were isotopically local, with two likely being managed in the same area year-round. More animals were kept closer to Kastro Kallithea than they were at Pharsalos, and none of the animals appear to have been managed using a mixture of local/non-local movement (Table 10.49). The two entirely non-local animals may have grazed in the Óthrys Mountains away from the main site similar to one of the sheep from Pharsalos.

The AX/XA Economic Network

Kastro Kallithea, or Peuma, participated in a collective economic network during the Hellenistic period. Evidence of a shared AX/XA monogram minted onto the coins from settlements in Achaia Phthiotis, including New Halos, Phthiotic Thebes, and Larissa Kremaste, may signify trade partners or market collectives in the area (Reinders *et al.*, 2016). Numerous coins were found in Building 10, which may have been a result of selling animal-based goods, including local exchanges with communities using the AX monogram, Melitaia, Larissa, and Pherae, or more widespread sale of goods within Macedonian, Aetolian, or Roman networks (Harvey, *forthcoming*). The largest assemblage of coins was minted in Larissa (n=8) and depicting the Macedonian leader Antigonus Gonatas (n=20) (Harvey, *forthcoming*). Currently no AX/XA monogrammed coins have been recovered from public buildings (Haagsma *et al.*, 2011); instead, they were found in the deposits at Building 10 (Haagsma *et al.*, 2015b, 2016).

One possible scenario for how SG23 was managed included grazing in the coastal area around Phalara or Larissa Kremaste during the spring season prior to returning to graze on Mount Óthrys (recall Section 9.4.3). If the owner of Building 10 had market networks with Larissa Kremaste, a member of the AX/XA network, it may signify the use of an Achaia Phthiotis-based economic network. It may also show why animals would be managed further away from Kallithea. Animals being kept around locally for the sale of cheese or other readily available goods (SG03, SG08, SG16, SG21) could sustain *poleis* within 10 km. Animals that were managed as part of larger, non-local herds (SG11, SG23) would have been able to support communities further than 10 km away, or potentially even sustain large-sale economic ventures with bigger business partners like Macedonian forces.

Ritual Goods (Cult)

Animals were also required locally for ritual purposes. Based on numerous artifacts and contexts, participation in religious practices must have been an important component of daily life at Building 10. Notably, a burned pot (*stamnoid pyxis*) and lid filled with bones of a newborn ovicaprid and a silver coiled snake ring were found buried inside the building's main hearth (Haagsma *et al*., 2019a, pp.57, 68). These remains may have been part of domestic worship and may have served as an offering to a household god (Zeus Ktesios), like contexts found at Halos or Aiani (Macedonian city) (Haagsma *et al.*, 2019a, p.68). Ovicaprid ankle bones (*astragaloi*) were also used in games and divination (Haagsma *et al.*, 2019a, p.69), and over 70 have been recovered from Building 10 (MacKinnon, 2016). Ovicaprids clearly have an important connection to ritual contexts at Building 10, which may have been another reason why SG03, SG08, SG16, or SG21 were managed locally.

Defensibility

Kastro Kallithea was also a highly defensible *polis* and the site includes the remains of at least 38 towers embedded into the outer wall (*enceinte*) and cross-wall (*diateichisma*) fortifications (Chykerda *et al.*, 2014a). These defensive elements would have relied on strategic sight lines and communication between scouts or neighbouring allies (Chykerda *et al.*, 2014a, 2014b). The Óthrys system forced enemies to enter Thessaly south and west of the mountains, passing through Melitaia before getting close to Kastro Kallithea or the vital port at Halos (recall Fig. 3.11). Chykerda *et al.* (2014b, p.300) discuss evidence of towers or small defensive camps that were likely located at vantage points through the Óthrys Mountains within the viewshed of Kastro Kallithea. If men were required to live or stay close to these towers, it would have been beneficial to manage animals at the same time.

Two animals from Building 10 (SG11, SG23) were potentially managed on Mount Óthrys for over a year. Traditional transhumant shepherds move to lower elevations during the cold harsh winters and higher elevations during the warm summers; this may not have been the trend recorded in either animal. If their shepherds were responsible for maintaining defensive towers on Mount Óthrys as part of strategies with Kastro Kallithea, they would have instead stayed at the site for longer periods of time. Shepherds could have kept these animals for daily milk or other subsistence, reduced suspicions about their presence at that spot, and be able to serve as a scout for the defensive tower itself. Elite men in society were often highly involved in the military, and it is possible that shepherds hired by the owner of Building 10 served multiple purposes. As an example, SG11 may have moved between one tower during the first year and another during the second because of changing defenses or the need for different sightlines.

10.4.2 Pharsalos

None of the ovicaprids analyzed at Pharsalos appear to have been managed on the same plot or nearby plots annually. Instead, animals were managed by movement to local plots on varied waterways, a mix of local and non-local management, or entirely non-local management (Table 10.49).

Horses/Military Training

The area north of Pharsalos is expected to have available strontium isotope values that are lower in the plains area compared to the more elevated area around Pharsalos (Fig. 7.43). No ovicaprids from the study show isotope values attributed to this area, potentially due to the area being characteristic of land used for military and horse training purposes ([Xenophon, *Horse*]; Thomas, 2014). One reason why ovicaprids were not managed on consistent plots near Pharsalos may have been due to local pastures being preferentially given to horses or cattle (Aston and Kerr, 2018; Cherry, 1988; Howe, 2011; Wagman, 2016, p.8). It is said that the wealthy estate owner Menon of Pharsalos (~4th c. BCE) managed hundreds of horses on the plains near the city [Demosthenes, *Arist.* 199] (Aston and Kerr, 2018, pp.7, 20; Thomas, 2014, p.100). If the plains and marsh pasture area around Pharsalos were restricted to horse breeding (e.g., [*Iliad*, 20.221-229]; Thomas, 2014, p.74) or cattle rearing (e.g., Howe, 2011, p.15), shepherds and ovicaprid herds would have been required to move or graze in more marginal landscapes further from the city. Horses are not well suited for training on hilly terrain, and swampy or muddy terrain was a risk for injury (Thomas, 2014). Although horses and cattle thrive on well-irrigated marshland (Howe, 2011, pp.15, 21), herds of sheep or goats would have likely used the swampy pastures closer to the Apidanos or Enipeas Rivers (e.g., SG38, SG40) or the hillsides that bordered the plains (e.g., SG39, SG42) for their grazing requirements.

Pastoral Dedications

Inscriptions recovered from areas surrounding Pharsalos also include dedications to various cults, including so-called pastoral deities (Decourt, 1995). An example comes from an ancient trail east of the acropolis walls, which includes a mid-5th c. BCE dedication to Hermes (Decourt, 1995, no. 69, pp.85-87). Hermes was often regarded as the god of herds, roads, and transhumant shepherds, and the trail that his dedication is marked on may have been an important part of pastoral movement for semi-local herds.

