An exploratory study of experimental cutmarks on mammalian bones and its implications for understanding tool selection and butchery skill in prehistory

A Thesis

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by

Ningnung Jakoinao

Indian Institute of Science Education and Research
Dr Homi Bhabha Road,
Pashan, Pune 411008, India

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Supervisor: Dr Parth R. Chauhan

Certificate

This is to certify that this dissertation entitled "*An exploratory study of experimental cutmarks on mammalian bones and its implications for understanding tool selection and butchery skill in prehistory*" towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune represents study/work carried out by Ningnung Jakoinao at Indian Institute of Science Education and Research, Mohali under the supervision of Dr Parth R. Chauhan, Associate Professor, Department of Humanities and Social Sciences, during the academic year 2022–2023.

Parth R. Chauhan

Dr Parth R. Chauhan

28 April, 2023

<u>Committee:</u>

Supervisor: Dr Parth R. Chauhan

Co-Supervisor: Dr Pankaj Goyal

TAC: Dr Pushkar Sohoni

This thesis is dedicated to my pugs, Gizzie and Minyu.

Declaration

I hereby declare that the matter embodied in the report "*An exploratory study of experimental cutmarks on mammalian bones and its implications for understanding tool selection and butchery skill in prehistory"* are the results of the work carried out by me at the Department of Humanities and Social Sciences, Indian Institute of Science Education and Research, Mohali, under the supervision of Dr Parth R. Chauhan and the same has not been submitted elsewhere for any other degree.

Ningnung Jakoinao

Date: 28 April, 2023

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Glossary

Ma – Megaannum or megayear; a period of one million years (King et al., 2007).

Ka – kiloannum or kiloyear; a period of one thousand years (kiloannum, n.d.).

Homo – Latin for 'human'; the genus of the family *Hominidae* that arose first from *Australopithecus;* includes the present *Homo sapiens*, and several other extinct species (such as *Homo naledi*, *Homo heidelbergensis*, *Homo erectus*, and *Homo neanderthalensis*) that share ancestry or some close relation to modern humans (*Homo*, 2022).

Hominins – Term given to humans and all of its extinct bipedal (those who walked on two feet) ancestors; the group includes members of the genera *Homo*, *Australopithecus*, *Paranthropus*, and *Ardipithecus* (Blaxland, 2020).

Hominids – The family *Hominidae*; one of the two currently existing families of the ape superfamily *Hominoidea*; these include the great apes (gorillas, genus *Gorilla*; orangutans, genus *Pongo*; bonobos and chimpanzees, genus *Pan*) and human beings, or *Homo* (*Hominidae*, 2022).

Ungulates – Members of the diverse clade *Ungulata* (a clade is a grouping of organisms comprising of a common ancestor and all its descendants); primarily consist of large mammals with hooves — these include the odd-toed ungulates (rhinoceroses, horses, tapirs) and even-toed ungulates (pigs, sheep, goat, cattle, deer, camels, giraffes, hippopotamuses) (ungulate, 2023).

Retouched/unretouched flakes – Retouching involves the act of producing scars on a stone flake, either to make it into a usable tool or to reshape a used tool (Hiscock, 2007).

Actualistic studies – Studies of modern phenomena carried out to acquire a finer discernment and assessment of phenomena in prehistory (Warme, 1979).

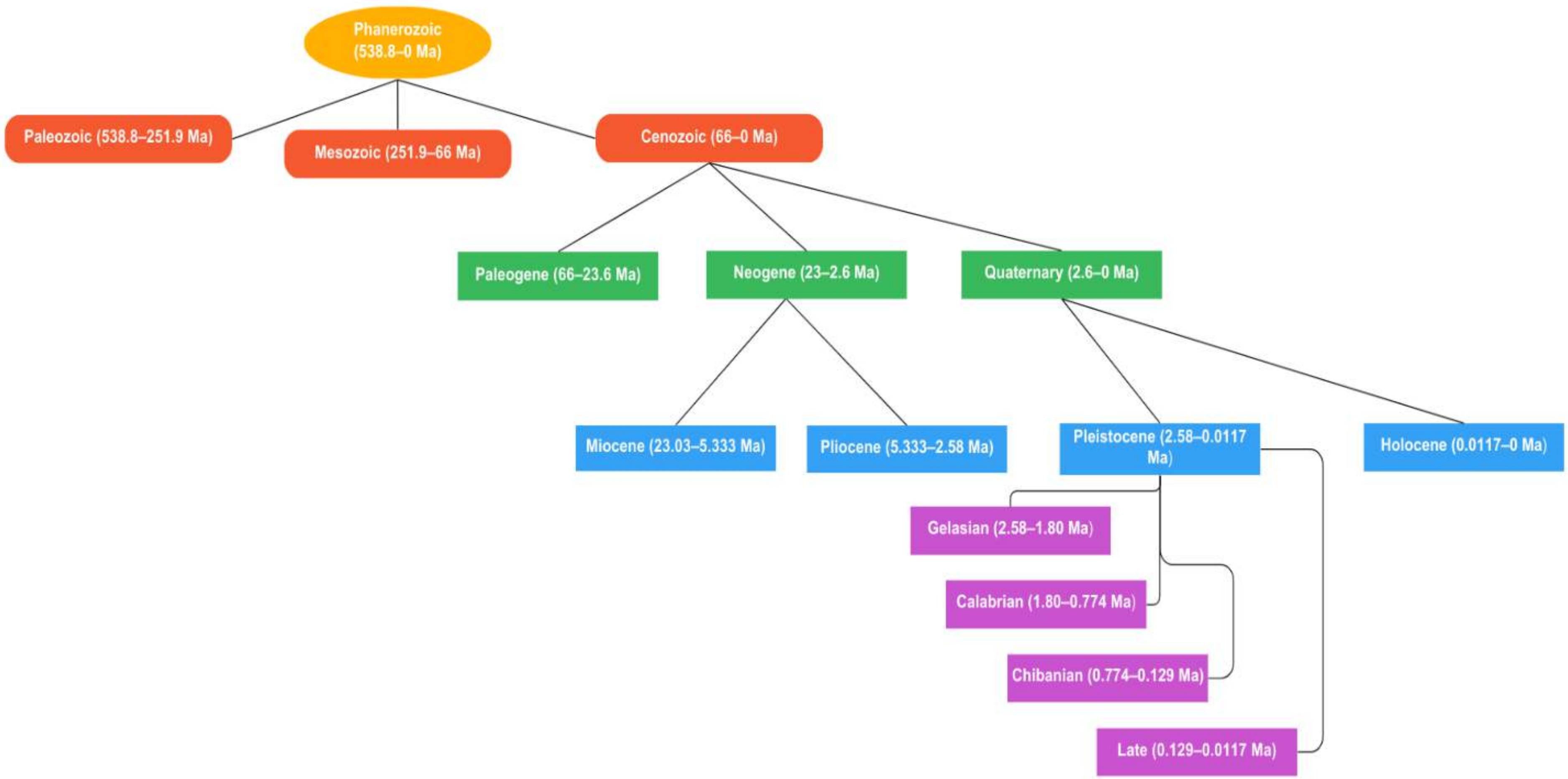
Ethnography – The study of observing people in their own environment to understand their experiences, perspectives, and everyday practices (ethnography, 2023).

Timelines

Timeline of Harappa (UNESCO, 2004)

Dates (BCE)	**Main phase**
7000–5500	Pre-Harappan
5500–3300	Pre-Harappan/Early Harappan
3300–2600	Early Harappan
2600–1900	Mature Harappan (Indus Valley Civilization)
1900–1300	Late Harappan
1300–300	Post-Harappan (Iron Age)

Geological timeline (post Phanerozoic eon; made by the experimentalist) (Gradstein et al., 2020)



Abstract

It has been known that early humans performed butchery on animals that were present at the time around them for meat consumption. Studies performed by archaeologists have not only confirmed this via excavations of faunal remains from parts around the world, but have also helped reconstruct, comprehend, conclude, and extrapolate information in comparison to modern-day humans. These experiments map out the entirety of the human evolutionary behaviour pertaining to the use of tools for cutting meat, and fossil specimens discovered from sites which bear cutmarks are a testimony to this.

This thesis aims to perform experimental butchery on goat and buffalo meat using stone tools made via knapping of raw material. The results of this investigation will then be compared to cutmarks of archaeological specimens found from a Harappan site. The study will help understand the evolution of tool technologies, how butchery was done in the past, and to look for similarities and differences between the two sets of cutmarked bones. I, the experimentalist, will perform the butchery and aim to remove as much soft tissue as possible from the bones using the stone tools of various sizes and types, knapped by me and other such individuals. All of these activities will be recorded via photography and videography. The bones will be cleaned and prepared for microscopic analysis, along with the same being done for the fossil samples. The cutmarks on the bones will be compared to those on the fossils, and inferences will be drawn. There will be stark differences in the expertise of butchery, the location of the cutmark, and the tool type used. These results will be vital for future investigations, which can include ethnographic and actualistic aspects as well, and also for performing comparative studies of the expertise levels of butchery.

Chapter 1: Introduction

1.1 Background

Butchery is very well known to have existed among early humans, with recorded instances spanning several millions of years across several studies carried out over time dating back at least 2.9 Ma — some studies even claiming that this can be extended far back at least 3.42 Ma (Potts & Shipman, 1981; Plummer et al., 2023; McPherron et al., 2010). These activities were carried out predominantly using tools made of materials found around at the time, including stone, bone, and eventually even metal (Pobiner, 2016; Potts & Shipman, 1981; Sano et al., 2020; Greenfield, 1999). Most studies on these activities suggest the use of stone tools by early hominins, focusing on the Plio-Pleistocene period (~5 Ma-12 ka); however, there has also been stark evidence of the use of bone tools, as is presented by Sano et al. (2020) in their premier study. With the gradual evolution and technological advancement of humans, these tools gave way to metal tools, with the Neolithic period coming to an end roughly ~4-2 ka and giving way to the Metal Ages (Philip, 2008). This thesis will focus primarily on butchery performed using experimental stone tools, given the large repository of studies present in the field and its ease of use.

Pobiner (2016) illustrates the difficulty in finding evidence of meat-eating among the early hominins, and how data collected from sites regarding the consumption of flesh is challenging to decipher. She mentions the "expensive tissue hypothesis", coined by Leslie Aiello and Peter Wheeler in 1995 (as cited in Pobiner, 2016), which stated that the increase in the size of the brains in hominins directly correlated to the shrinking of other vital organs such as the liver and the gastrointestinal tract. For the functioning of these relatively smaller organs, tissues that required high metabolism needed to be consumed, leading to the probable explanation for meat-eating in hominins, as it generally contained nutrients which would otherwise be difficult to acquire from other sources. The author mentions four critical observations from the fossil records:

1. Hominins were known to eat animals of all sizes, big or small (Bunn, 1981, as cited in Pobiner, 2016).
2. They generally used tools to obtain and process the meat from carcasses.

3. Much of the earlier investigations suggested a more scavenger role rather than a hunter role among hominins (Blumenschine, 1986; Blumenschine, 1989; Blumenschine & Cavallo, 1992, as cited in Pobiner, 2016).
4. Early humans were known to have collected and stored meat for later consumption (Pobiner, 2016, pp. 110-111).

The latter point is also supported by a study performed by Blasco et al. (2019), where Blasco and their team presented the first recorded instance of bone marrow storage and its delayed consumption from excavations at the Middle Pleistocene Qesem Cave in Israel. These samples date back to ~420-200 ka, and provide information into new modes of adaptations and behavioral/cognitive developments in Paleolithic humans. Pobiner's claim suggests the supposed reason for carnivory among humans, and while some evidence does exist towards this, as is seen in the zooarchaeological evidence of carnivory post-arrival of *Homo erectus*, it was a study done by Barr et al. (2022) that suggested that the absence of any such continued growth in evidence stating the presence of carnivory, indicating towards the possibility of other factors being the cause of the appearance of this trait.

A recent work by Plummer and their team argued the use of tools by *Paranthropus*, a separate branch of the hominid species, for widespread uses such as scavenging and hunting, dating back to ~3.032 Ma. The tool use-wear and bone damage in the fossils excavated from Kenya show that such species lived in varied ecosystems that were previously not predicted, and thus provide us critical information to understand the paleodiet and the ecology of the region (Plummer et al., 2023).

For the current archaeological record to manifest itself in the context of butchery, it is essential to address the trickle-down effect of knowledge. The importance of knowledge being passed down, starting from the very first early man to the modern man we know in the present, is elicited fairly well by quite a few bodies of work. Lombard (2015) talks about the skill of hunting and the development of various hunting technologies as an agent of imparting knowledge. They mention how the hunting arose due to several factors amongst early hominins as a response to evolutionary changes, relating it to their cognitive behaviour and ultimately the key to several phenomena we know in the present, such as fire usage for cooking, adhesives (then used to fix arrowheads), skill acquisition (bow and spear making), and more (Lombard, 2015). Forte et al. (2023) explicitly talk about skill development — be it hunting, foraging, or tool-knapping, to mention a few — and how the methodology of knowledge transmission occurs over generations and how these should be studied and interpreted. They emphasize the benefits of anthropological and ethnoarchaeological investigations in understanding these ‘novice-to-expert’ transformations, which generally get affected by “learning and cultural constraints” (Forte et al., 2023, p. 2).

The stone tools made by these hominins were sophisticated enough to leave evidence of cut-marked bones at several prehistoric sites worldwide. Excavations have been performed in the African regions of Ethiopia, Kenya, and Tanzania, the European areas such as England and the Balkans, the Middle East, and Russia, to mention a few (Bello et al., 2009; Blasco et al., 2019; Domínguez-Rodrigo et al., 2005; Greenfield, 1999; Potts & Shipman, 1981; Sano et al., 2020; Key & Gowlett, 2022; Kolobova et al., 2022; McPherron et al., 2010; Proffitt et al., 2021). These sites have yielded stone tools, knappers, bone handaxes, fossil specimens consisting of cutmarks, and even faunal assemblages suggestive of the area’s ancient ecology. Among all these sites, faunal remains seem to be a prevalent finding, which had led figures such as Binford to probe the link between faunal and lithic assemblages and interpret their associations (Binford, 1981) and Lyman to ask a critical question: “Was this animal eaten by the hominins that lived here?” (Lyman, 1987, p. 249). This question began to come up independently from various investigations and excavations; as studies like these began to be performed quite frequently, it became pertinent and vital to understand the cause behind such common findings all over the world. The logical path to follow was to analyze these remains and conduct studies to shed light on the subject. To date, several notable works (Bello et al., 2009; Bello & Soligo, 2007; Boschin & Crezzini, 2011; Dewbury & Russell, 2006; Greenfield, 1999; Egeland, 2017; Kooi & Fairgrieve, 2012) have performed extensive studies on butchery activity while considering several variables into their investigations. These studies have pioneered the reconstruction of how and what hominin activities took place in the past and to understand the behavioral and ecological context of all these activities. These works also provide insights into the past technologies of early humans, how they evolved, the cognitive and ethnographic aspects of the rise of tool technologies, and the cultural impacts they left behind in their wake.

To better understand these aspects, scientists have carried out experiments that have been performed on mammalian bones, particularly, but not limited to, deer, pig, bison, and cattle (cow, goat, sheep, and buffalo). A study performed by Bello et al. (2009) on mammalian bodies hints at the close relation between faunal remains discovered from excavation sites, as most hominin-occupied areas lived in close proximity to such animals. However, other carnivorous remains have also been discovered at these sites, hinting at the site's ecology in the past (Bello et al., 2009).

1.2 Literature review

A review of the existing literature on the subject provides a glimpse of the experimental work that scientists have done. These papers successfully present the methodologies, approaches, and techniques that have been used by researchers to understand the subject better and improve and build upon previously established knowledge. Most of the literature studies cutmarks created on mammalian bones, which can vary over the vast ungulates involved (Bello & Soligo, 2007; Kooi & Fairgrieve, 2012; Egeland, 2003; Yravedra et al., 2017). The experimental work generally consists of a replicable and comparative analysis of the cutmarks on bones ranging from ribs to carcasses, the main aim being to deflesh the soft tissue and take the resulting bones later for further evaluation.

For most of these studies, the preparation of experimental stone tools is the primary goal before beginning any experimental work. Scientists have performed key studies to understand the usage of the tools (knapped or excavated), breaking down features such as efficiency, cost, the material used, and resource availability, to name a few. In their paper, Key and Lycett (2017) questioned the influence of tool morphology over the efficiency and performance of a tool, taking a large set of data and using the time taken to cut the object as a measure of efficiency. They concluded that no such relationship exists between the two and alluded to the possibility of other external factors that could affect performance. In a later study, Key and Gowlett (2022) compared two sets of large handaxes (old and modern), keeping in mind the morphology (the form of the tool) and allometry (change in the tool efficiency with size). They concluded that both sets performed relatively the same; the differences present were instead due to external factors such as the past cultures and the purpose of the tool.

Kolobova et al. (2022) provide a seminal study on bone retouchers, where they suggest that the gripping technique of the tool had an influence over the loss of bone. They describe two ways — three-finger and five-finger — in which Neanderthals were known to have gripped the tool, suggesting a difference in technique and precision of the job. The three-finger grip was used for finer cutting and scraping, while the five-finger grip suggested a larger force application and, thus, more bone loss. The dominant preference for the former technique implied that hominins had developed and finessed tool making and usage to a significantly large extent, and that hominins had improved cognition and motor skills (Kolobova et al., 2022).

While stone was the common go-to medium for tool making at that time, bone tools are also known to have been used for activities such as cutting and sawing. In their breakthrough study, Sano et al. (2020) describe a bone handaxe made out of a hippopotamus femur excavated from southern Ethiopia. The tool showed evidence of anthropogenic intervention, courtesy of the multiple flaking and scars present on it. The discovery of this tool pushed back the known technological repertoire of Early Pleistocene *Homo* to ~1.4 Ma, suggesting that hominins had far better cognition and skill and could possibly manipulate materials other than stone to create tools for daily use (Sano et al., 2020).

While raw material availability was a factor in the tools that were created, Proffitt et al. (2021) also speak of the variability in the knapping skill across materials, i.e., whether the type of the raw material affected the way a tool was created. They discovered that this was not true for all cases; within the same raw material, the knapping skill varied on its morphology and quality, while it was difficult to observe any pattern across different materials (Proffitt et al., 2021). This investigation provided insights not just into the type and quantity of raw material, but also its effect on the usage of that material by the hominins, and the type of tools that were thus produced.

Using various approaches, methods, and techniques, scientists have produced countless studies to analyze cut-marked bones. These include the comparison of the efficiency in cutmark production using stone versus metal tools (Greenfield, 1999; Kooi & Fairgrieve, 2012; Bello & Soligo, 2007), the comparison of cutmarks produced by various stone flakes (Bello et al., 2009; de Juana et al., 2010; Dewbury & Russell, 2006), cutmarks produced on various types of bones under variable conditions (Kooi & Fairgrieve, 2012), and more. Each of these studies provides insights to understand and visualize butchery in the past.

Studies by Dewbury and Russel (2006) and Egeland (2017) were a few among many that helped understand the contrasts between tools used, such as obsidian and flint, and how the cutmark frequency on the bones could be affected by certain conditions, or not at all. While the former state the presence of various such factors, such as tool material, carcass size, and stiffness, the latter comments on the non-existence of any such relationship between the intensity (the number of tool strokes) and the frequency (how often a bone type is cutmarked) of the cutmarks made by the tools. A definitive view from both studies could be the carefulness required when studying such bone samples and how to devise a proper understanding of the cutmarks on samples correctly.

One of the oldest studies to come out on this subject is by Potts and Shipman (1981), where they discuss the fossils excavated from Olduvai Gorge in Tanzania consisting of cutmarks on animal bones produced by stone tools. Through the elimination of external environmental causes of the cutmarks, such as gnawing or biting by other potentially carnivorous species, and by comparing the marks found on the bones with known causes of such marks, Potts and Shipman were able to conclude the non-chance occurrence of these assemblages; it was not by accident that these animal bones were present along with stone tool artefacts, but was due to the presence of a "functional association" between the two (Potts & Shipman, 1981, p. 577).

Domínguez-Rodrigo and their team were able to record and collect preserved stone tools and faunal remains from sites at Gona in Afar, Ethiopia, where they excavated an extensive repository of cutmarked bone samples. It was easy to identify the V-shaped nature of the cutmarks, implying the anthropogenic use of tools. The presence of large carcasses leads to the conclusion of the access to large mammals at that period and the use of stone tools by hominins for hunting and, possibly, scavenging purposes (Domínguez-Rodrigo et al., 2005). Similarly, McPherron and their colleagues were able to report cutmarked bones found in Dikika, Ethiopia dating far back to ~2.5 Ma. Stratigraphic analyses and radioisotopic dating provide the possibility of the use of stone tools even before it was thought, and largely linking this usage to the species *Australopithecus afarensis* (McPherron et al., 2010).

One study done by Boschin and Crezzini (2011) describes how microscopic analysis was performed on the cutmarks made on bones using various tool types — a flint flake, a retouched flint tool, a steel blade, a bronze blade, and a copper blade — and thus producing a set of morphological data to identify different types of cutmarks, such that they are distinguishable from one another. The morphology of these cutmarks was influenced by various conditions (tool type, force applied, area of effect, frequency of cutting) and thus provided a crucial understanding of the process behind butchery experiments (Boschin & Crezzini, 2011).

Moretti and their colleagues (2015) performed a similar investigation, building up on Boschin and Crezzini's work. They performed digital microscopic analysis and experimental archaeology to assess cutmarks made on ungulate bones under various parameters. This study went ahead to build a metric and profile data on the morphology of these cutmarks, similar to the database made by Boschin and Crezzini. They concluded that tool type and method of cutting influence the cutmarks made on the material. While some of the parameters could be explained for, such as the type of tool used, other parameters (whether the bone was fresh, burnt, or dry) could not explain the condition of the cutmarks (Moretti et al., 2015), leaving more studies to address these questions in the future.

