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A Multi-Method Approach to Understanding Prehistoric Bone Tools

Doctor of Philosophy (DPhil) in Archaeology

'Physical evidence cannot be wrong, it cannot perjure itself, it cannot be wholly absent. Only human failure to find it, study and understand it, can diminish its value'.

Paul Kirk on the Locard Exchange Principle, 1953

'*The tools of the basket-maker are of the simplest character. But the one tool that is never absent is the bone awl or stiletto, which is useful with every type of manufacture, and is ever present in the graves of primitive women'.*

O.T Mason as quoted in G.W. James, 1904

This thesis is dedicated to Jane Desmond and Julius Koll

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Abstract

It is the task of archaeologists to account for a wide range of cultural practises and processes using a limited range of surviving artefacts and features. In Palaeolithic contexts, organic materials such as leather goods (bags/pouches, shoes, clothing, slings, etc.) and woven fibre artefacts (baskets, cordage, textiles, etc.) are vastly underrepresented (Croes 1997, Soffer et al. 2000, Taylor 1966). How, then, can archaeologists working in great time depths account for artefacts crafted from leather and/or plant materials? One approach is the systematic examination of osseous tools: a preferred tool material for perishable craft production in cultures around the world.

The aims of the following research were to apply new or novel inductive methods to prehistoric bone tools, in order to gain an enhanced understanding of their place(s) within the cultural repertoire of prehistoric groups, with an emphasis on perishable craft production. The basis for these analyses are bone tools from the North African Palaeolithic site of Taforalt, and ethnographic bone tools housed at the Phoebe A. Hearst Museum of Anthropology (PAHMA) and at the Pitt Rivers Museum (PRM). Investigations were organised using a *chaîne opératoire* approach (Leroi-Gourhan 1964, 1968). This approach encompasses the technical processes of bone tool creation and use, the tasks the bone tools were used to perform (and products they were used to produce), and ways in which information about bone tools can be shared in reproducible, high-fidelity formats.

In the broadest sense, these methods have illuminated a number of formerly unknown cultural strategies and capacities among the Palaeolithic inhabitants of Taforalt. By studying bone tools from Taforalt, it was possible to understand intentionality in raw material selection, to see an emphasis on the creation of small, thin pointed tools, and to

gain proxy evidence for coiled basketry production in the absence of the baskets themselves. These baskets, in turn, likely supported the collection, processing, cooking, and storage of food resources such as acorns, pine nuts, and snails. Crafted technologies would have enabled the population at Taforalt to maintain reliable food sources irrespective of seasonality, and to support an expanding population, in turn enabling people to continue to develop specialised cultural roles and technological forms.

The ultimate goal of this research has been to understand whether bone tools can be used as proxy stand-ins for activities, technologies, and people who are otherwise archaeologically imperceptible, especially in the remote past. The following studies show that these methods, when applied to bone tools, can successfully scaffold a more nuanced understanding of prehistoric lifeways, and in particular, perishable craft production.

1 Introduction

Osseous tools have been used by hominid species for millions of years, and occur in prehistoric archaeological contexts worldwide (e.g., Backwell and D'Errico 2001, Biddittu and Celletti 2001, Bouzouggar et al. 2019, Brain 1993, Mania 1962, Tourloukis et al. 2019, Yellen et al. 1995, Yizraeli 1967). However, in the archaeology of the eponymous 'Stone Age,' it is lithic industries which serve as benchmarks for human technological development. Because lithics are often the only technologies which survive after thousands of years, study of these tools has emphasised the roles of hunting and animal processing strategies in the Palaeolithic. Other cultural roles and technological forms remain more difficult to account for, and are sometimes deemed 'archaeologically invisible'. Osseous tools offer new avenues for understanding technological and cultural complexity in the remote past, and can provide evidence for a greater breadth of activities and actors in deep time. This research has specifically focused on understanding bone tools and their connections with perishable crafting practises in the North African Later Stone Age (LSA).

The aim of the following research was to develop novel approaches for understanding bone tools from prehistoric archaeological contexts. These studies take the form of a multi-method *chaîne opératoire* protocol, aimed at examining different chronological stages of bone tools' creation, use, and deposition. I have taken a Middle Range theoretical approach to developing an analytical programme. Specifically, I have sought to develop an

> ...accurate means of identification, and good instruments for measuring specified properties of past cultural systems.....seeking to build a paradigmatic frame of

> reference for giving meaning to selected characteristics of the archaeological record through a theoretically grounded body of research, rather than accepting folk knowledge - let alone implicit folk knowledge - as the basis for describing the past (Binford 2014:25).

Using this framework has meant asking what bone tools can tell us about prehistoric archaeological cultures, examining the scope and limitations of extant research methods, and developing methods that have the potential to fill-in gaps in our knowledge.

Papers 1-3 have as their basis archaeological material from the site of Taforalt Cave, representing the largest bone tool technocomplex from the North African LSA recovered to-date. Taforalt Cave contains archaeological deposits from the Iberomaurusian (an LSA culture), and illustrates a shift from seasonal itinerancy to reduced mobility and sedentism (Barton et al. 2019). Owing to the excellent preservation of archaeological materials on-site, researchers have an opportunity to examine emergent social and technological strategies which accompanied this shift. At the beginning of this research, the bone tools were largely unstudied and little was known about the role of these tools among the Iberomaurusians at Taforalt. As the results will show, the systematic study of bone tools using these methods has evidenced advanced perishable crafting strategies, suggested the presence of aesthetic conventions, and the potential for emergent role specialisation in the North African Palaeolithic. Ethnographic bone tool collections from the Phoebe A. Hearst Museum of Anthropology (PAHMA) in Berkeley, California, and the Pitt Rivers Museum (PRM) in Oxford were analysed (**Paper 3)**. Comparative analyses indicate that a subset of bone tools from Taforalt show use-traces consistent with those appearing on ethnographic bone tools used to create coiled basketry.

I have arranged the following papers in the order of the *chaîne opératoire* stage which they address, rather than in the order of publication. Broadly, these stages consist of initial taxa selection (in which raw material/bones are selected and formed into a tool [**Paper 1**]), typology (in which overall formal or morphological correspondences between tools are considered on an intra-assemblage basis [**Paper 2**]), determination of use (here based on use-trace analyses [**Paper 3**]), and reproducibility in use-trace analysis (**Paper 4**). These stages are largely heuristic, and naturally inform one another. However, a diachronic assessment of bone tool creation and use allows researchers to understand these tools in a more dynamic and comprehensive way than do considerations of bone tools as static objects.

In the next section I will consider the current research landscape surrounding each *chaîne opératoire* stage, and how the development of methods used here address or supplement extant research protocols.

2 Literature Review

The c*haîne opératoire* is an analytical method developed by Andrè Leroi-Gourhan (1964, 1968), which describes the diachronic operational sequence involved in sourcing, producing, using, and eventually depositing archaeological artefacts. The c*haîne opératoire* is a useful system for understanding artefacts not as static objects, but as materials acted upon by humans through time, within stages directed by human choice and cultural convention.

> Replication studies have suggested that the behaviors reflected in the various stages of the operational sequence were determined in part by the technical traditions of each human group. Within the group, the methods used for tool manufacturing were probably transmitted by imitation and/or by oral instructions from one generation to the next [Pelegrin 1985:57]. The individuals in the group possessed an array of techniques from which they were able to choose in relation to a preconceived notion of the shape of the blank and its potential use and to constraints such as the quality and availability of raw material. Identification of the most frequently recurring of those choices enables the archaeologist to characterize the technical traditions of the social group (Bar-Yosef et al. 1992:511).

Though initially applied to the study of European lithics, this system has come to be applied more broadly to a number of archaeological practises, technologies, and geographic regions. For example, c*haîne opératoire* analyses have been used to understand osseous artefacts from prehistoric North America, South America, the Levant, Europe, China, India, and other geographic regions (e.g., Bergsvik et al., 2015, Cunding 2019, Liolios 2006, Ludvik and Larson 2020, Martín et al., 2018, Mungur-Medhi et al., 2016, Smith 2015). Within Africa, a c*haîne opératoire* approach has been used in examinations of bone tools from southern Africa, as well as bone tools and retouchers from the North African Neolithic and Middle Stone Age (MSA) (e.g., Backwell and d'Errico 2005, Henshilwood et al., 2001, Lehnig and Linstädter 2020, Turner et al., 2020). The present

studies are the first to deploy this framework in interrogating bone tools from the North African LSA.

2.1 Initial taxa selection

The first stage in a bone tool c*haîne opératoire* is initial taxa or raw material selection. This stage can reveal strategies in preference (i.e., less commonly occurring taxa selected) or ideological relationships (i.e., 'special' taxa selected), and can serve as an indicator for the age or complexity of a bone tool industry. For example, were bones chosen from the most commonly hunted animals? Do the taxa selected for bone tool construction match in a representative way the taxa available on site? Or, were less-common taxa selected for tool creation? Do the taxa selected map onto the production of specific tool forms? Or can tools from specific taxa be seen in other ideological contexts, such as in burials?

Because bone tools from Taforalt are rarely identifiable at taxa level, I chose to use the relatively newly-developed method of ZooMS (or Zooarchaeology by Mass Spectrometry). This study represents the first application of ZooMS specifically to prehistoric bone tools. Before the advent of ZooMS, identifying which animals were used to create bone tools required morphological identification of the bone (e.g., Loponte and Buc 2012, Mozota et al. 2015, Selvaggio et al. 2001), histological identification of the bone (e.g., Bradfield 2018, Crowder and Stout 2011, Greenlea et al. 2010), or aDNA analysis (e.g., Grealy et al. 2016, Scott and Plug 2016, Wadsworth et al. 2017). Species-level morphological and histological identifications are not always possible owing to diagnostic features being obliterated during bone tool shaping and use. Ancient DNA testing requires a larger/better preserved sample, a narrower set of preservational conditions, and

is generally more costly than ZooMS. ZooMS uses the collagen peptides present in organic materials as the basic unit of analysis. These peptides can be extracted from archaeological bone and run through a mass spectrometer, and the resultant spectra can be compared to spectra from known animal samples to determine from which taxa the bone originally came. As such, ZooMS represents a reliable and minimally invasive means for gaining falsifiable data about which taxa were selected for bone tool construction.

This study provided proof-of-method that ZooMS could effectively be applied to bone tools from North African Palaeolithic contexts. First, it showed that protein preservation among the bone tools was sufficient to yield good resolution of the resultant ZooMS spectra. Second, results indicated that less common taxa were deliberately selected for the construction of tools. Such strategic taxa selection was already in place at the beginning of reduced itinerancy among the Iberomaurusians, indicating that bone tool construction (and pursuant craft production, discussed later) had a long history preceding enhanced sedentism at Taforalt. By examining this stage in the c*haîne opératoire*, selection strategies can serve as an index for the complexity of the industry, and uncover ideological relationships, such as the deliberate inclusion of an equid bone tool with a human burial on-site. A larger ZooMS programme is currently ongoing to help develop these ideas further.

2.2 Typology

The second bone tool *chaîne opératoire* stage is the production of bone tools, in which tools are formed into the shape desired by their users. Here, typology refers to a

descriptive assessment of the overall shape, size, and formal attributes of tools on an inter- and intra-assemblage basis.

Typology and use-determinations have often gone hand-in-hand in previous osseous tool analyses. Historically, osseous tool studies have been hampered by two main categorisational stumbling blocks. These consist of non-specific analysis and presumptive use categorisations (Langley 2018). Non-specific analysis occurs when osseous tools are described in publications in only the most basic terms (e.g., '22 bone points recovered'). Presumptive use categorisations occur when osseous tools are described within functionally presuppositional categories, based on morphology alone (e.g., '22 awls/arrowheads recovered'). These latter categorisations are often based on a perceived overall formal similarity to the objects after which they are named. There exists definite patterning in historical mis-categorisation of osseous tools: pointed tools were often ascribed a weaponised function (as projectiles), and non-pointed forms were often assumed to have been used in other hunting or animal processing activities (e.g., Kehoe 1999, Soffer et al. 1999, Soffer 2004, Stone 2009).

In recent years, there has been a widespread recognition that both nonspecific and presumptive osseous tool categorisations have hampered efforts to understand these objects fully. A growing body of researchers now agree that morphological and/or typo-functional descriptions alone are not trustworthy indicators of how an osseous tool was actually used (many of which can appear formally similar), and that the study of wear traces apparent on the tools themselves is the only way to diagnose use (Antonites et al. 2016, Akhmetgaleeva 2017, Arrighi et al. 2016, Bradfield 2012/2014/2020, Chomko 1975, Gates St-Pierre 2007, Griffits and Bonsall 2001, LeMoine 1994, Medina et al. 2018, Olsen 1979, Soffer 2004, Stone 2009).

In order to avoid presumptive use-categorisations, I did not make use of existing typologies with terms embedded in European Upper Palaeolithic classifications (e.g., Camps-Farber 1966). Here the typology is not intended to diagnose use, but rather to serve as a working description of the assemblage overall, and a platform for understanding patterns in industrial focus for later use-trace consideration. This typology was based on individual attributes of bone tools, and while these categorisations are fairly explicit and exhaustive, it became clear that not all these designations were meaningful after a study of ethnographic tools, which will be discussed in the conclusion section.

Size and feature based analyses of the Taforalt tools showed that small, thin, pointed tools with wear to the base were the most common forms. This type became the focus of the following use-trace investigation.

2.3 Determination of use

Once typological analysis revealed an industrial focus on small, thin, pointed forms with base-wear, it was possible to design a research programme aimed at comparing use-traces on these tools with use-traces on tools of a known function. This third bone tool *chaîne opératoire* stage involves understanding the ways in which bone tools were actually used. To do this, there are two potential comparative datasets: experimentally produced tools and ethnographic tools.

Experimental studies are the main comparative basis for archaeological osseous tool interpretation, and proceed by examining physical changes which occur during the creation and use of replica osseous tools for different tasks. Broadly (and with limited overlap), there have been two main ways of studying traces left on osseous tools: the

study of macroscopic fracture patterns produced by impact (generally used in experimental hunting scenarios [Arndt and Newcomer 1986, Bergman 1987, Bradfield and Brand 2013, Pétillon 2005/2006, Pokines 1998, Rozoy 1992, Stodiek 1993, Tyzzer 1936, etc.]), and the use of tribology (after LeMoine 1994), or microscopic use-trace analyses (generally used in experimental crafting scenarios). For an overview of osseous tool crafting experimentation, please refer to **Paper 4**.

However, some problems exist in the design and execution of modern experimental studies. For example, use-traces which develop on tools used in dynamic, lived scenarios by expert hunters and craftspeople (in the Palaeolithic or otherwise) will diverge, sometimes significantly, from those produced by experimentation (Griffits and Bonsall 2001, Legrand and Radi 2008, Pétillon et al. 2016, Stone 2013). These discrepancies are due in part to cultural, temporal, geographic, environmental, and stylistic (whether cultural or individual) factors which come together to comprise the tool's 'circumstances of use'. In replicative studies, all of these variables cannot possibly be controlled. Furthermore, a lifetime of expertise in a particular task cannot be replicated by archaeologists in a single experiment (Hurcombe 2008, Stone 2013). Most archaeologists conducting these experiments are self-taught, or will learn a given craft through an archaeologically specific 'community of practice' (Stone 2013). Use strategies will also vary between different cultural groups, or even within the same group through time. A single tool form may be used for a single crafting process, but different tool forms can be used for the same purpose, a tool can be used in different phases of a single process, and some tools will be used for a variety of different functions, either simultaneously, successively, or through intentional re-shaping over the life of the tool (Christidou and Legrand 2005, Gates St. Pierre 2007, Griffits 2001, Langley et al. 2016, Legrand and Radi

2008, Olsen 1979, Soffer 2004, Stone 2009). Experimental tools produced in order to examine the use-traces associated with a given function will necessarily be used only for that function, and generally for a limited duration. In other words, '...both the primary benefit and drawback to experimentation is the ability to simplify the history, context and pattern of use of any specific tool' (Stone 2013:28). A simplified *chaîne opératoire* will differ from the ways osseous tools are practically used, which will be far 'messier' and less scientifically compartmentalised.

Within a single culture, different scenarios produce different degrees of curation and wear, even for identically used tools. Members of a group will have different levels of skill (e.g., learners and masters), and tools will be deposited archaeologically at different stages of use (i.e., newly-made tools vs. repeatedly used and curated tools). Such complexities illustrate the dynamism of lived scenarios in which factors as subtle as individual competence play a role. I suggest that, along with circumstances of use, certain factors are crucial in an understanding of use-wear development in real-world scenarios, and may collectively be referred to as 'method of use'. This term includes the crucial gesture of use (Arrighi et al. 2016, Christidou and Legrand 2005, Griffits 2001, Parreño et al. 2018, Seetah 2008, Stone 2013), differences in product type (e.g., passing a point through tightly wound coils vs. open netting [Campana 1989]), idiosyncratic elements (e.g., haftedness, right vs. left hand use, holding a tool in the teeth, etc.), and the wider past community of practice (e.g., the culture and context-specific technological tradition[s] encompassing both osseous tool and perishable craft making).

While experimentation can be used to analyse wear associated with a specific function or material articulation, experiments can only take into account the realm of potential tool uses conceived by modern archaeologists. As a result, many experimental

studies may be inherently presuppositional. Because lithics are usually the only other technological components recovered from Stone Age sites, hunting and animal processing activities have dominated the understanding of Palaeolithic tool repertoires, and in many cases, osseous tools have been automatically assumed to belong to this same category of praxis. When perishable crafting is considered, it is often in a simplified form. This is due in part to the taphonomic vulnerability of perishable crafts and osseous tools, but also in part to conscious and unconscious biases within archaeological practice. Specifically,

> [f]iber technologies...are frequently archaeologically invisible in two ways: 1) physically, they are perishable and are thus recovered less frequently from the archaeological record; 2) intellectually, even when they are present, these technologies are often associated with the labor of women, children, and the elderly, who are frequently omitted from our reconstructions of the past. These two factors are interrelated and each feeds the other in the development of a gap in our knowledge about ancient perishable technologies: lack of interest in less powerful members of society – in the past and the present – limits the investigation of these individuals in the past, the difficulty of recovering this evidence minimizes the attention paid to these material classes (Stone 2013: 25).

Ethnographic tools can also show what composite tools looked like in their original form. Looking at composite ethnographic forms can help researchers imagine different perishable material associations (some of which, such as a wooden handle and twined haft, may have decayed), rather than presupposing osseous tools were used in isolation and/or in their archaeologically recovered form. Ethnographic tools can also showcase a vast array of uses for formally similar tools, bypassing biases in experimentation and design, which may favour only uses conceived of by the archaeologist.

Using ethnographic analogies to understand archaeological material has historically been subject to some criticism. With regard to bone tools specifically,

ethnographic analogy has sometimes been mis-used to suggest cultural continuity across large gaps in time, to 'primordialise' modern and/or ethnographic cultures, or to argue that ethnographic cultures are necessarily an extension of archaeological ones, based solely on formal likenesses between archaeological and ethnographic bone tools (Bradfield 2014, Pargeter et al. 2016). Though some researchers have argued that ethnographies offer fraught inroads into understanding past societies (e.g., Bednarik 2011, Cruz Berrocal 2011, Hiscock 2007, etc.), by scaling the analogy to microtopographic patterning occurring at an artefactual level, larger presumptive and/or deterministic pitfalls can be avoided (Stone 2013). Here I follow Currie's (2016) approach, wherein

> ...ethnographic analogy links a material remain with a cultural product (or a cultural product with another) either through a model, or along lines of ancestry. In neither case do we need the categories to be unified in a deep way (....) We do not need for them to fall within some general category for their use in a homoplastic inference: they just need to be similar in the relevant respects. Even if there are enormous differences between so-called 'hunter-gatherer' groups, what matters for ethnographic analogy is the robustness of the relevant similarities... (90).

Foremost, ethnographic tools provide a more thorough model for actualistic wear patterning as they display use-traces associated with a broader segment of the *chaîne opératoire* (i.e., a broader window into both circumstances and method of use)

> Ethnographic objects were created and used by individuals with learned, lifelong developed motor habits and were used in a living context in which they are tools with particular uses, but may also be used expediently in diverse ways. They are also subject to handling, storage, and transport over their life history. The complex surface attrition patterns on ethnographic tools may provide a good model for archaeological surface patterns. Wear on these objects was accumulated through use, handling, transport, repair, storage, and alternative uses of tools in a lived context (Stone 2013:29)

In selecting comparative ethnographic material, it is crucial that researchers focus only on reliably and well-documented collections with a high level of archival detail (Keddie 2012, Langley 2016, Legrand and Radi 2008, Olsen 1979, Stone 2009/2013, Struckmeyer 2011).

For example, was the object actually used for its described purpose? Or recovered archaeologically, and only presumed to have been used for that purpose? Was the tool created and sold as part of a tourist-trade, and never used at all? Artefact catalogues must be scrutinised, and only those tools with a well-documented provenance and specific use (and, when possible, material articulation) should be analysed. This is also why accessibility, reproducibility, and transparency are crucial in use-trace analysis. The capacity for researchers to create digital proxies of well-documented ethnographic or experimental tools would serve as an invaluable contribution to the research community, as researchers would no longer rely on finding and gaining physical access to these collections.

In this research, tools were located from ethnographic museum collections with extensively documented provenances (**Paper 3**). Tools were examined in-person using the same methods (here, digital microscopy and in some cases RTI). Best-fit use scenarios were only considered if tools had matching use-traces at both low (20-50x) and high (230x) magnifications. The published results of experimental studies were then used to understand and contextualise how specific surface topographies develop, and the mechanics by which specific deformations occur to a bone tool's surface during use. **Paper 3** shows how this method can be applied to recognise diagnostic patterning associated with a particular bone tool function (specifically, coiled basketry), and how bone tool use-wear can serve as an inductive proxy for archaeological forms with low taphonomic survival rates.

2.4 Reproducibility in use-trace analysis

The final *chaîne opératoire* stage of any artefact is its recovery as an archaeological object: in other words, the way archaeologists approach artefacts as objects of modern enquiry. In the case of osseous tools, this stage centres on researchers' need to document, analyse, and share use-trace results in a reproducible way, using widely accessible tools and techniques. One of the main problems in use-trace analysis is the need to compare only like datasets. When archaeological tools are compared to different documentary media, true matches in use can be obscured and false positive matches can occur. When possible, all tools considered (archaeological, taphonomic control, and ethnographic) must be examined in-person using the same methods. However, owing to logistical difficulties, isolating and accessing such collections is not always feasible. It is therefore necessary to find a means of reproducibly documenting one's 'control' collection (e.g., taphonomic, ethnographic, and/or experimental tools), and making these accessible to other researchers. For example, once patterning diagnostic of specific uses has been documented on ethnographic tools, it is useful to share these data in a reproducible format, enabling other researchers to compare these traces with use-traces present on archaeological tools, and to diagnose best-fit use scenarios for their own artefacts.

