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Taphonomic approaches to distinguish chewing damage from knapping marks in Palaeolithic faunal assemblages

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ABSTRACT

The imprint of human actions on mammal remains from archaeological sites is often fragmented and attenuated due to post-mortem processes, which add to the challenge of distinguishing human from natural modifications in faunal assemblages. Identifying minimally-worked bone tools poses a particular challenge when they are mixed with bones that have been modified by other agents. Bones, antlers and teeth used as hammers or pressure-flakers in flint-knapping can be particularly difficult to identify because knapping damage resembles carnivore chewing marks. This paper presents a methodological approach to establish diagnostic criteria for identifying whether bones from archaeological sites were modified by chewing or knapping, using observations at macroscopic and microscopic levels. We applied these criteria to case studies from the Upper Palaeolithic (Magdalenian) site of Gough's Cave (UK). Analysis of Magdalenian stone tools shows that blades were detached with a soft hammer, yet organic (soft) knapping tools appear to be scarce in Magdalenian contexts. We propose that the difficulty in identifying knapping damage on bones that have undergone only a short period of use, combined with the macroscopic similarity of these marks with natural modifications (e.g., carnivore chewing), are significant factors contributing to the rarity of minimally-modified knapping tools in archaeological contexts.

1. Introduction

One of the principal difficulties when studying archaeological bone assemblages is to determine the causal agent or agents responsible for the modifications. Experimental and fossil-based zooarchaeological research has attempted to identify distinctive patterns of bone modifications that are unique to human actions (e.g. butchery, manufacture and use of organic tools). This task is not always straightforward as a host of natural processes, such as carnivore chewing and trampling, can damage osseous materials in ways that mimic modifications produced by humans (Andrews and Fernández-Jalvo, 1997; Haglund and Sorg, 1997; Lyman, 1994). Identifying the impact of these factors in the formation of bone assemblages has focused largely on resolving the hunting-scavenging debate (e.g., Blumenschine, 1986, 1988, 1991; Blumenschine et al., 2007; Domínguez-Rodrigo, 1993; Domínguez-Rodrigo and Barba, 2006, 2007) and on gaining a better understanding of hominin carcass processing strategies. These studies examined the features created by natural processes (e.g. chewing and sediment abrasion) against humanly-induced modifications such as cut-marks, chop-marks and percussion damage (Andrews and Fernández-Jalvo, 1997; Blumenshine et al., 1996; Capaldo and Blumenshine, 1994; Lyman, 1987; Njau, 2012; Njau and Blumenschine, 2006; Potts and Shipman, 1981; Shipman and Rose, 1983). However, fewer studies have focused on differentiating natural modifications, specifically chewing marks, from the marks left by hominins when preparing and using osseous materials as knapping tools (i.e., tools used to strike lithic material with the intention to produce, shape, sharpen or retouch a lithic tool).

Sutcliffe (1973) described bones and antlers gnawed by Scottish red deer and Norwegian reindeer with split tips and zig-zag margins that mimic bone tools (Sutcliffe, 1973, page 429 and fig. 3). Binford (1981) highlighted problematic cases where he believed carnivores were responsible for modifying bones that were generally considered to be knapping tools. Based on his examination of approximately 134 Middle Palaeolithic examples from Combe Grenal (Dordogne, France), he argued that the pitting and scoring on these bones were natural damage from carnivore chewing contrary to original interpretations by Henri-Martin (1907–1910: Figure LXI, nos. 1, 3, and 5) and Bordes (1961). More recently, Backwell and d'Errico's description of indentations present on an elephant patella (FLKII 884; Backwell and d'Errico, 2004, page 108 and fig. 8) from Bed II, Olduvai Gorge (Tanzania), which they

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Table 1

List of specimens analysed for this study and detail of modifications observed. This table provides a key to the specimens illustrated in figures 1, 2, 3 5, 6 and 7.

				Faunal (non-human) agent		Human agent				Figure references
Site	Reference n.	Taxon	Element	Breakage	Chewing	Breakage	Cut-marks	Scraping	Knapping	
Boxgrove	NHMUK PV UNREG 4198	Large bovid	Radius-ulna shaft fragment	–	–	–	–	√	√	Fig. 5 e, f, g, h
	NHMUK PV UNREG 4199b	*Stephanorhinus* sp.	Femur shaft fragment	–	–	–	–	√	√	Fig. 5a
	NHMUK PV UNREG 4197	Cervid	Humerus (distal end)	–	–	√	–	–	√	Fig. 1d
Schöningen	Sch 4314	*Equus mosbachensis*	Metacarpal	–	–	–	–	√	√	Fig. 1a, 2d
	Sch 7785	*Equus mosbachensis*	Metacarpal	–	–	–	–	√	√	Fig. 2f
	Sch 13162	*Equus mosbachensis*	Metacarpal	–	–	–	–	√	√	Fig. 2e
	Sch 12882	*Equus mosbachensis*	Metacarpal	–	–	–	√	–	√	Fig. 2c
	Sch 10199	*Equus mosbachensis*	Long bone shaft	–	√	–	–	–	–	Fig. 3f, g
	Sch 698	*Equus mosbachensis*	Rib	–	–	–	√	√	√	Fig. 7a, b, c
	Sch 3481	Bovid	Femur	–	–	–	–	√	√	Fig. 3a
	Sch 3299	Large mammal, species undetermined	Long bone shaft	–	–	√	–	√	√	Fig. 1b, 3b, d
	Sch 1729	Large mammal, species undetermined	Long bone shaft	–	–	–	–	√	√	Fig. 3e
	Sch 3054	Large mammal, species undetermined	Long bone shaft	–	–	–	–	√	√	Fig. 5b, c, d
Kent's Cavern	NHMUK PV M 1003	*Ursus deningeri*	Tibia	√	√	–	–	–	–	Fig. 1i
	NHMUK PV M 727	*Panthera leo*	Canine	√	–	–	–	–	√	Fig. 1c
	NHMUK PV M 103301	*Panthera leo*	Canine	√	√	–	–	–	–	Fig. 1f
	NHMUK PV M 616	*Equus ferus*	Phalanx I	–	√	–	–	–	–	Fig. 1h
	NHM PV M 714	Cervid	Metatarsal	√	√	–	–	–	–	Fig. 2j, k, l
	NHMUK PV M 615	*Equus ferus*	Rudimentary metapodial	–	√	–	–	–	–	Fig. 3i, j
	NHMUK PV OR 16835	*Coelodonta antiquitatis*	Metacarpal III	–	√	–	–	–	–	Fig. 1g, 3k, l
Gough's Cave	NHMUK PV Unreg 3482	*Equus ferus*	Phalanx I	–	√	–	√	–	√	Fig. 1e, 6a
	NHMUK PV M 49788	*Equus ferus*	Phalanx I	–	√	–	–	–	–	Fig. 6b
	NHMUK PV Unreg 3846	*Equus ferus*	Rib	√	√	√	√	√	–	Fig. 7d, e, f
	NHMUK PV M 49934	*Equus ferus*	Metacarpal	–	–	√	√	–	√	Fig. 2b
	NHMUK PV M 49873	*Equus ferus*	Metatarsal	–	–	–	–	–	√	Fig. 2a
	NHMUK PV M 50025	*Equus ferus*	Metatarsal	–	√	√	√	–	√	Fig. 2g, h, i
	NHMUK PV M 54092	*Homo sapiens*	Femur	–	√	√	√	–	–	Fig. 3h

