STONE OR METAL?
DIAGNOSING THE MATERIAL AGENT OF EARLY BRONZE AGE CUT MARKS FROM LERNA, GREECE

REBECCA JONES

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF HONOURS
DEPARTMENT OF ARCHAEOLOGY
SCHOOL OF PHILOSOPHICAL & HISTORICAL INQUIRY
UNIVERSITY OF SYDNEY

ARCHAEOLOGY HONOURS 2011
ACKNOWLEDGMENTS

I am deeply grateful to my supervisor Dr Melanie Fillios for devoting her time, thoughts, and energy to my dissertation. It would not have been possible without her help. Also, thank you to Prof Alison Betts for her critiquing and words of encouragements and to Prof Dan Potts for listening to my ideas for a topic and guiding me to the present one.

In the Australian Centre for Microscopy and Microanalysis, I greatly appreciate Dennis Dwarte for his assistance and expertise on the Micro-CT and, likewise, to Matthew Foley on the SEM. Also, I am grateful to Dr Ina Kehrberg-Ostrasz for the use of the light microscope.

Thank you to Crawford’s Casting for providing the bronze tool and advice, and to Nina Kononenko for kindly providing obsidian tools. Again, a big thank you to Dr Melanie Fillios for providing the Lerna material and chert tool.

I am grateful to Prof Paul Halstead (University of Sheffield), Prof Haskel Greenfield (University of Manitoba), and Mr Andrew Reinhard (American School of Classical Studies at Athens, director of publications) for providing unpublished drafts and advice.

Lastly, thank you to family and friends who helped me through this dissertation with encouragement, advice, and distractions. In particular, Mum, Dad, and fellow students Peta Longhurst and Patricia Lemos for their editing skills and thoughtful comments.
This dissertation examines cut marks on animal bone from Early Bronze Age Lerna in Greece to determine the material agent; a stone or metal tool. An experimental group of cut marks was produced to compare to the Lerna material. Both materials were analysed using a method yet to be used for cut mark studies, Micro-CT. Micro-CT was assessed whether it is an appropriate method for diagnosing cut marks on bone by comparing the results to SEM and light microscopy. In diagnosing the cut mark it was hypothesised that the profile and surface features will be important factors based on previous research (Walker and Long, 1977, Potts and Shipman, 1981, Greenfield, 1999, 2002, 2006). This study found that Micro-CT is excellent for showing the profile of a cut mark but not detailed surface features. Micro-CT also portrayed how the profile could vary, even within a single cut. For these reasons it was found profile alone is not enough to diagnose a cut mark and surface features are equally important. It was also found that comparing SEM, light microscopy, and Micro-CT was extremely beneficial as each technique has strengths and weaknesses. In regard to the Lerna material, it was found that three cut marks are almost certainly from stone tools and two cut marks are probably from metal tools. The findings add to evidence for the Bronze Age being a transitory period between stone and metal technologies.
# TABLE OF CONTENTS

Title .............................................................................................................................. I

Acknowledgements .................................................................................................... II

Abstract ...................................................................................................................... III

Table of contents .......................................................................................................... IV

List of figures ................................................................................................................. VII

List of tables ................................................................................................................ XII

List of appendix .......................................................................................................... XII

Glossary ......................................................................................................................... XIII

## CHAPTER ONE INTRODUCTION .......................................................................... 1

1.1 Introduction ........................................................................................................... 1

1.2 Objectives ............................................................................................................. 2

1.3 Contextual background to study .......................................................................... 2

1.3.1 The material .................................................................................................. 2

1.3.2 Early Bronze Age Lerna ............................................................................... 3

1.3.3 Fauna of Lerna ........................................................................................... 4

1.3.4 Technology of Lerna: Metallurgy .................................................................. 5

1.3.5 Technology of Lerna: Lithics ....................................................................... 7

1.4 Importance of study to archaeology ..................................................................... 7

1.5 Scope and limitations ............................................................................................ 8

1.6 Organisation of thesis ........................................................................................... 9

Chapter one tables and figures .................................................................................... 10
CHAPTER TWO SCHOLARLY BACKGROUND

2.1 Introduction .......................................................................................................................... 17

2.2 Faunal studies in archaeology ........................................................................................... 17

2.3.1 Approaches to cut marks ............................................................................................... 18

2.3.1 Palaeolithic influences: tooth versus tool .................................................................... 18

2.3.2 Seeking the material agent .......................................................................................... 26

2.4 Summary ............................................................................................................................. 32

Chapter two figures .................................................................................................................. 33

CHAPTER THREE METHODS AND MATERIALS

3.1 Introduction .......................................................................................................................... 54

3.2 Aims and hypotheses .......................................................................................................... 54

3.3 Material ............................................................................................................................... 56

3.3.1 Lerna cut marks ............................................................................................................. 56

3.3.2 Selection of Lerna material .......................................................................................... 57

3.3.3 Experimental material: Pig bone .................................................................................. 57

3.3.4 Experimental material: Stone and metal tools ............................................................. 59

3.4 Method ................................................................................................................................ 60

3.4.1 Producing a non-human agent ..................................................................................... 60

3.4.2 Producing the human agent ......................................................................................... 60

3.4.3 Preparation for analysis ............................................................................................... 62

3.4.4 Micro-CT analyses ......................................................................................................... 62

3.4.5 Light microscope analyses ............................................................................................ 64

3.4.6 SEM analyses ............................................................................................................... 64
3.5 Summary ........................................................................................................................................... 65

Chapter three tables and figures ........................................................................................................... 66

CHAPTER FOUR RESULTS

4.1 Forward........................................................................................................................................... 75

4.2 LERNA CUT MARKS ......................................................................................................................... 76

4.2.1 BE289 cut mark 1 ......................................................................................................................... 76

4.2.2 BE289 cut mark 4 ......................................................................................................................... 78

4.2.3 BD435 ........................................................................................................................................... 81

4.2.4 BE323 ........................................................................................................................................... 83

4.2.5 J467 .............................................................................................................................................. 85

4.3 EXPERIMENTAL CUT MARKS ...................................................................................................... 87

4.3.1 Dog score marks .......................................................................................................................... 88

4.3.2 Dog tooth punctures ..................................................................................................................... 90

4.3.3 Bronze atlas ................................................................................................................................. 91

4.3.4 Bronze humerus #1 ..................................................................................................................... 93

4.3.5 Bronze humerus #2 ..................................................................................................................... 94

4.3.6 Bronze humerus #3 ..................................................................................................................... 96

4.3.7 Bronze humerus #4 ..................................................................................................................... 97

4.3.8 Chert humerus #1 ......................................................................................................................... 99

4.3.9 Chert humerus #2 ....................................................................................................................... 101

4.3.10 Chert humerus #3 ....................................................................................................................... 102

4.3.11 Obsidian humerus #1 ................................................................................................................ 103

4.3.12 Obsidian humerus #2 ................................................................................................................ 104
CHAPTER 5 DISCUSSION AND CONCLUSION

5.1 Introduction ........................................................................................................... 105

5.2 Restatement and summary of objectives ............................................................... 105

5.3 Experimental data .................................................................................................. 106

  5.3.1 Non-human agent: dog score and tooth punctures ............................................ 106

  5.3.2 Bronze tool cut marks ...................................................................................... 107

  5.3.3 Chert and obsidian tool cut marks ................................................................... 109

5.4 Lerna cut marks ...................................................................................................... 111

  5.4.1 Stone cut marks .............................................................................................. 111

  5.4.2 Metal cut marks ............................................................................................. 112

5.5 Summary of findings of experimental and Lerna cut marks ................................. 114

5.6 Limiting factors of the study .................................................................................. 116

5.7 Conclusions and implications to archaeology ...................................................... 117

Chapter five tables ...................................................................................................... 120

BIBIOGRAPHY ............................................................................................................. 122

LIST OF FIGURES

CHAPTER ONE

Fig. 1.2: Sample BD435, example of Lerna moulds used in this study ...................... 11

Fig. 1.2: Map of Lerna within Greece ......................................................................... 11

Fig. 1.3: Google map overlay of site plan of Lerna, (after Caskey and Blackburn 1997: 2) 12

Fig. 1.4: Map of Lerna from the Argolic Gulf ............................................................. 13

Fig. 1.5: Two black and white photos of the site of Lerna, (after Caskey and Blackburn 1997: 4) 13
Fig. 1.6: Photo of dog and ox cut marks from Lerna, (after Gejvall 1969: plate III) ................................................................. 14
Fig. 1.7: Graph of major domesticates from Lerna, (after Reese in press: 889-916) ................................................................. 15
Fig. 1.8: Bronze tools excavated from Lerna, (after Liritzis 1996: plates 2.2.1.1; 2.2.1.8; 2.3.1.1a; 2.4.2.1; 2.5.1.1; 2.5.2.1) ........................................................................................................ 16
Fig. 1.9: Lithics excavated from Lerna, (after Hartenberger and Runnels 2001: 259) ................................................................. 16

CHAPTER TWO

Fig. 2.1: Profile of different types of tool cuts, (after Walker and Long 1977: 607) ................................................................. 34
Fig. 2.2: Puncture and pitting marks, (after Binford 1981: 45) ................................................................................................. 35
Fig. 2.3: Score marks, (after Binford 1981: 48) ....................................................................................................................... 36
Fig. 2.4: Furrowing and channelling marks, (after Binford 1981: 52, 74, 75) ................................................................. 36
Fig. 2.5: Pseudo-tools, (after Binford 1981: 56, 59) ................................................................................................................... 37
Fig. 2.6: Scraping and slicing marks on SEM, (after Pots and Shipman 1981: 578) ................................................................. 37
Fig. 2.7: Chop and carnivore marks, (after Pots and Shipman 1981: 578) ................................................................. 38
Fig. 2.8: Rodent tooth and carnivore puncture marks, (after Pots and Shipman 1981: 578) ................................................................. 38
Fig. 2.9: Accidental excavator mark, (after Pots and Shipman 1981: 578) ................................................................. 38
Fig. 2.10: Fossil slicing and tooth marks, (after Pots and Shipman 1981: 580) ................................................................. 39
Fig. 2.11: Examples of bone smears, (after Bromage and Boyde 1984: 361) ................................................................. 39
Fig. 2.12: Examples of oblique faulting, (after Bromage and Boyde 1984: 365) ................................................................. 40
Fig. 2.13: Stone tool versus trampling marks, (after Behrensmeyer et al. 1986: 769) ................................................................. 41
Fig. 2.14: Stone tool cut mark before and after washing, (after Behrensmeyer et al. 1986: 769) ................................................................. 41
Fig. 2.15: Delayed versus immediate processing, fresh versus weathered, (after Shipman 1988: 272) ................................................................. 42
Fig. 2.16: Saw marks made by a stone tool, (after Olsen 1988a: 345) ................................................................. 42
Fig. 2.17: Saw marks made by a metal tool, (after Olsen 1988a: 347-348) ................................................................. 43
Fig. 2.18: Scraping marks made by a flint tool, (after Olsen 1988a: 348) ............................................................ 43

Fig. 2.19: Scraping marks made by a metal tool, (after Olsen 1988a: 350) ................................................................. 44

Fig. 2.20: A modified version of Greenfield’s generalised profiles of stone and metal tool cut mark diagram, (after Greenfield 1999: 803; 2002: 51; 2004: 246; 2006: 152; 2008: 1641) ................................................................. 44

Fig. 2.21: SEM image of obsidian unretouched wide blade cut mark, (after Greenfield 2002: 46) .......................... 45

Fig. 2.22: SEM image of quartzite wide blade cut mark, (after Greenfield 2002: 48) .................................................. 45

Fig. 2.23: SEM image of obsidian small flake cut mark, (after Greenfield 2002: 48) ..................................................... 45

Fig. 2.24: SEM image of flint flake cut mark, (after Greenfield 2002: 49) ................................................................. 45

Fig. 2.25: SEM image of obsidian blade retouched cut mark, (after Greenfield 2002: 45) ................................. 46

Fig. 2.26: SEM image of obsidian blade retouched cut mark, (after Greenfield 2002: 46) ........................................... 46

Fig. 2.27: SEM image of obsidian point cut mark, (after Greenfield 2002: 47) ............................................................ 46

Fig. 2.28: SEM image of obsidian scraper cut mark, (after Greenfield 2002: 47) ....................................................... 46

Fig. 2.29: SEM image of sharp metal knife cut mark, (after Greenfield 1999: 801) ....................................................... 47

Fig. 2.30: SEM image of flat-edged metal knife cut mark, (after Greenfield 2002: 50) .................................................. 47

Fig. 2.31: SEM image of dull metal blade cut mark, (after Greenfield 2002: 51) .......................................................... 47

Fig. 2.32: SEM image of serrated edge blade (saw-like) and tightly serrated blade cut mark, (after Greenfield 2002: 49, 50) .................................................................................................................. 47

Fig. 2.33: SEM image of stone slice cut mark from Afridar, EBA, (after Greenfield 2006: 160) ................................................................................................................. 48

Fig. 2.34: SEM image of stone slice cut mark from Afridar, EBA, (after Greenfield 2006: 160) .......................... 48

Fig. 2.35: SEM image of unifacial stone slice cut mark from Afridar, EBA, (after Greenfield 2006: 160) ........................................................................................................................................ 48

Fig. 2.36: SEM image of stone blade cut mark from Petnica, (after Greenfield 2002: 42) ................................................ 48

Fig. 2.37: SEM image of metal knife blade cut mark from Afridar, EBA, (after Greenfield 2006: 168) ........................................................................................................................................ 49
Fig. 2.38: SEM image of metal chop mark (weathered) from Afridar, EBA, (after Greenfield 2004: 250)

Fig. 2.39: SEM image of metal chop mark (clear example) from Afridar, EBA, (after Greenfield 2004: 252)

Fig. 2.40: Characteristic marks produced by metal knives, showing overlapping shelf, (after Binford 1981: 106)

Fig. 2.41: Example of metal cut marks from EH III Tsoungiza, (after Halstead in press: 779)

Fig. 2.42: Example of a less-obvious metal cut mark from EH II Tsoungiza, (after Halstead in press: 799)

Fig. 2.43: Example of a less-obvious metal cut mark from EH II Tsoungiza, (after Halstead in press: 800)

Fig. 2.44: Illustration of cross-sections; angles of incision; and how the floor radius was calculated in Bello and Soligo’s study, (after Bello and Soligo 2008: 1543-1545)

Fig. 2.45: Topomicroscopy of metal knife mark and flint mark, (after Bello and Soligo 2008: 1544)

Fig. 2.46: Floor radii for metal knife and flint flake at different angles and profiles, (after Bello and Soligo 2008: 1550)

CHAPTER THREE

Fig. 3.1: Chert stone tool used for experimental cut marks

Fig. 3.2: Obsidian tools used for experimental cut marks

Fig. 3.3: Bronze tool used for experimental cut marks

Fig. 3.4: Canine chewing distal humerus

Fig. 3.5: Cutting the humerus

Fig. 3.6: Practice cut marks

Fig. 3.7: Stone cut marks on posterior surfaces

Fig. 3.8: Metal cut marks on anterior surfaces
Fig. 3.9: *Sus* humerus used for obsidian cut marks ................................................................. 71

Fig. 3.10: Process of using electric saw to section bone for analysis ........................................... 71

Fig. 3.11: Diagram of a *Sus* skeleton showing bones used for Lerna and experimental analyses, (after Sack 1982: 63) ......................................................................................................................... 74

CHAPTER FOUR

LERNA CUT MARKS:

BE289 cut mark 1, figs. 4.1-4.12 ................................................................................................. 76

B289 cut mark 4, figs. 4.13-4.31 ................................................................................................. 78

BD435, figs. 4.32-4.40 .......................................................................................................................... 81

BE323, figs. 4.41-4.48 .......................................................................................................................... 83

J467, figs. 4.49-4.59 .......................................................................................................................... 85

EXPERIMENTAL CUT MARKS:

Dog score marks, figs. 4.60-4.65 ................................................................................................. 87

Dog tooth punctures, figs. 4.66-4.73 ............................................................................................... 88

Bronze atlas, figs. 4.74-4.76 ............................................................................................................. 90

Bronze humerus #1, figs. 4.77-4.85 ............................................................................................... 91

Bronze humerus #2, figs. 4.86-4.91 ............................................................................................... 93

Bronze humerus #3, figs. 4.92-4.100 ............................................................................................. 94

Bronze humerus #4, figs. 4.101-4.105 .......................................................................................... 96

Chert humerus #1, figs. 4.106-4.115 ............................................................................................ 97

Chert humerus #2, figs. 4.116-4.126 ............................................................................................ 99

Chert humerus #3, figs. 4.127-4.134 ........................................................................................... 101

Obsidian humerus #1, figs. 4.135-4.139 ..................................................................................... 102
Obsidian humerus #2, figs. 4.140-4.144 ............................................................................................................ 103
Obsidian humerus #3, figs. 4.145-4.149 ............................................................................................................ 104

LIST OF TABLES

CHAPTER ONE

Table 1.1: Summary of figures of Gejvall and Reese, (after Reese in press: 889-916) ........................................ 15
Table 1.2: Number and percentage of obsidian and chert tools excavated from Lerna, (after Hartenberger and Runnels 2001: 261) ........................................................................................................ 16

CHAPTER THREE

Table 3.1: Lerna cut mark details ................................................................................................................ 67
Table 3.2: Details of experimental cut marks ................................................................................................ 72
Table 3.3: Summary of variabilities and potential problems considered throughout methodology process .................................................................................................................. 73

CHAPTER FIVE

Table 5.1: Summary of results and findings of experimental cut marks ....................................................... 120
Table 5.2: Summary of results and findings of Lerna cut marks .................................................................. 120

APPENDIX

APPENDIX: Parameters for Micro-CT Skyscan and Xradia scans .......................................................... 135
GLOSSARY OF TERMS

Anterior: In anatomy, term refers to a structure being closer the front of the body than other structure.

*Bos*: Domesticated cattle genus, full term *Bos primigenius*.

Bronze Age: Greek Bronze Age c.a. 3,000-1,000 BC which is then subdivided into Early, Middle, and Late Bronze Age. This thesis deals with the Early Bronze Age or Early Helladic Period c.a. 3,000-2,000 BC.

Cancellous: In anatomy, spongy bone that is located in the epiphyses and diaphysis of long bones, the bodies of vertebrae, and bones without cavities.

*Canis*: Domestic dog genus, full term *Canis lupus familiaris*.

*Capra*: Domesticated and wild goat, genus.

Cortical (also known as compact bone): In anatomy, dense bone that forms thick walls along the shaft of long bones. Cortical bone is thinner in bones where there is not articular cartilage, for example the skull.

Cut mark: A cut or group of cuts produced during the butchery in a particular moment in time. An example is chop marks at the distal end of a humerus made during disarticulation.

Distal: In anatomy, terms used only in reference to limbs it refers to a structure being further away from the origin, attachment or median plane than another structure.

Dorsal: See posterior.

Fossa, fossae (plural): A pit, groove or depression on a bone.

Inferior: In anatomy, term refers to a structure being closer to the feet or lower body than another structure. Not used with reference to the limbs, see distal.