Southwest of the city and in the mountains neighbouring the Rizi Plateau is the Cave of the Nymphs, which is another example of pastoral cult (Wagman, 2016). Numerous dedications (Decourt, 1995, no. 72, 73) and artifacts from this cave have been studied and suggest an occupation between at least the Archaic and late Hellenistic periods (Wagman, 2016, pp.51-52). Iconographies of Pan and the Nymphs were commonly displayed among the votive offerings, which are often attributed to pastoralism and weaving [*Odyssey*, 13, 103-108], respectively

(Wagman, 2016, p.50). Sites like the Cave of Nymphs are embedded into the hillside and require an intimate familiarity with the local landscape for access (Mili, 2015, p.178). Although these sites were not used exclusively by shepherds, herders likely travelled to them as part of mobile management, either to seek refuge during different seasons or as part of ritual life. Artifacts from the cave were considered local and non-local (i.e., foreign coins, ceramic styles, and goods), indicating that visitors may have specifically stopped at this site to pay tribute (Mili, 2015, pp.146, 178). Grazing in areas around pastoral shrines like the Cave of Nymphs may have been why numerous ovicaprids at Pharsalos (SG39, SG42) were local and non-local to the region depending on the year. Shepherds of non-local animals (SG30, SG33) may have also stopped at this cave on their way to sell animal byproducts at markets in Pharsalos or surrounding areas; paying tribute to the Nymphs may have ensured a profitable return at market.

10.5 Summary

Sheep and goats played an important part in the economic, social, and political aspects of Thessalian history. Although the agropastoral debate is largely centred on aspects of mobility and the impacts animal grazing would have had on agriculture, it often fails to consider the intrinsic reasoning for *why* landowners and shepherds would have managed animals, and what ripple effects these considerations have on various aspects of history. If further work is done to tighten the isoscape mapping for the region, movement between different areas of cultural or political importance could better define the impact local and non-local animals had on this area. Kastro Kallithea and Pharsalos were unique *poleis* with different approaches to agropastoralism. Animal management clearly shaped ancient life in these cities and had a lasting impact on the history of the region.

CHAPTER 11: Conclusions and Future Research

Our understanding of agropastoralism in Thessaly has increased in the past 40+ years of study. Although researchers are often divided over the extent or prevalence of specialized animal management (e.g., Chandezon, 2020; Forbes, 1998; Halstead, 1981; Hodkinson, 1988; Howe, 2008), it is clear that pastoralism was an important part of human livelihood and aspects of animal husbandry are integral to the history of the region. The research presented in my dissertation provides new insights into different ways animals were fed, moved, or potentially interacted with people and the landscape. This research also both contributes to and benefitted from the extensive archaeological interpretations of domestic contexts at Pharsalos (e.g., Karapanou, 1998, 2008; Stamatopoulou, 2007, 2013) and Kastro Kallithea (e.g., Chykerda *et al.*, 2014; Haagsma *et al.*, 2011, 2012, 2015a, 2019ab; Surtees *et al.*, 2014; Tziafalias *et al.*, 2006ab). In particular, evidence of different management strategies supports the archaeological evidence that animals and animal byproducts were important for the economies of Pharsalos and Kastro Kallithea. Agriculture and pastoralism were occurring simultaneously and likely contributed to the increased urbanization and settlement of these towns during the Hellenistic period. In this conclusion I revisit my initial research goals and objectives, summarize the significance of my research, and express future goals and directions for this and similar projects.

11.1 Re-Addressing the Agropastoral Debate

Initially, the goal of this research was to document the use or extent of transhumance in Thessaly during the Hellenistic period. Although there are examples of ovicaprids at Kastro Kallithea (SG23) and at Pharsalos (SG39) that likely moved from higher to lower altitudes seasonally (i.e., transhumance), I found that each form of specialized pastoralism presented evidence of unique human-animal relationships in Thessaly. As a result, my research objectives became about painting a more holistic picture of what pastoralism entailed in the region to better understand the implications of different pastoral strategies for the economic, social, and political aspects of ancient life.

11.1.1 What Management Styles Did They Use?

Throughout this dissertation I emphasized that by integrating multiple forms of data, I could begin to discuss animal management and the relationships between shepherds and landscapes. Analysis of sequential enamel samples and the resulting intra-individual isotope patterns were successful in determining the extent of animal mobility, different foddering practices, and seasonal variation in management strategy. Although each animal was managed in a slightly different way, there are four broad categories of pastoral strategies that are evident. In my study ovicaprids were either:

1. Local and sedentary (SG08, SG21),
2. Non-local and mobile (SG11, SG23, SG33),
3. Mixed-local and mixed-mobile (SG30, SG39, SG42), or
4. Locally mobile with varied water intake (SG03, SG16, SG38, SG40).

Additionally, Kastro Kallithea and Pharsalos are equally represented in the management categories, and all 12 animals showed signs of similar yet unique trends. Eleven of the individuals came from contexts spanning roughly 20 years (ca. 217-197 BCE), so it was not unexpected that all individuals would have unique isotope trends. What is interesting is that in a 20-year span, only two individuals were managed using what was considered 'standard backyard grazing' (Halstead, 1996, 2006). When considering the agropastoral debate, evidence from Kastro Kallithea and Pharsalos show that both sites emphasized agriculture, pastoralism, and the mixing of local and non-local sheep and goats.

11.1.2 How Did They Shepherd?

Shepherds required access to pasture, either through ownership, other private access, or permissions to use public lands. Based on the ovicaprids in my study, shepherds may have moved to the marginal lands around Pharsalos or Kastro Kallithea to feed their animals, similar to modern shepherds. Moving between different regions also required access and, in some cases, safe passage. Being allotted land or being granted access to graze were documented at Pharsalos and likely the cause of shepherds at the Arsenopoulos and Alexopoulos Plots moving with their animals. Kastro Kallithea was also home to animals that grazed locally and potentially moved into the Óthrys Mountain range, similar to modern transhumant shepherds. It is likely that shepherds in antiquity used similar approaches, practices, or areas that modern herders use for their animals today.

11.1.3 Why Did They Keep Animals?

The ovicaprids studied at Kastro Kallithea and Pharsalos were likely kept for a number of different reasons. The faunal assemblage data (mortality profiles) suggests that animals were kept as part of a wool- and/or dairy-based economy (MacKinnon, 2016), although most remains were likely the result of consumption at older ages. It is possible that these animals were not managed directly by the inhabitants or hired hands of Building 10, the Arsenopoulos Plot, or the Alexopoulos Plot, but instead by other local shepherds or those who sold their goods at Kastro Kallithea or Pharsalos. The animal-based economy may have been rooted in local products (e.g., SG08, SG16) or extended to non-local trade partners (e.g., SG11, SG23, SG33).

More sheep were included in my study than goats, reflecting the preponderance of sheep at both sites. This may be due to an emphasis on sheep husbandry for wool or sheep's milk products rather than goat hair or dairy products. Interestingly, there were no discernible differences in how sheep or goats were managed, which had been the case for other studies (e.g., Isaakidou *et al.*, 2019); at least one sheep and one goat presented as examples of each of the four management styles. Modern herds often include a mix of both animals, as goats help to guide and manage sheep (Campbell, 1964; Hall, 2019), and it is possible that mixed herds were similarly used in antiquity. Overall sheep and goats were kept in great numbers at and around Kastro Kallithea and Pharsalos, likely for the production of byproducts (dairy, hair/wool, manure) and terminal products (meat, sinew, hide), and those that could not be managed locally were part of mobile herds in nearby or distant mountain ranges.