Current documentary methods for osseous tool use-wear include light microscopy (Antonites et al. 2016, Bradfield 2014, Bradfield and Antonites 2018, Gardner 2019, Gates St. Pierre et al. 2007, LeMoine 1994, Mata Parreño et al. 2018), digital microscopy (Antonites at al. 2016, Bradfield 2014, Bradfield and Antonites 2018, Campana and Crabtree 2018, Langley et al. 2016, Mata Parreño et al. 2018, Stammers et al. 2017, Tapia et al. 2018), metallurgical microscopy (Buc 2011, Christidou and Legrand 2005, Gates St.

Pierre 2018, Griffits 2001, Legrand and Radi 2008, Medina et al. 2018, Van Gijn 2005, Wojtczak and Kerdy 2018), stereomicroscopy (Langley et al. 2016, Legrand and Radi 2008, Van Gijn 2005, Wojtczak and Kerdy 2018), 3D imaging and printing (Arrighi et al. 2016, Krause 2012), CT scans (Backwell et al. 2018, Bouzouggar et al. 2018), scanning electron microscopy (SEM) (Bouzouggar et al. 2018, Buc 2011, LeMoine 1994), focus-stacking (Campana and Crabtree 2018) and texture-analysis techniques (Watson and Gleason 2016). While the use of the same methods within a single study allows for coherent and logical comparisons to be made between objects, methods (and therefore results) are not always comparable between studies.

Reflectance Transformation Imaging (or RTI) is a method which uses standard camera equipment to photograph an object from a number of different lighting positions. These photos are then compiled into an RTI file, which captures objects' surface detail interactively and in seeming three-dimensions. In brief,

> [t]he interactive output produced from the approach is comprised of information from multiple photographs that are taken from one stationary position, while the surface of the subject is illuminated from different raking light positions in each shot. Specially developed software compiles surface reflectance and texture information from the entire image set on a pixel by pixel basis. Multiple algorithms have been developed to process the images...The resulting output, referred to as an RTI file, can be opened using dedicated viewing software that enables the subject to be interactively re-lit. The enhanced legibility of the surface relief provides a powerful resource for the study of faint surface detail. (Duffy et al. 2018:1-2)

To date, RTI has been used in a single bone tool study, but the author found it time consuming and able to reveal only features already visible to the naked eye (Newman 2015). With these limitations in mind, the RTI design was developed to run image captures automatically, and to reveal microtopographic patterning with the use of a macro-lens. These RTI files can serve as a proxy for physical access to a given tool or

reference collection, and allow for consistency in use-trace analysis on inter- and intra-study levels.

While RTI should not replace conventional photography and microscopy in osseous tool analysis, it can supplement these methods in meaningful ways. RTI provides control over variables (such as lighting colour, brightness, and position) in documenting use-wear features, rendering RTI files comparable between objects and between studies. This RTI design is portable, inexpensive, open-source, and easy to modify, and it can be used in field and museum settings. RTI can also be used to document and analyse use-traces which are difficult to document via other methods, such as polish, which generally indicates a point of repeated wear-contact on a bone tool's surface (Fornaro et al. 2017, Peter et al. 2017). Furthermore, RTI can provide a better representation of a tool's surface than naked-eye or microscopic visual analyses: filters such as 'diffuse grain' and 'specular enhancement' can be applied to the RTI file, providing an enhanced view of an object's height, depth, smoothness, roughness, and other surface features. There were a number of iterative stages in the design and effective deployment of this system, which will be discussed in the conclusion section.

2.5 Contextualising the results of these studies

As discussed in **Paper 4** (p. 157-161), perhaps the most major recent development in prehistoric osseous tool research has been moving away from use-categorizations based on gross tool morphology, and toward studies which use use-wear analysis to determine tool function (**Paper 4,** 157-158). While most archaeological use-trace analyses use experimentally produced tools for use-wear comparisons, there is a growing body of

literature which uses ethnographically produced tools as comparative materials. To date, ethnographic tools have been used to interpret use-trace patterning found on archaeological tools from North American, European, southern African, and Australian contexts (Bradfield and Antonites 2018, Bradfield 2020, Langley et al. 2016, LeMoine 1994, Olsen 1979, Soffer 2004, Stone 2009). The present studies are the first to apply this method to bone tools from the North African LSA. Indeed, osseous materials from the North African Palaeolithic remain largely understudied, even in a regional context. When compared to literature surrounding contemporaneous southern African LSA and Levantine (pre-)Epipalaeolithic osseous tools, comparatively little research has been published on osseous materials from Palaeolithic North Africa. The current studies are the first to comprehensively describe bone tools from Taforalt, or from the Iberomaurusian culture generally. As such, these studies provide a valuable contribution to understanding the LSA in a North African setting.

In the past 30 years, a great deal of progress has been made toward standardisation of osseous tool terminology (e.g., Camps-Fabrer et al. 1998, Julien 1982, Pétillon 2006, etc.). Owing to the specific features of the bone industry at Taforalt, some of the most universally applicable terminologies detailed in these works are not applicable. For example, though different techniques for osseous tool formation have been differentiated and described in great detail (e.g., Camps-Fabrer et al. 1998) the method of bone tool production at Taforalt seems to have exclusively been longitudinal lithic scraping; there is no evidence for groove-and-splinter or other production and shaping techniques (pers. observation).

Osseous tool categories derived from European Palaeolithic industries (e.g., *poincon, alene, lissoir,* etc) have been used previously to describe bone tools from the North

African Palaeolithic (e.g., Roche 1963, Camps-Fabrer 1966). So far, archaeological and genetic data does not suggest direct connections between North African LSA populations and Palaeolithic Western European cultures. Recently, Ancient DNA studies have shown genetic affinities between the Iberomaurusian population at Taforalt and Levantine Natufian peoples (Van de Loosdrecht et al. 2018). There also exist a number of meaningful cultural similarities between contemporaneous Levantine Epipalaeolithic cultures and North African LSA groups. Bone tools similar in size and shape to those at Taforalt have been recovered from a variety of Levantine pre- and early Epipalaeolithic contexts (e.g., Campana 1989, Copeland and Hours 1977, Maher et. al. 2012, Newcomer 1974, Newcomer and Watson 1984, Rabinovich and Nadel 1995, etc.). Analogous cultural developments between Iberomaurusian and Levantine pre-Epipalaeolithic and Epipalaeolithic cultures also include increased sedentism, emergent burial practice, and complex hunter gathering, as well as evidence for crafted vegetal forms including matting and weaving (e.g. Ashkenazy et al. 2011, Coinman 1993, Maher et al. 2012, Nadel et al. 2004, etc.).

In the following studies I have sought to describe the tools from Taforalt in ways that are taxonomically independent of European Upper Palaeolithic industries. Because of the cultural, technological and genetic affinities between North African and Levantine populations, I believe these provide a better descriptive framework for contemporaneous North African bone tools. Much of the following research is modelled on Douglas Campana's 1989 study of Natufian and Zagros Protoneolithic bone tools, and on Mark Newcomer's 1974 study of Natufian bone tools. Though these studies were made some time ago, they deal with tool forms similar to those found at Taforalt, and both include robust experimental components. For these reasons, some of the terms used here diverge from nomenclatural standards based in European osseous tool traditions (e.g.,

Camps-Fabrer 1966, Camps-Fabrer et al. 1998, Julien 1982, Pétillon 2006, Roche 1963, etc.). For example, rather than using, 'proximal', 'medial/mesial', and 'distal' to refer bone tool locations, I follow Campana's (1989) terminology:

> Although the terms 'distal', 'proximal', 'medial', and 'lateral', are in common use to describe bone implements, I have intentionally avoided them here. My intent is to avoid confusion between bone tool landmarks and the anatomical terminology that is applied to the bone from which the tool has been made. The working end [active edge] of the implement is designated as the 'tip'; the handle or hafted end is referred to as the 'base'. If the shaft of an implement is wider than it is thick the broader surfaces are called 'faces' and the narrower surfaces are called 'sides'. Terms such as 'distal', 'proximal', etc. always refer to the anatomical landmarks of the bone from which the tool was made (45).

These designations make the following works directly comparable to a number of osseous tool studies performed on Epipalaeolithic Levantine materials, and preclude confusion between the anatomical position of the skeletal element used to make a tool (e.g., a distal epiphysis) and the part of the tool under discussion (e.g., a 'proximal' tool base made from a distal epiphysis).

The following papers serve as proof-of-method for new techniques in interrogating prehistoric North African bone tools from a *chaîne opératoire* perspective, and have illustrated how these bone tools (and their products) can be shown to correspond with other lines of archaeological data. Through using these methods a number of hitherto unknown and/or archaeologically invisible behaviours were discovered at Taforalt. These include deliberate raw material selection from less common animals, a well-developed bone tool industry in place preceding the shift to sedentism at Taforalt, an industrial focus on small, thin, pointed forms with hand-held uses, concentrations of these pointed forms in well-lighted workshop areas, and proxy evidence for the creation of coiled baskets. These baskets (and presumably other crafted forms) would in turn have enabled more efficient harvesting and collection methods that

would have been integral to resource intensification, demographic expansion, and enhanced sedentism. Ideological themes, such as relationships with specific taxa in burial contexts, advanced stylistic and aesthetic modes in the use of pigment, and the potential for role-specialisation in craft production were also revealed by using these methods together. Finally, I provide a method for sharing use-trace results remotely and in high-fidelity over a web-based platform using RTI. RTI enables transparency and reproducibility in use-trace analysis in formerly impossible ways, and RTI files can serve as a digital proxy for both artefacts and comparative collections. Together these methods allow researchers to examine formerly imperceptible cultural strategies and technologies among prehistoric groups and provide novel inroads into archaeologically invisible activities such as perishable crafting.

3 Paper 1: ZooMS identification of bone tools from the North African Later Stone Age

Published in:

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Abstract

This study applies peptide mass fingerprinting (also known as 'ZooMS') to bone tools from the North African Palaeolithic, as the first stage in a research programme aimed at understanding distinct phases within a bone tool *chaîne opératoire*. We report on the largest collection of bone tools from the North African Later Stone Age (LSA), from the cave site of Taforalt (Grotte des Pigeons) in eastern Morocco. Their appearance at this site from c. 15,000 cal BP appears to coincide with other changes in human behaviour which led to increased sedentism, cemetery use, and intensive exploitation of certain food resources. As such, bone tools can provide insights into how such broad-scale cultural renegotiations may have been brokered technologically, independent of the lithic record. Here, we explore initial raw material selection and manufacture strategies through use of ZooMS, a technique that permits identification of specific animals from very small bone samples. We found that ZooMS is highly suitable for use on the Taforalt material, and that bone tool morphology and construction tracks closely with the original animal from which a tool was made. Our results indicate that the Iberomaurusian occupants of Taforalt embedded bone tools within culturally-mediated technological strategies, potentially involving other perishable materials.

3.1 Introduction

Osseous tools are recurring elements of the modern human archaeological record, particularly from the Late Pleistocene onwards. They differ from the ubiquitous stone tool record in that they articulate more closely with human subsistence behaviour, being made from many of the same animals used for food and clothing. As such, tracking osseous tools through their complete life history reveals otherwise inaccessible parts of the interlinked cultural system present at a site. Here, we present the first modern study of bone tools from the Later Stone Age site of Taforalt, focusing on the identification of the animal species exploited by the site's occupants.

A historical focus on Palaeolithic stone technologies has often led to osseous tools being described cursorily, or using functionally-eponymous descriptions. For example, pointed tools are often classed merely as 'points,' or as 'awls' or 'spear-tips', without recourse to use-wear analyses (Allen et al. 2016, Bradfield, 2016, Desmond, 2017, Pargeter et al. 2016, Soffer, 2004). At many archaeological sites, the loss of perishable crafted forms has likely contributed to the miscategorisation of osseous tools that had been used to produce such items (Chomko 1975, Soffer 2004, Stone 2015). Tools used in Palaeolithic craft production have generally either been classed erroneously (often as weapons), or as having indeterminate or enigmatic functions (Bradfield 2016, Soffer 2004). Equifinality—multiple processes leading to a similar outcome—is a problem when osseous tools are ascribed use-categories based on gross morphology alone (e.g., Premo 2010, Rogers 2000). Historic and ethnographic records show that tools of different shapes and sizes, constructed from different materials, have been used to perform the same technical function. Similarly, nearly identical-looking tools can be used in completely

different ways by different communities, or even within the same community over time. Furthermore, a single tool may have been used for a number of different purposes synchronously. For example, a long, thin, gracile tool may make an excellent ad-hoc toothpick, or be used to pierce a snail shell. In the absence of organic materials on which a tool may have been used, and in view of issues of eponymous-tool categorisation and equifinality, it is necessary to develop a multi-method research programme aimed at disentangling bone tool form and function. As part of this programme, we aim to identify and interrogate different stages within a tool's 'life history.' One model for doing so is the *chaîne opératoire*; as applied to osseous tools, this includes understanding the tools' initial material selection and formation strategies, through use and curation, to eventual deposition (e.g., Leroi-Gourhan 1963, 1968, Bar-Yosef et al. 1992, Henshilwood et al. 2001, etc.). This approach maintains a dynamic focus on tools as objects of use, providing a discursive and relational approach to material culture in the Iberomaurusian, wherein tasks and technologies together form a mutually constitutive culture of material and practice. This approach requires us to contextualise bone tools in a site- and culture-specific way, and to consider them alongside other lines of evidence with which they co-occur archaeologically.

3.1.1 Species identification by ZooMS/Peptide mass fingerprinting

This study uses ZooMS, or Zooarchaeology by Mass Spectrometry, to gain insights into initial taxon selection as the first stage in a bone tool *chaîne opératoire*. ZooMS has a number of advantages when compared with other biomolecular identification techniques, as it can work on Palaeolithic bone material from warm, arid environments, requires

minimally invasive sampling, and is less expensive and labour intensive than, for example, DNA sequencing. The results can indicate degrees of industrial maturity, by revealing indiscriminate or strategic taxa selection for the production of specific tool types, as well as iterative stages through time. ZooMS data can also serve as a platform for investigating stages of an object's chaîne opératoire, such as use-wear and depositional relationships. For the former, use-wear correspondences among types created from specific taxa may indicate whether tools were constructed to a preconceived specification in order to effect particular tasks. ZooMS may also help identify ideological relationships with particular taxa; for example, if tools created from particular taxa are repeatedly associated with burials or other meaningful features. Because ZooMS uses collagen peptides as the basic unit of analysis, this circumvents many of the preservation issues that can limit and constrain DNA extractions. For example, ZooMS can work on material recovered from hot, arid climates (e.g.,, Harvey et al. 2016), because over time minerals encase, preserve, and prevent the collapse of the collagen fibrils used in ZooMS identifications. As collagen becomes entrapped in this mineral matrix, collagen peptides gain a heightened resistance to high temperatures and other deleterious long-term burial processes (San Antonio et al. 2011). When a bone or osseous tool is archaeologically recovered, the collagen peptides can be extracted and high-throughput mass spectrometry used to accurately determine the animal taxa (Hounslow et al. 2013, Von Holstein et al. 2014). ZooMS also minimises the need for destructive analysis with good project designs dictating that any such sampling be as minimally invasive as possible. ZooMS meets these criteria, as very small sample sizes (as small as 5 mg from modern material) have yielded tenable results. Finally, lab-based scientific analyses are often constrained by 'real-world' considerations such as labour and materials costs. ZooMS

costs and working hours are significantly lower than those associated with DNA analysis, allowing for more rapid analysis of a greater volume of material (e.g.,, Buckley et al, 2016, Brown et al. 2016).

3.1.2 Taforalt

The cave site of Taforalt (34° 48′ 50″ N, 2° 24′ 14″ W) is located in the Oujda region of northeastern Morocco, approximately 40 km from the Mediterranean coast (**Fig. 3.1**). This site has yielded the largest collection of bone tools from the North African Later Stone Age (Iberomaurusian), providing a unique opportunity for insight into the archaeological culture that produced them. To date, more than 500 bone tools have been recovered from Iberomaurusian levels at Taforalt, 200 of which are currently available for study.

The Iberomaurusian first appeared in North Africa around 25,000 cal BP (Hogue and Barton 2016) and may have continued into the Holocene after 11,600 cal BP (Barton et al. 2008). At Taforalt, the bone tools first appear in Iberomaurusian deposits dating from c. 15,000 cal BP, which coincided with major changes in human behaviour at the site linked to dietary shifts and likely a reduction of group mobility (Humphrey et al. 2014). They are one of a number of novel social and technological behaviours that appear at Taforalt against a background of climatic changes at the beginning of Greenland Interstadial GI-1e (Rodrigo-Gámiz et al. 2011. Barton et al. 2013). This phase of the Iberomaurusian is also marked by a major change in sedimentation within the cave (hereafter 'Grey Series' levels) that, in the area where the tools were recovered, began to accumulate between 15,190 and 14,830 cal BP (Barton et al. 2013). Rather than a significant change in cultural

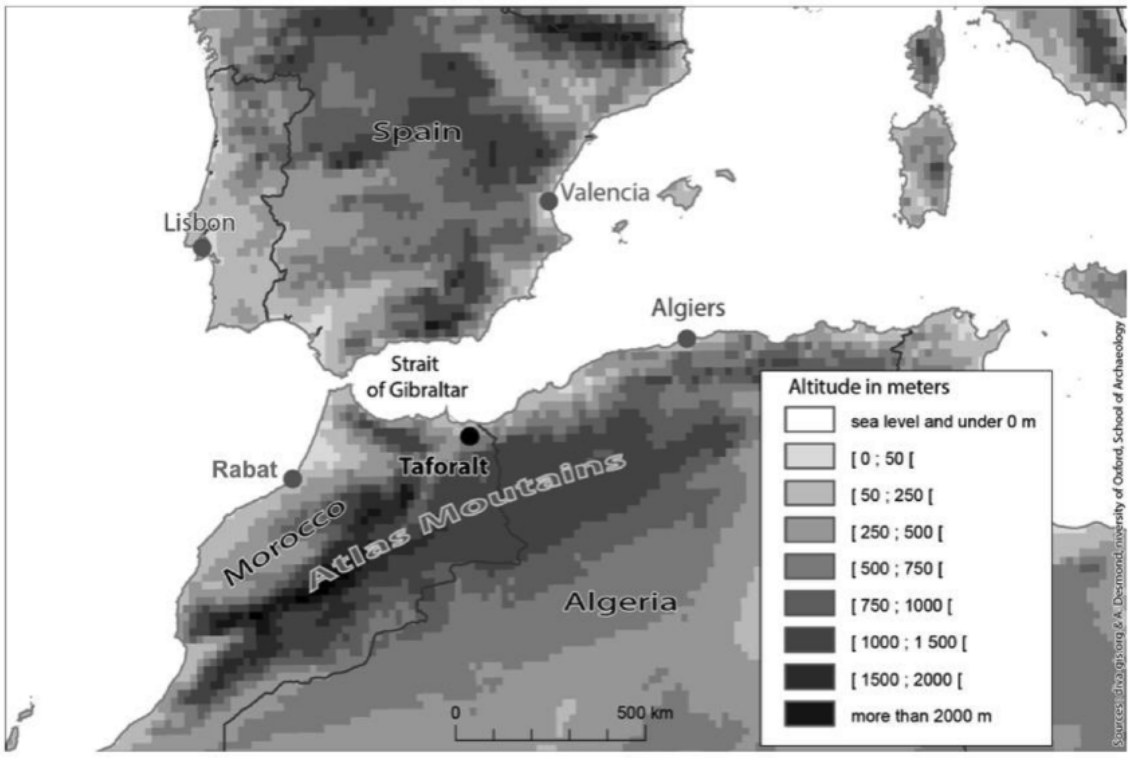


Figure 3.1: Map of the Maghreb and Western Mediterranean, showing the location of Taforalt

material, the onset of Grey Series sedimentation may mark a subtle behavioural transition that led to an early form of sedentism, intensification in the exploitation of specific food resources and the first examples of funerary activity (Humphrey et al. 2012/2014).

Of the 200 available tools, 40 were excavated since 2003, of which 38 were recovered from the earliest burial deposit located in the Sector 10 alcove at the rear of the cave. All tools analysed here were among those recovered from grey ashy deposits in Sector 10 which correspond with the onset of Grey Series sedimentation. The remainder of the tools were excavated during the mid-20th century; between 90 and 160 of these were excavated from related Iberomaurusian burial areas (Necropolis I [NI] and Necropolis II [NII]) by Abbé Jean Roche in the 1950s (Desmond 2017, Roche, 1963). Overall morphologies and repetition of specific tool features are similar between the tools excavated by Roche and those found in Sector 10, indicating that these are members of a

continuous Iberomaurusian bone tool industry (Desmond 2017, Desmond **Paper 2**). While Iberomaurusian stone tools have been relatively well-documented (Lubell 2001, Hogue 2014, Hogue and Barton 2016, McBurney 1967, etc.), no modern study has been made of bone tools from the Iberomaurusian, either from Taforalt or elsewhere. Stone or lithic tools are the most taphonomically robust components of the archaeological record, in contrast to organic materials, such as wood, bone, skins, and vegetal remains. Because of their durability and ubiquity, stone tools have served as de-facto benchmarks for defining cultural entities, and even as indices for human species (Bordes 1950, Debénath and Dibble 2015, Hoffecker 2011, Kuhn and Zwyns 2014, etc.). However, reliance on a single aspect of material culture cannot typify a culture's entire technological strategy. This is especially true when examining the evolution of technologies through time, and during wide-scale cultural renegotiations. Lithics may also show conservatism across cultural thresholds; it has yet to be determined whether wood, bone, and other perishable material forms may allow more plastic responses to short-term environmental, demographic, or cultural pressures. Bone tool studies therefore permit a broader understanding of how the Iberomaurusians negotiated changes in both external forces such as palaeoclimatic processes, and internal forces such as increased sedentism, burial as an emergent ritual practice with respect to the dead, and resource intensification.

3.1.3 Aims

Although ZooMS has been applied to much more recent bone implements (e.g., Viking combs; Von Holstein et al. 2014), the present study is the first to apply it to Palaeolithic bone tools, and as such we created a nested set of aims that explore the power

of this technique. First, we aimed to identify the taxa from which each sampled bone tool was made, to the genus or species level if possible. Second, we aimed to track any correspondence between the selected animal and the tool morphology, including its cross-section and robustness/size. And third, we assessed the likely role of the sampled bone tools within the overall technological strategies evident at Taforalt in the Iberomaurusian period.

