Journal of Archaeological Science 49 (2014) 398–413

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Experimental projectile impact marks on bone: implications for identifying the origins of projectile technology

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ARTICLE INFO

Article history:
Received 16 November 2013
Received in revised form
27 May 2014
Accepted 30 May 2014
Available online 11 June 2014

Keywords:
Zooarchaeology
Projectiles
Hunting lesions
Projectile impact marks
Southern African Middle Stone Age

ABSTRACT

The ability of *Homo sapiens* to kill prey at a distance is arguably one of the catalysts for our current ecological dominance. Despite the importance of projectile technology in human hunting strategies, there is still no consensus on when it first emerged. Most evidence has stemmed from analysis of the lithic projectiles themselves, not the trauma left on the bones of hunted prey. There is a growing body of research focused on zooarchaeological projectile impact marks in European assemblages; however, comparable investigations are rare in the African Middle Stone Age (MSA), where it has been suggested that simple hafted projectile technology first arose. There are no standardised criteria for identifying projectile impact marks on bone and no large experimental studies exist that examine marks left by MSA points specifically. This paper defines the various forms of stone-tipped projectile impact marks on bone using a large and variable experimentally-produced sample, and then applies this system to description of marks left by replica MSA Levallois and Howieson's Poort points. The differences between projectile impact marks and slicing cut marks, marks created by different projectile modes (spear and arrow), lithic typologies (Levallois and Howieson's Poort), and distances (long versus short range) are examined. It is shown that although most projectile marks do not resemble slicing cut marks, the projectile mode, point type, and distance cannot be differentiated based on mark morphology.

1. Introduction

1.1. Overview

The emergence of hunting using projectile technology is seen as a major innovation in human behavioural evolution (Binford, 1981a; Blumenschine, 1986; Klein, 2000; McBrearty and Brooks, 2000; Ambrose, 2001; Henshilwood and Marean, 2003; Brooks et al., 2006; Churchill and Rhodes, 2009). The ability to kill from a distance gave our ancestors a distinct advantage over competing predators and enhanced their capacity for hunting larger and/or dangerous prey (Knecht, 1997; Crosby, 2002; Smith et al., 2007; Faith, 2008; Rhodes and Churchill, 2009; Dusseldorp, 2010; Weaver et al., 2011).

Projectiles that pre-date the crossbow come in both simple and complex forms. Simple projectiles rely solely on the user's mechanical energy for propulsion, such as thrusting and throwing spears. The thrusting spear is included as there is no definitive ethnographic evidence that separates the functions of the thrusting and throwing spears (Schmitt et al., 2003). Other projectiles like simple rocks, throwing sticks, and boomerangs are not included as these are difficult, if not impossible, to identify in the archaeological record. The spear-thrower (or atlatl) and bow are defined as complex projectiles, as they achieve a higher velocity by storing or enhancing energy in non-projectile components of the armature (Knecht, 1997; Hughes, 1998).

The manufacture of hafted projectiles has been suggested as a major breakthrough in the transition of our species toward behavioural modernity (Foley, 1989; Hughes, 1998; Milo, 1998; Shea, 1998; Boëda et al., 1999; Shea et al., 2001; Schmitt et al., 2003; Finlayson, 2004; Shea, 2006; Schrenk and Müller, 2009; Sisk and Shea, 2009, 2011). However, they can be challenging to detect archaeologically. Complete projectile armatures are rarely preserved. Indirect evidence for specific adaptations to throwing in our lineage appears as early as approximately 2 million years ago (Roach et al., 2013), suggesting that *Homo erectus* grade hominins may have hunted with simple projectiles. The earliest direct evidence for any projectile technology lies with the Schöningen

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http://dx.doi.org/10.1016/j.jas.2014.05.036

spears, which are unhafted wooden javelins dating to 520 ± 60 ka (Thieme, 1997; Richter and Thieme, 2012). The earliest archaeological evidence for the spearthrower is from Combe Saunière, France dating to 17,500 BP (Cattelain, 1988, 1989) and the earliest bows were found at Stellmoor, Germany dating to 11,000 BP (Cattelain, 1997). The earliest stone-tipped projectiles have been dated to >279 ka, at the site of Gademotta, Ethiopia (Sahle et al., 2013). However, it is unknown when use of stone-tipped armatures became common or how widespread the use of this technology was at different times in the past. As such, archaeologists seeking to understand the origins of this behaviour must develop alternative ways to recognise the archaeological use of stone-tipped projectiles.

The hunt for the origins of projectile technology has focused on experimental replication and analysis of lithic artefacts from archaeological sites. Although some researchers had already addressed the problem in the 1980s (Fischer et al., 1984; Odell and Cowan, 1986), much of the recent emphasis has been given to the analysis of features of the points that are considered to be diagnostic of having experienced impacts (Hughes, 1998; Hutchings and Brüchert, 1997; Knecht, 1997; Lee, 2010; Lombard, 2005, 2011; Lombard and Pargeter, 2008; Lombard and Phillipson, 2010; McBrearty and Tryon, 2006; Schmitt et al., 2003; Schoville and Brown, 2010; Schoville, 2010; Shea, 2006; Sisk and Shea, 2009, 2011; Wurz and Lombard, 2007). Based on data from stone artefacts, hafted projectile technology is argued to have originated during the Middle Stone Age of Africa (MSA, from ca. 500 – ca. 20 ka) (Jacobs et al., 2008; Lombard and Haidle, 2012; Sahle et al., 2013).

There is a complementary and growing body of research with a focus on studying the trauma caused by lithic projectiles to faunal remains. However, limited experimental research and ambiguous definitions have kept the identification of Projectile Impact Marks (PIMs) from becoming standard in zooarchaeological analysis (Noe-Nygaard, 1989; Pétillon and Letourneux, 2003; Smith et al., 2007; Castel, 2008; Letourneux and Pétillon, 2008; Pétillon and Letourneux, 2008).

A large sample of experimental PIMs produced by replica MSA points is needed as a point of reference. Standardised descriptions of shape, size, and other attributes of marks will facilitate their identification in archaeological contexts and aid in differentiating PIMs from marks produced through butchery or other taphonomic processes.

1.2. Aims

This paper aims to provide an experimental framework for identifying PIMs in the zooarchaeological record, with particular application to the origins of large ungulate hunting by early *Homo sapiens* in the MSA. Although the absolute and relative frequencies of anthropogenic marks can vary substantially between southern African MSA fossil assemblages, the most common forms they take are stone tool butchery marks. As such, this research was specifically designed to determine differences between marks produced during projectile impacts and simple slicing marks produced through stone tool butchery. This is then followed by an assessment of differences in the morphologies of marks made by different projectile systems (spears and arrows), lithic technologies (Levallois points and Howieson's Poort [HP]), and different casting distances (9 m and 1.4 m).

This paper explored two research questions: 1) Are impact marks from stone-tipped projectiles distinguishable from slicing cut marks?; and 2) Are there discernible differences between the marks created by different lithic technologies, projectile modes, and distances?

1.3. Background

Understanding how early *H. sapiens* acquired their food enables insights into the development of social, organisational and planning skills as well as their ability to share the knowledge and technologies required to hunt successfully (Brooks et al., 2006). The introduction and development of projectile technology requires tool manufacture at a level that implies a degree of cognitive and social complexity not seen in other species (Lombard, 2012; Lombard and Haidle, 2012).

Though there is consensus that complex projectiles were widespread by 40–45 ka (Shea, 2006), their origins are difficult to discern owing to differential preservation of the organic components of the armatures (Hughes, 1998; Brooks et al., 2006). Researchers have used several different techniques to examine the origins of projectiles and the various functions of their lithic components. First, understanding the properties and characteristics of various armatures, such as velocity and kinetic energy, is important in understanding why one particular armature was developed and chosen over another (Hutchings and Brüchert, 1997; Hughes, 1998). With respect to the characteristics of the candidate stone tool tips themselves, Tip Cross-Sectional Area or Perimeter (TCSA/TCSP) are advocated by Hughes (1998) and Shea (Shea, 2006; Sisk and Shea, 2009, 2011) to examine ballistically significant properties such as cross-sectional area, tip convergence angle, and mass. Combining data from points of 'known' ethnographic function with experimental testing of points enables researchers to infer the function of points. Other researchers have chosen to investigate various hafting techniques (Pargeter, 2007; Lombard and Pargeter, 2008; Lombard, 2011; Pargeter, 2011), gross morphometric changes over time in lithic size (Brooks et al., 2006), use-wear and residue analysis (Dockall, 1997b; Rots, 2003), or macrofracture or diagnostic impact fractures (DIFs) (Fischer et al., 1984; Lombard, 2005; Lombard and Pargeter, 2008; Schoville and Brown, 2010; Schoville, 2010; Lombard, 2011; Wilkins et al., 2012).