Lithic: In archaeology, lithic artifacts can refer to stone tools as well as the debris resulting from their manufacture.

Medial: In anatomy, term refers to a structure being closer to the medial plane / centre of the body than another structure.

MNI: Stands for minimum number of individuals.
**Ovis**: A genus made up of at least five species of sheep. *Ovis aries* is the common modern domesticated species.

**Posterior**: In anatomy, term refers to a structure being closer to the back of the body than another structure.

**Proximal**: In anatomy, term is used only with reference to the limbs it refers to a structure being closer to the origin, attachment or median plane than another structure.

**Superior**: In anatomy, term refers to being closer to the head than another structure. Not used with respect to the limbs, see proximal.

**Sus domesticus**: Also known as *Sus scrofa domesticus*, term for domesticated pig.

**Sus sp.**: Covers both wild and domesticated pig species.
CHAPTER ONE
INTRODUCTION

“Science is based on the premise that the external world is knowable, and knowable directly; that is, it is accessible. When our tools for apprehending the world are questioned there is but one recourse: to seek experiences in the world, experiences that can elucidate the usefulness and accuracy of our tools for apprehending and describing reality.”

Binford 1978: 5

“Butchering implements leave identifying signatures on bone. From these signatures it is possible to distinguish the different raw materials and types of... butchering tools.”

Greenfield 2006: 147

1.1 Introduction
Cut marks on bone have long intrigued archaeologists for their ability to portray the butchering techniques, diet, behaviour, and the technology of past human/hominid groups. The study of cut marks has recently undergone dramatic change in the methods and reasons of how and why they are studied. Technological advances in SEM have greatly improved the ability to see surface detail of a cut mark and 3D imaging techniques have the ability to display the profile of the mark (Greenfield, 1999, 2002, 2006; Bello and Soligo, 2008). This has stimulated research to widen its scope. Cut mark studies have a strong background in Palaeolithic research where the question of agent is usually tooth or stone tool, animal or hominid. In later periods, where different technologies are available the situation becomes more complex and the agent could represent a number of different materials and tool types. The Bronze Age is thought to be a period at the beginning of the transition between stone and metal technologies (Liritzis, 1996; Sherratt, 2007). Concurrent to the rise of metallurgy is an increase in social complexity and urban development (Greenfield, 2005: 178). Metal tools first appear in the Neolithic and during the subsequent periods, stone tools seem to decline (Greenfield, 1999: 797). However, the amount of metal tools recovered from excavations remains relatively low (Greenfield, 1999: 797). This has been presumed to be a reflection of the value of metal and its infinite recyclability but this is problematized by biased recovery of post-Neolithic excavations, which
are typically not as interested in stone tools, as well as the chemical instability of early metals, which decompose relatively rapidly (Greenfield, 1999: 797-800). Further, most of the metal assemblage is derived from funerary contexts so it is possible the assemblage does not represent the full range of items or those in everyday use (Halstead, In press: 797). This makes it difficult to gauge how this technological transition takes place by purely studying metal artifacts. Thus, cut marks become an important potential proxy indicator of the spread of metallurgy or the continuation of lithic technology. This dissertation analyses cut marks on animal bone from Early Bronze Age Lerna to determine their material agent; a stone or metal tool. This chapter outlines the main objectives to the study before giving the full contextual and site information of the material.

1.2 Objectives

There are three main aims to this study:

1) To determine whether cut marks on animal bone from Early Bronze Age Lerna, Greece were produced by stone or metal tools, using Micro-CT, SEM and light microscopy and to compare them to a modern experimental sample.

2) Assess whether the use of Micro-CT is an appropriate method for diagnosing cut marks on bone.

3) Add to knowledge about the spread of metallurgy and butchery practices in Early Bronze Age Greece and add to knowledge and discussion about cut mark studies in general.

1.3 Contextual background to the study

1.3.1 The material

The material used in this study consists of Early Bronze Age cut marks from Lerna as well as cuts experimentally produced by the author to allow comparison. The Lerna material consists of small moulds of cut marks from pig bones obtained in 2005 by my supervisor Melanie Fillios (2007: 131) whilst she was examining the Lerna faunal material in the Archaeological Museum of Argos (fig. 1.1).
This material was originally excavated by John Caskey from the University of Cincinnati during the years 1952-1958 (Wiencke, 2000: ix) and studied by Nils-Gustaf Gejvall (1969). Whilst studying the faunal material held in Argos, Fillios (2007: 130-131) discovered that it did not match with the material published by Gejvall (1969). Thus, the exact province of the material is not known other than that it is from Early Bronze Age Lerna.

1.3.2 Early Bronze Age Lerna

The site of Lerna is situated in the Argolid on the eastern coast of the Peloponnese (fig. 1.2). Lerna’s position allowed easy access to eastern trade routes and it lay directly across from the contemporaneous site of Tiryns which was a relatively large site for the time (Fillios, 2007: 128-129). Lerna is now approximately 1.5 kilometres inland (figs. 1.3-1.5) but during the Early Bronze Age it was probably a coastal village (Fillios, 2007: 129). The site is surrounded by vineyards in the modern village of Myloi and to its north runs the Lernaean spring, as mentioned in the tasks of Herakles (figs. 1.3-1.5) (Crane 2010).

Excavations at Lerna by Caskey (Caskey and Blackburn, 1997: 5; Wiencke, 2000: 1) found evidence of discontinuous occupation from the Neolithic to the Roman period. Lerna began as a simple village but grew in wealth and importance, nevertheless, by modern standards it was small; at most there may have been 150 houses with 800 inhabitants (Caskey and Blackburn, 1997: 5).

Bronze Age chronologies are problematic but because dates are not central to this study, and for the sake of clarity, a general span of 3,000-2,000 BC will be given for the Early Helladic period (Dickinson, 2006: 13, 19; Cline, 2010: xxx). This period is often subdivided into three phases. Early Helladic II (Lerna III) seems to have been the height of Lerna’s occupation, as during this time the settlement was well-fortified and contained a number of large buildings, including the well-known House of Tiles which was two-storeys high and contained over 150 clay sealings which adds to evidence of trade (fig. 1.3) (Wiencke, 2000: 213, 302-304; Fillios, 2007: 18, 129-130; Wiencke, 2010). The period
the cut marks originate from is the following period, Early Helladic III (Lerna IV). During this time the Peloponnese as a whole seemed to have experienced depopulation, decrease in trade, and decrease in building size (Fillios, 2007: 130; Wiencke, 2010: 663-664). This seems to be mirrored at Lerna as the House of Tiles and fortifications were destroyed, houses were smaller, and pottery decreased in technical ability (Caskey, 1960). The differences between Lerna III and IV appeared so great to Caskey (1960: 301-302) that he concluded an invasion or influx of new people had occurred. Although this interpretation has been criticised, debate and speculation remain as to the cause of the change (Shriner and Dorais, 1999; Forsén, 2010: 59). The following periods, Middle and Late Helladic (approx. 2,000-1,000 BC) show a flowering of culture characterised by the palace-based civilization of the Mycenaean kingdom (Dickinson, 2006: 13, 19). The Early Helladic is thus a period at the beginning of a great change in the organisation of society as well as technological developments.

1.3.3 Fauna of Lerna

The faunal material of Lerna was first studied by Gejvall (1969) and his main interest was recording the various species of domestic and wild animals in order to examine change in species composition throughout time. One of the disadvantages Gejvall had was that he was not present during the excavation and had to rely on notes with little specific contextual information (Fillios, 2007: 132; Reese, in press: 868). As mentioned before, Fillios (2007: 130-131) found it impossible to correlate the material in Argos with that published by Gejvall (1969). Reese (2008; in press: 868-870) was recently given the task of organising the Lerna fauna and discovered that the material was stored in different museums and storerooms and that Gejvall must have only analysed part of the assemblage. Thus, the cut marks in the present study were probably not analysed by Gejvall. Unfortunately, less than 5% of Gejvall’s original samples from Lerna IV were saved (Reese, in press: 887).
Compared to the amount of butchered dog bones found by Gejvall (1969, 17-18, 53) the evidence for butchery of other major domesticates is slight and this probably reflects Gejvall’s interest in the practice of skinning and eating of dogs (fig. 1.6). Reese (in press) updated the data and found significant changes in the number of species and butchered specimens. Reese (in press: 889-916) found out of 29 sample lots; 444 burned bones, and 525 cut bones compared to Gejvall’s 48 burned bones and 22 cut bones out of 661 sample lots (table 1.1). Further, now the assemblage is being brought together from the disparate storage areas, the numbers of bones have significantly increased. Gejvall’s (1969: 10) original figures place the MNI of sheep/goat as first, pigs second, and cattle as third, followed by domestic dogs (table 1.1, fig. 1.7). Reese’s (in press: 889-916) revised figures place sheep/goat, pigs, and cattle at much higher amounts with a smaller margin between them (table 1.1, fig. 1.7). Since large parts of the assemblage that Gejvall worked on are now missing or destroyed it may prove difficult to obtain an accurate measure of species composition. However, it is clear that the standard domesticates were the main source of meat.

It cannot be certain the degree of domestication or management of the pigs at Lerna (Fillios, 2007: 57-66). Thus, the generic term Sus sp. will be used in relation to the pig bones from Lerna. The experimental bones will be termed Sus domesticus to differentiate between the Lerna pig bones and modern domesticated pig bones.

1.3.4 Technology of Lerna: Metallurgy

Renfrew (1972: 308-338) greatly influenced the study of Aegean metallurgy by proposing that developments began slowly in the Late Neolithic (end 5th millennium) and by Early Bronze Age II (3rd millennium) had become a rapid process that was largely autonomous despite the considerable trade and exchange of ideas that characterise the Early Bronze Age. Although the evolutionist and autonomist assumptions have been criticised, Renfrew’s approach of emphasising technology as a driving point towards complexity within a wider economic and social context is seen as an important contribution (Liritzis, 1996: 17-35; Sherratt, 2007: 245-246). Recently, metallurgists have shown that
evidence for metal-processing as well as metal objects appear earlier, in greater numbers, covering a wider area, and with an increasing range of tool types (Sherratt, 2007: 247). Sherratt (2007: 250) argues rather than a dramatic surge during the Early Bronze II period the development of metallurgy should be seen as a seamless and sturdy process from the Late Neolithic. Although metallurgy increases, lithic technology seems to have remained important and Rosen (1984: 504) argues the adoption of one technology does not involve a wholesale replacement of the previous technology. Rosen (1984: 504) explains this by the practical reason that one technology does not get discarded until the alternative is a significant improvement. Recently, cultural and symbolic factors have been expressed as contributing factors. Indeed, Sherratt (2007: 250) argues the Early Bronze Age should be seen as a transition in the patterns of cultural attitudes and symbolic use of metal which is only indirectly related to its practical use. The beginning of the Early Bronze Age is seen as a process of switching metal from a symbolic asset at a community level to becoming a symbolic asset at an individual level (Sherratt, 2007: 250).

In terms of the bronze items found in Lerna, 73 metal objects were found including 12 tools representing a mixture of blades, knives, axes and chisels (fig. 1.8) (Liritzis, 1996: 299-302). However, most of the assemblage is made up of small artifacts such as pins, awls, and needles (Liritzis, 1996: 300-302). As Greenfield (1999, 2000, 2002, 2005, 2006, 2008) points out, it is difficult to ascertain the true proportion of metal objects available during the Bronze Age as metal was probably recycled and passed down the generations instead of being discarded or buried with the dead. Halstead (In press: 797) also argues that although many of the metal objects from the Early Helladic period are ornamental rather than practical, the pieces are largely derived from funerary contexts which skews our perception of tools that were in regular use. Hence, cut marks can potentially help to clarify this and be of great assistance in understanding the development of metallurgy.
1.3.5 Technology of Lerna: Lithics

Despite the growing developments in metallurgy, lithic technology continued to play an important role throughout antiquity in the Mediterranean (Kardulias, 1992: 423). Obsidian and chert make up most of the stone tool assemblage (Kardulias, 1992: 423). Evidence for stone tools and their production is well attested at Lerna; imported Melian obsidian was the most popular material making up over 90% of lithics in the assemblage, followed by chert at under 10% (table 1.2, fig. 1.9) (Kardulias, 1992: 430; Hartenberger and Runnels, 2001; Wiencke, 2010: 661). A range of different lithic types have been found (fig. 1.9) and Hartenberger and Runnels (2001: 257) believe that obsidian and chert were used for different types of tools and purposes. Heavily retouched tools such as drills, sickles, and arrow heads are mainly chert, whereas, obsidian was mainly used for expedient daily tasks. Hartenberger and Runnels (2001: 280) used the Lerna lithics to demonstrate continuity in production from the Neolithic to the Bronze Age rather than diminishing when bronze tools were added to the tool kit. Thus, during Lerna IV, there is evidence to suggest there were two material technologies being used simultaneously. The question remains whether both metal and stone were being used to butcher animals?

1.4 Importance of study to archaeology

The majority of scholarship on cut marks has focused on the Palaeolithic period and, as such, they have different emphases (e.g.; Blumenschine, 1995; Blumenschine et al., 1996; Dominguez-Rodrigo, 1997, 2002, 2008; Dominguez-Solera and Dominguez-Rodrigo, 2009; de Juana et al., 2010; Dominguez-Rodrigo et al., 2010). The material of the cutting agent is not a major concern as it is in later periods, where a cut mark could represent a number of different materials; there would be no point in asking whether a cut was made by stone or metal in the Palaeolithic. Instead, the main focus is on ascertaining whether the mark was human or animal induced, or from environmental and taphonomic processes.
Recently, Greenfield (1999, 2002, 2005, 2006, 2008) has been pioneering cut mark studies in the Bronze Age in the Near East using SEM with success. Greenfield (1999: 803; 2002: 39; 2005: 180; 2006: 152; 2008: 1641) emphasises the importance of the cut mark profile in determining whether the mark was made from stone or metal. The importance of using the Bronze Age as a subject of analysis is that it is a transitional period between technologies and analysis of cut marks can lend an insight into how this transition occurred, whether it was relatively slow or fast at different sites, and if metal and stone were used for separate tasks.

Further, previous studies have mainly used a light microscope or SEM to analyse cut marks (Bunn, 1981; Potts and Shipman, 1981; Bromage and Boyde, 1984; Blumenschine et al., 1996; Greenfield, 1999, 2002, 2006). This is the first study to use Micro-CT. Although the resolution on SEM is much higher, Micro-CT allows the user to build a 3D image of an object and peel away at layers allowing the user to effectively see inside the object without damaging it.\(^1\) In theory, Micro-CT should be better at viewing the profile of a cut mark than SEM.

**1.5 Scope and limitations**

This dissertation is mainly concerned with the study and analysis of cut marks in the diagnosis of their agent; human or non-human, stone or metal. It does not pretend to be a history on animal butchery, taphonomy or faunal archaeology which are all substantial sub-fields within their own right. Neither does this thesis go into huge detail about Bronze Age Greece. Attention to contextual background has been paid where relevant. Further, due to time restrictions and the time-consuming methods employed a combination of five Lerna and thirteen experimental samples were analysed. The small number of samples studied hampers the ability to provide statistical conclusions or large statements on the amount of stone or metal tools used at Lerna.

In regard to the definition of cut marks used for this dissertation, a cut mark is defined as a cut or group of cuts produced during butchery in a particular moment in time, for example, chop marks on the distal end of a humerus made during disarticulation. The profile is the shape of the cut produced by the tool when looking along the line of the cut. Surface features can be within or around a cut mark and are related to the tool edge, pressure of the blade, and density of the bone. Surface features can include; striations, buckling, smearing, and folding. More detailed discussion of the definitions of cut marks and butchery occurs in the next chapter.

1.6 Organisation of thesis

This introductory chapter gives the main objectives, context to the study, and most of the detail about Lerna. Following this chapter is the scholarly background, which gives a brief outline of faunal studies in archaeology and in Greece before going into detail about approaches to the study of cut marks. The third chapter details the methods and materials used in this dissertation and also explains why certain methods were chosen over others. The fourth chapter gives the results of experimental and Lerna cut mark analyses. The fifth and final chapter discusses these results and offers some overall critiques and conclusions of the study. An appendix of the parameters of each Micro-CT scan can be found at the end. It was decided to place the figures and tables after each chapter rather than all at the end to facilitate the reading of this dissertation.
CHAPTER 1

INTRODUCTION
Figure 1.1: Sample BD435, an example of the Lerna moulds used in this study. Details of each mould can be found in Table 1, chapter 3; and photographs of each mould can be seen in results section.

Figure 1.2: Map showing position of Lerna within Greece (Google Maps 2011).
Figure 1.3: Site plan of Lerna showing Neolithic and Bronze Age features and the modern enclosing wall (site plan from Caskey and Blackburn, 1997: 2). Above, the site plan overlayed on a Google map (Google Maps 2011). The Argolic Gulf is approximately 150m to the east, and the small town Myloi is to the north-west.
Figure 1.4: Looking towards Lerna from the Argolic Gulf, the white line at the bottom of the image marks the beach (Google Maps 2011). A small river runs to the north of the site visible by the line of trees.

Figure 1.5: Above, a view of site from the West. Building covers The House of Tiles. Below, the main excavated area looking from the north-west. Both images from Caskey and Blackburn (1997: 4).
Figure 1.6: The images of cut marks Gejvall published (Gejvall, 1969: plate III). Top, three dog mandibles: 1-2; cut marks and 3; erosion marks. Below, cut mark between the talus and calcaneus of a wild ox.
Table 1.1: Summary of major differences between Gejvall and Reese’s figures (Reese, in press: 889-916).

<table>
<thead>
<tr>
<th>Major domesticates</th>
<th>Gejvall (661 samples)</th>
<th>Reese (29 samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sus</em></td>
<td>121</td>
<td>397</td>
</tr>
<tr>
<td><em>Ovis/Capra</em></td>
<td>159</td>
<td>392</td>
</tr>
<tr>
<td><em>Bos</em></td>
<td>57</td>
<td>360</td>
</tr>
<tr>
<td><em>Canis</em></td>
<td>23</td>
<td>72</td>
</tr>
<tr>
<td>Total species</td>
<td>360</td>
<td>1221</td>
</tr>
<tr>
<td>Total cut marks Lerna IV</td>
<td>22</td>
<td>525</td>
</tr>
<tr>
<td>Total burned Lerna IV</td>
<td>48</td>
<td>444</td>
</tr>
</tbody>
</table>

Figure 1.7: Graph showing proportion of major domesticates in Lerna IV based on MNI (Reese) and MIND (Gejvall) based on figures in Table 1.
Figure 1.8: Bronze knives, axes, chisels, blades from at Lerna (Liritzis, 1996: plates 2.2.1.1; 2.2.1.8; 2.3.1.1a; 2.4.2.1; 2.5.1.1; 2.5.2.1).

Table 1.2: Numbers and percentage of obsidian and chert lithic found at Lerna (Hartenberger and Runnels, 2001: 261).