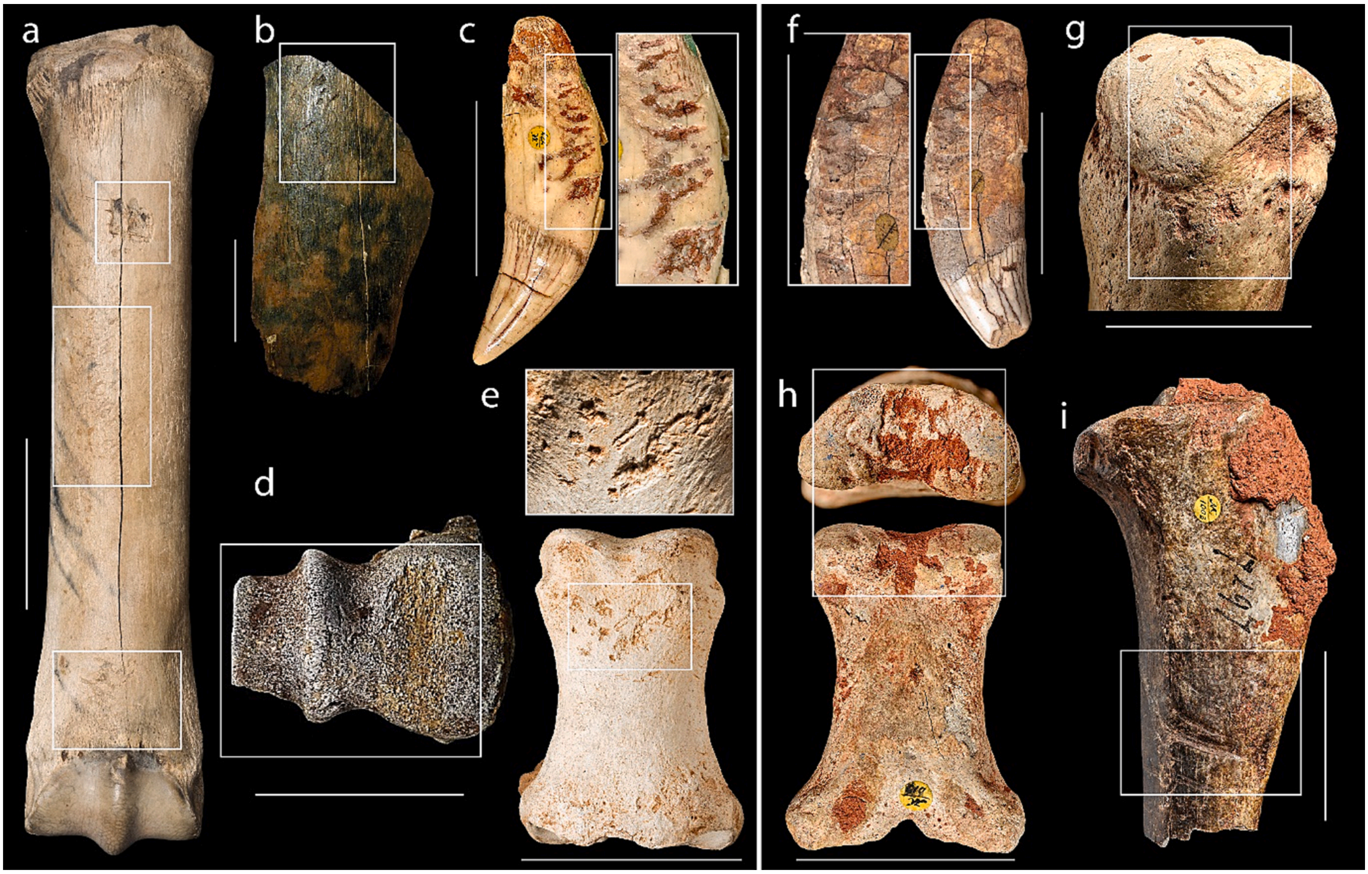

Fig. 1. Location of knapping damage (a-e) and carnivore chewing marks (f-i) on complete and fragmented bones and teeth. White boxes indicate the location of the modifications. Scales = 50 mm. Boxgrove: (d) fragment of distal humerus, cervid. Schöningen: (a) metacarpal of *Equus mosbachensis*; (b) long bone shaft fragment, undetermined species. Kent's Cavern: (c) canine of *Panthera leo*; (f) canine of *Panthera leo*; (g) metacarpal III of *Coelodonta antiquitatis*; (h) phalanx I of *Equus ferus*; (i) tibia of *Ursus denigeri*. Gough's Cave: (e) phalanx I of *Equus ferus*.

attributed to percussion damage, has been re-interpreted as the result of crocodile chewing (Pante et al., 2020, page 3).

The foregoing examples illustrate how knapping marks are a particularly difficult category of bone surface alterations to distinguish from chewing marks. One of the possible reasons for the misidentification of knapping tools in the archaeological record may be the lack of published resources that integrate illustrations of knapping modifications with illustrations of non-anthropic modifications, such as chewing marks. An essential criterion for identifying the causal agent responsible for the modification of archaeological assemblages is linked to the use of adequate image resources. Some of the more consulted and comprehensive books on zooarchaeological taphonomy, such as Shipman (1981), Brain (1981), Lyman (1994) and Fernández-Jalvo and Andrews (2016), and some of the more influential books on knapping technologies, such as Hutson et al. (2018a), Patou-Mathis (2002), Semenov (1964), are based primarily on archaeological evidence. However, none of the books on zooarchaeological taphonomy mention how to recognise knapping modifications, while the books on knapping technologies overlook the question of distinguishing natural modifications from knapping marks. Reliance on published sources which lack a shared focus on identifying and differentiating between these types of modifications, may have led to the under-recognition or misinterpretation of the modifications related to the production and utilization of organic knapping tools. We propose that combining both lines of evidence within one paper will help to make more informed distinction between chewing and knapping marks on archaeological assemblages.

In this paper, we focus on macro- and microscopic characteristics of archaeological material that can be used to distinguish anthropic from non-anthropic modifications. Our aim is to highlight the features that allow damage on osseous tools from knapping (direct percussion and pressure flaking) to be distinguished from chewing modifications that mimic knapping marks. Reliable identifications of knapping tools in ambiguous cases can usually be resolved from microscopic features, which are illustrated with macro-photographs, three-dimensional optical scans and scanning electron microscope images. We applied this approach to reassessing the interpretation of modifications observed on selected faunal remains from the Magdalenian site of Gough's Cave (Somerset, UK).

2. Methods and material

The modifications produced by chewing and knapping are examined at different scales from the macroscopic (type of osseous element, anatomical location, density of the marks, depth of features and morphological types) to the microscopic level (e.g., microstriations, lithic inclusions). We utilized various imaging techniques to analyse and visualize the bone surface modifications following the approach developed by Bello and Galway-Witham (2019) and Bello et al. (2013).

Modified areas were first examined macroscopically using a hand lens, and photographs were taken at the Photography Unit of the Natural History Museum (NHM) in London, UK. To examine the topography and microscopic details, we employed a Focus Variation microscope (FVM) - the Alicona InfiniteFocus G5+ (AIF) optical surface measurement system (Optimax Ltd, Market Harborough, UK), which produced three-dimensional (3D) reconstructions of the scanned surfaces. The images were captured using a 2.5x objective (magnification 45.72x) or a 5x objective lens (magnification 91.44x) in both cases with a vertical resolution of 1.755 mm, and lateral resolution of 900 nm.

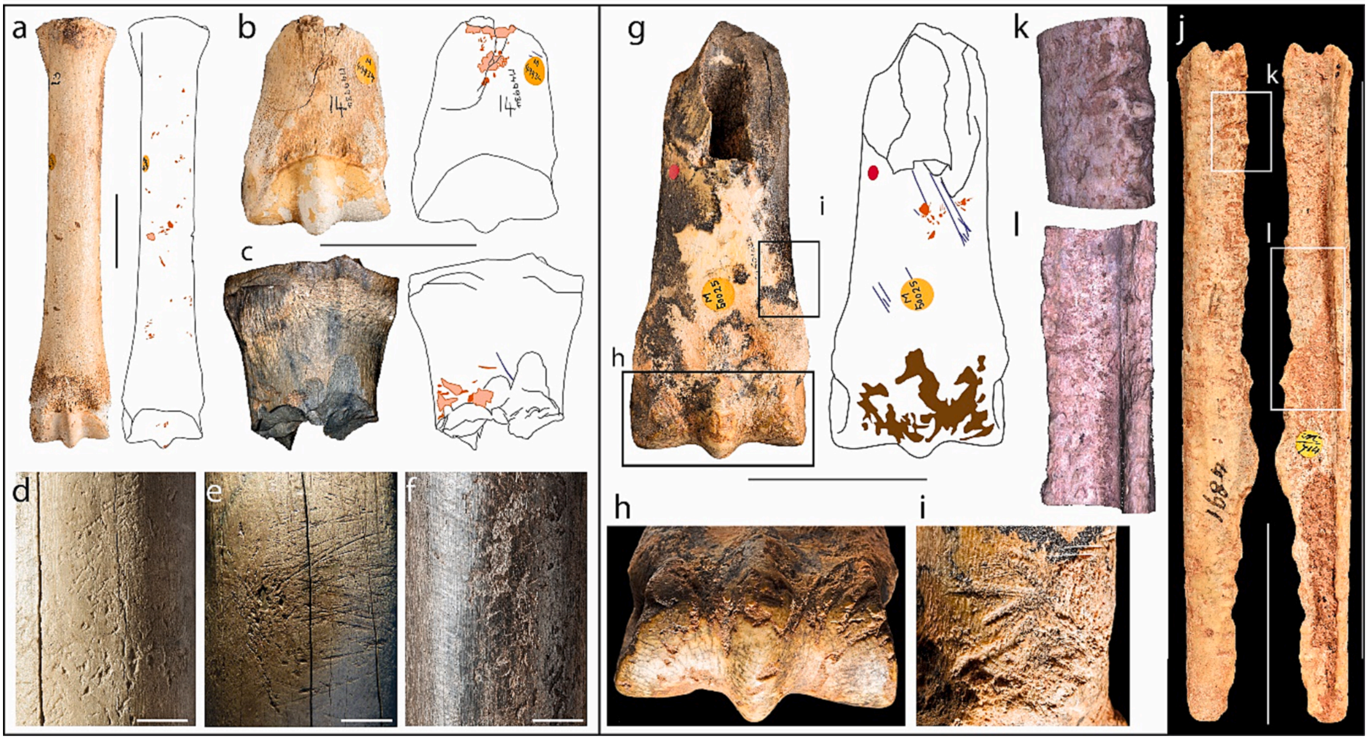

Fig. 2. Macroscopic appearance of knapping marks (a-f) and carnivore chewing (g-l). FVM 3D images of chewing damage on cortical (k) and medullar (l) bone surfaces. Scale a-c, g-i = 50 mm, Scale e-f = 10 mm. Orange indicates knapping areas, brown indicates chewed areas, and blue lines indicate cut-marks. Schöningen: (c) metacarpal and (d-f) details of metacarpal shafts of *Equus mosbachensis*. Kent's Cavern: (j-l) metatarsal shaft of a cervid. Gough's Cave: (a, g-i) metatarsals and (b) metacarpal of *Equus ferus*.