11.2 Research Significance

11.2.1 Agropastoral Debate

This research adds to our growing understanding of domestic economy at Kastro Kallithea and Pharsalos and specifically contributes data on subsistence (e.g., seasonal variation in C_3 plants or plant portions consumed, and some consumption of C_4 plants), migration and mobility (e.g., local and non-local isozones), land use patterns (e.g., marginal landscapes, altitudes, and mountain zones), and temporal aspects of husbandry (e.g., seasonal or non-seasonal). These data contribute to a more complete understanding of the human-animal relationships in Thessaly, which adds a novel voice to the agropastoral debate. Through the use of intra-individual stable isotope patterning, I have shown that multiple forms of management were in concurrent use in antiquity. Instead of adhering to a strict agropastoral model or transhumance model, my research supports the third scenario of the agropastoral debate that argued for a mixed-model approach to agropastoralism (e.g., Howe, 2014; Papanastasis *et al.*, 2010; Skydsgaard, 1988). Animals were managed in southeast Thessaly using a system that involved a multitude of different management strategies for pastoralism *and* agriculture. Many of these pastoral strategies are similar to what local shepherds use today, including home fed, intensive (lowland local), and extensive (with or without transhumance) farming systems (Hadjigeorgiou *et al.*, 1999). Although the sociopolitical circumstances that facilitated specialized management in antiquity were different from those in modern day, this research connects modern shepherds with the distant history of pastoralism in Thessaly.

11.2.2 Community History

What people were doing with their herds, how they were able to do it, and for what purpose this was done all have implications for past lifeways and can connect with communities of the region today. Part of working in Thessaly means working for local descendant groups and ensuring that research is accessible to these communities for their use. This research has already been presented as part of community outreach initiatives in Pharsalos and Narthaki as part of the Kastro Kallithea Archaeological Project and will continue to be part of archaeological accounts and local history at the sites in Pharsalos and Kastro Kallithea. In particular, these data can be used to discuss settlement patterning (e.g., migration and the use of public/private grazing spaces), the use or incidence of artifacts (e.g., abundance of wool-processing equipment), or evidence of foreign or domestic wealth (e.g., coins and trade networks). Overall my research contributes to our understanding of human-animal-landscape relationships and lived histories in Thessaly during the Hellenistic period.

11.2.3 Research Datasets

In addition to contributing to the agropastoral debate and archaeological understanding of the area, the stable isotope interpretations are now part of the available data for southeast Thessaly. Isotope research in Thessaly is a relatively new approach (e.g., Panagiotopoulou *et al.*, 2018; Sparkes, 2018) and many of the interpretations have been made through extrapolations of research from other areas or using few local data values. My research followed this pattern but will now add to the available datasets. Data, interpretations, and approaches from this study are already being used as comparative examples for studies in Thessaly or more widely in Greece (e.g., Aiken, 2019; Frank *et al.*, 2021). Much valuable information from this region is going to come from work being done by Dimitris Filioglou (PhD Candidate, University of Groningen), which will both complement the research in my dissertation and expand our understanding of isotopes and animal management in the region even further (e.g., Filioglou *et al.*, 2021). Future research in this region will help to better define interpretations and create a more complete picture of animal movement in the area.

11.3 Future Directions

Although this project has consumed the better part of the last six years, there are more avenues of research or application of existing data that can and will be done. In addition to using the finalized part of this research in community outreach endeavours, presenting it at academic conferences, publishing it in academic journals, and using it as case studies in teaching, I believe there are three directions for this research, including methodological developments, isotope applications in husbandry, and applications in the general archaeology of the region.

11.3.1 Method and Approach

For the purposes of this project I adapted a sequential analysis technique that, although necessary for the arid conditions I faced in Edmonton, is unnecessary in other more humid environments. Traditional drilling of bands of enamel will be a sufficient approach if I am to continue analysis in other labs. Additionally, the impressive and extensive research of Lazzerini *et al.* (2021) is a new avenue for analysis on a much larger scale. Although there are still contamination risks associated with LA-ICP-MS, advances are being made to improve the versatility of this approach. A similar study that followed goat herds around Mount Óthrys or other mountains in Thessaly would provide an incredible resource for archaeological isotope studies in the region. As it stands, forthcoming isotope-based pastoralism research by Dimitris Filioglou in neighbouring regions will provide the opportunity for collaborative discussions on animal management throughout Thessaly.

Another future direction of this research is to assess issues of inter- and intra-individual variation in animal isotope data. A large part of the discussion in Chapter 4 related to the variability of enamel growth, maturation, and mineralization and the potential for different livelihoods to impact dental development. Although I focused on how I could limit issues of intra-individual variation (through the selection of the mesial surface of the M_3), future directed research can study isotope variation among ovicaprids grazing under the same management strategy in Thessaly (similar to Lazzerini *et al.*, 2021).

11.3.2 Further Pastoralism and Subsistence Studies

Initially the emphasis for my analysis was on the strontium (location) and oxygen (seasonality) data, with carbon isotope data to only be collected as part of general interests. The inter- and intra-individual variation in stable carbon isotope values was unexpected and may be useful for future research in human dietary analysis, studies involving animal milk consumption, or with seasonally-varied carbon isotope values. Because this variation can impact the isotope values of the animal's milk, and thus of dairy foods, this could have important consequences for the interpretation of the stable isotope values of human remains (Bourbou and Garvie-Lok, 2015). Another area of future research that I am interested in pursuing includes stable isotope analysis of equid remains from this and other areas of Thessaly. Pharsalos is known for horse management and applying the current approach to equid remains would increase our understanding of the human-animal relationships in animals not kept for their byproducts.

11.3.3 Landscape Archaeology

Another direction for this research is landscape archaeology. CAPS (Central Achaia Phthiotis Survey), which developed out of the Kastro Kallithea Archaeological Project, has started to explore the landscape around Kastro Kallithea and the greater Achaia Phthiotis area in an attempt to increase our understanding of environmental, geopolitical, cultural, and social factors of human livelihood during antiquity. Part of my research discussed shepherd and animal movement between major regions and grazing in the more marginal landscapes. I believe that my research can contribute to CAPS' growing knowledge of animal and shepherd mobility between major regions of Achaia Phthiotis, grazing in more marginal landscapes, and pastoral landscape use in antiquity. Additionally, if environmental samples were to be collected as part of CAPS' survey and detailed geological and geomorphological assessment, strontium isotope data at different environmental, ecological, or cultural areas of importance could contribute to their and future studies of landscape use in Achaia Phthiotis.

11.4 Closing Remarks

At the start of this project, the emphasis was largely on the utility of stable isotope analysis and the applicability of this method to contexts like Hellenistic Thessaly. The main question was 'would we find evidence of transhumance?' Over the last six years this project grew to include ethnographic work with shepherds, discussions with community members, analysis of archaeological materials, and physically being in the mountains with the animals. Although the project never really changed, my approach and understanding of the research evolved into being about the evidence of shepherding in antiquity, with the emphasis on the human-animal-landscape (shep-herd) relationships. I can now conclude on the importance of pastoralism and how it intersects with aspects of identity, domestic economy, and culture in the Mediterranean, now and in antiquity.