3.2 Materials and methods

A sample of 13 bone tools was selected from those excavated since 2003, from one restricted area of Taforalt (Sector 10). These represent the only tools which have both known three-dimensional archaeological coordinates and broken ends and edges (all other tools with obvious breakages were excavated in the mid-20th Century). Bone was removed for analysis from tools with broken ends or edges in order to minimise the impact of sampling, leading to a relatively small sample size. This study served as a proof-of-concept, and a further ZooMS study with a greater sample size is currently ongoing (Desmond et al., forthcoming). Most bone tools recovered from Taforalt are similarly gracile, so breakages (and therefore this subsample) do not appear to have arisen as a result of particularly vulnerable tool forms: the average maximum length among all complete tools is 83.4 mm, and the average maximum width is 11.9mm (Desmond **Paper 2**). The selected bone tools consist of seven gracile pointed tools with a rounded cross-section (find no.'s 8580, 2334, 2458, 2706, 3531, 4066, and 10871), two gracile pointed tools with a flattened cross-section(2590 and 2514), one pointed tool with an irregular cross-section (10532), one indeterminate point fragment (2453, possibly

similar in initial form to 4331), one large point with a flattened cross-section (2478), and one large point with a rounded cross-section (4331) (**Fig. 3.2**). Cross-section here refers to an assessment of the general shape profile of the tool, 'foreshortened' and viewed from the point-tip end.



Figure 3.2: Tools subjected to ZooMs analysis

Sector 10 incorporates a dense scatter of human burials near the rear of the cave, and the sampled tools were found in close spatial association with articulated human skeletons, such as is seen in **Fig. 3.4** (see also Desmond **Paper 2**). Radiocarbon dates on

human bone in this sector give ages of 15,077–13,892 cal BP (Humphrey et al. 2014), near the base of the Grey Series sediments. Some of the smaller sampled tools may have unintentionally been moved from habitation areas, as 'fill' in a matrix brought to the rear of the cave and used to bury people without disturbing previous burials [Desmond, **Paper 2**]). However, all tools were found in close association with burials. It is therefore extremely unlikely that any tools present within these burials and closely surrounding deposits are younger than the skeletons themselves (as they were deposited, if not made, contemporaneously to burial), and we thus consider the date range of 15,077–13,892 cal BP as a minimum age for these objects (ibid.). Reference bone material was acquired from modern taxa, and morphologically identifiable North African archaeological taxa excavated from Palaeolithic contexts. Modern reference taxa sampled from the National Museums Scotland included hartebeest (*Alcelaphus buselaphus*; unregistered), Barbary sheep (Ammotragus lervia; Z.2011.165.2), red-fronted gazelle (*Gazella rufifrons;* Z.2010.46.43), and roan antelope (*Hippotragus equinus*; Z.2001.149.12). Ancient reference material included *Bos primigenius, Alcelaphus buselaphus, Gazella sp., and Equus mauritanicus;* these consisted of morphologically diagnostic elements acquired from Grey Series Iberomaurusian archaeological levels at Taforalt.

3.2.1 ZooMS (peptide mass fingerprinting)

Our ZooMS (peptide mass fingerprinting) analysis follows the protocol outlined in Van der Sluis et al. (2014), itself a modification of Buckley et al. (2009). Each bone sample was first demineralized with 0.6M hydrochloric acid (HCl; Fischer Scientific) for approximately 20 h at 4 °C. Following 1 min centrifugation at 12,400Å~g, the supernatant

was further centrifuged for 20 min in 10 kDa molecular weight cut-off ultrafilters, followed by two washes with 0.5 mL ammonium bicarbonate (ABC). After this second centrifuging cycle, the filtrate for each sample was resuspended in 0.1 mL ABC and then digested with 0.4 μg trypsin (Promega, UK) at 37 °C for 20 h. Next, the peptides (fragments of protein) were acidified to 0.1% trifluoroacetic acid (TFA; Sigma-Aldrich, UK), and were purified and fractionated using C18 pipette tips (OMIX). These were then divided into a 0–10% acetonitrile (ACN) fraction and a 10–50% ACN fraction (following Van der Sluis et al., 2014, Buckley et al., 2009). The fractions were dried down, and then resuspended with 10 μL 0.1% TFA. Following this, 1 μL was co-crystallised with 1 μL α-cyano-4-hydroxycinnamic acid (Sigma-Aldrich, UK) solution (10 mg/mL in 50% ACN), and samples from each fraction were deposited onto a Bruker stainless steel matrix-assisted laser desorptionionization (MALDI) target plate. MALDI analysis involved a Bruker Ultraflex II, wherein 2000 laser acquisitions were accumulated over a m/z range of 700–3700. The resultant spectra were then inspected manually using Bruker Daltonics FlexAnalysis 3.3 software. MALDIToF-MS spectra were acquired for each of the 0–10% ACN and 10–50% ACN fractions of collagen, indicating that all 13 samples produced viable collagen fingerprints with visible peptide peaks, likely to allow for taxonomic identification. We followed this same method in the analysis of modern and archaeological reference taxa.

3.3 Results

3.3.1 ZooMS identification of the Taforalt bone tools

Peptide mass fingerprints that were clearly representative of good collagen preservation were acquired from all 13 samples, which were compared with peptide spectra produced from known species. Gazelle was initially difficult to distinguish from hartebeest (Alcelaphus), with only a potential high mass marker that was repeatedly observed as a candidate biomarker separating the two (**Fig. 3.3, Table 3.1**). The majority of these (n=7) were attributable to gazelle, with three from hartebeest, two from Barbary sheep, and one from an equine (**Table 3.1**).

3.4 Discussion

The ZooMS data show that the Iberomaurusians practised strategic and preferential selection of taxa from which to construct bone tools. **Table 3.2** shows the total number of unmodified faunal elements from the Sector 10 burial alcove. Contrary to what we would expect from an indiscriminate and unplanned selection of bone 'blanks,' results show that the most common taxa selected are not the two most numerous Sector 10 fauna, Barbary sheep and equids (**Table 3.2**).

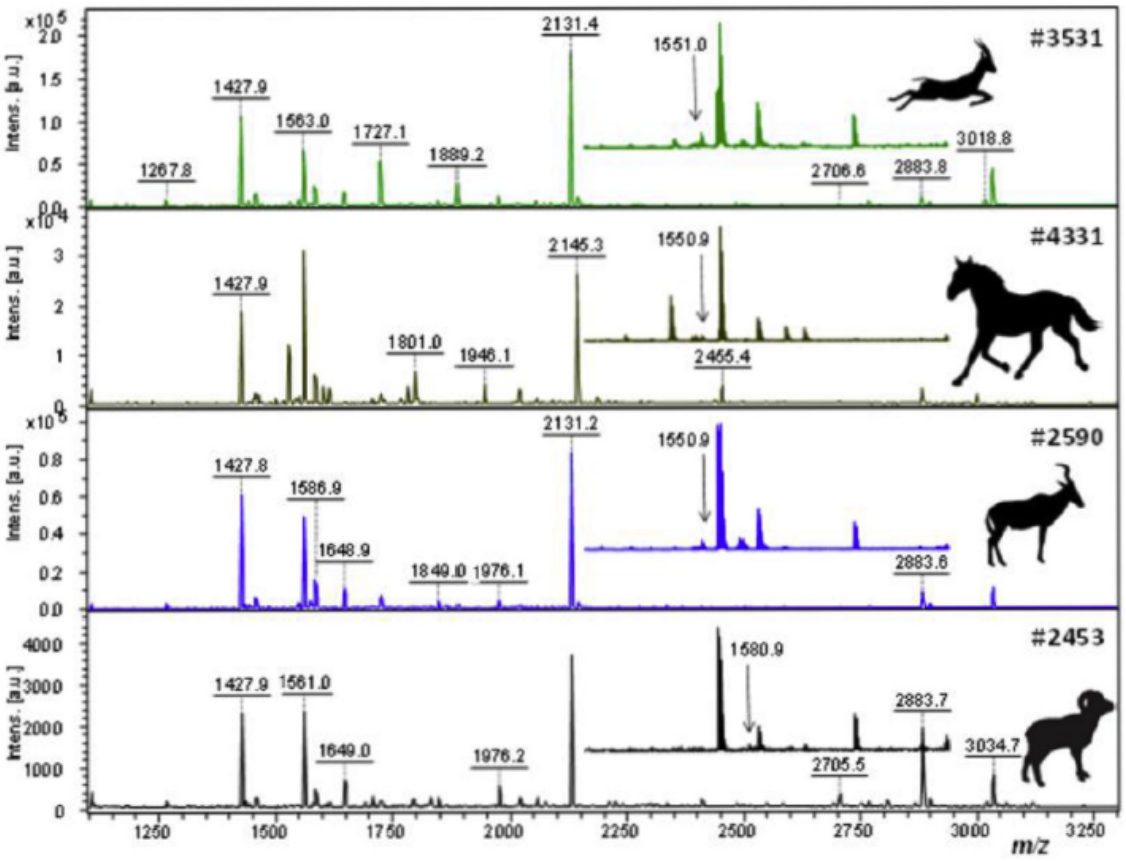


Figure 3.3: Example of spectra of bone tools

Since Barbary sheep is the most processed animal on-site by a wide margin, and most bone points fall within the size-range of Barbary sheep longbones, we would expect that this should be the dominant taxon used in tool construction. However, results show that these tools were preferentially made from species which occur at much lower frequency. Gazelle remains, which represent only 11% of the identifiable fauna (*Gazella sp.*), were used to make 7 (or 54%, $p < 0.001$) of the tools, followed by hartebeest, which represents only 3% of the identifiable fauna (*A. buselaphus*, n=3). These were then followed by Barbary sheep (*A. lervia*, n=2), and a single equid (*Equus sp.*, n = 1). Even though the results must be read in light of the constrained sample size, an exact statistical test shows that the probability to draw 7 or more gazelle tools in a sample of size n=13 is 0.018%,

assuming that the underlying probability of drawing gazelle is identical to its percentage in the identifiable fauna (11%).

Sample	2t85	2t43	2t45	2t69	1t55/56	2t67	x	ID
2334	1196	1427	1550	2131	2883	3033	3227	Gazelle (*Gazella* sp.)
4066	1196	1427	1550	2131	2883	3033	3227	Gazelle (*Gazella* sp.)
2514	1196	1427	1550	2131	2883	3033	3203	Hartebeest (*A. buselaphus*)
8580	1196	1427	1550	2131	2883	3033	3203	Gazelle (*Gazella* sp.)
2478	1196	1427	1580	2131	2883	3033	3227	Barbary sheep (*A. lervia*)
2706	1196	1427	1550	2131	2883	3033	3227	Gazelle (*Gazella* sp.)
10532	1196	1427	1550	2131	2883	3033	3203	Hartebeest (*A. buselaphus*)
3531	1196	1427	1550	2131	2883	3033	3227	Gazelle (*Gazella* sp.)
4331	1198	1427	1550	2145	2883	2999	3242	Equid (*Equus* sp.)
2458	1196	1427	1550	2131	2883	3033	3227	Gazelle (*Gazella* sp.)
2590	1196	1427	1550	2131	2883	3033	3203	Hartebeest (*A. buselaphus*)
10871	1196	1427	1550	2131	2883	3033	3227	Gazelle (*Gazella* sp.)
2453	1196	1427	1580	2131	2883	3033	3227	Barbary sheep (*A. lervia*)

Table 3.1: Markers observed in archaeological bone tools derived from mammals and their resulting identification (conventions based on Buckley et al. 2016; x indicates sequence for peptide could not be determined for all taxa)

Taxa/Common name	Faunal remains Sector 10		Bone tools Sector 10	
	NISP	% NISP	NISP	% NISP
Gazelle	78	10.88	7	53.85
Hartebeest	18	2.51	3	23.08
Barbary sheep	433	60.39	2	15.38
Equid (large = 85, small = 6)	91	12.69	1	7.69
Large bovines	48	6.69		
Fox	4	0.56		
Canid	3	0.42		
Jackal	1	0.14		
Bear	1	0.14		
Rhinoceros	1	0.14		
Wild pig	1	0.14		
Felid	1	0.14		
Total	*681*	*95*	*13*	*100*
Medium-Large undiagnostic	552	67.65		
Large undiagnostic	120	14.71		
Small undiagnostic	25	3.06		
Ovicaprid	10	1.23		
Indeterminate	15	1.84		
Total	*722*	*88*		

Table 3.2: Faunal remains recovered from Sector 10 (based on Turner, 2019)

We can thus strongly reject the null hypothesis that the available bones were used uniformly at random. Similarly, the exact probability of at least 10 tools from gazelle and hartebeest together is 0.32%. The probability of drawing this sample (7 gazelle, 3 heartbeest, 2 Barbary sheep, and 1 equid) if the percentage of tools from each species corresponds to the percentage of identifiable fauna is smaller than 3*10^-8 (multinomially distributed sample).

Before the application of ZooMS, it was impossible to identify which species' bones were used to construct the majority of bone tools at Taforalt (and for all samples considered here). While there exists an industrial focus on the production of gracile pointed forms, it would be impossible to say which taxa most of these tools came from using traditional morphological identifications. As a general rule, morphologically identifiable features are obliterated through tool shaping and use processes. Though in some cases it is possible to determine the relative size of the animal (i.e., small, medium, or large), ZooMS has allowed us to identify precisely which taxa were selected for the construction of individual tools. Generally, the size of the taxa tally with the size of the tool produced; larger tool forms are produced from larger taxa. This aligns with the evidence for tool shaping strategies in the Iberomaurusian, as all bone tools that retain construction traces show evidence for longitudinal lithic scraping (Desmond **Paper 2**, Desmond pers. observation). As lithic scraping is the primary means for shaping tools at Taforalt, it would make sense that smaller taxa are selected for the creation of small, gracile tools, reducing the amount of shaping and modification required. This technique may also account for the lack of evidence for 'groove-and-splinter' bone blank production on site, as seen in other prehistoric bone and antler tool assemblages (e.g., Palaeolithic

European, prehistoric American, southern African, etc. [Clark and Thompson 1954, Frison and Ziemens 1980, Smith and Poggenpoel 1988, etc.]).



Figure 3.4: Bone tool no. 4331 (*Equus sp.*) in-situ, present in the thoracic area of Individual 1 in Sector 10.

However, if the Iberomaurusians merely wished to exploit already long and thin pieces of bone for the construction of small tools, we should expect at least some of these to have been created from Barbary sheep or equid long bone fragments/splinters, which are abundant in these levels, together comprising 76% of identifiable faunal remains (**Table 3.2**). Because no small tools were created from long bone fragments of these larger animals (even though these are markedly numerous at the site), we know that tool material was not selected indiscriminately; moreover, it appears that tools with similar to identical morphologies also group by taxon (with the possible exception of the indeterminate Barbary sheep point fragment). Each taxon groups the tools by overall shape: gazelle and hartebeest bones were used to produce all of the long, thin, gracile

pointed tools; Barbary sheep bones were used to produce a large spatulate point (and an incomplete point tip fragment, which may have had an original shape similar to the equid tool [4331]); and the equid bone was used to produce the other large tool in the sample, pointed with a rounded cross-section.

Beyond the scope of traditional morphological identifications, ZooMS analyses have shown that overall taxa size not only maps onto overall tool size, but also onto specific tool form. Here, tools are produced from particular animals to preconceived specifications, which points to a long-term and formalised cultural production of bone tools. The current study provides an initial proof-of-method, and more work needs to be done to substantiate whether this industrial strategy continues to hold true within a larger sample of bone tools from Taforalt. Even at this analytical stage, however, there are a number of suggestive lines of evidence. The studied tools were recovered from a burial area broadly coincident with the onset of Grey Series sedimentation. This indicates that a reasonably well developed Iberomaurusian bone tool industry was already present when the occupants were exhibiting signs of more sedentary behaviour. Even if we allow for the maximum difference in time (~1300 years) between the onset of the Sector 10 Grey Series and the creation of these tools, we do not see evidence for an iterative, trial-and-error bone tool production process, beginning with expedient tool production in the earliest levels and ending with more strategic production in later levels. Rather, we see continuity in tool form production between the Sector 10 burial area tools and tools recovered from the younger levels within the NI and NII Grey Series deposits, and trends in overall shape, size, and feature patterning are broadly consistent among all 200 tools currently available for study, indicating that these are members of a continuous bone tool tradition (Desmond **Paper 2**).

Along with the earliest burials on-site, the Grey Series levels from which these bone tools were recovered illustrate an intensification in wild plants such as *Quercus sp.* (acorns), *Pinus pinaster* (pine nuts), and five dominant species of edible mollusc (Humphrey et al. 2014, Taylor et al. 2011). Archaeological signifiers of this subsistence behaviour include macrobotanical evidence and precocious dental caries (Humphrey et al. 2014). Intensification in these food resources would have enjoined specific mechanisms for collecting, transporting, processing, cooking, and/or storing them (e.g.,, Bissonnette 2003, Farjado et al. 2015, Fauvelle 2013, Fenenga 1975, etc.). As there is no evidence for pottery or constructed storage features (e.g.,, storage pits) at the site, these processes were likely brokered through the use of perishable, organic materials, such as baskets or hides. Vegetal crafting among the Iberomaurusians is implied by the presence of *Stipa tenacissima* (esparto grass) rhizomes throughout the Grey Series deposits. The grasses were uprooted and transported to the site whole, and while the esparto stalks were likely used in the creation of crafted objects (baskets, cordage, netting, matting, etc.), the rhizomes were discarded and burned (Humphrey et al. 2014). *A. lervia* (Barbary sheep) dominates the faunal profile in Grey Series levels (**Table 3.2**), and these and other animal skins may also have provided a suitable material for crafted storage and processing forms, clothing, bedding, etc. The Taforalt bone tools were likely used in articulation with these resources, as tools related to perishable craft production. Though there is a clear industrial focus on pointed forms, the bone tools from Taforalt do not display features usually associated with projectile production. Most pointed tools at Taforalt have an asymmetrical shaft, making their use as projectiles implausible, and none display diagnostic impact-fracturing (Bradfield and Brand 2013, Desmond **Paper 2)**. Rather, the majority of pointed tools retain evidence for hand-held or hafted uses; most tools display

smoothing on the base (consistent with tools held in the hand during use), as well as smoothing/rounding to the point-tip, indicating repeated abrasive articulations with materials softer than bone (**Desmond Paper 2**, Campana, 1989). The presence of specific micro-topographic patterns suggestive of particular crafting activities is currently under study. If an examination of use-traces further confirms that these bone tools were used in craft production, this may indicate that perishable crafting strategies have a long history in the North African Palaeolithic. This notion would be supported by the presence of charred esparto rhizomes in earlier MSA levels at Taforalt (Barton et al. 2016). Tools and organics associated with advanced vegetal crafting are becoming increasingly evident in African, European and Levantine Palaeolithic cultures, both earlier than and contemporary with the Iberomaurusian in North Africa (Adovasio et al. 2001, Nadel et al. 1994, Nadel et al. 2006, Soffer 2004, Stone 2015, Ramsey et al. 2018, Wadley et al., 2011 etc.).

Using extant technologies (e.g.,, crafted forms) in new ways to facilitate sedentism would be analogous to what we see in terms of food procurement (i.e., an intensification in the exploitation of locally available food resources). Under this scenario, LSA and Epipalaeolithic cultures scaffold new behaviours and technologies by modifying existing components of a mobile hunter-gatherer repertoire, rather than undergoing punctuated, broad-scale reorientations to technology, climate, and landscape. This could also help explain why lithic production strategies do not markedly change during an otherwise clear archaeological transition.

Finally, this work has provided evidence for symbolic/ritual behaviour, here marked by the inclusion of equid remains as grave goods (Humphrey et al. 2012/2014, Belcastro et al. 2010). One of the two large and robust tools within the analysed dataset is

tool no. 4331 (**Fig. 3.2**); because of this tool's size, it is extremely unlikely to have been inadvertently transported within matrix or fill to the Sector 10 burial area. Among the tools analysed by ZooMS, this is the only specimen that was found to have come from an equid, and it was recovered from the thoracic region of the Individual 1 burial (Humphrey et al. 2012) (**Fig. 3.4)**. This burial exhibited an elaboration in grave goods, including large bovid horn cores on either side of the body, a Barbary sheep mandible under the pelvis, a number of animal bones in various states of fragmentation, and a blue stone atop the cranial region; additionally, a horse incisor was found deliberately placed near the skull (Humphrey et al. 2012). Given this assemblage, it seems probable that the bone tool was a deliberate grave inclusion, and as both it and the horse tooth were placed on Individual 1's axial skeleton, it may reflect a symbolic funerary relationship with equids.

3.5 Conclusion

This study has shown that ZooMS can be profitably applied to Late Pleistocene bone tools from North Africa, and that this technique provides an effective means for exploring technical and social processes in the Iberomaurusian. In investigating bone tools from Taforalt, we are presented with a unique opportunity for understanding how broad-scale cultural renegotiations may have been brokered technologically, without recourse to lithics alone. The minimum age of the tools studied here suggests that a well-developed bone tool production strategy was already in place near the beginning of reduced itinerancy among the Iberomaurusian population, marked by a major change in sedimentation and behaviours illustrated on-site. If this finding is borne out by future

work, then the Iberomaurusian bone tool industry has an extensive history preceding the shift to sedentism. Further enquiry into the specific characteristics of bones selected to create various tool types may, in combination with use-wear analyses, shed light on why these specific taxa and skeletal elements were chosen. For example, the histological features present in different species (and even different skeletal elements within a species) determine how a bone will respond to directional use of force and impact through a degree of flexibility or rigidity. Though potentially mediated through long-term cultural traditions, the physical properties of diverse types of bone and antler have been exploited by cultures in the ethnographic present, and would have been known to Palaeolithic peoples, who may have selected specific animal bones to create tools for particular tasks based on their physical characteristics (Dominy et al., 2018, Newcomer, 1974).

ZooMS analyses have revealed a number of hitherto unknown characteristics of the Iberomaurusian bone tool industry at Taforalt. These include evidence for a strategic selection of bone tool raw material from less common taxa, the repeated construction of specific tool types from specific faunas, and evidence for ideological relationships: specifically, the deliberate placement of an equid tool along with an equid tooth on the axial skeleton of an individual burial. Furthermore, ZooMS analyses provide a platform from which to approach later stages in the tools' *chaîne opératoire*. By using ZooMS alongside feature-based analyses (such as evidence for hand-held uses) and use-wear studies, issues of equifinality can be effectively minimised or circumvented. Ultimately, a combination of a *chaîne opératoire* approach to bone tools and contextual data at Taforalt—including the ubiquitous presence of esparto on site, and the necessity for collection, processing, and storage technologies in the absence of pottery and constructed features—may serve as proxy evidence for material culture with low taphonomic survival

rates. ZooMS therefore provides a powerful new quantitative method for exploring technological and industrial strategies in the North African Palaeolithic.