<table>
<thead>
<tr>
<th>Phase</th>
<th>Obsidian n</th>
<th>Obsidian %</th>
<th>Chert n</th>
<th>Chert %</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>2,176</td>
<td>94.1</td>
<td>136</td>
<td>5.9</td>
<td>2,312</td>
</tr>
<tr>
<td>III/IV</td>
<td>627</td>
<td>94.4</td>
<td>37</td>
<td>5.6</td>
<td>664</td>
</tr>
<tr>
<td>IV</td>
<td>4,007</td>
<td>92.3</td>
<td>334</td>
<td>7.7</td>
<td>4,341</td>
</tr>
<tr>
<td>IV/V</td>
<td>1,056</td>
<td>92.4</td>
<td>87</td>
<td>7.6</td>
<td>1,143</td>
</tr>
<tr>
<td>V</td>
<td>2,660</td>
<td>87.1</td>
<td>393</td>
<td>12.9</td>
<td>3,053</td>
</tr>
<tr>
<td>Mixed contexts (Bronze Age)</td>
<td>269</td>
<td>95.4</td>
<td>13</td>
<td>4.6</td>
<td>282</td>
</tr>
<tr>
<td>Total</td>
<td>10,795</td>
<td></td>
<td>1,000</td>
<td></td>
<td>11,795</td>
</tr>
</tbody>
</table>

Figure 1.9: Examples of different types of Lerna IV lithics; a, d, j, k (right two); chert; b, c, e, f, g, h, l, k; obsidian (Hartenberger and Runnels, 2001: 259).
CHAPTER TWO

SCHOLARLY BACKGROUND

2.1 Introduction

This chapter gives a brief overview of faunal studies within archaeology in general and more specifically in Greece. The main concentration is on differing approaches to cut marks. Firstly, it will show the influence that researchers with a Palaeolithic background have had to the study of butchery and cut marks. Secondly, research that deals specifically with determining the material agent of the cut mark tool will be dealt with, with an emphasis on recent scholarship.

2.2 Faunal studies in archaeology

Since the late 1960s, faunal analyses, or zooarchaeology, has been popularised through scientific Processual archaeology, which put at the forefront of its interests environmental and ecological influences on human behaviour and the archaeological record (Crabtree, 1982: 20-23; 1990: 155; Lyman, 1994: 2-3; Sofaer-Derevenski, 2006: 14). According to Lyman, (1994: 2-3; Greenfield, 2002) the two main goals of faunal studies are the reconstruction of hominid subsistence patterns, and the reconstruction of palaeoecological conditions. Both of these goals have in common the emphasis on diet and it is interesting to note Lyman’s predisposition to associate faunal studies with the Palaeolithic. Studies on butchery and faunal analyses have their roots within the domain of Palaeoanthropology and even within Processualism, hunter-gatherer type groups were favoured in faunal analyses, hence, the emphasis on reconstructing diet and the environment (Binford, 1981, 1983). Both Binford (1981) and Lyman (1994) are considered significant to the development of faunal studies and their works are often used as a standard reference.

Post-Processualism sought to acknowledge the cultural and symbolic importance animals often have within a society rather than simply bones-equals-meat (Hodder, 1982; Crabtree, 1990; deFrance,
This saw a shift towards using complex societies from the Bronze Age to historical archaeology and use of a more holistic analysis of not only what people ate but whether politics, status, and cultural identity affect the faunal record (Hodder, 1982; Crabtree, 1990; Landon, 2005; deFrance, 2009; Campana et al., 2010). As Crabtree (1990: 155-156) points out, without the thrill of Neolithic firsts, complex societies need more specific questions as there is no point in conducting elaborate studies to determine whether Bronze Age farmers in the Levant had goats. The challenge of faunal studies today is to no longer see Processual and Post-Processual approaches as two different alternatives but to attempt to combine the biological and cultural into one holistic goal.

In terms of zooarchaeology in Greece, although archaeology has a long tradition, faunal analyses have been lagging behind other parts of the world (Fillios, 2007: 4). However, thorough attempts are being made to demonstrate the ‘loss of innocence of zooarchaeology in Greece’ (Kotjabopoulou et al., 2003: 33) by not only analysing the data but also considering the social and political implications of owning livestock and feasting (Hodkinson, 1990; Halstead, 1992, 1996, 2007, In press). Studies of cut marks seek to not only determine patterns in butchery but also to tie technological changes with the broad social and political transformations (Snyder and Klippel, 2003; Halstead, In press).

2.3 Approaches to cut marks

2.3.1 Palaeolithic influences: tool versus tooth

As mentioned above, it is only in relatively recent times that fauna has been seriously analysed for later periods; faunal studies have a firm Palaeolithic background. As such, the main interest of Palaeolithic researchers in relation to butchery is whether the marks on bone were made by hominids, animals, or trampling (natural erosion from the mixing sediment) (Andrews and Cook, 1985; Behrensmeyer et al., 1986; Blumenschine, 1995; Dominguez-Rodrigo, 2002). A major concern is equifinality, that is, all of the possible causes of bone modification can leave similar traces that can be difficult to distinguish from one another (Behrensmeyer et al., 1986; Lyman, 2005). Lyman (1994:
20) notes that taphonomic research with an archaeological purpose was rare during the early twentieth century, although, there was some interesting work in the nineteenth century motivated by curiosity of the distant past. Both Lyman (1994: 13) and Binford (1981:7-8) note the contribution of Buckland, writing in 1823, who experimentally gave a bone to a hyena and detailed the process of its destruction. Buckland stressed the similarities between the hyena-destroyed bone and bone from prehistoric assemblages.

Before Binford’s (1981) seminal work on bones, there were a few notable studies on butchering including Guilday et al (1962) and Walker and Long (1977). These studies are interesting and unusual for their time partly because they are not focused on prehistoric butchery. Guilday et al. (1962) studied faunal remains from a historic site of the Susquehannock tribe in Pennsylvania and described butchering techniques made by iron knives and axes. In determining a cut mark, the anatomical position was deemed to be an important factor as well as a degree of repetitiveness in placement and appearance (Guilday et al., 1962: 63). It was also noted that chop marks create a cut that is straight-walled and sharply defined, conversely, knife cuts were fine, deep V-shaped cuts often in parallel groups (Guilday et al., 1962: 63). Guilday et al. (1962: 63-64) also cautioned that although coarser, U-shaped marks from prehistoric sites are known to be associated with stone tools, the distinction between V and U marks should not be taken too seriously. Yet, they admit that the metal cut marks in their assemblage seemed quite consistent in this respect (Guilday et al., 1962: 63-64).

Walker and Long’s (1977) study was the first to systematically analyse the difference between metal and stone cut marks. They created experimental marks using a steel axe, a steel knife, an obsidian knife, and chert and obsidian bifacially flaked tools to compare with butchered bones from a Chumash site in California which had both prehistoric and historic levels. In relation to the experimental cut marks Walker and Long (1977: 607-611) summarised that, in general, metal tools will produce a V-shaped groove with straight edges and a distinct apex, while stone tools show more variability and tend to have wider, irregular grooves, with no distinct apex (fig. 2.1). They made a
number of cautions including, sharp obsidian flakes can mimic a metal mark, yet, the width and depth of the cut had consistent differences (Walker and Long, 1977: 609-613). Obsidian tool cuts were wider than metal tool cut marks at comparable pressures, further, metal could withstand higher pressures than obsidian which meant that metal marks could be much deeper than obsidian cuts (Walker and Long, 1977: 609-613).

Despite these examples, Binford (1981: 9-10) stressed the overt anthropocentrism in previous Palaeolithic faunal studies and in his work set about trying to demonstrate and rectify their mistakes. Binford (1981: 5) believed this tendency towards anthropocentrism within Palaeoanthropology stemmed from the Biblical importance given to man over nature as well as Victorian ideals of progress. The problem of how to recognise hominid behaviour in a faunal assemblage was thought to be solved by prehistoric definitions of man as toolmaker and homemaker; artifacts and habitations were recognised only by association with other objects (Binford, 1981: 4-7). A collection of bones with a few stone tools led to the assumption that hominids were responsible for the entire assemblage and, hence, all modifications on bones were a result of hominid action; “since man was responsible for the deposit he must also be responsible for the patterning manifest in and on its contents! ... anthropocentrism- the assumption that if any evidence exists for the presence of hominids everything present is the product of hominid action...” (Binford, 1981: 8, 9-10).

Binford’s (1981: 33) purpose was to detail modifications on bone by humans and other agents in a four year study of the Nunamiut of north-central Alaska. Bone modifications by domestic dogs and wild wolves were given a thorough analysis (Binford, 1981: 35-86). Binford (1981: 44) detailed four basic types of marks that animal teeth can produce on bone which have become standardised criteria; (a) punctures, (b) pits, (c) scores, (d) furrows. Punctures result when the pressure of a tooth causes the bone to collapse leaving an imprint of the tooth (fig. 2.2). Pitting is similar the only difference being the bone is stronger and does not collapse under gnawing (fig. 2.2). Scores are a result of the tooth being dragged across the surface of the bone (fig. 2.3). Furrowing is when
extensive gnawing occurs, usually by starting in soft cancellous bone and working towards harder bone (fig. 2.4). If extensive furrowing occurs, this can cause channels (fig. 2.4). Both punctures and pits are relatively clear signs of animal activity but scores and channelling can convincingly mimic cut marks and bone tools (figs 2.3, 2.5).

Although Binford (1981: 27-30) drew the attention to equifinality within faunal assemblage and was severe towards previous scholarship he was confident that differentiation was achievable if proper attention was paid. Like most Processualists, Binford was optimistic about the ability of science in archaeology which is evident in the opening quote of this dissertation. Despite Binford’s confidence, within Palaeolithic research today, debate still rages over the argument that Binford essentially began over modifications on bone and the problems of equifinality (Bunn, 1981; Potts and Shipman, 1981; Behrensmeyer et al., 1986; Shipman, 1988; Gifford-Gonzales, 1989; Blumenschine, 1995; et al., 1996; Dominguez-Rodrigo, 1997, 2002; Lyman, 2005; Dominguez-Rodrigo, 2008; Dominguez-Rodrigo and Yravedra, 2009; de Juana et al., 2010; Dominguez-Rodrigo et al., 2010). The main debate is centred around the notion of whether hominids were essentially meat-eating hunters or bone-marriage scavengers. It is usually assumed that cut marks imply filleting of meat, whereas, percussion marks are attempts to smash the bone to get at the marrow (Blumenschine, 1995; Dominguez-Rodrigo, 1997). Hominid butchery marks, animal tooth marks, and trampling marks are used in an attempt to determine who had primary and who had secondary access to carcasses.

During the same year of Binford’s (1981) influential work, Bunn (1981) and Pots and Shipman (1981) published articles about butchery marks on fossil bones from Olduvai Gorge, Tanzania and Koobi Fora, Kenya. Bunn (1981: 576) analysed the bones under ‘a strong light’ and found evidence of a variety of hominid butchering and scavenging, animal tooth marks, and post-depositional processes, and concluded faunal material is part of a complex and dynamic system. According to Bunn (1981: 576), meat-eating should be seen as a significant part of hominid evolution, although, the mode of acquisition (hunting, scavenging, or both) was still uncertain.
Pots and Shipman (1981) used SEM to study modern stone tool and animal tooth marks on bone and compared these to fossil samples in order to create criteria for distinguishing different types of marks on bone. Pots and Shipman (1981: 577) concluded that on a microscopic level, no process mimicked hominid butchering marks. In terms of slicing and scraping marks, fine parallel striations within the groove was noted to be an important characteristic of stone tools, especially if the bone was cut fresh (Potts and Shipman, 1981: 577) (fig. 2.6). Chopping marks were without striations and were broader in profile with fragments of bone crushed at the bottom of the groove (fig. 2.7). Tooth marks were found to usually have rounder or flatter grooves than stone tool marks and lacked striations (figs. 2.7-2.8). Trampling marks also lacked striations and differed from tooth marks because the erosive effect exposed more surface of the bone (Potts and Shipman, 1981: 577).

Finally, accidental marks from excavation with a metal tool were distinguished as they lacked striations and had an irregular edge (fig. 2.9). Interestingly, several fossil bones were found to have both slicing and tooth marks, and three specimens showed intersections between these marks which suggests hominids and carnivores were able to gain access to the same parts of the carcass at different times (Potts and Shipman, 1981: 577, 579, 580)(fig. 2.10). Yet, Pots and Shipman (1981: 579) found butchery was not consistent and cut marks occurred equally on meat-bearing as well as non-meat bearing bones, whereas tooth marks mainly appeared on meat-bearing. Their conclusions in regard to the hunting versus scavenging debate were similar to Binford’s (1981) in emphasising patterns on bone are not solely attributable to hominids and that hominids and carnivores were in competition for carcasses but may have relied on different substances (meat versus marrow) (Potts and Shipman, 1981: 579). The important step of this study was the use of SEM to distinguish characteristics of various modifications at a microscopic level. Bunn (1981) and Pots and Shipman (1981) both emphasised the complexity of the faunal assemblage and stressed multiple agents can affect a single bone. Consequently, it is understandable the degree of concern regarding equifinality within Palaeolithic research.
These studies by Binford, Pots and Shipman, and Bunn led to a greater experimental investigation of various taphonomic affects on bone during the 1980s (Bromage and Boyde, 1984; Andrews and Cook, 1985; Behrensmeyer et al., 1986; Olsen, 1988a; Shipman, 1988; Gifford-Gonzales, 1989; Noe-Nygaard, 1989). Inspired by the SEM images of cut marks, Bromage and Boyde (1984) experimentally produced over 200 cut marks using flint and obsidian tools on bone and analysed them using SEM, in order to determine whether directionality of force, and by implication handedness, could be ascertained. In particular, bone smears and oblique faulting were observed to be consistent criteria for directionality (Bromage and Boyde, 1984: 359). Bone smears were often seen on the floors, walls, and shoulders of the cut and usually point in the opposite direction of the cutting motion or sometimes towards the centre of the cut (fig. 2.11). This can be further clarified by the presence of oblique faults in which the ends point towards the centre of the mark (opposite direction of force) (fig. 2.12). Images show the agent producing the marks was right-handed (Bromage and Boyde, 1984: 366) (figs. 2.11-2.12).

Behrensmeyer et al. (1986) were the first to use SEM as a warning for mimicry cut marks produced by trampling marks. In a short article they experimentally reproduced marks from stone tool and trampling and found great variability in trampling marks and some of these marks closely resembled stone cut marks; fine multiple, parallel marks with striations (fig. 2.13). Also, it was noted that stone cut marks could lose some of their characteristics, especially striations, when subject to trampling, washing, or boiling during cleaning (fig. 2.14). It was argued that placement of the cut was therefore important in identifying cut marks, as hominid behaviour is more likely to result in marks on areas of ligament attachment or in recessed areas (Behrensmeyer et al., 1986: 770). The quality of these SEM images is, however, much less than what is achievable today. Although placement is still deemed to be an important factor to consider when attempting to identify a cut mark, it would be interesting to see SEM images comparing trampling and cut marks now, as modern technology is much improved since 1986.
Another influential work of the late 1980s was the publication *Scanning electron microscopy in archaeology* (Olsen, 1988c) which had a number of articles related to studying faunal material with SEM. Of particular interest is Shipman’s (1988) and Olsen’s (1988a) articles (Olsen’s will be detailed below). Shipman (1988) gives an introductory article on using experimental archaeology and SEM for the hunting versus scavenging debate. Her main interest in regard to cut marks is to show the difference between immediate and delayed processing of bone. The weathering process on a carcass begins at about 6 months to one year post-mortem and cut marks made prior to weathering loose the detail of fresh cut marks, in contrast, cut marks made after the process of weathering begins keep the original features of a fresh mark (Shipman, 1988: 272-273) (fig. 2.15). This has the potential to show delayed processing in an assemblage, although, whether hominids would have often delayed their processing by this much is questionable. Further, Shipman received a number of criticisms for her method of cutting defleshed bone as Haynes (1991: 163) and Gifford-Gonzales (1989: 181-185) argue this does not reflect an authentic butchery process (see methodology section for more detail). Nonetheless, the fact that weathering and trampling affects a cut mark made originally on fresh bone has implications for faunal material on all archaeological sites.

Scholarship from the 1990s onwards has been more comprehensive as scholars started to realise the potential of cut marks to archaeology and scientific techniques have been frequently used and analysed for their application to the study of cut marks (Cruz-Uribe and Klein, 1994; Lyman, 1994; Blumenschine, 1995; Fisher, 1995; et al., 1996; Dominguez-Rodrigo, 1997, 2002; Lyman, 2005; Braun et al., 2008; Dominguez-Rodrigo, 2008; Dewbury, 2009; Dominguez-Rodrigo and Yravedra, 2009; Zhang et al., 2009; de Juana et al., 2010; et al., 2010). Lyman (1994: 294-353) and Fisher (1995) gave valuable overviews of cut mark scholarship and worked to help clarify terminologies, such as, how to define a cut mark and the butchering process. The use of the term ‘cut mark’ suggests a singular cut but cut marks often appear in close groups and a single cutting action can create more than one mark (Dewbury, 2009: 4). Most researchers treat clusters of cut marks as incidents representing one behavioural episode, such as disarticulating a femur from the pelvis, rather than
counting each individual cut (Lyman, 1994: 304). Lyman (1994: 294-295) defines butchering as the “human reduction and modification of an animal carcass into consumable parts” and emphasises the word ‘human’ as many organisms process carcasses for consumption. While Binford (1978: 48) defines butchering as a task of dismemberment: “butchering is not a single act but a series of acts beginning when the animal is killed and continuing at various junctures until the animal is totally consumed or discarded.” In contrast, Lyman (1994: 295) believes that butchering does not include transport, cooking processes, or consumption. However, all processes on a carcass can potentially modify the bone; thus, it could be argued from the view of bone modification that all human-induced processes affecting the bone soon after the death of an animal is part of the butchery process.

Within this context, the hunting versus scavenging debate continued to be a major source of discussion with cut marks themselves being the main source of evidence (Blumenschine, 1995; Blumenschine et al., 1996; Domínguez-Rodrigo, 1997, 2002; Lyman, 2005; Domínguez-Rodrigo, 2008; Dewbury, 2009; Domínguez-Rodrigo and Yravedra, 2009; de Juana et al., 2010; Domínguez-Rodrigo et al., 2010). High among the debate is what is known as ‘cut mark frequencies’ as well as the old problem of equifinality. It is not the purpose of this dissertation to detail this debate as it is very complex and is not directly related, however, it is important to show the background to cut mark studies and where much of the debate lies. Cut mark frequency simple refers to the amount of cut marks on any given element, and it is usually inferred that if a hominid had direct access to a carcass, cut mark frequencies would be higher and tooth marks lower, conversely, if hominids had secondary access there should be less cut marks and more tooth marks (Domínguez-Rodrigo and Yravedra, 2009: 885). The major debate is based on equifinality and variability within the assemblage, that is, butchery practices can be extremely variable and taphonomic and animal processes on a carcass add to the confusion. Domínguez-Rodrigo (2002: 5; Domínguez-Rodrigo and Yravedra, 2009) is one of the scholars who believe the problem with equifinality and variability is mainly methodological rather
than inherent within the assemblage and he correctly states that in this debate, our ideas about our ancestors have always been more important than the data, which is why the debate is so heated.