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Appendices

Appendix 2.1 Summary of key authors in the so-called agropastoral debate (discussed in text)

Author	Position	Summary of Reasoning and/or Evidence
Cardete (2019)	Short-distance transhumance occurring in Arkadia	Range of no more than 10 km, suitable for rugged but not severely elevated terrain in Arkadia, and the scattered settlement model.
Chandezon (2003)	Agropastoralism in Athens, the Cyclades and S. Ionia; Transhumance likely in the Peloponnese, central Greece, north Ionia-Aeolia, NW. Greece and Macedonia	Epigraphic evidence and literary accounts with other archaeological evidence to analyze what was likely occurring in different regions and during different time periods. Regions with favourable mountain pasture would have practised transhumance; others were expected to keep smaller herds in accordance with agropastoralism
Chang (1993)	Transhumance in pre-modern times	(see above) Was not concerned with a temporal period, but instead created analogies that can now be applied to other sites
Chang (1994)	Transhumance in prehistoric times, possibly as early as the Bronze Age	Summarizes the debate according to ethnography and anthropology; advocates for more pastoral archaeology and is critical of those who disregard the evidence of transhumance
Chang & Koster (1986)	Transhumance (specialized pastoralism) likely arose out of agro-pastoralism	Each context requires more evidence; currently there is limited archaeology of pastoralism. Researchers need to go "beyond the bones" to consider social interactions and landscape
Chang & Tourtellotte (1993)	Transhumance in pre-modern times	Request more "pastoral archaeology" but use ethnoarchaeological case study from sites of Macedonia Grevena (Pindos Mountains) in Greece as an example (modern ethnography with archaeological data)
Chaniotis (1995)	Some specialized pastoralism, mostly agropastoralism (arable cultivation and small-scale animal husbandry) until Hellenistic and Roman times	[Crete-specific] Focuses on animals predominantly for their meat; large herd sizes were not required for meat-supplying animals; wool-products were only for the household (prior to the Roman period) so farm-raised animals in small quantity were required; evidence from Hellenistic treaties suggests transhumance was practised (but not everywhere)
Chaniotis (1999)	Some specialized pastoralism is plausible but only under a specific context, and only in certain areas [Crete specific]	Specialized pastoralism requires upland pasture (most did not) and crossing extensive boundaries; would have caused too much conflict. The Hellenistic period could have had some specialized pastoralism (evidence in Crete based on literature, wool/leather tools), but it relied on specific demographic and sociopolitical conditions
Cherry (1988)	Selective, yes and no; modern transhumance originated in the Medieval period	Evidence is "patchy" either way; likely only occurred during the Mycenaean era, then it reverts back to agropastoralism; animals eaten when there was need
Forbes (1994)	Rural farmsteads used pastoralism; seasonal grazing likely	Advocates for ethnographic models, especially when considering rural sites and pastoralism. Focus is on rural sites.

Author	Position	Summary of Reasoning and/or Evidence
Forbes (1995)	Both were likely between Archaic and Roman; transhumance was occasional	Focus is on larger estates and pastoralism between Archaic and Roman period. First to really advocate for transhumance *and* agropastoralism. We cannot have pastoralism without some form of cultivation.
Forbes (1998)	Both were required in temperate areas	Ethnographic approach; fodder provisioning required that agropastoralism and transhumance were conducted simultaneously.
Forbes (2007)	Transhumance probable in the Peloponnese (around Methana)	Analyzed population mobility around Methana, including large groups and families. Many sites were seasonally occupied, supporting claims of transhumance.
Hadjigeorgeiou (2011)	No transhumance in Classical Period	It required well-developed lowland agriculture, high demand for pastoral products, and a politically unified territory
Halstead (1981)	Agropastoralism in Neolithic and Early Bronze Age; Transhumance only occurred with surplus (winter fodder)	Provides estimates for wool-based economy and suggests that wool requirement was there; however herds would have needed to be huge, which is not evidenced by the osteology or available pasture. Argues flax use as predominant resource for textiles
Halstead (1984)	Agropastoralism only	Pollen studies do not support evidence of deforestation; upland grazing and transhumant pastoralism-required deforestation did not happen until more recent history
Halstead (1987a)	Agropastoralism in most areas; areas with larger herds have pasture to support them	Mortality profile supports animals for mostly meat, with milk and meat production likely. Little *accessible* grazing in forested areas limits herd sizes during the Bronze Age and Early Iron Age
Halstead (1987b)	Transhumance not likely until more recent times	(1) Mountain pasture is not natural and would have required serious deforestation, which did not occur until more recently; (2) lowland grazing would have required deforestation or agricultural clearance, cutting necessary farming and subsistence growth; (3) social markets were not sufficient for byproducts economies until more recent times; (4) palynological data does not support (1) or (2).
Halstead (1996)	Small-scale, mixed farming (agropastoralism)	Debates large-scale pastoralism and small-scale mixed farming according to (1) scale: faunal remains ultimately match small-scale, mixed farmers raised for meat; (2) available nutrition: landscape does not support pasturage for larger herds; and (3) production and social.
Halstead (2006)	Small-scale farming with "garden animals" kept locally	Animals were required to be managed nearby for manuring to maintain soil fertility, sufficient fodderage, and agricultural economy
Hodkinson (1988)	Agropastoralism, but open to the concept of a specialized mix	Evidence of mountain huts, shrines, and sheep shears do not equate to transhumance; there is not sufficient evidence; pastoralism was too economically risky.
Howe (2003)	Specialized pastoralism thrived if all conditions were met (p.132)	(1) environment must have winter and summer pastures; (2) society's elite must be involved for pastoral production; and (3) there needs to be a ready market
Howe (2008)	Specialized pastoralism and agropastoralism	Increasing pastoral politics, notions of wealth, and rising political and economic cultures during the Classical-Hellenistic

Author	**Position**	**Summary of Reasoning and/or Evidence**
Howe (2011)	Specialized pastoralism and agropastoralism	Social, environmental, and economic variables changed and facilitated transhumance and agropastoralism concurrently
Howe (2014)	Specialized pastoralism and agropastoralism	Value economics promoted investment of goods (e.g. larger flocks), marketable byproducts, and notions of surplus (images of wealth)
McHugh (2017)	Transhumance was important aspect of agricultural economy	By-products facilitated trade along routes and manure could support agricultural endeavours; large-scale transhumance was a fully realised economic activity located away from settlements (p.22)
Papanastasis *et al.* (2010)	Agropastoralism and transhumance likely co-occurring	Examines environmental conservation in ancient Greece to examine whether flocks had sufficient pasturage to support transhumance. Ultimately, the natural environment was transformed but not destroyed.
Sherratt (1981)	Transhumance in prehistoric times	Long distance seasonal transhumance arose from the advent of the "Secondary Products Revolution", when animals were important for more than just their meat and herd sizes had to be larger
Skydsgaard (1988)	Transhumance likely	Questions use of terminology and suggests that multiple forms of pastoralism were likely in antiquity

Appendix 3.2 General Chronology for Greece (Adapted from Bintliff 2012, p.6)

Period	Start	End
Palaeolithic	ca. 300,000-40,000 year BP	9,000 BCE
Epipalaeolithic/Mesolithic	ca. 9,000 BCE	7,000 BCE
Neolithic	ca. 7,000 BCE	3,500/3,200 BCE
Early Bronze Age	ca. 3,500/3,200 BCE	ca. 2,100/1,900 BCE
Middle Bronze Age	ca. 2,100/1,900 BCE	1,700 BCE
Late Bronze Age	ca. 1,700 BCE	ca. 1,200/1,100 BCE
“Dark Age”/Early Iron Age	ca. 1,200/1,100 BCE	ca. 800/700 BCE
Archaic Era	ca. 700 BCE	ca. 480 BCE
Classical Era	ca. 480 BCE	323 BCE
Early Hellenistic Period	323 BCE	ca. 200 BCE
Late Hellenistic Period	ca. 200 BCE	30 BCE
Early Roman Era	30 BCE	200 CE
Middle to Late Roman Period	ca. 200 CE	ca. 650 CE
“Dark Age”/Early Byzantine Era	ca. 650 CE	842 CE
Middle Byzantine Period	842 CE	1204 CE
Late Byzantine/Frankish-Crusader Era	1204 CE	ca. 1400 CE
Ottoman Period	ca. 1400 CE	1830 CE
Early Modern Era	1830 CE	1950 CE
Modern Era	1950 CE	present