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4 Paper 2: Bone Industry

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4.1 Chapter 13.1: Bone Industry

The following will form a preliminary account of bone tools recovered from Iberomaurusian archaeological levels at Taforalt Cave, Morocco. Materials studied include bone tools excavated from 2003 to 2016 (n = 40), as well as a number of tools from excavations undertaken in the 1950s (n = 160). These tools will be analysed as a unitary group, as all were recovered from Grey Series units and all but two are associated with Iberomaurusian burial areas. There exists a further published record indicating that 543 additional tools were recovered during excavations during the 1950s (Roche 1963). In addition to the 200 tools currently under study, this brings the total number of bone tools known to have been excavated from the site to 743. While only a subset of these tools remains available for study, the size of this subset alone represents the largest Palaeolithic North African bone tool industry recovered to date and indicates a numerous, widespread and well developed bone tool industry within the Iberomaurusian. The study of these tools is the focus of an ongoing research project, aimed at examining the bone tools from a *chaîne opératoire* perspective. This analytical method seeks to understand tools from initial selection and creation, through to use and function, and finally to their eventual deposition and recovery as archaeological artefacts. As a part of this larger study, a number of methods will be used together to investigate different stages along this operational chain. The first stage of the *chaîne opératoire* will continue to be assessed through the use of ZooMS (zooarchaeology by mass spectrometry), in order to identify patterning in the taxa selected for tool construction (Desmond et al. 2018). How the tools may have functioned will be assessed through a comparative examination of tool microtopography. These can then be compared to use-traces found on ethnographic tools

of known function, from geographically and technologically commensurate cultures (e. g. prehistoric groups from thermo-Mediterranean biozones, semi-sedentistic groups, groups which exploit similar food resources, etc.).

The current study describes an intermediate stage in the *chaîne opératoire* and details the development of a typological framework used to analyse the tools' individual and collective attributes. In deploying such a typology, it will become possible to assess repeatedly occurring size, shape and, in some cases, wear patterns, to examine the relationship of individual tools to the assemblage overall, and to determine whether the Iberomaurusians were engaged in the repeated production of specific industrial types. When features such as overall shape and wear patterning are combined with an examination of construction patterning (e. g. taxa selected for raw material) and use-wear correspondences among types, repetition in tools withlike overall features can indicate the repeated construction of tools for particular purposes through time. As such, the typological assessment of the tools described here represents a single methodological avenue among many, situated within a diachronic, life-history approach to the study of these tools. These descriptions do not represent the catalogue as an end-goal; rather, the following typology serves merely as a descriptive record, itself a platform for continued assessment of use-trace correspondences among like tools. These categorisations will form the basis for a synthetic research programme which can demonstrate most likely specific uses for individual tools and tool-types, based on ethnographic analogy, and with the potential for an experimental programme. Following this, we wish to understand how these tools functioned as constituent components within a larger cultural complex, by attempting to situate tools within the larger themes of subsistence, craftsmanship, industry, practice, ideology and meaning. For example, if a number of tools are consistent

with perishable-crafting activities, one might ask what this can tell us about the relationship between increasing sedentism and the emergent creation of perishable food collection, transportation, processing and storage technologies.

Reports from the Abbé Roche excavations undertaken at Taforalt during the 1950s indicate that 543 bone tools were recovered, the present location of which remains unknown (Roche 1963). Based on reconstructions of Roche's *Niveaux* system (in particular, its interpolation with the initial stratigraphic units of A, B and C), 206 tools (37.9%) were recovered from interior parts of the cave, 139 (25.6%), from the central parts and 198 (36.5%) from the more exterior parts. Though the subset of 200 tools currently available for study were recovered primarily from burial areas, it should be noted that over 60% of the Roche reported collection (present whereabouts unknown) were present in the centre of the cave and near its entrance, positions to be expected from 'everyday' manufacture and use activities. Additionally, those bone tools classed by Roche as 'points' in one form or another (e. g. *poinçons, alènes*, etc.) show an even greater bias towards the 'light zone' of the cave, where daylight would have made crafting and other activities practicable (**Fig. 4.2**). Pointed tools occur in the highest frequency near the exterior of the cave (n=108, or 47.3%), followed by the middle of the cave (n=64, or 27.9%), with fewest found in the cave's interior (n=57, or 24.9%) (**Fig. 4.1,** see Collcutt 2019 on the spatial distribution of Roche's Niveaux). Through an examination of such 'zones' of recovery, it may be possible to deduce where activities necessitating bone tools were likely to have taken place. For example, Roche recovered a total of 66 pointed bone tools from *Cav/Niveau C en avant*, (**Fig. 4.2**) a small area abutting the northern cave wall near the cave entrance (Collcutt 2019). While the fact that these tools cluster near the cave wall may indicate a passive accumulation, the much higher frequency in occurrence here suggests that the

manufacture and/or use of these tools was happening nearby, within probably the best-lit area of the cave. The presence of bone tools in great numbers outside burial areas necessarily informs the understanding of bone tools recovered within burial areas, and will be discussed further at the appropriate juncture.

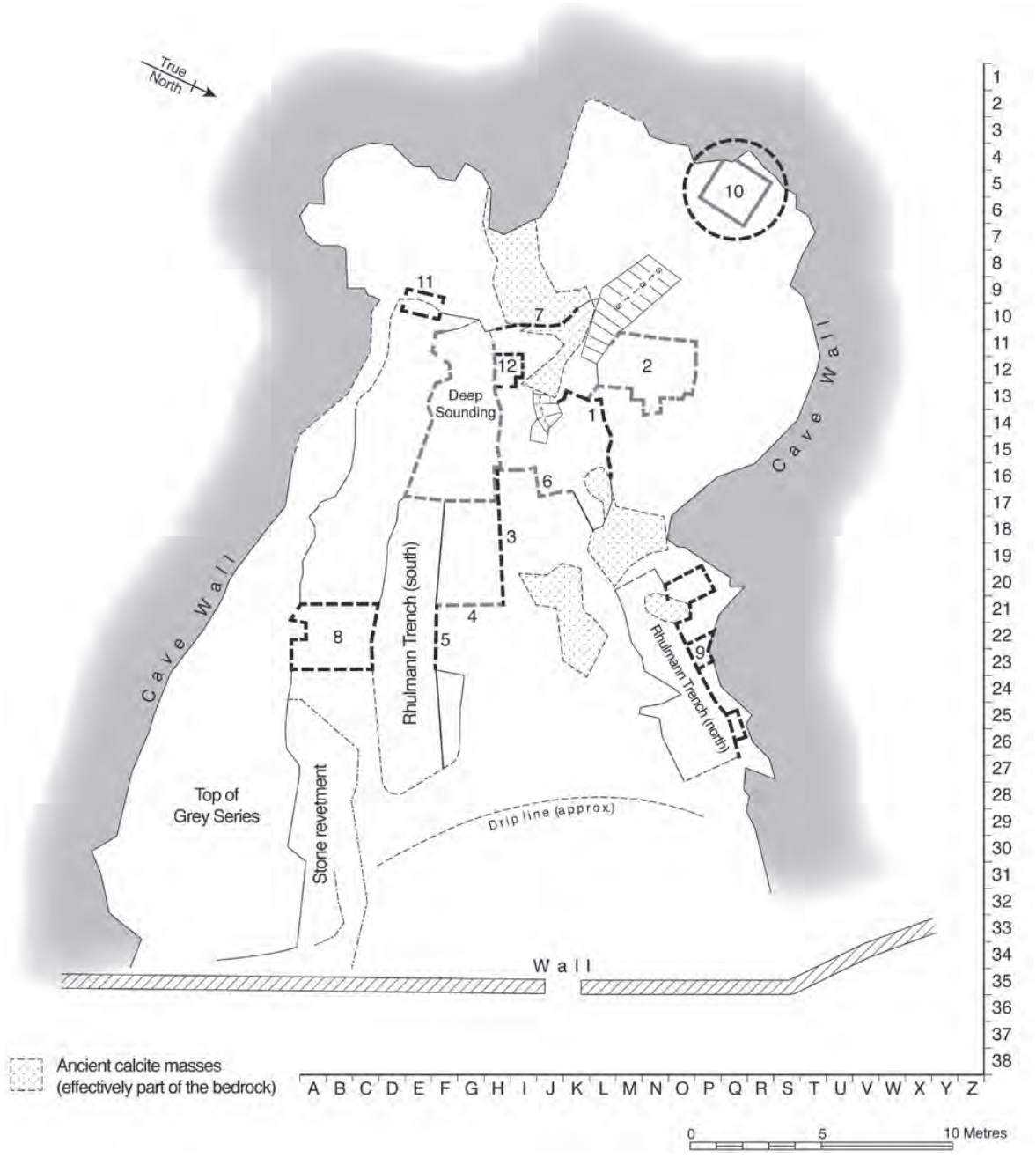


Figure 4.1: Site plan with current and former excavation sectors (Collcutt 2019)

Of the 200 tools currently available for study, 40 were excavated since 2003, during the current research programme. All but 2 of these (95%) were excavated from Sector 10

(**Figs. 4.1 and 4.3**, see Humphrey et al. 2019). Two tools were also recovered from Sector 8, during the excavation of a molluscan column. In November 2016, a collection of previously unpublished tools (n=161) was located in the Rabat Archaeological Museum, material which had been recovered during excavations at Taforalt in the 1950s. These are distinct from the collection of 543 tools reported in Roche (1963) and, like the post-2003 tools, were excavated primarily from burial areas (specifically *Nécropole I* and *Nécropole II*). These tools were contained in 16 different boxes and, in some cases, provenience data were written on either the boxes or the tools themselves. Four of these boxes retain a written date of '1952' (boxes 4, 6, 12 and 14). Many annotations found on the outside of these boxes remain obscure, and may refer to a variety of stratigraphic references (see Chapter 2). Following annotations where 'Sep' stands for *Sépulture*, seemingly indicating either single burial groups or wider zones within particular coarse stratigraphic units of the GS in the cemetery areas, and 'N' for *Nécropole*, indicating a cemetery area, 13 of the 16 boxes containing bone tools indicate that they were recovered from such areas (boxes 7 and 8 were determined not to contain bone tools). In his writings, Roche defined two different cemetery areas; namely, N1 (or NI) in the main alcove and N2 (or NII) further west (deeper into the cave) (Humphrey et al. 2019). Of the 16 boxes, seven are associated with *Nécropole I* (boxes 1, 2, 3, 9, 10, 14 and 15a) and two are associated with *Nécropole* II (boxes 4 and 11). Additionally, five different boxes relate to specific burial groups, boxes 5, 9, 12 and 12a, relationship to burial areas account for 97 of the 161 total tools; however, this may be an underestimation, as the remaining 64 tools came from boxes which had either indeterminate or no provenience data.

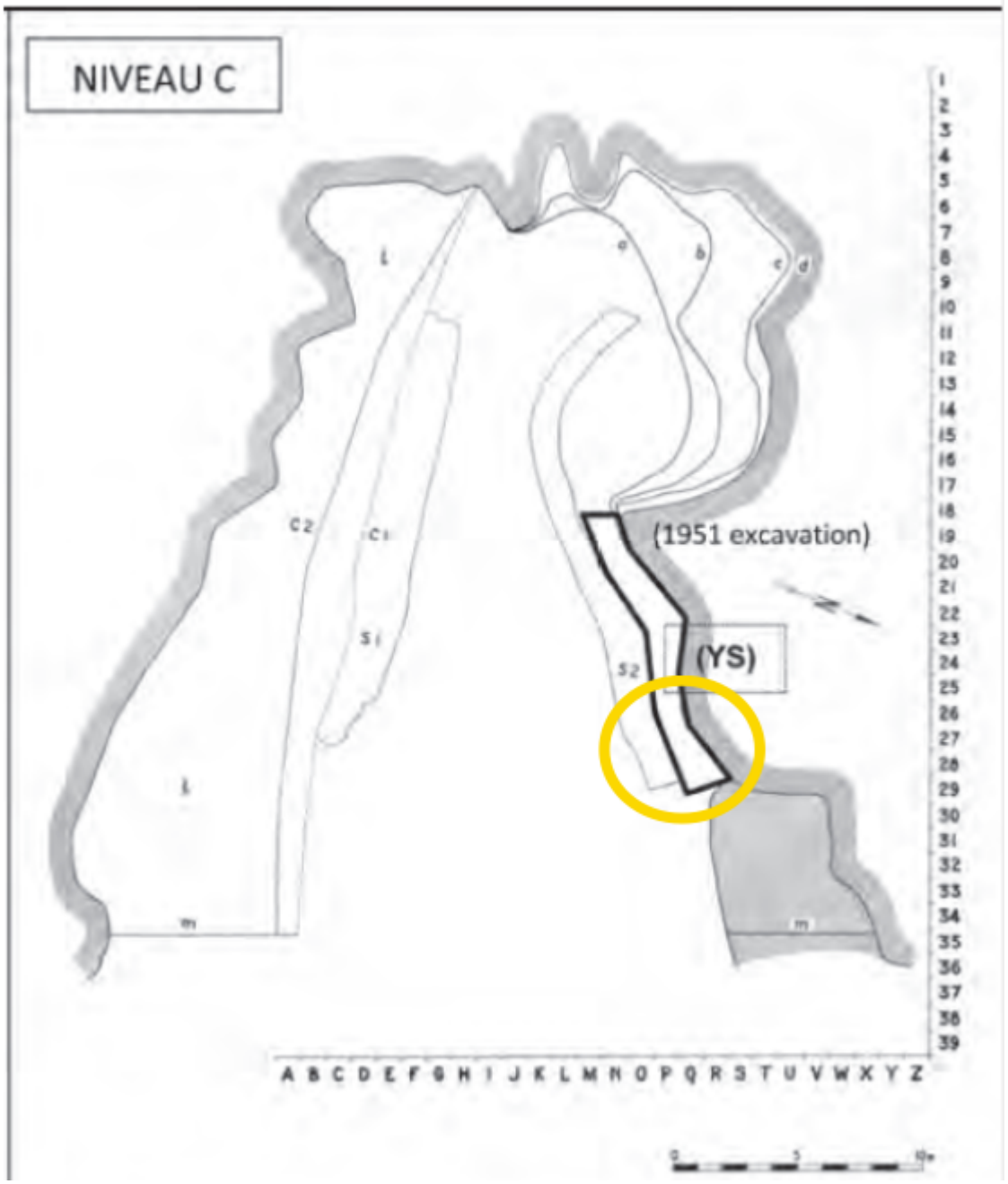


Fig. 4.2: Niveau C 'en avant' (modified from Collcutt 2019)

Because the majority of the tool subset available for study was recovered from burial areas, it is tempting to ascribe these tools a ritual or symbolic function, and/or to presume their deliberate placement as grave goods. Distinctively modern ontological categories of 'symbolic' vs. 'utilitarian' notwithstanding, it is, at present, difficult to untangle whether those tools found in burial areas do consist of deliberately placed tools, whether they are accidental inclusions present in the burial matrix, or a combination of

both. Among the 'missing' collection of 543 tools, the higher frequency in tools reported near the front of the cave in non-burial areas is suggestive. As sequential, intercutting burial episodes have been attested in Sector 10 (Humphrey et al. 2012), there is an indication that elements from previous burials were treated with care, and sometimes included in subsequent burials, placed to the side, etc. This suggests that burials were (at least initially) localised to a special, rear area of the cave, and due to the spatially delimited nature of the burial area, sometimes earlier burials were disturbed in the process of later ones. One obvious solution to this would have been to 'import' matrix from other areas of the cave; this could serve as a suspension medium for any new bodies being interred, and minimise the chances of disturbing earlier burials. That some Grey Series sediment was brought to Sector 10 for this explicit purpose is indicated by a number of other lines of evidence. For example, in the Grey Series, Sector 10 contains no structures associated with habitation areas (hearths, etc.), yet the matrix does contain artefacts associated with living areas, workshop areas, processing areas, etc., in the form of burnt and unburnt animal bones, lithic debitage, charcoal, etc. It is extremely unlikely that these activities were taking place in situ in Sector 10; at the very rear of the cave, Sector 10 is the least-lighted area of the cave and all such activities would have had to have taken place atop the burials (**Fig. 4.1**). It is far more likely that some of the Sector 10 Grey Series sediment was brought in from other areas of the cave, in order to facilitate new burial episodes and minimise the disturbance of previous ones. As such, any small habitation or industrial related inclusions in the Sector 10 Grey Series must be considered 'imported'; this, of course, should include the possibility that some of the smaller bone tools came to be deposited in the same fashion. Nevertheless, preliminary ZooMS analyses have suggested the inclusion of some of these tools with specific burial episodes;

for example, the placement of equid remains on the axial skeleton of Individual 1 (Desmond et al. 2018).

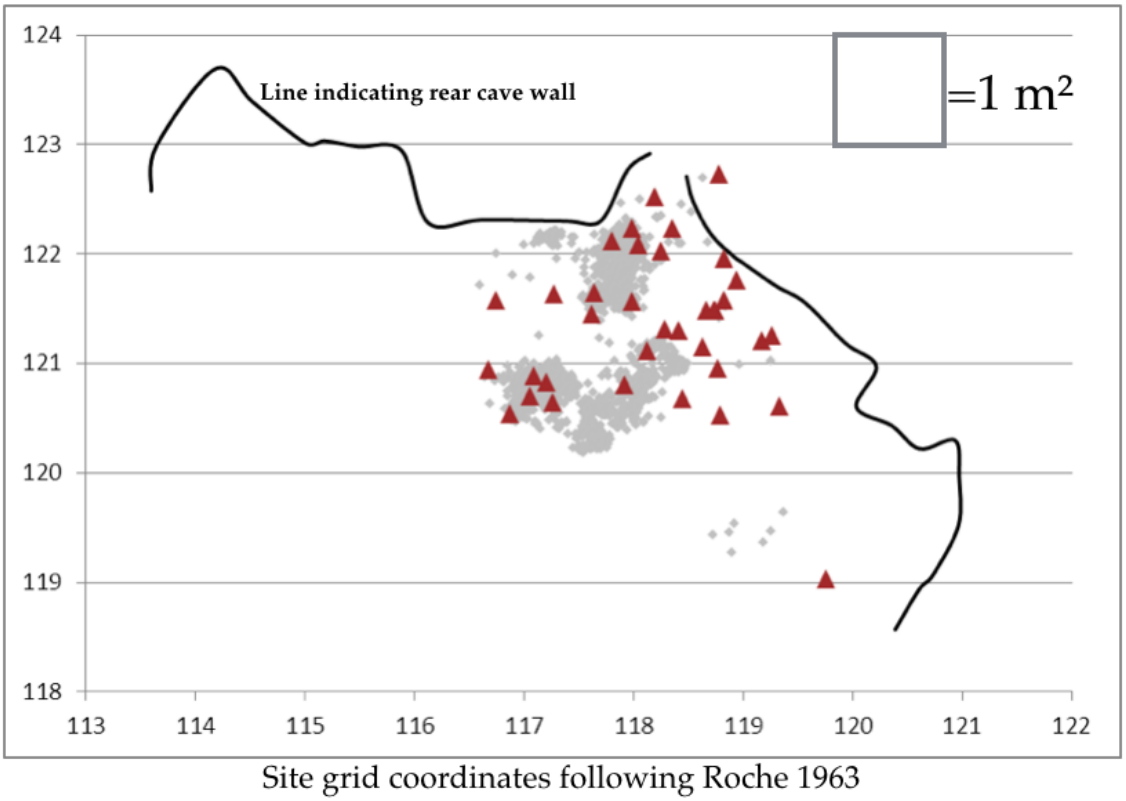


Figure 4.3: Sector 10 bone tools and all human bones plotted (red triangles indicate bone tools, grey patches indicate human bones [after Desmond 2017])

Furthermore, an initial analysis of the Sector 10 bone tools' spatial distribution appears to show that these do not form what we would expect from a passive accumulation, as evident, for example in '*Cav/Niveau C en avant*'; they do not cluster around the cave wall, but rather generally spread across the burial area (**Fig. 4.3**). Again, this could indicate either their deliberate inclusion as grave goods, or their unintended presence in imported Grey Series matrix. What is not indicated by this pattern is that Sector 10 served as a bone tool workshop area. Research into the distribution of tools within burials in *Nécropoles* I and II is ongoing; until such a point, however, specific determinations about the inclusion of smaller tools as deliberate or accidental should be

suspended. Further ZooMS research is currently underway, and this may shed light on a deliberate inclusion of tools created from particular taxa.

4.1.1 Methods and Terminology

In Palaeolithic North Africa, as elsewhere, osseous tools have generally not served as diagnostic elements of technocomplexes; lithic technology has usually served to define cultural entities. Though osseous tools are omnipresent in the world archaeological record, non-systematic descriptions and presuppositional, functionality-based characterisations of osseous tools (e. g. 'needles' or 'arrowheads' to describe gracile pointed tools) have served to obscure their true functions, and have hindered comparability between collections, both on an inter-site and inter-industry basis. For this reason, this study uses a morphological, feature-based typology without resorting to subjective categories (e. g. 'awls' or 'pins'). While a morphologically descriptive typology must be developed in order to assess tools' quantitative and qualitative attributes, this is undertaken only as a preparatory stage in order to facilitate a more broad *chaîne opératoire* understanding of tools, based on specific correspondences in construction and use-wear, rather than on general correspondences in overall size and shape.

The first step in developing a descriptive typology is to examine the tools physically, to create descriptive categories, and to use these to guide the collection of comparable quantitative and qualitative data. At present, few typological studies have been undertaken on North African bone tool technologies. One notable exception is the work of Camps-Fabrer, whose 1966 study analysed tools from a number of North African

Palaeolithic sites, including Bou Zabaouine, Columnata, Afalou Bou Rhummel, Tamar Hat and a few tools from Taforalt, among others (Camps-Fabrer 1966). As had Roche (1963) originally, Camps-Fabrer assigned tools to different categories based on an assessment of functionality due to gross form, largely following the French prehistoric bone tool tradition (with categories including *tranchets, lissoirs, poinçons, alènes*, etc.) (Camps-Fabrer 1966:51). Camps-Fabrer's work therefore provides a ready comparative study for interrogating typological correspondences, particularly between the European Aurignacian and Magdalenian and the North African Palaeolithic. Though some authors posit cultural and/or technological connections between the European and North African Palaeolithic, as yet no evidence has been found linking contemporary North African and French/European Palaeolithic technocomplexes (contra Ferembach 1962, Pallary 1909, etc.). For these reasons, I have chosen to develop an independent typological schema, rather than use Camps-Fabrer's (or Roche's) extant categorisations, which are themselves embedded in the study of the European Upper Palaeolithic.

In creating an analytical approach to tools from Taforalt, I have also chosen to eschew whole-tool typological descriptions, as most extant bone tool typologies use functional descriptors (e. g. awl, pin, polisher, etc.) as category names. These can serve to presuppose (and potentially obscure) individual tool functionality from a use-wear perspective, as tools are de facto presumed to have been used as members of their eponymous classes. Ethnographic and archaeological collections worldwide prove that a similarity in gross morphology often belies any similarity in use. Long thin pointed tools, classed together as 'needles', are shown to have specific applications, ranging from roof-thatching tools, to tools for threading fish, to spindles (Soffer 2004:408). While initial typological categories must rely, to a certain extent, on overall shape and tool

morphology, these typological categorisations will here serve only as a basis for assessments of tool functionality driven by use-wear criteria. It is our hope that the future application of associative statistics and/or cluster analyses to these quantitative and qualitative characteristics (such as degree of completeness, tip type, profile type, base type, size class, etc.) will eventually provide a firmer basis for apprehending correspondences and differences in use-wear patterning, and therefore functionality.