This surge in interest in cut marks and a general concern about equifinality also led to a number of studies on the modification produced by animals on bones and taphonomic processes (Greenfield, 1984, 1988; Dominguez-Rodrigo and Piquerás, 2003; Ioannidou, 2003; Coard, 2007; Faith, 2007; Delaney-Rivera et al., 2009; Dominguez-Solera and Dominguez-Rodrigo, 2009; Fillios and Chang, unpublished). A recent study by Fillios and Chang (unpublished) compared dog and pig tooth marks using SEM and light microscope and found, despite the differences in canid and suid food processing and skull and jaw morphology, no significant differences could be seen in the tooth marks. A number of other researchers have also found it difficult to attribute tooth marks to specific carnivore taxa and contextual factors are often emphasised as important, such as, age and size of the animal, domestication, number of individuals at the carcass and food availability (Dominguez-Rodrigo and Piquerás, 2003; Coard, 2007; Delaney-Rivera et al., 2009; Fillios and Chang, unpublished).

### 2.3.2 Seeking the material agent

Cut mark scholarship since the 2000s has taken on a wider range of applications and periods in history. As shown above, Palaeolithic cut mark studies are primarily interested in determining who/what was the cause of the cut mark, hominin or otherwise. In later periods, where the number of available materials increases, the question becomes wider; is it human induced and what by? Possibly the earliest detailed study on differentiating between stone and metal marks on bone was by Olsen (1988a) who studied worked bone artifacts from the Bronze and Iron Ages from sites in Britain. Olsen (1988a: 341) used a number of techniques to identify and describe the marks including, the unaided eye, hand lens, light microscopy, and SEM. Olsen (1988a: 341) found that, in general, metal tools leave a more uniform pattern, remove material more effectively, and leave little striations or striations of a uniform depth and spacing. Not only was Olsen (1988a: 343) able to differentiate between the material of the tool, but different types of cuts could also be
distinguished, such as, saw, chop, file, scrape, drill, and chisel marks. Saw marks, if well preserved, are square (as opposed to V-shaped) and contain parallel striations on the bottom and sides of the cut (figs. 2.16-2.17) (Olsen, 1988a: 343). Scraping tools continued to be used except during the Iron Age, when metal began to replace stone and differences were distinguishable between these materials (Olsen, 1988a: 349). Stone scraping marks have striations that are wavy and variable in depth, whereas, metal scraping marks have striations that are finer, straighter, shallower, and of uniform depth (figs. 2.18-2.19). Olsen (1988a: 349) also coined the term ‘chattermarks’ which are transverse ripples that are created when a tool is used in a scraping action (figs. 2.18-2.19). Differences between stone and metal chop marks were also noted as metal chop marks can be sharper and deeper than stone (Olsen, 1988a: 349-352). Olsen (1988a: 337) was able to conclude that there was an increase in the use of metal tools from the Bronze Age to the Iron Age. Although Olsen’s work is an interesting exception to cut mark studies by Palaeolithic researchers, the material she was analysing was bone artifacts as opposed to butchered bone. As such, the context and the type of cut marks expected are quite different; in butchering, slicing and chop marks are expected as opposed to the great variety Olsen found.

Apart from the early studies of Walker and Long (1977) (mentioned above), and Olsen (1988a), in regards to seeking the material agent of a cut mark, Greenfield (1999, 2000, 2002, 2004, 2005, 2006; Greenfield et al., 2006; 2008) has been pioneering this branch of cut mark studies. Greenfield has concentrated on the Bronze Age where stone and metal tools were potentially being used simultaneously and he attempts to use cut marks not only to determine their material agent but also as a proxy indicator for the spread of metallurgy. Greenfield (1999: 803; 2002: 51; 2004: 246; 2006: 152; 2008: 1641) is confident that he can consistently differentiate between metal and stone as well as different types of tools using SEM. Greenfield emphasises the importance of the profile of the cut mark in determining its material agent and he has developed a generalised diagram of characteristic profiles which has become the model for such studies (fig. 2.20). This diagram and the SEM results of Greenfield are the most important comparative study for this thesis (figs. 2.20-2.39). As noted by
earlier authors (Guilday et al., 1962; Walker and Long, 1977; Olsen, 1988a), sharp metal tools have a V-shape, blunt metal tools a U-shape, and metal saws or serrated edges have a wider and irregular U-shape (fig.20.2). Other authors (Guilday et al., 1962; Walker and Long, 1977; Olsen, 1988a) noted that stone tools were more U-shaped than metal tools and were more irregular. Greenfield added that, in general, stone tools will have one side that rises more gradually than the other (fig. 2.20).

Greenfield has also made extensive use of SEM analyses for experimental and archaeological samples and his results have a considerably superior resolution since they are more recent than other SEM works detailing cut marks (Potts and Shipman, 1981; Bromage and Boyde, 1984; Behrensmeyer et al., 1986; Olsen, 1988a). Greenfield (2002: 37-40) summarised the main criteria of stone tools as (see figs. 2.21-2.28):

(a) Bifacial tools will create a groove with one side rising steeply and the other gradually 
(b) Striations running parallel to the apex/groove of the cut are common, which reflects the uneven (and often retouched) side of the blade
(c) Scrapers produce a messier, shallower pattern, and exhibit more variability
(d) The production (unifacial or bifacial) and use (retouching) affect the appearance of the cut more than material of the stone, although, obsidian cut marks tend to be thinner and smoother
(e) Overall, stone tools produce cuts that are more shallow, less even, and variable in appearance than metal cut marks

Greenfield (2002: 38-40) summarised metal tool marks as (figs. 2.29-2.32):

(a) A sharp V-shape or hard corned |_|-shape groove that meets at a distinct apex at the bottom of the cut (depending on how sharp the blade is)
(b) Uniform patterns, often removing material within the groove more effectively, and produce a cleaner and more even cut (except serrated-edge blades)
(c) Leave either no striations or striations of more uniform depth and spacing than stone tools

However, archaeological samples are subject to a wide range of post-depositional modifications and are often not as clear as modern experimental examples as has been previously noted by Shipman (1988) and Behrensmeyer et al. (1986). In some of Greenfield’s (1999, 2002, 2004, 2006) comparative studies he portrays archaeological cut mark samples alongside modern experimental ones for contrast. Some archaeological samples show less-defined edges and striations, and it can be difficult to distinguish between metal and stone (figs. 2.33-2.39). This presents a potential problem when studying archaeological cut marks and comparing them to modern examples. Greenfield (2002: 37) notes that one of the ways to assist this problem is to look at the sample under a lower magnification so all of the cut is visible as some parts of the cut may preserve better than others.

Another potential problem that was first noted by Walker and Long (1977: 609-613) is that sharp obsidian tools can leave a similar sharp V-shape to metal tools. Although, as mentioned above, metal tools were also found to handle more pressure and produce deeper cuts than obsidian. In Greenfield’s (2002: 40) study of the differences between a variety of stone and metal tools, he found that obsidian tools were recognisably different from metal cuts and concluded there was no support for Walker and Long’s hypothesis. Yet, Halstead (In press: 798-799) cautions that the distinction between sharp, straight obsidian or flint, and copper or bronze knives of a medium hardness could be difficult. Halstead’s (In press) recent work of the fauna from Tsoungiza offers an interesting comparison to Lerna as both sites are contemporary Early Bronze Age and are geographically nearby. Halstead’s (In press: 798) criteria for determining whether marks were from stone or metal tools were based on three variables:

(a) Stone tools often leave clusters of short marks while metal tools tend to leave fewer, sharper, and sometimes longer cuts

(b) Relatively wavy cuts are suggestive of stone while straight cuts are suggestive of metal
Within the internal morphology, subsidiary groove within the cuts are suggestive of stone while an overlapping ‘shelf’ is suggestive of metal.

These differences are based upon the morphology of the cutting blades themselves as originally noted by Binford (1981: 105-106). Stone tools usually have a relatively short blade and the clusters of short mark are a reflection of the need for repeated cutting, while the wavy cut and subsidiary grooves are indicative of the irregular edge of a stone blade (see figs. 2.6, 2.15). Conversely, metal knives tend to be longer with a straighter, sharper edge which results in fewer, sharper, and sometimes longer cuts with a distinctive overlapping shelf (fig. 2.40). Interestingly, based on these characteristics, Halstead (In press: 799-800) found that most of the butchered specimens at Early Helladic Tsoungiza were the result of metal knives (or possibly sharp obsidian) and there was no firm indication for stone tools being used for this purpose (fig. 2.41). Halstead (In press: 799) noted that although some of the cut marks were clustered and had subsidiary grooves, typical of stone tools, he concluded this was probably the result of changing the angle of the blade whilst working around the curved surface of the bone (figs. 2.42-2.43). Halstead does not mention what techniques he used to look at the bone, but based on the images, it looks as though they were taken from a camera or light microscopy. Unfortunately, the images are quite small and not the best quality which makes it difficult to judge.

Since the work of Greenfield there has been investigation into other types of cut marks on bone including bamboo (West and Louys, 2007), and forensic and trauma related cuts on bone have received interest (Lewis, 2008; Thompson and Inglis, 2009; Dixon et al., 2010; Freas, 2010). There has also been an interest in investigating techniques that will allow 3D imaging (Gilbert and Richards, 2000; Bello and Soligo, 2008). Bello and Soligo (2008) used an Alicona 3D Infinite-Focus imaging microscope to capture 3D images of cut marks made experimentally from a metal knife and flint flake. The cuts were made at three different angles; 25, 45, and 90 degrees to the bone surface and seven cross-sections along the length of the cut were chosen for quantitative analysis (fig. 2.44).
imaging microscope allows the user to accurately measure the captured image and one of the main measurements Bello and Soligo (2008: 1544-1545) were interested in was the floor radius which was expected to reflect the sharpness of the tool and, therefore, the material type. This technique proved effective for displaying morphological characteristics as well as detail of surface features (fig. 2.45). Bello and Soligo (2008: 1550) found that it is important to analyse the full length of a cut mark as its measurements can vary dramatically. This was especially true of the flint flake, whereas, the metal knife was relatively constant (fig. 2.46). The floor radius was shown to be an effective way for inferring the tools material, as the flint flake had a noticeably larger floor radius and it was more variable along the length of an individual cut (fig. 2.46) (Bello and Soligo, 2008: 1550).

Bello and Soligo (2008: 1542-1543) also pointed out a debate that has been common since the early days of cut mark studies which is: which technique is the best for analysing cut marks? (Bunn, 1981; Potts and Shipman, 1981; Olsen, 1988b; Blumenschine et al., 1996). As shown above, analyses originally began on light microscopes but as scientific techniques improved SEM was favoured. However, debate continues as to which method is best as advocates of light microscopy argue that SEM is costly, time-consuming, and places more emphasis on the morphology of the mark rather than its context (Blumenschine et al., 1996; Freas, 2010). In a blind-test study by Blumenschine et al. (1996) they argued they could accurately diagnose the agent of a cut mark with a light microscope and concluded SEM is over-rated. Bello and Soligo (2008: 1543) also add that although the SEM gives a better idea of the profile of a cut mark than a light microscope, the main issue with the SEM is its sensitivity to accurate determination of calibration data when the platform is tilted at an angle. Bello and Soligo (2008) thus promote 3D imaging models as the way forward. However, the calibration complaint of Bello and Soligo is beyond the necessary precision for this dissertation and archaeology in general as it concerns measurement accuracy down to 10 nanometres or below. Further, most scholars prefer SEM analyses for cut marks and argue it has the best resolution which is often necessary for marks that are not obvious to the eye.
2.4 Summary

Research on cut marks was, until relatively recently, dominated by studies with a Palaeolithic bias. A broadening in the scope of research as well as advances in technology has benefitted cut mark studies by increasing knowledge and ability of diagnosing different tool types and materials. In light of the continuing debate of the best method of analysis, it will be interesting to see how Micro-CT compares to other techniques. Although Micro-CT is not an accurate measuring device like the Alicona imaging microscopes, Micro-CT allows the user to ‘cut into’ the 3D image of your object, whereas, imaging microscopes take images only of the surface. The ability to cut into the image should, in theory, make viewing the profile, surface features, and general morphology in hard-to-see places easier.
Figure 2.1: Profiles of different types of tools; A: steel axe, B: steel knife, C: obsidian knife, D: bifacially flaked chert tool, E: bifacially flaked chert tool. From Walker and Long (1977: 607).
Figure 2.2: Puncture and pitting marks (Binford, 1981: 45).
Figure 2.3: Score marks, note how these can mimic cut marks (Binford, 1981: 48).

Figure 2.4: Top: furrowing marks, below: channelling (Binford, 1981: 52, 74, 75.).
Figure 2.5: Examples of pseudo-tools created by dog gnawing (Binford, 1981: 56, 59).

Figure 2.6: Stone tool slicing (left) and scraping (right) modern marks on bone. Note the characteristic striations. SEM images from Pots and Shipman (1981: 578).
Figure 2.7: Chop mark (left) on modern bone showing two magnifications; left (lower mag) note no striations, right (higher mag) note show bone is crushed within groove. Carnivore tooth-scoring mark on modern bone (further left) note although this is the functional equivalent to a slicing mark there are no striations, the mark is also a broader U shape. SEM images from Pots and Shipman (1981: 578).

Figure 2.8: Rodent gnawing mark on modern bone (left) functionally equivalent to a scraping mark but this mark is broader, shallow, and without striations. Canine puncture mark on modern bone (right) functionally equivalent to a chop mark in that pieces of bone get crushed inwards except the mark gives an outline of the tooth. SEM images from Pots and Shipman (1981: 578).

Figure 2.9: An accidental metal mark produced during excavation on a fossil bone. Although this is similar in action to slicing, the mark does not have striations and has a very irregular edge. SEM image from Pots and Shipman (1981: 578).
Figure 2.10: Fossil bone of two slicing marks running horizontal, the lower slicing mark is overlaid with tooth marks which must have been made after the slicing mark. A micrograph (left) and tracing of main features (right) from Pots and Shipman (1981: 580).

Figure 2.11: Examples of bone smearing, the white arrows point to the ends of the smears. On the left the smears point inwards towards the centre of the cut and on the right the smears point in the opposite direction to the force applied (left to right cut) which is more common. SEM images from (Bromage and Boyde, 1984: 361).
Figure 2.12: Examples of oblique faulting pushed towards the centre of the cut in opposite direction of force. Although a tilt towards the right can be seen in directly above as well as the above right as a result of the blade being drawn from the left to the right. SEM images from (Bromage and Boyde, 1984: 365).
Figure 2.13: (a) cut marks made by a stone tool on a bone; (b) same specimen after subject to trampling for 3 minutes in sand; (c) and (d) close up of select area showing cut and trampling marks. SEM images from Behrenmeyer et al (1986: 769).

Figure 2.14: (a) and (c) cut mark from stone tool before washing; (b) and (d) after washing, showing loss of detail. SEM images from Behrensmeyer at al. (1986: 769).
Figure 2.15: Top left shows a fresh bone with a fresh cut mark, top right is a close-up. Note the striations, bone smears, faulting and clear profile. Bottom left shows an old cut mark originally made on fresh bone that is now weather and bottom right is a close-up. Note the loss of detail. SEM images from Shipman (1988: 272).

Figure 2.16: Saw mark made with stone tool on a West Row bead (Olsen, 1988a: 345).
Figure 2.17: Profile of experimental metal saw mark (above), and SEM image showing vertical sides, flat bottom and fine straight striations. Images from (Olsen, 1988: 348).

Figure 2.18: Experimental scraping mark made with a flint tool. Direction is horizontal, note the irregularly spaced striations and the ‘chattermarks’ or transverse ridges. SEM image from (Olsen, 1988: 348).
Figure 19.2: Scraping marks made by a metal tool from a Friskerton gouge. Note the striations are finer than in Fig. 18 and the transverse ridges are more uniform. Photo from (Olsen, 1988a: 350).

Figure 2.20: A modified version of Greenfield’s (1999: 803; 2002: 51; 2004: 246; 2006: 152; 2008: 1641) generalised profile of metal and stone tool cut marks diagram.
Unretouched stone tools, SEM images, experimental marks. NOTE: most of Greenfield’s images are taken of negative casts, hence, the cuts appear to stick out rather than in.

Figure 2.21: Obsidian wide blade Greenfield (2002: 46).  
Figure 2.22: Quartzite wide blade Greenfield (2002: 48).

Figure 2.23: Obsidian small flake Greenfield (2002: 48).  
Figure 2.24: Flint flake Greenfield (2002: 49).
Retouched stone tools, SEM images, experimental marks

Figure 2.25: Obsidian blade retouched Greenfield (2002: 45).

Figure 2.26: Obsidian blade retouched Greenfield (2002: 46).

Figure 2.27: Obsidian point retouched Greenfield (2002: 47).

Figure 2.28: Obsidian scraper retouched Greenfield (2002: 47).
Metal knives with sharp edges, SEM images, experimental marks

Figure 2.29: Sharp metal knife Greenfield (1999: 801).

Figure 2.30: Metal flat-edged knife Greenfield (2002: 50).

Figure 2.31: Dull metal knife Greenfield (2002: 51).

Figure 2.32: Metal serrated edge (saw-like) and bottom left tightly serrated metal knife Greenfield (2002: 49, 50).
SEM images of archaeological samples of stone tool cut marks

Figure 2.33: Stone tool slice from Afridar, Israel, Early Bronze Age I Greenfield (2006: 160).

Figure 2.34: Stone slice from Afridar, Greenfield (2006: 160).

Figure 2.35: Unifacially retouched stone tool slice from Afrida., Note the roughening on both sides of the apex although it is gentler on the right side, visable on the bottom right side of the image. Greenfield (2006: 160).

Figure 2.36: Stone blade from Petnica, Serbia Greenfield (2002: 42).
SEM images of archaeological samples of metal tool marks

Figure 2.37: Metal knife blade from Afridar Greenfield (2006: 168).

Figure 2.38: Metal chop mark from Afridar note how crushed the mark appears compared to Fig. 39, Greenfield (2004: 250).

Figure 2.39: Metal chop mark from Afridar, a very clear example Greenfield (2004: 252).
Figure 2.40: Characteristic marks produced by metal knives, note the cuts are further apart, longer, and the overlapping shelf coined by Binford as a result of the slicing action and sharp knife. Image from Binford (1981: 106).

Figure 2.41: An example of a metal cut mark on an EH III proximal pig radius from Tsoungiza. The overlapping shelf is not as obvious as in Fig. 40 (possibly due to the poorer quality of the image) but it is a good example of the straight and sharp edge. Image from Halstead in press: 779.
Figure 2.42: Metal cut mark on EH II sheep scapular from Tsoungiza, showing subsidiary grooves usually typical of a stone tool but, according to Halstead, probably caused by changing the angle of the knife while cutting. Image from Halstead (In press: 799).

Figure 2.43: Metal cut mark on a EH II pig calcaneum from Tsoungiza also illustrating subsidiary grooves caused by change in knife angle while it follows the curve of the bone. Image from Halstead (In press: 800).
Figure 2.44: (Top left) illustration of the seven cross-sections for which quantitative analyses were performed. (Top right) angles of incision (a) 25°, (b) 45°, (c) 90° approximate degrees to bone surface. (Bottom) regression model showing how floor radius was calculated. From Bello and Soligo (2008: 1543-1545).
Figure 2.45: Topomicroscopy of experimental knife mark held at 45° (a), and flint flake held at 45° (b). From Bello and Soligo (2008: 1544).