Appendix 3.3 Archaeobotanical remains recovered from Thessalian sites (adapted from Megaloudi, 2006)

PLANT		A	B		C	D				E	
Common Name	**Species**	**MN**	**EN**	**MBA**	**EN**	**MN**	**L/FN**	**EBA**	**MBA**	**L/FN**	**LBA**
Barley	*Hordeum vulgare*		X	X	17	5	6	844		X	
	Hordeum vulgare nudum		X							100	
	Hordeum sp.	2			12			5			
Broomcorn Millet	*Panicum miliaceum*		X								
Emmer Wheat	*Triticum dicoccum*	9		X	826	1	5	161		97	
Einkorn Wheat	*Triticum monococcum*	7		X	285	13	9			X	
Wheat	*Triticum dic./mono.*							19			
	Triticum sp.							5			
Chickpea	*Cicer arietinum*									32	
Wild pea	*Lathyrus ccicera*									8	
Legume	*Lathyrus sativus*			X	200					80	
	Lathyrus sp.						1				
	Leguminosae									32	
Lentil	*Lens culinaris*			X	13	1	1			123	
Pea	*Pisum sativum*									82	
	Pisum sp.	2			281						
Bitter Vetch	*Vicia ervilia*			X		1300	793	421		13	
Broad Bean	*Vicia faba*			X						X	
Wild Flax	*Camelina sativa*			X							
Flax	*Linum usitatissimum*			X							
Almond	*Amygdalus communis*									18	
Common Fig	*Ficus Carica*			X							
Dogwood Cherry	*Cornus mas*				14						
Apple	*Malus sp.*	1									
Olive	*Olea sp.*									X	
Pistachio	*Pistacio sp.*	2									
Oak	*Quercus*	29	X	X	47				58		6
Grape	*Vitis sylvestris*									X	
	Vitis vinifera			X							

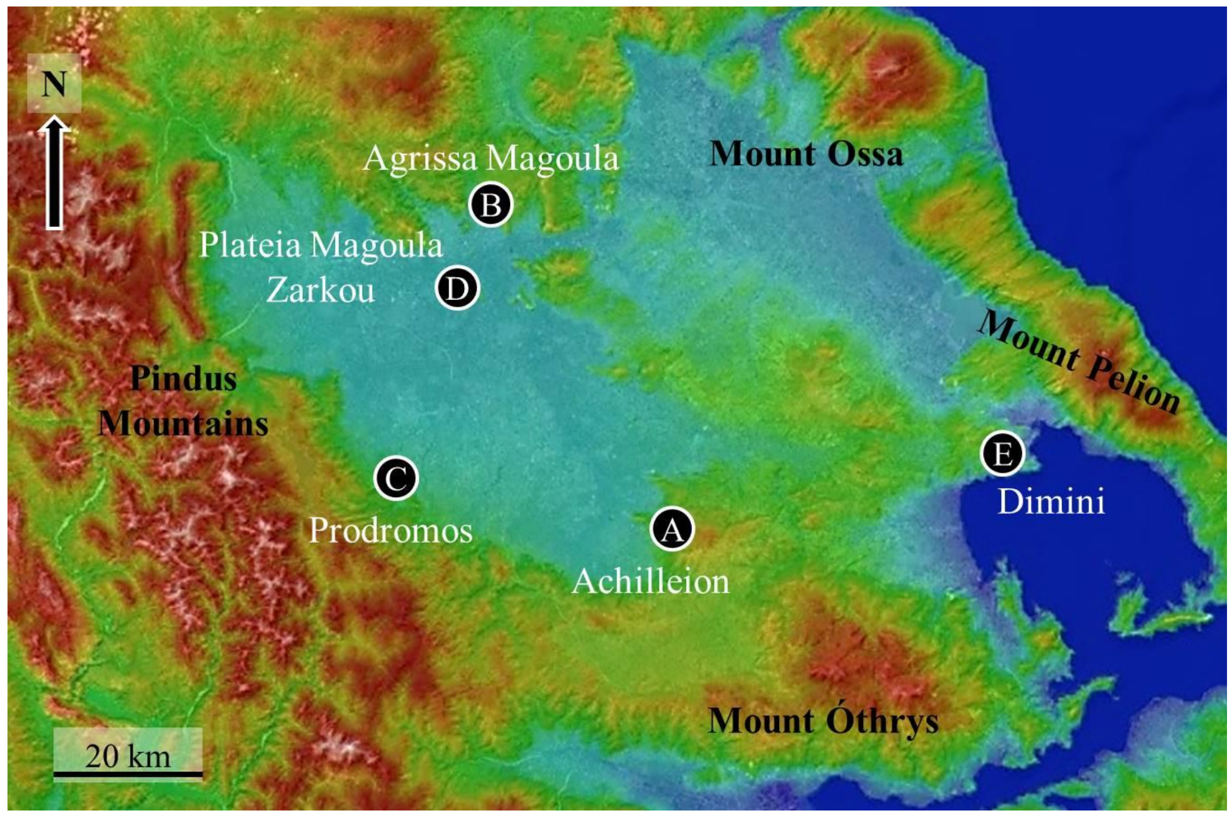
PLANT		A	B		C	D				E	
Common Name	**Species**	**MN**	**EN**	**MBA**	**EN**	**MN**	**L/FN**	**EBA**	**MBA**	**L/FN**	**LBA**
Oats	*Avena sp.*	6		X			1	15			
Goosefoot	*Chenopodium sp.*			X							
False Cleavers	*Galium spurium*			X							
Corn Gromwell	*Lithospermum arvense*	1595									
Rygrass / Cockle	*Lolium temulentum*					1					
Mallow	*Malva sylvestris*			X							
Fieldmadder	*Sheradia arvensis*			X							

LEGEND:
(A) Achilleion
(B) Agrissa Magoula
(C) Prodromos
(D) Platia Magoula Zarkou
(E) Dimini

EN: Early Neolithic
MN: Middle Neolithic
L/F N: Late/Final Neolithic
EBA: Early Bronze Age
MBA: Middle Bronze Age
LBA: Late Bronze Age

X indicates that it was present; numbers indicate the prevalence (if available)

Approximate site locations discussed in Appendix 3.2 are illustrated in the figure of Thessaly on the right. ESRI Images (2020)



Appendix 6.4 Building 10 samples removed for analysis.

