Table of Contents

ABSTRACT 2

TABLE OF CONTENTS 3

LIST OF FIGURES 11

LIST OF TABLES 14

AKNOWLEDGEMENTS 17

FRONTISPIECE 18

CHAPTER 1 – INTRODUCTION 19

1.1: The nature of the Archaeological Problem 19

1.2: Aims and Objectives 20

1.3: The Structure of the Thesis 22

CHAPTER 2 – DEFINITIONS AND THE THEORETICAL FRAMEWORK 25

2.1: "Taphonomy" Defined 25

2.2: The concept of Analytic Absence 26

2.3: Establishing a Theoretical Framework for Taphonomic Analysis 27

CHAPTER 3 – DESTRUCTIVE PROCESSES AND THEIR MEDIATING FACTORS 33

3.1: The Structure of Mammal Bone 33

3.2: "Bone Density" Defined 36

3.3: The Primary Taphonomic Processes 37

3.3.1: Weathering 37

3.3.2: Gnawing and digestion 40

3.3.2.1: *Bone dispersal by gnawing* 40

3.3.2.2: *Bone destruction by gnawing* 41

3.2.2.3: *Bone destruction by digestion* 43

3.2.2.4: *The destructive effects of ungulate and rodent gnawing* 43

3.3.3: Trampling 45
3.3.4: Butchery 46
3.3.5: Heating 48
3.4: The Primary Diagenetic Processes 51
3.4.1: Collagen loss 52
3.4.2: Mineral loss 55
3.4.3: Histological destruction 56
3.4.4: Actualistic diagenetic observations 57
3.4.5: Identifying and accounting for diagenesis 59
3.5: Summary 62

CHAPTER 4 – THE STRENGTH OF BONE 64
4.1: Bone Biomechanics 64
4.1.1: Porosity 65
4.1.2: Mineralisation 67
4.2.3: Density 70
4.2.4: Bone histology 72
4.2.5: Collagen orientation 73
4.2.6: Direction and nature of the load 74
4.3: Summary 77

CHAPTER 5 – FACTORS AFFECTING BONE DENSITY 79
5.1: Introduction 79
5.2: The Impact of Each Factor on Bone Density 80
5.2.1: Skeletal location 80
5.2.2: Age 80
5.2.3: Disease 83
5.2.4: Physical exercise 85
5.2.5: Sex 86
5.2.6: Nutrition 87
5.2.7: Heredity and breed 89
5.3: Summary 90

CHAPTER 6 – THE MEASUREMENT OF BONE DENSITY 92
6.1: Introduction 92
6.2: The Methodologies of Previous Investigations 92
6.2.1: Brain 1969 92
6.2.2: Behrensmeyer 1975 94
6.2.3: Boaz and Behrensmeyer 1976 95
6.2.4: Binford and Bertram 1977 96
6.2.5: Lyman 1984 97
6.2.6: Lyman Houghton and Chambers 1992 101
6.2.7: Kreutzer 1992 101
6.2.8: Butler and Chatter 1994 103
6.2.9: Elkin 1995 104
6.2.10: Willey, Galloway and Snyder 1997 105
6.2.11: Lam, Chen and Pearson 1999 106
6.2.12: Pavao and Stahl 1999 107
6.2.13: Stahl 1999 108
6.2.14: Ioannidou 1999 110
6.2.15: Dirrigl 2001 110
6.3: The Available Measurement Techniques 111
6.3.1: Radiogrammetry 112
6.3.2: Photodensitometry 112
6.3.3: Single photon absorptiometry 113
6.3.4: Dual photon absorptiometry 114
6.3.5: Dual X-ray absorptiometry (DEXA) 114
6.3.6: Quantitative computed tomography (QCT) 115
6.3.7: Low angle X-ray scattering (LAXS) 116
6.3.8: Direct density measurement 116
6.4: Summary and Experimental Design 118
6.4.1: Sample size 118
6.4.2: Taxon choice 118
6.4.3: Element selection 119
6.4.4: Scan-site selection 119
6.4.5: Material source 120
6.4.6: Measurement method 120