For higher resolution images and better characterization of finer details, we used a scanning electron microscope (SEM), the JEOL-IT500, operated in variable pressure mode. For this study, the operating parameters were: accelerating voltage of 13 to 15 kV; spot size 500; pole-piece to specimen working distance of 10–15 mm. We also combined electron microscopy with energy dispersive X-ray spectroscopy (EDX) - Oxford Instrument X-Max 80 Silicon Drift Detector with INCA software - to conduct elemental analyses of surface features. We conducted analyses of specific areas of interest to identify exogenous elements embedded within the modifications (e.g., micro-chips within knapping marks). In the case of the studied sample, micro-chips of flint (predominantly silicon dioxide) were found embedded in the calcium-rich bone surface. The distribution of silicon (flint) and calcium (bone) within a single area was illustrated by assigning different colours to each element.

The diagnostic features associated with chewing and knapping have been collated from new analyses and imaging of archaeological specimens from Boxgrove (UK, ~500,000 BP), Schöningen (Germany, ~ 350,000 BP), Kent's Cavern (UK, ~ 42,000 BP) and Gough's Cave (UK, ~ 15,000 BP). Details of these specimens and the modifications observed on each of them are presented in Table 1.

3. Results

3.1. Diagnosing knapping and chewing

3.1.1. Macroscopic appearance

3.1.1.1. Knapping marks. In the Palaeolithic, complete long bones (e.g. Bello et al., 2021; Henry Martin, 1906; Parfitt et al., 2022; van Kolfschoten et al., 2015) and shaft fragments (e.g. Abrams et al., 2014; Blasco et al., 2013; Daujeard et al., 2014; Doyon et al., 2018; Holgueras, 2009; Rosell et al., 2011, 2015) were commonly used as knapping tools. The impact damage on long bones used as knapping tools is typically found on the flatter or convex mid-shaft areas, as shown in Fig. 1a and e (also seen in many archaeological and experimental samples: e.g. Armand and Delagnes, 1998; Henri Martin, 1907; Martellotta et al., 2020). This suggests that smooth and featureless areas with thick cortical bones were selected for knapping work.

These bones were used as percussion tools and swung like a baton to strike flakes from a core or from the edge of a flake tool or biface (e.g., Hutson et al., 2018b; Moignet et al., 2016; Parfitt et al., 2022; Parfitt and Bello, 2020; Roberts and Parfitt, 1999; Valensi, 2002). Articular ends were also used in this way, as exemplified by examples of artiodactyl distal humeri at Boxgrove (Fig. 1d) and Cagny-l'Épinette, France (Pitts and Roberts, 1997; Sévêque and Auguste, 2018). Bones also provided supports ('anvils') in bipolar knapping, as illustrated by a horse innominate from Schöningen (van Kolfschoten et al. 2015); shafts of horse metapodials and other long bones from Schöningen may have been used in a similar way.

Bone fragments, typically pieces of long bone shaft, were commonly used as knapping tools (Fig. 1b). These are the 'classic' retouchers and compressors that are often a significant component of Middle Palaeolithic bone assemblages (Chase, 1990; Hutson et al., 2018a; Rosell et al., 2011). Knapping areas on these tools are frequently found near the ends of the bone fragment (Fig. 1b); however, in some instances, the knapping marks can be concentrated in the central part of the bone fragment (e.g. Abrams et al., 2014; Rosell et al., 2015). These handheld tools were utilized by tapping or pressing them against the lithic tool edge to detach resharpening flakes.

In addition to long bones and shaft fragments, other bone elements were less commonly used for knapping; these include, ribs (Armand and Delagnes, 1998; van Kolfschoten et al., 2015), phalanges (Fig. 1e) (Bello et al., 2021; Chase, 1990), pelves (Parfitt and Bello, 2020; van Kolfschoten et al., 2015), astragali (Pante et al., 2020), and cranial vault fragments (Verna and d'Errico, 2011). Teeth and tusks (Fig. 1c; Abrams, 2018; Bello et al., 2021; Castel et al., 2003; Castel and Madelaine, 2006; Neruda and Lázničková-Galetová, 2018; Neruda et al., 2011; Taute, 1965) and antler tines and bases (Bello et al., 2016; Doyon et al., 2018; Stout et al., 2014) have also been used as knapping tools.

Macroscopically, knapping marks are visible as pitted areas (knapping area, *sensu* Mallye et al., 2012) with a concentration of overlapping impact marks, which can form an oval (Rigaud, 2007) or heart-shaped configuration (Pante et al., 2020). Typically, retouchers/compressors were used on the spot and discarded after they had been employed to remove a few re-sharpening flakes from a tool edge (e.g. Rosell et al., 2015). Other examples, however, were used to make numerous stone tools and transported from place to place as part of a mobile knapping kit (e.g. Parfitt and Bello, 2020). These differences in the intensity of use are a contributing factor resulting in different morphologies of the knapping marks. With minimal use, only a few scattered knapping marks are created (Fig. 2a, d), but with more extended use, the knapping marks occur as a single cluster or multiple areas of concentrated damage (Patou-Mathis and Schwab, 2002; Schwab, 2005; Mallye et al., 2012), which exhibit deeper surface attrition (Fig. 2e). More forceful actions can result in the removal of small bone plaques (Fig. 2f) ('scaled areas' *sensu* Mallye et al., 2012), or even the breakage or disintegration of the tool (Fig. 2b, c).

Knapping areas on bone fragments have only been observed on the outer surface of the compact bone and more rarely on break surfaces, but no examples have been reported on the medullary surface of long bone fragments.

3.1.1.2. Chewing marks. Chewing marks can be found on almost any anatomical element, although they are generally absent on antlers, teeth and tusks. However, hyaenas chew bones as well as teeth (Fig. 1f) and antler, and their actions often result in the almost complete destruction of these tissues (Fig. 2j) (Blumenschine, 1986; Brain, 1981; Domínguez-Rodrigo, 1993; Faith, 2007; Sutcliffe, 1970). The chewing of antlers and bones by artiodactyls has also been observed to be part of feeding behaviours in red deer, reindeer, caribou, camels and cattle (Brothwell, 1976; Sutcliffe, 1973 and references within).

Carnivores typically follow a consistent sequence when consuming prey, and these patterns can be used to distinguish between carnivore taxa as taphonomic agents in forensic and archaeological cases (Blumenschine, 1986; Camarós et al., 2016; Domínguez-Rodrigo, 1999; Pickering, 2001; Pobiner et al., 2020). On long bones, prominent chewing marks are typically located on or near the epiphyses, followed by near-epiphyseal areas and midshaft (Fig. 1g-i). The destruction of bone by carnivores is thought to be a density-mediated process (Blumenschine, 1991; Brain, 1981; Lam et al., 1998; Marean et al., 1992). However, Kuhn et al. (2009), while considering in their observational study the weathering stage of the bones as well as the chewing modification produced by different carnivore size classes, demonstrated a negative and positive correlation (although not all them were significant) between the presence of tooth marks and bone density on the epiphyses of long bones. Similarly, Faith et al. (2007) proposed that tooth marks may be more prevalent on denser portions of bone that are harder to consume, or alternatively, on lower density epiphyseal or near-epiphyseal portions due to carnivores' heightened interest in fatty areas of bone.

Macroscopically, chewing marks on complete shafts are generally present on corresponding opposite sides of the bone, due to the combination of the attrition produced by the maxillary and mandibular teeth (Fig. 2g-i). Carnivore chewing marks can also be found on the medullary surfaces of the compact bone fragments where breakage has exposed the internal surface to continued chewing (Fig. 2j-l). Tooth marks on bones can be variable in their distribution and density and they may include multiple pits and scores resulting from intensive gnawing and chewing (Fig. 2h-i), which can resemble the pattern of wear found on heavily-used knapping tools.