Figure 2.46: The floor radii of metal knife and flint flake at different angles and sections. Modified version of Bello and Soligo (2008: 1550).
CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This chapter details the materials and methods used in this study. It was also decided to give a detailed analysis of the main decisions and reasons behind them in this chapter as the methodology of this type of experimental faunal study is often the main source of debate in scholarship. Immediately below is a detailed statement of the aims and hypotheses that this dissertation rests on. This is followed by the material section which details the Lerna cut mark moulds, selection of material, experimental pig bone, and bronze and stone tools. The methodology section follows which details producing the non-human and human agent, preparation for analysis, and the procedure for Micro-CT, light microscopy, and SEM. A brief summary is at the end of the chapter.

Firstly, it is beneficial to restate the aims and hypotheses in detail now that the context of the study and previous scholarship has been dealt with.

3.2 Aims and hypotheses

There are three main aims to this study:

1) To determine whether the cut marks on animal bone from Early Bronze Age Lerna were produced by stone or metal tools using Micro-CT, SEM and light microscopy by;
   a. Comparing cut marks from Lerna to marks from a modern experimental group
   b. Determining whether the marks are made by human or natural agency

2) Assess the utility of Micro-CT for diagnosing cut marks on bone. This will be determined by comparing the results and practical considerations of Micro-CT to the established techniques of SEM and light microscopy.
3) Add to knowledge about the spread of metallurgy and butchery practices in Early Bronze Age Greece and add to knowledge and discussion about cut mark studies in general.

This study rests on three main hypotheses:

1) The main hypothesis rests on the notion that stone and metal cut marks will have different characteristic profiles primarily based upon the work of Greenfield (1999, 2002, 2004, 2005, 2006). It is proposed that:
   a. Metal cut marks will generally have sharper sides with a pointed tip at the base, although, this base may be more flat if the blade is blunt. The mark should be more even and cleaner with less debris.
   b. Stone tool cut marks will generally have one side that rises steeply and another that is gradual. Striations within the groove are expected to be common and the mark should be more uneven and messy with debris.

2) In terms of diagnosing human versus non-human marks it is hypothesised that a number of factors are important including:
   a. Placement in regard to muscle attachments or fossae
   b. A degree of repetition in placement and style of butchery
   c. The appearance of the cut mark itself

3) Lastly, the most general assumption rests on a degree of uniformitarianism that is inherent in the scientific method and experimental archaeology. This study assumes that experimental cut marks produced in controlled circumstances will be similar enough to archaeological cut marks to allow for comparison.
3.3 Material

3.3.1 Lerna cut marks

The Lerna material was obtained through my supervisor Melanie Fillios. Fillios’ (2007) study on the role of pigs in Early Bronze Age Greece had access to faunal material from Lerna in the archaeological museum of Argos. Whilst there, Fillios (2007: 131) made small moulds of eight different groups of cut marks on Sus sp. bones intended for later study (table 3.1). Unfortunately, photographs of the original bones are not available. The moulds were created by applying a polyvinylsiloxane addition-type silicone elastomer\(^1\) directly onto the cut mark. Once the material was set it was peeled off producing a negative image of the surface. Positive moulds were made by using President Fast Soft Putty\(^2\) and pressed onto the surface of the negative image and peeled off to set.

Previous studies of cut marks using SEM have used moulds rather than bone (some examples include Potts and Shipman, 1981: 577; Bromage and Boyde, 1984: 360; Greenfield, 1999: 799; 2002: 36-37; 2006: 149-151; West and Louys, 2007: 513). One of the reasons for this is the sample does not need to be cut to fit into the SEM chamber, which only permits samples up to about 3cm. Also, it is easier to obtain permission to take moulds of cut marks out of a country rather than the bones themselves. Moulds are quick and inexpensive to make and are not considered to be original artifacts (Greenfield, 2006: 151). Although moulds may remove tiny, fragile pieces of the surface of the bone and sometimes slightly discolour the bone, in all cases scholars have noted that there was no difference between using moulds or bone samples (Greenfield, 2002: 37; 2006: 150-151). Rose (1983: 259-260) also noted moulds can sometimes have ‘artifacts’, such as bubbles, created during the process of making them but these are few and easily recognisable. For the experimental cuts marks both moulds and bone were used in order to test whether there were any perceivable differences.

\(^1\) *Coltene Whaledent Affinis* perfect impressions light body silicone based impressions material.
\(^2\) As above.
3.3.2 Selection of Lerna material

Given the time-consuming nature of the analyses used in this study all of the Lerna cut mark moulds were not able to be analysed. It was essential that experimental data was analysed as well as the Lerna material and extra time for error needed to be factored in. Initial selection of the Lerna cut marks was based on the desire to analyse a range of different types of marks. Tentative identifications were made as to whether the marks looked more like slice or chop marks (table 3.1). The next selection criteria was the quality of the mould, as some of the moulds were superior to others, hence, one group of cut mark had at least three different moulds (table 3.1). Also, for at least the first couple of analyses it was decided to have an ‘obvious’ cut mark to start.

As the analyses progressed, and some of the benefits and shortcomings of Micro-CT were realised, adjustments were made as to the type of technique and cut mark used (see discussion section for more detail). In the end, five different groups of Lerna cut marks were analysed using various techniques (table 3.1).

3.3.3 Experimental material: Pig Bone

In order to have an experimental control, it was necessary to have material in which the agent of modification (stone, metal, tooth) was known to allow comparisons to be made. Since the Lerna moulds were all pig bones it was logical to use pig bones for the experimental material. The Lerna moulds are from a variety of different parts of the pig’s anatomy (table 3.1, fig. 3.11). One of the variables within faunal studies is bone density, which differs within bones of the same individual as well as between individuals (Ioannidou, 2003; Lam and Pearson, 2005). Although it is possible that this variance in density will affect cut marks, the extent of this is not known and most studies on bone density have focused on how density affects bone survival (Lyman, 1994: 238-258; Dominguez-Rodrigo, 2002: 12-13). To help eliminate some variability caused by density, cut marks of each material were made on one bone from a single individual. Long bones were used as they have, on
average, more cut marks than other elements in assemblages due to behavioural and taphonomic factors (Lam and Pearson, 2005: 100, 105-106; Dominguez-Rodrigo and Yravedra, 2009: 885, 889). A right Sus domesticus humerus that had an articulated scapula still attached was purchased from the butchers for the dog gnawing, chert and bronze cut marks. For the final analyses only marks from the humerus were used. A separate Sus domesticus humerus was obtained for the obsidian cut marks.

The other important variable that needed to be decided upon was whether to use bone with or without meat attached. Some early studies that used bone without the meat attached to create experimental cuts (Shipman, 1988) were criticised for their methodology as this does not reflect true butchering of an animal (Gifford-Gonzales, 1989: 181-185; Haynes, 1991: 163). Nonetheless, most studies on cut mark morphology since then have still opted for bones with meat removed, and for good reasons. One of the problems when butchering a bone with meat still attached is that it greatly reduces the amount of cut marks on the bone (Shipman, 1988: 266; Braun et al., 2008). Thus, in studies that are primarily concerned with the material agent or the morphological appearance of the cut mark itself, the choice is usually made to use bones with meat removed (Bromage and Boyde, 1984; Shipman, 1988; Greenfield, 2002, 2006; Braun et al., 2008; de Juana et al., 2010). Whereas, studies that are primarily concerned with cut mark frequency and placement, attempt to reproduce the whole butchering process (Blumenschine, 1995; Dominguez-Rodrigo, 1997; Lyman, 2005; Dewbury, 2009). The stated reason why de Juana et al. (2010: 1842) used defleshed bone was that flesh decreases the amount of control over the angle of the cutting tool, however, in their study some fleshed bones were also cut for comparison and it was found they both had similar characteristics. Indeed, Greenfield (1999: 799; 2002: 36; 2006: 149) went so far as to use a soft wood instead of bone to reduce the issue of bone density variability. The decision to use soft wood seems slightly odd, as variability in density is an inherent factor in all bones and all faunal studies, and the extent to which bone density affects cut marks is not agreed upon anyway. Using another material does not ‘fix’ the problem of variability; instead, it could be argued it creates the illusion of greater
uniformity. If what was of primary interest was cut mark placement or frequency, then it may have been necessary to attempt to butcher the pig in a similar method to an Early Bronze Age person. However, the primary concern of this dissertation is the material agent of the mark, thus, defleshed bone was used for the experimental studies.

3.3.4 Experimental material: Stone and metal tools

In order to make the cut marks, stone and metal tools similar to what would be expected for Early Bronze Age Lerna were needed. Local chert and imported obsidian tools were common finds at Lerna and cores suggest these tools were manufactured onsite (Hartenberger and Runnels, 2001: 273; Wiencke, 2010: 661). Thus, there is reason to believe animals may have been butchered using chert or obsidian tools. A modern chert tool of approximately 10 cm length (fig. 3.1) was obtained from Melanie Fillios and two approximately 5cm and 5.5cm length obsidian tools were obtained from Nina Kononenko (fig. 3.2).

For the metal tool, it was desirable to use a metal similar to what would have been available given the techniques at the time. Crawford’s Casting, which specialises in casting bronze, were happy to donate some scrap bronze for the project. The option that was decided on was to use a medium-hardness bronze of approximately 95% copper, 4% silicon, with manganese and other trace elements (fig. 3.3). Compared to modern bronze this is relatively soft and is, in theory, similar to the type of bronze available during the Early Bronze Age, whilst, at the same time being durable enough to be used for butchering an animal. This scrap piece of bronze was sharpened at Crawford’s Casting although it was suggested to not sharpen the tool as sharp as possible using the electric grinder as this technique would be less authentic to the Bronze Age. In regard to the type of metal objects found at Lerna, there have been small chisels and knives excavated similar to the experimental bronze tool (fig. 1.8)(Liritzis, 1996: 40-42; 49-51; 54-55; 62-63; 65; 74-75; 77; 299-302).


4 Pers comm.,Crawford’s Casting.

5 As above.
3.4 Method

3.4.1 Producing a non-human agent

A control sample of marks that were not human-induced were made to help confirm that the Lerna cut marks were produced by the action of humans. A number of non-human factors were feasible contenders especially dog and pig tooth marks and trampling marks. Gejvall (1969: 19, 53) noted the presence of dog remains and gnawing on pig bones at Lerna and Fillios (2007: 134) believed it was a strong possibility the assemblage had been subject to canine gnawing. Thus, dog gnawing marks were used as the non-human agent. An approximately 27 kilogram 11 year old Golden Retriever was the chosen agent. As mentioned above, in order to control bone density the same bone was used for the non-human and human marks. Thus, the pig humerus was cut into two using a 0.5mm hack saw and the dog was given the distal end to chew (figs. 3.4-3.5). If dogs are left with a bone they often consume it entirely or chew it until the bone is destroyed, and this is especially prevalent in domestic dogs, which Binford (1981: 49) termed boredom chewing. Therefore, after about 15 minutes the bone was taken away from the dog in order to preserve some tooth marks.

3.4.2 Producing the human agent

One of the other variables that is often mentioned in scholarship is the degree to which the skill of the butcher affects cut marks. It is generally agreed upon that the more skilled the butcher the, less cut marks on the carcass and cut marks are seen as accidents rather than a direct reflection of the number of butchered bones (Lyman, 1994: 301-302; Fisher, 1995: 55; Braun et al., 2008). Again, since this study is not concerned with cut mark frequency or placement but, rather, the appearance of the cuts themselves, this variable was not such a big influence. The bones were cut by myself as, noted by Seetah (2008: 144), obtaining advice from a professional is to be encouraged but using the professional to butcher the bones undermines our ability to understand and interpret the process.
Before the cuts were made, the bones were inspected for any marks that may have been created by the butcher. Test and final cut marks were made a number of times over a period of a week (fig. 3.6-3.9). During the creation of the test marks, it was discovered how difficult it is to create a mark on bone. This was partly due to the muscle and periosteum that covers and protects the bone as well as the hardness of the bone itself.

The final cut marks for the chert and bronze tools were made on a pig proximal humerus and scapula. To help avoid confusion, the stone marks were created on the posterior surface and metal marks were created on the anterior surface (figs. 3.7-3.8). Obsidian stone tool marks were made at a later date also on a pig humerus (figs. 9.3-10.3). Since there was still some muscle attachment and periosteum on the bone, the butchery process was emulated and cut marks were created where they would be typically found on the bone, such as muscle attachment areas and fossae (Binford, 1981). Firstly, the humerus was disarticulated from the scapula. In some areas it was necessary to scrape the periosteum away from the bone in order to create a cut mark. When creating the cut mark, an area would be chosen, then a series of 1-5 discrete marks were made with an attempt to keep the angle and pressure similar. Another area would then be chosen and a slightly different angle and pressure used to emulate the type of variability that may occur.

During the butchery and cut mark process it was realised that the stone tool was relatively effective as a butchering and cutting device, whereas, the metal tool was quite inefficient because it was too blunt. The marks that the metal tool created were quite superficial compared to the stone tool marks. The blade of the metal tool was sharpened as it was unlikely a blade that blunt would have been used to butcher an animal. Once the blade was sharpened more cut marks were made and there was a notable difference. However, the small chisel-like size of the blade, combined with a lack of friction, still made it more difficult to butcher with than the stone tool.
In regard to cutting with obsidian, although it did feel sharper than the chert tool, it could not be pressed as hard as a metal knife. To the eye, the marks possibly looked sharper than the chert tool but still appeared to look like a typical stone tool (figs. 3.9-3.10).

3.4.3 Preparation for analysis

Before the cut marks and dog chew marks could be analysed they needed to be thoroughly cleaned and preferably dried for a few days. An accepted method to clean bones is to use slightly detergent water and slowly boil for a few hours until the meat and periosteum is easy to pull away (Dewbury, 2009: 26-27). Although, it has been noted by some scholars that cooking or boiling bones can affect the surface detail, there is no other quick and easy method of cleaning bone (Potts and Shipman, 1981; Pearce and Luff, 1994). Some scholars opt for using natural taphonomic methods, such as, burying the bone, but this method is time-consuming (Andrews and Cook, 1985).

In order to test whether moulds make a difference to the appearance of a cut mark, a combination of moulds and real bone were used (tables 3.1-3.2). The moulds were created using the same method mentioned for the Lerna moulds. The areas of bone with cut marks were cut into small sections using a diamond saw and an electric saw with a 2.5mm tungsten carbide blade. Both saws were effective in cutting the bone without it shattering, with relatively little pressure, much easier than using the hand saw (fig. 3.10).

For the samples that underwent SEM analyses palladium coating was required in order to make the sample conductive (Rose, 1983). An Emitech K550X sputter coater,\(^6\) coated the samples in palladium for approximately two minutes.

3.4.4 Micro-CT analyses

Analysis was performed in the Australian Centre for Microscopy and Microanalysis (ACMM) at the University of Sydney using a Skyscan 1072 Micro-Computed Tomography.\(^7\) Specialist Dennis Dwarte

---


\(^7\) Specialist Dennis Dwarte
provided instruction and assistance throughout the process. The sample was placed onto a platform then placed into the chamber. A number of parameters had to be decided on including; magnification, rotation step (amount of x-rays taken for each angle it rotates) and exposure time. These parameters would determine resolution of the image and compromises needed to be made. For instance, the higher the resolution, the smaller the area in focus, and the longer the scan. Conversely, the lower the resolution, the larger the area in focus, resulting in a shorter scan. Since no cut mark study has used Micro-CT, some trial and error was necessary depending on the size of the sample and the cut mark itself. On average, between 5-10µm pixel size was used, but even with 5µm pixels, there were problems with resolution of surface features on finer cut marks, such as, Lerna sample BE289 cut mark #1 which was scanned once on Skyscan and twice on Xradia (table 3.1). A rotation step of 0.23° was maintained which meant the samples were scanned each time the platform rotated 0.23° and exposure time per scan varied from 885-1770 milliseconds (see appendix for raw data). Scanning on the Skyscan took around 2-3 hours for each sample. An attempt was made to fix problems with resolution and noise by using the Xradia MicroXCT-400 Micro-Computed Tomography\(^8\) which has the capability for higher resolution. Scanning on the Xradia took longer, around 8 hours, as the resolution was set to a higher level. Overall, four separate scans on the Xradia and eleven scans on the Skyscan were performed (tables 3.1-3.2).

After scanning on the Skyscan the first stage of reconstruction using the computer software NRecon\(^9\) began. This stage filters the raw data so that it is readable for the next imaging reconstruction stage. Two main filters or adjustments may be needed including the smoothing of ring artifacts as well as checking the shift of the objects, both are artifacts of the machine as it scans. A decision also needed to be made as to whether all image slices are kept or whether some of the slices can be cropped. In all cases some cropping of unnecessary edges were employed which decreased the amount of time

---

\(^7\) Skyscan, Kontich, Belgium, accessed 08/09/2010 http://www.skyscan.be
taken to reconstruct the image and reduced the size of the file. On average, this stage took about 1.5-2 hours per sample. It should be pointed out that scans using the Xradia machine do not need this step as Xradia performs this reconstruction step automatically after the scan and, therefore, NRecon is not used.

The second and final stage of reconstruction uses the imaging software VG Studio Max to create a 3D image of the cut mark. This software allows the user to slice into the object, change the orientation, create light and shadows, and small movies. As well as the 3D image, axial, sagittal and frontal slices of the object can be viewed and these scenes were useful for displaying the profile of the cut mark. As mentioned above, there were some problems with resolution and noise and for this reason it was necessary to use SEM and light microscopy to compare with the Micro-CT and determine whether this issue could be resolved.

3.4.5 Light microscope analyses

A digital light microscope, Dino-Lite Digital Microscope Pro AM413T;\textsuperscript{10} was borrowed from the archaeology lab of Sydney University. This microscope can be connected straight into a computer to download the images using the Dino Capture 2.0 software. Getting the angle and light on the object correct was difficult, but this technique was relatively quick and easy to learn. Overall, five samples were analysed under the light microscope (tables 3.1-3.2). A variety of magnifications were used, ranging from 37x to 215x.

3.4.6 SEM analyses

Preparation and analysis was performed in the ACMM labs using a Zeiss EVO 50.\textsuperscript{11} Before analysis began, the samples were coated in palladium in order to make them conductive; an Emitech K550X

\textsuperscript{11} Carl Zeiss AG. Oberkochen and Jena, Germany, accessed 11/10/2011 for specs of this particular instrument see: http://www.speciation.net/Database/Instruments/Carl-Zeiss-AG/EVO-50-Series-j663
sputter coater was used for this. The samples were then fixed onto a platform and placed into the chamber. The chamber is pumped down under vacuum. For the samples that were moulds, this vacuuming took a few minutes but the bone samples took much longer due to the porosity of the material. After the first attempt with the bone samples, the samples were left to vacuum overnight and it took about 16 hours! Another benefit of using moulds instead of bone became clear.