Many comparative studies have been done on the subject to understand and replicate past skills, methods, techniques, and actions and map out its evolutionary line over time. Bello et al., in their 2009 study, performed a series of analyses of 3D micromorphology of cutmarks on fossil mammalian remains (these remains consisted of several species, ranging from beavers, *Castor fiber*, to rhinoceroses, *Stephanorhinus hunsdheimensis* and *Stephanorhinus megarhinus*) and on experimental samples of roe deer (*Capreolus capreolus*) using a replica handaxe. Their pivotal investigation compared these cutmarks and alluded to several factors creating distinctions between the two samples, such as the variations in the characteristics of tool edges, the condition of the carcass at that time, and the robusticity of *Homo heidelbergensis* — the hominin species present around the area during that period (Bello et al., 2009). This study and several others along the same lines became paramount for future studies to understand the past and to pursue further investigations into the field to discover more about our untouched history.

Several such comparative examinations of tool types, cutmarks, and samples have been conducted throughout the years. Bello and Soligo (2007) did a study comparing the cutmarks made on pig ribs using a steel knife versus an unretouched flint flake at varying angles. It was discovered that the cutmarks made by the knife were V- or √-shaped and very precise, while the ones made by flakes were more rugged and undefined. Such a study has implications for the evolution of the first tool users among hominins via the type of tool they used (Bello & Soligo, 2007). de Juana et al. (2010) investigated the contrast between the cutmarks made with unretouched stone flakes versus handaxes on different bones of deer carcasses. They found out that the cutmarks made by handaxes tend to have broader grooves, which are similar to those made by retouched flakes. Meanwhile, cutmarks made by unretouched flakes have narrow 'V-shaped' grooves. Kooi and Fairgrieve (2012) compared cutmarks made on fresh and burnt pig ribs using smooth and serrated metal knives. These cutmarks were then studied under a scanning electron microscope (SEM) for discrepancies in various features; about a 40% decrease was noticed in how the features (such as V-shaped cutmarks and linear fractures) manifested themselves compared to the ones present on the fresh bones (Kooi & Fairgrieve, 2012). This study, in particular, could provide insights into understanding when the discovery of fire took place and how the shift to consumption of cooked meat occurred among hominins.

A relatively older piece of work done by Greenfield (1999) was done to understand the spread of metallurgy across generations of our ancestors. He compared the cutmarks made by stone and metal tools by carrying out experimental work on wood and bones, and then compared those cutmarks with the ones made on early bone samples. His conclusions were also similar to the ones produced by researchers later on: metal tools make sharper, narrower cuts on all forms of media, while stone tools have variable and irregular grooves. This particularly older study led to an assemblage of experimental works being produced in the field which helped understand the spread of technologies and the gradual introduction of metal tools into societies (Greenfield, 1999).

1.3 Shortcomings

Thus, extensive comparative analyses of cutmarks made on bones while considering multiple tool types have been performed by researchers. These studies have drawn varying conclusions, which have helped establish databases and reference guides for researchers to use in future probing, build upon previously known theories about the past and improve/correct them, and discover how, why, when, and where the activities of hominins occur. While these studies have been performed worldwide, there is still a necessity for similar works to be done in the Indian context. The Indian subcontinent harbours a large variety of archaeologically rich material, therefore making it a perfect hotspot for such investigations to be carried out. Analyses such as studying cutmarks made on modern versus ancient fossil specimens, comparison of various tool types, and predictions of the levels of the expertise of butchery are a few possible works that are yet to be done.

Presently, a large bank of literature exists providing evidence for butchery and cutmarks on bones in India. Paddayya et al. (1995) conducted their investigatory research at the ash mound site of Budihal near Gulbarga district, Karnataka. Their surveys discovered faunal remains of various domestic and wild species showing anthropogenic marks such as cutting, chopping, and splitting performed by stone tools for carcass processing, clearly depicting the implementation of an old practice of butchery in the region. Malassé et al. (2016) carried out a study between 2009 and 2011 of bones showing butchery cutmarks excavated from the Masol Formation, Siwalik Frontal Range in the north of Chandigarh. When compared to the experimental cutmarks made by the authors using a flake, these bovid fossil cutmarks proved the use of stone blades and flakes as butchery tools and a fair understanding of bovid anatomy by the hominins of that period. Sathe and Paddayya (2012) in their paper presented faunal remains that were discovered in the Hunsgi and Isampur regions of Karnataka. Along with these remains, a considerable number of flakes were also obtained from here, implying the close link between animal-human interactions. Chauhan (2008), in his study on the occurrence of large mammalian assemblages in the Indian subcontinent, also mentions the case of faunal remains being discovered along with stone tools of various industries (Acheulian, Paleolithic, Soanian) across several river valleys such as Son, Narmada, Mahanadi, and Krishna, to name a few, sporadic areas such as Gujarat, West Bengal, Tamil Nadu, and Northeastern India among many, and also pieces of evidence from Sri Lanka, hinting at the possibility of butchery occurring in these regions; this yet needs to be confirmed via taphonomic analyses.

A few works have tried to tackle this area of study in the Indian context. Chase (2018), in his dissertation, performed a reconstruction of the faunal diversity via the faunal remains discovered at Ter, Osmanabad, Maharashtra, where he carried out an extensive analysis of all archaeological material found there, including the determination of any taphonomic observations (butchery, cutmarks, biting, gnawing, abrasion). These samples consisted of various species, such as dogs, pigs, buffaloes, deer, birds, and more, hinting at the region's rich ecology (Chase, 2018). A similar reconstructive examination was done by Deshpande-Mukherjee and her team on the animal remains found in Chandankhera, Chandrapur, Maharashtra, where they analysed these remains and tried to ascertain the ecology of that period (Deshpande-Mukherjee et al., 2014).

An older study by Gilmore (1999) carried out an assessment of butchery samples to understand the act of butchery in the past and its reproducible and reconstructive nature relative to modern times. It also pushed for the use of better techniques and approaches for comprehending these themes, so that future researchers can have a proxy to carry out similar assessments of archaeological samples found during excavations (Gilmore, 1999).

This area of study still requires more work, as it needs more in terms of the material presented through research papers and dissertations. Over the decades, many scientists have worked towards acknowledging and apprehending how our ancestors functioned, and hence, this field holds great potential, with discoveries being made frequently. This project aims to fill some caveats when examining butchery samples by studying the cutmarks made by tools of various raw materials on animal bones (particularly goat and buffalo) and comparing this data with archaeological samples excavated from a Harappan site.

Chapter 2: Materials and Methods

2.1 Materials

2.1.1 Experimental stone tools

Part of the stone tools used in this thesis were made by knapping raw materials procured from a trader here in Pune, Maharashtra. These rocks predominantly include jasper and chert, which were sourced from nearby regions. Rose quartz, sourced from the same regions and provided by the trader, was also acquired, but knapping and creating tools from it was challenging as the material breaks off unevenly and is relatively brittle. The total weight of the entire bulk of the raw material was ~5 kg. Hammer stones were used to create and knap the stone tools, which the same trader also supplied. These hammer stones ranged in shape and size (~8–10 cm in length) for ease in the tool-making process.

These tools have been created while referencing works from previous papers (Key & Gowle, 2022; Key & Lycett, 2017; Kolobova et al., 2022; Lombard, 2015; Proffitt et al., 2021) and online tutorials. Workshop experience and in-person classroom teaching have benefited the knowledge of tool knapping for the purpose of this research. These tools have been created under an enclosed space with proper precautionary gear (face masks, gloves, safety goggles, first aid kit at hand) and safety, and several tool types have been obtained as a result.

The tools that have been made are less than 9 cm in length. These consist of small and medium-sized blades. Jasper proved to be the best raw material, as knapping the material was relatively easy compared to chert. The tools obtained from knapping jasper were sharp, precise, and more varied in shape. Due to the gritty texture of the raw material, chert blades were not very sharp and were few in number. However, they proved to be easier to handle due to their relatively smoother surfaces.

Along with debitage, many possible projectile points have also been obtained from the experiment. These specimens are debitage that unintentionally came out to be pointed as a result of knapping, and were not knapped or shaped purposefully. However, these can be hafted into arrows and spears. A large number of tools have thus been acquired from this procedure. However, due to the small size of the tools, it is advised to use bigger raw materials to obtain larger blades and tools. All tools have been recorded for posterity via photography and stored separately in collection bags. Scales have been later added for size reference to those images that do not consist of any.

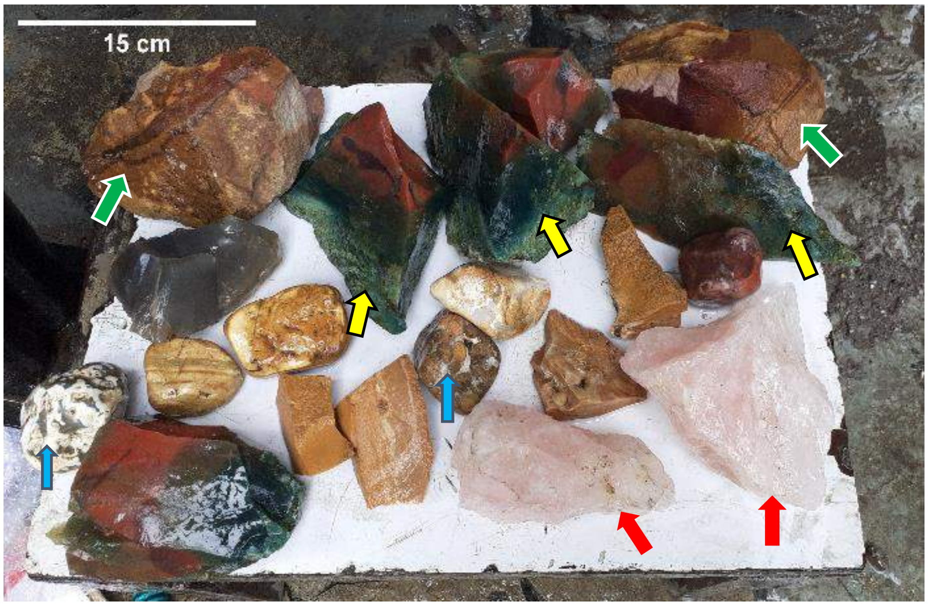


Fig. 1. Raw material used for stone tool knapping. Yellow arrows show jasper, green arrows show chert, and red arrows show rose quartz. Hammer stones have been shown with blue arrows.

Fig. 2 (a).

Fig. 2 (b).

Fig. 2 (c).

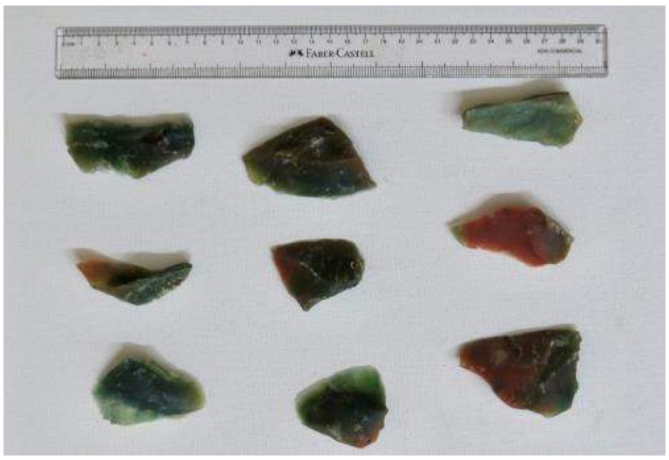


Fig. 2 (d).

Figs. 2 (a)–(d) show stone blades and flakes made out of jasper.

Fig. 3. Blades made out of chert.

Fig. 4 (a).

Fig. 4 (b).

Figs. 4 (a), (b) show potential projectile points obtained while knapping jasper.

Fig. 5. Potential projectile points (large-sized) acquired while knapping.

Deccan College, Pune, organized a workshop for stone tool knapping on 29 October 2022, where jasper and chert were used as raw materials sourced by the supervisor. More chert blades were produced here by the participants and were thus collected and used for this thesis. The tool-making process was recorded via photography, and the tools created were appropriately stored and preserved for later purposes.

Fig. 6 (a).

Fig. 6 (b).

Figs. 6 (a), (b) show tools made by students at Deccan College, Pune (29 Oct 2022). Resources obtained by Parth R Chauhan. More tools were produced from chert as seen in **Fig. 6 (b)** — marked in yellow and red are possible projectile points and in blue are blades.

Apart from these, experimental stone tools have also been shipped here from IISER Mohali, made by Vivek Singh, a former PhD student of the thesis supervisor. These tools have been made from chert, quartzite, limestone, granite, and sandstone, sourced from northern India. These tools are larger in size compared to the ones made in Pune — around 9–15 cm in length — possibly due to the availability of larger chunks of raw material. These tools are also bulkier, have a greater surface area, and have a better gripping ability. However, a small drawback is that these tools are relatively less sharp than the ones made by the experimentalist. Based on initial observation of all combined tool, these had thicker blade edges and, when used to cut material, left behind a broader groove. These large handaxes can be used as the initial tools for carcass defleshing and butchery, and then slowly be replaced with the smaller blades and flakes for finer tissue removal.

Fig. 7 (a).

Fig. 7 (b).

Fig. 7 (c).

Figs. 7 (a)–(c) show some of the tools knapped in IISER Mohali. These tools are large in size, as can be seen from the scale (1 unit = 1 cm).

Fig. 8 (a).

Fig. 8 (b).

Fig. 8 (c).

Fig. 8 (d).

Figs. 8 (a)–(d) shows experimental stone tools stored in separate bags and weighed.

Fig. 9 (a).

Fig. 9 (b).

Figs. 9 (a), (b) show all the usable stone tools marked for identification. **Fig 9 (b)** shows letters indicating the raw material used; C - chert, Q - quartzite, L - limestone, G - granite, S - sandstone.

All usable stone tools created so far were carefully weighed, measured, and marked. This helped keep track of the tools used and the total number of blades that were functional for this thesis. Tables 1 and 2 below show the recorded data.

Sample	Weight (grams)	Length (cm)	Breadth (cm)	Width (cm)
PS01	27.2	6.4	3.7	1.2
PS02	9.2	4.4	4.4	0.4
PS03	11.1	4.9	3.3	1
PS04	14.4	4.4	3.3	0.8
PS05	46	7.9	4.4	2
PS06	22.8	5.8	2.7	1.9
PS07	53.8	7.9	4.7	2.2
PS08	22.8	5	4.3	1.4
PS09	41	6.7	4.9	1.3
PS10	22.3	6.3	3.7	0.8
PS11	22.7	6.6	3.3	1.5
PS12	35.1	5	4	2.5
PS13	16	6	2.5	1.4
PS14	31.4	5	4.1	1
PS15	17.8	6.5	3.2	1.2
PS16	26.9	7.1	3.3	2
PS17	13.4	5	4.2	0.6
PS18	15.2	4.5	3.7	0.6
PS19	6	5	3	0.4
PS20	6.8	3.5	2.7	0.6
PS21	10.9	4	2	0.7
PS22	8	4.9	2.6	1
PS23	8.9	5.5	3	0.8
PS24	14.3	4	3.2	1
PS25	19.5	3.8	2.8	0.8
PS26	11.2	3.8	3.3	0.6
PS27	11	4.3	3	0.7
PS28	6.7	4.6	2.2	0.5
PS29	13	3.5	3.2	0.7
PS30	13.1	4.9	3.8	0.8
PS31	8	3.4	3.1	0.4
PS32	8.5	4	2.7	0.7
PS33	8.3	3.3	2.9	0.9
PS34	9.5	3.7	2.5	0.7

Table 1. Measurements of the stone tools created by the experimentalist and those collected from Deccan College (PS = samples from Pune)

Sample	Weight (grams)	Length (cm)	Breadth (cm)	Width (cm)
MS01	143.4	9	6.1	1.5
MS02	174.4	10.5	6.6	2.2
MS03	132.9	10	7.3	2.5
MS04	66.2	8.7	4.3	2.7
MS05	114.2	10	6	1.6
MS06	117.7	9.4	5	2.4
MS07	36.7	6.5	4.9	0.5
MS08	54.6	6.4	4.3	1.4
MS09	240.6	11.5	7.7	3
MS10	82.5	9.9	4.4	1.6
MS11	228.3	9.8	6.7	2.1
MS12	156.9	10.5	4.3	2.8
MS13	170.9	10.3	6	2
MS14	139.3	10.8	7.3	1.5
MS15	273.5	13.4	6.5	2.7
MS16	344.1	7.9	6.8	4.2
MS17	209.7	11.6	6.4	3
MS18	123.7	7.9	6.5	1.5
MS19	208.8	10.5	7.4	2.6
MS20	101.6	9.5	4.6	1.8
MS21	107.8	9.4	4.5	2.4
MS22	313.3	12.2	8	2.1
MS23	74.2	6.5	6.2	1.7
MS24	95.8	8.1	4.9	1.5
MS25	37.6	7.9	4	1.2
MS26	33.5	8.4	3.5	1.5
MS27	48.1	7.5	4.5	1
MS28	14	5.7	2.8	1.5
MS29	8.1	4.6	2.4	0.6
MS30	33.4	7.4	3.2	1.4
MS31	58.8	7.9	3.9	2
MS32	19.7	6	2.7	1.3
MS33	66.2	6.1	5	1.6
MS34	37.4	5.3	4.5	0.8
MS35	414.5	14	8.7	2.4
MS36	680.7	13	9.7	3
MS37	393.2	13	8.6	2.7

Table 2. Measurements of the stone tools created by Vivek Singh (PS = samples from Mohali)

2.1.2 Experimental bone samples

The bone samples were collected from a nearby butcher shop. These consisted of goat and buffalo meat. The buffalo parts consisted of a humerus, taken from the carcass that was butchered around 12–14 hours before the defleshing process. Similarly, the goat parts consisted of metatarsals, one of which was half-split. The goat had been butchered 7–8 hours before the bones were defleshed. All material were collected such that most remained intact right before the removal of the soft tissues. The preliminary samples were stored in separate bags and transported to the open space for defleshing.

Fig. 10 (a).

Fig. 10 (b).

Figs. 10 (a), (b) show the buffalo meat samples procured by the experimentalist. **(a)** is the humerus, **(b)** consist of the ribs.

Fig. 11 (a).

Fig. 11 (b).

Figs. 11 (a), (b) show the goat meat samples procured by the experimentalist. Both present the legs (metatarsals with the joints attached) of the goat.

2.1.3 Archaeological bone samples from Harappan site

The fossil samples were excavated by a team led by P. Goyal, P. Shirvalkar, and P. Rawat, along with a joint effort by Deccan College, Pune and the Gujarat State Department of Archaeology, Gandhinagar, from 2010 to 2013 (Shirvalkar & Rawat, 2012; Shirvalkar et al., 2015, as cited in Goyal et al., 2018). The samples were discovered from the site of Kotada Bhadli (23° 20' N; 69° 20' E), located in the Nakhatrana Taluka, District Kachchh, Gujarat. In their premier investigation, they write,

> "…The excavated ceramic assemblage (of typical Mature Harappan as well as regional Sorath Harappan types) and material culture such as spherical weights, terracotta beads, and construction style of structures indicate that the site belonged to the Late Mature Harappan period. Based on these evidences, the site can be dated between 2300 BCE and 2100 BCE…" (Shirvalkar & Rawat 2012–13, p. 77, as cited in Goyal et al., 2018).

Due to the large number of animal bones recovered from the site, a primary objective of this study was to identify each species to which the bones belonged. The authors took the help of several keys published by notable archaeologists in the field for the identification of various animals; specifically for the purpose of this thesis, the references of Haraniya et al. (2016) and Olsen (1960) for buffalo bones, Boessneck (1969), Prummel and Frisch (1986), and Zeder and Pillar (2010) for goat bones will work (as cited in Goyal et al., 2018). Each fossil specimen was marked with a unique identification number via a method called the number of identified specimens (NISP), a simple tallying technique to count the number of bones or bone fragments (Goyal et al., 2018).

A major hindrance was the identification of bones between closely related species, such as cows (*Bos indicus*) and buffaloes (*Bubalus bubalis*) and sheep (*Ovis aries*) and goats (*Capra hircus*). The authors tackled this by creating "broad-level groups" such as *Bos/Bubalus* and *Capra/Ovis* and segregating the unidentifiable bones into these categories (Goyal et al., 2018, p. 69).

A common observation while excavating for bones was the well-preserved state of bones, such as carpals, tarsals, and phalanges, showing no signs of wear and tear. However, breakage of the bones, either ancient or fresh, was quite common. Several skeletal fragments of animals were found to have butchery-related cutmarks. These cutmarks could have been made by metal tools, although studies have shown the use of stone tools as late as the Late or the post-Urban Harappans, ranging from 1900–1400 B.C. (Soni, 2011).

For the intent of this thesis, data was obtained from Holocene samples of buffalo, cow, and goat, particularly the humeri, radii and ulnae, femora, and tibiae. Goat bones were relatively lesser in number, and only the tibiae and femora were considered. All samples had to be thoroughly cleaned to remove loose dust and dirt by brushing off the surface with water and were then left to dry for 20 hours, after which the ones showing more evident signs of butchery under the naked eye were kept ahead for microscopic analysis.

Figs. 12 (a), 12 (b), and 13 show the anatomy of buffalo and goat legs. These have been sketched by the experimentalist, referencing Hornaday (1904).