This approach will also allow tools to be grouped inclusively, rather than solely by assigning each tool to one of a number of mutually exclusive type categories. This is important, as a single tool may display characteristics of more than one functional class (e. g. being both spatulate and pointed, incised and fragmentary, etc.). I use Douglas Campana's 1989 study of Natufian and Zagros Proto-Neolithic osseous tools and Mark Newcomer's 1974 study of Natufian osseous tools as the basis for much of the following typology. These studies have been chosen because they investigate transitional Levantine Epipalaeolithic bone tool technologies in many ways similar to the Iberomaurusian, and both studies include robust experimental components. The typological methods (and therefore results) employed here will also then be comparable with those describing many pre-Neolithic Levantine bone tools. In the descriptions, rather than 'distal', 'medial' and 'proximal', I use the terms 'tip', 'shaft' and 'base' to refer to the ends and body of the tool (Campana 1989, Newcomer 1974). I use this terminology to avoid confusion with anatomical descriptions of the skeletal element from which the tool was created; for example, sometimes a distal epiphysis served as a tool's base, though in other categorisations this would be called the proximal part of the tool. To simplify, here the term 'tip' refers to the working end of the tool, the term 'base' refers to the held, hafted or

otherwise articulated non-main working end, and 'shaft' refers to what otherwise might be considered the medial or mesial portion of the tool (between the base and tip).

4.1.2 Typological Categories

4.1.2.1 Degree of Completeness

In considering the tools, the degree of completeness of each tool is first assessed into a binary, as being either complete or broken. Next, examination is made of where the tool shows breakage(s): e.g., to the tip, base, etc. (**Tab. 4.1**). By using these categorisations, relevant data can still be extracted even from incomplete tools. For example, when calculating the average tip-diameter of pointed tools, complete, relatively complete, and pointed tip fragments shall all be considered. When determining the types and degrees of smoothing evident on bases, complete, relatively complete, and base fragments will all be considered. This format allows for a more inclusive appraisal of individual features, without having to discount all but complete tools. As many tools have elements which may not have been modified even at the time of their use (e.g., tools with a broken or epiphyseal base), these are categorised as 'relatively complete'. This category includes tools which do not display clear recent or taphonomic alteration (e.g., different colours, sharp angles, etc., at breaks), and may have functioned as tools in their current form. This category includes tools with indeterminate levels of completeness, such as weathered tools. It also includes tools with re-fitting breaks which can be examined as though they were whole. Points which show breaks only at the very point tip are also considered relatively complete, as their morphology, formation strategies, use-traces, etc., can all be

examined given the extant tool, and size-categorisations will not be greatly affected. In these cases, however, tip-diameter cannot be assessed.

Breakages	Category
Broken tip	Base fragment
Broken base	Point/ovoid/spatulate etc. fragment
Broken base and tip	Shaft fragment
Broken irregular/indeterminate	Broken end
With refitting breaks or without visible breakages	Relatively complete
No breakages	Complete

Table 4.1 Breakage categories

4.1.2.2 Size Measurements

Next, all tools are measured and their maximum length, maximum width and tip diameter (for points) are recorded. These measurements are taken on all complete and relatively complete tools, and these data are plotted in order to determine size-clustering of the tools and tool types. Measurements were taken using digital callipers at the longest/widest point for each tool. For points and point fragments, tip-diameter measurements were taken in accordance with Campana's 1989 study of Natufian tools, in order that these data should be comparable between the two studies. Because of the nature of varied point-tip symmetries, shapes, etc., the tools were measured using digital callipers as close to the point-tip as possible, and along the widest cross-sectional platform when the point tip is asymmetric.

After determining the most prominent typological features among the tools, tool size can be plotted to uncover correspondences and patterning within and between different types. Here I use two different analyses: a basic length/width size plot (**Fig. 4.4A**), and a surface-area proxy (here called 'size-value') (**Fig. 4.4B**). Though all tools were measured, only complete or relatively complete tools are plotted for size (to the exclusion

of all fragments) based on their maximum length and maximum width (**Fig. 4.4A**). For **Figure 4.4A**, size category determinations were constructed using the following criteria: small tools are considered as such if their length times width is 70% or less of the average length times width, medium tools have size-values within 71% to 129% of this average, and large tools have size-values of 130% or more of this average. As is evident from this chart, there exists quite a wide spread of tool-size, but most tools fall into the small size category. This clustering is interesting, as, although larger tools are represented, their presence is not enough to pull the average size toward 'medium'.

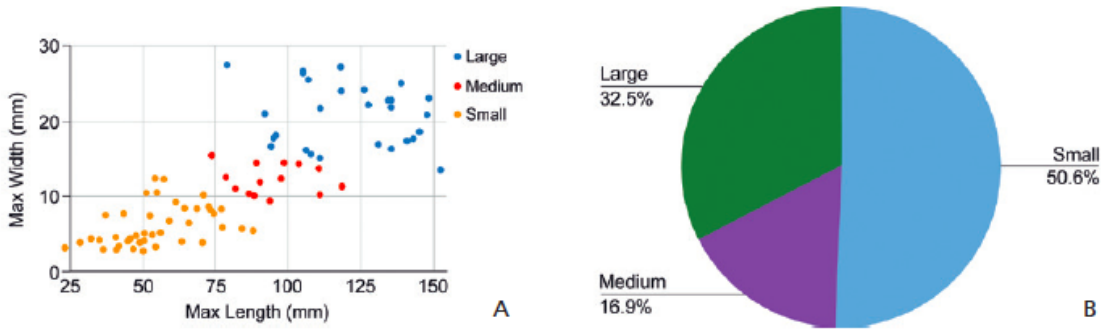


Figure 4.4: A: Complete tool size distribution plot; B: Complete tool size-value determinations (After Desmond, 2017)

While this length times width value is a useful metric for constructing tool size categories, it does not give any idea as to the tools' surface area. For this reason, a size proxy for the surface area of each tool has also been created, using the square root of maximum length times maximum width for each (**Fig. 4.4B**) (following Hodgkins et al. 2016). While this size-value does not provide a mathematically exact representation of a tool's total surface area, it has the advantage of assigning each tool a single, individual size-value. This value can then be plotted and compared to the size-values of other tools and tool-types. At Taforalt, the average size-value for all 83 complete and relatively

complete tools of all types is 30.99 mm. Here, surface area size-value determinations were constructed using the same criteria as size categories: small tools are considered as such if they have size-values of 70% or less of the average (50.6% of total); medium tools have size-values within 71% to 129% of the average (16.9% of total), and large tools have size-values of 130% or more of the average (32.5% of total) (**Fig. 4.4B**). Both of these analyses provide useful benchmarks in understanding the size and surface area of complete tools. When considering use-wear and functionality at a later stage, it is important to understand where an individual tool falls within a comparative size spectrum specific to that assemblage being examined.

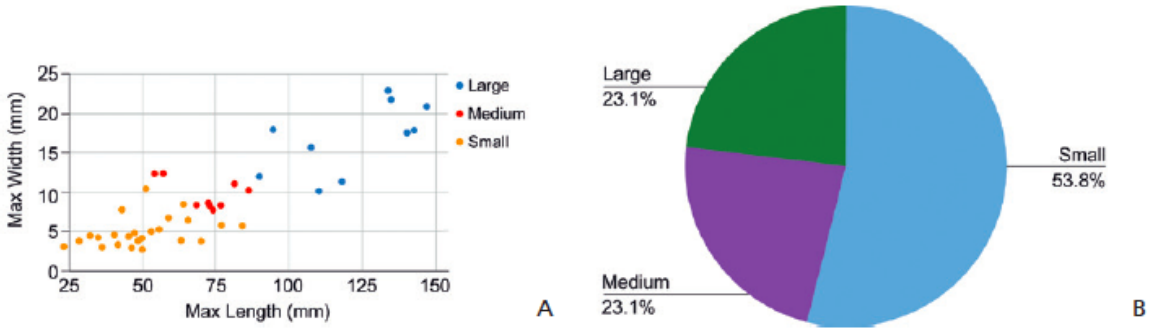


Figure 4.5: A: Complete point size distribution plot; B: Complete point size-value determinations (After Desmond, 2017)

Understanding both tool size and rough surface area are crucial when attempting to understand correspondences between overall shape, formation strategy, and use-wear.

As pointed tools are the most numerous type at Taforalt, these were naturally included in the first size distribution assessment. However, because of the great number of pointed tools (67.9% of the total assemblage; see **Fig. 4.5**), I have also established internally relative size groupings for pointed tools, to the exclusion of all non-pointed forms. As with the first size class assessment, only complete and relatively complete

pointed tools have been considered. As **Figure 4.5** illustrates, most points again cluster within the smallest size class and size-value, even when larger tool-types (e.g., spatulate pointed and metapodial pointed tools) have been included. While small pointed tools are the dominant component of the assemblage, medium and large pointed tools both represent 23.1% of total pointed tools (in contrast to large tools representing 32.5% of the total overall assemblage; see **Fig. 4.4B**). Future comparative use-wear studies must be based on comparison with ethnographic tools of a similarly small size. While not enough to determine specific tool uses, it is clear from size class data alone that the spectrum of possible functional categories for the smallest Taforalt points can be constrained.

Following points, the next most common tool characteristic is spatulate tools. All complete and relatively complete tools which can be classed as 'spatulate' (inclusive of spatulate ovoid [spatulate tools with an ovoid tip], spatulate point [spatulate tools with a pointed tip], etc.) have been considered. This analysis was based on a total of 15 complete or relatively complete spatulate tools (15% of total complete or relatively complete tools). Represented here are the proportions of small, medium, and large tools within the general length times width size categories (rather than surface area approximations/size-values) (**Fig. 4.6**). Following points and spatulate tools, the next most numerous tool categories contained less than ten elements, shown in **Tab 4.2**.

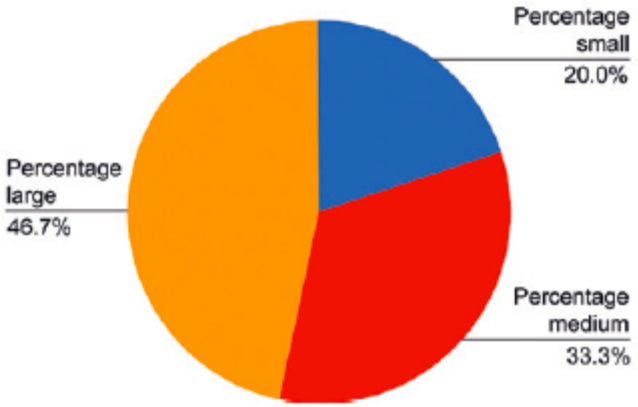


Figure 4.6: Size categories for spatulate tools

4.1.2.3 Shaft Types

All tools and tool fragments are then assigned a shaft type, consisting of one of the types shown in **Table 4.2** and **Figure 4.3**. Shaft type assessments were made by laying the tool on its widest face and viewing the shaft in profile. Here tools with a 'faintly x' profile have been grouped in with the general profile; for example, tools with a 'faintly concave' profile will be grouped with tools with a 'concave profile'. Though these types function as discrete categories, it is important to remember that similar or identical uses may produce different shaft types, and/or different uses may produce similar shaft types, in part based on the original morphology of the bone used and the degree of use. For example, concave (**Fig. 4.7f**), asymmetric steep mid-shaft angle (**Fig. 4.7m**) and asymmetric concave (**Fig. 4.7g**) could be formed by similar kinds of use-wear, or may represent different use-wear stages for the same tool type. Since the true shape of a shaft type may not be evident in broken tools, only complete or relatively complete tools were assessed for diagnostic shaft-type (**Tab. 4.4**).

Metapodial tools (n=7)	• **7 large tools, 100 %**
Double-ended tools (n=6)	• 6 small tools, 100 %
Ovoid tools (n=5)	• 1 small tool, 20 % 4 large tools, 80 %
flat bevels (n=5) *see **fig. 13.1.8n**	• 4 small tools, 80 % 1 large tool, 20 %

Table 4.2: Size categories for other tool types

Parallel (fig. 13.1.4a)	**Curved (fig. 13.1.4h)**
Parallel converging (**fig. 13.1.4b**)	Angled (**fig. 13.1.4i**)
Convex (**fig. 13.1.4c**)	Asymmetric angled (**fig. 13.1.4j**)
Asymmetric Convex (**fig. 13.1.4d**)	Asymmetric peak (**fig. 13.1.4k**)
Convex tapering (**fig. 13.1.4e**)	Steep mid-shaft angle (**fig. 13.1.4l**)
Concave (**fig. 13.1.4f**)	Asymmetric steep mid-shaft angle (**fig. 13.1.4m**)
Asymmetric concave (**fig. 13.1.4g**)	Irregular (**fig. 13.1.4n**)

Table 4.3: Shaft type

Parallel n=8, 7.8 %	**Curved n=8. 7.8 %**
Parallel converging n=34, 33 %	Angled n=1, 1.0 %
Convex n=7, 6.8 %	Asymmetric angled n=11, 10.7 %
Asymmetric Convex n=6, 5.8 %	Asymmetric peak n=2, 1.9 %
Convex tapering n=6, 5.8 %	Steep mid-shaft angle n=1, 1.0 %
Concave n=2, 1.9 %	Asymmetric steep mid-shaft angle n=6, 5.8 %
Asymmetric concave: n=3, 2.9 %	Irregular n=3, 2.9 %

Table 4.4: Shaft type percentages

Shaft types in themselves can reveal some information as to the nature of a tool's function. For example, tools with a marked shaft asymmetry can provide clues as to the direction-of-movement of the tool, if, for example, one side or edge is worn down more than another (assuming an initial symmetry in shaping). Shaft asymmetries resulting from preferential wear can be borne out by an investigation of polish along the affected areas (with higher polish indicating more extensive use/handling), and/or the presence of lithic striations or undulations (discussed below). Considering the overall shape of a tool shaft is a crucial step in finding best-fit matches among ethnographic tool collections, as the location and degree of wear (e.g., polish to the tip end only or along the whole tool)

affect the entire shaft profile, and can demonstrate concentrated and/or diffuse use foci along the tool's shaft.



Figure 4.7: Shaft type (after Desmond, 2017)

Straight/non-undulating (fig. 13.1.5a)	Undulating (one side) (fig. 13.1.5c)
Faintly undulating (fig. 13.1.5b)	Undulating (fig. 13.1.5d-e)

Table 4.5: Shaft profile

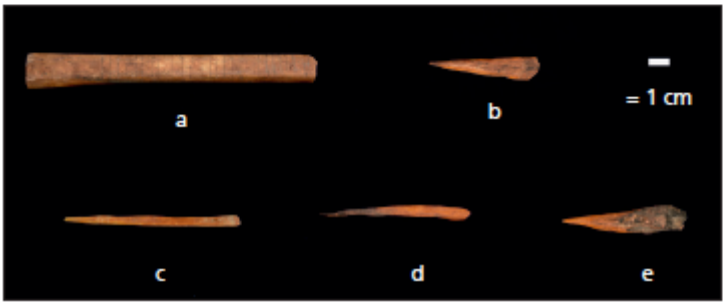


Figure 4.8: Shaft profile (after Desmond, 2017)

4.1.2.4 Shaft Profile

Following shaft type, all tools are assessed for their shaft profile, and grouped into one of the categories shown in **Table 4.5** and **Figure 4.8**. The profile of the tool shaft (straight or undulating) may also offer clues as to the tool's degree, stage and manner of use. Undulating profiles occur when a tool's natural morphology or breakages have been smoothed over, rounded and or obliterated, indicating lithic shaping or long-term repeated use. Manner-of-use categories in tools with undulating profiles can also be inferred, because, in order to gain this profile, they must be continuously abraded against a material softer than bone (e.g., repeatedly passed through a softer yielding material), held in the hand, etc. Undulating profiles can also be a product of lithic (re-)sharpening (Newcomer 1974, Campana 1989). In cases where the tool was deliberately shaped or reshaped, longitudinal lithic striations will be visible; if lithic striations are obliterated/not present, the tool can be inferred to have long-term repeated articulations with a material softer than bone (Campana 1989). At Taforalt, 35.3% of tools exhibit some degree of undulation, ranging from faint to strong undulation (**Fig. 4.9**).

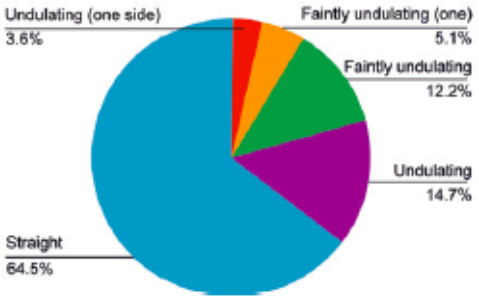


Figure 4.9: Shaft profile percentages for all types, complete and fragmentary

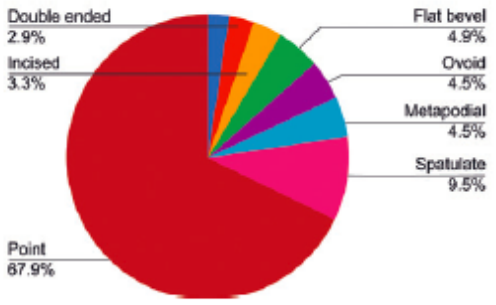


Figure 4.10: Inclusive types

While the lack of an undulating profile does not preclude re-sharpening and re-use of tools, the presence of undulations is an excellent indicator that a tool has been smoothed through repeated use, lithic re-sharpening or a combination of both. For example, a bone tool which was shaped from a splinter with irregular edges will, through repeated contact with material softer than bone, display smoothing and rounding of these irregular edges consistent with an undulating profile. Undulation then is a useful criterion in determining the stage of a particular tool's use, as it implies long-term and repeated articulations with a material softer than bone, and/or, in the case of lithic re-sharpening, the deliberate curation of tools. There is an observable difference between initial shaping and resharpening of used bone tools: for example, the presence of polish and/or use wear obliterating and/or overlying lithic scraping striations (e.g., striations seeming to 'fade' into polish) indicate that the tool has been used since it was initially shaped. When imparted as a result of longitudinal lithic scraping, undulating profiles can appear in the form of chattermarks. These are visually distinctive and, according to Newcomer (1974:149):

> [...] chattermarks seem to be caused by the stone tool bouncing over uneven parts of the bone surface and thus failing to maintain contact with the bone throughout its sweep. An analogous situation occurs on unmetalled roads, which inevitably develop ruts, and corrugations perpendicular to these ruts through the failure of passing vehicles wheels to maintain constant contact with the road's surface.

4.1.2.5 Discrete and Inclusive Types

Once measurements, degree of completeness, shaft type and shaft profile have been assessed, the gross form of the tool will be typed as a member of one of the discrete

categories listed below. These categories, however, do not preclude inclusive analyses of individual features, wherein all tools exhibiting a certain characteristic (e.g. 'pointed tools') are considered together (e.g., spatulate pointed, point fragment, irregular point, etc.).

Name of parent category	**Total number of elements, and percentage of overall assemblage**	**Name, number, and percentage of subtypes**
Pointed tools	n=101 50.5%	• Point: n=64, 32% • Point fragment: n=37, 18.5%
Incised tools	n=8 Approx. 4%	• Incised point: n=2, 1% • Incised hollow: n=4, 2% • Incised irregular: n=1, >1% • Incised shaft fragment: n=1, >1%
Flat bevel tools (those tools with a flattened platform at the tip)	n=9 4.5%	• Flat bevel: n=5, 2.5% • Flat bevel fragment: n=4, 2%
Ovoid tools	n=5 2.5%	• Ovoid: n=5, 2.5%
Metapodial tools	n=11 Approx. 5.5%	• Metapodial point: 4, 2% • Metapodial burin: n=1, >1% • Metapodial fragment: n=6, 3%
Spatulate tools	n=23 Approx. 11.5%	• Spatulate: n=3, 1.5% • Spatulate point: n=7, 3.5% • Spatulate burin: n=1, >1% • Spatulate point fragment: n=3, 1.5% • Spatulate ovoid: n=5, 2.5% • Spatulate ovoid fragment: n=1, >1% • Spatulate shaft fragment: n=3, 1.5%
Double ended tools	n=3 Approx. 1.5%	• Double ended: two points: n=2, 1% • Double ended: one point one burin: n=1, >1%
Irregular tools	n=5 Approx. 2.5%	• Irregular: n=2, 1% • Irregular point: n=1, >1%

		• Irregular fragment: n=1, >1% • Irregular: tooth: n=1, >1%
Indeterminate tools	n=6 Approx. 3%	• Point/double ended: n=2, 1% • Point/double ended fragment: n=2, 1% • Base/shaft fragment: n=1, >1% • Burin/shaft fragment: n=1, >1%
Shaft fragments	n=18 9%	Shaft fragment: n=18, 9%
Base fragments	n=11 5.5%	Base fragment: n=11, 5.5%

Table 4.6: Percentages of discrete types

Though there exists a wider spread of potential categories (e.g., ovoid fragment), only those categories represented within the Taforalt data-set are included. Here tools are assigned to either the 'parent' category (e.g., 'spatulate') or to a relevant descriptive sub-category (e.g., 'spatulate flat bevel') (**Tab. 4.6**). From these data, it is clear that most of the discrete types only contain a few elements, with points, point fragments, shaft fragments and base fragments accounting for nearly 65% of total tools. While types containing only one element may have the potential to be diagnostic, those represented here are not, and as such the study of categories with few elements (one or two) will be left until later.

Category	Subtypes
Symmetrical	Symmetrical pointed (**fig. 13.1.8a**) Symmetrical rounded (**fig. 13.1.8b**) Symmetrical gouged (**fig. 13.1.8c**) Symmetrical rounded gouged (**fig. 13.1.8d**) Symmetrical irregular (**fig. 13.1.8e**)
Acute	Acute pointed (**fig. 13.1.8f**) Acute rounded (**fig. 13.1.8g**) Acute rounded gouged (**fig. 13.1.8h**) Acute irregular (**fig. 13.1.8i**)
Obtuse	Obtuse pointed (**fig. 13.1.8j**) Obtuse asymmetric (**fig. 13.1.8k**) Obtuse rounded (**fig. 13.1.8l**) Obtuse gouged (**fig. 13.1.8m**)
Flat bevel	Snapped (**fig. 13.1.8n**)
Spatulate	Convex spatulate (**fig. 13.1.8o**)

Table 4.7: Point types

Triangular n=12 (**fig. 13.1.10a**)	Minimally modified n=43 (**fig. 13.1.10f**)
Angular n=10 (**fig. 13.1.10b**)	Intact anatomical n=14 (**fig. 13.1.10g**)
Ovoid n=12 (**fig. 13.1.10c. d**)	Flattened n=6 (**fig. 13.1.10h**)
Irregular n=8 (**fig. 13.1.10e**)	

Table 4.8: Base type counts

Within this discrete categorisation, tools which possess more than one diagnostic feature are seperated (e.g., spatulate points), and grouped in a qualitative way as members of the category which describes their most 'prominent' feature (e.g., metapodial flat bevels are classed as metapodial tools, rather than as flat bevels). Discrete categorizations necessarily prevent tools being considered as members of more than one category. For this reason, an inclusive attribute typology has also been created, wherein a single tool may be counted in multiple attribute categories at once. For example, in this inclusive attribute typology, a spatulate point would be grouped with both 'spatulate' and 'point'. Though some tools will be counted more than once, inclusive categorization allows for more robust comparisons to be made among tools with like features (**Fig. 4.10**).