Taking images on SEM was much quicker than on Micro-CT as one simply used the controls on the specialised keyboard of the computer to capture each image. Apart from the voltage, which was kept constant at 3.00kV, the specifications of each image were automatically adjusted depending on how far zoomed-in the camera was. The possible resolution and magnification obtainable on the SEM is much higher than the Micro-CT (see footnote above), thus, some trial and error was necessary as if the camera was too close the cut mark becomes obscured. The best images were obtained around 100-200 μm and a range of wide and close shots were taken. Overall, nine samples were analysed under SEM (tables 3.1-3.2).

3.5 Summary

In total, Micro-CT analysis was performed fifteen times on four Lerna and nine experimental samples. SEM analyses were performed nine times on three Lerna and six experimental samples. A light microscope was used five times for four Lerna and one experimental samples. Table 3.3 details the main decisions and reasons behind them discussed in this chapter.
TABLES AND FIGURES

CHAPTER 3

MATERIALS AND METHODS
Table 3.1: Lerna cut mark details. Those highlighted in light blue were the cuts selected for this study. LM = light microscope.

<table>
<thead>
<tr>
<th>Item #</th>
<th>Bone</th>
<th>Placement</th>
<th># casts</th>
<th>Side</th>
<th>Techniques used</th>
</tr>
</thead>
<tbody>
<tr>
<td>J467</td>
<td>Humerus</td>
<td>Distal</td>
<td>3</td>
<td>R</td>
<td>SEM, LM</td>
</tr>
<tr>
<td>BE351</td>
<td>Scapula</td>
<td>Distal</td>
<td>3</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>G164</td>
<td>Humerus</td>
<td>Distal</td>
<td>5</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>BE289</td>
<td>Scapula</td>
<td>Dorsal</td>
<td>3</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>BE289 Cut mark #2</td>
<td>Scapula</td>
<td>Dorsal</td>
<td>3</td>
<td>L</td>
<td>Skyscan, SEM, LM</td>
</tr>
<tr>
<td>BE289 Cut mark #4</td>
<td>Scapula</td>
<td>Dorsal</td>
<td>3</td>
<td>L</td>
<td>Skyscan and Xradia (twice), SEM, LM</td>
</tr>
<tr>
<td>BE289 Cut mark #1</td>
<td>Scapula</td>
<td>Dorsal</td>
<td>3</td>
<td>L</td>
<td>Skyscan, LM</td>
</tr>
<tr>
<td>BD435</td>
<td>Calcaneus</td>
<td>Dorsal</td>
<td>3</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>BE323</td>
<td>Ulna</td>
<td>Dorsal</td>
<td>3</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item #</th>
<th>Possible cut type</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>J467</td>
<td>slice</td>
<td>Adult Sus. About 3 long cut marks, 2 parallel 1 adjacent.</td>
</tr>
<tr>
<td>BE351</td>
<td>chop</td>
<td>Just above glenoid on neck below spine. 1 short mark.</td>
</tr>
<tr>
<td>G164</td>
<td>chop</td>
<td>7 short marks, parallel.</td>
</tr>
<tr>
<td>BE289 Cut mark #2</td>
<td>slice</td>
<td>Long, fine marks, about 10 cuts.</td>
</tr>
<tr>
<td>BE289 Cut mark #4</td>
<td>chop</td>
<td>2 short marks in same direction.</td>
</tr>
<tr>
<td>BD435</td>
<td>slice</td>
<td>Juvenile Sus. 1 short sharp mark.</td>
</tr>
<tr>
<td>BE323</td>
<td>chop</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1: Chert stone tool used to create experimental cut marks. Approximate measurements: length 10cm, height 6cm, width 1cm, length of cutting edge: 8cm.
Figure 3.2: Obsidian tools used to create experimental cut marks. Approximate measurements: (left) 5.5cm length, 3cm height, 0.5cm width. (Right) 4.5cm length, 4cm height, 1cm width.

Figure 3.3: Bronze tool used for experimental cut marks. Approximate measurements: length 10cm, height 3cm, width 0.5cm, length of blade: 3cm.
Figure 3.4: Golden Retriever chewing the distal end of the humerus.

Figure 3.5: Cutting the pig humerus in two using a 0.5mm hack saw.

Figure 3.6: Making some practice cut marks on a pig atlas using the stone and metal tools.
Figure 3.7: Stone cut marks on posterior surfaces of the humerus and scapula.

Figure 3.8: Metal cut marks on anterior surfaces.
Figure 3.9: Pig humerus used for experimental obsidian stone tool cut marks.

Figure 3.10: Process of using an electric saw with a 2.5mm blade to section the humerus into samples small enough for analysis.
Table 3.2: Details of experimental cut marks. LM = light microscope.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Techniques used</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog</td>
<td>Skyscan</td>
<td>Mould</td>
</tr>
<tr>
<td>Dog</td>
<td>Skyscan</td>
<td>Mould</td>
</tr>
<tr>
<td>Bronze atlas (test)</td>
<td>Skyscan</td>
<td>Mould</td>
</tr>
<tr>
<td>Bronze humerus #1</td>
<td>Skyscan</td>
<td>Bone</td>
</tr>
<tr>
<td>Bronze humerus #2</td>
<td>Xradia, SEM</td>
<td>Bone</td>
</tr>
<tr>
<td>Bronze humerus #3</td>
<td>Skyscan, SEM</td>
<td>Bone</td>
</tr>
<tr>
<td>Bronze humerus #4</td>
<td>SEM</td>
<td>Bone</td>
</tr>
<tr>
<td>Chert humerus #1</td>
<td>Skyscan, LM</td>
<td>Mould</td>
</tr>
<tr>
<td>Chert humerus #2</td>
<td>Skyscan</td>
<td>Bone</td>
</tr>
<tr>
<td>Chert humerus #3</td>
<td>Xradia</td>
<td>Bone</td>
</tr>
<tr>
<td>Obsidian humerus #1</td>
<td>SEM</td>
<td>Bone</td>
</tr>
<tr>
<td>Obsidian humerus #2</td>
<td>SEM</td>
<td>Bone</td>
</tr>
<tr>
<td>Obsidian humerus #3</td>
<td>SEM</td>
<td>Bone</td>
</tr>
</tbody>
</table>
Table 1.3: Summary of variabilities and potential problems that needed to be considered throughout the methodology process.

<table>
<thead>
<tr>
<th>Variability / potential problem</th>
<th>Decision</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone with or without meat</td>
<td>Without meat</td>
<td>Emphasis is on cut mark morphology and material agent rather than frequency or placement</td>
</tr>
<tr>
<td>Use skilled or unskilled butcher to cut bone</td>
<td>Myself (unskilled)</td>
<td>Learn more by performing task by yourself</td>
</tr>
<tr>
<td>Density of bone</td>
<td>Use 1-2 bones from 1 individual</td>
<td>Will decrease variability</td>
</tr>
<tr>
<td>Lerna cut marks – moulds instead of bone</td>
<td>Use of both moulds and bone in experimental material</td>
<td>Will help to test whether there are differences</td>
</tr>
<tr>
<td>Metal and stone tools- how accurate are they to Bronze Age technology</td>
<td>Use of chert, obsidian, and bronze</td>
<td>Use materials that are known to be excavated from Lerna</td>
</tr>
<tr>
<td>Dog marks- use of older, domestic dog and being watched- may affect what would normally be expected in an assemblage</td>
<td>Used a domestic, older dog and watched while the bone was being chewed and took away the bone before it was completely eaten</td>
<td>Needed to be watched so bone could be taken away before destroyed and notes could be taken on how the dog chewed the bone</td>
</tr>
<tr>
<td>Angle and pressure at which the blade is held when cutting</td>
<td>Use of number of angles and pressures</td>
<td>Hope to represent natural variability in assemblage</td>
</tr>
<tr>
<td>Cleaning the bone could affect surface detail</td>
<td>Used lightly detergent water and slow boil</td>
<td>Most simple and quick method employed by many scholars</td>
</tr>
<tr>
<td>Micro-CT and SEM – magnification, rotation step, exposure time = resolution</td>
<td>Higher resolution- longer time, smaller area</td>
<td>Compromise needed</td>
</tr>
<tr>
<td></td>
<td>Lower resolution- shorter time, larger area</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.11: Diagram of a ‘boar skeleton’ highlighting bones used for Lerna and experimental analyses (Sack 1982: 63).
4.1 Forward

Below are the results of analyses of the Lerna and experimental cut marks. The images were carefully selected for their ability to display the range of variability of the cut marks in order to give the reader a thorough understanding of each sample. It is also intended that these results will provide a useful reference guide for stone and metal cut marks. Some Micro-CT scans that did not work were included for comparison in order to display weaknesses of the technique and the necessity for trial and error. The selection of images represents much less than half of the images actually taken.

The Lerna cut marks are displayed first, followed by the experimental cut marks which are organised according to material agent. Details of images of each sample are on a separate page before each section along with a photo of the sample/s used for the analyses. Unfortunately, it was not possible to obtain a photograph of some samples.

Overall, five Lerna cut marks were analysed using various techniques detailed below. For the experimental cut marks, two dog marks, one test cut mark on an atlas, four bronze tool marks, three chert marks, and three obsidian marks were analysed with various techniques which is detailed after the Lerna section. As mentioned in chapter three, Xradia and Skyscan are Micro-CT instruments and LM is an abbreviation of light microscopy.
4.2 Lerna cut marks

Overview:

BE289 CUT MARK 1: XRADIA, SEM, LM – 12 images
BE289 CUT MARK 4: SKYSCAN, SEM, LM- 19 images
BD435: SKYSCAN, LM- 9 images
BE323: SKYSCAN- 8 images
J467: SEM, LM- 11 images

4.2.1 BE289 CUT MARK 1: XRADIA, SEM, LM

4.1) Photograph of sample BE289 cut mark #1. The two moulds are from the same group of cut marks.
4.2) Example of first Xradia scan that did not work
4.3) Second Xradia scan, whole image showing three cut marks. Not sample itself is not round but Xradia focused on one section of the sample so that image appears round.
4.4-4.6) Close-ups slicing into the image showing profiles
4.7) A 2D slice taken from using one angle showing profiles
4.8) LM showing whole sample (can see more cut marks than Xradia and SEM). Specs for each LM images are at the left top and bottom but unfortunately the writing is very small. Mag. 53x; scale bar 1mm.
4.9) Close-up showing profile and striations (?). Mag. 215x; scale bar 0.2mm.
4.10) Close-up showing rough edges. Mag. 105x; scale bar 0.5mm.
4.11) SEM showing about four cut marks
4.12) Close-up on striations
4.2.2 BE289: CUT MARK 4, SKYSCAN, SEM, LM

4.13) Photograph of BE289 cut mark #4. This mould was cut into four parts to facilitate analysis. The section #2 was not used in the analyses.

4.14) Skyscan of whole image of section #2 showing three cut marks

4.15-4.19) Close-ups showing profiles of section #2

4.20-4.24) 2D slices from one angle showing variability of profiles of section #2. Slicing from the opposite side, from ‘behind’ shown in the 3D images above.

4.25) LM of whole image of section of #2. Mag. 48x; scale bar 1mm.

4.26) Close-up of above. Mag. 80x; scale bar 0.5mm.

4.27) Section #1 showing one cut mark. Mag. 77x; scale bar 0.5mm.

4.28) SEM close-up of section #2

4.29) Close-up of above showing a subsidiary groove

4.30) Section #1 with one cut mark

4.31) Section #3 showing the cut mark at the far right
4.2.3 BD435: SKYSCAN, LM

4.32) Photograph of mould BD435.
4.33-4.34) Whole image of sample showing two cut marks (this sample did not turn out well in skyscan)
4.35) Close-up on one profile
4.36-4.37) 2D slices from one angle showing profile
4.38) LM showing whole image of two cut marks and one small cut. Mag. 37x; scale bar 1mm.
4.39) Another angle. Mag. 60x; scale bar 1mm.
4.40) Close-up of one cut mark showing striations. Mag. 58x; scale bar 1mm.
4.2.4 BE323: SKYSCAN

Unfortunately, a photograph of the sample is not available.

4.41) Whole image of sample showing one cut mark
4.42-4.44) Showing profile of cut mark
4.45-4.48) 2D slices from one angle showing profile
4.2.5 J467: SEM, LM

4.49) Photograph of sample J467 with a close-up.
4.50) Showing intersection of about three cut marks (two at a parallel angle and one at the top of the image in a perpendicular direction)
4.51) A long cut mark, showing striations
4.52) Close-up of fig. 51
4.53) The end of a cut mark showing signs of age- loosing detail
4.54) Showing the top perpendicular mark (as mentioned in fig. 1) where something seems to have gone wrong in the mould process, the bottom of the cut appears too smooth and flat compared to the other marks
4.55) Far view of top perpendicular mark intersecting with the two parallel cut marks below. Top right part of the image shows where the perpendicular mark and the right bottom cut mark intersect. Image also shows there is a series of fine perpendicular marks that run parallel to the ‘obvious’ one at the top.
4.56) Showing the end of top perpendicular mark which suggests something went wrong during mould process, it looks as though something was in-between the mould and the bone
4.57) LM, image of intersecting marks. Mag. 123x; scale bar 0.5mm.
4.58) Close-up of one cut mark showing striations. Mag. 55x; scale bar 1mm.
4.59) Close-up of top cut mark. Mag. 83x; 0.5mm.
4.3 EXPERIMENTAL CUT MARKS

Overview:
DOG SCORE MARKS: SKYSCAN - 6 images
DOG TOOTH PUNCTURES: SKYSCAN - 8 images
BRONZE ATLAS: SKYSCAN - 3 images
BRONZE HUMERUS #1: SKYSCAN - 9 images
BRONZE HUMERUS #2: XRADIA, SEM - 6 images
BRONZE HUMERUS #3: SKYSCAN, SEM - 9 images
BRONZE HUMERUS #4: SEM - 5 images
CHERT HUMERUS #1: SKYSCAN, LM - 10 images
CHERT HUMERUS #2: SKYSCAN - 11 images
CHERT HUMERUS #3: XRADIA - 8 images
OBSIDIAN HUMERUS #1: SEM - 5 images
OBSIDIAN HUMERUS #2: SEM - 5 images
OBSIDIAN HUMERUS #3: SEM - 5 images

4.3.1 DOG SCORE MARKS: SKYSCAN

4.60) Photograph of dog score marks
4.61) 2D slice view from one angle showing profile
4.62-4.64) Different angles of the surface, attempting to show mark the score mark did not turn out well on skyscan
4.65) 2D slice view from one angle showing profile that looks similar to a cut mark
4.3.2 DOG TOOTH PUNCTURES: SKYSCAN

4.66) Photograph of dog tooth punctures.
4.67-4.68) Whole image of two puncture marks
4.69-4.71) Various angles and slices showing the shape of the tooth marks. NB, Fig. 3 contains light blue lines in the image, these should be ignored as they are a product of the software rather than the sample.
4.72-4.73) 2D sagittal and axial slices
4.3.3 BRONZE ATLAS: SKYSCAN

4.74) Photograph of bronze atlas sample
4.75) Whole image of surface which did not turn out well
4.76) 2D slice from one angle, no features can be seen
4.3.4 BRONZE HUMERUS #1: SKYSCAN

Unfortunately, a photograph of sample is not available.

4.77) Whole image of cut mark
4.78-4.82) Various angles and slices showing profile
4.83-4.85) 2D slices from one angle showing profile
4.3.5 BRONZE HUMERUS #2: XRADIA, SEM

4.86) Photograph of bronze humerus #2 sample. Note, sample is mounted onto as SEM platform.
4.87-4.89) Xradia images of the surface showing two cut marks. Images turned out small with a low resolution.
4.90-4.91) SEM images of the surface showing how blunt cut marks are, porosity of bone helps to disguise marks.
4.3.6 BRONZE HUMERUS #3: SKYSCAN, SEM

4.92) Photograph of bronze humerus #3 sample
4.93) Skyscan whole image of the surface showing all the cut marks
4.94) Opposite angle
4.95-4.96) Different angles and slices showing profile of marks
4.97) SEM showing most cut marks and curved surface of bone
4.98) Another view of the surface
4.99) Close-up on fig. 98 of two cut marks, one with striations, the other with lots of surface folding but quite sharp
4.100) Another angle showing a cut mark that is quite straight and long
4.3.7 BRONZE HUMERUS #4: SEM

4.101) Photograph of bronze humerus #4 sample. Note sample is attached to SEM platform.
4.102) Whole image of surface showing about four cut marks
4.103) Close-up on one side, showing surface folding and a chunk of bone that was removed/pushed to the side
4.104-4.105) Showing three cut marks with surface folding but also straight and sharp
4.3.8 CHERT HUMERUS #1: SKYSCAN, LM

4.106) Photograph of chert humerus #1 sample.
4.107) Whole image of surface
4.108, 4.110-4.112) Various angles and slices showing profiles
4.109, 4.113) 2D slices from one angle showing profiles
4.114) LM image of cut marks showing curvature of bone. Magnification on image 230x is incorrect closer to: Mag. 60x; scale bar 0.2mm.
4.115) Close-up of three cut marks. Mag. 75x; scale bar 0.5mm.
4.3.9 CHERT HUMERUS #2: SKYSCAN

Unfortunately, a photograph of the sample is not available.

4.116) Whole image of surface showing lots of buckling and surface folding
4.117) View from opposite angle
4.118-4.122) Different angles and slices into object showing profiles and surface folding. Images 118-120 slicing into the object one direction and images 121-122 slicing into the object from the opposite direction.
4.123-4.126) 2D slices from one angle showing profiles, also Fig. 8 highlights the surface folding feature
4.3.10 CHERT HUMERUS #3: XRADIA

Unfortunately, a photograph of the sample is not available.

4.127) Whole image showing problem with noise
4.128-4.131) Showing profiles slicing into object, NB, ignore the light blue lines which are a product of the software and not the sample
4.132-4.134) 2D slices from one angle showing profiles
4.3.11 OBSIDIAN HUMERUS #1: SEM

4.135) Photograph of obsidian humerus #1. Note sample is attached to SEM platform.
4.136) Whole surface showing about four cuts, all figures show lots of surface folding and debris left on the surface of the bone which obscures the profile of the cut marks
4.137) Close-up on two cuts
4.138) Close-up on one cut
4.139) Close-up on two cuts
4.3.12 OBSIDIAN HUMERUS #2: SEM

4.140) Photograph of obsidian humerus #2. Note sample is attached to SEM platform.
4.141) Far view of two cuts showing a change in bone structure in the middle from porous to dense bone, which affects how the cut marks appear. Denser bone retains more surface features, whereas, porous bone blurs the features.
4.142) Denser end of fig. 141, more surface folding
4.143) Close-up on porous bone section, surface features are blurred
4.144) Close-up on denser bone and striations
4.3.13 OBSIDIAN HUMERUS #3: SEM

4.145) Photograph of obsidian humerus #3. Note sample is attached to SEM platform.
4.146) Far view of three cut marks with surface folding, cuts are relatively sharp
4.147-4.149) Close-ups showing lots of surface folding which obscures the profile of the cut and makes it difficult to see striations. Relatively sharp but also superficial.
5.1 Introduction

Experimental data is discussed first and is organised into dog scores and punctures, bronze tool marks, and stone tool marks. This is followed by the Lerna data which is divided into stone and metal tool marks. The results of both experimental and Lerna cut mark data are then summarised. Subsequently, general limiting factors of the dissertation are noted. This is followed by the conclusion of the study which details implications to archaeology and assessment of techniques. Immediately below is a restatement and summary of the main objectives and hypotheses of this study.