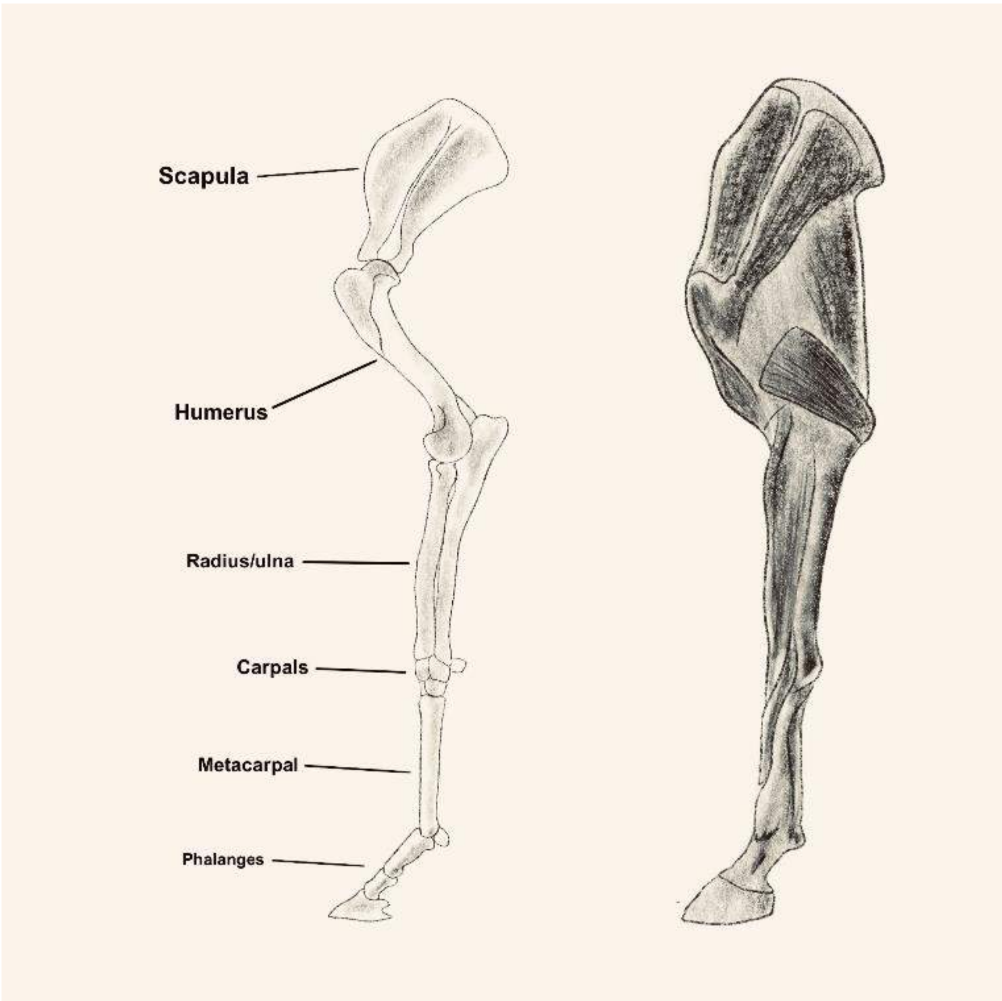


Fig. 12 (a). Diagram explaining the front leg of a buffalo. Sketched by the experimentalist.

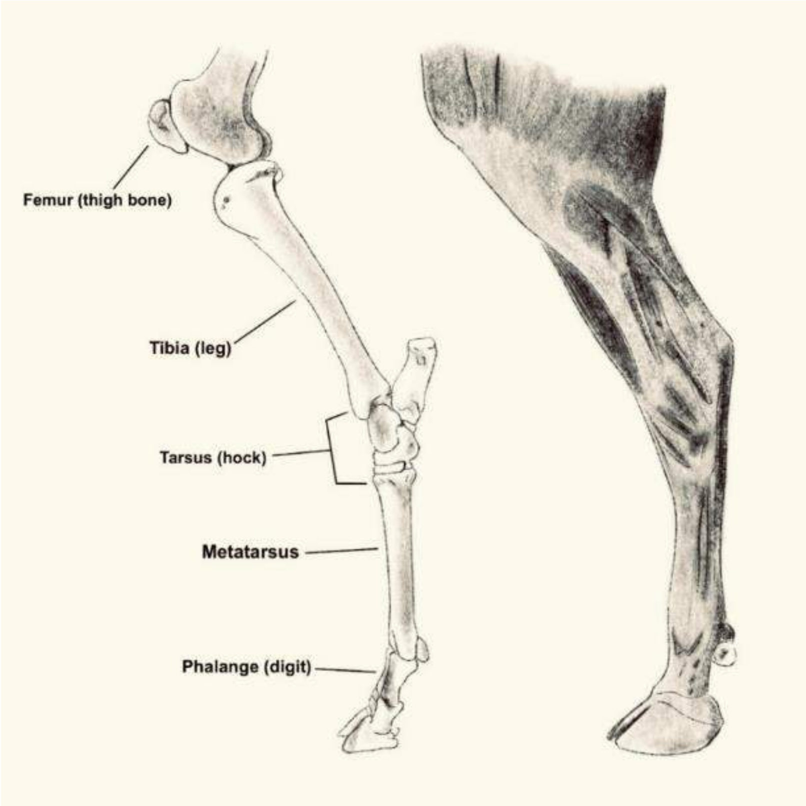


Fig. 12 (b). Diagram explaining the hind leg of a buffalo.
Sketched by the experimentalist.

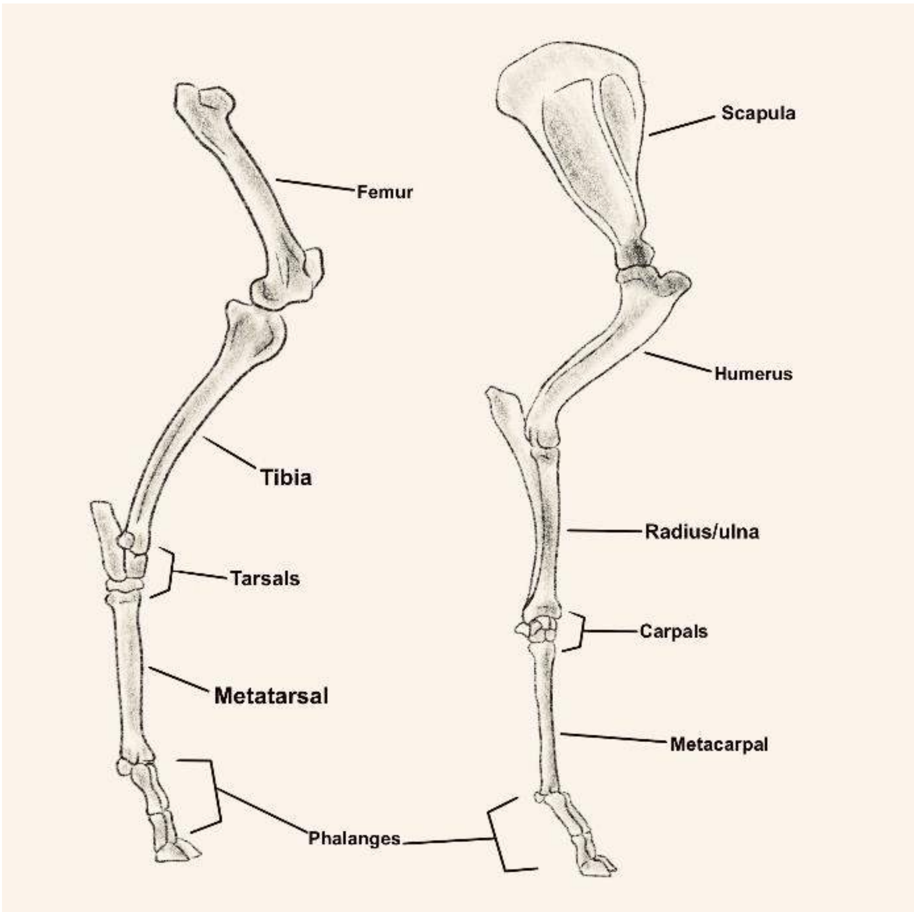


Fig. 13. Diagram explaining the hind and front legs of a goat.
Sketched by the experimentalist.

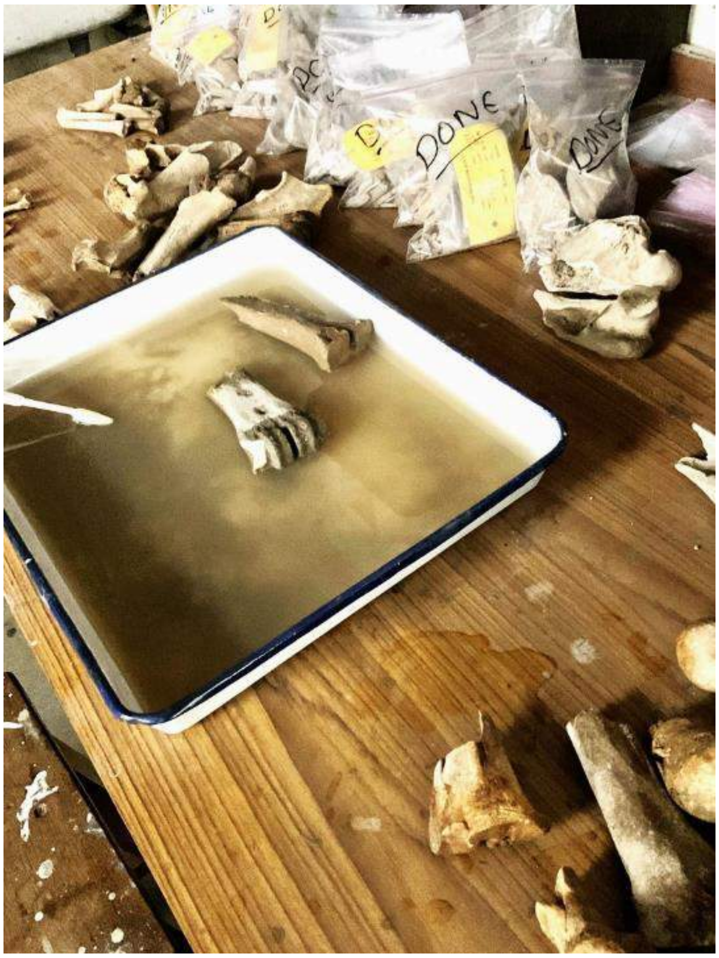


Fig. 14 (a). The archaeological samples are cleaned with water and brush to remove all loose dirt.

Fig. 14 (b). Cleaned samples of goat kept for drying.

Fig. 14 (c). Cleaned archaeological samples of cow.

Fig. 14 (d). Cleaned archaeological samples of buffalo.

Fig. 14 (e).

Figs. 14 (a)–(e) show Holocene samples after cleaning and brushing off loose dirt from their surfaces. These were left overnight for drying and selectively chosen later for analysis.

2.2 Methods

2.2.1 Butchery of the portions of the animal carcass

Defleshing of the meat from the buffalo and goat bones was performed by the experimentalist. It was done in an open space close to the area of residence with proper safety equipment (face mask and gloves) to avoid any form of contamination. Before the defleshing process, the butchery samples were weighed to keep track of the quantity of meat that would be removed and the final weight of the bare bones. Several photographs were taken of the meat before the cutting procedure.

The experimentalist used various experimental tools at hand, beginning with the larger tools made in IISER Mohali, and then eventually moving on to the smaller ones made by the experimentalist. The entire process was documented via photography and videography for both buffalo and goat meat. The time taken to remove all the flesh from the bones completely was also recorded.

The experimentalist used linear, repeated strokes to cut through the meat and reach the bone, thus leaving cutmarks behind. Whatever soft tissue could not be removed was left to be taken out during bone processing. Butchery was performed while referencing several published works (Greenfield, 1998; de Juana et al., 2010; Bello et al., 2009; Boschin & Crezzini, 2011; Moretti et al., 2015) to keep the defleshing procedure consistent, but not to the point that it would hinder the outcome of a novice butcher's method of leaving cutmarks.

Fig. 15. The setup for defleshing.

Fig. 16 (a).

Fig. 16 (b).

Figs. 16 (a), (b) exhibit the defleshing of the buffalo meat.

Fig. 17. Defleshing the goat meat.

Fig. 18 (a).

Fig. 18 (b).

Fig. 18 (a), (b). Some of the experimental stone tools used during the meat removal process.

2.2.2 Processing of the bones

After defleshing all the meat, the bones were processed for later analysis. As a reference, Gilbert's (1980) body of work was used for processing the experimental samples. He mentions several methods to prepare fresh material, such as burial, using dermestid beetles (Senkin, 1975, p. 77, as cited in Gilbert, 1980, p. 31), and chemical treatments, to name a few. From the ones mentioned, maceration (simply boiling the samples) and washing with soap/detergent were employed.

The bones, along with the experimental stone tools, were first thoroughly washed with cold water to get rid of any loose meat. The remaining flesh and cartilage attached to the bones were removed by boiling the bones in water in a deep vessel for an hour. Adding baking soda to this helped loosen out the flesh. These were also washed in a detergent solution to remove stains and smells. The bones were kept out in the open air and left to dry for a few days, after which they were stored in separate bags. The meat and the bones were weighed separately for the records. All the meat was given away for consumption.

2.2.3 Microscopic analysis

All the samples were taken to the Computational Archaeology Laboratory at Deccan College, Pune, for microscopic analysis. The experimentalist used a Leica© S9i stereomicroscope integrated with a 10 MP CMOS-camera, which helped in the documentation of the cutmarks through photography. The stage plate and the base of the microscope were cleaned off of any dust particles. Once the fossil specimens and the experimental samples had dried up, they were brushed again to remove any remaining dust/dirt. Microscopy was performed in a cool, undisturbed, well-lit environment to remove disruptions and noise and avoid the production of blurry images of the cutmarks.

Each sample was first viewed under the naked eye to look for easily discoverable signs of butchery. Then, each sample was carefully viewed under the microscope, targeting areas where evident signs of cutmarks were visible, and images of the corresponding areas were taken under desirable lighting and focal adjustments. The same was done again after a thorough scan of the specimens under the microscope, such as to target those marks that are not inherently visible to the naked eye. Several images were captured for all specimens to prevent noise from filtering into the data.

After all the fossil specimens of buffalo, cow, and goat were thoroughly analysed along with corresponding images taken, the same was repeated for the experimental samples of buffalo and goat. These were viewed under relatively lower settings of focal and zoom adjustments to achieve high-quality images, as the relatively larger sizes of these samples hindered their optimal placement under the microscope.

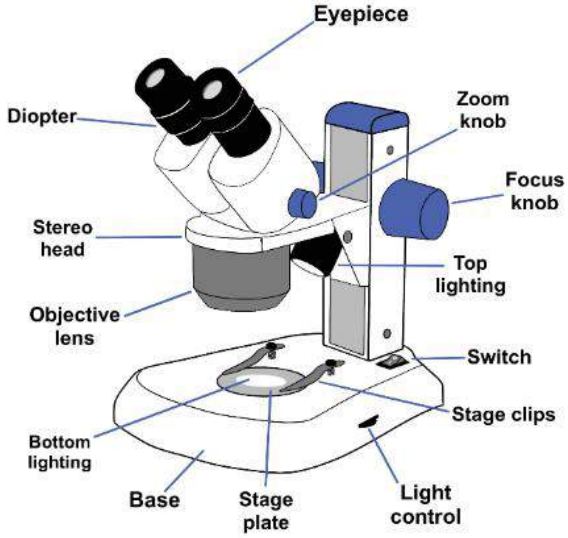


Fig. 19. Parts of a microscope. Diagram made by the experimentalist.

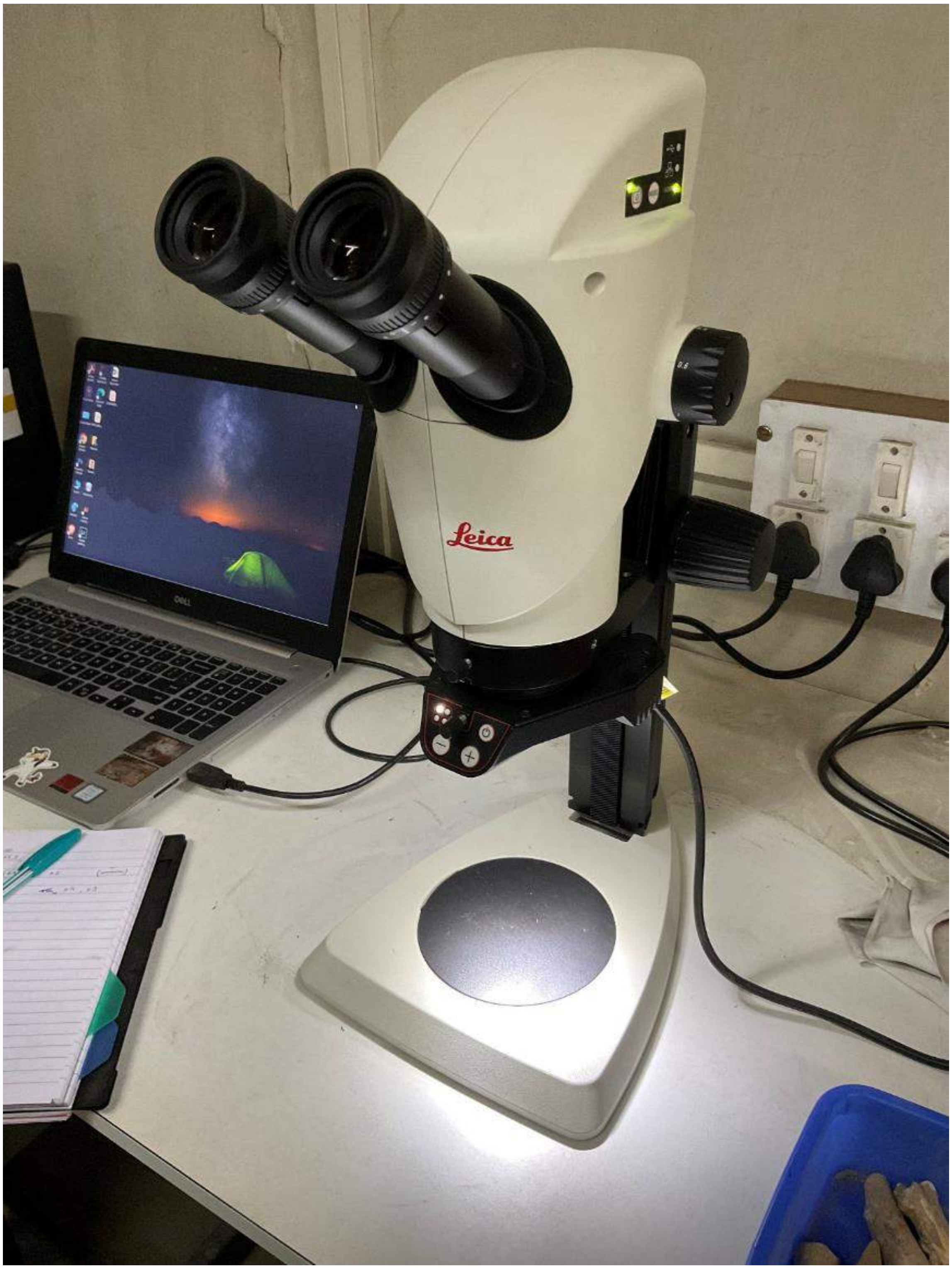


Fig. 20. Image of the stereomicroscope used for viewing and capturing images of cutmarks. The device is attached with an SD card where the images will be stored and later transferred to the laptop.

Chapter 3: Results

3.1 Butchery and bone preparation

The experimentalist successfully removed most of the meat from the bones (~ 71%). The bones accounted for ~19% of the total mass acquired (including goat and buffalo). The remaining percentage of the weight was discarded as cartilage, fragmented bones, and fat. For the purpose of this experiment, the smaller experimental tools (in the range of 7–11 cm) proved to be the best tools for defleshing. These included jasper and chert blades made by the experimentalist. The handaxes made in IISER Mohali, being large (>11 cm), were more useful in the initial parts of the experiment for removing bigger portions of meat, but proved not as effective as the experimentalist's smaller blades and flakes for finer defleshing. Smaller experimental tools (<7 cm) made by the experimentalist were left entirely unused. Non-Mohali tools were incredibly sharp and hence required careful handling; the novice experimentalist here received minor cuts which were duly medicated and treated.

The cutmarks made by the smaller blades and flakes of jasper were the most noticeable and prominently visible under the naked eye; the rest of the experimental stone tools left behind more minor gashes and cuts on the bones. Most of these marks were not distinctly visible at first glance and could only be seen under the microscope.

Buffalo meat proved to be the toughest to cut through compared to goat meat. Sharper tools were required eventually to cut through the flesh and reach the bone. Cartilage in both goat and buffalo was difficult to remove; this was removed later during bone preparation.

A camera, placed such that the butchery process could be in view, was successfully able to capture photographs and videos of the entire process. Photographs of the bones soon after defleshing and also of the total meat removed were taken.

S. No.	Animal	Part	Weight before butchery (kg)	Start time of defleshing (hrs)	End time of defleshing (hrs)	Time taken to deflesh (minutes)
1	Buffalo	Humerus	2.8	20:11	20:42	31
		Ribs	1.2	20:51	21:03	12
2	Goat	Metatarsals (legs) and joints	0.58	21:15	21:37	22

Table 3. Data of the butchery.

S. No.	Animal	Part	Weight before butchery (kg)	Weight after butchery	
				Weight of the meat (kg)	Weight of the bones (kg)
1	Buffalo	Humerus	2.8	1.87	0.8
		Ribs	1.2	0.87	0.08
2	Goat	Metatarsals (legs) and joints	0.58	0.52	0.01

Table 4. Data collected post-butchery. Notice that the total weight after butchery does not coincide with the weight before. This is due to some of the material not being used for consumption (such as fat and cartilage), and some loose fragments and flesh being discarded.

S. No.	Animal	Part	Length (cm)	Minimum breadth (cm)	Maximum breadth (cm)	Minimum width (cm)	Maximum width (cm)
1	Goat	Metatarsal – 1	17	1.2	2.8	0.3	0.5
		Metatarsal – 2	9.5	1.1	2.9	0.2	0.3
2	Buffalo	Rib – 1	16.8	2.7	4.5	< 0.1	
		Rib – 2	9.9	4.6	5.6	< 0.1	
		Humerus	30.9	4.5	10.4	7.4	11.6

Table 5. Dimensions of the experimental bone samples.