3.1.2. Microscopic appearance

3.1.2.1. Knapping marks. Focusing on the form of individual marks, knapping can result in features of varying morphology, classified in

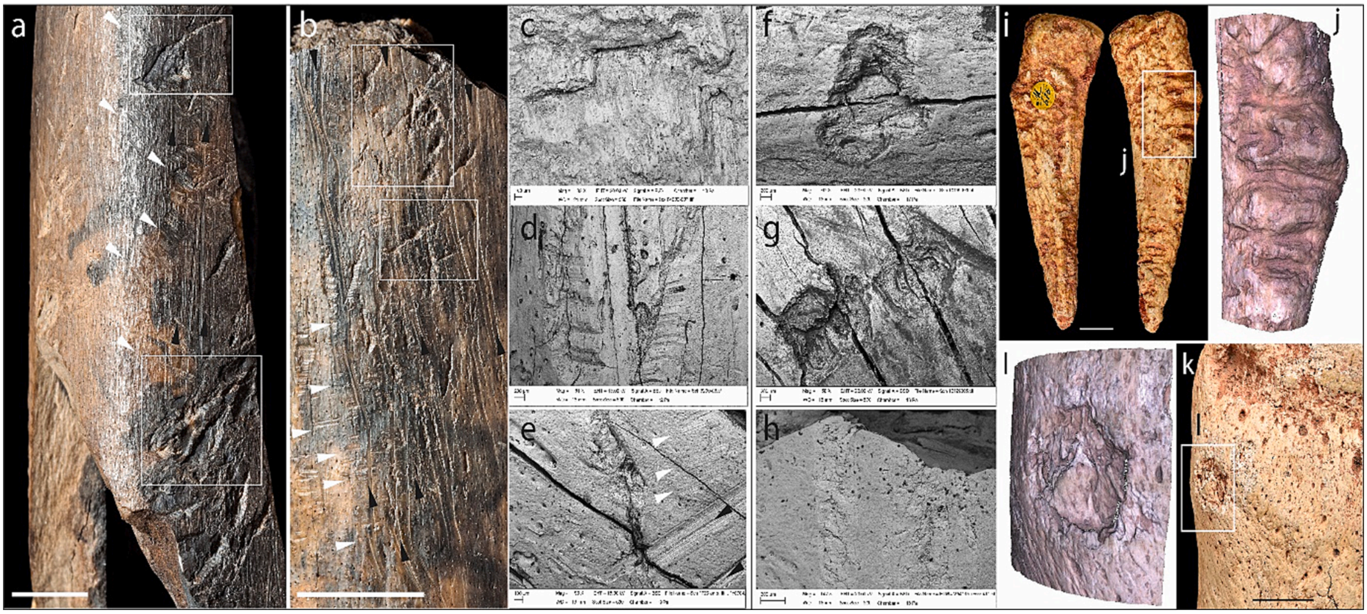

Fig. 3. Microscopic appearance of knapping indentations (a-e) and carnivore chewing (f-l). Tool edge scratches are indicated with white arrows and black arrows indicate preparatory scraping marks (scales = 10 mm). SEM images of (c) a knapping pit and (d, e) knapping scores with internal micro-striations indicative of the direction of the blow. SEM images of (f, g) tooth pits; (h) tooth scores. Photographs and FVM 3D images of (i-j) furrowing and (k, l) a large tooth pit. Schöningen: (a) fragment of a bovid femur; (b, d) long bone shaft, undetermined species; (e) undetermined fragment; (f, g) long bone shaft, *Equus mosbachensis*. Kent's Cavern: (i, j) rudimentary metapodial of *Equus ferus*; (k, l) metacarpal III of *Coelodonta antiquitatis*. Gough's Cave: (h) femur, *Homo sapiens*.

Table 2
Tooth pit dimensions by taxon, knapping pit summary statistics and references used. Measurements are in mm. References: (1) Andres et al., 2012; (2) Young et al., 2015; (3) Domínguez-Rodrigo and Piqueras, 2003; (4) Delaney-Rivera et al., 2009; (5) Van Kolfschoten et al., 2015.

Species	No	Mean length	StDev length	Mean Width	StDev width	References
Chewing pits						
Large-sized animals						
American alligator	16	1.7	0.72	0.95	0.49	(4)
Bear	14	2.9	0.88	1.88	0.58	(3)
Lion	28	2.87	1.8	1.7	1.41	(1)
Lion	10	3.45	0.48	2.2	0.31	(3)
Lion	33	1.81	1.03	1.1	0.37	(4)
Tiger	12	1.3	0.69	0.8	0.44	(4)
Wolf	236	2.49	1.15	1.8	0.87	(1)
Medium-sized animals						
Baboon	66	0.94	0.48	0.8	0.35	(1)
Baboon	34	2.55	1.03	1.54	0.63	(3)
Humans	31	1.06	0.57	0.76	0.47	(1)
Humans	50	1.53	0.75	0.87	0.34	(4)
Hyena	46	2.71	3.11	1.55	1.2	(1)
Hyena	456	1.57	0.98	1.19	0.75	(1)
Hyena	38	3.27	2.13	2.24	1.34	(3)
Jackal	40	1.45	0.75	0.85	0.46	(3)
Small-sized animals						
Badger (captive)	9	2.72	0.83	2	0.76	(2)
Bobcat	10	1.08	0.51	0.77	0.4	(4)
Caracal	6	1.71	0.62	1.1	0.58	(4)
Cougar	40	1.32	0.53	0.94	0.37	(4)
Coyote	3	1.4	0.63	0.9	0.43	(4)
Dog	66	1.77	0.91	1.36	0.66	(1)
Dog	16	3.87	1.47	2.38	0.84	(3)
Dog	39	1.31	0.64	0.83	0.25	(4)
Dog (small)	8	3.25	1.21	1.88	0.52	(2)
Dog (Staffordshire)	7	2.95	0.67	2.2	0.92	(2)
Fox	67	1.54	1.18	0.99	0.87	(1)
Fox	8	2.83	2.83	1.5	0.5	(4)
Fox (captive)	7	2.05	0.71	1.48	0.55	(2)
Fox (wild)	376	1.46	0.72	0.92	0.34	(2)
Ocelot	25	1.15	0.56	0.74	0.26	(4)
Racoon	6	0.85	0.2	0.62	0.1	(4)
Serval	4	1.09	0.27	0.68	0.15	(4)
South American Coati	3	1.31	0.98	0.7	0.36	(4)
knapping pits	***48***	***1.59***	***0.73***	***0.95***	***0.49***	(5)

some schemes as notches, striae, punctiform dents, linear impressions, gouges, pits and scores (Holgueras, 2007; Jéquier et al., 2012; Mallye et al., 2012; Patou-Mathis, 2002; Valensi, 2002; Vincent, 1993). A simplified terminology distinguishes three types of surface modifications:

- Knapping indentations (gouges, pits, and scores): these features are produced when a knapping tool strikes the edge of a stone tool during percussion or pressure-flaking. The range of plan-forms varies from pits to elongated scores and gouges and the damage is superficial with compaction of the bone matrix and lateral deformation resulting in microscopic faulting. Depending on the type of stone tool-edge being worked and the knapping action involved, the individual marks may take the form of deep gouges (larger depressions sometimes associated with bone flaking and chipping; Fig. 3a), pits (depressions with a triangular or ovoid form; Fig. 3b, c) and scores (depression with a longer linear appearance, which can be either rectilinear or sinuous; Fig. 3b, d, e). Internally, these indentations typically exhibit microstriations that are oriented perpendicular to the longer axis of the indentation (Fig. 3c, d).
- Tool-edge scratches or sliding striations are superficial linear marks that appear on the surface of bones near the indented features. Tool-edge scratches (*sensu* Vincent, 1993) are formed when a stone tool's edge glides across the surface of a knapping tool during percussion or when the retoucher is pressed against the tool edge. They are closely-spaced, shallow marks that are typically found on one, or both sides of a knapping indentation and have a W-shaped profile similar to scrape marks (Fig. 3 a, b and e). Tool-edge scratches and knapping indentations can create "comet"-like structures in which the scratches terminate and align with microstriae within the pits or gouges (Fig. 3a). If tool-edge scratches occur beyond the trailing edge of a knapping indentation, they are caused by projections on the side of the lithic tool brushing against the knapping tool during the "follow-through" phase of the knapping blow.
- Knapping notches are semi-circular or arcuate-shaped features resulting from breakage of a knapping tool during use. This can occur after intensive use or powerful blows (Fig. 2b, c). The internal conchoidal fracture and surface pitting associated with this damage can resemble percussion features from marrow fracture (Parfitt et al., 2022; Pickering and Egeland, 2006).