For a number of reasons, PIM research has lagged behind lithic-based research of projectiles. It has been proposed that PIMs would be both rarely created and rarely identified. This is because hunters would try to miss the bones of their prey, and by recovering the points from the animal after the event they would leave only marks that lack any diagnostic embedded stone (Morel, 2000; Smith et al., 2007; Castel, 2008; Letourneux and Pétillon, 2008; Leduc, 2012). Another reason may be that the misidentification of butchery marks and other taphonomic processes may have caused the number of reported projectile impacts to be underrepresented in zooarchaeological analysis (Noe-Nygaard, 1989; Morel, 2000; Parsons and Badenhorst, 2004; Smith et al., 2007; Castel, 2008; Leduc, 2012). In the few cases where archaeologists have proposed examples of PIMs, generally leading to inferences about hunting techniques, most of the marks were open to differing interpretations (Noe-Nygaard, 1989; Bratlund, 1991; Milo, 1998; Boëda et al., 1999; Marean and Assefa, 1999; Shea et al., 2001; Waters et al., 2011; Nikolskiy and Pitulko, 2013). For example, in the southern African MSA, Milo (1998) suggested that stone embedded in the cervical vertebrae of an extinct giant buffalo (*Pelorovis* [now *Syncerus*] *antiquus)* was 'smoking gun' evidence of the hunting of large, dangerous prey. However, Marean and Assefa (1999) have countered that a hafted stone butchery tool could also produce the same signature.

It is only recently that researchers have begun experimentally testing and creating a framework within which to classify marks caused by hunting practices (Table 1). Experimental research into PIMs is separated into zooarchaeological work on the impact of lithic projectiles (Morel, 2000; Parsons and Badenhorst, 2004; Castel, 2008), osseous points (Letourneux and Pétillon, 2008),

Table 1
PIM areas of research.

References	Time frame
Stodiek 1991, 1993; 2000	Magdalenian
Morel 1993, 1995; 2000	Magdalenian
Parsons and Badenhorst 2004	MSA
Smith et al. 2007	General
Castel 2008	Solutrean, Upper Palaeolithic
Letourneux and Pétillon 2008; Pétillon and Letourneux 2008	Upper Magdalenian
Churchill et al. 2009	Neanderthals, Shanidar Cave, N. Iraq
Pétillon et al. 2011	Magdalenian

composite points (Pétillon et al., 2011), and wooden javelins (Smith, 2003), while the hominin osteological evidence provides complementary evidence of habitual throwing behaviours (Smith et al., 2007; Churchill and Rhodes, 2009; Rhodes and Churchill, 2009; Roach et al., 2013).

Much of the initial PIM research and identification has been published in French (Morel, 1993, 1995, 2000; Pétillon and Letourneux, 2003, 2008) and German (Stodiek, 1991, 1993). Parsons and Badenhorst (2004) subsequently published a small PIM study specific to the MSA, but it was not until relatively recently that Smith et al. (2007) and Pétillon et al. (2011) brought experimental PIM identification to wider attention in zooarchaeological research. However, this body of research lacks consensus in the definition of what constitutes a hunting lesion or projectile impact and the examples derive from a broad range of ancient cultures, time periods, and projectile types, or are based only on small samples.

One of the major issues is the variety of terms used to define the diagnostic marks created by projectiles. A total of seven different categories have been used with ten different terms to describe them (Table 2). Letourneux and Pétillon (2008), and Pétillon and Letourneux (2008) take their characterisations further by separating the marks into primary (notches, punctures, and perforations) and secondary (points embedded and cracking). Secondary marks are those marks which may or may not be present on the primary marks and are not associated with only one type of primary mark. This range in classification systems makes it difficult to amalgamate and compare all the results and apply them universally to the zooarchaeological record.

Despite this, there have been some consistent trends. Most authors have found roughly 40–50% of marks had stone embedded, independent of raw material type (the exception was Morel (2000), with 20%). For osseous points, Letourneux and Pétillon (2008) found during experimentation on an ox (*Bos primigenius taurus*) that the points were embedded 24.5% of the time, but only in 1.3% of instances on a smaller cervid. Unfortunately, Pétillon et al. (2011) did not provide details on the incidence of stone embedded, as PIMs were a secondary consideration. Parsons and Badenhorst (2004) believe that different grain size in lithic artefacts may affect the amount of stone that becomes embedded. Punctures, sometimes referred to as internal bevelling, and slicing, or drag marks, (similar to cut marks) are the other two commonly recognised marks. Drag marks are most similar to butchery marks because they are long, generally thin marks containing micro-striations. Punctures, especially those on scapulae, are commonly seen in the experimental and better-preserved archaeological samples (Leduc, 2012; Noe-Nygaard, 1989), but the scapulae are elements which are highly fragmented in most zooarchaeological assemblages. Cracking was recognised most often in association with punctures in both experimental and archaeological samples (Noe-Nygaard, 1989; Letourneux and Pétillon, 2008).

2. Materials and methods

2.1. Experimental parameters

The experiments were divided into two groups. Experiment Group One (EG1) used the results of PIMs that had been created under a range of conditions. Therefore, EG1 included PIMS produced by many types of projectiles, lithic raw materials, and casting variables. This work was designed to elucidate what specific characteristics PIMs share with one of the simplest and archaeologically most common types of anthropogenic modifications. The null hypothesis was that there would be no discernable difference in their morphologies.

Experiment Group 2 (EG2) was designed to address the second research question, under which the null hypothesis was that different modes of delivery (spears and arrows), different lithic types (HP and Levallois), and variable distance (1.4 m and 9 m) would result in PIMs that had no significant differences in characteristics such as shape, size, feathering, and flaking.

2.2. Experiment Group One

EG1 includes a large sample of PIMs that was generated from ten experiments. These ten experiments were supplied from other projectile research being conducted at The University of Queensland and Arizona State University. The original aims of those ten experiments varied depending on the objectives of the researchers, who were testing a variety of stone materials, targets, hafting methods, lithic typologies, and casting methods (Table 3). Once these experiments were completed, the bones were processed and then analysed for PIMs. This had several advantages. First, it broadened the applicability of the study away from strictly the southern African MSA. It allowed synthesis of existing work with data from these experiments to establish a more universal system for describing PIMs, which could then be applied to the controlled

Table 2
Descriptive systems used by PIM researchers.

Authors	Slicing/drags	Puncture	Pitting/crushing	Perforation	Stone embedded	Fracture/breaks	Cracking
Pétillon et al. 2011	Notches	Puncture	Crushing	Perforation	x	x	x
Parsons and Badenhorst 2004	x	Puncture	x	x	Lithic fragment	x	Bruising
Churchill et al. 2009	x	x	Crushing	x	x	Hinging/Wastage	Radiating fractures
Castel 2008	Scratch/Cut	Penetration	x	x	Dislocation	Breakage	Cracking/Splitting
Morel 1993, 1995; 2000	Scraping	x	x	Perforation	Implementation	Breakage	Cracking/Splitting
Smith et al. 2007	Internal Striations	Internal Bevelling	x	x	Embedded fragments	x	X
Letourneux and Pétillon 2008	Notches (primary)	Puncture (primary)	x	Perforation (primary)	Embedding (secondary)	x	Crack (sec.)
Stodiek 1991, 1993; 2000	x	Puncture	x		Osseous point embedded	Fracture	x

Table 3
Overview of experimental methods.

Exp. Group	Exp.	Body size class	No. of marks	Gelatine w/bone or carcass	Calibrated, hand thrown or thrusting	Weapon system(s)	Raw material	Lithic technology	Bones	How processed?	Maceration (time)
Experiment Group 1	B	2	4	Gelatine with bone	Hand thrown	Mixed	Mixed	Mixed	Ribs	Boiled	No
	C	2	11	Gelatine with bone	Hand thrown	Mixed	Mixed	Mixed	Ribs	Left out in open for 5 days and boiled	No
	M	3	89	Carcass	Calibrated	Mixed	Flint	Howiesons Poort & Wardaman	Ribs, vertebra, scapula & humerus	Decomposed for two months	Yes (5 days)
	O	3	30	Carcass	Hand thrown	Mixed	Mixed	Mixed	Ribs	Decomposed for two months	Yes (5 days)
	P	3	33	Carcass	Mixed	Mixed	Mixed	Mixed	Tibia, Femur & fragments	Decomposed for two months	Yes (7 days)
	Q	3	79	Carcass	Mixed	Mixed	Mixed	Mixed	Ribs & Femur	Decomposed for two months	Yes (9 days)
	R	2	93	Carcass	Mixed	Mixed	Mixed	Mixed	Ribs & Femur	Decomposed for two months	Yes (5 days)
	S	2	37	Carcass	Calibrated	Arrow	Heat treated Silcrete	Howiesons Poort	Ribs, mandible, vertebra, scapula & pelvis	Decomposed in sealed hole for 12 months	No
	T	2	143	Carcass	Mixed	Mixed	Obsidian, Flint & Dacite	Mixed	Ribs, vertebra, scapula, tibia & fibula	Decomposed for two months	Yes (5 days)
	X	2	19	Gelatine with bone	Mixed	Mixed	Mixed	Mixed	Ribs, scapula & vertebra	Boiled	No
Experiment Group 2	L	2	82	Carcass	Calibrated	Spear & Arrow	Flint	Levallois	Whole Carcass	Decomposed for two months	Yes
	H	2	59	Carcass	Calibrated	Spear & Arrow	Flint	Howiesons Poort	Whole Carcass	Decomposed for two months	Yes
	K	2	79	Carcass	Calibrated	Spear & Arrow	Flint	Howiesons Poort	Whole Carcass	Maceration for one month	Yes

experiments conducted for EG2. Second, the many variables that contributed to EG1 provided more confidence in the results of initial comparisons between PIMs and butchery marks. This was because similarities between the two could not be attributed simply to coincidental similarities in variables such as raw material type, stone artefact shape and so on.