Fig. 21. On the left is the intact humerus of the buffalo, with most of the flesh removed. Some of the flesh and cartilage can still be seen stuck to the bone. On the right is the bulk of the meat that was successfully removed from the bone.

Fig. 22 (a).

Fig. 22 (b).

Figs. 22 (a), (b) show lateral and longitudinal views of the defleshed buffalo humerus.

Fig. 23. The defleshed ribs of the buffalo. Notice that the topmost rib has chipping and fragmenting of the bone from the edges, and the bottommost rib shows the surface where the metal blade cut through the bone.

Fig. 24. The total meat that was removed from all the bones.

Fig. 25. The defleshed metatarsals (legs) and joints of the goat. The bottom right sample has cartilaginous material still stuck to it.

Fig. 26. The total meat that was defleshed from the goat bones. The bottom left specimen is the broken metatarsal of the goat, which was discarded due to fragmentation.

After boiling the bones, all loose flesh and cartilage came off quite easily, and these were picked off by hand. Due to the initial butchery being done by the butcher using metal knives, the fragmentation in the bones became slightly increased during the boiling process, and more pieces started to chip off (especially from the ribs). These fragments were discarded as data from them was of no use.

Even after several washes and drying, the bones still had residual cartilage stuck to them. These could have been removed if an alternative, long-period defleshing method (such as the burial of the bones over a few months) had been used, but they had to be avoided due to time constraints.

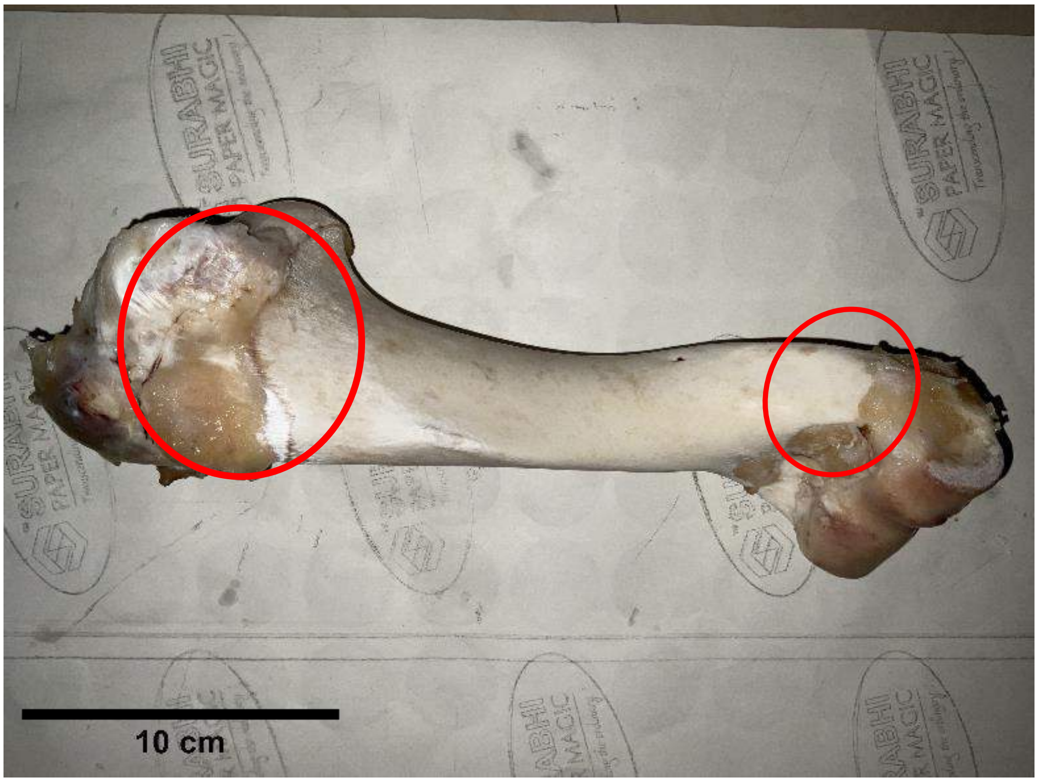


Fig. 27 (a).

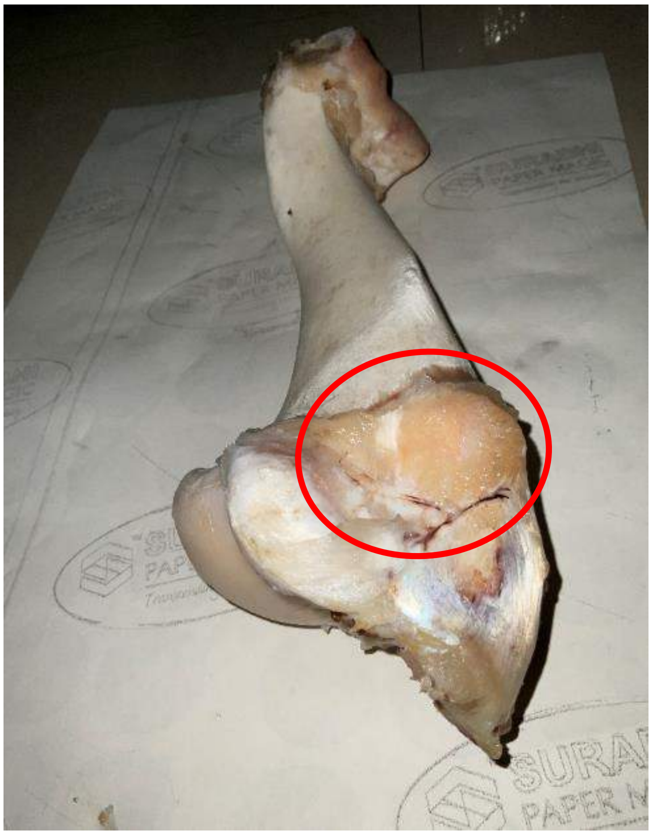


Fig. 27 (b).

Fig. 27 (c).

Fig. 27 (d).

Figs. 27 (a)–(d) depict experimentally butchered bone samples of buffalo. **(a)** and **(b)** are lateral and longitudinal views of the humerus respectively; **(c)** and **(d)** show the ribs. Notice that some cartilage is still stuck to the meat in **(a)** and **(b)**.

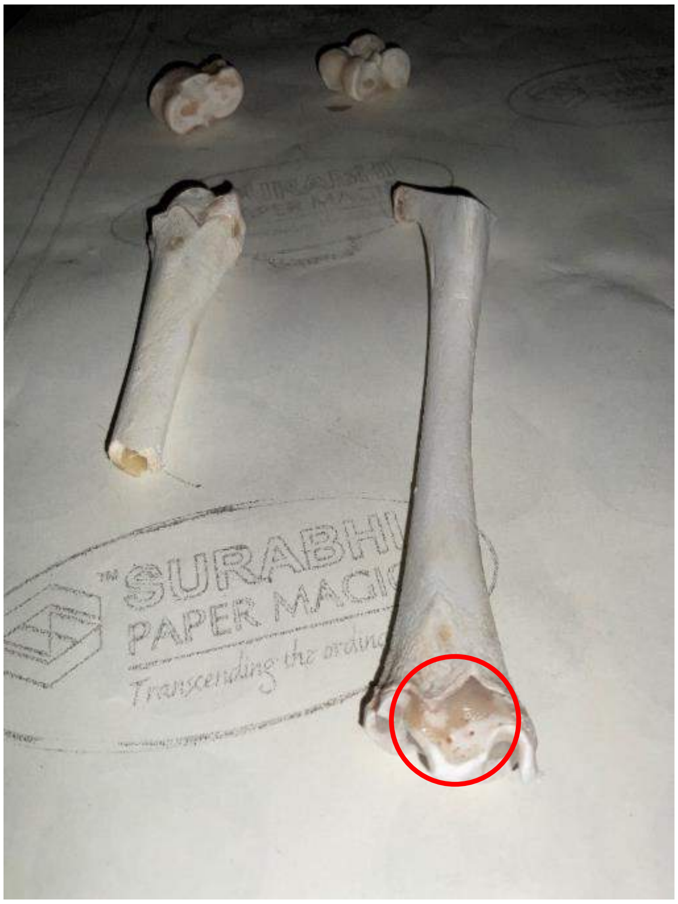


Fig. 28 (a).

Fig. 28 (b).

Figs. 28 (a), (b) show experimentally butchered goat bones (joints and metatarsals). Notice a bit of the cartilage still stuck to the bone in **(a)**.

Fig. 29. All the experimentally butchered bone samples.

3.2 Archaeological sample analysis, microscopy, and imaging

The archaeological samples and the experimental samples were viewed and analyzed under the microscope, and images were taken for posterity.

The archaeological samples showed remarkable amounts of cutmarks on them, indicating they were subjected to butchery. These cut marks varied in size (from a few millimetres to a few centimetres) and generally ran diagonally or perpendicular to the length of the bone. The bulbous regions, such as the femur, had cutmarks and scrape marks in irregular directions. The depth of the cutmarks varied across species and specimens, some being fairly deep while others were relatively shallow. Most cutmarks made were clean, sharp, and precise, with little to no irregularities across the length. The location of these cutmarks also varied across samples, but they were generally more common towards the ends of the bones (i.e., where the joints are connecting).

Cow and buffalo bones had cutmarks that ran deeper and were generally longer, although small cutmarks were also observed. Goat bones, in comparison, had shallower, thinner, and smaller cutmarks, but were more numerous and localized in specific areas.

Along with these cutmarks, striations, cracks, and other markings were also present and could be easily distinguished from regular tool-made cutmarks. The fossils generally showed dark spots, which could be denotative of mineral deposition and coating. Some marks were also present due to the growth of roots and rootlets on the surface, as suggested by Goyal et al. (2018. p. 72), and were identifiable and distinguishable.

A common hindrance to the microscopic analysis was the presence of encrustation on the upper fossil layer. These prevented the experimentalist from carefully examining for further cutmarks on the bone surface. Some fossils even showed the removal of this sediment layer, exposing the lower bone surface, which was devoid of any marks. Therefore, a large number of fossil samples could not be analyzed and thus had to be discarded for the purpose of this experiment.

A significant number of images were taken of the fossil samples from the microscope to avoid noise and improve cutmark viewing. However, some noise did end up creeping into the data via blur and incorrect lighting. All noise-filled images were discarded, and the best components were used.

Fig. 30 (a).

Fig. 30 (b).

Fig. 30 (c).

Fig. 30 (d).

Figs. 30 (a)–(d) consist of Holocene samples of buffalo (*Bubalus bubalis*).

Fig. 31 (a).

Fig. 31 (b).

Fig. 31 (c).

Fig. 31 (d).

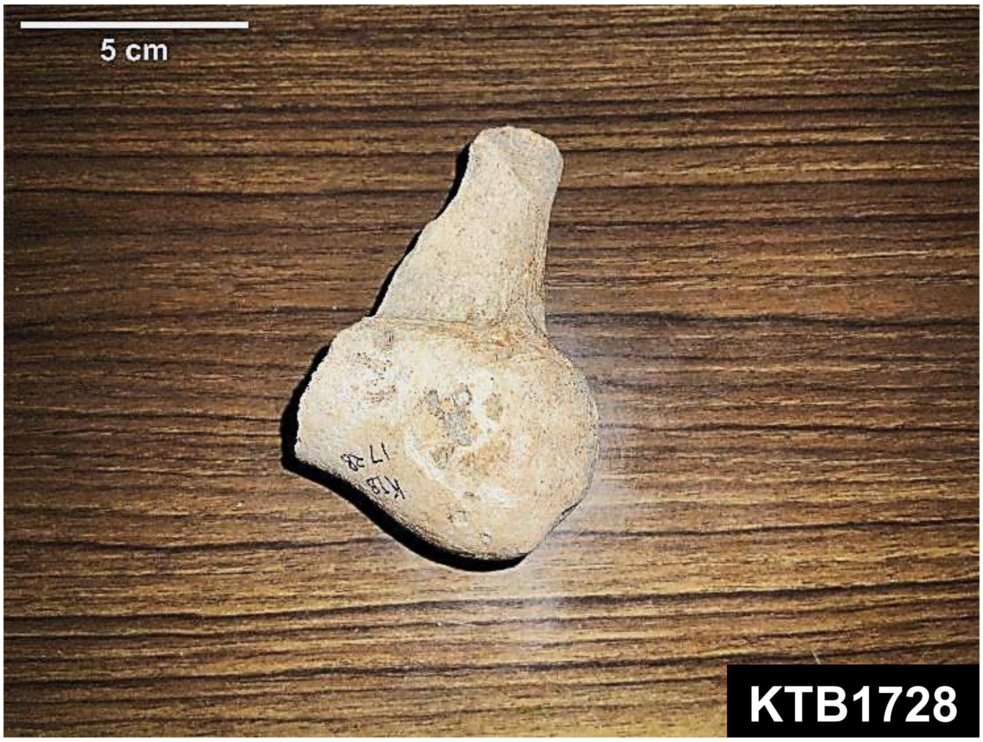


Fig. 31 (e).

Fig. 31 (f).

Figs. 31 (a)–(f) consist of Holocene samples of cow (*Bos indicus*).

Fig. 32 shows Holocene samples of goat (*Capra hircus*).

S. No.	Animal	Name	Length (mm)
1	Cow (archaeological)	KTB1458	18.8
2		KTB1704	17.7
3		KTB1720	9.9
4		KTB1728	13.5
5		KTB1737	15.2, 14.8
6	Buffalo (archaeological)	KTB1110A	14
7		KTB1110B	7.9
8		KTB1258A	10.5, 6.7, 13.7, 1.7, 0.5
9		KTB1258B	6.8
10		KTB1665	10.9, 22.3, 16.1, 7.6, 7.1
11	Goat (archaeological)	KTB1120A	17.2
12		KTB1120B	6, 5.8, 5.9, 8.8, 3.5, 4.7
13		KTB1120C	12.5, 8.9
14		KTB1127A	16.7
15		KTB1127B	9.6
16		KTB1214A	6.6, 6.4, 6.1
17		KTB1214B	1.6, 1.4, 1.3

Table 6. Lengths of the cutmarks on various archaeological samples.

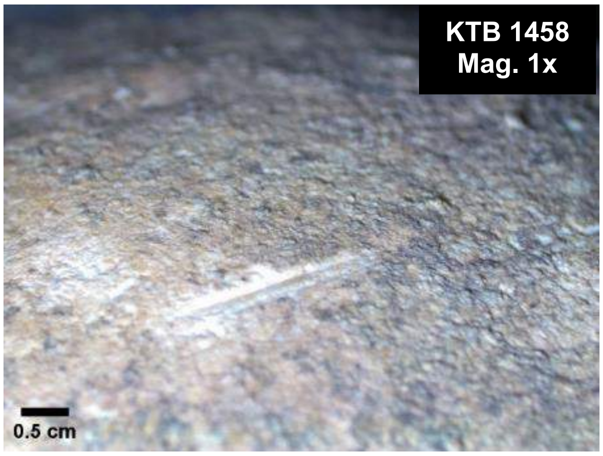


Fig. 33 (a).

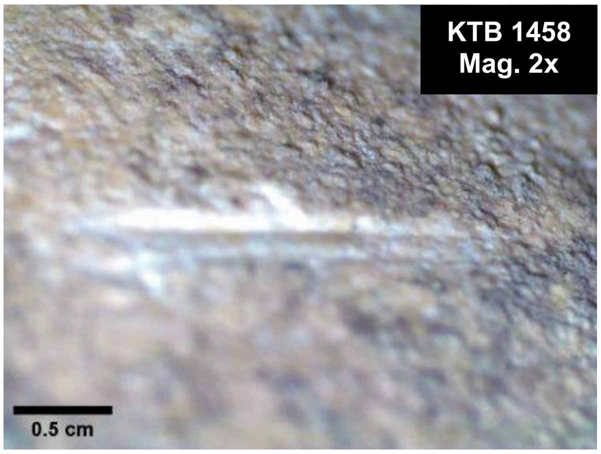


Fig. 33 (b).

Fig. 33 (c).

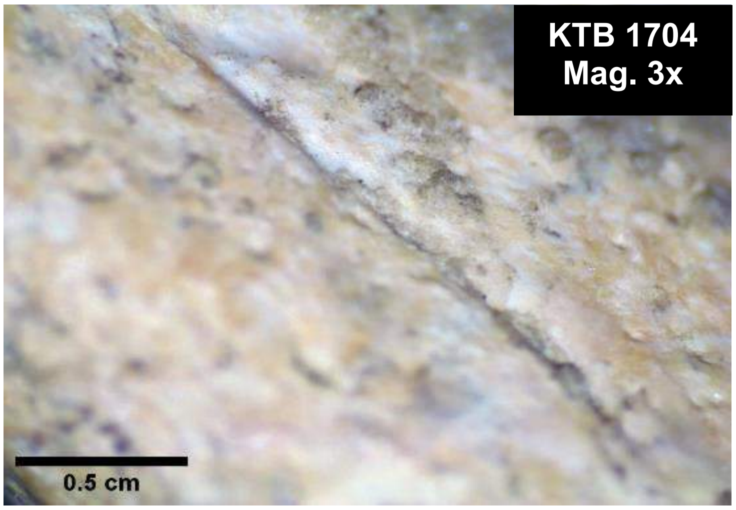


Fig. 34 (a).

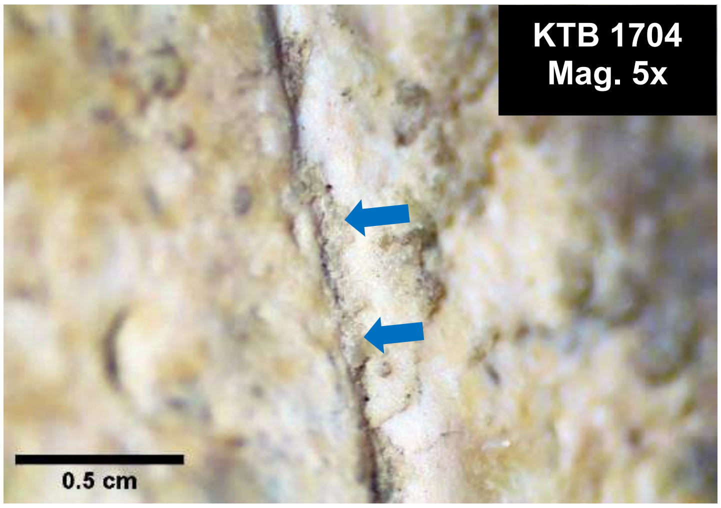


Fig. 34 (b). Signs of crystal formation and sediment encrustation on the fossilized bone.

Fig. 35. The cutmarks are faintly visible.

Fig. 36.

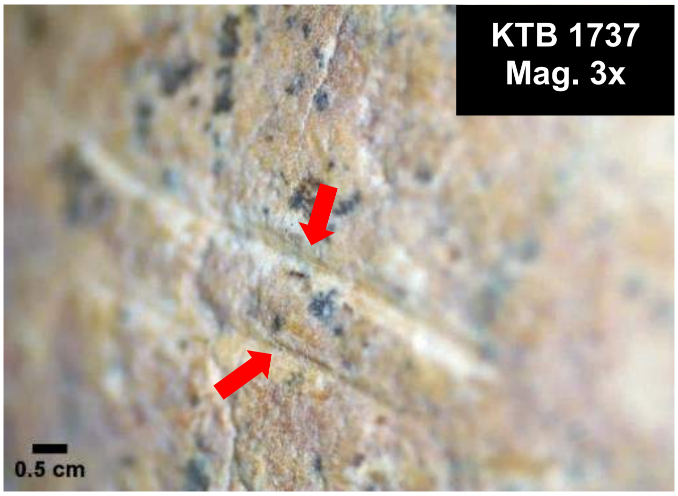


Fig. 37 (a). Cutmarks as shown by arrows.

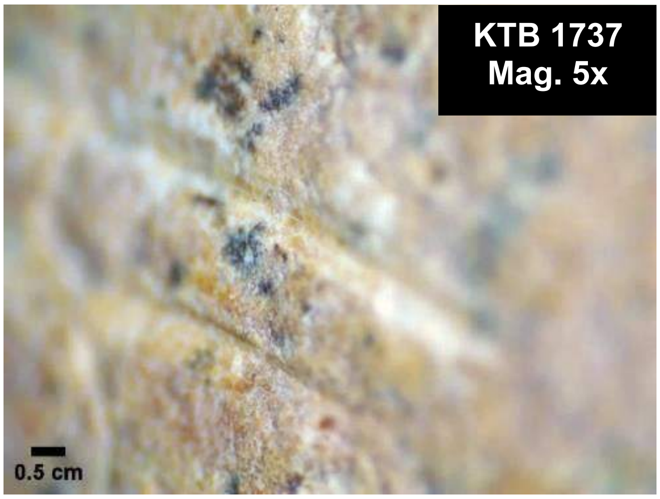


Fig. 37 (b).

Fig. 33 (a)–(c), 34 (a)–(b), 35, 36, 37 (a)–(b) show various archaeological samples of cow with marks of butchery on them. Different magnifications used have been indicated along with the identification

Fig. 38. Cutmarks faintly visible. Much data is lost due to blurring.