Variation in the morphology of knapping indentations is partly determined by the type of lithic material being worked (e.g., coarse-grained quartzite vs. obsidian; Mallye et al., 2012), the type of knapping action (Tartar, 2012), the technical ability of the knapper and the way retouchers are handled in use (Kolobova et al., 2022; Mozota, 2013). The density of the knapping tools and type of hard tissue whether bones, teeth or antlers and the fresh or dry state of the material can also influence the morphology of the marks left on the tool (Bello et al., 2021; Rosell et al., 2018; van Kolfschoten et al., 2015). Finally, the different knapping actions, which can involve direct percussion with force ranging from heavy blows to gentle tapping, indirect percussion using a punch, and pressure-flaking can all influence the morphology of the indentations (Armand and Delagnes, 1998; Doyon et al., 2019; Parfitt et al., 2022; Semenov, 1964).

Table 3

Tooth score dimensions by taxon, knapping score summary statistics and references used. Measurements are in mm. References: (1) Andres et al. 2012; (2) Young et al 2015; (3) Domingez-Rodrigo and Piqueras, 2003; (4) Delaney-Rivera et al. 2009; (5) Van Kolfschoten et al., 2015.

Species	No	Mean length	StDev length	Mean Width	StDev width	Reference
Chewing scores						
Large-sized animals						
American alligator	1	2.98		0.33		(4)
Bear	14	10.92	5.02	1.65	1.31	(3)
Lion	124	0.96	5.05	0.32	0.58	(1)
Lion	5	8.4	1.14	2.2	0.27	(3)
Lion	6	3.95	1.82	0.97	39	(4)
Tiger	12	3.01	0.78	0.72	0.27	(4)
Wolf	306	8.62	4.31	1.68	1.12	(1)
Medium-sized animals						
Baboon	96	2.77	1.98	0.46	0.19	(1)
Baboon	19	8.08	3.18	1.09	0.84	(3)
Humans	18	1.91	0.9	0.56	0.29	(1)
Humans	27	5.52	2.1	0.78	0.8	(4)
Hyena	603	3	2.01	0.6	0.63	(1)
Hyena	59	7.34	4.67	1.29	1.22	(3)
Hyena	17	8.4	4.46	1.27	0.38	(4)
Hyena	1	9.53		0.73		(4)
Jackal	40	3.35	1.09	0.41	0.15	(3)
Small-sized animals						
Badger (captive)	2	3.57	0.25	0.91	0.35	(2)
Bobcat	5	3.45	1.48	0.68	0.14	(4)
Cougar	11	3.19	1.34	0.76	0.34	(4)
Dog	164	5.06	2.76	0.66	0.3	(1)
Dog	23	12.8	6.12	1.5	0.76	(3)
Dog	14	4.43	1.71	0.6	0.27	(4)
Dog (small)	18	9.75	4.54	1,91	0.95	(2)
Dog (Staffordshire)	7	8.1	3.2	1.5	0.69	(2)
Fox	96	3.64	2.1	0.42	0.32	(1)
Fox (captive)	31	8.53	3.03	1.07	0.47	(2)
Fox (wild)	59	6.03	2.83	0.96	0.65	(2)
Ocelot	10	3.2	1.65	0.55	0.11	(4)
South American Coati	2	3.27	0.66	0.85	0.12	(4)
knapping scoes	***40***	***3.01***	***1.3***	***0.6***	***0.35***	(5)

3.1.2.2. Chewing marks. Chewing by carnivores, herbivores and rodents can produce a range of morphologically and morphometrically different modifications, such as large deep punctures inflicted by sharks or crocodiles (Egeland and Pickering, 2020 and reference within; Njau and Blumenschine, 2006; Sahle et al., 2017), to straight, parallel, and flat-bottomed scores produced by rodent or lagomorph gnawing (Pokines et al., 2017; Shipman and Rose, 1983), to microscopic bites left by insects (Backwell et al., 2012; Huchet et al., 2011). Crocodile feeding bites on bones often result in damage that bears a striking resemblance to some of the types of marks produced during knapping and other percussion activities (e.g. marrow processing). This is illustrated by a Pleistocene elephant patella from Olduvai with marks that were interpreted as potential percussion damage, but which are almost certainly produced by a crocodile (Pante et al., 2020). However, crocodile bite marks display a different constellation of features (including pivoted and hook marks) that distinguish crocodile feeding marks from knapping marks and marrow processing percussion features (Baquedano et al.,2012; Njau and Blumenschine, 2006; Njau and Gilbert, 2016; Sahle et al., 2017). Crocodile-induced damage can also be excluded in contexts and geographical areas lacking crocodiles.

Chewing marks on bones that mimic knapping damage can be grouped into five categories:

- Pits: superficial circular or semi-circular depressions (Fig. 3f, g), although crocodile tooth pits have been described as more angular, with a bisected shape sometimes associated with scores with V-shaped cross-sections (Baquedano et al., 2012; Njau, 2012; Njau and Gilbert, 2016). Pits occur when teeth and beaks make contact with a bone surface and deform the compact or cancellous bone without penetrating fully into the underlying cavity or cancellous matrix. Tooth pits can show crushing of the outermost lamellae (Binford, 1981; Domínguez-Rodrigo and Barba, 2006; Fisher, 1995; Haynes, 1983). According to Pobiner (2008), both tooth pits and punctures are defined as having a long axis no more than three times the length of the short axis.
- Scores: superficial elongated channels, sometime associated with a change in the colour of the bone surface, that occur when teeth or beaks drag across the surface of a bone without penetrating into the underlying cavity (Fig. 2h, i; Fig. 3h). According to Selvaggio (1994), tooth scores are defined as marks with a length measuring three or more times its breadth. Tooth scores have a U shape section, they are typically shallow features, and the bottom and side of the channel can either appear smooth (Domínguez-Rodrigo and Barba, 2006), show superficial micro-fracturing and flaking (Fig. 3h; Rowe, 2018; Sala et al., 2014; Saladié et al., 2013), chattered-marks, more common in the case of herbivores gnawing (Hutson et al., 2013) or, occasionally, can be marked by internal micro-striations parallel to the long axis of the score (Potts and Shipman, 1981; Rowe, 2018; Saladié et al., 2013; Shipman and Rose, 1983). Longitudinal micro-striations are also common features of scores produced by the beaks of vultures (Domínguez-Solera and Domínguez-Rodrigo, 2011).
- Furrows: wide, deep, and long crenulated marks that penetrate the compact or spongy bone (Fig. 3i, j). Persistent chewing can result in the destruction of bones with lower density, particularly in axial elements and the epiphyses of long bones. Carnivores tend to begin consuming long bones at the softer epiphysis and gradually move towards the denser diaphysis, leading to chipping, gnawing, or licking polish on the exposed surfaces. This process creates crenulated edges and smooth, polished surfaces with indentations (Fig. 2j-l).
- Punctures: circular, semi-circular or sub-triangular perforations that penetrate the compact bone (Fig. 3k, l). They occur when teeth or a beak penetrate the thickness of a flat bone or enter into the medullary cavity of a long bone.