Obtaining this highly variable sample came at sacrifice to experimental control. Different stone types (flint, obsidian, quartz, silcrete, chalcedony and tuff) had been used by some researchers in order to measure their effectiveness as projectile points and to measure the types of DIFs produced. The different types of targets and animal analogues (defleshed bone, bone in gelatine, and whole carcasses) had been used to test their utility in projectile experiments, while the different hafting methods and lithic typologies had been tested to determine their effectiveness for use as projectiles. The use of different casting methods in EG1 was owing to different researchers choosing to hand cast their projectiles to ensure actualistic results, whereas others chose to use a calibrated crossbow to ensure accuracy, consistent firing speeds, and draw weights. Access to this large and variable pool of experimentally-produced PIMs proved useful for the initial establishment of the descriptive criteria presented here, which were then applied to analysis of the more controlled results of EG2. Following completion of the experiments, the bones were defleshed using two different methods. The first two experiments were defleshed using boiling water. However, following research by James (2010), where it was shown that boiling bones may affect the appearance of marks on the bones, natural decomposition and maceration was preferred for the remaining experiments in both EG1 and EG2.

A sample of stone tool slicing cut marks had been created by James (2010) on a defleshed pig (*Sus scrofa domesticus*) femur, and this was used as a comparison to the projectile marks. The cut marks were produced by slicing an unretouched flint flake across the bone surface. These marks accompany the considerable body of published cutmark research also available and used as a reference for comparison to the PIMs (Walker and Long, 1977; Jones, 1980; Binford, 1981b; Potts and Shipman, 1981; Blumenschine et al., 1996; Greenfield, 1999; Nilssen, 2000; Dewbury and Russell, 2007; Domínguez-Rodrigo et al., 2009; Merritt, 2012).

2.3. Experiment Group Two (EG2)

EG2 was designed to determine if PIMs created by different lithic technologies, projectile modes, and distances had statistically significant differences in their characteristics at either the individual or assemblage level. The two MSA lithic technologies used in EG2 were chosen as they are two technologies MSA researchers have argued were potentially used as projectiles (McBrearty and Brooks, 2000; Shea et al., 2001; Pargeter, 2007; Lombard and Pargeter, 2008; Lombard and Phillipson, 2010); the convergent points are also represented within the earliest known assemblage of projectile armatures (Sahle et al., 2013). Two modes of projectiles (spear and arrow) were chosen, along with two casting distances (1.4 m and 9 m). This enabled contextualisation of this research into the sometimes contested nature of the use and timing of the origins of different projectile armatures (McBrearty and Brooks, 2000; Shea et al., 2001; Lombard, 2011).

Flint was chosen for both the spear and arrow heads, as its crystalline structure falls in the mid range of lithic crystal structures (Smith et al., 2007). While flint is not found in southern Africa, it was useful in these experiments because in the southern African MSA Levallois points are most commonly manufactured on quartzite, whereas finer-grained materials such as heat-treated silcrete and hornfels were preferred for HP segments (Brown et al., 2009). Standardisation of the raw material for these experiments using an intermediate crystal size enabled direct comparison between PIMs created by both the Levallois and HP points, whilst ensuring that PIMs were not produced exclusively by only coarse-

Fig. 1. Experimental Howieson's Poort Spear (left) and Arrow (right).

or fine-grained raw materials. It also ensured comparability to the cut mark sample.

Twenty spear and twenty arrow tips were made for each Levallois and HP experiment (Figs. 1 and 2). In general, the larger points were used for spears, with the smaller for arrows, with some overlap in these sizes (Table 4). The spear points were hafted with an industrial poxy glue to 12 mm dowels and arrows to 9 mm dowels, each approximately 20 cm long. The industrial poxy was chosen to ensure a standard hafting strength across the experiments. These were then attached to either a 40 cm arrow (9 mm dowels) or a 1.2 m spear shaft (12 mm dowels). During these experiments all shots, hits, and misses were recorded to help assess the probability of a hit leaving a mark.

A calibrated crossbow was built by the senior author, following the design by Shea et al. (2001) and Schoville and Brown (2010), before being fitted with a compound bow. The calibrated crossbow was chosen over hand throwing as it ensures accuracy and a consistent firing draw weight (22 kg [48 lbs]) for the duration of the experiments, thus meaning that each projectile was fired with the same amount of force. Two shooting distances were chosen: 1.4 m and 9 m. This was designed to test if distance and any loss in velocity and thus kinetic energy affected the formation of a mark.

The target for each of the experiments was a 20 kg near-mature lamb (*Ovis aries*) carcass, which had been skinned and gutted by a butcher (this step was required for acquisition from a licensed abattoir). The research was conducted in Brisbane, Australia, where a direct analogue from southern Africa would have been extremely difficult to obtain. The lamb was of a similar body size to size 2 African antelope such as springbok (*Antidorcas marsupialis*), following the body size classes defined by Brain (1981). The butcher took care not to come into contact with bones during skinning and gutting. The carcass was split into quadrants, with the right side used for the 20 spear points and the left side for 20 arrow points. Each half was then separated in half again with one shot at a distance of 9 m and the other at 1.4 m. The lamb carcass was stuffed with gelatine and foam to simulate the organs and ensure the projectiles did not break through the carcass.

Each point was fired a maximum of five times, whether or not it hit the carcass. This enabled creation of marks without rendering the bones useless by over-shooting and fracturing them, and it also ensured that marks were not inflicted by points that had been extensively damaged through prior impacts. During subsequent testing, it was shown that -speeds for arrows ranged between 120 and 130 km/h (75–80 mp/h) and spears 75–95 km/h (46–59 mp/h). These speeds may seem faster than expected, however observation of projectile experiments conducted by other researchers at The University of Queensland showed these were only slightly faster than hand casting or hand-held bows. Each carcass was then carefully butchered by the senior author, with the aim to remove as much flesh as possible without coming into contact with the bones. The butchery was conducted with metal knives to further ensure that if any contact was made with the bones it could be distinguishable from the lithic-produced PIMs (Houck, 1998; Greenfield, 1999; Bello and Soligo, 2008; Lewis, 2008).

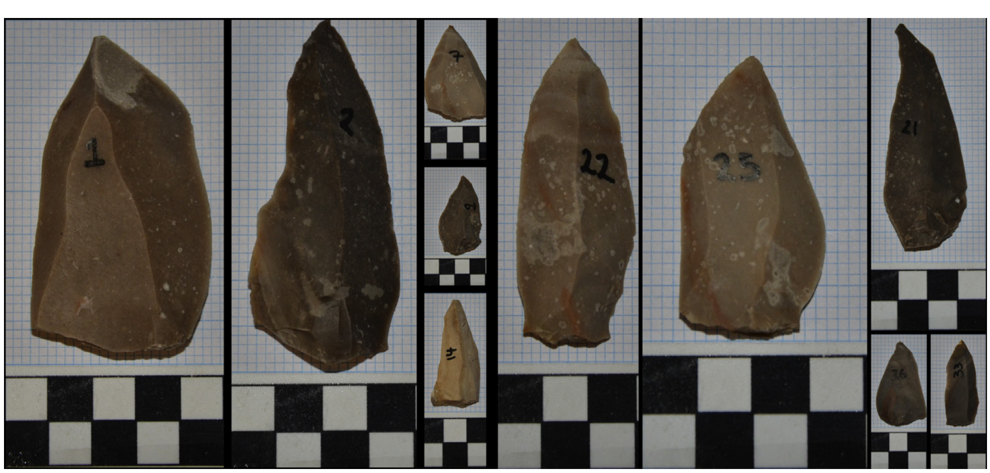

Fig. 2. Experimental Levallois points – Spear tips (left) and Arrows (right).

Table 4
Averages for measurements and weights of EG2 projectile points.

		Max. length (mm)	Max. width (mm)	Max. thickness (mm)	Weight (g)
Levallois	Spear	55.61	28.24	9.55	12.46
	Arrow	47.67	19.78	6.9	5.18
Howieson Poort	Spear	30.73	18.17	5.32	2.81
	Arrow	29.47	16.15	4.9	1.98

2.4. Data collection and analysis

Identification of marks was conducted using a classification system developed from a review of PIM research and observations on EG1 (Table 5). Six formal categories of marks were created to enable recording within a standardised and simplified system based on extant literature: drag, puncture, fracture, drag/fracture, drag/puncture and puncture/fracture. A drag is defined as a cut-like mark, with multiple striations and either a V or U shaped kerf (floor) (Fig. 3a). A puncture is where a point has directly hit the bone and caused either pitting (crushing), and broken through the bone wall or through the bone (Fig. 3b). A fracture is a complete or partial fracture through the whole bone (Fig. 3c). The following are sub-categories of the former. Drag/fractures are when a drag mark terminates with a fracture (Fig. 3d), drag/puncture where a drag mark terminates with a puncture (Fig. 3e) and finally, a puncture/fracture is a puncture terminating into a fracture (Fig. 3f).

Several secondary traits were then used to help describe each mark: length, shape, flaking, feathering, cracking, complete break, partial break, and stone embedded (Fig. 3g–l and Supplementary data). These secondary traits were based on a list created by Lewis (2008). While that study was based on modern steel swords and sharp force trauma, the list proved comprehensive and effective based on the initial observations of EG1. Breadth, embedded bone shards and aspect (angle) used by Lewis (2008) were inapplicable to these experiments; the irregularity of PIMs meant that breadth and aspect were unable to be recorded with any accuracy and bone shards were only present in very small numbers. Where it was possible, each mark was given a shape designation, its length measured with digital callipers, and then observations were recorded on the presence of attributes such as unilateral or bilateral feathering/flaking, cracking, and stone embedding.