5.2 Restatement and summary of objectives

There are three main aims to this study:

1) To determine whether the cut marks on animal bone from Early Bronze Age Lerna were produced by stone or metal tools or a non-human agent.

2) Assess the utility of Micro-CT for diagnosing cut marks on bone.

3) Add to knowledge about the spread of metallurgy and butchery practices in Early Bronze Age Greece and add to knowledge and discussion about cut mark studies in general.

Main hypotheses tested:

1) The main hypothesis rests on the notion that stone and metal cut marks will have different characteristic profiles (Walker and Long, 1977; Greenfield, 1999, 2002, 2004, 2005, 2006). It is proposed that:
a. Metal cut marks will generally have sharper sides with a pointed tip at the base. This base may be more flat if the blade is blunt. The mark should be more even and cleaner with less debris.

b. Stone tool cut marks will generally have one side that rises steeply and another that is gradual. Striations within the groove are expected to be common and the mark should be more uneven and messy with debris.

2) In terms of diagnosing human versus non-human marks it is hypothesised that placement, a degree of repetition, and the appearance of the mark is expected to be important.

5.3 Experimental data

The main results and findings for the experimental dog scores, punctures and cut marks are summarised in table 5.1. Overall, the expected characteristics of stone and metal cut marks were accurate, although, there was more variability in profile than anticipated. It was realised that bone density can greatly affect the quality and appearance of a cut mark.

5.3.1 Non-human agent: dog scores and tooth punctures

Whilst watching the dog gnaw the bone several trends noted by Binford (1981: 46) were perceivable in the way the gnawing proceeded from soft to hard bone. The dog began by attacking the diaphysis and worked its way down the shaft. A combination of incisors, canines, and molars were used with the canines and molars puncturing the softer bone and molars scoring the surface of the shaft. However, after the bone was cleaned it was difficult to find any ‘obvious’ score marks for analysis and, unfortunately, the score marks did not turn out well in the Micro-CT (figs. 4.62-4.64; compare to fig. 2.3). The 2D slice-views (figs. 4.61, 4.65) showed a few indents that may have been score marks, although, they do not consistently appear in the same area. The fact the dog did not produce clear score marks may have been a result of her being an older dog with sensitive teeth. However, there were two rather obvious canine puncture marks on the cancellous bone which were clear on
the Micro-CT in both the 3D and 2D images (figs. 4.67-4.73). The marks are cone-shaped with a rounded base. As can be seen, puncture marks are unlikely to be confused with cut marks produced by a human agency.

Domínguez-Rodrigo and Piqueras’ (2003: 1387) study of carnivorous tooth-pits gave an average length of 3.87mm and a breadth of 2.38mm for 16 dog tooth-pits. And Delaney-Rivera et al. (2009: 2601) gave an average length of 1.3mm and a breadth of 0.831mm out of 39 dog tooth-pits. Unfortunately, the Micro-CT is not a measuring device, so approximate measurements were made using a ruler and were noted in centimetres since the ruler is not as accurate as callipers; the largest puncture has a length of 0.5cm and a width of 1cm, and the smaller puncture has a length of 0.3cm and a width of 0.5cm. This places these marks towards the larger end of the scale for canids based on the findings above. However, both Domínguez-Rodrigo and Piqueras (2003: 1386-1387) and Delaney-Rivera et al. (2009: 2600-2602) cautioned there was great variability in size of pits and punctures within taxa, especially for the diaphyses where the bone is soft. The size of the punctures are, therefore, likely to be a function of the cancellous bone rather than the strength or size of the dog.

5.3.2 Bronze tool cut marks

The cut marks that worked the best in the analyses were bronze humerus #1, #3, #4. The practice cut mark made on the atlas was faint to the eye and Micro-CT was not able to pick it up (figs. 4.75-4.76). This is probably caused by the lack of contrast between the surface and the groove. Bronze humerus #2 was made before the blade was resharpened and is on comparatively more cancellous bone than the other bronze humerus marks (figs. 4.87-4.91). The porous nature of the bone results in blurring the features and a fainter mark. Although the SEM images show a typical |__| mark that you would expect from a blunt metal blade, they are quite superficial. It is interesting to note some slight striations on the bottom of the groove. This mark is comparable to the saw mark from Olsen (1988a) and blunt metal blade from Greenfield (2002) (figs. 2.17 and 2.21).
Bronze humerus #1 was also made before the blade was resharpened but either the bone is less-cancellous and/or the pressure of the blade was harder as the mark is distinct (figs. 4.77-4.85). Some of the images show a profile where the left side falls steeply and the right rises gradually, similar to expectations of a stone tool profile (figs. 4.79-4.80, 4.84-4.85). This is likely to be a result of the blade being held at an acute angle (around 45°) and shows the author is right-handed. Other images (figs. 4.81-4.83) show a distinct V-shape. There is no perceivable surface folding or striations. Also, the cut appears relatively straight and ‘clean’ with no debris within the groove, which are further characteristics of a metal tool.

Bronze humerus #3 (figs. 4.93-4.100) and #4 (figs. 4.102-4.105) were made after the blade was resharpened and shows considerable difference in the definition of the cut, especially to bronze humerus #2. The SEM images are particularly informative in displaying how sharp and straight the cuts are. Bronze humerus #3 is interesting as there are two cut marks side-by-side that are quite different in appearance (figs. 4.99 and 4.100); the mark on the left is relatively shallow with multiple, clear striations within the groove, whereas, the mark on the right is so narrowly V-shaped that it is difficult to tell whether the floor of the cut also has striations. The SEM images of bronze humerus #3 and #4 show abundant surface folding and debris within the cuts. The surface folding on bronze humerus #4 on all four cut marks seems to have buckled in a horizontal line across the bone which suggests surface folding may be affected by the freshness of the cut as well as bone structure. There is an abundance of surface folding and debris which is in stark contrast to bronze humerus #1, however, the cuts are still straight and sharp. Also, there are only Micro-CT images available of bronze humerus #1 and the SEM seems to be better at detailing surface folding; compare the Micro-CT and SEM image of bronze humerus #3. These marks are comparable to the experimental metal marks from Greenfield (1999, 2002) and Bello and Soligo (2008) (figs. 2.29, 2.30, and 2.45(a)).
5.3.3 Chert and obsidian tool cut marks

The images of chert humerus #1 are useful in displaying the variability of the profiles which range from a V-shape, to a \(\sqrt{\text{-shape}},\) to a U-shape. Although, as can be seen from figs. 4.107-4.108, there were problems with noise on the surface of the light microscope images, figs. 4.114-4.115, help to show surface details. The profile in the light microscope images appears as a general shape with the right side descending steeply and the left side rising gradually \(\sqrt{\text{-}}.\) The edge of the left side is also rough compared to the right side which is straight and smooth. This feature is also perceivable in the Micro-CT images of chert humerus #2, where the left side of the cut marks show more buckling/surface folding and are generally rougher (figs. 4.116-4.122, note some of the images are from opposite angles). This is caused by the pressure of the blade pushing down and smoothing the right side and forcing upward while buckling the left side, as well as the uneven surface of the chert blade. The long pyramid-shaped buckling feature (figs. 4.116, 4.118-4.119) is particularly striking and is visible in the 2D slice fig. 4.123. The distinct surface features of chert #2 are comparable to fig. 2.12 of oblique faulting. The profiles are also clear in figs. 4.118-4.126 and although there is considerable variability in the 2D slices, the overall picture, especially in the 3D reconstruction, is one side rising steeper than the other \(\sqrt{\text{-}}.\) Both chert humerus #1 and #2 are thus what is expected of stone tools. Chert humerus #3 did not turn out well on the Micro-CT, although, the 2D slices are relatively clear (figs. 4.132-4.134). Overall, the profile conforms to the stone tool type although the left mark in fig. 4.132 looks similar to a blunt metal tool \(|\_\_\|_.\) The general appearance of the chert cut marks is similar to many of the images of stone tool marks in chapter 2.

Obsidian tools were used to ascertain whether sharp obsidian is similar to bronze as this has been debated in scholarship (Walker and Long, 1977; Greenfield, 2002; Halstead, In press). Obsidian humerus #1 was made by using the blade in a chopping action which resulted in debris within and around the cut marks making it difficult to view the profile of the cuts. Obsidian humerus #1 and #2 were created using a slicing action similar to the chert humerus samples. The SEM images of
obsidian humerus #2 are interesting because they show how the porosity of the bone can affect the cut mark. Fig. 4.141 displays how the left half of the bone is porous while the right side is dense. Comparing the close-ups of figs. 4.142 and 4.143 helps to demonstrate how porous bone does not retain features as well as dense bone. Fig. 4.144 is a close-up of clear striations on the dense side of the bone and it shows how the blade has created a ‘shelf’ or ‘roof’ over part of the groove.

This is perhaps related to the sharp and thin nature of the blade. A similar affect can be viewed in humerus #3, figs. 4.146 and 4.149 which show the marks are sharper and narrower than the chert tool cut marks. However, the obsidian cuts are relatively superficial and retain an overall stone profile with striations. This supports the findings made by Walker and Long (1977: 609-613) that although obsidian marks may be sharper and narrower in areas than the average stone tool, they are more superficial than metal tools. If an obsidian blade is used in a sharp chop action the mark appears messier and is shallow compared to a metal chop mark (obsidian #1, figs. 4.136-4.139; compared to an ancient metal chop mark in fig. 2.29). Obsidian humerus #1, #2, and #3 support Greenfield’s (2002: 40) claim that sharp obsidian cut marks can be distinguished from metal cut marks as they possess the same characteristics of a stone tool cut. The obsidian cut marks are comparable to Greenfield’s (2002: 45, 46) experimental obsidian cuts in figs. 2.21, and 2.25.

It should be pointed out that the amount of surface folding and debris of the surface of the cut mark may be affected by whether the sample is mould or bone. Although previous scholars have used mainly moulds and report little to no difference (Greenfield, 1999, 2006) the moulds used in this study had overall less surface features than the bone samples but the profile did not seem to be affected. As was noted by Rose (1983), the process of creating a mould can remove fragile pieces of bone and this has probably resulted in ‘cleaner’ cut mark images from the moulds. However, this is not a major problem affecting the identification of the cut.
5.4 Lerna cut marks

The results and findings of the Lerna cut marks are summarised in table 5.2. Based on analyses and comparison with experimental data and previous scholarship, three moulds represent stone cut marks and two moulds represent metal cut marks.

5.4.1 Stone cut marks (BE289 cut mark #1, J467, and BD435)

Cut marks on BE289 (cut mark #1), J467, and BD435 have the appearance of typical stone tool marks. Mark BE289 (cut mark #1) was from a *Sus sp.* scapula and consists of a series of long slicing-like marks in approximately the same direction. The Micro-CT images (figs. 4.2-4.7) have focused on three marks and are useful in showing their profiles. Some of the images (figs. 4.6-4.7) show profiles that are relatively V-shaped but the general profile is \( \backslash / \). The Micro-CT images also show how the gradually sloping side is rougher on the edge of the cut, which is characteristic of the rough edge of a stone tool blade, whereas, the steeply declining side is relatively straight and smooth which represents the smooth side of the blade (figs. 4.3-4.5). The light microscope images (figs. 4.8-4.10) show more of the sample and further characteristics of stone tools. From these images, it is perceivable that one side of the mark is rougher than the other and striations can be seen at the end of the cut mark in fig. 4.8. The SEM images (figs. 4.11-4.12) highlight these striations particularly well.

Cut mark BD435 consists of two parallel, slice-like marks from a *Sus sp.* calcaneus. The Micro-CT images did not work as well as hoped due to problems with noise but they help to show a general profile which matches that of stone tools \( \backslash / \) (figs. 4.35-4.37). The light microscope assists in observing that the gradually sloping side has a rougher edge than the steeper side (figs. 4.38-4.39) and also show striations at the end of the mark (fig. 4.40). SEM analysis was attempted on this sample but, unfortunately, the adhesive failed to retain the sample to the platform and the sample kept falling off.
Sample J467 was from the distal humerus of a *Sus sp.* and is relatively complex. The sample consists of two parallel, slicing-like cut marks and another mark that runs in a perpendicular direction to the cut marks at one end (fig. 4.49). There are also a series of approximately twenty fine, abrasive-like marks which run in roughly the same direction as the perpendicular mark. The two parallel marks have the appearance of typical stone tool cut marks as they have striations and multiple subsidiary grooves within the cut as well as a stone tool profile (figs. 4.50-4.52, 4.59). Fig. 4.53 is a close-up on the end of the cut mark in fig. 4.51 and the close-up reveals signs of age in the cut mark in its loss of detail. Figs. 4.54-4.56, and 4.59 are close-ups of the perpendicular mark which shows that something has possibly gone wrong in the mould-making process. The base of the mark appears too smooth and flat compared to the sides of the cut and the surface of the bone. It is not clear whether this mark represents a cut mark, especially when one takes into account the series of fine marks that run in roughly the same direction. The fine perpendicular marks do not look like typical stone tool cut marks as there are so many of them concentrated together. If the marks were from trampling one would expect them to be irregular in orientation, although, regular marks caused by abrasion have been noted (Behrensmeyer et al., 1986). It is difficult to tell whether these marks were made before or after the oblique, parallel cut marks. If the perpendicular marks were made before the cut marks it could represent skinning or an accidental slip of the butchers tool. If these marks were made after the oblique cut marks it could be some type of accidental abrasion, or scraping to remove the periosteum. Either way, the difference in appearance of the oblique, parallel cut marks to the series perpendicular marks suggests a different kind of action. Nevertheless, the two parallel cut marks running in an oblique direction to the perpendicular marks are examples of typical stone tool cut marks.

**5.4.1 Metal cut marks (BE289 cut mark #4, BE323)**

Cut mark BE289 (cut mark #4) was from a *Sus sp.* scapula and consists of seven short, parallel marks. The mould was cut into four separate parts to facilitate analysis on the Micro-CT and SEM. Section #2 was not analysed. Section #3 was analysed with the Micro-CT, SEM, and light microscopy as it has
three cut marks close together that allowed for comparison. The Micro-CT images of section #3 unfortunately resulted in a small, low resolution image which means the image becomes blurred when it is enlarged (figs. 4.14-4.19). Figs. 4.18-4.19 show a profile \( \sqrt{ } \) that is sharp and leans towards the right. Figs. 4.15-4.17 are difficult to see but show some variability. The profile is more evident in the 2D slice images (figs. 4.20-4.24) and shows a combination of V and \( | \_ | \) type profiles. Also, the middle cut mark displays a splitting in two (fig. 4.24) which represents a subsidiary groove. This feature is evident particularly in the light microscope (figs. 4.25 and 4.26) which show a subsidiary groove at the extremity of both ends of the middle cut mark. These images also portray how the marks lean on an inclination to the right which suggests the force of the blade leaned towards the right of the image (see limitations below). The light microscope images show the cut marks are quite straight, sharp, and smooth. The SEM images do not show the whole mark but focus on the end with the obvious subsidiary groove. Unfortunately, there is no SEM image of the whole cut marks of section #3 as the close-up slightly distorts the idea of what the mark looks like.

The light microscope and SEM image of section #1 show a mark that is very straight, sharp and smooth (figs. 4.27, 4.30). It has a sharp, pointed V-shaped base. The SEM image of section #4 (fig. 4.31) focuses on the far-right cut mark and is interesting because it looks different from the other marks. The base of the cut is smooth and flat creating a blunt profile \( | \_ | \) but the cut also extends from a very skinny base at the bottom of the image to a wide opening at the top of the image. The surface of the bone is noticeably more porous than the other images and this could be the reason for the difference in appearance. As was noted in the experimental cut marks, cancellous bone does not retain features as well as cortical or dense bone (see bronze humerus #2 for an example of this).

All seven marks must have been made by the same tool as they are less than 1cm apart and are of similar angle, length and depth suggesting they were made in a similar cutting action. When taking all of the marks into consideration it is probable they were made by a sharp metal tool. This is especially evident in section #1 (figs. 4.27, 4.30) and the marks on the left and right side of section
#3 (figs. 4.14-4.26) which are similar in appearance to bronze humerus #1 (4.77-4.85). The mark in the middle of section #3 (figs. 4.25-4.26, 4.28-2.29) is slightly wider and has a subsidiary groove which is common to stone tool marks. However, as noted by Halstead (In press: 799-800) and seen in bronze humerus #3 (figs. 4.93-4.100), metal cut marks can create subsidiary grooves and this is probably the result of a slight shift in the angle of the blade whilst cutting rather than an uneven surface of the blade.

The material agent of cut mark BE323 is not as clear as the other samples and, unfortunately, only Micro-CT analyses were performed due to time constraints. The sample was from the ulna of a juvenile Sus sp. and consists of one cut that is deeper than the other cut marks. Envisaging the profile and the sides of the mark was quite difficult in the 3D images as the sides are both steep and deep which resulted in a dark shadow within the cut (figs. 4.41-4.44). This shadow is a feature of the VG Studio Max software which is possible to turn off but when this shadow was removed there was not enough contrast in the image to see the cut mark. Nevertheless, 3D (figs.4.42-4.44) and 2D slices (figs. 4.45-4.48) show a profile that ranges from |___| to U which suggests an overall deep and blunt profile. The right side of the cut in figs. 4.43, and 4.45-4.47 seems to lean towards right of the image as seen in the cut BE289 (cut mark #4) above. The depth of the cut suggests that a metal tool produced it. Obsidian would be unable to produce a cut this deep as was realised by experimental obsidian humerus #1-3. A harder stone such as chert may be able to with force, but one would expect a rougher mark with more surface features. It is possible that the surface features are lost or obscured since the cut is ancient and Micro-CT is not as effective as SEM for detailing surface features. However, as can be seen from Micro-CT (figs. 4.41-4.44) of BE323 both edges of the cut are straight and smooth.

5.5 Summary of findings of experimental and Lerna cut marks
The dog puncture marks images confirmed that punctures are unlikely to be confused with human butchery whilst the score marks did not produce a result on the Micro-CT because the marks were
too fine. However, by comparing the experimental and Lerna samples with previous scholarship it is evident the Lerna cut marks were almost certainly produced by a human agency. The placements of the cuts are at typical areas of muscle insertions and fossae where cut marks are expected. This outcome is not particularly surprising as Melanie Fillios was strict in selecting cuts that were almost certainly from butchery. The only sample that has some marks of questionable origin are perpendicular marks on J467 but the fact that it is possible to easily distinguish the perpendicular marks from the oblique cut marks on J467 is encouraging.