CHAPTER 7 – MATERIALS AND METHODS 122
7.1: Materials 122
7.1.1: Taxon choice 122
7.1.2: Element selection 123
7.1.3: Scan-site selection 124
7.1.4: Material source 127
7.2: Material Attributes 128
7.2.1: Breed 129
7.2.2: Sex 129
7.2.3: Preparation method 130
7.2.4: Age 131
7.2.5: Month of death 131
7.2.6: Material distribution and analytical method 132
7.3: Methods 134
7.3.1: Location of scan sites 137
7.3.2: Taking the density measurements 137
7.3.3: Measuring bone thickness 139
7.3.4: Summary (materials) 142
7.3.5: Summary (methods) 142
7.4: Methodological Tests 142
7.4.1: The representativeness of the results 142
7.4.2: Repeatability of the method: intra-observer error 146
7.4.3: The effects of organic material on the radiographically derived density 153
7.4.4: Image magnification 156
7.4.5: Artificially density inflation at the film periphery 158
7.4.6: The representativeness of the scan-sites 161

CHAPTER 8 – RESULTS AND DISCUSSION 164
8.1: Bone Density and Bone Survival: A Note on the Aims of this Chapter 164
8.2: Bone Density Variation with Age: Examining the Experimental Material as a Whole 165
8.2.1: Graphically assessing the bone density of non-identical animals 165
8.2.1.1: *Scatter plots* 165

8.2.1.2: *Line graphs* 166
8.2.2: The nature of the data and the two types of variation 168
8.2.3: General trends: results and discussion 169
8.2.4: Erratic variation: results and discussion 170
8.2.5: Understanding erratic variation 170
8.3: Research Methods, Definitions and Presentation of Results 171
8.3.1: Research methods and "Background Variation" 171
8.3.2: Presentation of the results 172
8.4: The Impact of Background Variation on Bone Density 175
8.4.1: Materials 175
8.4.2: Results 176
8.4.3: Discussion 180
8.4.4: Summary 182
8.5: The Impact of Variation in Preparation Method on Bone Density 182
8.5.1: Materials 183
8.5.2: Results 184
8.5.3: Discussion 186
8.5.4: Summary 189
8.6: The Impact of Variation in Breed on Bone Density 190
8.6.1: Materials 190
8.6.2: Results 192
8.6.3: Discussion 195
8.6.4: Summary 196
8.7: The Impact of Variation in Sex on Bone Density` 197
8.7.1: Materials 197
8.7.2: Results 198
8.7.3: Discussion 201
8.7.4: Summary 202
8.8: The Impact of Variation in Month of Death on Bone Density 203
8.9: The Impact of Variation in Age on Bone Density 204
8.9.1: Materials 204
8.9.2: Results 206
8.9.3: Discussion 210
8.9.4: Summary 211
8.10: Summary of Results 212

CHAPTER 9 – THE ARCHAEOLOGICAL APPLICATION OF THE DATA 214

9.1: The Presentation of Data Suitable for use in Archaeological Interpretation 214

9.1.1: Introduction 214

9.1.2: Presentation of the Data 215

9.1.3: Post neonatal animals – results and discussion 216
9.1.3.1: *Density range – "Whiskers"* 219
9.1.3.2: *Interquartile range – "Boxes"* 220
9.1.3.3: *Median* 221
9.1.3.4: *Outliers* 221

9.1.4: Neonatal animals – results and discussion 221

9.1.5: Summary and some implications for the analysis of element frequencies from archaeological sites 223

9.2: Implications of the Results for the use of Age Data in Archaeological Interpretation 225