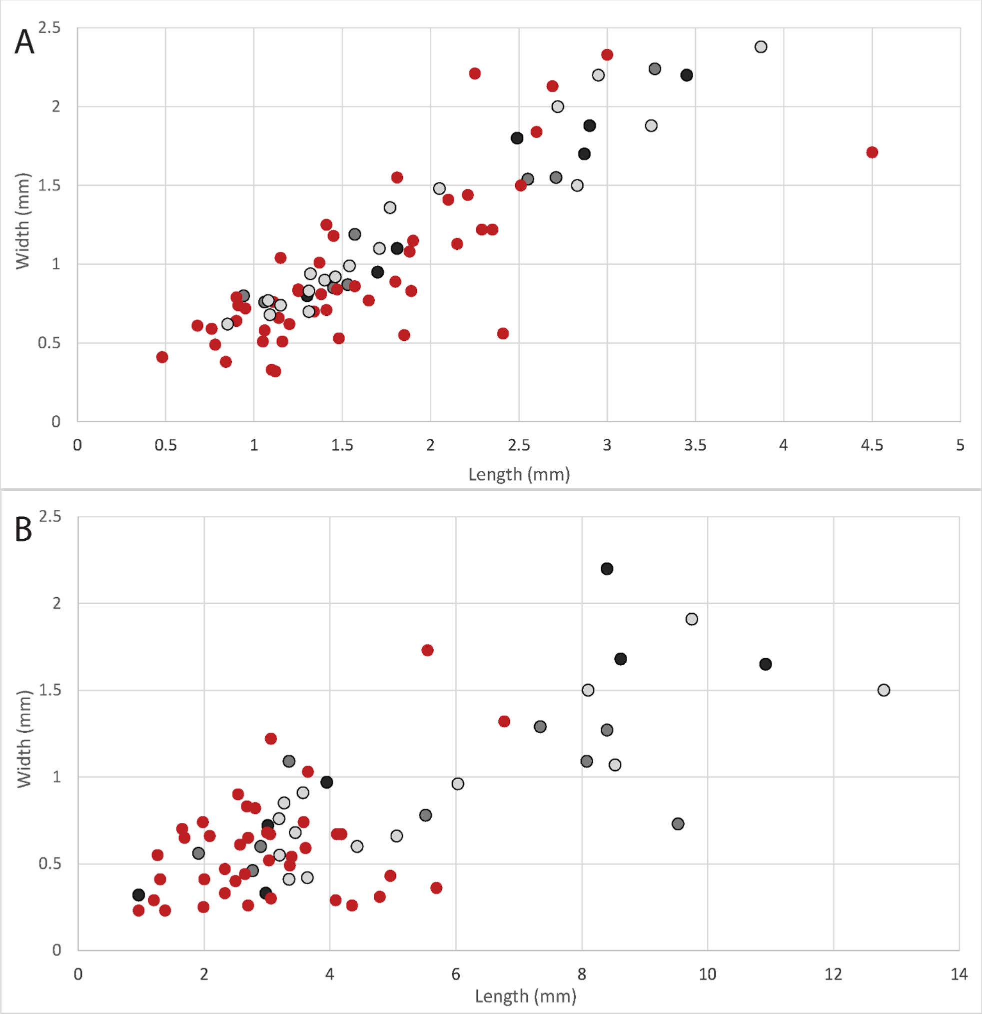

Fig. 4. Scatter plots of lengths and widths of pits (A) and scores (B): mean values for chewing marks produced by different carnivores and omnivores (in grey) and discrete values of 48 knapping marks (in red). Chewing marks produced by small-sized animals are in light grey, by medium-sized animals are in medium-tone grey and by large-sized animals are in dark grey. (Refer to Tables 2 and 3 for details).

- Tooth notches: semi-circular or arcuate-shaped indentations on fracture edges with corresponding negative scars on medullary surfaces (Fig. 2j-l). They are associated with fracture features that penetrate the entire thickness of the bone. Carnivores employ static loading by increasing pressure with opposing teeth until bone fracture is attained. This can produce extreme fragmentation, limiting the application of any diagnostic techniques to recognise the causal agent (Capaldo and Blumenshine, 1994).

The shape of carnivore tooth marks varies based on the cusp shape, which varies depending on tooth type (incisor, canine, premolar, molar) (Fig. 3f, g) and species. Cusp shape also changes based on tooth wear, with the permanent teeth of younger carnivores having sharper cusps that become blunter as they age. Efforts have been made to identify the carnivore species that caused the marks by measuring tooth pit/score dimensions (Andres et al., 2012; Andrews and Fernández-Jalvo, 1997; Arriaza et al., 2023; Domínguez-Rodrigo and Piqueras, 2003; Njau and Blumenschine, 2006; Pickering et al., 2004; Selvaggio and Wilder, 2001). However, studies measuring tooth marks left by different captive and wild animal species have shown that tooth mark sizes can vary based on the density of the bone chewed (Andres et al., 2012; Arriaza et al., 2023; Domínguez-Rodrigo and Piqueras, 2003; Young et al., 2015). Therefore, Selvaggio and Wilder (2001) suggest that this parameter should not be used exclusively to identify the taxon responsible for the modification.

A comparison of the average length and width of tooth pits and scores produced by different species of captive and wild animals (collated from: Andres et al., 2012; Delaney-Rivera et al. 2009; Domínguez-Rodrigo and Piqueras, 2003; Young et al., 2015) shows the lack of correlation between chewing-mark dimensions and the size of the animals that produced them (for consistency, we only considered measurements recorded for tooth pits and tooth scores found on the diaphysis of bones, where knapping marks are more commonly recorded; Table 2 and 3). The average dimensions of knapping modifications (collated from: van Kolfschoten et al., 2015) cluster with small to medium-size tooth pits and the smaller tooth scores. However, the comparison of discrete measurements of knapping marks (van Kolfschoten et al., 2015, Supplementary Online Material 2) with the mean values of chewing marks produced by different animal species shows that the variability in the dimensions of knapping pits almost completely overlaps the variability in the dimensions of tooth pits produced by different size of carnivores and omnivores (Fig. 4A).

3.1.3. *Other microscopic attributes*

Most Palaeolithic organic knapping tools consist of unmodified bone fragments, however some of these show traces of preparatory scraping of the knapping area to enhance its knapping properties. Experiments have shown that scraping is an effective way of removing remnants of flesh

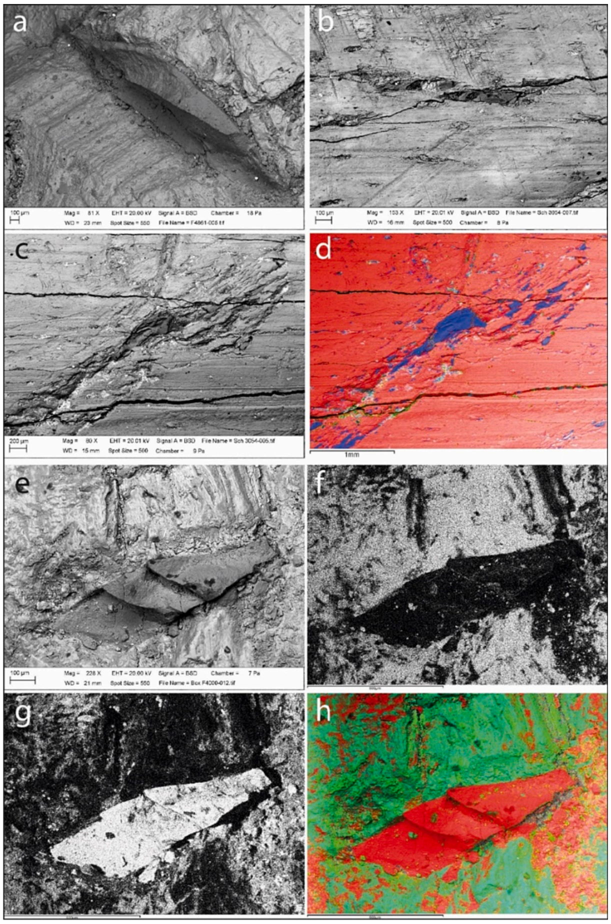

Fig. 5. SEM images of flint knapping debitage embedded in bones (note transverse microstriations): (a) single flint fragment; (b) several flint chips in a line; and (c) scattered and crushed flint chips associated with multiple parallel and overlapping knapping scores, cracks and faulting. (d) EDX mapping image (colour code red = calcium, blue = silicon): (e) SEM image of a large embedded micro-lithic fragment and EDX elemental recognition of (f) calcium (light grey tones) and (g) silicon (light grey zone). (h) EDX elemental mapping image (colour code green = calcium, red = silicon): Boxgrove (a, e-h) fragments of bone shaft of a large mammal; Schöningen (b-d) fragment of bone shaft of a large mammal.

and the periosteum and that the resulting smoother and harder surface is better suited for knapping activities (Armand and Delagnes, 1998; Holgueras, 2009; Mozota, 2018). Preparatory scraping has been identified on several archaeological knapping tools (e.g. Blasco et al., 2014; Brugal et al., 2013; Neruda et al., 2011; van Kolfschoten et al., 2015; Verna and d'Errico, 2011). In most of these examples, scraping marks are overprinted by knapping marks and their associated tool-edge scratches (Fig. 3a-b, e), but examples from Schöningen show that the knapping surface was sometimes scraped to further modify the knapping area during use (van Kolfschoten et al., 2015).

Another diagnostic feature of knapping tools is the occasional presence of microscopic chips of lithic material embedded in the impacted area. These are shattered pieces from the core or edges of lithic tools that were detached and forced at the point of impact into the matrix of the bone, tooth or antler used as knapping tools. Such embedded chips are commonly found in archaeological and experimental percussors and pressure flakers (Abrams et al., 2014; Bello et al., 2016, 2021; Parfitt and Bello, 2020; van Kolfschoten et al., 2015). They usually occur as lithic flakes that are often deeply embedded in a pit or score (Fig. 5a, e). In other examples the flakes have shattered, and this has resulted in a linear configuration of lithic debris embedded within a knapping score (Fig. 5b). In yet other examples, small lithic chips occur in a scattered conformation across a more extensive region of the knapping area. These irregular and dispersed chips appear to be less deeply embedded than the larger flake chips, and they are often associated with linear, broadly parallel surface cracks and faulting (Fig. 5c). This last category occurs on a number of knapping tools from Schöningen (van Kolfschoten et al., 2015), particularly on the midshafts of horse metapodials. These bones may have been used as anvils in bipolar knapping, although experimental studies are required to test this suggestion.