Sample ID	Bag ID	Unit	Context (layer, spit)	Taxa	Element(s)	Isotopically Analyzed
R01	388-1	4, Pithos 1	L3, S1	Mouse	Multiple teeth	Y
R02	416-2	L2, Pithos 2	L1, S3	Mouse	Multiple teeth	Y
R03	404-6	L2, Pithos 1	L2, S1	Mouse	Multiple teeth	Y
R04	163-33	A2	L4, S1	Rat	Maxillary incisor	Y
R05	205-2	C2A	L2, S2	Shrew	Mandibular molar	Y
R06	117-19	A2	L3, S3	Mouse	Maxillary incisor	Y
SG01	418	F2	L2, S5	Goat	LM^3	N
SG02	303-8	I1/I1B	L3, S1	Sheep	Associated RM_2/RM_3	N
SG03	303-9	I1/I1B	L3, S1	Sheep	Associated LM_2/M_3	Y
SG04	364	I2	L3, S1	Sheep	LM^3	N
SG05	356	K1	L3, S1	Goat	LM_3	N
SG06	356-5	K1	L3, S1	Sheep	Mandible with LM_2/LM_3	Y
SG07	375-4	K1	L4, S1	Goat	Mandible with RM_1/RM_2	N
SG08	204-11	B1	L3, S3	Goat	RM_3	Y
SG09	400-1	K2	L4, S1	S/G	LM^3	N
SG10	400-2	K2	L4, S1	S/G	LM^3	N
SG11	440-5	K2, Feature α	L1, S1	Sheep	Mandible with LM_1-LM_3	Y
SG12	440-7	K2, Feature α	L1, S1	Sheep	Mandible with LP_3-LM_3	Y
SG13	104	B2	L3, S1	Goat	Mandible with Lp_3-LM_1	N
SG14	82	Rm. 2	L5, S4	S/G	LM^3	N
SG15	203-15	B1, Feature α	N/A	Goat	R M^3	N
SG16	87	E4	L2, S2	Goat	RM_3	Y
SG17	112-7	E3	L2, S3	Sheep	Mandible with RP_4-RM_3	N
SG18	261	I1B	L2, S2	Sheep	LM_3	N
SG19	51	1	L5, S1	Goat	LM_3	N
SG20	191-12	G4	L1, S2	Goat	RM_3	N
SG21	197-3	E2	L3, S2	Sheep	LM_3	Y
SG22a/b	283-1	I2	L2, S2	Sheep	R&L Mandible with P_3-M_3	N
SG23	440-7	K2, Feature α	L1, S1	Goat	Mandible with RP_3-RM_3	Y
SG24a/b	112-12	E3	L2, S3	Sheep	$LM_2$and RM_1	N
SG25	110-27	C2	L4, S1	Sheep	R M^3	N
SG26	176-63	B1	L3, S1	S/G	LM^2	N
SG27a/b	188-6	G2	L1, S2	S/G	LM^2 and RM^2	N
SG28a	57-29	C2	L2, S1	Sheep	LM^3	N
SG28b	57-29	C2	L2, S1	Sheep	RM^3	N
SG29	78-29	C2	L2, S2	Sheep	RM^3	N

Appendix 6.5 Arsenopoulos Plot samples removed for analysis.

Sample ID	Bag ID	Unit	Context (strata, level)	Taxa	Element(s)	Isotopically Analyzed
R07	391	Z	#143, 2β	Hare	Mandible	Y
R08	257	Γ2	#093, 2	Shrew	Loose incisor	Y
SG38	284	B, special	#090, 2α	Sheep	RM_3	Y
SG39	340	D	#130, 3α	Goat	LM_3	Y
SG40	340	D	#130, 3α	Sheep	RM_3	Y
SG41	814	E3-E4	#223	Sheep	Mandible with RP_3-RM_3	N
SG42	462	Θ	#161, 3β	Sheep	RM_3	Y
SG43	700	Γ3-Γ4	#193	Sheep	Mandible with RP_4-RM_3	N
SG44	531	B3	#168, 1α	Sheep	Mandible with LP_3-LM_3	N
SG45	520	Γ3/Δ3-Γ3/Γ4 Γ4/Δ4-Δ4/Δ4	#172, 1	Sheep	Mandible with RM_3	N
SG46	693	Z4	#188	Sheep	Mandible with RM_2-RM_3	N
SG47	226	B1-Γ1	#081, 1	Sheep	Mandible with LP_3-LM_3	N
SG48	233	B2-Γ2	#083, 1	Sheep	Mandible with RP_3-RM_3	N
SG49	207	B2-Γ2	#076, 1	Sheep	Mandible with LP_4-LM_3	N
SG50	360	B2-Γ2	#134, 1α	Sheep	Mandible with LP_2-LM_3	N
SG51	9	Γ2	#005, 1	Sheep	RM_3	N
SG52	306	B2	#111, 1	Sheep	RM_3	N
SG53	186	Γ1-Γ2	#069, 2α	Sheep	RM_3	N
SG54	99	Γ4	#031, 4	Sheep	LM_3	N
SG55	142	B3	#055, 2	S/G	LM^3	N
SG56	105	E3	#034, 1	Sheep	Mandible with RM_1-RM_3	N
SG57	244	B1-Γ1	#088, 1α	Sheep	Mandible with RP_3-RM_3	N
SG58	127	B3	#046, 1β	Sheep	Mandible with LM_2-LM_3	N
SG59	239	B1-Γ1	#086, 1α	Goat	Mandible with RP_3-RM_3	N
SG60	370	Bτ	#137, 2α	S/G	Mandible with LM_1	N
SG61	81	Δ4, north	#030, 2	Sheep	Mandible with LP_2-LM_3	N
SG62	117	B3	#041, 1α	Sheep	RM_3	N
SG63	4	Γ2	#001, 1	Sheep	RM_3	N
SG64	134	Γ2, east	#051, 1β	Sheep	Mandible with LM_3	N
SG65	180	Γ1-Γ2	#066, 1	Sheep	RM_3	N
SG66	303	Δ1	#161, 2	Goat	RM_3	N
SG67	462	Θ, south	#161, 2β	Sheep	RM_3	N
SG68	462	Θ, south	#161, 2β	Sheep	LM_3	N

Appendix 6.6 Alexopoulos Plot samples removed for analysis.

Sample ID	Bag#	Unit	Context (strata, level)	Taxa	Element(s)	Isotopically Analyzed
SG30	242	B1: ■ 9-11	#155, 3	Sheep	Mandible with LM_1-LM_3	Y
SG31	263	E1	#162, 2α	S/G	Mandible with Lp_3-Lm_1	N
SG32	133a	Δ	#098, 2α	Sheep	RM_3	N
SG33	198	A2-B2	#134, 2	Sheep	LM_3	Y
SG34	107	Φ1-Γ2, west	#089, 2	Goat	LM_2	N
SG35	265	Γ	#163, 3	Sheep	Mandible with RP_3-RM_2	N
SG36	244	Γ, west	#156, 3α	Sheep	Mandible with RM_2-RM_3	N
SG37	67	A3, west	#054, 2α	Sheep	Mandible with LM_1-LM_3	N

Appendix 6.7 Carbon and oxygen isotope values recorded from sequentially sampled mandibular molar (M_3) enamel of SG12 according to treatment type. The difference (Δ) is recorded for $\delta^{13}C_{no\text{-}treatment\text{-}chemical}$ and $\delta^{18}O_{no\text{-}treatment\text{-}chemical}$