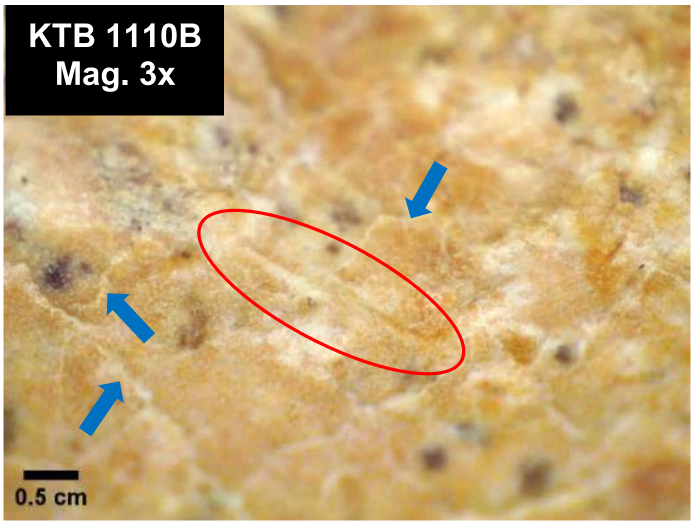


Fig. 39. Faint cutmark present. Striations on the fossil shown by arrows.

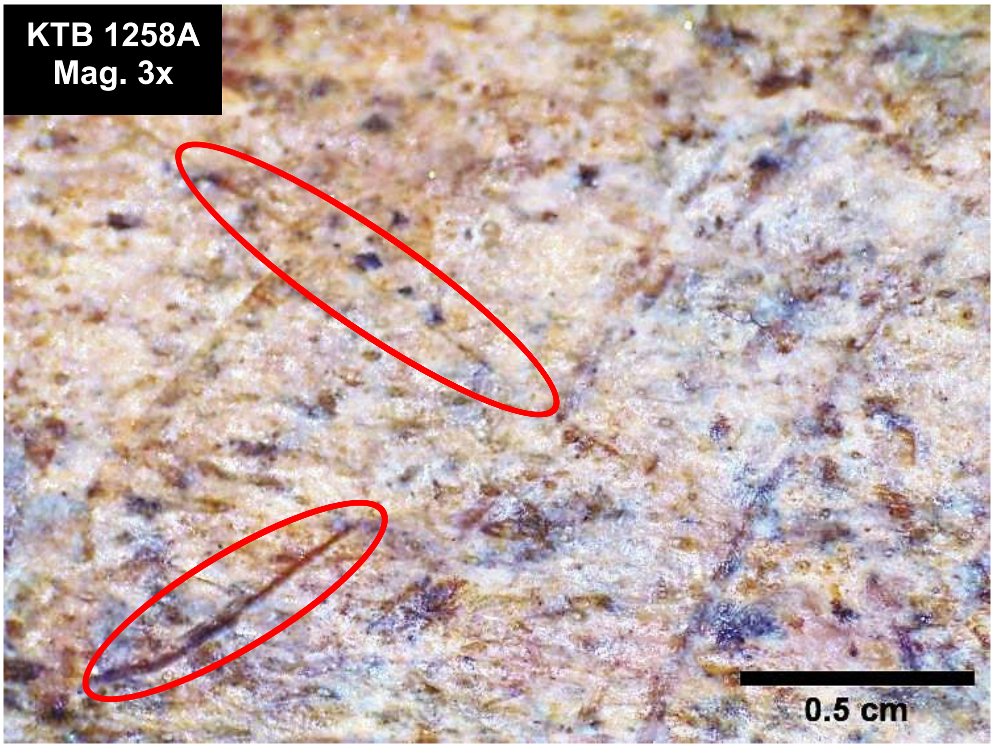


Fig. 40 (a).

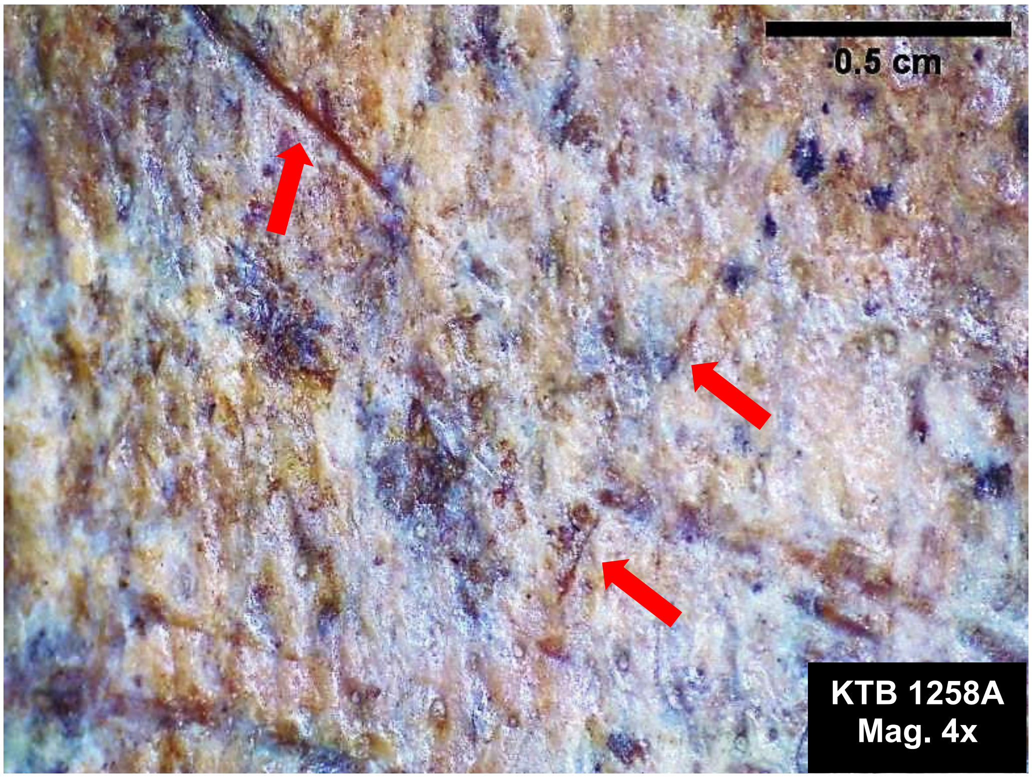


Fig. 40 (b).

Fig. 41.

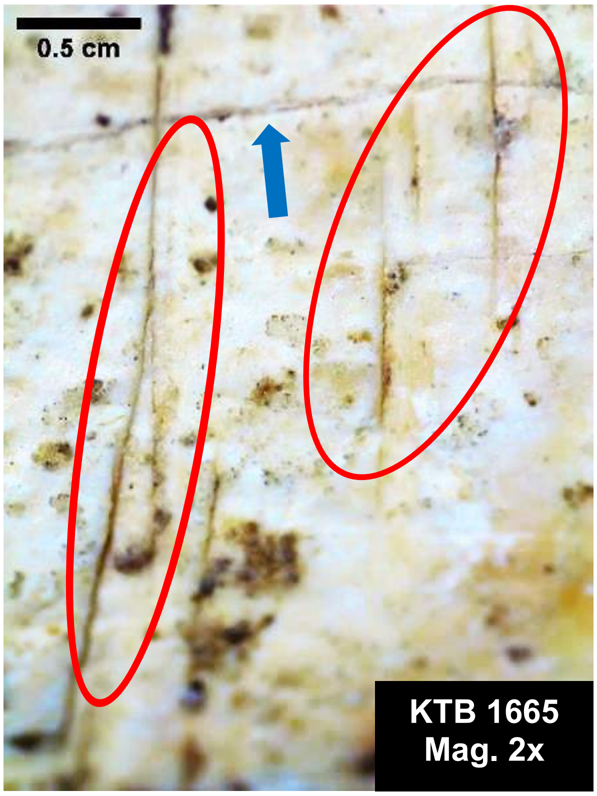


Fig. 42 (a).

Fig. 42 (b).

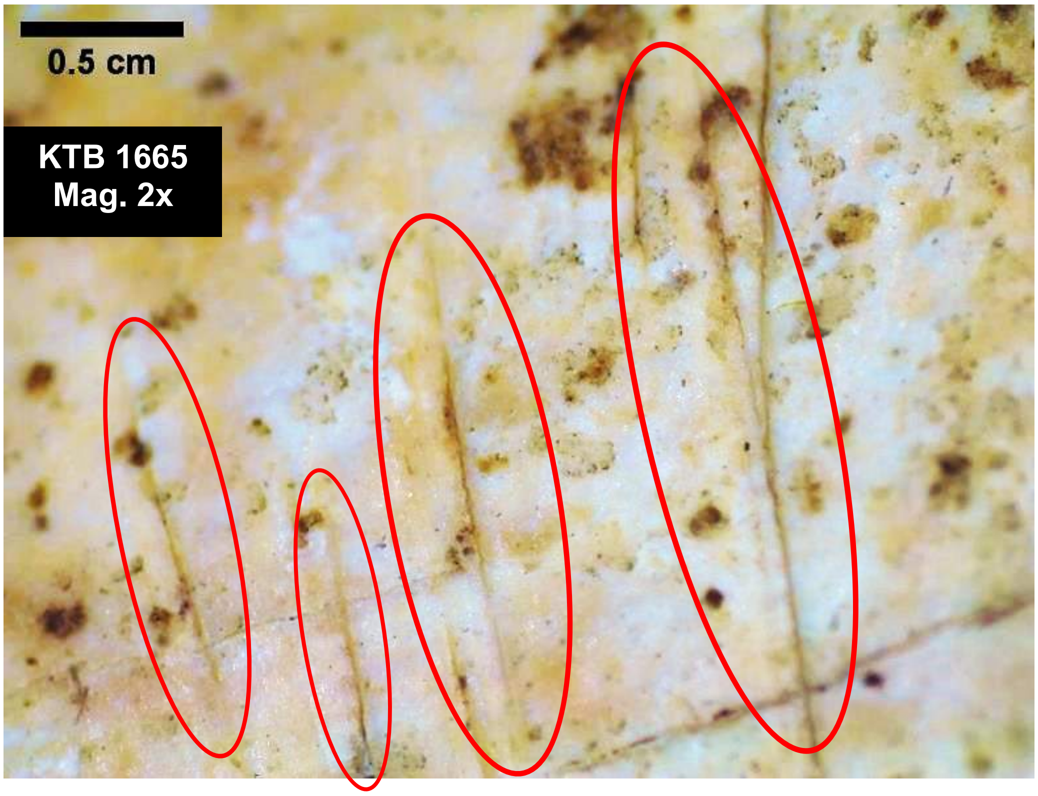


Fig. 42 (c).

Fig. 38, 39, 40 (a)–(b), 41, 42 (a)–(c) show microscopic images of cutmarks on archaeological samples of buffalo. Cutmarks have been marked in red (circles and arrows) for better identification. Blue arrows show striations on the surface.

Fig. 43.

Fig. 44 (a).

Fig. 44 (b). Possible scrape marks.

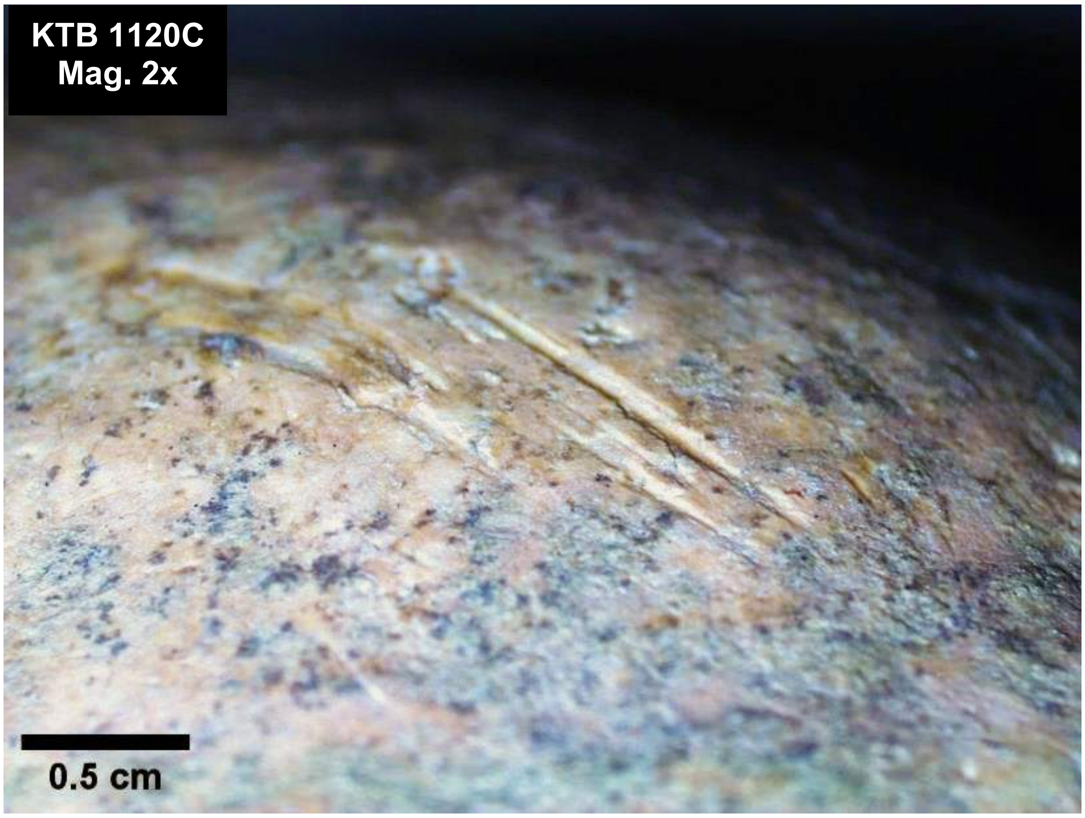


Fig. 45 (a).

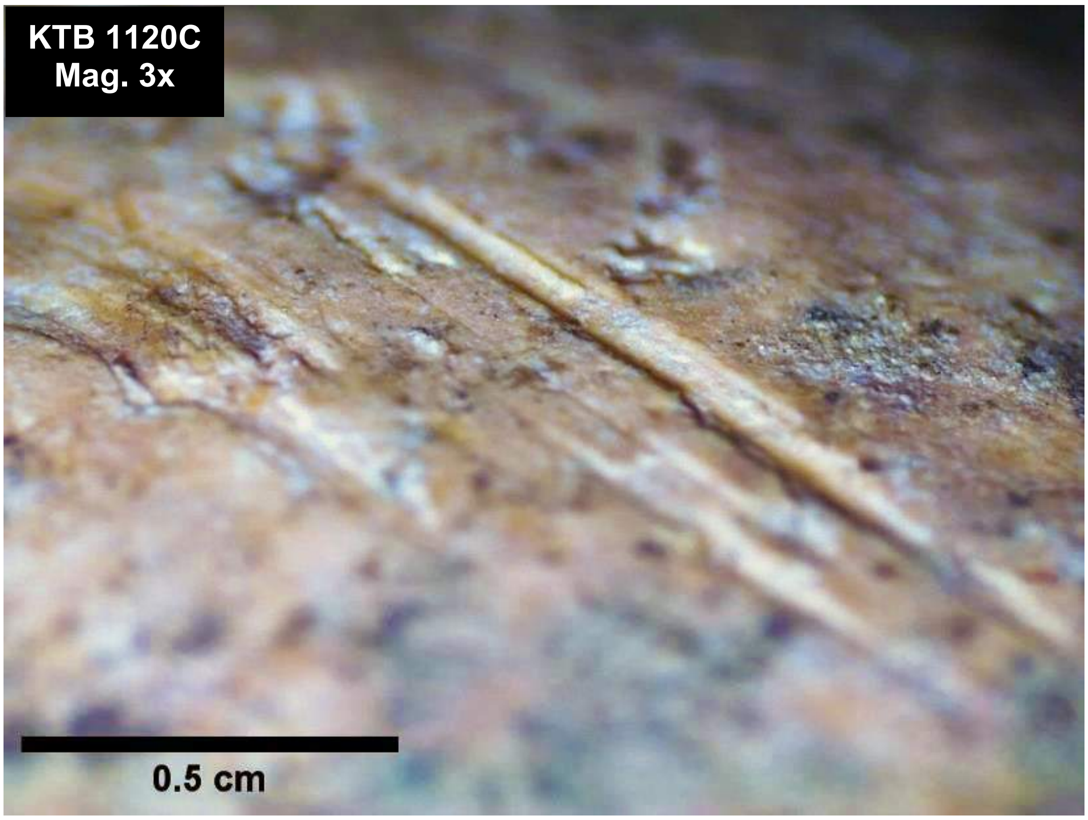


Fig. 45 (b).

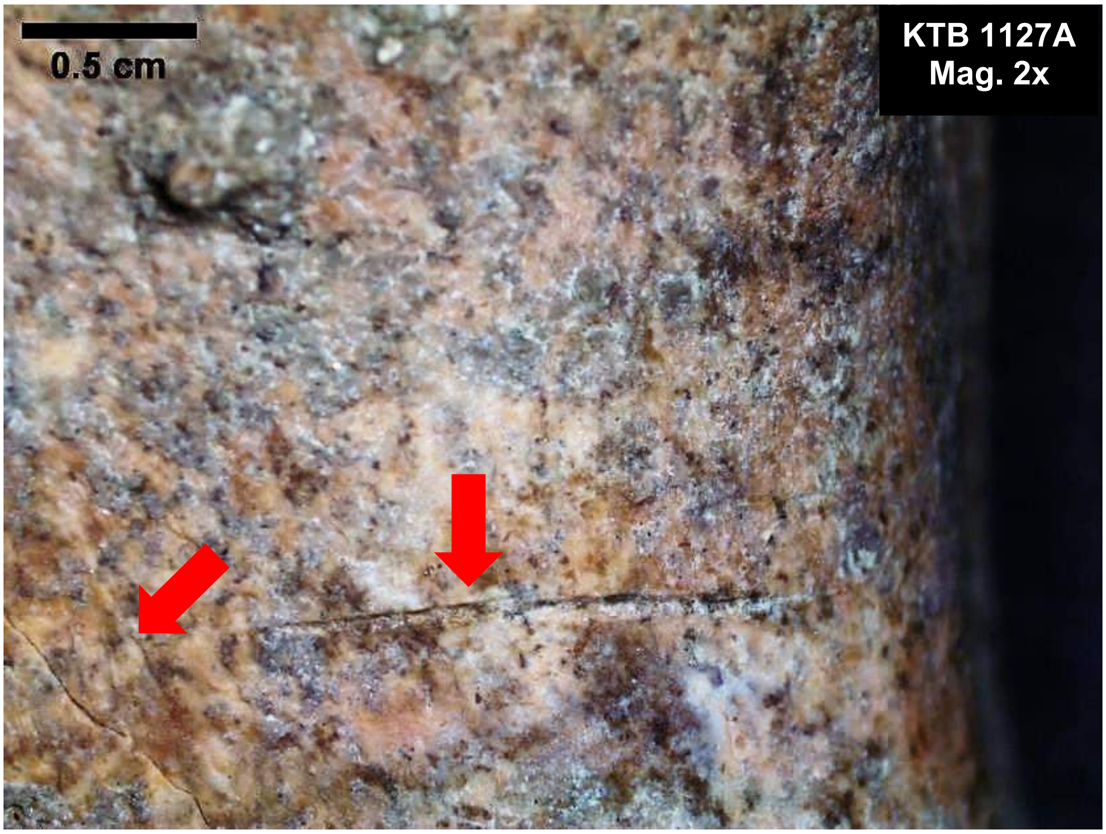


Fig. 46 (a).

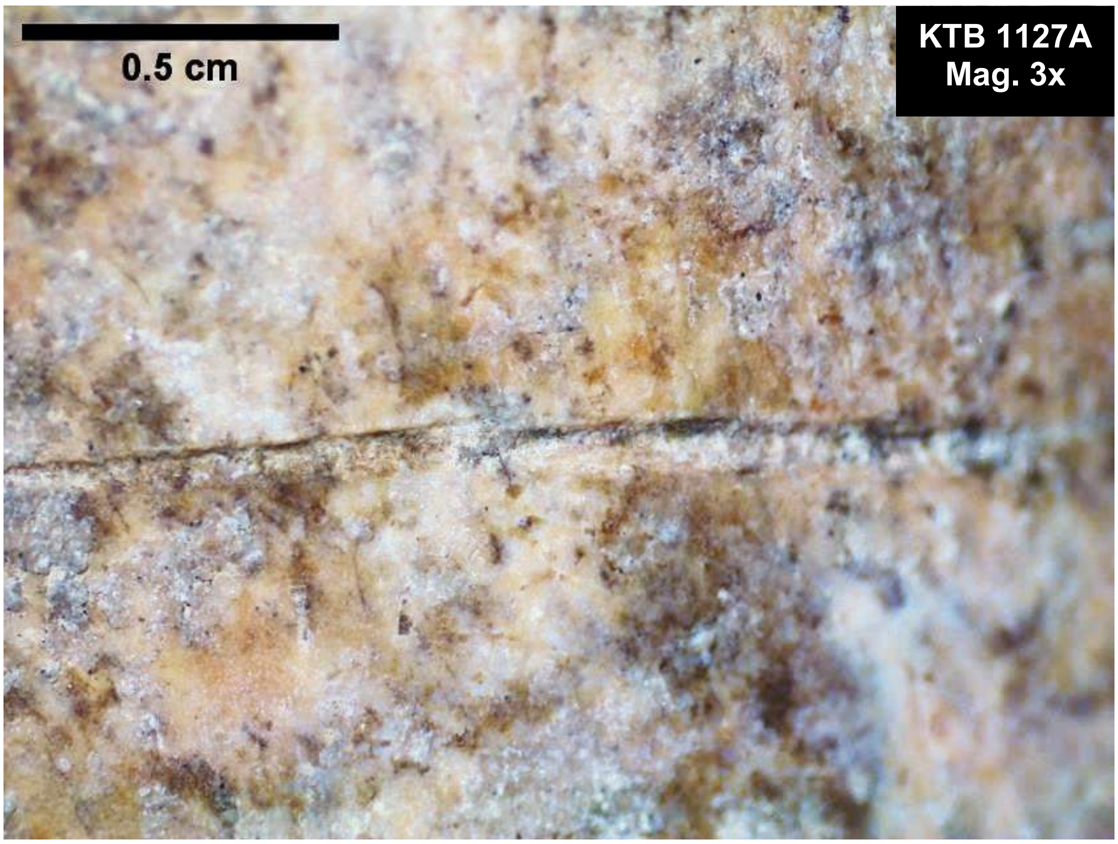


Fig. 46 (b).