Once the bones from each experiment had been cleaned they were observed under a 10× hand lens or a maggy-light, with each mark given a unique code and recorded into a database. Each bone was then observed under a binocular zoom light microscope (10–45×) and photographed. Any marks not observed in the first stage of analysis were then recorded and photographed, as a light microscope has been shown to improve the recognition of surface modifications and limit inter-observer disagreements (Blumenschine et al., 1996).

Fisher's Exact Tests were used for EG1 to compare proportions of marks with different attributes to those observed in the experimental butchery mark sample. Chi^2 Tests were conducted for EG2 because they were better able to handle the large quantities of data and comparisons that were required to determine if any differences existed between attributes of PIMs created under the different experimental parameters. All analyses were conducted using the free software PAST (Hammer et al., 2001).

3. Results

3.1. Overview

EG1 contributed 538 PIMs, with a further 220 from EG2, for a total of 758 PIMs. The butchery mark experiment yielded 201 cut marks. During EG2 there were 170 shots for 145 hits in the HP sample and 112 shots for 88 hits with Levallois points (Table 6). From the total of 220 hits, the following numbers of PIMs were identified: 138 HP, 82 Levallois, 115 spear, 105 arrow, 166 from 9 m, and 54 from 1.4 m.

The majority of projectile marks from both EG1 and EG2 combined were categorised as a drag, fracture or puncture (88.6%), with the remaining 11.4% spread across the other sub-categories (Table 7). Drag marks were the most frequent mark (264, 34.8%), followed by fractures (242, 31.9%) and punctures (166, 21.9%). As many marks had no clear initiation or termination, length could only be recorded on 122 of 758 PIMs and ranged from 2.01 mm to 46 mm (median of 13.67 mm).

3.2. Projectile marks

This analysis is of the combined PIM sample from EG1 and EG2. The most commonly and easily identified PIM in zooarchaeological analysis is stone embedded in puncture marks. However, only 16.64% of the PIM sample from all the experiments had stone embedded. Stone was found in 50% of all puncture marks, but in much lower frequencies in drags (4.17%) and fractures (1.24%) (Fig. 4). Stone was found most often in oval (40%) and triangular (28%) shaped marks.

Ribs and vertebrae had the highest incidence of stone embedded, with 33% and 21% respectively of the 111 marks. The high frequency of marks with stone embedded in ribs is most likely a result of the total number of marks on ribs (491) as only 13% of all marks on ribs had stone embedded. This frequency is not significantly different when compared to all other skeletal elements ($p = 0.45$). In contrast, vertebrae had a significantly higher proportion of stone embedded (29 of 134 marks on vertebrae) when compared to all other skeletal elements ($p = 0.02$). No other skeletal element had more than 18% of marks with stone embedded, except the mandible (one of only three marks).

The most common shape trait was amorphous (48.94%), which was designated for marks with no clear termination or where the projectile had dislodged sections of bone. The next most common shapes were line (16.49%), triangular (11.87%), and oval (10.16%). No other shape occurred in more than 5% of marks.

Table 5
Definitions of categories used by authors.

Category	Used	Definition
Drag	Notches, scratches, cuts, scraping or internal striations	Cut-like marks
Puncture	Crushing or Internal Bevelling	Point did not break through bone wall leaving an indented mark
	Partial punctures	Point broke through bone wall but not all the way through the bone
	Perforations	Complete punctures
Fracture	Breakage, hinging/wastage	Bone has been broken with a section of bone breaking off
Cracking	Bruising, radiating fractures, cracking/splitting	Cracking on bone, radiating from the mark
Stone embedded	Lithic fragment, embedding or embedded fragments	Part or all of the lithic point becoming embedded in the bone

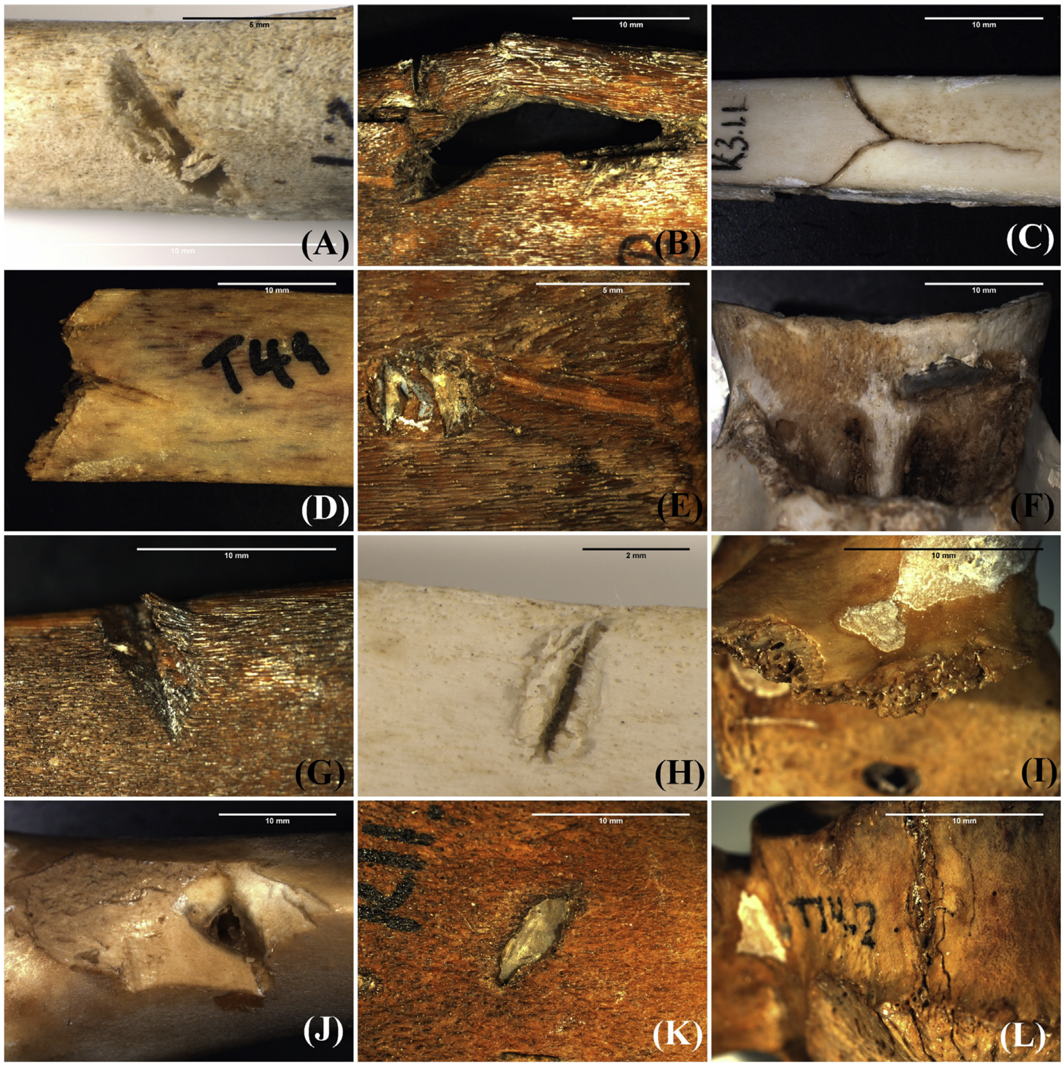

Fig. 3. Overview of categories and traits. (A) Drag; (B) Puncture; (C) Fracture; (D) Drag/fracture; (E) Drag/puncture; (F) Puncture/fracture; (G) Unilateral feathering; (H) Bilateral feathering; (I) Unilateral flaking; (J) Bilateral flaking; (K) Stone embedded; (L) Cracking.

Approximately 30% of all marks had flaking (249) or feathering (234), with the extent of feathering and flaking favouring unilateral at 70% over 30% bilateral. Only 62 marks had both flaking and feathering together (8.2%). The shape of the mark typically had no bearing on the occurrence of flaking or feathering, though flaking did occur significantly more often in amorphous (147, $p < 0.01$) and triangular (21, $p = 0.04$) marks when compared to all other shapes. In all PIMs, cracking occurred in 30.2% (229) of all marks, and in approximately 30% of all shapes except for line (20%) and circular (10%).

It was noted during analysis that there were several groupings of shapes and categories. These included fractures-amorphous (233) drag-line (110), drag-amorphous (68), puncture-triangular (47) and puncture-oval (47). Fractures were commonly not designated a shape and as such they were classed as amorphous. A drag is a cut-like mark and so they were often classed as line shaped. Due to the parameters of the PIM experiments, the majority of marks were concentrated on the ribs (64.8%) and vertebrae (17.7%). This is also expected to be common in real hunting events, as the lungs are a large target where mortal damage is likely to be inflicted (Pokines, 1998). Ribs had a high percentage of drags (38.9%), followed by fractures (31%) and punctures (21.8%). The most commonly shaped marks on ribs were amorphous (47.7%, due to the high number of fractures), line (20.8%, due to the number of drags), oval (10.4%), and triangular (9.8%, both of the latter due to the number of punctures).

Table 6
Hits and misses in each experiment in EG2 (those in brackets were not able to be recovered for analysis and thus were removed from the sample).

	Exp L spear		Exp L arrow		Exp H spear		Exp H arrow		Exp K spear		Exp K arrow	
	Hits	Total	Hits	Total	Hits	Total	Hits	Total	Hits	Total	Hits	Total
1.4 m	30	34	19	22	(28)	(29)	(26)	(26)	30	31	24	25
9 m	21	29	18	27	24	31	25	28	19	29	21	31
Total	51	63	37	49	52	60	51	54	49	60	45	56

Table 7
Mark categories from all PIMs and butchery marks.