Interpretations of the lithic debris embedded in knapping marks can be further enhanced with the use of an X-ray detector (EDX) coupled with SEM imaging to map the elemental composition of lithic fragments. Currently, only knapping tools used to work flint have been analysed in this way (Fig. 5d, f-h), but at archaeological sites where a wider range of lithic raw materials were knapped, there is a potential to link the elemental composition of the embedded lithic debris with specific stone tool types or knapping scatters; it may even be possible to determine the number of distinct knapping episodes undertaken with a knapping tool.

While exceedingly uncommon, it is still plausible for microscopic fragments of carnivore teeth to occasionally fracture during biting and become embedded within the bones of their prey. We are not aware of any evidence of this occurrence for Pleistocene faunal assemblages, however it has been recorded for older material: a small fragment of tooth crown of *Tyrannosaurus rex*, has been found embedded in a hadrosaurid caudal centrum (DePalma II et al., 2013), for example. Nonetheless, Pleistocene records do present instances such as a lion canine fragment found embedded in the hide of a frozen Pleistocene bison (Guthrie, 1989). Additionally, Van Valkenburgh (1988) and Van Valkenburgh and Hertel (1993) have documented a relatively high incidence of tooth breakage in both recent and Pleistocene carnivores, indicating that these teeth broke during feeding.

3.2. *Applications*

We utilized this methodology to conduct a comprehensive analysis of faunal remains from Gough's Cave, a Magdalenian site located in Somerset, UK. The site was first discovered in the 1880s, with extensive excavations carried out by R.F. Parry between 1927 and 1931 (Stringer, 2000). The most recent excavations were conducted by a team from the Natural History Museum (London, UK) between 1986 and 1992. The archaeological findings include a mixed lithic assemblage of both late Magdalenian and early Federmesser-Gruppen technologies (Barton et al., 2003; Jacobi, 2004), a significant collection of butchered human and faunal remains (Andrews and Fernández-Jalvo, 2003; Bello et al., 2011, 2015, 2017; Currant, 1986), and organic artifacts (Bello et al., 2021; Charles, 1989; Lucas et al., 2019).

Parkin et al. (1986) and Andrews and Fernández-Jalvo (2003) conducted the first detailed taphonomic studies of the Gough's Cave assemblage; however, the identification of knapping tools was only recently made by Bello and colleagues (2021).These newly identified tools consist of two horse teeth with signs of knapping damage, several metapodials marked by knapping marks near their distal ends, and a horse first phalanx with particularly prominent knapping marks.

A comparison between two horse phalanges from Gough's Cave (NHMUK PV M 49788 and NHMUK PV Unreg 3482; Fig. 6) highlights macroscopic features of (location and morphology of the modified areas) of carnivore chewing and the recently identified knapping marks. Andrews and Fernández-Jalvo (2003, page 68 and fig. 7), for instance, described the horse first phalanx NHMUK PV M 49788 as marked by 'very heavy percussion marks [which] are present on the ventral (palmar) surface of the distal articulation, seen as two rosette-shaped multiple marks with a single additional mark laterally, and at the proximal end there are two extensive areas of percussion damage ventrally, on either side of the proximal articular surface and extending round on to this surface'. However, the location of these modifications, on (or near) the epiphysis, is more commonly associated with chewing

Fig. 6. Photos of the dorsal, medial, plantar, and lateral views and distal epiphyses of two horse phalanges from Gough's Cave: (a) knapping tool NHMUK PV Unreg 3482; (b) carnivore chewed example NHMUK PV M 49788. Black arrows indicated knapping marks, white arrows indicate chewing marks.

modifications. The overall morphology of the damage is also consistent with chewing traces made by a medium-sized carnivore (Fig. 6b). On the other hand, the horse first phalanx NHMUK PV Unreg 3482 exhibits percussion pits concentrated on the flatter area of the dorsal surface of the shaft near its distal end. These marks show macro- and micro-morphological features that are consistent with the use of the bone in direct percussion during knapping activities (Fig. 6a).

Distinguishing knapping marks from chewing marks can be even more challenging when other modifications are present on the bone. This problem is exemplified by comparing marks on a rib of *Equus mosbachensis* (Sch 698) from Schöningen, used as a knapping tool, with a chewed rib of *Equus ferus* from Gough's Cave (NHMUK PV Unreg 3846). The combination and configuration of the marks on these specimens show close similarities in their macroscopic morphology (Fig. 7). In the case of the Schöningen rib fragment, a cluster of knapping pits and scores is located on the side of the 'neck' of the rib just below the proximal epiphysis; these marks cut across an area of long scraping marks on the rib's ventral side (Fig. 7a-b). In the case of the fragment of horse rib from Gough's Cave, macroscopically similar pits and scores occur in a comparable location, although closer to the proximal epiphysis, where they overlie longitudinal cuts (in blue in Fig. 7d) and scraping marks (in green in Fig. 7d).

The Gough's Cave specimen was originally identified by Ruth Charles, who interpreted it as a 'drawing slate', similar to a rib engraved with a horse's head from Robin Hood Cave in Creswell Crags, UK (Charles, 1989, page 403 and figs. 6, 7), which also presented preparatory scraping of the bone surface. The Gough's Cave rib may have been prepared in the same way as the Robin Hood Cave example, but it was not engraved and was later chewed by carnivores. The presence of scraping marks, which are often found in association with knapping damage, is particularly misguiding and after conducting only a preliminary macroscopic observation we were not sure about the causal agent responsible for the indentations. However, microscopic analyses of the pits and scores allowed us to confirm the indentations were the result of chewing by a medium size carnivore. The pits and scores on the horse rib NHMUK PV Unreg 3846 from Gough's Cave are rounded in profile and associated with crushing of the bone surface accompanied by the presence of internal micro-striations longitudinal to the longer axis of the scores (Fig. 7f). When compared to the marks on the Gough's specimen, the scores and pits on the Schöningen specimen (Sch 698) have all the typical features of knapping marks. In this case, the knapping indentations display angular cross-sectional profiles and are accompanied by tool-edge scratches (Fig. 7b), along with minute embedded flint micro-fragments that became detached from the lithic implement during the knapping process (Fig. 7b-c).

4. Discussion and conclusion

The Gough's Cave case-studies show how knapping marks and chewing marks can be remarkably similar and difficult to distinguish using macroscopic features alone. However, there are important differences, particularly at a microscopic level, that can be used to distinguish between carnivore chewing and knapping modifications. These are summarised in Table 4 and the presence or absence of characteristic features are further detailed in Table 5.

Distinguishing the causal agent in the case of bones that have been lightly chewed or minimally used as knapping tools can be a challenging exercise, because the morphology of isolated tooth pits and scores are often very similar in morphology to isolated knapping pits and scores. The examples presented in the case studies show that in such cases, microscopic analysis is essential for identifying the features that are useful in distinguishing these types of alterations.

We have employed this methodology to examine the large mammal remains from Magdalenian levels at Gough's Cave, where the absence of knapping tools was a perplexing phenomenon given the abundant evidence for flint knapping and tool maintenance at the site (Jacobi, 2004). The Magdalenian, a widespread cultural tradition of the Late Upper Palaeolithic that spanned a significant portion of Late Glacial Europe