Fig. 47 (a).

Fig. 47 (b).

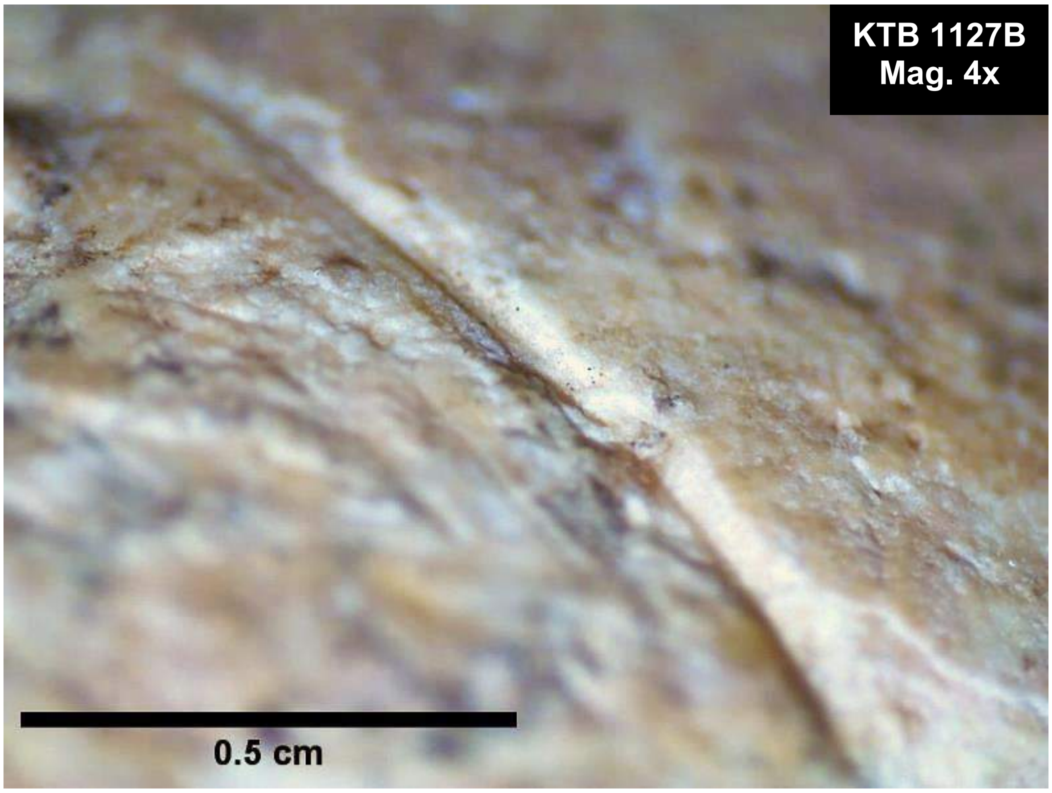


Fig. 47 (c).

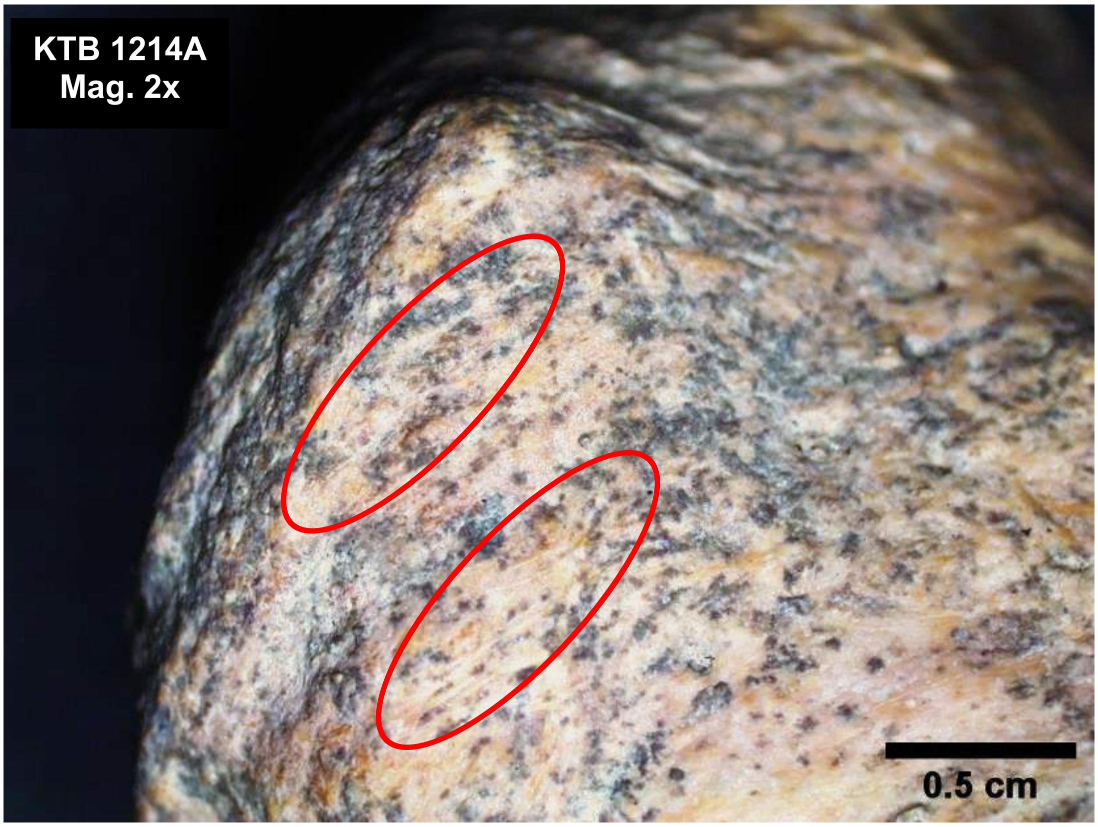


Fig. 48 (a).

Fig. 48 (b).

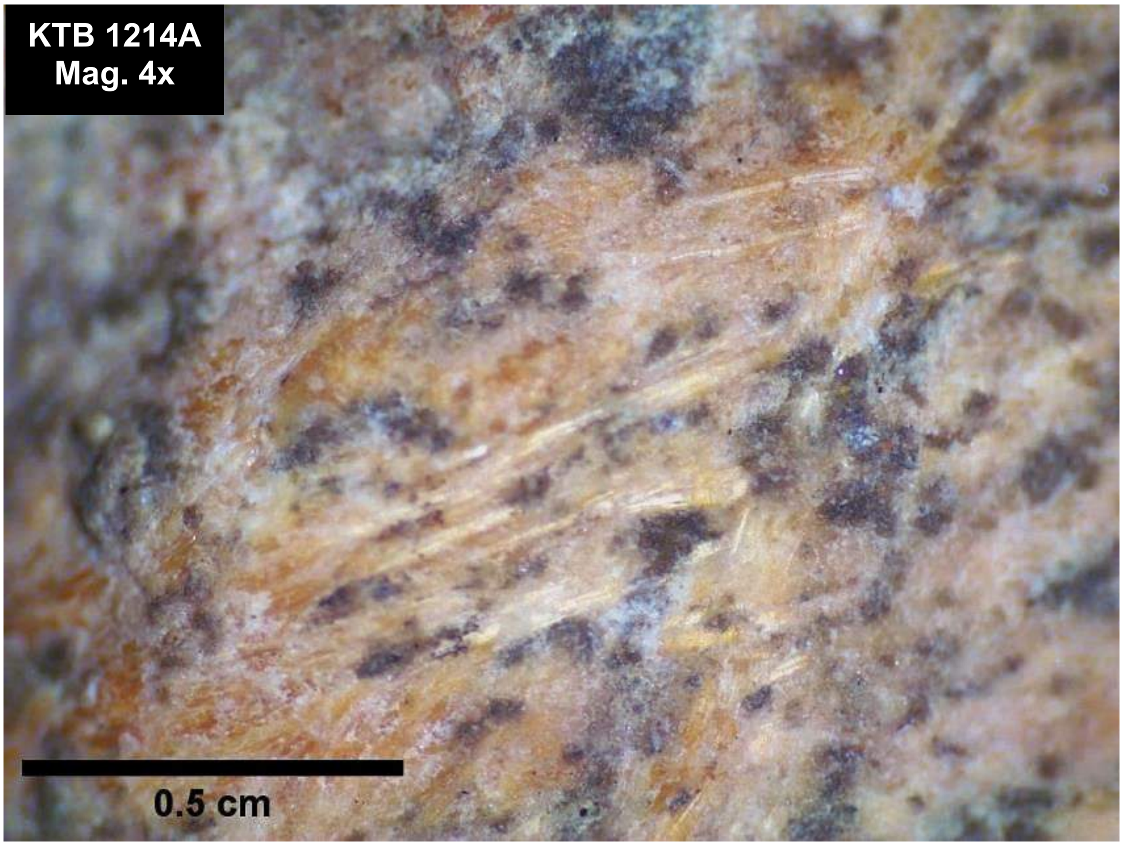


Fig. 48 (c).

Fig. 49 (a).

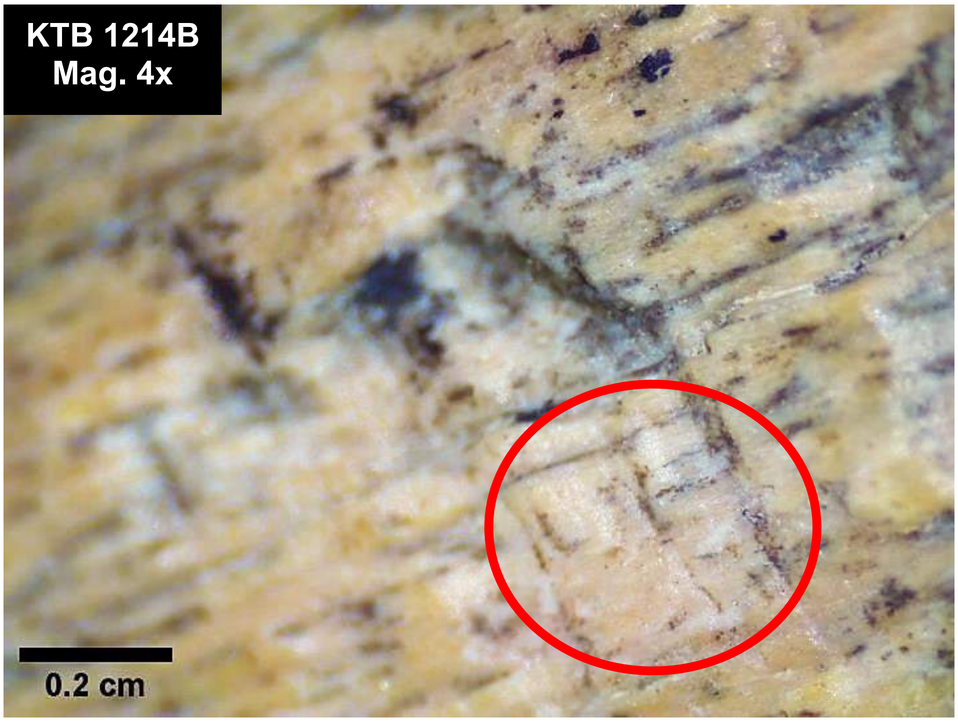


Fig. 49 (b).

Fig. 43, 44 (a)–(b), 45 (a)–(b), 46 (a)–(b), 47 (a)–(c), 48 (a)–(c), 49 (a)–(b) are images of cutmarks on archaeological samples of goat. Some of these appear to be scrape marks, as in **44 (a)–(b)** and **48 (a)–(c)**.

The experimental samples showed cutmarks of various sizes. Some cutmarks were longer than those found on the archaeological samples (~6–12 cm). Most of the cutmarks were jagged and irregular, but a fineness was noticeable in them. The cutmarks made by experimental tools such as jasper were very sharp and narrow, while those made by others were relatively broader and had large grooves.

The experimental samples could only be viewed up to a magnification of 2x, as the samples were too large to be kept stably on the stage. Compared to the cutmarks on the archaeological material, the experimental cutmarks were irregularly placed all over the length of the bone, and had no general directionality. The cutmarks on the buffalo bones were longer and more prominently noticeable as compared to those made on goat bones, which were smaller in size.

Apart from these cutmarks, debris, detergent clumps, and flesh particles were also present on the bone when viewed under the microscope. Images of all these cutmarks were taken with varying lighting and focal adjustments. All cutmarks were given an identification number for ease of familiarity.

S. No.	**Animal**	**Name**	**Length (cm)**
1	Buffalo (humerus)	BHC1	5.2, 5.4, 4.2
2		BHC2	0.88, 0.85
3		BHC3	4.5, 2.3, 1.7, 1.4, 1.9
4		BHC4	1.4, 1.3, 1.2, 1.1
5	Buffalo (ribs)	BRC1	2.4
6		BRC2	3.1
7		BRC3	3.1, 3.3
8		BRC4	3.4
9		BRC5	3.2, 1.5
10		BRC6	3.1
11	Goat (metatarsals)	GMC1	1.9
12		GMC2	2.4, 2.7
13		GMC3	1.4, 1.3, 1.1
14		GMC4	1.2, 1.3
15		GMC5	2, 2.8
16		GMC6	4.9, 3.4, 3.7

Table 7. Length of the cutmarks on experimental samples.

Fig. 50 (a).

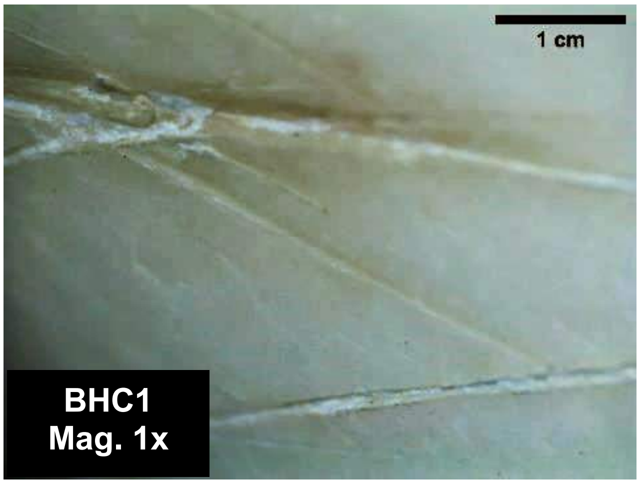


Fig. 50 (b).

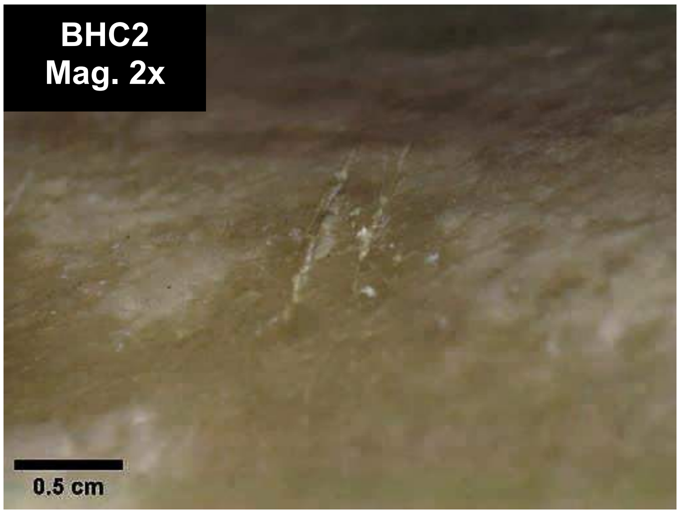


Fig. 51.

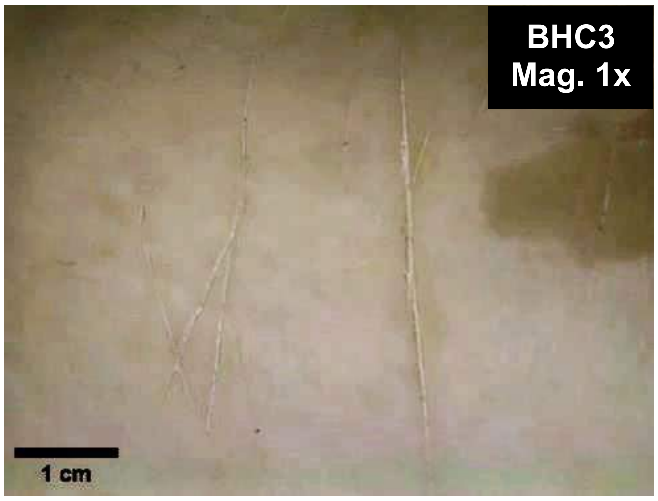


Fig. 52 (a).

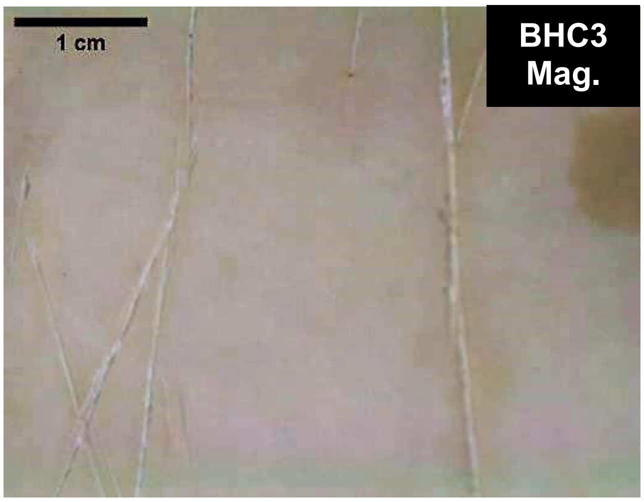


Fig. 52 (b).

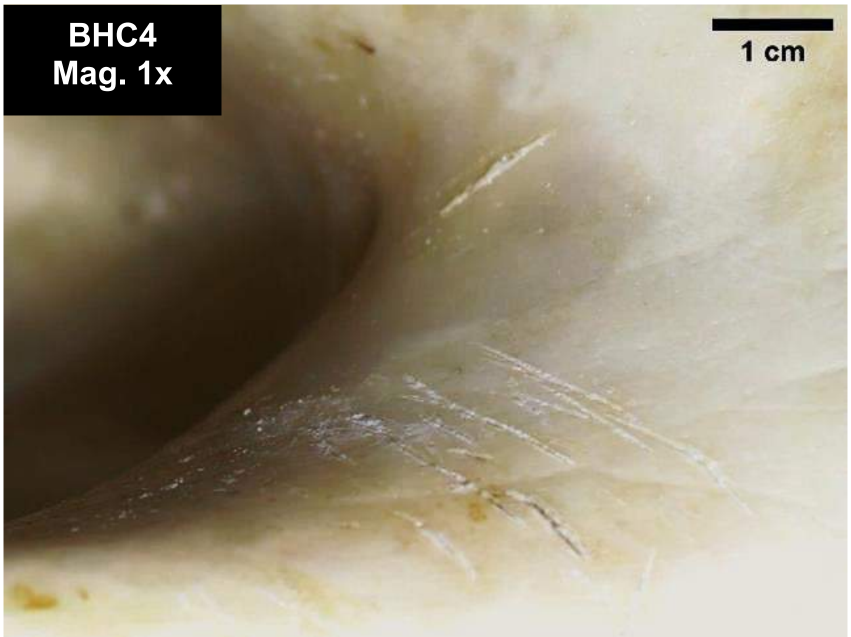


Fig. 53 (a).

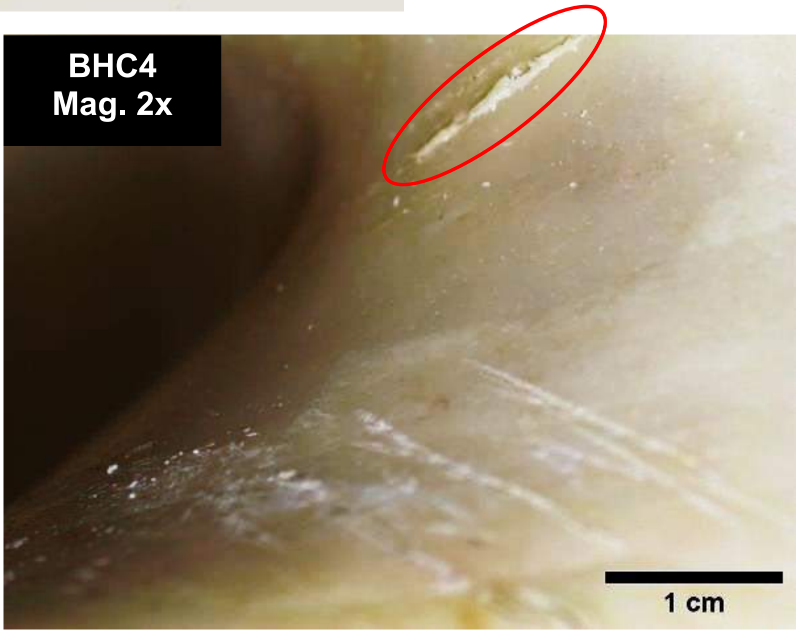


Fig. 53 (b).