Category	Projectile	Butchery
Drag	264	201
Drag/Fracture	21	0
Drag/Puncture	21	0
Fracture	242	0
Puncture	166	0
Puncture/Fracture	44	0
Total	758	201

Table 8
Butchery and all PIMs comparison.

Trait	Butchery	PIM	*P* value
Flaking	14	249	<0.0001
Unilateral flaking	10	180	0.9442
Bilateral flaking	4	69	0.9442
Feathering	63	234	0.9317
Unilateral feathering	53	177	0.1329
Bilateral feathering	10	60	0.1329
Cracking	0	229	0
Stone embedded	0	111	0
Most frequent Shape	Line (201)	No Shape (371)	N/A
Most frequent Category	Drag (201)	Drag (264)	N/A

The distribution of marks on vertebrae was similar, with most of the marks being fractures (38.8%), drags (28.4%), and punctures (22.4%). The most frequent shapes on vertebrae were amorphous (53%) and triangle (18.6%). The frequency of marks on vertebrae with flaking was significantly higher than all other skeletal elements combined (42.54%, $p = 0.01$). The frequency of feathering on ribs was also significantly higher than all skeletal elements combined (35.44%, $p < 0.01$). All skeletal elements except ribs had approximately a 70/30 split in favour of unilateral over bilateral flaking and feathering. Ribs exhibited significantly less (64%, $p = 0.03$) unilateral feathering than all other skeletal elements. Flaking occurs frequently on vertebrae (42.5%), while ribs contributed 74% of all marks with feathering. This was likely a result of the direction the projectile impacted, and when the bone fractured the interior of the bone exhibited feathering.

3.3. Projectile and cut marks

Of the 758 PIMs, 111 contained embedded stone, whereas none of the 201 cut marks contained lithic fragments (Table 8). All the butchery marks were classed as drag, line-shaped marks with none exhibiting cracking or embedded stone. As a result, the number of tests that could be run was limited. A general observation of the PIM sample was that they exhibited much greater variability in their morphologies and attributes than the cut mark sample. Fisher's Exact Tests showed that the number of marks exhibiting flaking was significantly different between the cut mark and PIM samples ($p < 0.01$) with 26.8% of PIMs having flaking compared to 7.0% of cut marks. However, flaking may be quite variable amongst butchery samples, and may be influenced by what type of flake was used to create the marks. For example, Domínguez-Rodrigo et al. (2009) found that approximately 15% of marks produced by simple stone flakes exhibited flaking, in comparison to 51% of marks produced using retouched flakes. However, the flaking exhibited in Domínguez-Rodrigo et al. (2009) appears to be more closely aligned to what is defined in this paper as feathering, meaning that 15% of simple stone flake cut marks and 51% of retouched flake cut marks exhibited feathering. Because the raw material type, bone type, and other experimental conditions for creation of these marks were not described, it is also possible that other variables may be responsible for the amount of observed flaking. Within the PIM and butchery samples described here, marks with flaking had the same ratio of unilateral and bilateral flaking, with each having approximately a 70/30 split in favour of unilateral flaking. There was no significant difference between feathering ($p = 0.09$) and feathering extent ($p = 0.13$) between cut and projectile samples.

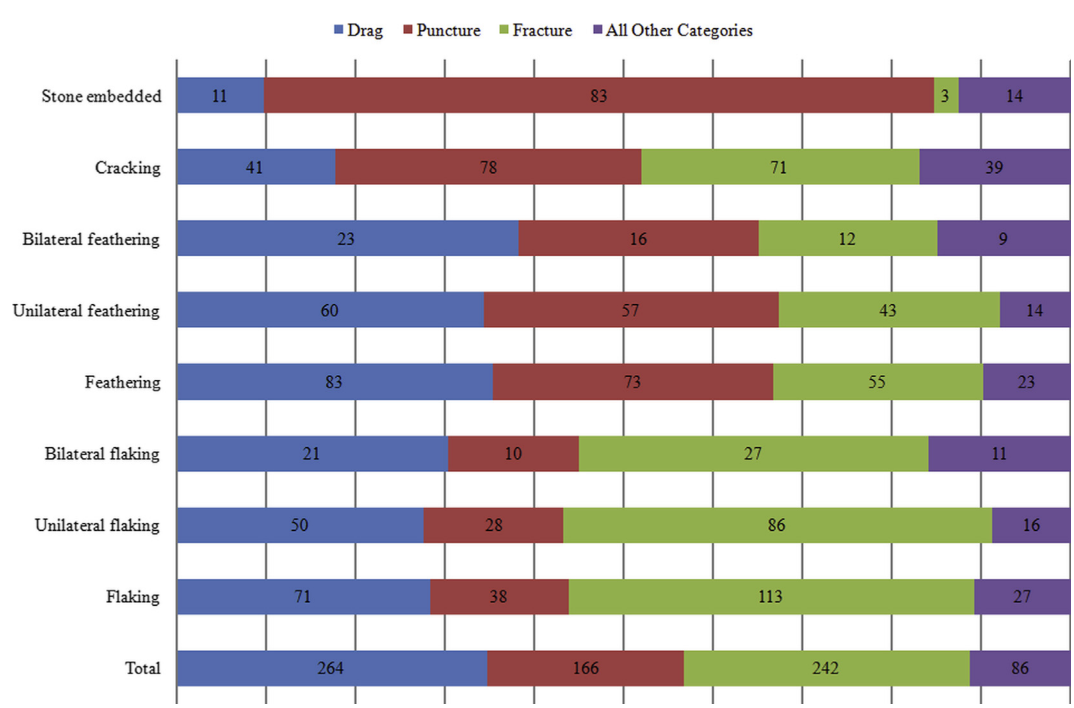

Fig. 4. Overview of all PIMs.

Table 9
Summary of Levallois and HP marks.

	Levallois ($n = 82$)			Howiesons Poort ($n = 138$)		
	Drag	Puncture	Fracture	Drag	Puncture	Fracture
Total	17	17	35	42	18	55
Flaking	3	6	18	10	9	20
Unilateral flaking	1	3	15	8	8	17
Bilateral flaking	2	3	3	2	1	3
Feathering	2	4	8	18	9	8
Unilateral feathering	1	4	6	14	6	7
Bilateral feathering	1	0	2	4	3	1
Cracking	4	15	9	14	11	9
Stone embedded	0	6	0	0	5	1
Most frequent shape	No Shape/Triangle (4)	Triangle (7)	No Shape (34)	Line (21)	Triangle (6)	No Shape (50)

3.4. Howieson's Poort and Levallois technology

Chi^2 tests between the HP and Levallois samples showed there was no significant difference in the distribution of the categories (Table 9). The distribution of flaking, feathering and the extent of both were not significantly different between the samples.

The distribution of cracking on both of the samples showed that it occurred in significantly higher amounts in drag/fractures (80%, $X^2 = 25.73$, DF = 5, $p = 0.04$ for HP; 83%, $X^2 = 26.24$, DF = 5, $p = 0.04$ for Levallois) and punctures (61%, $X^2 = 25.73$, DF = 5, $p = 0.02$ for HP; 88%, DF = 5, $X^2 = 26.24$, $p < 0.01$ for Levallois) than in other categories. Cracking occurred in significantly lower proportions in fractures, with only 16% of HP ($X^2 = 25.73$, DF = 5, $p = 0.02$) and 25% of Levallois ($X^2 = 26.24$, DF = 5, $p < 0.01$) marks exhibiting cracking. When the samples were compared, cracking was significantly more common for puncture/fractures in HP ($X^2 = 11.7$, DF = 5, $p = 0.02$) than Levallois, and cracking significantly more common in punctures for Levallois than HP ($X^2 = 11.7$, DF = 5, $p = 0.04$).

3.5. Mode of projectile

There were very few significant differences between the characteristics of spear and arrow PIMs (Table 10). Chi^2 tests showed that the distribution of embedded stone, cracking, flaking and categories did not differ within and between the spear and arrow samples. Rectangular-shaped spear marks (7) had significantly more feathering than rectangular arrow marks (0) ($X^2 = 18.49$, DF = 8, $p < 0.01$). Feathering in triangular arrow marks (7) was significantly more common than in triangular spear marks (0) ($X^2 = 18.49$, DF = 8, $p = <0.01$).

3.6. Casting distances

The distributions of both casting distance samples followed a similar pattern to the overall assemblage detailed earlier (Table 11). The experimental design of EG2 meant the lamb carcass was halved sagittally and then medially, just past the base of the rib cage, and the casting distances were each given a designated half. As a result, the only skeletal element comparison possible was on the vertebrae. The casting distances did not differ in the spread of categories of marks nor in most of the traits.

Chi^2 tests showed no significant difference in the distribution of embedded stone, flaking, feathering, and extent of feathering and flaking between the two casting distances. The one area in which the casting distance samples differed was again in cracking. Cracking in both triangular shaped marks ($X^2 = 14.48$, DF = 8, $p = 0.04$) and in vertebrae ($X^2 = 56.15$, DF = 7, $p < 0.01$) was statistically higher at 1.4 m than at 9 m, with both samples having the similar number of marks with cracking (1.4 m = 8 and 9 m = 9) in spite of the much larger sample size at 9 m (166 compared to 54 at 1.4 m).