This kind of analysis allows trends across otherwise discrete types to become much more clear. From most to least common, the most prominent features of tools from Taforalt are: pointed, spatulate, metapodial, ovoid, flat bevel, incised, double-ended, and irregular.

4.1.2.6 Point Type

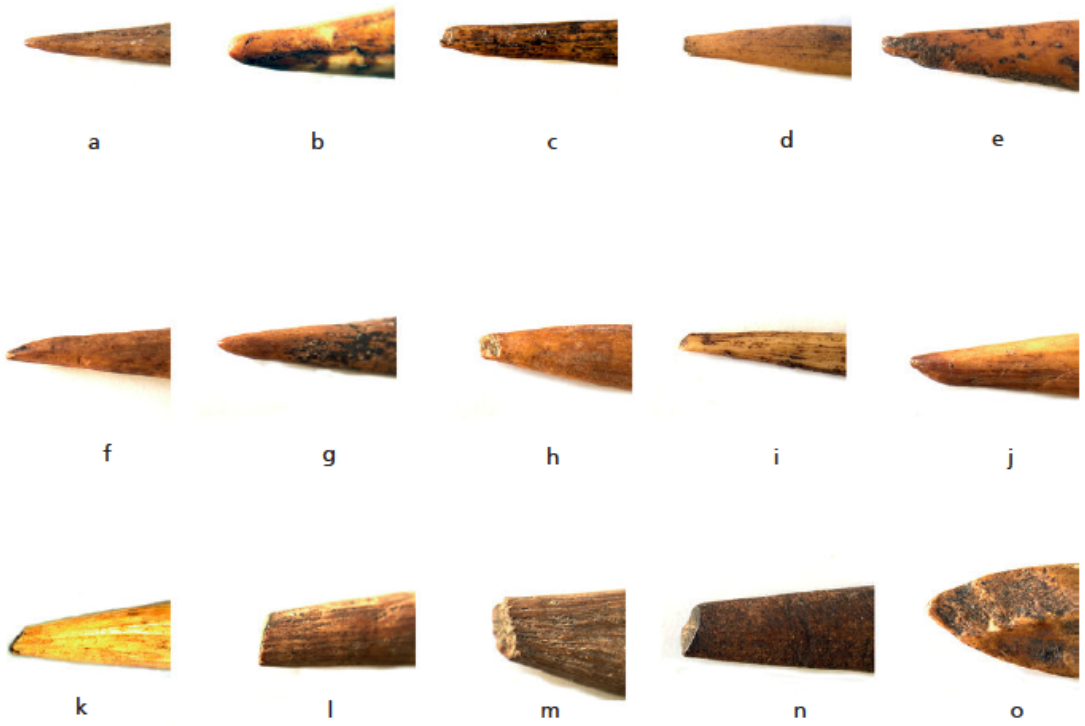


Figure 4.11: Point types (after Desmond, 2017)

Points, flat bevels (tools with a flattened platform at the point tip; see **Fig. 4.11n**), and spatulate points (and fragments thereof) are then further classed by point type, based on their point-tip profile. Point-tip profile assessments were made by laying the tool on its widest face and viewing the tip of the pointed end of the tool in profile. This category considers only the very tip of the point, as the tool itself may have concave, convex or

irregular sides, faces or edges (accounted for in the shaft profile). Though other point-type combinations are possible, only those categories represented within the Taforalt data-set are listed in **Table 4.7** and **Figure 4.8**. As with shaft type, these categories may represent different stages of use within the same manner of use, or differences may be due to repurposing, sharpening, etc. There may be correspondences across types as well; for example, 'acute pointed' (**Fig. 4.11f**) and 'obtuse pointed' (**Fig. 4.11j**) may have effectively served the same purpose, and similarly 'symmetrical rounded' (**Fig. 4.11b**) and 'acute rounded' (**Fig. 4.11g**). The notion that tools served a singular purpose within their life must also be avoided; along with re-purposing, it is possible that an individual tool could have served many different functions, both synchronically (e.g., using a thin tool as a convenient toothpick) and diachronically (a tool used for one purpose becomes better suited for another purpose as it is used). However, using these data to track correspondences between tip-type and other tool features may allow for an understanding of congruences between different forms, morphologies and kinds of use-wear, and, as such, is considered a useful typological metric. Since in most cases the active edge (or tip) of the tool manifests the bulk of the information relating to use, these categories have been expanded to include more types rather than less, in order to get a higher resolution picture of correspondences between tip-type and other tool features. The results of this analysis are as follows (**Tab. 4.8**, with cross-references to the photographs in **Fig. 4.11**). For pointed tools, the most common tip-type is 'symmetrical pointed'. Not all symmetrically pointed tips are perfectly sharp; the tip-diameter and roundedness of the point tip should be viewed on a continuum and as potentially representative of different stages of use (e.g., Campana 1989:69).

4.1.2.7 Tip Diameter

Another useful tool for understanding potential uses of pointed implements is to measure the tip diameter. Experimental studies have shown that among pointed bone tools, different tip diameters are suited to different practises; for example, point-diameters above 2 mm are not effective in the penetration of leather (e.g., Campana 1989, Legrand and Radi 2008, Stone 2009, Wojtzack and Kerdy 2018, etc.). Tip diameters were measured on a sample of 60 implements with intact points; the average tip diameter is 1.26 mm, with the distribution of tip diameters as shown in **Fig. 4.12**. As this chart shows, the most common tip-diameter range is between 0.5 mm and 2 mm, which account for just over 88% of all tools measured. These data underline the trend in small features, size-classes, etc., among points, indicating that these gracile bone points generally had very small tips as well. Clues as to function are further indicated through use-wear present on the tools' tips, discussed at a later stage, which suggests that these were not sharpened to a fine point and then abandoned before use. In order to address the potential for equifinality, however, the only way to investigate particular functionalities is through an examination of use-wear. Though a small point tip size is suggestive, it is the presence of wear to the tip which will suggest specific functions, whether basketry weaving, hideworking, projectile use, or otherwise. Tip diameter data taken together with forthcoming microscopy and micro-topographic analyses may help to uncover specific size-class, point type, point-diameter and use-wear patterning, revealing the presence of repeated industrial types with similar use-wear through time.

4.1.2.8 Base Type

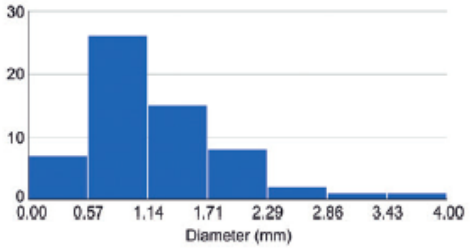


Figure 4.12: Point tip diameter counts

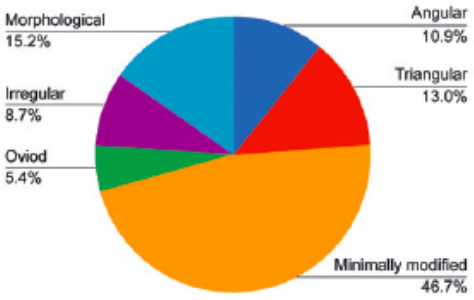


Figure 4.13: Base type percentages

Next, complete tools, relatively complete tools and base fragments are categorised by base-type. Here the presumed 'base' of the tool is considered. This category describes the shape of the base when (if applicable) the tool is lying on its widest face (**Tab. 4.8 and Fig. 4.13**). 'Base type' represents solely a categorisation based on overall shape, and yielded the results shown in **Table 4.8** and **Fig. 4.14.**

That the most numerous category among base types is 'minimally modified' is perhaps no surprise; it is this feature, in large part, that allows us to identify the (opposed) working end of the tool. However, correspondences between base type and point type, or base type and shaft type, may be revealed under a more thorough examination of use-wear.

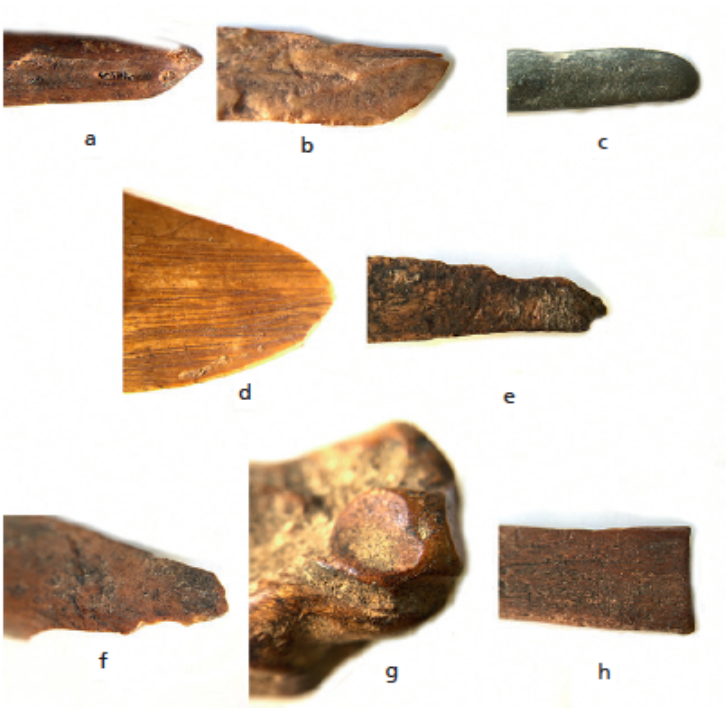


Figure 4.14: Base types (after Desmond, 2017)

For example, tools with an unmodified base and an irregular shaft are less likely to show use-wear on the base end, indicating that the working portion of the tool/active edge was highly concentrated at the tip, or, in some cases, extending no more than halfway down the shaft. Tools which were only used at the tip eliminate a number of potential uses, and, when combined with an examination of use-wear patterning, may suggest specific uses.

4.1.2.9 Base Smoothing

After the shape of the base has been assessed, I then categorise tools by the degree of smoothing or polish present on the base. Smoothing at the base is a meaningful feature of tools, as it may indicate the stage of use (e.g., from faintly smoothed/less used to very smoothed/highly used). Smoothing and/or polish specifically were not assessed for the tips of the tools; as the tips are the 'working end' of the tool, it is to be expected that they will exhibit use-wear here. Smoothing/polish on the base, however, may provide clues as

to how the tool was engaged during use, with significant smoothing indicating repeated abrasive contact with a material softer than bone, and can be a good indication of hand-held uses or hafting (Campana 1989:68). I have chosen to examine for 'smoothing' rather than 'polish', as tools which exhibit very smoothed bases may not exhibit polish because of the nature of the bone; e.g., weathering, differential cleaning techniques or the base being obscured by matrix/concretions. In order to assess base-smoothing, tools have been classed into three categories (**Fig. 4.15**).

- Faintly smoothed (**Fig. 4.15b**)
- Moderately smoothed **(Fig. 4.15c**)
- Well smoothed (**Fig. 4.15d**)

Tools with a well-smoothed base may in some cases have been double-ended tools, although, unless an equal amount of diagnostic use-wear is present at the base of the tool, it will not be typed as such. As a result, the number of double-ended tools may be an underestimation. Degrees of smoothing may also indicate different stages and/or degrees of use, and as such, tools with different degrees of smoothing on the base should not necessarily be considered to have been used in different ways. For example, tools with well-smoothed and faintly-smoothed bases may have been used the same way, and exemplify different stages of wear imparted by the same function, rather than different uses. In order for tools to have been classed as possessing 'faintly smoothed' bases, these tools must display more roundedness and/or polish on the base than do tools examined as unmodified taphonomic control samples (e. g. **Fig. 4.15a**).



Figure 4.15: Base smoothing: a: unmodified bone; b: faint smoothing; c: moderate smoothing; d: highly smoothed (after Desmond, 2017)

Photos of these control samples show the degree of rounding that one might expect to occur on unmodified animal bone excavated from the same or neighbouring archaeological contexts. Since some unmodified faunal controls show incipient rounding (assumed to be post-depositional), a slightly more advanced (yet still 'faint') degree of rounding has been taken as the threshold for recognition as an artefactual effect here. The degree of smoothing on base types is shown in **Fig. 4.15.**

As **Table 4.16** shows, the degree of smoothing when all tool bases are considered together is almost equally distributed between the three categories. One can further examine degrees of base smoothing by tool-type, to see if this internal ratio holds true among different tool-classes, particularly points (**Fig. 4.16B**). Among points, a different patterning of abrasion to the tools' bases emerges. Here, faint smoothing is present on 39.4% of tool bases, moderate smoothing on 18.2%, and well-smoothed bases are evident on 42.4%. Clearly there is a visibly higher percentage of well-smoothed and faintly

smoothed bases among pointed types, which may be an indication of different curation of pointed tools (e.g., used for longer durations).

The presence of different degrees of base smoothing demonstrates that the tools at Taforalt likely represent different 'life' stages of tools with similar uses. Faint smoothing at the base of the tool can be an indication of earlier stage uses, where the abrasive, repeated contact of the hand or haft has only begun to wear-down the tool's base. This stage logically exists on a continuum with later-stage tools, which would themselves display heavily smoothed bases; these tools may also display other signs of heavy use and/or curation in the form of an undulating profile, high all-over tool polish, a rounded or re-sharpened tip, etc. While this analytical stage merely represents an assessment of particular attributes extant among Iberomaurusian bone tools from Taforalt, it is still possible to detect a number of use-stages among tools which likely served similar functions. The next research stage will be to identify ethnographic tools with like morphologies, which may have had analogous functions. The specific use-wear imparted as micro-typography through performing specific tasks (e.g., in piercing hides, crafting basketry, etc.) can then be identified, and an assessment of similar functionality can be further constrained through the comparison of archaeological and ethnographic tools with similar overall morphological attributes. Even in this initial comparison of size-class, shape, tip-type, base-type, base smoothing and undulating profiles, there are clear indications of long-term, repeated technological traditions present in the bone tool assemblage.

4.1.2.10 Emergent Typological Categories

One of the benefits of using an assessment of individual tool attributes rather than an eponymous functional-based typology (with categories such as 'pins', '*lissoirs*', etc.) is that unique features of the collection can be described as they emerge. In this way, features which would not be accounted for under prefabricated typological schema can be considered, classed, and used to direct later stage use-wear investigations.

At Taforalt, a number of pointed tools retain distinctive use-wear to the point-tip in the form of a rounded gouge or divot (**Fig. 4.17**). This repeatedly occurring use-wear element is evident as a smoothed-over hollow, appearing at one side of a point-tip. It is possible that these represent slightly broken points which have subsequently been worn (because the overall point was still functional), or a concavity attributable to the interplay between stresses and bone structure, such as a step- or bevel-fracturing with crushing and rounding. This feature is also consistent with descriptions of some basketry use-wear (i.e., a 'trough' which forms at the point tip [Olsen 1979:355]), but as basketry tools with this feature have not been viewed personally, potential correspondences can neither be substantiated or dismissed. Rounded gouges appear on 13 complete, relatively complete or point fragment tools.

Furthermore, a number of tools at Taforalt have distinctive macroscopic transverse striations, either in the form of use-wear visible to the naked eye (**Fig. 4.18a-c. e-f**) or intentional decorative/functional notching (**Fig. 4.18d. g-k**) to the tools' shafts. In these cases, transverse use-wear occurs in the form of scratches, incisions, scoring, etc., perpendicular to the tool's main axis.

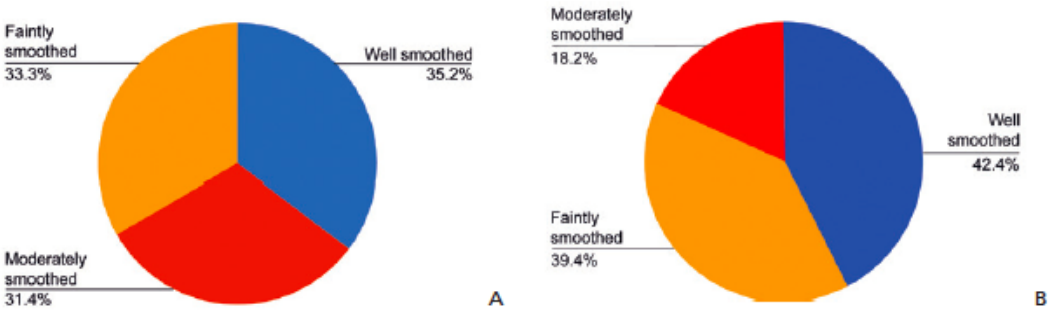


Figure 4.16: Base smoothing percentages. A: all types; B: points

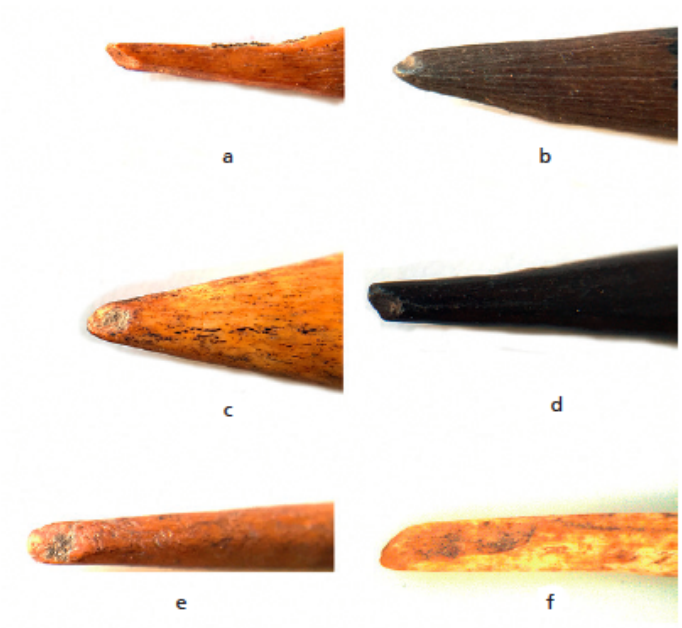


Figure 4.17: Rounded gouges

Transverse traces are particularly useful, as these can indicate a working direction-of-movement inconsistent with longitudinal uses (e.g., a piercing-motion), and can serve as evidence for more complex articulations with other materials (e.g., hafting). Incised tools also provide important data relating to use and/or function.

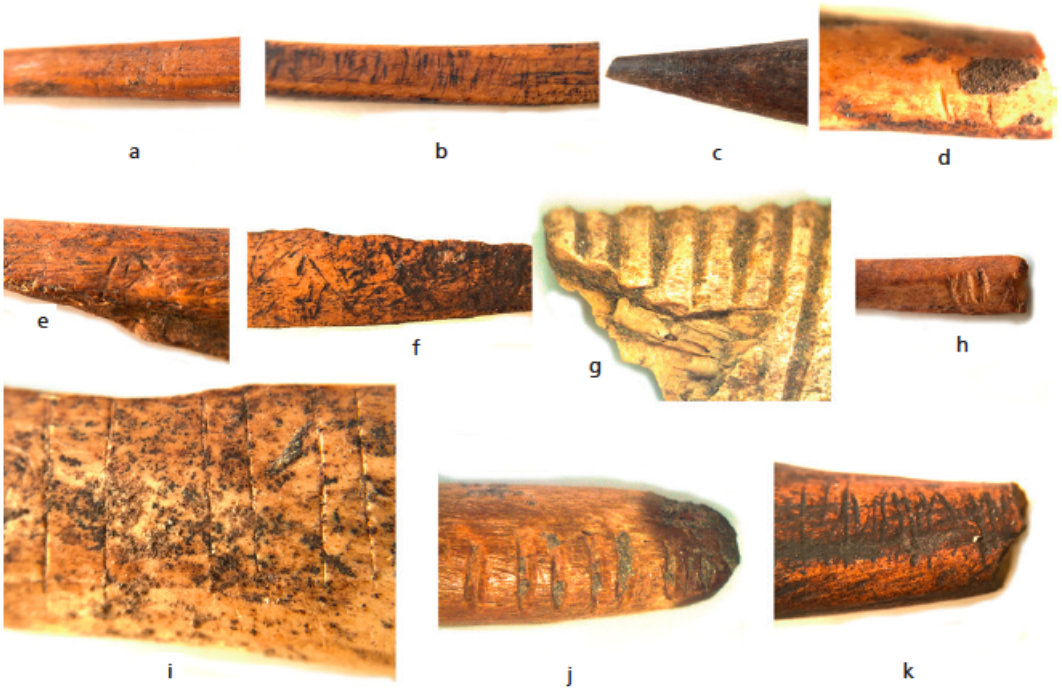


Figure 4.18: Incisions (g, i), hafting notches (d, h, j, k), hafting use-wear (f, e?), and transverse use-wear (a, b, c)

Preliminary naked-eye and low magnification microscopic assessments revealed transverse traces of one kind or another on a total of 27 tools from the categories shown in **Figure 4.15**. It is interesting to note that transverse traces appear on almost every tool type evident at Taforalt, from points to ovoid tools to spatulate tools. This is crucial in the understanding of each of these types' uses, as these can indicate haftedness, use-wear, etc. The specific location, angle, and degree (e.g., diffuse, clustered) and nature of these traces also provide a much stronger platform for comparison with ethnographic tools.

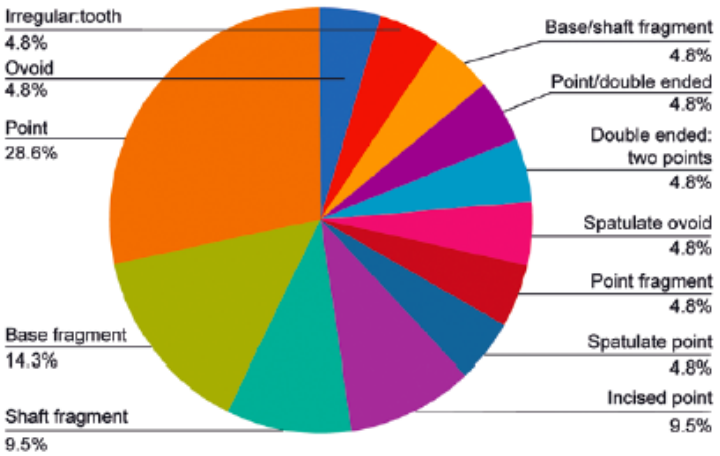


Figure 4.19: Transverse use-wear by type

4.1.2 Discussion and Conclusions

As a typological description of the Iberomaurusian bone tools from Taforalt cave, this study aims merely to provide a preliminary description of the 200 tools currently available for analysis. These descriptions serve as a record of the patterning of specific tool attributes and features, so that these can inform future taxa selection and use-wear investigations. These data can provide a basis for assessing typological use-wear patterning, which will then be compared with ethnographic wooden and osseous tools (Bradfield and Antonites 2018, Bradfield 2020, Langley et al. 2016, LeMoine 1994, Olsen 1979, Soffer 2004, Stone 2009). As such, the goal in collecting and extracting patterning from these data is not merely to type the tools but also to allow for coherent comparisons of inter- and intra-assemblage use-wear patterns (such as whether transverse use-wear occurs only on tools of a certain size class, whether tools from geographically proximate sites show the same repeated types, etc.).