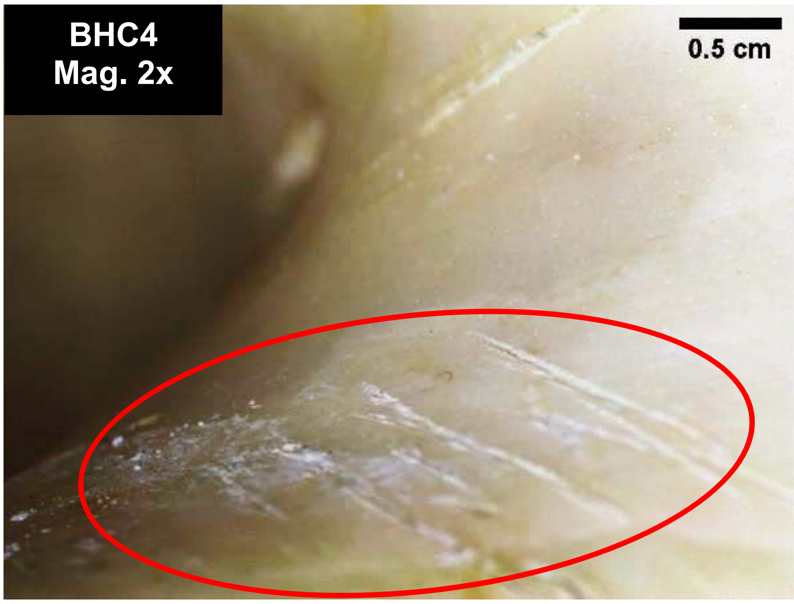


Fig. 53 (c).

Fig. 54 (a).

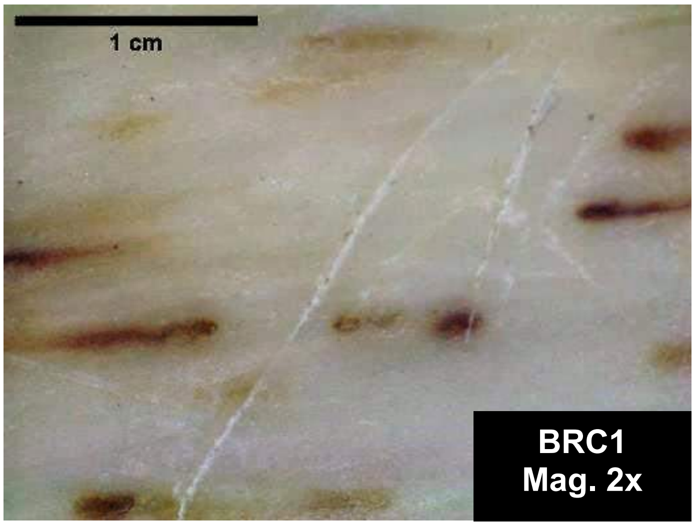
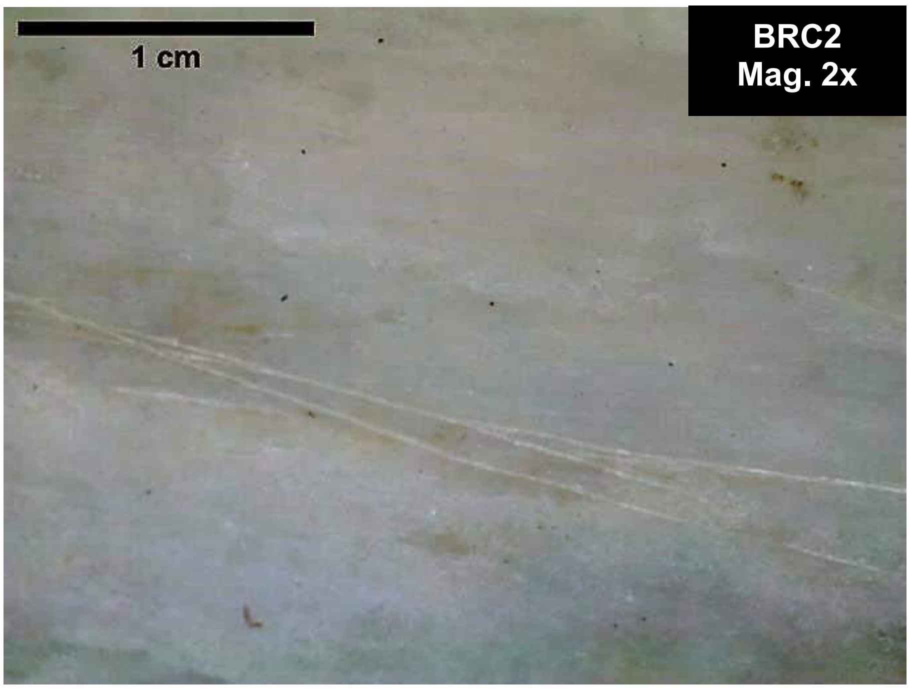


Fig. 54 (b).

Fig. 55.



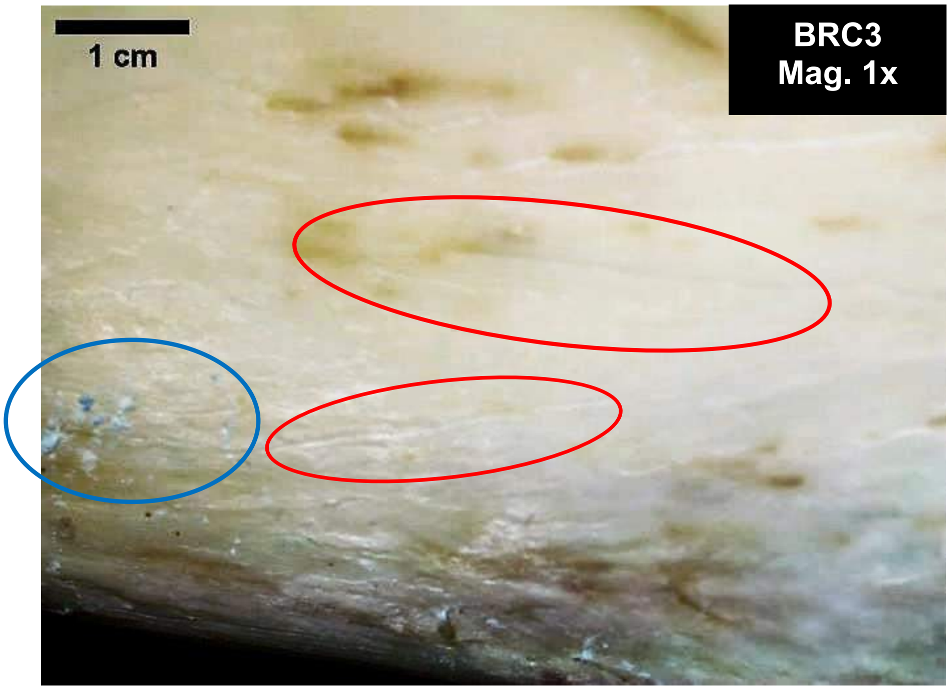


Fig. 56 (a). The area marked by a blue circle shows of detergent stuck to the bone that did not wash off. Red circles show the cutmarks.

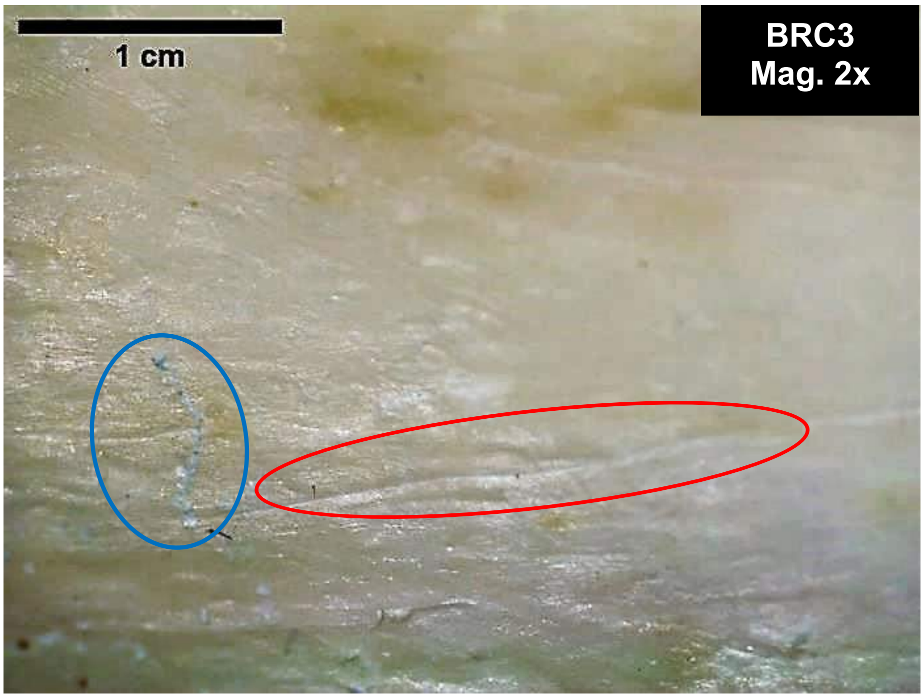


Fig. 56 (b).

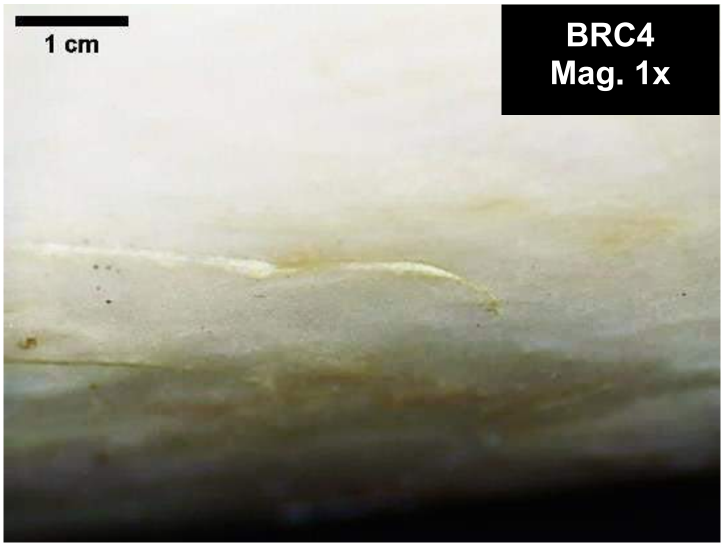


Fig. 57 (a).

Fig. 57 (b).

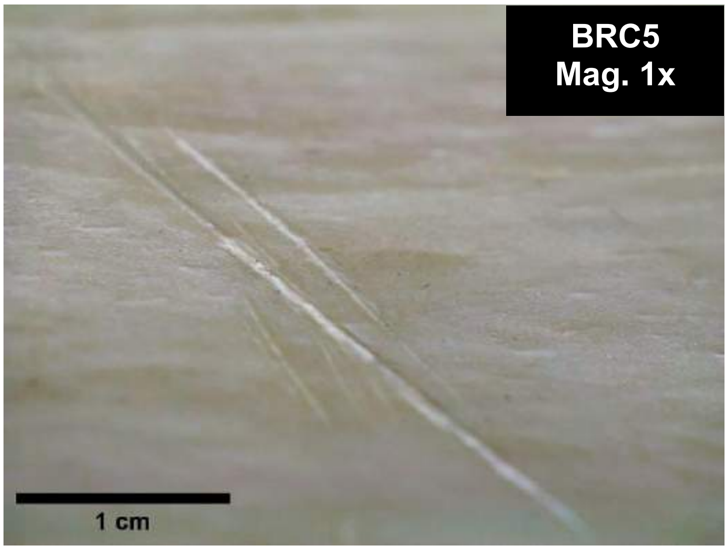


Fig. 58 (a).

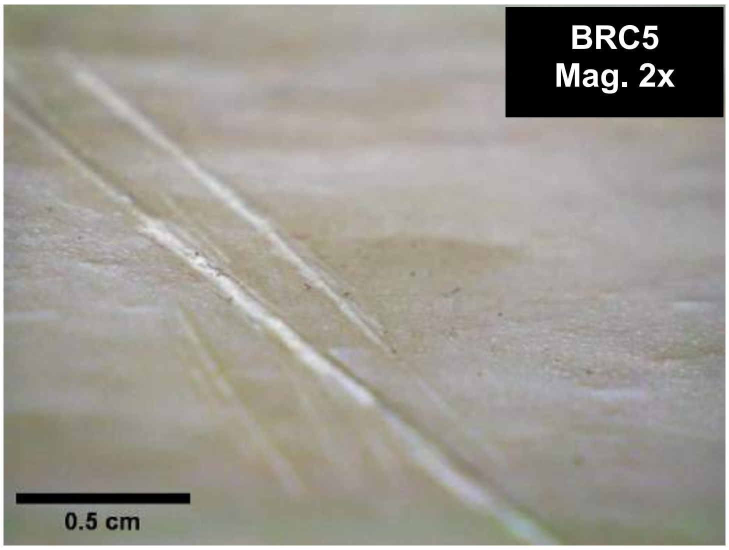


Fig. 58 (b).

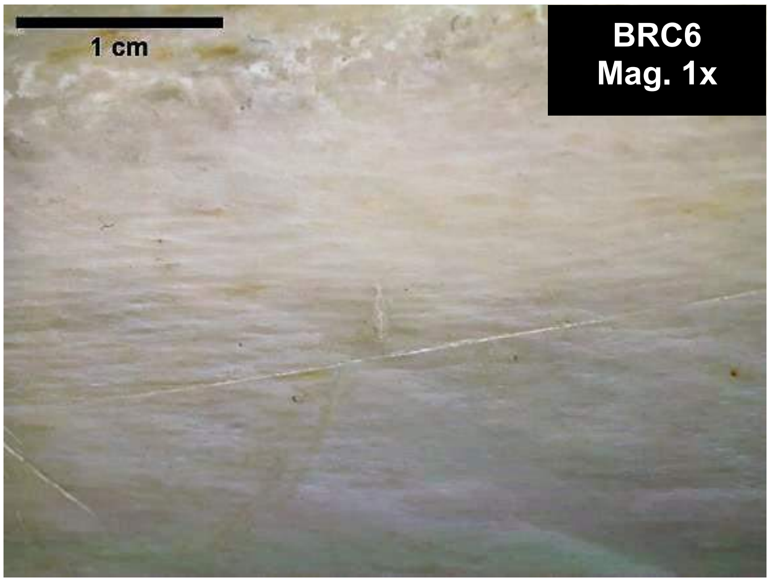


Fig. 59 (a).

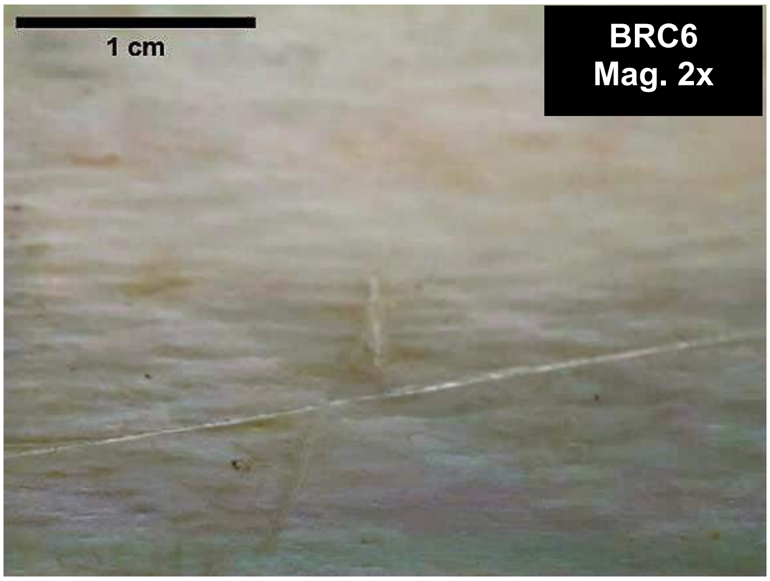


Fig. 59 (b).

Figs. 50 (a)–(b), 51, 52 (a)–(b)-, 53 (a)–(c), 54 (a)–(b), 55, 56 (a)–(b), 57 (a)–(b), 58 (a)–(b), 59 (a)–(b) show experimental cutmarks on buffalo bones. **50 (a)–(b), 51, 52 (a)–(b), 53 (a)–(c),** are from the humerus, **54 (a)–(b), 55, 56 (a)–(b), 57 (a)–(b), 58 (a)–(b), 59 (a)–(b)** are from the ribs.

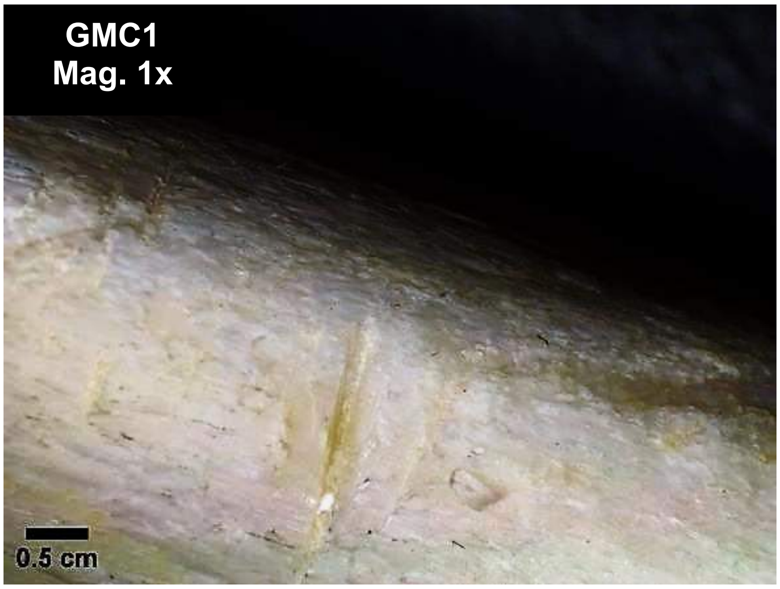


Fig. 60 (a).

Fig. 60 (b).

Fig. 61.

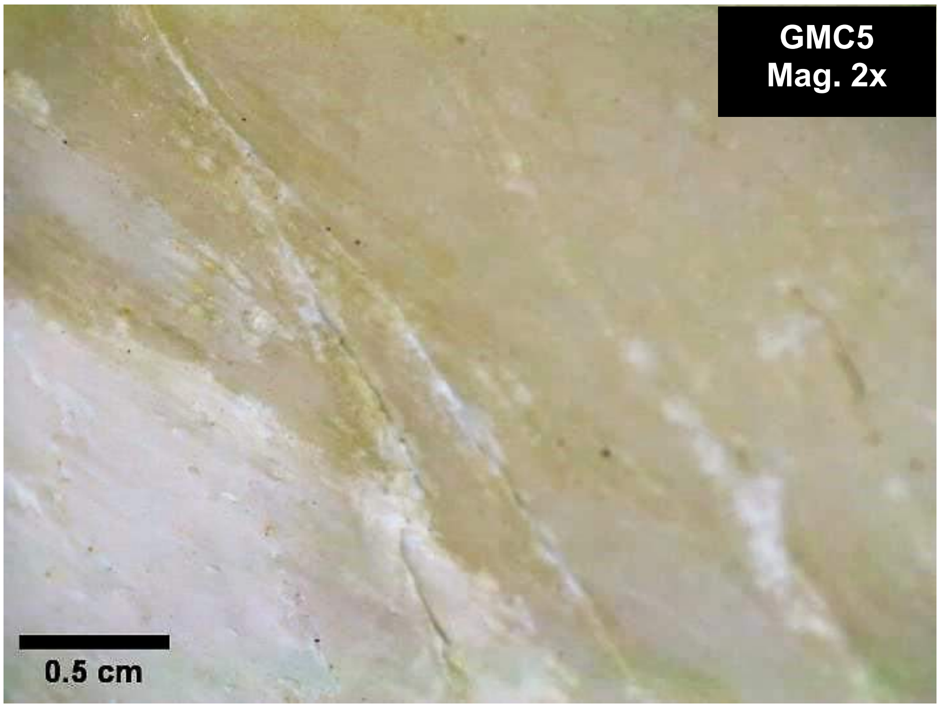


Fig. 62 (a).

Fig. 62 (b).

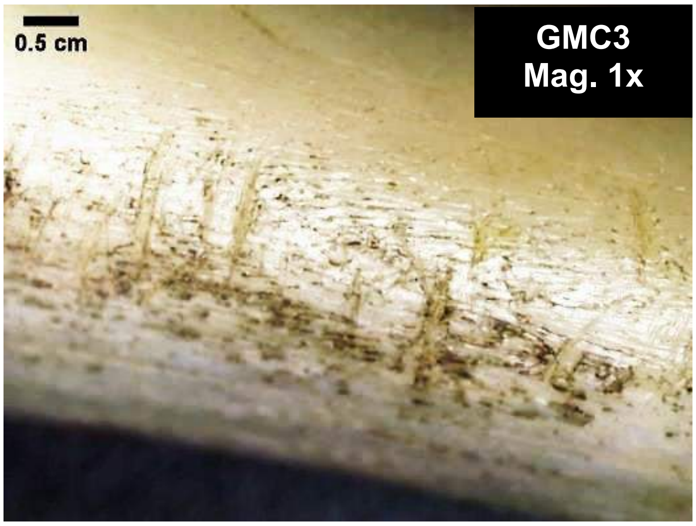


Fig. 63 (a).

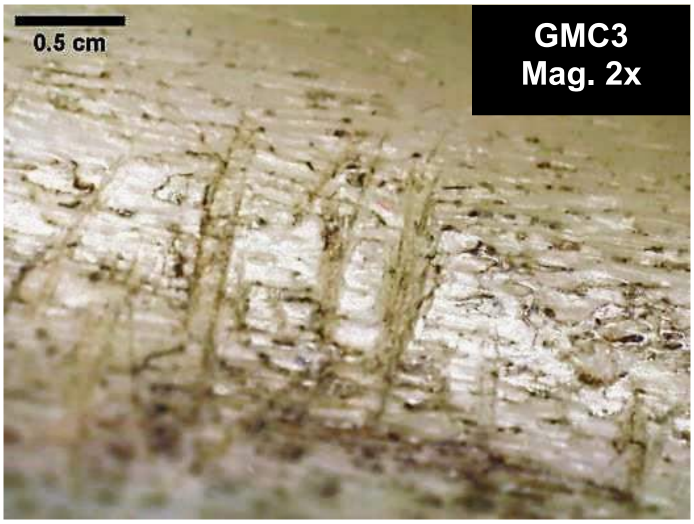


Fig. 63 (b).