4. Discussion

The biggest dissuasion to the adoption of PIM identification by zooarchaeologists is the idea that such marks are indistinguishable from butchery marks (Marean and Assefa, 1999; Smith et al., 2007; Castel, 2008). However, this study has shown with a large sample that there are a number of statistically significant differences between projectile marks and simple slicing cut marks. Most prominently, these types of cut marks fall into consistent shapes and categories (e.g. drags and lines), whereas PIMs take on a variety of forms and characteristics (Fig. 5).

Some authors have stated that during butchery experiments there has been evidence for embedded stone (Milo, 1998; Parsons and Badenhorst, 2004), yet in the 201 butchery marks analysed here and during several other anecdotal butchery experiments conducted by the authors there has not been a case of stone becoming embedded. During the PIM experiments it was noted that a considerable amount of force was required to embed the

Table 10
Summary data from spear and arrow marks.

	Spear ($n = 115$)			Arrow ($n = 105$)		
	Drag	Puncture	Fracture	Drag	Puncture	Fracture
Total	27	16	51	32	19	39
Flaking	6	5	19	7	10	19
Unilateral flaking	5	2	17	4	9	15
Bilateral flaking	1	3	2	3	1	4
Feathering	11	4	9	9	9	7
Unilateral feathering	7	7	4	8	3	9
Bilateral feathering	2	2	3	3	1	0
Cracking	6	13	7	12	13	11
Stone embedded	0	4	0	0	7	1
Most frequent shape	Line (13)	Oval/Triangular (5)	No Shape (47)	Line (11)	Triangle (8)	No Shape (37)

Table 11
Summary of 1.4 m and 9 m datasets.

	1.4 m ($n = 54$)			9 m ($n = 166$)		
	Drag	Puncture	Fracture	Drag	Puncture	Fracture
Total	13	11	17	46	24	73
Flaking	1	4	9	12	11	29
Unilateral flaking	1	3	6	8	8	26
Bilateral flaking	0	1	3	4	3	3
Feathering	3	3	1	17	10	15
Unilateral feathering	2	3	1	13	7	12
Bilateral feathering	1	0	0	4	3	3
Cracking	5	9	1	13	17	17
Stone embedded	0	6	0	0	5	1
Most frequent shape	Line/Triangle (4)	Triangle (5)	No Shape (16)	Line (20)	Triangle (8)	No Shape (68)

stone to the depth generally seen in the experimental and archaeological PIM samples (Milo, 1998; Boëda et al., 1999). This does not mean it is impossible to find embedded stone in a butchery mark; rather that it is significantly more likely to occur in a PIM.

Across a number of PIM experimental studies, 40–50% of identified marks had stone embedded (Smith et al., 2007; Castel, 2008; Churchill et al., 2009). The results here (16.45%) are closely aligned to Morel's (2000) 20% occurrence. This may be a result of the large sample sizes both used here and by Morel in comparison to other studies, or it may be a result of the different sized animals used in each experiment as shown by Morel (1995) and reiterated by Castel (2008) and Letourneux and Pétillon (2008). In our study, across both EG1 and EG2, punctures contained the most instances

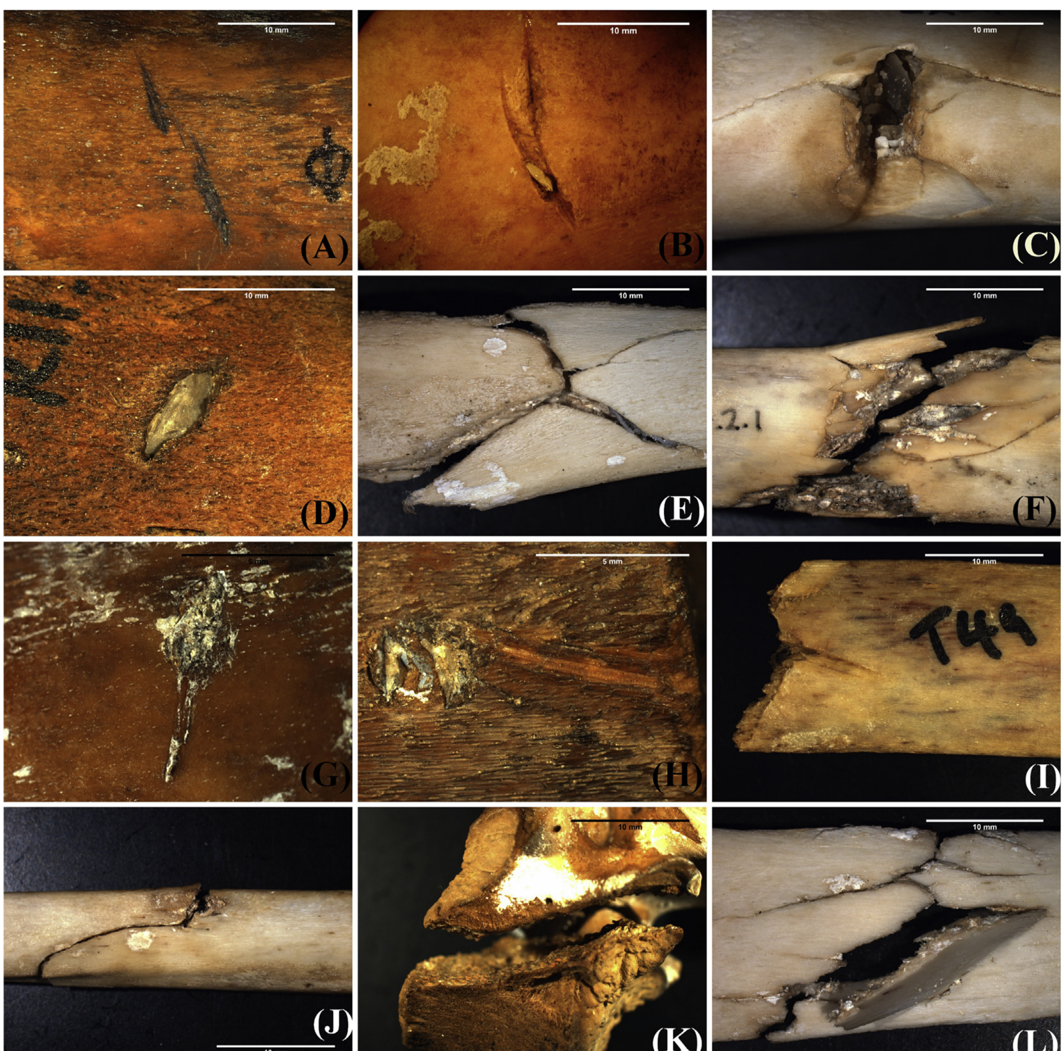

Fig. 5. Range of PIMs. (A) Drag mark; (B) Drag mark with stone embedded on a mandible; (C) Puncture mark on tibia; (D) Puncture mark with stone embedded on a rib; (E) Fracture mark on rib; (F) Fracture mark on rib; (G) Drag/puncture mark on rib; (H) Drag/puncture mark on rib; (I) Drag/fracture mark on rib; (J) Drag/fracture mark on rib; (K) Puncture/fracture on vertebra; (L) Puncture/fracture on rib.

of stone (83 of 111), which is consistent with other experimental studies and archaeological samples (Noe-Nygaard, 1989; Bratlund, 1991; Milo, 1998; Boëda et al., 1999; Morel, 2000; Shea et al., 2001; Parsons and Badenhorst, 2004; Smith et al., 2007; Castel, 2008; Churchill et al., 2009; Leduc, 2012). Thus, the implication is that between 50 and 80% of PIMs in the archaeological record will not be able to be identified based on the presence of embedded stone.

There was no difference in the proportion of marks with feathering in the projectile and cut mark samples, but there was for flaking. The reasons for these differences may be attributable to the way in which projectiles enter bones, with feathering occurring when bones are scraped and flaking requiring more force achieved by greater kinetic energy, as would be produced by projectiles. Interestingly, flaking, feathering, and cracking each occurred individually in ~30% of all projectile marks, which is likely attributable to the way the points entered the prey and struck the bone with force. Oval and triangular shaped punctures are likely a result of the shape of the tips of the projectile points, although there was no discernible difference between shapes in the Levallois and HP groups.

During cut mark and PIM experiments, cracking and flaking of bone were seen in greater numbers in the PIM samples than in butchery. However, butchery is a highly variable and condition-specific process that can include many actions other than simple slices with unretouched flakes. Cut marks in particular have been found to be some of the most variable forms of bone surface modification (Domínguez-Rodrigo and Yravedra, 2009). In some cases, such as hammerstone percussion, butchery activities may also include the application of substantial force. Domínguez-Rodrigo et al. (2009) identified instances where one or more grooves intersect with the primary groove in the form of "oblique grooves or a fork" (Domínguez-Rodrigo et al., 2009:2652). These irregular cut marks are most likely a result of the flake being used in an up-and-down motion, thus making some of the marks with the 'shoulder effect' and intersecting grooves. Similar marks have been found in PIMs (Fig. 6). The bisecting marks on the PIMs create a 'fork' like shape, or double drag marks originating from a single point. However, unlike the cut mark where the flake is used in an up-and-down motion, these projectile marks appear to be a result of the projectile point coming into contact with the bone and then bouncing or moving. The PIMs with these double drag marks can often be further differentiated from cut marks by the termination of the mark. PIM double drags often terminate with stone becoming embedded or the point embedding and leaving a pit.