While individual data-sets (like size-class) cannot enumerate specific functions, they do eliminate certain functional possibilities, and constrain comparative analyses to ethnographic tools exhibiting like features. Patterning in size-class does reveal a concerted technological strategy at Taforalt; the repeated construction and use of implements with a specific shape and size suggests a well developed bone tool industry, rather than an opportunistic and haphazard use of bones as tools. The repetition in formal consistencies suggest use-based, repeated articulations through time and space; whatever process(es) imbued tools with the specific macro-wear patterning seen here, it can be said that these processes are industrial, repeated undertakings rather than one-time extemporaneous occurrences. The developed nature of the bone tool industry at Taforalt is bolstered by data gleaned from ZooMS testing, which suggests that specific and less-common taxa are repeatedly selected for the construction of particular tool types (Desmond et al. 2018).

Points are the most numerous type evident within the Taforalt tools. A basic trend in size-patterning shows us that points are overwhelmingly 'small' when compared to other elements of the bone tool assemblage (**Fig. 4.5**); however, size and shape are not enough to suggest functionality among these tools. Based on size and shape alone, the point assemblage from Taforalt matches the dimensions of South African bone arrowheads, as well as bone awls from Prehistoric Missouri (Bradfield and Lombard 2011:69, Chomko 1975:34). For this reason, it is necessary to look for indications of use on the tool itself. The presence of polish on the base (indicative of long-term repeated handling and/or hating), tip-ends displaying rounding, and the absence of diagnostic impact fracturing (e. g. Letourneux and Pétillon 2008, Bradfield and Lombard 2012, etc.) suggest that tools from Taforalt were likely not a projectile-focused industry. Future micro-topographic analyses will further bolster the understanding of these types by

examining minute use-wear traces, and either refute or substantiate particular functional uses (e.g., as projectile-points), based on comparisons with ethnographic collections exhibiting like features (e.g., tools with similar size-ratios, profiles, bases and tips, tip points, polish, etc.).

Points and point fragments also, therefore, comprise the most common type represented in exclusive categorisations, wherein each tool is counted as a member of a single class. Points and point fragments account for 101 out of 200 total elements, or 50.5% of the total assemblage. The next most common types are shaft and base fragments, which account for 29 out of 200 total elements, or 14.5% of the total assemblage. However, because base and shaft fragments lack a diagnostic tip end, points could in fact represent up to 65% of the total assemblage (if all base/shaft fragments were originally pointed tools).

Moreover, other tools with a pointed tip (such as metapodial and spatulate pointed tools) were not classed as 'points' within the exclusive type categorisations, indicating a further potential for underrepresentation. The third most numerous tool category (spatulate points) accounts for only seven elements out of 200 (or 3.5% of the total assemblage). The fourth most common exclusive type (metapodial fragments) accounts for six elements, comprising 3% of the total assemblage. Each of the remaining exclusive type categories have less than five elements each, and individually represent less than 3% of the total assemblage (Table 4.6).

Exclusive tool categories are useful in determining the overall industrial focus of a given assemblage; at Taforalt, this focus clearly seems to have been the production of pointed tools. However, classifying the tools within an inclusive typology is also useful. Within an inclusive typology, a single tool may be counted multiple times; however, this

analysis effectively circumvents the over- or underrepresentation of specific tool features that arise as a result of assigning individual tools to exclusive categories. Here again, tools with a pointed element dominate the assemblage, representing 67.9% of inclusive tool types. The next most commonly recognised feature is tools which are spatulate, representing 9.5% of inclusive tool types. Even within an inclusive appraisal of features, all other types each represent less than 5% of the total assemblage. This finding underlines the results from exclusive typologies; namely, that pointed tools overwhelmingly dominate the Taforalt assemblage.

In addition to individual features (e.g., pointedness, shaft shape, etc.) represented on a given tool, size plays an important role in constraining the potential uses of the bone tools considered here. In an assessment of all complete or relatively complete tools of all types, the average length is 83.4 mm, and the average width of a tool is 11.9 mm. These provide an average 'size-value' of 31.5 mm. This average size-value can be used to plot the relationship of an individual tool or group of tools to the assemblage overall. For example, it is clear that pointed tools have smaller overall size-values than the average of all types; pointed tools have a smaller average length (71.6 mm) and an average width (8.65 mm). Furthermore, this categorisation includes the potentially larger pointed metapodial tools and pointed spatulate tools, indicating an industrial emphasis on the creation of small, gracile pointed tools. It is therefore prudent to examine what exactly constitutes a 'point'. The most obvious way to assess points is by looking at the point-tip itself, and attempting to characterise differences which appear here (**Fig. 4.11**). Among pointed tools, the most common point types are as follows:

- Symmetrical pointed: 28%
- Symmetrical rounded: 19.5%

- Gouged: 11.9%
- Acute rounded: 11.9%
- Snapped (flat bevel): 10.2%
- Acute pointed: 5.1%

Other point types do exist, but each accounts for less than 5% of the total. As discussed previously, diverse point types may be the result of similar to identical uses, merely representing different stages of use or idiosyncratic use (e.g., individual handedness, technique, etc.), representing a mix of initial shaping/resharpening and use-related damage. For this reason, it is also informative to collapse these refined categories into broader ones. One example is points which display a degree of smoothing/roundedness; indicating repeated abrasive articulation with materials softer than bone. Such point types include symmetrical rounded, acute rounded, obtuse rounded, snapped, and convex spatulate points, which together account for 46% of pointed tools. As smoothing and roundedness only develop at a sufficiently advanced stage of use, some of the remaining tools may have been used for similar or identical functions but were simply lost/deposited at an earlier stage of use. Furthermore, tools may have been resharpened to re-establish an effective point, which would have obliterated any rounding or polish which had previously accrued through use.

The diameter of individual point-tips can be useful in exploring what functions these tools could have effectively served. At Taforalt, tools with tip diameters between 0 and 2 mm account for 88.3% of pointed tools, tools with tip diameters greater than 2 mm account for 11.7%, and the average tip diameter of pointed tools overall is 1.26 mm. So far, we see that most tools are small, pointed, and have point-tip diameters of around 1.26 mm. These data suggest that a likely utilisation for refined mechanical tasks which would

necessitate such gracile tools, and eliminate other functional purposes, such as functions involving torsion or forceful impacts (e.g., as tools used as chisels, prises, etc.), which would certainly have left an archaeological signature in the form of repeatedly broken point-tips without smoothing or rounding.

Another consideration which can provide clues as to tool function is the presence of features on the tools' bases. When all tools which have intact bases are considered, the degree of smoothing evident on each falls into three roughly equal categories. Tools with faint base smoothing account for 33.3% of this subset, moderate base smoothing 31.4% and well smoothed bases 35.2%. Clearly, tools with moderately and well-smoothed bases comprise the majority of the assemblage, and it would be reasonable to infer that these differential degrees of smoothing may be linked with different stages of use. Tools with well-smoothed bases are commensurate with hand-held uses, where they articulate with the user's hand and become smoothed-over through time, or were fixed in hafting which repeatedly abraded the tools' bases.

Interestingly, when only points (as the dominant component of the assemblage) are considered, a different pattern of base smoothing emerges. Among pointed tools with intact bases, faint smoothing accounts for 39.4%, moderate smoothing 18.2% and well-smoothed bases 42.4%. Among pointed tools, there is thus a higher percentage of well-smoothed and faintly smoothed bases, differing from the more regular continuum seen when considering all tools with intact bases. This smoothing may be an indication of different use-stage or curation patterns evident among pointed tools, and may further indicate their use in effecting tasks in which they were held in the hand.

Considering a tool's shaft can likewise provide insight into tool construction and use patterning. For example, tools with a marked asymmetry to their shaft may indicate

functional gestures necessitating preferential use or abrasion to one 'side' of the tool. Tools which retain anatomical shafts or have ancient breaks (present during use) indicate that in these cases, the shaft was not heavily shaped or worked. As such, the method of use in these cases did not put the tool's shaft into repeated contact with abrasive material. This knowledge can be used to constrain further the potential functions. Among all complete and relatively complete bone tools at Taforalt, the most common shaft types are:

- Parallel converging: 28.4%
- Asymmetric angled: 12.3%
- Parallel: 7.4%
- Asymmetric convex: 7.4%
- Asymmetric steep mid-shaft angle: 7.4%
- Convex tapering: 6.2%
- Irregular: 6.2%
- Convex: 6.2%

All other shaft types present within the assemblage each represent less than 5% of the total. Through assessing the shape of tools' shafts, patterns indicating or precluding specific functions already begin to emerge. For example, tools with asymmetrical shafts would normally preclude an effective use as projectile tips (Henshilwood et al. 2001, Bradfield 2016). We see that symmetrical shaft types account for 46.9% of the assemblage and asymmetrical shaft types account for 53%. While a tool's having a straight shaft is not enough to suggest projectile use (based on this feature alone), having an asymmetrical shaft usually makes use as a projectile implausible. As over half of the total tools within the Taforalt assemblage could not have been effectively used as projectiles (based on shaft asymmetry), this, along with other data (such as smoothing present on bases,

roundedness and polish to point tips, etc.), suggests that production of bone points as projectiles at Taforalt was not the primary industrial objective. The 46.9% of tools with symmetrical shafts should be assessed for other features which may give clues as to their function, projectile or otherwise.

In addition to the overall shape of a tool's shaft (described in 'shaft type'), tools' shafts may also display different degrees of undulation. Here, 64.1% of tools have a straight (or non-undulating) profile, and 35.3% of tools exhibit some degree of undulation. Like shaft-type, if shaft undulation is asymmetrically distributed, this may give clues as to the working portion of the tool (e.g., with one side or edge more smoothed over). Undulation may also provide evidence for a given tool's stage and manner of use; for example, heavily undulating tools which do not retain clear lithic striations indicate an advanced degree of use-wear, during which the tool was repeatedly abraded against another material, resulting in smoothing to elevated shaft surfaces.

Repeating suites of features present within the assemblage suggests the repeated production of specific industrial types (presumably with related industrial functions). This hypothesis has been bolstered by ZooMS analyses, showing that gazelle and hartebeest were being preferentially selected for the construction of long, thin, gracile points (Desmond et al. 2018). Examinations of osseous tools in the ethnographic present have shown that particular taxa were selected for tool construction based on favourable histological properties (Dominy et al. 2018), and Palaeolithic peoples would have been familiar with the mechanical properties of different animals' bones (Bradfield 2018; Newcomer 1974). Bone tools considered here come from all levels of the cemetery including those dating from shortly after the onset of Grey Series sedimentation to potentially later levels (such as the 'Sep A' stratigraphic level in *Nécropole* 1).

At this analytical stage, it is necessary to situate the emergent bone tool trends and features discussed above within their larger cultural and archaeological contexts. Bone tools do not constitute a natural ontological category as 'artefacts', but are rather constituent components of a wider cultural and technological complex, based on materials engaged in human practice through time. As such, results gained from complementary lines of archaeological inquiry can serve to illuminate bone tool patterning in suggestive ways. At Taforalt, the Grey Series levels in which these bone tools were found show an intensification in three main food resources; *Quercus sp*. (acorns) and *Pinus pinaster* (pine nuts), and five dominant species of edible mollusc (Taylor et al. 2011). As evidenced in both the skeletons (in the form of dental caries; see Humphrey et al. 2014) and in macro-botanical analyses, this intensification in acorns, pine nuts, and edible molluscs as food resources would have necessitated advanced collection, transport, processing, cooking, and/or storage techniques and technologies. The ubiquitous presence of *Stipa tenacissima* (esparto grass) rhizomes throughout the Grey Series deposits suggests that the Iberomaurusians were using this as a material for bedding and/or the production of vegetal crafts. It is clear that the grasses were carried to the site whole with roots intact: esparto rhizomes (root portions) were discarded and burned, and the stalks were likely used as a crafting material (e.g., for baskets, cordage, netting matting, etc.) (Humphrey et al. 2014). Esparto crafting persists into the ethnographic present, particularly in Morocco and southern Spain; in the region surrounding Taforalt, modern artisans still practice esparto weaving with use of a long, thin, pointed tool (**Fig. 4.20**).



Figure 4.20: Modern esparto crafting in Tafoughalt (Photo courtesy of Jacob Morales)

Grey Series faunal remains are dominated by *Ammotragus lervia* (Barbary sheep) (Desmond et al. 2018, Barton et al. 2019); animal skins, fur/wool, etc. could also have served as raw material for the construction of food collecting, processing, and storage technologies, as well as other uses (such as clothing, bedding, etc.). Though hides, baskets, and other perishable crafted forms are not prone to archaeological survival, the technology used to produce such forms may still be in evidence; namely, in the bone tools used to produce these items. The above feature-based analyses of the Taforalt tools indicate that 53% have markedly asymmetrical shafts, making their use as projectiles implausible (Henshilwood et al. 2001, Bradfield 2016).

While pointed forms overwhelmingly dominate the Taforalt assemblage, most pointed forms also show base-wear. Among those pointed forms with anthropogenic smoothing on the base (i.e., greater smoothing/rounding than that which would be expected to occur postdepositionally), 39.4% exhibited faint smoothing, 18.2% moderate

smoothing, and 42.4% had well-smoothed bases, indicative of tools at different stages of use and/or curation. Further, 46% of pointed tools displayed visible rounding and polish at the point-tip; this may be an underrepresentation, as such wear-patterning only develops at a significantly advanced stage of use, and may be obliterated by subsequent re-sharpening. Within the Taforalt assemblage, 88.3% of pointed tools had tip diameters between 0 and 2 mm. Furthermore, no tools display diagnostic impact fracturing, here taken to be spin-off fractures of greater than 6 mm (Bradfield and Brand 2013).

It is crucial to deploy such a framework at an early analytical stage, in order to avoid the pitfalls of 'received wisdom' in bone tool categorisations. For example, studies based on use-wear and experimentation have revealed a world-wide bias in the Palaeolithic bone tool interpretive record, wherein many osseous tools are presuppositionally (mis-)characterised as weapons. An in-depth analysis of morphology and use-traces among Natufian and Zagros bone tool assemblages has shown that from a total of 312 Natufian bone objects, only 17 had use-wear consistent with hunting/projectile weaponry (Campana 1989). Use-trace analyses instead indicate that craft-related activities (such as net-making, basketry, hide-working, weaving, and other textile arts) account for the majority of the assemblage, formerly assumed to be weapons-dominated (Campana 1989).

Rather than being an isolated case, mischaracterisations of bone tools seem to have occurred widely and consistently. Osseous tools from a number of Upper Palaeolithic European sites (from France, Germany, Czech Republic and Russia) were shown to retain clear weaving use-wear. These, however, were catalogued primarily as weapons, tools for animal-processing, or as enigmatic objects (Soffer 2004). Original categorisations of these tools include *pointes de sagaie*, *lissoirs* and *polissoirs*, *bâtons de commandement*, *lochstabe*,

baguettes demi-rondes, spatules, etc. (Soffer 2004). Studies of Magdalenian bone and antler tools showed that these too displayed hitherto unrecognised use-traces commensurate with perishable crafting (Stone 2011; 2015, Waguspak et al. 2009). In southern Africa, a study of putative MSA and LSA 'arrowheads' revealed similar inconsistencies (Bradfield 2016). Many tools initially classed as weapons were shown to retain use-traces consistent with hide-working and woodworking (Bradfield 2016). Taken together, these studies indicate that simplistic and/or presuppositional appraisals of osseous tools' function are both insufficient and inaccurate.

World-wide, bone tool assemblages have been shown to contain a great internal functional diversity, and historical frameworks for categorising osseous tools have effectively obscured this variety in use (Bradfield 2016, Soffer 2004, Stone 2011). Such potential under-recognition probably extends beyond miscategorisation, as many tools used in the creation of textiles will display wear only on the tool's shaft (e.g., battens), and it is disconcerting to consider the number of weaving/crafting tools which might not have been identified as tools at all, due to their lack of diagnostic 'ends' (e.g., Soffer 2004). This under-recognition is likely due, in part, to preservational vagaries inherent at sites dating to the Palaeolithic. For example, if the organic products of craft activities have not survived burial for tens of thousands of years, these products (and the technological know-how used to make them) are unlikely to be accounted for in the development of bone tool typo-functional frameworks.

Insights into this 'missing' technocomplex can be glimpsed through a comparative assessment with recent prehistoric sites with favourable preservation. In many dry cave sites, fibre artefacts outnumber stone artefacts by a factor of 20, and in waterlogged sites, wood and fibre artefacts often account for more than 95% of recovered materials (Taylor

1966, Croes 1997 [as referenced in Soffer et al. 1999], Waguspak et al. 2009). While organic and crafted products in the Palaeolithic may have been less elaborate and/or less numerous than more modern examples, even conservative estimations of their archaeological underrepresentation are high. One suggestion places the Old World archaeological recovery-rate at a mere 15% of the cultural materials actually in-use, and many believe even this figure to be a modest estimation of cultural-product loss (Clarke 1968, Soffer et al. 2000).

The formulation of an in-depth descriptive catalogue serves here not as an end-goal of the study but, rather, as a platform from which to approach different stages in the bone tool *chaîne opératoire*. The use of an individual feature-based typology allows emergent features of the collection to direct archaeological investigations; in other words, the tools 'describe' themselves. In a feature-based schema, typological categories (shape, size-class, etc.) emerge from a consideration of the tools at hand. This method does not rely on the ex post facto application of pre-conceived typological tool categories (e.g., '*lissoirs*', 'awls', etc.). When the results of each feature assessment are considered together, patterns in construction and use clearly begin to emerge. Perhaps most importantly, this typology provides a firm and scientific basis for selecting like comparative material from ethnographic and experimental tool collections. Ethnographic tools with similar typological features to those recovered from Taforalt can be assessed for use-traces, and these traces can be compared to the traces evident on the bone tools from Taforalt. When there exists a good match between overall feature patterning and microwear patterning, it will become possible to create best-fit use scenarios for the Taforalt tools, and to build an evidence-based understanding of how these tools may have actually been used. Following the forthcoming comparative microscopy and micro-topographic analyses, and

when paired with ZooMS analyses, it will become possible to determine robust best-fit scenarios for both individual tool and tool-class functionalities based on biological taxa (the source bones) and ethnographic use-wear congruences (e.g., Soffer 2004, Stone 2011, Desmond et al. 2018).

After bringing together data regarding the taxa from which the tool was created, ethnographically and/or experimentally consistent usewear patterning, it will be possible to tailor experimental studies in order to substantiate specific tool-uses and life-history narratives. The applications of this method are potentially quite profound, as understanding bone tool functionality in early sedentistic LSA contexts (like those evident at Taforalt) is a vital step in understanding how cultural transitions (and concomitant new lifeways) were orchestrated technologically, without having to rely solely on the lithic record. Once the life history of a tool has been tightly defined, it will become possible to subject tools to more qualitative analyses, aimed at understanding the associated meanings and larger cultural contexts within which tools were used. For example, do certain types of bone tool (or bone tool taxa) occur repeatedly within burial contexts (see Desmond et al. 2018)? Are tools notched for functional purposes (e.g., to aid in hafting) or as exemplars of aids to memory and/or notation (e.g., tally sticks)? Do pigment-bearing tools indicate a superficial post-depositional transfer, or is pigment found within use-traces, indicating use-based contact with pigmented materials? Are bone tools or bone tool types associated with other artefacts (e.g., lithic cores, ochre, etc.) in a statistically meaningful way? It is our hope that the application of diverse and multi-scalar methods to bone tools will elicit a coherent scientific narrative, encompassing and bridging this critical cultural and technological phase.

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5 Paper 3: Bone tool proxy evidence for coiled basketry production in the North African Palaeolithic

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Abstract

Bone tools from Taforalt cave constitute the largest North African Later Stone Age (LSA) bone tool technocomplex recovered to-date. Use-trace analyses show that the small pointed forms which dominate the assemblage show microtopographic patterning consistent with ethnographic bone tools used to make coiled basketry. The presence of coiled basketry likely scaffolded emergent cultural forms reflected in increased sedentism, resource intensification, and greater population density at Taforalt. This study explores the relationship between coiled basketry and archaeologically co-occurring technologies. Ethnographic analogies derived from Indigenous Californian groups provide a model for how resource-specific collection, processing, storage, and preparation requirements may have been supported technologically.

5.1 Introduction

Taforalt Cave (also known as Grotte des Pigeons) is an archaeological site situated in the Beni Snassen mountain range of Northeastern Morocco near the Algerian border (**Fig. 5.1A,** 34° 48′ 50″ N, 2° 24′ 14″ W). Archaeological deposits represent a well-stratified sequence from the Iberomaurusian Later Stone Age (LSA), ranging from around 23,000 to 12,600 cal BP (calibrated radiocarbon years before present) (Staff et al. 2019). The site contains a wealth of well-preserved material from the Iberomaurusian culture, including faunal remains and bone tools. Along with the depth of the deposits, this exceptional preservation has allowed researchers to examine and understand the lifeways of North African LSA people in high resolution; a valuable opportunity in the North African Palaeolithic.

In order to understand bone tools created by this culture, it is necessary to examine their wider archaeological context. Early Iberomaurusian deposits from Taforalt show ephemeral use of the cave as expected by seasonally mobile hunter-gatherer groups. These deposits are referred to as the Yellow Series (**Fig. 5.1B**), and begin around 22,912-23,459 cal BP (OxA-35509, Staff et al. 2019). A marked depositional shift can be seen as the Iberomaurusians transitioned to intensive year-round occupation of the cave. These deposits are referred to as the Grey Series (**Fig. 5.1B)**, with an onset at c.15,000 cal BP and persisting to 12,566-12,713 cal BP (OxA-24111, Staff et al. 2019). Iberomaurusians at Taforalt did not fit into the mobile hunter-gatherer framework broadly expected of Palaeolithic/late Pleistocene peoples, and Grey Series deposits indicate degrees of sedentism and broad-spectrum behaviour often associated with the pre-Neolithic in a Mediterranean context (Barton et al. 2019a, Humphrey et al. 2012, 2014). A recently

published overview and synthesis of finds from the 2003-2020 field seasons explores a number of themes related to emergent sedentism and cultural changes associated with this shift (Barton et al. 2019a). These changes manifest both behaviourally and technologically.