Project Sample	Sample ID	mm from CRJ	Treatment Type	$\delta^{13}C$ (‰ VPDB)	Avg $\delta^{13}C$	ΔC	$\delta^{18}O$ (‰ VPDB)	Avg $\delta^{18}O$	ΔO
S170	P-1	20	Abrade	-9.44	-9.32	-0.94	-3.36	-3.65	2.29
	P-1 rep			-9.21			-3.93		
S171	P-2		Chemical	-10.29	-10.27		-1.46	-1.36	
	P-2 rep			-10.25			-1.26		
S172	P-3	18.5	Abrade	-9.28	-9.11	-0.94	-3.60	-3.63	1.50
	P-3 rep			-8.94			-3.67		
S173	P-4		Chemical	-10.29	-10.06		-2.33	-2.13	
	P-4 rep			-9.82			-1.94		
S174	P-5	17	Abrade	-9.39	-9.32	-1.29	-4.24	-4.46	2.13
	P-5 rep			-9.25			-4.69		
S175	P-6		Chemical	-10.34	-10.61		-2.40	-2.33	
	P-6 rep			-10.88			-2.27		
S176	P-7	15.5	Abrade	-9.52	-9.16	-1.00	-5.03	-4.71	2.37
	P-7 rep			-8.91			-5.04		
	P-7 rep			-9.05			-4.06		
S177	P-8		Chemical	-10.36	-10.16		-2.31	-2.33	
	P-8 rep			-9.95			-2.36		
S178	P-9	14	Abrade	-9.66	-9.63	-0.99	-5.18	-5.13	2.48
	P-9 rep			-9.28			-5.03		
	P-9 rep			-9.95			-5.19		
S179	P-10		Chemical	-10.61	-10.62		-2.59	-2.66	
	P-10 rep			-10.87			-2.79		
	P-10 rep			-10.38			-2.59		
S180	P-11	12.5	Abrade	-10.27	-10.09	-0.67	-4.77	-5.04	1.79
	P-11 rep			-10.10			-4.59		
	P-11 rep			-9.93			-6.06		
	P-11 rep			-10.07			-4.73		
S181	P-12		Chemical	-10.52	-10.76		-3.10	-3.25	
	P-12 rep			-11.00			-3.39		
S182	P-13	11	Abrade	-10.70	-10.18	-1.15	-4.99	-5.49	1.71
	P-13 rep			-9.97			-5.47		
	P-13 rep			-9.88			-6.01		
S183	P-14		Chemical	-11.28	-11.33		-3.66	-3.78	

Project Sample	Sample ID	mm from CRJ	Treatment Type	$\delta^{13}C$ (‰ VPDB)	Avg $\delta^{13}C$	ΔC	$\delta^{18}O$ (‰ VPDB)	Avg $\delta^{18}O$	ΔO
	P-14 rep			-11.27			-3.74		
	P-14 rep			-11.44			-3.94		
S184	P-15	9.5	Abrade	-10.17	-10.39	-1.4	-6.35	-6.26	1.9
	P-15 rep			-10.57			-6.22		
	P-15 rep			-10.42			-6.22		
S185	P-16		Chemical	-11.50	-11.76		-4.05	-4.34	
	P-16 rep			-12.02			-4.64		
S186	P-17	8.0	Abrade	-10.41	-10.76	-1.6	-6.38	-6.24	1.6
	P-17 rep			-11.11			-6.11		
S187	P-18		Chemical	-12.43	-12.35		-4.44	-4.61	
	P-18 rep			-12.29			-4.76		
	P-18 rep			-12.32			-4.64		
S188	P-19	6.5	Abrade	-10.49	-11.38	-1.3	-5.41	-5.97	1.3
	P-19 rep			-11.89			-6.29		
	P-19 rep			-11.76			-6.20		
S189	P-20		Chemical	-12.72	-12.66		-4.49	-4.71	
	P-20 rep			-12.61			-4.94		
S190	P-21	5.0	Abrade	-11.33	-11.07	-0.6	-6.25	-6.22	1.0
	P-21 rep			-10.82			-6.19		
S191	P-22		Chemical	-11.66	-11.70		-5.16	-5.20	
	P-22 rep			-11.75			-5.23		
S192	P-23	3.5	Abrade	-10.09	-10.50	-1.6	-5.51	-5.92	1.9
	P-23 rep			-10.33			-6.60		
	P-23 rep			-11.09			-5.64		
S193	P-24		Chemical	-12.16	-12.08		-4.20	-4.04	
	P-24 rep			-12.00			-3.89		
S194	P-25	2.0	Abrade	-10.27	-10.75	-0.9	-5.35	-5.43	0.8
	P-25 rep			-11.23			-5.50		
S195	P-26		Chemical	-11.24	-11.61		-4.00	-4.62	
	P-26 rep			-12.05			-4.90		
	P-26 rep			-11.84			-4.64		
	P-26 rep			-11.64			-4.60		
	P-26 rep			-11.29			-4.98		
S196	P-27	0.5	Abrade	-10.76	-10.67	-0.8	-4.54	-4.86	2.2
	P-27 rep			-10.57			-5.18		
S197	P-28		Chemical	-11.49	-11.49		-2.65	-2.65	

Appendix 7.8 Calculated $^{87}Sr/^{86}Sr$ ranges based on samples in Thessaly. Lower to upper limit (mean +/- 2 SD) ranges coordinate with Figure 7.43.

Area	Sample	Sr Value	Reference
Anavra	L1	0.708400	This study
	L3	0.708385	
	L5	0.708407	
	L7	0.708466	
	L9	0.708149	
	Mean	0.708361	
	SD	0.000123	
	Upper Limit	0.708606719	
	Lower Limit	0.708116081	
Kastro Kallithea	R1	0.708664	This study
	R2	0.708702	
	R3	0.708771	
	R4	0.708367	
	R5	0.708421	
	R6	0.708868	
	Mean	0.708632167	
	sd	0.000197832	
	Upper Limit	0.70902783	
	Lower Limit	0.708236503	
Pharsalos	R07	0.708676	This study
	R08	0.708526	
	FS03s	0.7084	Panagiotopoulou et al. (2018)
	FS04s	0.7082	
	FS11s	0.7088	
	Mean	0.7085204	This Study
	sd	0.000234292	
	Upper Limit	0.708988984	
	Lower Limit	0.708051816	
Halos: Area 1	HL01s	0.7078	Panagiotopoulou *et al.* (2018)
	HL04s	0.7080	
	Mean	0.7079	This Study
	sd	0.000141421	
	Upper Limit	0.708182843	
	Lower Limit	0.707617157	
Halos: Area 2	HL14s	0.7088	Panagiotopoulou *et al.* (2018)
	HL18s	0.7089	
	Mean	0.70885	This Study
	sd	0.00007107	
	Upper Limit	0.708991421	
	Lower Limit	0.708708579	
Chloe: Area 1	CH03s	0.7088	Panagiotopoulou *et al.* (2018)
	CH09s	0.7089	
	Mean	0.70885	This Study
	sd	7.07107E-05	
	Upper Limit	0.708991421	
	Lower Limit	0.708708579	

Appendix 7.9 Known and measured $\delta^{13}C$ and $\delta^{18}O$ values for NBS-19 recorded at the Stable Isotope Laboratory (SIL) concurrently with samples included in the current study. Measurement accuracy is recorded to two standard deviations (2SD).