Drag marks can also in general be differentiated from cut marks by the way the mark terminates and the severity of the mark as observed in its width and depth. Drag marks are generally (though not always) deeper, wider, and terminate with more dislodged bone than a cut mark, likely because of the relatively higher amount of force with which projectiles contact the bone. As with double drags, the termination of even simple drag marks can result in dislodgement of bone, stone embedding, or pitting of the bone (Fig. 7). The location of the PIM can also differentiate it from cut marks. When hunting an animal the preferred location to hit is the chest, which contains the vital organs and thus results in marks more often located on the scapulae, ribs, and vertebrae. According to Nilssen (2000) these bones are also less likely to have butchery marks present than other elements, such as long bones. Unfortunately, these elements are amongst the most easily fragmented and least dense (Lam et al., 2003), and thus tend to not preserve well in a complete state in the archaeological record. Because of these variables, a future line of research should be to increase the range of variability in the experimental sample of butchery marks for specific comparison to PIMs. The descriptive system synthesised here and the results of EG1 can provide a useful recording system and comparative database for such research.

It was noted during the experiments in EG1 that ribs of animals of size class 2 (lamb and springbok *[A. marsupialis]*) more commonly had fractures, but size class 3 (horse *[Equus caballus]* and cow *[Bos taurus]*) had higher numbers of punctures. In contrast, drags occurred equally in both. Owing to the fragile nature of ribs and their location in the largest target on an animal, ribs are more likely to be struck. The experiments in this study showed that ribs will also often fracture. However, it was noted on larger animals in EG1 that the ribs were less likely to fracture and they should therefore retain evidence of hunting in the form of punctures, embedded stone, or other PIMs. This is a result that supports Morel's (1995), Castel's (2008), and Letourneux and Pétillon's (2008) conclusion that the bones of smaller mammals will more

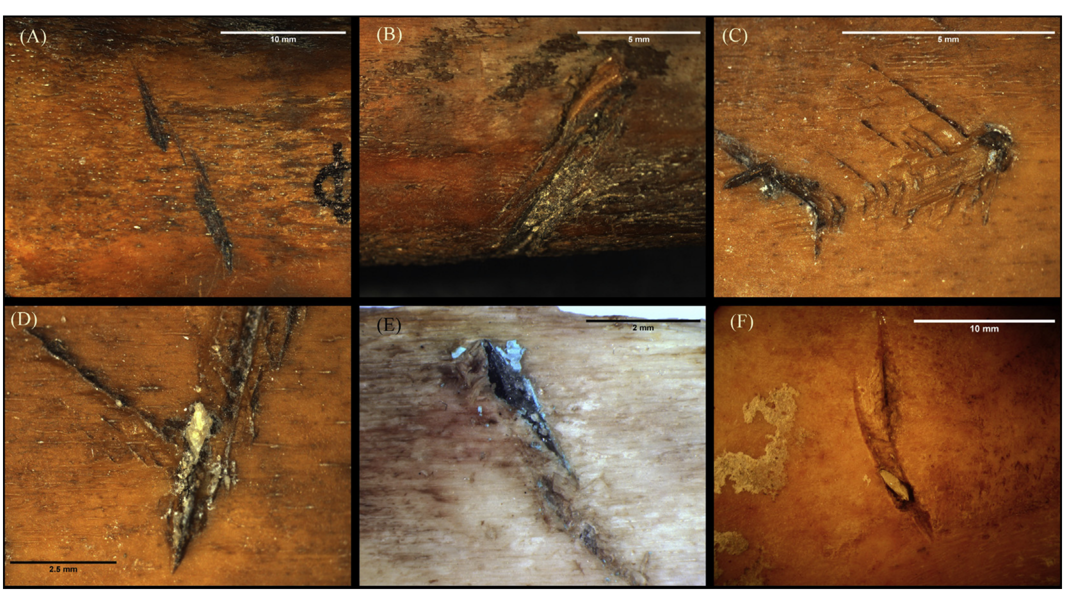

Fig. 6. A selection of 'double drag' PIMs.

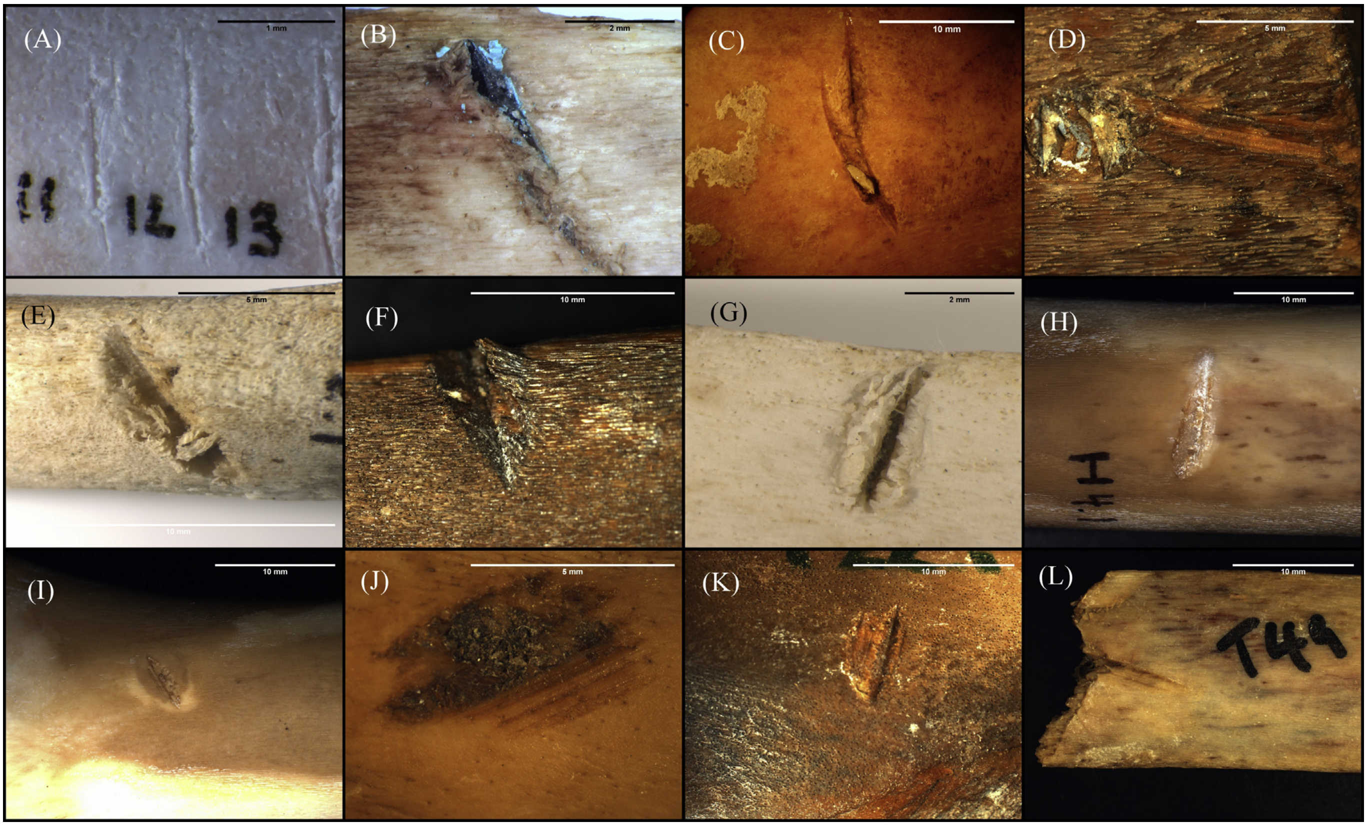

Fig. 7. Comparison of drag marks. (A) slicing cut marks; (B)–(L) a collection of various PIM drag marks.

often shatter and fracture rather than puncture, thus resulting in stone embedding. Therefore, PIMs may be more easily recognisable on larger than on smaller animals. However, other aspects of the experimental design may have affected PIM creation, such as the presence or absence of skin or the use of a carcass that had previously been refrigerated. Thus, future work should systematically explore the effects of different characteristics of the prey animal on PIM creation (Badenhorst, 2012). It may have to be accepted that most experiments will not be able to completely reconstruct all the variables of true hunting events, simply because there are few people who regularly hunt live, wild animals using Stone Age technology. However, future work would benefit from trading experimental control for simulation of more realistic hunting scenarios (Badenhorst, 2012).

As shown in the results, certain shapes occurred more commonly on ribs and vertebrae than other elements. Ribs had high numbers of amorphous, line, oval and triangular shapes, while vertebrae more commonly had amorphous and triangular marks. Vertebrae had high numbers of fractures and punctures, resulting in a high number of amorphous and triangular shaped marks. They also had the second highest incidence of stone being embedded. This suggests that their position in the skeleton, the number of times they occur in it, and their shape and density are all factors that make vertebrae likely to acquire highly diagnostic PIMs. During analysis of the vertebrae it was observed that different marks were more common on the different sections of the vertebrae. The vertebral spinous processes tended to become fractured or have drag marks slicing through the bone (Fig. 8a–c). In contrast, the vertebral body tended to retain puncture marks with several cases of stone embedding or fractures where the body of the vertebra was completely split (Fig. 8d–f).

There were only a few cases where significant differences were observed between the proportions of different categories, shapes, flaking, feathering, and extent of flaking and feathering in the HP and Levallois samples. The same was true for the casting distances. Given the large number of tests that were conducted, it might be expected that a small number of them would produce a significant result purely by chance. Thus, we consider it likely that the few cases of significance observed between the Levallois and HP samples may have been the result of Type I errors – where the null of there being no difference was rejected when in fact it was true. In a practical sense, the differences that did occur – mainly in the incidence of cracking – were observable only at the level of a large assemblage of known PIMS. These bones had also not undergone any of the taphonomic processes such as fragmentation that archaeological assemblages commonly undergo. Thus, attributes such as the incidence of cracking are not good candidates for differentiating point types, modes of projection, or casting differences that led to the creation of PIMs in archaeological samples.