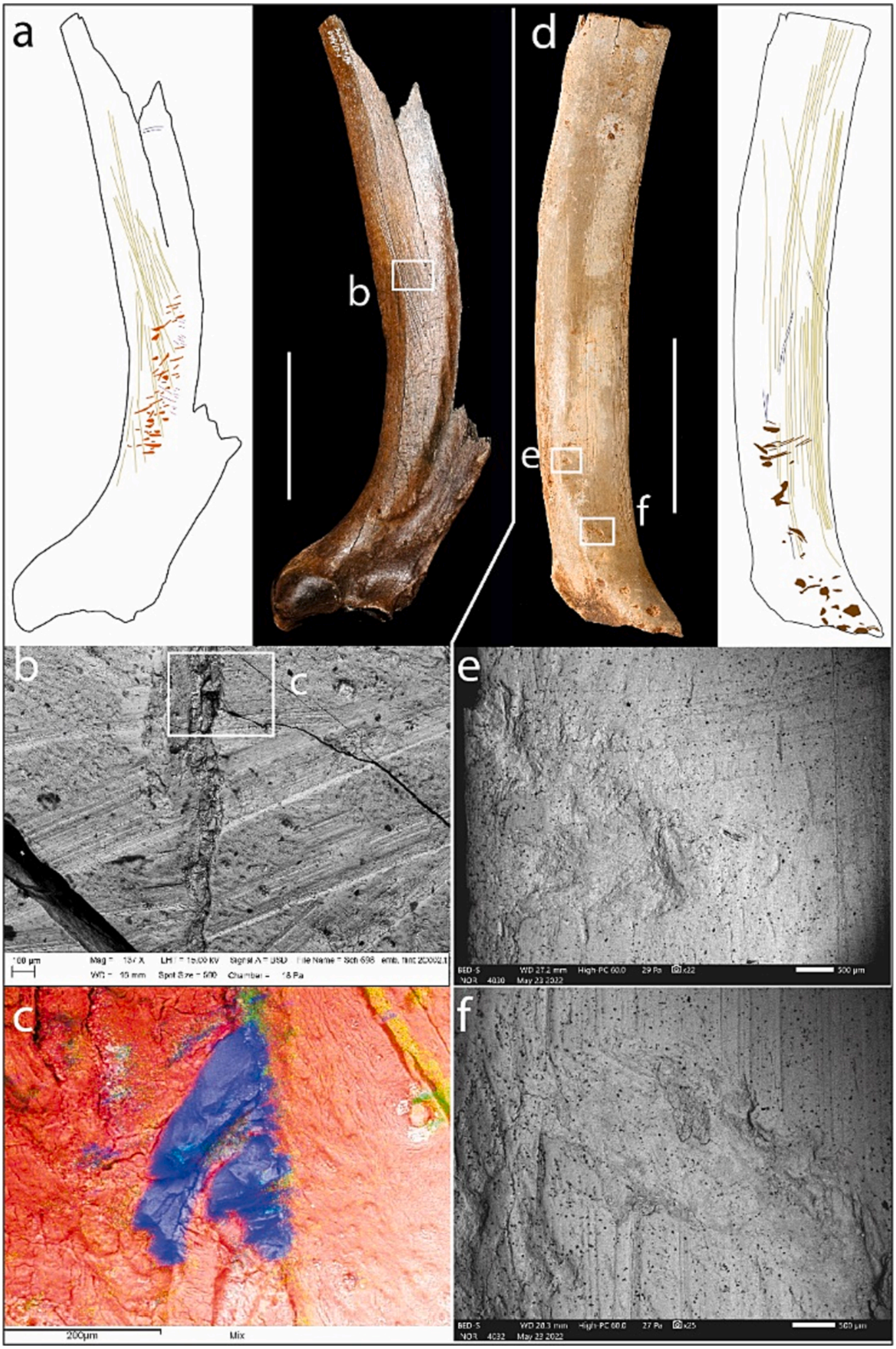

Fig. 7. Comparison of horse ribs from (a-c) Schoningen (Sch 698), used as knapping tool (green = scrape marks, orange = knapping marks) and (d-f) from Gough's Cave (NHMUK PV Unreg 3846) with scrape marks overprinted by chewing marks inflicted by a medium-sized carnivore (blue = cut-marks, green = scrape marks, brown = chewing marks). Scale = 50 mm. SEM images of (b) knapping score with a cluster of embedded flint chips and overlapping scraping marks, (c) EDX elemental mapping image of an embedded flint (blue), (e) tooth pit and (f) tooth score imprinted on scrape marks.

Table 4
Summary of diagnostic features of knapping and chewing modifications.

CHARACTERISTIC	KNAPPING MARKS	CHEWING MARKS
Location on bones	- Flat or convex areas of the diaphysis that combine relatively smooth and featureless surfaces with thick cortical bone. - In percussors, modifications can be found on the articular areas of a bone.	Closer to the epiphyses, followed by near-epiphyseal and midshaft portions of long bones.
Macroscopic appearance of modified area	- Knapping damage is normally localised in single or multiple areas, which are generally oval in shape. - Knapping areas on bone fragments have only been observed on the outer surface of the cortical bone, no archaeological examples are known with knapping marks on the medullar surface of a compact bone.	- Chewing marks can be found in localised or dispersed zones. They are generally multiple. - Chewing marks can be found on the outer and medullar surfaces of the compact bone. - In most cases, chewing marks occur on both sides of the bone, due to the combination of the chewing of the opposing maxillary and mandibular teeth.
Microscopic appearance of individual modifications	- Knapping indentation: gouges (larger depressions sometimes associated with bone flaking), pits (depressions with a triangular or ovoid form) and scores (depression with a longer linear appearance, which can be either rectilinear or sinuous). Internally, these indentations can exhibit micro-striations that are oriented perpendicularly to the longer axis of the indentation. - Knapping notches: semi-circular or arcuate-shaped features resulting from breakage of a knapping tool during use. - Tool-edge scratches or sliding striations: shallow, closely-spaced striations that occur on either side, or on both sides, of the knapping indentations.	- Pits: superficial circular or semi-circular depressions that fail to penetrate fully into the underlying cavity. - Scores: superficial elongated channels, with a length measuring three or more times its breadth. - Puncture: circular, semi-circular or sub-triangular perforations that penetrate the compact bone. Both tooth pits and punctures have a long axis no more than three times the length of the short axis. - Tooth notches: semi-circular or arcuate-shaped flaking of fracture edges with corresponding negative scars on medullary surfaces. - Furrow: wide, deep, and long crenulated marks that penetrate the bone.
Other microscopic attributes	- Most Lower and Middle Palaeolithic organic knapping tools consist of unmodified bone fragments, however some of these show traces of preparatory scraping of the knapping area. - Presence of microscopic chips of lithic material embedded in the impact area of a knapping indentation. This is a quite common feature.	Presence of microscopic fragments of teeth embedded within the pits or scores. This is an extremely rare feature.

Table 5
Summary of knapping modifications compared to other types of bone modification that produce similar marks (modified from Njau and Gilbert, 2016). Y = present; Y(O) = occasional presence; N = absent; NR = not reported.

Modifications	**Knapping modifications**	**Marrow processing with hammerstone percussion**	**Mammalian carnivores**	**Crocodylian modifications**
V-shape cross section mark	Y	Y	NR	Y
Multiple fine striations parallel to the main axis of the groove	N	N	Y(O)	NR
Multiple fine striations perpendicular to the main axis of the groove	Y	Y	NR	NR
Periosteal crushing/subcambial spawling, sometimes with associated striations and/or V-shape cross section mark	Y	Y	Y	NR
Bone flake removal usually associated with deep pit and/or fracture on midshaft	Y	Y	NR	NR
Multiple fine parallel striations across broad area of bone	Y[1]	Y[2]	NR	NR
Drag snags	Y[3]	Y[4]	NR	NR
Pivoted V-shape cross section mark	N	N	NR/N	NR/Y
Hook marks (curved scores)	N	N	NR	NR
Pits	Y	Y	Y	NR
Bisected pits or marks	Y	Y	Y	NR
Striation pivots	N	N	NR	Y
Embedded lithic chips	Y	NR	N	N

[1] Preparatory scraping;
[2] anvil and hammerstone scratches;
[3] tool-edge scratches/sliding striations resemble ‘drag snags’ on bones bitten by crocodiles;
[4] scratches associated with percussion pits.

between roughly 18,000 and 13,000 years BP, was distinguished by the extensive use of ivory, bone, and antler to craft various symbolic and utilitarian objects (Breuil, 1956; Charles, 1989; d'Errico, 1993; Fritz, 1999; Lucas et al., 2019; McComb, 1989). Although studies of Magdalenian stone tools carefully modified from blades removed using a soft hammer, it is puzzling that organic knapping tools are infrequently observed in Magdalenian contexts (Bello et al., 2021). The apparent decline in the incidence of organic retouching tools throughout the Upper Palaeolithic has been associated with the increased use of stone hammers (Riek, 1973; Taute, 1965) or a possible disinterest among archaeologists in the simplest 'unspecialised' organic tools, compared to the diverse range of elaborated specialized tools that typified the Magdalenian period (Bello et al., 2021). The assumption that antler hammers, which were the main type found in French cave sites, were the primary organic knapping tools employed by Magdalenian groups may also have influenced the decisions to search for knapping tools among the bone and teeth debris at these sites.

The scarcity of knapping tools in Magdalenian contexts can be attributed, at least in part, to the challenge of distinguishing knapping damage on bones that have undergone only a brief period of use and may be erroneously interpreted as being modified by other natural causes, such as carnivore chewing. The examination of Gough's Cave highlights that the issue may also stem from the lack of consistency and reproducibility of results among analysts due to the difficulty of discerning knapping marks from natural taphonomic alterations.

The misidentifications of the taphonomic alterations on bones have been shown to lead to erroneous conclusions regarding human behaviour and the role of carnivores in modifying and accumulating bone assemblages. We believe that the proposed list of macro- and microscopic characteristics can facilitate a more informed differentiation between chewing and knapping marks. Making accurate identifications of surface features resulting from knapping is vitally important if we are to understand why, where and when different types of organic knapping tools appear in the archaeological record.

CRediT authorship contribution statement

Silvia M. Bello: Conceptualization, Methodology, Visualization, Formal analysis, Funding acquisition, Investigation, Project administration, Writing – original draft, Writing – review & editing. **Simon A. Parfitt:** Methodology, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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