SIL Run ID	Standard ID	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)
3040	NBS-19	1.94	-2.16
3041	NBS-19	1.97	-2.19
3514	NBS-19	1.96	-2.17
3526	NBS-19	1.96	-2.22
3556	NBS-19	1.96	-2.18
3572	NBS-19	1.93	-2.21
3708	NBS-19	1.89	-2.22
3887	NBS-19	1.97	-2.18
3917	NBS-19	1.96	-2.19
3926	NBS-19	1.91	-2.22
3981	NBS-19	1.96	-2.08
4076	NBS-19	1.95	-2.21
4077	NBS-19	1.95	-2.17
4114	NBS-19	2.00	-2.17
4150	NBS-19	1.98	-2.15
4207	NBS-19	1.93	-2.22
4219	NBS-19	1.95	-2.29
4230	NBS-19	1.96	-2.24
5293	NBS 19	1.93	-2.21
5294	NBS 19	1.96	-2.13
5295	NBS 19	1.94	-2.24
5305	NBS 19	1.91	-2.17
5316	NBS 19	1.99	-2.10
5317	NBS 19	1.97	-2.14
5330	NBS 19	1.95	-2.10
5362	NBS 19	1.93	-2.21
5373	NBS-19	1.97	-2.22
5373	NBS-19	1.97	-2.22
5423	NBS-19	1.95	-2.15
5458	NBS-19	1.96	-2.14
5472	NBS 19	1.96	-2.27
5534	NBS 19	2.00	-2.28
	Average	**1.95**	**-2.19**
	Accepted	**1.95**	**-2.20**
	2SD	0.05	0.10

Appendix 7.10 Known and measured $^{87}Sr/^{86}Sr$ ratios for SRM 987 recorded at the Stable Isotope Laboratory concurrently with samples included in the current study. Measurement accuracy is recorded to two standard deviations (2SD).

Sample	$^{87}Sr/^{86}Sr$	2se
SRM 987	0.710272	0.000008
SRM 987	0.710291	0.000008
SRM 987	0.710259	0.000008
SRM 987	0.710282	0.000003
SRM 987	0.710295	0.000004
SRM 987	0.710269	0.000003
SRM 987	0.710255	0.000004
SRM 987	0.710260	0.000003
Average	**0.710273**	
Accepted	**0.71024**	
2SD	0.000030	

Appendix 8.11 Summary of standard deviations from isotope studies discussed in text

Study	Animal(s)	Sample Strategy	Standard Deviation ($^{87}Sr/^{86}Sr$)	
			Highest Value for Sedentary Animals	**Lowest Value for Mobile Animals**
Arnold *et al.,* 2016	Donkey, Sheep, Goat	n=6, M_1-M_3, sequential	0.000124	N/A
Balasse *et al.,* 2002	Sheep, Cattle	n=3, M_2-M_3, sequential	0.000084	0.001212
Bogaard *et al.,* 2014	Sheep	n=7, M_2, top/mid/bottom	0.000118	N/A
Britton *et al.,* 2009	Caribou	n=5, M_2-M_3, sequential	0.000079	0.000232
Britton *et al.*, 2011	Bison, Caribou	n=4, M_2-M_3, sequential	N/A	0.000153
Chase *et al.,* 2014	Bovine, Caprine	n=39, molars, sequential	0.000100	0.000208
Chase *et al.*, 2020	Bovine, Caprine	n=151, molars, sequential	0.000096	0.000142
Chazin *et al.,* 2019	Sheep, Goat, Cattle	n=35, M_2, top/mid/bottom	0.000108	0.000159
Copeland *et al.*, 2016	Wild antelope sp.	n=42, molars, sequential	0.000059	0.000196
Evans *et al.*, 2019	Cattle	n=64, molars, sequential	0.000099	0.000134
Isaakidou *et al.* 2019[72]	Sheep, Goat	n=9, M_2-M_3, top/mid/bottom	0.000047	0.000117
Meiggs *et al.*, 2018	Sheep, Goat, Equid	n=18, PM_3, M_2-M_3, sequential	0.000113	N/A
Trentacoste *et al.,* 2020	Sheep, Goat	n=12, M_2, top/mid/bottom	0.000054	0.000106
Valenzuela-Lamas *et al.,* 2016	Sheep	n=7, M_3, top/mid/bottom	0.000093	0.000101
Valenzuela-Lamas *et al.,* 2018	Sheep, Goat	n=17, M_2, M_3, top/mid/bottom	0.000093	0.000101
Viner *et al.*, 2010	Cattle	n=15, M_2-M_3, sequential	0.000107	0.000104

[72] Materials from a similar context as mine (i.e. Crete)

Appendix 8.12 Summary of stable isotope signature patterns by proposed explanation and study

Analyzed	Pattern	Proposed Explanation	Study
Sequential Stable Carbon Isotopes	Sinusoidal	Seasonal (same as oxygen)	Balasse *et al.* (2002, 2017); Isaakidou *et al.* (2019); Mainland *et al.* (2016); Vaiglova *et al.* (2018); Valenzuela-Lamas *et al.* (2016)
		Inverse Seasonal: fodder or grazing source, climatic, context-specific	Bocherens *et al.* (2001); Chase *et al.* (2014); Chazin *et al.* (2019); Isaakidou *et al.* (2019); Makarewicz & Pederzani (2017); Makarewicz *et al.* (2017); Tornero *et al.* (2016b, 2018)
	Flat, Limited variation	Seaweed	Balasse *et al.* (2009)
		Wild Animal	Balasse *et al.* (2017)
		Crop/browse feeding only	Chase *et al.* (2014); Isaakidou *et al.* (2019); Vaiglova *et al.* (2020)
		Canopy Effect	Balasse *et al.* (2012a, 2013)
	Major Short-Term Changes	Foddering strategy with seasonal availability	Balasse *et al.* (2003); Bocherens *et al.* (2001); Chase *et al.* (2014); Makarewicz & Pederzani (2017)
		Altitudinal changes in food	Isaakidou *et al.* (2019); Janzen *et al.* (2020); Vaiglova *et al.* (2020)
		Varying C_3 & C_4 plants	Chakraborty *et al.* (2018); Chase *et al.* (2014); Janzen *et al.* (2020)
	Variable	Foddering: summer crops	Balasse *et al.* (2013); Mainland *et al.* (2016); Trentacoste *et al*. (2020)
Sequential Stable Oxygen Isotopes	Sinusoidal	Seasonal humidity	Sample: Balasse (2003); Balasse and Tresset (2007); Balasse *et al.* (2002, 2003, 2009, 2017); Blaise and Balasse (2011); Britton *et al.* (2009); Chazin *et al.* (2018); Makarewicz *et al.* (2017)
	Exaggerated	Extreme weather (precip.)	Chase *et al.* (2014)
		Leaf consumption	Makarewicz *et al.* (2017)
	Flat, Limited Variation ('dampening')	Wells, large lakes, or artesian sources	Balasse (2003); Balasse *et al.* (2002); Bocherens *et al.* (2001); Chazin *et al.*, (2019); Janzen *et al.* (2020)
		Transhumance movement	Isaakidou *et al.* (2019); Tornero *et al.* (2016b, 2018); Vaiglova *et al.* (2020)
		Canopy effect/foddering	Balasse *et al.* (2012a); Marciniak *et al.* (2017)
		Physiology or metabolism	Britton *et al.* (2009)
		Reservoir effect	Balasse *et al.* (2009); Chazin *et al.* (2019)
	Varied	Changes in source	Balasse (2003); Balasse *et al.* (2002, 2009); Bocherens *et al.* (2001); Makarewicz *et al.* (2017); Valenzuela-Lamas *et al.* (2016)