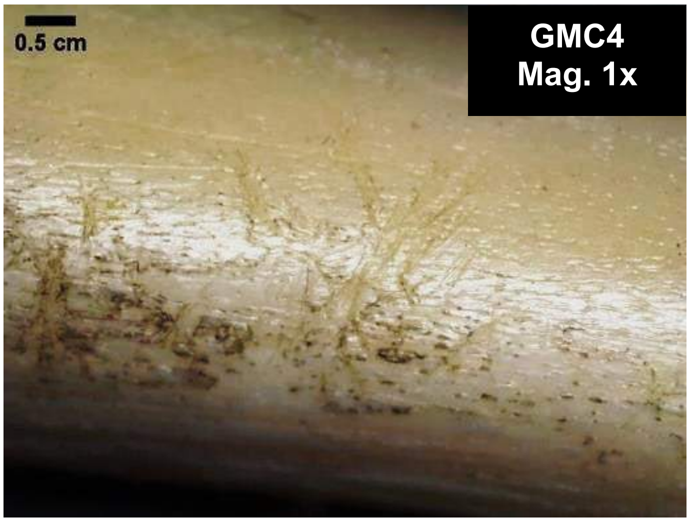


Fig. 64 (a).

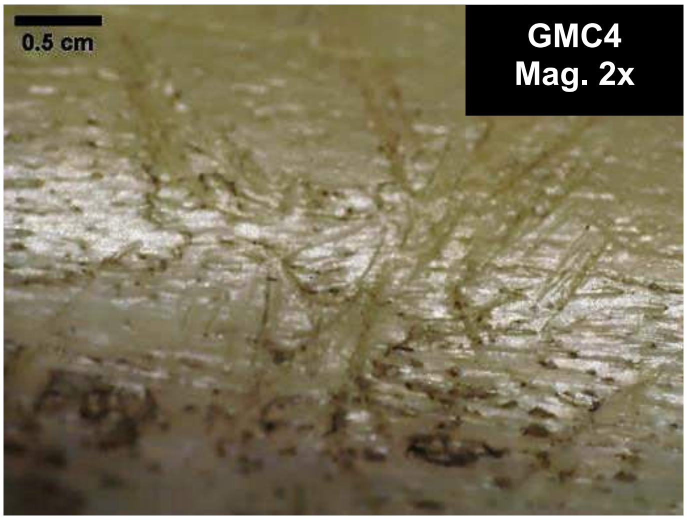


Fig. 64 (b).

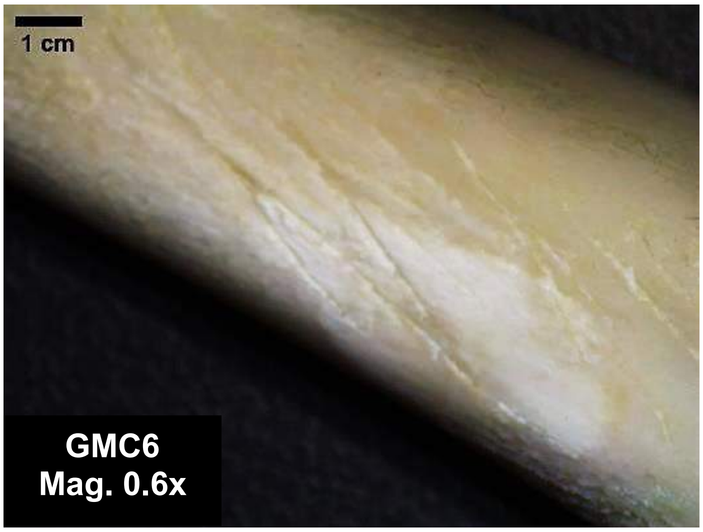


Fig. 65 (a).

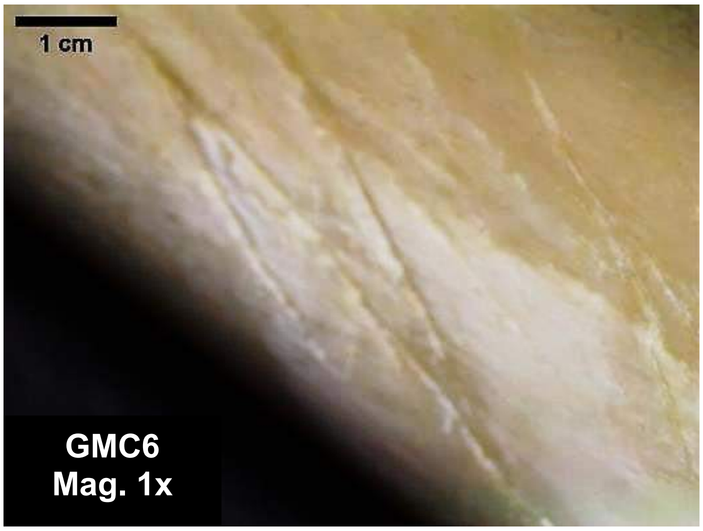


Fig. 65 (b).

Fig. 65 (c).

Figs. 60 (a)–(b), 61, 62 (a)–(b), 63 (a)–(b), 64 (a)–(b), 65 (a)–(c) show experimental cutmarks on goat bones. **63 (a)–(b), 64 (a)–(b)** have dark spots on the cutmarks; these are debris and dirt particles.

Chapter 4: Discussion

From this detailed experiment, it is easy to point out that stone tools used by past hominins were technologically quite advanced for that period, and the skill level and knowledge have an emphasis on this. In the grand evolutionary scheme, stone tool knapping and use are considered to be a big step towards later and modern hominins, gradually leading to hunter-gatherer behaviour, as is proven by ecological evidence (Lombard, 2015; Marlowe, 2005). The material and resources available at the time were especially valuable for tool creation, and still hold significance thousands of years later, as these stone tools can be easily created and replicated using currently available raw materials. While these tools are not as efficient as compared to those made of metal, and since the transition to metal ages (Iron, Bronze, Copper) happened over the course of millennia and was thought to be another technological advancement for hominins, these tools still proved to be the most widely used, over the course of prehistory and history, as the Stone Age was even predicted to have lasted at least 3.4 Ma (Domínguez-Rodrigo et al., 2012; Domínguez-Rodrigo & Alcalá, 2016).

4.1 Experimental stone tools

Some of the experimental stone tools proved to be better for cutting and defleshing of soft tissue. These include the smaller blades and flakes made of jasper and chert (knapped by the experimentalist), and the larger, robust handaxes made of chert and quartzite (made by Vivek Singh of IISER Mohali). These tools provided several advantages in terms of comfort and ease of use, grip ability, time taken to cut soft tissue, and the cutmarks produced on the bone. These tools had sharp edges that could efficiently remove most of the meat from the bone. Meanwhile, the rest of the tools (both made by the experimentalist and the ones made in IISER Mohali) proved relatively inadequate in meat removal and cutting due to their relatively broader edges. These tools could not pierce through the given amount of meat with ease. Due to the small amount of meat procured for the purpose of this experiment, large handaxes and blades could, therefore, not be used to the fullest capacity. However, they can be used for the butchery of entire animal carcasses, as the area of work is large, and the amount of meat that can be defleshed is more significant in quantity. Experimental archaeologists have done this in the past in multiple seminal studies (Dewbury & Russell, 2006; Boschin & Crezzini, 2011; de Juana et al., 2010), proving the vast array of proficiency that stone tools possess.

Of all the stone tools used, jasper demonstrated to be the best raw material for meat cutting. The edge of the blade is very sharp and can be easily manipulated by the butcher to remove the soft tissue from the bone. Experimental tools of jasper in various sizes made by the experimentalist were used thoroughly throughout the defleshing process due to the favorable output. The only reasons why these particular jasper blades and flakes proved to be disadvantageous to the butcher were:

- The small size of the experimental tools. Due to the initial raw material used to create these tools being small in size, the yielded blades and flakes were at most ~9 cm in length and hence proved to be slightly tricky to hold.
- The sharp edges of the tools produced. Apart from the cutting edge, the gripping area of the tools also had sharp regions, which could be dangerous to handle without proper precautions.

If a large enough raw material were to be used and stone tools knapped from it, these jasper stone tools could easily be the best defleshing tools among all the raw materials used. For the purpose of this experiment and due to the unavailability and difficulty in handling the raw material, large blades and flakes could not be created. Further experimental butchery needs to be performed using larger handaxes made of jasper to confirm its versatility and hardiness.

Metal tools, if used in place of these experimentally knapped tools, would definitely prove to be more effective. This has been shown in studies such as those of Greenfield (1999) and Boschin & Crezzini (2011). Prior to the actual butchery experiment, the meat had been separately butchered using a metal knife. This led to the fragmentation of several of the bones procured, such as those of buffalo ribs and goat metatarsals. It is evidently clear that the experimental stone tools used in this experiment could not have produced these fragments due to the relatively brittle and delicate nature of the raw material compared to metal. However, upon using one of the larger experimental handaxes and on application of enough force, fragmentation of bones can be achieved, although the breakage will be less clean and even as produced by metal blades. This is the case with many case studies of the past, where several fragmented bones have been excavated from sites, suggestive of hominins' robust use of stone tools in the past (Bello et al., 2009; Blasco et al., 2019; Goyal et al., 2018; Deshpande-Mukherjee et al., 2014).

Cutmarks produced by different tools varied remarkably. Sharp tools such as jasper and chert produced thin, narrow, long, and irregular cuts (e.g., see figs. 50 (a), (b), 52 (a), (b), 55, 60 (a), (b)). These differed significantly from those produced by relatively duller tools, which had broader, more numerous strokes, and cutmarks were short, reasonably regular and linear but easily visible under the naked eye (e.g., see figs. 58 (a), (b), 65 (a)–(c)). Therefore, cutmarks can be distinguished based on the tools used, and this data can be extrapolated to the archaeological samples, thus predicting the morphology of the tool used in the past. This is evident even from pioneering studies produced by Bello et al. (2009), Domínguez-Rodrigo et al. (2005), and Kolobova et al. (2022).

4.2 Butchery and bone preparation

Butchery of the meat resulted in the successful removal of the soft tissue from the bones. One hindrance during the defleshing process was the toughness of the meat. This is due to rigor mortis setting in the flesh of the animal. Rigor mortis is a change that occurs after the death of an animal, resulting in the stiffening of the body's muscles due to chemical changes transpiring in the flesh. This concept is generally used in forensic sciences to determine the time of death of the body (Gill & Landi, 2011). Due to the prolonged length of time between the death of the animal and the time when the defleshing of the bones was carried out, this process was a cause for the delayed and labored effort to cut through the soft tissue, thus posing a challenge for the experimental stone tools.

While the soft tissues were sizably extracted from the bones via experimental butchery, much cartilage remained stuck to the samples. Post-processing, more of it was able to be removed, yet a visible amount of cartilage was still present (see figs. 27 (b), 28 (a)). The bone processing method used for this experiment was simple boiling of the bones in a water-baking soda solution for an hour. Although a quick procedure to remove loose bits and fragments from bones, it is not entirely effective in removing all the soft material. Long-term processes, such as soil burial, and even stronger techniques, such as chemical treatments or the use of live insects such as dermestid beetles, would have efficiently removed all material and left behind just the bones. Due to the duration of this experiment being short for the purpose of completing this thesis, it was not feasible to take the approaches as mentioned earlier, and thus boiling was the best and quickest alternative.

4.3 Archaeological sample analysis, microscopy, and comparison between cutmarks on experimental samples versus archaeological samples

All microscopy images of the cutmarks reveal essential data and insights. The archaeological samples showed remarkable features of taphonomy and anthropogenic intervention on the bone specimens. However, some of these samples showed no sign of cutmarks on the bone surface. This absence was due to encrustation — the setting down and accretion of sediments on the bone layer due to prolonged burial and the occurrence of constant geological processes (de Sousa et al., 2020). This deposition of the sediment layer made it difficult for the experimentalist to observe any data and make inferences.

A preliminary observation of the archaeological samples provides some insights into the bones' past. Most of the cutmarks on these fossils were present towards the joints, indicating the removal of flesh and cartilage from these regions. The observable data shows that skilled individuals made these cutmarks, as the cuts are clean, precise, and regular. Many cutmarks had deep, linear grooves, suggesting the use of a large force and a robust tool (possibly metal or a hard, sharp stone handaxe). Some cutmarks show a repetition of strokes, which imply a to-and-fro motion used by the past butcher.

After preparing the bones, a preliminary analysis showed the placement of cutmarks. Most cutmarks were localized near the ends (closer to the joints) as cartilage is generally more prominent here, and thus required more force from the tool on the bone, leaving behind several noticeable marks (see figs. 53 (a)–(c)).Comparing the archaeological cutmarks to experimental cutmarks, it is evident that there is an apparent difference in skill level, with the experimentalist being a novice butcher and making relatively sloppy, haphazard cutmarks on the bone. The archaeological samples show that the past butcher possibly had an intricate knowledge of the animal's anatomy and had made exact, measured cuts to remove the flesh from the bones. Due to the differences in skill level, it is also noticeable that the cutmarks made in the past had more force applied to the bone, unlike the experimental bones. However, it is challenging to comment on the time of the butchery of the animal carcass and whether the meat was removed from a fresh carcass. The length of the cutmarks, too, were starkly different, with the experimental samples having measurably longer cutmarks than the archaeological samples.

Most of the grooves of the cutmarks formed are comparable to those made by metal tools, which is supported by the use of metal during the time to which these bones belong (Wright, 2009). Metal blades have been known to have existed during the Harappan period, but there is also evidence of stone tools being used during this span (Soni, 2011), indicating the possible use of both or either of the tools. Some of the cutmarks on these bones resemble those made by experimental stone tools on the experimental bone samples (see figs. 48(a)–(c)). This unique observation could be a glimpse into a transitionary period — from a Late Stone Age to an early Bronze Age (Wright, 2009). Some of the cutmarks even appear to be scrape marks (see fig. 44 (a), (b)); given that they were observable closer to the connecting regions (near joints), these were likely made to remove cartilage from that part of the bone. Further analysis is required to confirm these observations and to better understand the underlying reasons for these points.

The site of Kotada Bhadli, where these archaeological samples were excavated, belonged to the Late Mature Harappan period, based on material found from there (Goyal et al., 2018). This places a date range of 2300–2100 BCE (Shirvalkar & Rawat, 2012-13, p. 77, as cited in Goyal et al., 2018). Harappans have been known to have emerged around 2600 BCE, and this site falls neatly into what is known as the "Mature Harappan phase", i.e., 2600–1900 BCE (UNESCO World Heritage Convention, 2004). Harappa was essentially a Bronze Age civilization, with evidence suggesting the widespread use of metal tools (Kenoyer & Miller, 1999). However, with works such as that of Soni (2011) and Kenoyer & Miller (1999), it is likely that Harappans possibly used both stone and metal tools at the same time period. Thus, the faunal remains excavated from the site showing taphonomic marks of butchery could have been butchered with both tool types, as can also be seen by comparing the cutmarks with those on the experimental bone samples.

Since a stereomicroscope was used for the purpose of this experiment, there could be biases in the observations and deliberations put out in terms of understanding and analyzing both archaeological and experimental cutmarks. More investigative studies need to be performed using higher-grade microscopes, such as scanning electron microscopes (SEM) and environmental scanning electron microscopes (ESEM), which have been known to be used in studies of these kinds and have provided better image qualities and views of the cutmark morphology.

Conclusion

In this thesis, the experimentalist performed butchery of buffalo and goat meat using stone tools knapped by himself and a PhD student of the supervisor. An extensive literature review was conducted before the experiment to understand the subject's current knowledge bank and contextualize this study's purpose. The bones, procured from a local butcher shop, were defleshed of as much meat as possible through the use of various experimental stone tools, and then later prepared by boiling for further microscopic analysis. Cutmark data was collected from archaeological samples excavated from a Harappan site and compared with experimental cutmarks. All cutmarks were studied using a Leica© S9i stereomicroscope, and images were taken for study.

The following points briefly summarize the entire procedure and experience of the work done so far:

- The experimentalist is a novice in the field and, for the purposes of this experiment, had to refer to several bodies of work and read the current literature to get an understanding of the field. Before beginning with stone tool knapping, familiarity with raw material, tool handling, and the method of tool creation had to be self-taught, and he has been successful at it.
- Experimentally knapped stone tools that were received from sources other than the ones created by the experimentalist provided a reference for him to compare the tools he generated. The manner in which the experimentalist knapped the tools versus those produced by other individuals must have involved skill and background, to which the novice had only now been introduced.
- Acquisition of the meat samples for this experiment would have ideally been for the entire animal carcass, but due to the feasibility of transportation and limited availability of resources and workforce, this task could not be undertaken and thus had to have resorted to individual parts of the animal. Since the experimentalist was alone in this venture, the outcome of a larger group working on the butchery of entire carcasses is yet to be seen in the future.
- Archaeological samples obtained from Deccan College, Pune, also came with the purpose of learning the preparation of such specimens before carrying out any analysis.

The experimentalist duly performed all the required tasks over the duration spent in the laboratory at the institute.

- The experimentalist began with the aim to work alongside potential butchers who could pose as experts in the defleshing process, which would have provided insightful data into the ethnography of the practice, but due to several constraints, it could not be pursued. Such a “social” experiment is yet to be seen in literature and can be pursued in future investigations.

The cutmarks produced experimentally differed from those seen on the archaeological samples in terms of skill proficiency, positioning, type of tool used, and morphology of the cutmarks. Those found on the Holocene samples were much less densely packed than those on the experimental specimens. It is noteworthy to mention that cutmarks are not always easily distinguishable; while a general reference does exist in the literature thanks to the contributions of several studies that have also been touched upon earlier (Boschin & Crezzini, 2011; Moretti et al., 2015), without such databases existing this task would be pretty challenging. Comparing and observing cutmarks on such samples is being improved to better distinguish them and how they might have been formed in the first place (Cifuentes-Alcobendas & Domínguez-Rodrigo, 2019; Cifuentes-Alcobendas & Domínguez-Rodrigo, 2021).

The cutmarks on the archaeological samples suggested the possible use of stone and metal tools for butchery, given the period in which they were situated. All these results further surmount to understand how the practice of butchery has transformed over the course of several thousand years, and predictions can be made on the proficiency of the past butcher, the choice of tool used, and the evolution in the technological advancement of the Harappans that lived in the past.

While the experimental samples had clean surfaces to view and analyze, the encrustation on the Holocene samples, as discussed earlier, proved to be a significant hindrance to studying cutmarks. This leaves out a large amount of data to be lost due to weathering and natural causes, which is a common issue when it comes to studying such specimens of archaeological importance.

Another question to ponder is the manner in which the meat is procured, i.e. either by purchasing from a vendor or by hunting in the wild. While the former has advantages in terms of convenience, and the latter is a risky endeavor due to several ethical and ecological issues that could arise, with the correct method and under all legalities, it is worthwhile to pursue this goal, as the data that could be obtained from it would be valuable to understand not just the practice of butchery but also to recreate a hunter-gatherer practice and the techniques that might have been deployed to cull the animal. This type of study thus furnishes the knowledge of the dynamic relationship that hominins had with their environment.

Therefore, this study lays one of the foundation stones for further research in the area, particularly to study the comparison between butchery skills (a novice versus an expert butcher) and its implications for tool use and how the same can be compared to past data on hominins. Understanding how butchery was performed in the past provides a glimpse into how technologies advance and change over time and thus also has implications for actualistic and ethnographic studies in the field, especially in the Indian context.

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Appendix

Minutes of the Meeting
(IEC IISER Mohali meeting held on 6th December 2022)

The meeting of Institutional Ethics Committee, IISER, Mohali was held in a hybrid mode on 6th December 2022 at ll:00 AM. The meeting was chaired by Prof. Pallab Ray (PGIMER, Chandigarh) and the following members were in attendance.

Prof. Anand Bachhawat (IISER, Mohali), Prof. Shyam Sunder Sharma (NIPER, Mohali), Mr Shirish Gupta (Advocate), Dr Gurpreet Singh (Medical Officer, IISER, Mohali), Dr Samrat Mukhopadhyay (HoD, Biology, IISER, Mohali), Dr Sarmistha Sinha (INST, Mohali), Dr Neeraj Khatri (IMTECH, Chandigarh), Dr Sharvan Sehrawat (Alternate Member Secretary), Prof. R. Vijaya Anand (Dean R and D, IISER, Mohali and Member Secretary).

Prof. R. Vijaya Anand, Member Secretary, welcomed and thanked all the members for joining the meeting. The following agenda items were discussed and resolved:

1. The signed-in-confidentiality forms were obtained from all the members.
2. The committee stressed on the point that the IEC needs to be registered with the department of Health and Research and deliberated upon the requirements for the same.
3. It was also resolved that the submitted projects could be discussed and if approved, the approval letter can be issued to the PIs contingent upon the registration of the IEC with the department of Health and Research.
4. It was also resolved that the revised consent letter by the respective PIs need to be resubmitted and circulated to the members of the committee for scrutiny.
5. The protocols submitted by different investigators were evaluated and discussed with the following recommendations.

Protocols:

Project Title: An exploratory study of experimental cut marks on mammalian bones and its implications for understanding tool selection & butchery skill in prehistory

Submitted by: Parth R. Chauhan & Ningnung Jakoinao (ID 20181143, IISER Pune)
Recommendation: Approved

The meeting ended with a vote of thanks by Prof R. Vijaya Anand, Member Secretary.

Prof R. Vijaya Anand (Dean R&D, Member Secretary)

Dr Shaman Sehrawat (Alternate Member Secretary) 9.1.23

Dr Samrat Mukhopadhyay

Prof Anand Bachhawat

Dr Gurpreet Singh

Prof Shyam Sunder Sharma

Dr Sarmistha Sinha

Dr Neeraj Khatri

Mr Sirish Gupta

Prof Pallab Ray (Chairperson)