In regard to the profile of cut marks it was found that, in general, Greenfield’s (1999, 2002, 2004, 2006) diagram is accurate. Metal marks appeared as V, U or \( \underline{\_} \) shaped and both edges were straight. Other features such as striations, subsidiary grooves, and folding and buckling of the bone were sometimes visible and this was related to the angle and pressure of the blade as well as the density of the bone. Stone tools, in general, had an overall \( \bigvee \) shape and had more striations, surface features, and were messier in appearance. All the stone tool cut marks examined had a rough edge and a smooth edge. Obsidian cut marks had the appearance of typical stone tool cut marks instead of metal. When obsidian was pressed hard it resulted in messier surface features rather than depth. One of the superiorities of Micro-CT over SEM was demonstrating the variability of profiles. As shown by slicing the images, within a single cut mark the profile can change dramatically from V, \( \underline{\_} \), to \( \bigvee \). In some ways, the high resolution of the technology is misleading as the slices are so minute that one needs to average the different profiles in order to obtain an overall idea of the profile. It was found that one of the contradictions of stone tools is that although they have a general profile, they are also characteristically variable, hence, a range of diverse profiles within a single cut and between cuts is expected.

It was discovered that a number of aspects can significantly affect the appearance of the cut mark. One of the most influential is the porosity of the bone; the more porous the bone, the less features it retains and the more difficult it is to diagnose. Conversely, denser bone produced more visible cut
marks with evident surface features. Also, the angle at which the blade is held as well as the handedness of the user affects the inclination of the cut. Since the author is right-handed most of the experimental cut marks leaned slightly towards the right, even for metal profiles.

In regard to the Lerna cut marks, samples BE289 (cut mark #1), BD435, and J467 have the typical characteristics of stone tools cut marks and the author is confident the samples were cut with a stone tool. Samples BE289 (cut mark #4), and BE323 were not as apparent at first and more consideration was needed. Once they were compared to the experimental data and the work of other scholars it became apparent these samples were more characteristics of metal than stone tool cut marks and the author is fairly confident these samples represent metal cut marks.

5.6 Limiting factors of the study

Due to the small number of Lerna samples analysed this study cannot offer statistical results or extensive conclusions relating to the percentage of stone and metal tools used to butcher animals by the Bronze Age people of Lerna. It would not be fair to conclude on the basis of five samples that this is a representative percentage of stone to metal tools. Further, due to time constrictions not all of the Lerna or experimental samples were analysed with the same methods. One of the disadvantages of this study was photographs of the original bones from Lerna were not available and contextual information was gathered from the notes made by Melanie Fillios, such as, Sus sp. distal humerus. This information does not give an idea of, for example, which side of the mould is lateral or medial. This means that, although an inclination of the cut mark to the right or left side of the image was noticed on many samples, it is not possible to comment on whether this was a ‘right’ or ‘left’ inclination in relation to the rest of the bone and carcass. Therefore, this author feels more information is needed before conclusions of left or right handedness for the Lerna samples is possible.
5.7 Conclusions and implication to archaeology

The findings of this study suggest that both stone and metal tools were being used to butcher animal bone in Early Bronze Age Lerna. This was slightly surprising as although there is plenty of evidence of stone tools for this period the evidence of metal tools is more suggestive of small items or weapons rather than a typical kitchen knife (Liritzis, 1996: 299-302). This adds weight to the caution of many scholars (Greenfield, 1999, 2000, 2002, 2004, 2005, 2008; Halstead, In press) who argue the metal assemblage is not reflective of the diversity of the tool kit of the Bronze Age. It also suggests metal technology was adopted from early on in its history for practical, everyday activities. This would imply the Early Bronze Age was a transitional period where both technologies were in common usage for similar tasks. The potential of cut marks for determining the material agent has thus been shown to have significant application to later prehistoric and historic periods where a number of different technologies or tool types exist.

In regard to the second aim, it was shown by Micro-CT that profile alone is not enough to diagnose the material agent of a cut mark as the profile can vary. Rather, one needs to combine all available evidence and factor it into analysis and conclusions. It was especially helpful to compare the profile with the surface features of a cut mark. For these reasons, combining and comparing light microscopy, SEM, and Micro-CT was valuable as each technique has difference strengths and weaknesses. Light microscopy and SEM were superior at displaying surface features. Light microscopy gave a better idea of the whole sample while SEM had superior resolution and was better at details. However, neither were particularly effective for displaying the profile as it was necessary for the sample to be tilted rather than viewed at a 90° angle and this was not always possible or easy with these techniques. Conversely, the strength of micro-CT was its ability to show the range in profile of a particular cut which could then be averaged to achieve an overall idea of the profile. However, as mentioned above, the imaging software VG Studio Max can create difficulties when attempting to view the profile or floor of a cut mark as the shadow obscures the view and if
the shadow is removed there is not enough contrast in the image. Using all three methods in conjunction was beneficial as each technique displayed diverse aspects of the samples. In a perfect scenario it would be ideal to use all techniques available when diagnosing cut marks. On a practical level this may not be possible due to time and funding pressures. Micro-CT is expensive and takes significantly longer than SEM analyses. Light microscopy is the cheapest and easily available but achieving the correct light and angle can be difficult and the resolution is considerably inferior to SEM. Overall, SEM is the better technology for this type of study but the best policy would be to use it in conjunction with different techniques. What is needed for cut mark studies, and archaeology in general, is a technique that has the resolution of SEM, and the 3D imaging of Micro-CT. It would also be beneficial to analyse larger, samples of porous material, such as bone, and in less time.

In relation to the hypothesis one, it was found the profile of cut marks follow Greenfield’s (1999, 2002, 2004, 2006) model in general. However, as discussed above Micro-CT analyses displayed the variability of profiles and the need to compare all available evidence. Hypothesis two proposed contextual factors are important in determining whether marks are human or non-human induced. The hypothesis was strengthened as, based on placement on the bone and similarity in appearance, each Lerna cut mark was concluded to be human induced.

It would be interesting to analyse more material from Lerna or other Early Bronze Age sites for comparison. The contemporary site Tsoungiza offers an interesting contrast to Lerna as Halstead (In press: 797-800) found clear evidence of metal cut marks while no solid confirmation for stone tool cut marks. Conversely, despite the small sample size there is evidence for both stone and metal tool cut marks at Lerna. This suggests lithic technology was still important and in daily use at Lerna while there is no clear indication of this for contemporary Tsoungiza. Gaining more information about Lerna and contemporary sites can help build a better picture of the extent to which sites compare or contrast to one another and lend insight into reasons for this. Analysing moulds with SEM and comparing the data with light microscopy would not take a copious amount of time. To gain a
clearer picture of the technology available and in use during the Early Bronze Age, it would be advantageous to study enough samples to attain statistical conclusions on the extent of stone versus metal cut marks. Creating a database of cut marks would be valuable for different periods and regions of the world and would assist diagnosis of the agent.
TABLES

CHAPTER 5

RESULTS AND DISCUSSION
Table 5.1: Summary of results and findings of experimental cut marks

<table>
<thead>
<tr>
<th>Agent</th>
<th>General Profile</th>
<th>Surface features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog</td>
<td>Can’t tell</td>
<td>Score marks</td>
</tr>
<tr>
<td>Dog</td>
<td>Cone-shaped tooth marks</td>
<td>Punctures X2</td>
</tr>
<tr>
<td>Bronze atlas (test)</td>
<td>Can’t tell</td>
<td>Too faint</td>
</tr>
<tr>
<td>Bronze humerus #1</td>
<td>V</td>
<td>1 cut smooth without debris</td>
</tr>
<tr>
<td>Bronze humerus #2</td>
<td></td>
<td>_</td>
</tr>
<tr>
<td>Bronze humerus #3</td>
<td>V</td>
<td>6-7 cuts, sharp, some striations and subsidiary grooves, folding and debris</td>
</tr>
<tr>
<td>Bronze humerus #4</td>
<td>V</td>
<td>4 cuts, buckling/debris in a horizontal plane</td>
</tr>
<tr>
<td>Chert humerus #1</td>
<td>Varies but mostly</td>
<td>_</td>
</tr>
<tr>
<td>Chert humerus #2</td>
<td></td>
<td>_</td>
</tr>
<tr>
<td>Chert humerus #3</td>
<td>Combination of</td>
<td>_</td>
</tr>
<tr>
<td>Obsidian humerus #1</td>
<td>Difficult to tell due to debris</td>
<td>4 short cuts, ‘messy’ with debris</td>
</tr>
<tr>
<td>Obsidian humerus #2</td>
<td></td>
<td>About 7 cuts, striations, big difference between porous and dense bone in detail of features</td>
</tr>
<tr>
<td>Obsidian humerus #3</td>
<td>sharp but not deep</td>
<td>About 5 cuts, lots of folding, striations, subsidiary grooves</td>
</tr>
</tbody>
</table>

Table 5.2: Summary of results and findings of Lerna cut marks

<table>
<thead>
<tr>
<th>Item #</th>
<th>General profile</th>
<th>Surface features</th>
<th>Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE289 cut mark #1</td>
<td></td>
<td>_</td>
<td></td>
</tr>
<tr>
<td>BE289 cut mark #4</td>
<td>V and</td>
<td>_</td>
<td></td>
</tr>
<tr>
<td>BD435</td>
<td></td>
<td>_</td>
<td></td>
</tr>
<tr>
<td>BE323</td>
<td></td>
<td>_</td>
<td>and U</td>
</tr>
<tr>
<td>J467</td>
<td></td>
<td>_</td>
<td></td>
</tr>
</tbody>
</table>


BINFORD, L. R. 1983. *In pursuit of the past: decoding the archaeological record*, London, Thames and Hudson.


FILLIOS, M. A. & CHANG, Y. unpublished. Differentiating between *Canid* and *Suid* tooth-marks on bone: a pilot study light microscopy and scanning electron microscopy (SEM).


APPENDIX

Parameters for Micro-CT Skyscan and Xradia scans

Skyscan summary

BD435

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files= 1565; Source Voltage (kV)= 59; Source Current (uA)= 167; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 5.00; Object to Source (mm)=47.560; Camera to Source (mm)=217.930; Vertical Object Position (mm)=36.500; Optical Axis (line)= 460; Filter=No; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (20); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=May 31, 2011 16:29:08; Scan duration=01:55:50

[Reconstruction]
Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0; Time and Date=Jun 01, 2011 05:40:22; First Section=181; Last Section=904; Reconstruction duration per slice (seconds)=23.693371; Postalignment=1.00; Section to Section Step=1; Sections Count=724; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=4.99803; Reconstruction Angular Range (deg)=359.95; Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=2; Ring Artifact Correction=20; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam Hardening Correction (%)=58; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0019; Maximum for CS to Image Conversion=0.0967; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.998257; Cone-beam Angle Vert.(deg)=6.303796

BE289 cut mark #4

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files= 1565; Source Voltage (kV)= 59; Source Current (uA)= 167; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 5.00; Object to Source (mm)=47.560; Camera to Source (mm)=217.930; Vertical Object Position (mm)=36.500; Optical Axis (line)= 460; Filter=No
filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)=1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (20); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=May 31, 2011 14:20:22; Scan duration=01:55:53

BE289 cut mark #1

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1.5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files=1565; Source Voltage (kV)=100; Source Current (uA)=100; Number of Rows=1048; Number of Columns=2000; Image Pixel Size (um)=5.00; Object to Source (mm)=47.560; Camera to Source (mm)=217.930; Vertical Object Position (mm)=38.000; Optical Axis (line)=460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)=1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (10); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun 14, 2011 12:03:29; Scan duration=01:55:51

BE323

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1.5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files=1565; Source Voltage (kV)=59; Source Current (uA)=167; Number of Rows=1048; Number of Columns=2000; Image Pixel Size (um)=9.99; Object to Source (mm)=95.080; Camera to Source (mm)=217.930; Vertical Object Position (mm)=45.000; Optical Axis (line)=460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)=885; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (20); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=May 31, 2011 11:59:59; Scan duration=01:26:04

Dog dist ep humerus scores

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1.5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 9.99; Object to Source (mm)=95.080; Camera to Source (mm)=217.930; Vertical Object Position (mm)=39.000; Optical Axis (line)= 460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (20); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun 07, 2011 18:44:48; Scan duration=01:55:51

[Reconstruction]

Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0; Dataset Origin=Skyscan1172; Time and Date=Jun 08, 2011 19:58:01; First Section=117; Last Section=799; Reconstruction duration per slice (seconds)=18.493412; Postalignment=0.00; Section to Section Step=1; Sections Count=683; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=9.99211; Reconstruction Angular Range (deg)=359.95; Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=2; Ring Artifact Correction=20; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam Hardening Correction (%)=52; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0028; Maximum for CS to Image Conversion=0.1312; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.998564; Cone-beam Angle Vert.(deg)=6.303958

Dog punctures dist ep humerus

[System]

Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)= 11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]

Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 9.99; Object to Source (mm)=95.080; Camera to Source (mm)=217.930; Vertical Object Position (mm)=39.000; Optical Axis (line)= 460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (20); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun 07, 2011 16:32:27; Scan duration=01:55:53

[Reconstruction]

Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0; Dataset Origin=Skyscan1172; Time and Date=Jun 08, 2011 07:08:06; First Section=101; Last Section=909; Reconstruction duration per slice (seconds)=23.468479; Postalignment=0.00; Section to Section Step=1; Sections Count=809; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=9.99211; Reconstruction Angular Range (deg)=359.95 Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=2; Ring Artifact Correction=18; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam
Hardening Correction (%)=52; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0028; Maximum for CS to Image Conversion=0.1311; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.998564; Cone-beam Angle Vert.(deg)=6.303958

Metal atlas

[System]

Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]

Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 5.86; Object to Source (mm)=55.750; Camera to Source (mm)=217.930; Vertical Object Position (mm)=38.000; Optical Axis (line)= 460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1770; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (2); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun 07, 2011 14:24:11; Scan duration=01:40:06

[Reconstruction]

Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0; Dataset Origin=Skyscan1172; Time and Date=Jun 08, 2011 01:51:19; First Section=61; Last Section=791; Reconstruction duration per slice (seconds)=23.303694; Postalignment=0.00; Section to Section Step=1; Sections Count=731; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=5.85929; Reconstruction Angular Range (deg)=359.95; Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=2; Ring Artifact Correction=10; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam Hardening Correction (%)=52; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0017; Maximum for CS to Image Conversion=0.0082; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.999459; Cone-beam Angle Vert.(deg)=6.304431

Stone humerus #1

[System]

Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]

Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 5.86; Object to Source (mm)=55.750; Camera to Source (mm)=217.930; Vertical Object Position (mm)=38.000; Optical Axis (line)= 460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1770; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (2); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON;
Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun 07, 2011 12:33:17; Scan duration=01:39:51

[Reconstruction]

Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0; Dataset Origin=Skyscan1172; Time and Date=Jun 07, 2011 21:07:05; First Section=48; Last Section=675; Reconstruction duration per slice (seconds)=23.883759; Postalignment=0.00; Section to Section Step=1; Sections Count=628; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=5.85929; Reconstruction Angular Range (deg)=359.95; Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=2; Ring Artifact Correction=10; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam Hardening Correction (%)=52; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0032; Maximum for CS to Image Conversion=0.1125; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.999459; Cone-beam Angle Vert.(deg)=6.304431

Stone humerus #2

[System]

Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]

Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 5.00; Object to Source (mm)=47.560; Camera to Source (mm)=217.930; Vertical Object Position (mm)=35.000; Optical Axis (line)= 460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (10); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun 14, 2011 16:33:29; Scan duration=01:55:52

[Reconstruction]

Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0 Dataset Origin=Skyscan1172; Time and Date=Jun 16, 2011 09:54:10; First Section=48; Last Section=786; Reconstruction duration per slice (seconds)=23.152910; Postalignment=0.00; Section to Section Step=1; Sections Count=739; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=4.99803; Reconstruction Angular Range (deg)=359.95; Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=2; Ring Artifact Correction=20; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam Hardening Correction (%)=65; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0046; Maximum for CS to Image Conversion=0.1567; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.998257; Cone-beam Angle Vert.(deg)=6.303796
Metal humerus #1

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 5.86; Object to Source (mm)=55.750; Camera to Source (mm)=217.930; Vertical Object Position (mm)=35.500; Optical Axis (line)= 460 Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (10); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jun  14, 2011 14:19:54; Scan duration=01:55:42

Metal humerus #3

[System]
Scanner=Skyscan1172; Instrument S/N=022; Hardware version=A; Software=Version 1. 5 (build 8); Source Type=Hamamatsu 100/250; Camera=Hamamatsu 10Mp camera; Camera Pixel Size (um)=11.45; CameraXYRatio=0.9910; Incl.in lifting (um/mm)=1.0920

[Acquisition]
Number of Files= 1565; Source Voltage (kV)= 100; Source Current (uA)= 100; Number of Rows= 1048; Number of Columns= 2000; Image Pixel Size (um)= 7.93; Object to Source (mm)=75.430; Camera to Source (mm)=217.930; Vertical Object Position (mm)=31.000; Optical Axis (line)= 460; Filter=No filter; Image Format=TIFF; Depth (bits)=16; Screen LUT=1; Exposure (ms)= 1475; Rotation Step (deg)=0.230; Frame Averaging=ON (2); Random Movement=OFF (20); Use 360 Rotation=YES; Geometrical Correction=ON; Camera Offset=OFF; Median Filtering=ON; Flat Field Correction=ON; Rotation Direction=CC; Scanning Trajectory=ROUND; Type Of Motion=STEP AND SHOOT; Study Date and Time=Jul 04, 2011 17:26:50; Scan duration=01:55:22

[Reconstruction]
Reconstruction Program=NRecon; Program Version=Version: 1.6.0.2; Reconstruction engine=NReconServer; Engine version=Version: 1.6.0; Dataset Origin=Skyscan1172; Time and Date=Aug 15, 2011 13:19:30; First Section=12; Last Section=635; Reconstruction duration per slice (seconds)=22.924679; Postalignment=0.00; Section to Section Step=1; Sections Count=624; Result File Type=BMP; Result File Header Length (bytes)=1130; Result Image Width (pixels)=2000; Result Image Height (pixels)=2000; Pixel Size (um)=7.92757; Reconstruction Angular Range (deg)=359.95; Use 180+=OFF; Angular Step (deg)=0.2300; Smoothing=0; Ring Artifact Correction=20; Draw Scales=OFF; Object Bigger than FOV=OFF; Reconstruction from ROI=OFF; Filter cutoff relative to Nyquisit frequency=100; Undersampling factor=1; Threshold for defect pixel mask (%)=0; Beam Hardening Correction (%)=50; CS Static Rotation (deg)=0.0; Minimum for CS to Image Conversion=0.0175; Maximum for CS to Image Conversion=0.1342; HU Calibration=OFF; BMP LUT=0; Cone-beam Angle Horiz.(deg)=11.999340; Cone-beam Angle Vert.(deg)=6.304369
Xradia scans summary

BE289 cut mark 1
120 KV, 921 images, pixel 1.0142 um, exposure 50 sec

BE289 cut mark 1 (did not work well)
140KV, 921 images, exposure 15 sec

Stone humerus #3 (bone)
100kv, 1801 images, 3.2528 um, exposure 20 sec

Metal humerus #2 (bone)
100kv, 1801 images, 3.4315 um, 20 sec