We infer that this lack of readily observable difference is because projectile marks have basic diagnostic features that separate them from simple slicing cut marks at an assemblage level but not from one another, no matter the variables involved. This inference is supported by the fact that the same characteristics were observed in EG1, which employed a range of different hafting or lithic materials, different projectile modes, velocities, and distances. Given the large sample examined here, this study shows that inferring different technologies from individual marks or even small numbers of them would invite unwarranted interpretations. While PIMs may be under-diagnosed in the archaeological record, the nature of their infliction does make them unlikely to be a common occurrence. Therefore, without additional supporting evidence –

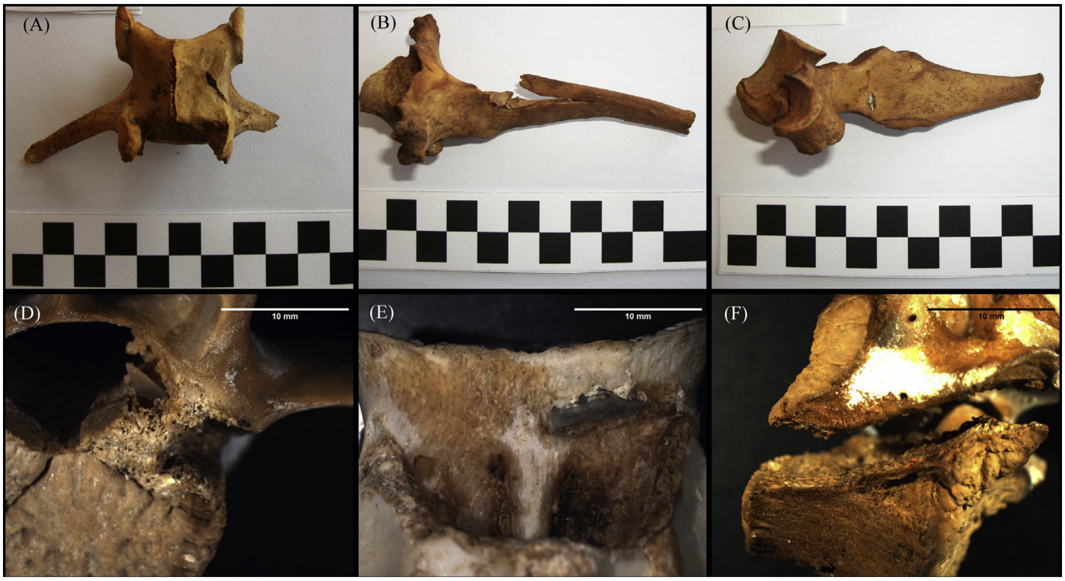

Fig. 8. (A)–(C) vertebral spinous process; (D)–(F) vertebral body marks.

for example, from the stone artefacts themselves – PIMs should not be used to differentiate between modes of projectile delivery or projectile technologies found in the MSA. Recent work by Rots and Plisson (2014) suggests that damage to lithic points themselves may also be equivocal with respect to determining the mode of delivery.

This paper and other experimental PIM studies open up several avenues for future research, as well as recommendations for methodology to be adopted in subsequent analysis of these traces. The use of drag, puncture, fracture and three sub-categories were found to be sufficient to describe the features of each mark, and use of this system keeps definitions simple enough to be applied widely and easily. However, upon completion of this study, it was found that some of the attributes used in the original recording of marks were not useful for describing them. For example, several shapes can be removed from the list of traits (trapezoidal, pentagon, rhombus and square), as they are uncommon and can largely be amalgamated together or into other shapes.

One consideration for future work is the reliance on the calibrated crossbow. This was used for EG2 in order to ensure each projectile was fired with the same force and increased accuracy. However, Pétillon et al. (2011) believes that a calibrated crossbow may change the aerodynamics of the projectile. For the purposes of meeting the research goals of EG2, the advantages of standardisation conferred by the calibrated crossbow outweighed the disadvantages. However, an observation during the experiments was that at 1.4 m the 22 kg draw weight on the calibrated crossbow may have been too powerful to simulate realistic short range or thrusting scenarios, which is an action upon which different forces act than in the casting of projectiles (Cotterell and Kamminga, 1992; Hutchings, 2011). The data from EG1 capture much of the variability that would have been lost by exclusive use of the crossbow, and provide further confidence that future work will benefit from use of the recording system synthesised here from that dataset and existing literature. However, further attention should be given to determining how to simulate thrusting versus throwing scenarios. One of the most important questions this line of research has the potential to address is the origins of projectile technology, and therefore any work that finds differences between PIMs created using the two different approaches (thrusting versus projectiles) would be extremely valuable.

Finally, future work should explore the dimensions of marks beyond simple length and breadth, which were difficult to record for PIMs because of their frequent association with breaks, cracks, and fractures. This association also makes it possible that PIMs may be mistaken for hammerstone percussion marks or tooth marks, which commonly occur near the edges of fractured long bone shafts where the medullary cavity has been breached (Blumenschine et al., 1996). The PIMs in this study did differ from percussion and tooth marks, specifically in contextual variables such as where they were located in the skeleton, and in morphological attributes such as their angular shape. The shape, the presence of abundant internal microstriations, and the cases where stone was embedded all served to differentiate PIMs from carnivore tooth marks. The fractures associated with many of the PIMs provided evidence of forceful initiation that is not expected from mammalian carnivore tooth marks, although it is likely to occur with crocodile damage (Njau and Blumenschine, 2006; Westaway et al., 2011). Although hammerstone percussion also may be performed with considerable force, the area of the contact of the stone to the bone is usually much larger than with a projectile, thus resulting in fractures that propagate more widely than those observed in the PIM sample (Blumenschine and Selvaggio, 1988). Furthermore, percussion marks frequently consist of multiple pits and/or striae fields (Pickering and Egeland, 2006), rather than the single marks in isolation that characterise PIMs.

5. Conclusions

Projectile technology gave *H. sapiens* a distinct advantage over their ecological rivals, because for the first time a predator had the ability to kill their prey from a distance (Knecht, 1997; Crosby, 2002; Smith et al., 2007; Rhodes and Churchill, 2009). This ability relaxed constraints around prey choice and subsistence practices, enabling humans to spread to new regions knowing they could capture a variety of prey. It has been hypothesised that the origins of projectiles lie in the African MSA or the European Middle Palaeolithic (Hughes, 1998; Shea, 2006).

Investigations of the origins of projectile technology have taken many forms, most of which have been from the perspective of candidate projectiles themselves. Evidence for early use of projectiles and the prevalence of ancient projectile technology would be strengthened by identification of the lesions they leave on bones, which requires the development of a widely-applicable diagnostic framework that is also specifically tailored to the lithic projectiles commonly proposed for use during the MSA/Middle Palaeolithic.

The category and traits system outlined in this study proved to be an effective and efficient way to characterise PIMs and differentiate them from other taphonomic marks. When the system described here is applied in a standardised way to an assemblage, there is a high probability of identifying PIMs in the archaeological record. When these data are used in conjunction with other lines of evidence – such as from the projectiles themselves – stronger inferences can then be made about the origins and use of projectile technology.

This study found that there is a distinct and statistical difference between populations of simple slicing cut marks and projectile marks, although further study is required to determine the differences between PIMs and other types of butchery marks, such as hammerstone percussion marks or cut marks inflicted using different actions. In comparison to the slicing butchery marks, there is far more variability in the forms taken by PIMs. These also have a much higher likelihood of stone becoming embedded. Thus, it is easier to fail to recognise a PIM and mistake it for a cut mark than it is to incorrectly diagnose a PIM with stone embedded.

These results will help to resolve the agency behind debated marks, such as the puncture and embedded stone on the cervical vertebra of a *Pelorovis* (*Syncerus*) *antiquus* specimen from Klasies River Mouth (Milo, 1998; Marean and Assefa, 1999), Neanderthal use of projectiles (Dockall, 1997a; Boëda et al., 1999; Shea et al., 2001), and ability of prehistoric hunters (Bratlund and Ullrich, 1999; Leduc, 2012). However, the experiments also showed that it is not possible to infer more detail from such marks about the technological system of which the projectiles were a part. There were no statistically significant differences in the distribution of morphologies or traits between different technology types, projectile modes and distances tested during these experiments. Rather, projectiles leave characteristics on bones that are distinct from simple slicing cut marks but which cannot differentiate from one another within the context of the technological systems recovered from MSA deposits. In light of these results, future avenues of research should include more work on a wider variety of butchery marks in comparison to PIMs, how prey characteristics such as body size may influence PIM production, and what specific differences there might be between PIMs produced by projectiles versus thrusting spears.

Acknowledgements

The authors would like to thank The University of Queensland for some funding toward the experiments. We would also like to thank Ben Schoville, Kyle Brown, Chris Clarkson, Aaron Kelly and Jared Brindley for providing some of the skeletal remains for examination. Thanks to Chris Clarkson for producing the Levallois points for this paper and supplying the lithic raw material. Emma James provided the butchery marks. Thank you must go to Terry Simpson and Tammy-Lee Purssell for your input on early drafts. Finally, thanks are owed to Brendan and Gai O'Driscoll for supplying an area for the bone processing to take place.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.05.036.

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