9.2.1: The comparative density of unfused, fusing and fused bones 225
9.2.1.1: *The tendency of unfused scan-sites to be less dense than fused scan-sites* 226
9.2.1.2: *The tendency of certain bones to show a large discrepancy in density between fused and unfused specimens* 227
9.2.1.3: *The tendency of the earliest fusing scan-sites to have the highest bone density* 227

9.2.2: Discussion of the age related variation of bone density 227
9.2.2.1: *The tendency of unfused scan-sites to be less dense than fused scan-sites* 227
9.2.2.2: *The tendency of early fusing bones to show a large discrepancy in density between fused and unfused specimens* 228
9.2.2.3: *The tendency of other, later fusing bones to show a large discrepancy in density between fused and unfused specimens* 229
9.2.2.4: *The tendency of the earliest fusing scan-sites to have the highest bone density* 232
9.2.3: The creation of age profiles from fusion data 233

9.2.4: The "under-representation" of immature animals in age profiles 235

9.2.5: The relative densities of the fusion groups 236

9.2.6: The possible relationship between density difference and age difference between two individuals 236

9.2.7: Bone density at the time of fusion 237

9.2.8: Summary and some implications for the analysis of age profiles from archaeological sites 238

9.3: An Introduction to the Neolithic Site of Çatalhöyük, Turkey 241
9.3.1: Site background..... 241
9.3.2: The archaeological faunal material 245
9.4: The Impact of Taphonomic Processes on the Element Frequencies from Çatalhöyük..... 246
9.4.1: Ancient conceptions of "space" and "rubbish" 246
9.4.2: Building an archaeological model..... 248
9.4.3: Defining the contexts used in the model 250
9.4.4: Testing the archaeological model..... 251
9.4.5: Discussion of the internal assemblage 253
9.4.6: Discussion of the external assemblage..... 255
9.5: Taphonomic Profiles of the Internal and External Assemblage 256
9.5.1: "Taphonomic Signatures" 256
9.5.2: Weathering 257
9.5.3: Gnawing 259
9.5.4: Digestion 260
9.5.5: Butchery 261
9.5.6: Burning..... 263
9.5.7: Fragment length 264
9.5.8: Completeness indices 265
9.5.9: Summary 267
9.5.10: The ability for density to shape the element profiles of archaeological assemblages 267
9.6: The Impact of Density Mediated Destruction on the Age Profiles of the Two Assemblages 268
9.6.1: Building and archaeological model for the age profiles 269
9.6.2: Testing the age model 270
9.6.3: Discussion 273
9.6.4: Why the archaeological data were not fully predicted by the model 273
9.6.5: Summary 276

CHAPTER 10 – CONCLUSIONS..... 278
10.1: Aims: The General Aims of the Project Addressed 278
10.2: Objectives: The Specific Research Questions Answered..... 279

10.2.1: To what extent is the destruction of animal bones by taphonomic processes mediated by bone density? 279

10.2.2: How does bone density change according to factors other than element or species (eg age, sex, breed etc.)? 280

10.2.3: How might this information be used to improve the ability of zooarchaeologists to interpret archaeological assemblages? 280

10.2.4: What impact have taphonomic processes had on the animal remains recovered from Çatalhöyük, Turkey? 281

10.2.5: Which taphonomic processes are responsible? 281

10.2.6: How are taphonomic processes capable of distorting archaeological age profiles (particularly those from Çatalhöyük)? 281

10.3: Project Limitations and Suggestions for Further Work 282

10.3.1: Project limitations 282

10.3.2: Suggestions for further work 283

APPENDIX A: THE LOCATIONS OF THE SCAN SITES 286

APPENDIX B: THE EXPERIMENTAL MATERIAL 291

APPENDIX C: THE BONE DENSITY DATA 298

APPENDIX D: GRAPHICAL REPRESENTATIONS OF THE BONE DENSITY DATA 335

APPENDIX E (ON CD ROM): RADIOGRAPHIC IMAGES OF THE EXPERIMENTAL MATERIAL 380

BIBLIOGRAPHY 384