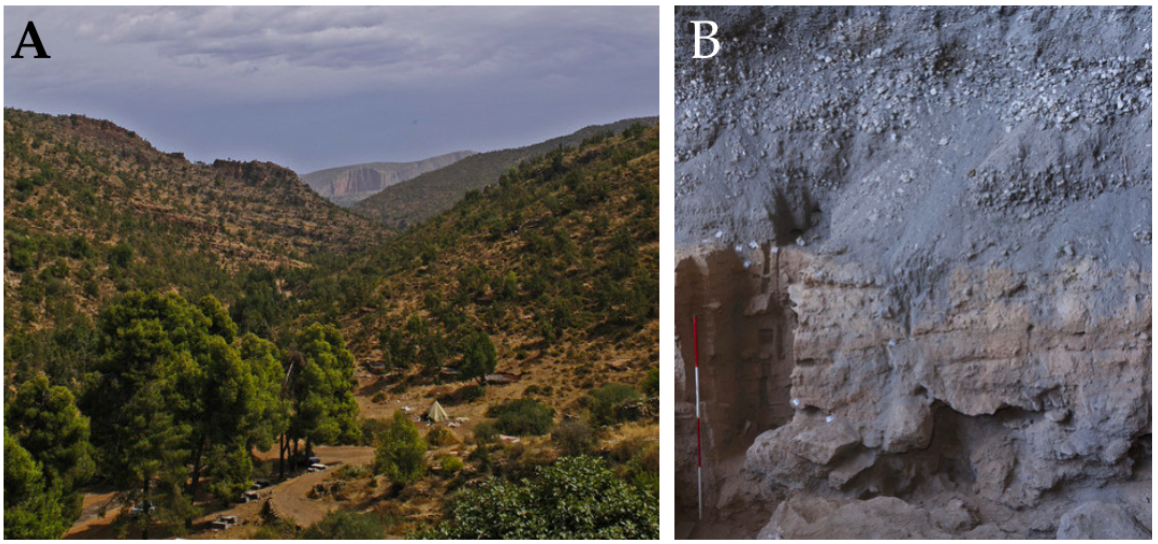


Figure 5.1: View from the mouth of the cave (A) and Grey and Yellow Series stratigraphic levels (B) (Desmond 2017)

Behaviourally, a major cultural development commensurate with the Grey Series occupation of the cave is funerary behaviour in the form of on-site burials (Humphrey et al. 2012, 2014, 2019). Another is the development of seasonally-organised resource procurement. While *Ammotragus lervia* (Barbary sheep) remained the main animal hunted in both the Yellow and Grey Series, there is a marked differentiation and expansion in the use of plant resources beginning in the Grey Series (Barton et al. 2019c, Morales 2019). These include a dramatic increase in the harvesting of locally available edible plants such as acorn, pine nuts, wild pulses, and fruits (Carrión Marco et al. 2018, Carrión Marco 2019; Morales 2018, 2019), and also in non-edible esparto grass, which was collected and brought to the site in great quantities (Humphrey et al. 2014, Morales 2019). Land snails

were also collected and eaten in very large numbers, and Grey Series middens are estimated to have contained up to 60 million snail shells (Barton et al. 2019c, Taylor and Bell 2019).

At the same time, a number of new technologies appear in the Grey Series deposits. Grindstones are first attested to in these levels and some were used to process colourants, while others were likely used to process acorns, nuts, or other plant materials (Barton et al. 2019b). Also evident are a wealth of non-local limestone rocks, apparently selected and transported into the cave. Evidence shows these rocks were repeatedly heated, indicating that the Iberomaurusiansans had an advanced understanding of the thermal properties of limestone, as well as suggesting their use in boiling or roasting in cooking (Barton et al. 2019c, Collcutt 2019a). Tantalisingly, deliberately shaped and sometimes fired bits of clay are evident through the Grey Series though evidence for developed forms of pottery is wholly absent (Barton and Collcutt 2019).

Lithics have often served as a proxy for cultural development among Palaeolithic peoples. However, there is no marked difference in microlithic bladelet technology at Taforalt between the Yellow and Grey series (Hogue and Barton 2019, Hogue and Bouzzougar 2019). This conservatism in lithic production may be related to the continued reliance on *A. lervia* (Barbary sheep) as the main animal food resource, but also implies that the wide-scale changes evident in the Grey Series must have been enabled and scaffolded by other technological forms (Barton et al. 2019c, Desmond et al. 2018).

The emergent diversification in and large-scale harvesting of seasonally available food resources likely entailed perishable food processing and storage technologies, and enabling such food surpluses 'would have constituted a vital element of risk management' in year-round occupation of the site (Barton et al 2019c). The presence of food collection,

processing, and storage tools made from organic materials (such as leather, wood, and plant fibres) and are inferred rather than observed directly (Barton et al. 2019c, Desmond et. al 2018, Desmond 2019, Humphrey et al. 2014, Morales et al. 2015). By modifying and expanding crafting practises (such as leatherworking or weaving), it would have been relatively easy for Iberomaurusians in the Grey Series to scale up production or create new forms as necessary (Desmond et al. 2018).

Finally, bone tools exist in great numbers within the Grey Series. These are present in the earliest Grey Series levels, and at least one bone tool was deliberately included in an early human burial on-site (Desmond et al. 2018). ZooMS analysis shows that the Iberomaurusians strategically selected less common taxa for bone tool construction from the onset of Grey Series sedimentation (Desmond et al. 2018). Though bone tools are more numerous in later Grey Series levels, tool forms remain consistent even from the earliest Grey Series levels, and advanced taxa selection-strategies were already in place at the beginning of reduced itinerary among the Iberomaurusians (Desmond et al. 2018, Desmond 2019). This indicates that whatever tasks the bone tools were used to perform were already within the technological capacities of the Iberomaurusians before the shift to sedentism, and that these tasks expanded in importance during the Grey Series occupation of the cave (Desmond et al. 2018).

5.2 Materials and Methods

To date, 743 bone tools have been excavated from Iberomaurusian levels at Taforalt (Desmond 2019). These include 704 bone tools excavated by Abbé Jean Roche in the 1950s, of which 161 are housed in the collections of the Rabat Archaeological Museum, and an

additional 543 are reported (Roche 1963), but their current location is unknown. A further 40 bone tools were excavated between 2003 and 2016 under the current project, bringing the number of tools available for study to 200. Even though this subset represents less than half of the total number of bone tools found at Taforalt, it remains the largest known collection of North African LSA bone tools (Desmond 2019).



Figure 5.2: Examples of long, thin, pointed tools from Taforalt

Size, shape, and feature-based analyses performed on this subset (n=200) show that the most common bone tool form is a small, slender, pointed tool, constituting up to 65% of the total tools available for study (Desmond 2019). These tools average 71.6 mm in length and 8.65 mm in width. Most tools displayed a greater degree of smoothing and/or rounding to the tool base than unmodified taphonomic controls from the same or neighbouring archaeological contexts (Desmond 2019:410). The average point-tip size is 1.26 mm, and no tools were found to have diagnostic impact fracturing (Letourneux and Pétillon 2008; Bradfield and Brand 2013). Rather, rounding and polish of the point-tip was visible on 46% of pointed tools. Together, these data suggest bone tool use and curation patterns inconsistent with being used in forceful impact activities (e.g.,, as chisels, gouges,

prises, etc.) or as weaponry (Desmond 2019). Such small slender points dominate the bone tool assemblage throughout the Iberomaurusian deposits, and are the focus of this study.

Excavation data from the missing 543 tools shows that more than 60% were excavated from the front and middle interior of the cave, indicating concentrations in the best lit areas on site (Desmond 2019). Pointed tools are particularly abundant in these areas, with 75.2% of pointed tools found in the front and middle interior of the cave. A small area representing perhaps the brightest area of the cave (Cav / Niveau C en avant [see Barton et al. 2019a] alone yielded 66 pointed bone tools. The distribution of bone tools (and pointed forms in particular) is further indicative of their use in everyday crafting processes, taking place on site in daylight 'workshop' areas, as small pointed forms are concentrated in the best-lit areas of the cave, and occur less frequently in the rear of the cave (Desmond 2019, see **Paper 2 Figs. 1-3**). Use-wear analysis (or tribological analysis, which considers the interaction of surfaces in motion) considers the tool as a whole, and the relationship of microscopic patterns on different parts of the tool to one another (LeMoine 1994). A tool which is used repeatedly for a specific purpose will exhibit microscopic changes to surfaces which come into contact with the material being worked, the human hand if the tool is held, etc. (Campana 1989, LeMoine 1994, Soffer 2004, Stone 2009, Struckmeyer 2011, Van Gijn 2005, etc.). By analysing the wear patterns which develop during use in experimental scenarios, researchers have been able to define and differentiate patterns associated with different osseous tool functions (see **Paper 4** p. 156-160). This approach allows for a more scientifically coherent assessment of use than morphological descriptions alone. Use-wear studies have come to dominate how many archaeological bone tool industries are interpreted, and there is a growing recognition that typo-functional categorisations based on whole tool morphology (i.e., shape and size)

are often found wanting (Antonites et al. 2016, Akhmetgaleeva 2017, Arrighi et al. 2016, Bradfield 2012/2014, Chomko 1975, Desmond 2018, Gates St-Pierre 2007, Griffits and Bonsall 2001, LeMoine 1994, Medina et al. 2018, Olsen 1979, Soffer 2004, Stone 2009). Indeed, use-wear based reassessments of Upper Palaeolithic European bone and antler tool collections have shown that articles classified variously as *sagies*, shaft straighteners, *batons de commandment*, and enigmatic/art objects retain use-traces commensurate with the production of perishable crafts (Soffer et al. 1999, Soffer 2004, Stone 2011). The nature of microtopographic wear patterns on these tools suggests that perishable crafting was taking place at a wider scale than initially appreciated by Palaeolithic archaeologists (Desmond et al. 2021, Dobres 1995, Soffer et al. 1999, Soffer 2004).

In order to understand what processes led to an industrial emphasis on small, thin pointed tools at Taforalt, a representative sample of 21 tools was selected. Only complete or relatively complete (after Desmond 2019) tools with good preservation (i.e., not weathered/friable) and minimal taphonomic alteration (e.g., concretions, burning) were chosen for analysis. The Iberomaurusian tools from Taforalt were analysed in collections at the Rabat Archaeological Museum, and at the Institut National des Sciences de l'Archéologie et du Patrimoine (INSAP) in Rabat, Morocco. The tools were photographed using a Nikon D7000 camera, and examined and imaged with a DinoLite (AM3113T) digital microscope at 20-50x and 230x magnification.

In order to understand how these tools were used, it is necessary to compare the location and nature of use-wear patterning found on them to use-wear patterning on bone tools with known functions. Rather than using experimentally produced bone tools as the basis for comparative use-wear analysis, we have chosen to examine tools from ethnographic museum collections. Provided an ethnographic collection is both reliably

and explicitly documented, these tools afford a comprehensive model for actualistic use-wear development which can circumvent many problems or simplifications associated with experimental studies alone (Keddie 2012, Langley et al. 2016, Legrand and Radi 2008, Olsen 1979, Stone 2009, Stone 2013, Struckmeyer 2011). While some handling and curation of artefacts may be expected to occur in a museum setting, any use-traces developed through these processes (apart from gross changes such as the application of lacquer etc.) would generally not be extensive. Ethnographic tools are not a scientific approximation of certain use conditions, but rather objects repeatedly used and curated in dynamic everyday life scenarios by expert craftspeople.

Since Palaeolithic cultures cannot be assumed to have a direct ancestral relationship to any modern groups, comparative materials were chosen from groups with environmental and potentially cultural parallels to Palaeolithic North Africa. Metal tools are generally used in modern Moroccan and North African esparto crafting, so we must look farther afield for appropriate ethnographic analogs. In order to be useful, ethnographic analogs must be, at least in part, site specific; that is, meaningfully congruent with the specific archaeological site and culture from which the archaeological bone tools were recovered (Binford 1962, 1978; Stone 2013, Wylie 1985). Morales et al. (2015) note widespread similarities between Palaeolithic North African Iberomaurusian and Capsian cultures and some Indigenous Californian cultures, specifically in terms of climate, emergent sedentism, and in the intensive use of pine nuts and acorns as food resources. For this reason, bone tools created and used by indigenous groups including Klamath Lake, Modoc, Yurok, Hupa, Pomo, Yokut, Eastern Miwok, Maidu, and Cahuilla peoples were analysed at UC Berkeley's Phoebe A. Hearst Museum of Anthropology (PAHMA).

In order to avoid selection bias, a 'control group' of bone tools was selected and analysed from PAHMA and the Pitt Rivers Museum at the University of Oxford. These artefacts included ethnographic bone tools made and used among geographically and culturally disparate peoples in Alaska, Arizona, New Mexico, Montana, Indonesia, Guatemala, Sudan, India, Algeria, Australia, Melanesia, and New Guinea.

Ethnographic tools were selected for analysis only if they had detailed provenance records, which were broken down into three main categories; location/culture/time period, function, and, when possible, articulation and product. In this way, tools were selected which had not only known uses/functions (i.e., basketry awl), but also known articulations (i.e., vegetal/hide/wood) and, when possible, recorded details of the specific artefacts produced (i.e., used to make moccasins, coiled baskets, etc.). Ethnographic tools selected for analysis included arrowheads, marrow spoons, hide and skin scrapers, leather awls (for piercing), flensing tools, lithic retouchers, woodwork polishers, netting needles, wedges, knife sharpeners, woodworking gouges, matting needles, tule mashers and splitters, woodworking finishing tools, leather creasers, mesh-measures, bark strippers, sap gathering tools, netting shuttles, knot slippers (marlinspikes), warp-lifters, crocheting needles, sweet potato-, tuber-, and pandanu-cutters, eel splitters, and basketry awls.

Ethnographic tools were analysed on site in collections at the PAHMA in Berkeley, California and at the Pitt Rivers Museum in Oxford, England. The tools were examined visually, photographed with a Nikon D7000, and imaged with a DinoLite (AM3113T) digital microscope at 20-50x and 230x.

5.3 Results

The most common suite of features found on small, pointed tools from Taforalt consists of rounding to the tip of the point, varying degrees of smoothing and/or polish along the tip and shaft of the tool, and smoothing and/or polish occurring to the base of the tool (Desmond 2019). Consistent use-trace patterning on these tools is made up of short clustered parallel striations occurring on the tools' point tips and shafts, and overlapping transverse striations directly below the point tip on the tools' shafts (**Table 1, Figs. 2-4**). It was first necessary to examine whether these patterns could have resulted from tool construction and/or taphonomic factors, and were compared to reference unmodified bone from Taforalt at INSAP, and bone tools with chattermarks and grinding striations at PAHMA. These traces were observed to be distinct from examples of chattermarks which are related to lithic shaping of the tool (**Fig. 5.3A**), and are inconsistent with striations associated with axial grinding as a tool formation strategy (Campana 1989, Newcomer 1974). This use-wear patterning was also found to be visually inconsistent with and distinct from damage as a result of bioturbation and/or rodent/carnivore gnawing, by comparison with unmodified weathered (**Fig. 5.3B**) and gnawed bone from the same or adjacent contexts at Taforalt. The nature of the Grey Series deposits from which the tools were excavated precludes many other kinds of taphonomic alteration (Collcutt 2019a), and taphonomic scenarios inconsistent with the nature of the deposits were not considered (e.g., water or wind dispersal/transport, trampling, extensive sedimentary abrasion or rockfall, ice movement, volcanic activity, digestive etching, etc. [Fisher 1995, Lyman 1987]).

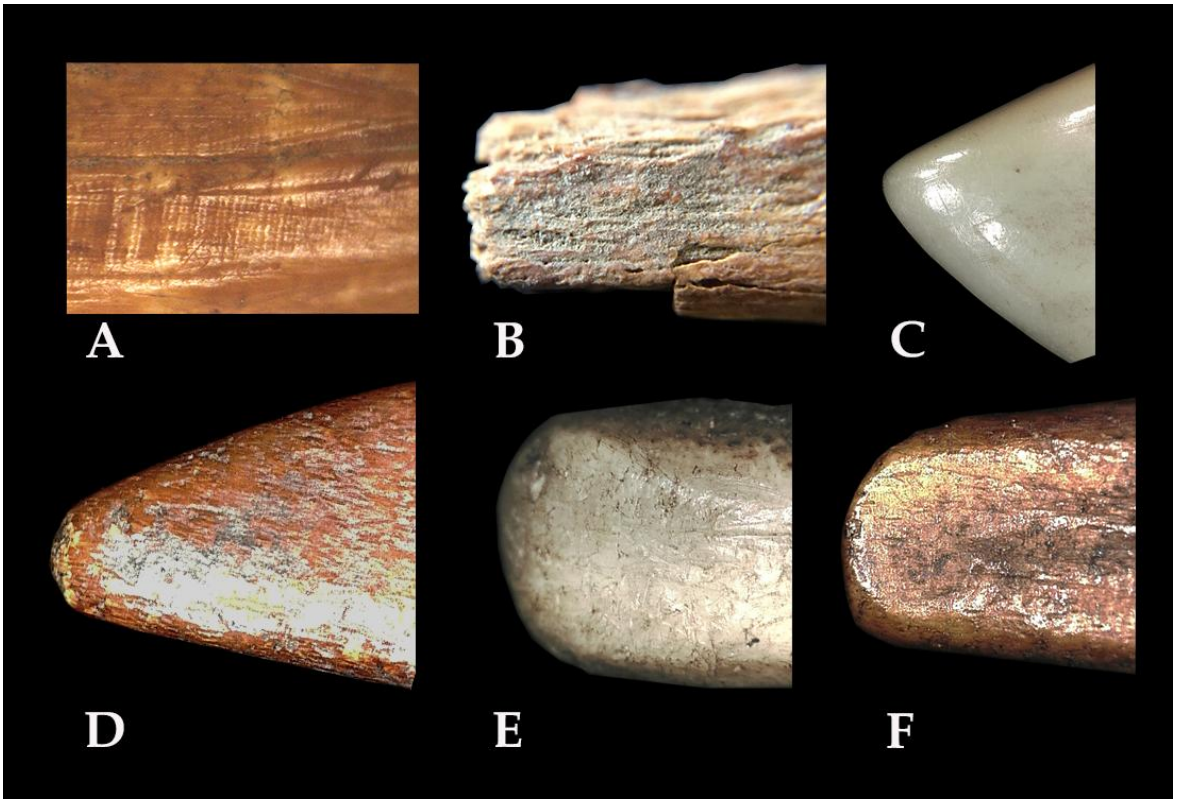


Figure 5.3: Examples of natural, anthropogenic, and ethnographic bone and bone tool features which do not conform with patterning on Taforalt tools, 50x. A: chattermarks; B: unmodified bone from Taforalt; C: hide-scraping; D: leather creasing; E: lithic flaking; F: woodworking.

None of the ethnographic tools used as arrowheads, marrow spoons, hide and skin scrapers (**Fig. 5.3C**), leather awls, flensing tools, lithic retouchers (**Fig. 5.3E**), woodwork polishers, netting needles, wedges, knife sharpeners, woodworking gouges, matting needles, woodworking finishing tools (**Fig. 5.3F)**, leather creasers (**Fig. 5.3D)**, mesh-measures, bark strippers, sap gathering tools, netting shuttles, or knotslippers displayed use-wear patterning consistent with that found on the Taforalt subset.

Portion of tool under consideration	**Features consistent between Ethnographic and Taforalt tools**	**Citations**
Tool tip	Pointed tip with smoothing, rounding, and polish	Mason 1904, Campana 1989, Legrand and Radi 2008
Tool shaft	Polish, smoothing along the tool's shaft	Olsen 1979, Legrand and Radi 2008, Stone 2009, Struckmeyer

		2011
Tool base	Rounding and polish due to repeated contact with hand in crafting	Campana 1989
Specific Microwear patterning	Small, short, shallow, parallel clustered transverse striations (originating at and/or below the point tip)	Griffits 2001, Soffer 2004, Legrand and Radi 2008, Stone 2009, Buc 2011, Campana and Crabtree 2018, Medina et al 2018

Table 5.1: Bone tool features associated with plant fibre manipulation and basketry in experimental studies

Figure 5.3 provides some examples of functional use-wear incommensurate with the patterns found on this subset of Taforalt tools. These include an invasive, glossy polish on the point-tip of a bone tool used in hide-scraping (**Fig. 5.3C**), non-invasive smoothing with crushing and pitting to the point-tip of a bone tool used in creasing leather (**Fig. 5.3D**), randomly oriented scratches, gouges, divots, and the formation of smoothed-over chipped platforms on a bone tool used as a lithic retoucher (**Fig. 5.3E),** and a roughened surface with areas of high polish occurring at highest topographies of a bone tool used in woodworking finishing (**Fig. 5.3F**). For more examples of use-traces incommensurate with those found on this Taforalt subset, please see **Paper 4**.

Initial basketry use-stage	**Intermediate basketry use-stage**	**Advanced basketry use-stage**
Initial lithic formation striations visible; these appear as longitudinal scoring along the entire surface to the tool, parallel to the tool's axis.	Short, clustered parallel or overlapping transverse striations occurring at tool's point tip or just back from point tip along tool's shaft. Rounding and polish begin to develop on the tool's tip, shaft and base.	High degree of smoothing and polish to tool, rounding of tool tip, smoothing of tool base where it is held in the hand.

Table 5.2: Use-wear indicative of *chaîne opératoire* stages in silicate-rich basketry crafting

The small, thin, pointed tools from Taforalt displayed an overwhelming similarity in use-trace patterning to a specific subset of ethnographic basketry tools. These consistencies in patterning are borne out by a review of experimental bone tool research (**Table 1**), wherein descriptions of basketry and plant working use-trace development match those observed in this study. These use-traces consist of rounding and polish to the tools' tips and bases, smoothing and/or polish extending along the shaft of the tool, and specific microwear patterning consisting of short, shallow, parallel striations beginning at or slightly below the point tip (**Table 5.1, Fig. 5.6 A-D**).

The patterning described here is a synchronic compression of use-traces which develop at different diachronic stages of use within a tool's life history, or *chaîne opératoire.* Specifically, *chaîne opératoire* refers to the operational sequence from raw material selection, tool construction, tool use, and eventual deposition (Bar-Yosef et al. 1992, Desmond et al. 2018, Henshilwood et al. 2001, Leroi-Gourhan 1993; 2009). As with any archaeological technology represented in sufficient numbers, bone tools at Taforalt are representative of different stages in these objects' *chaîne opératoire*. Because lithic scraping was the bone tool formation strategy used at Taforalt, one would expect to see some lesser used tools retaining clear longitudinal lithic striations (**Fig. 5.4, Table 5.2: Initial basketry use-stage**) (Campana 1989:31, Desmond 2019).

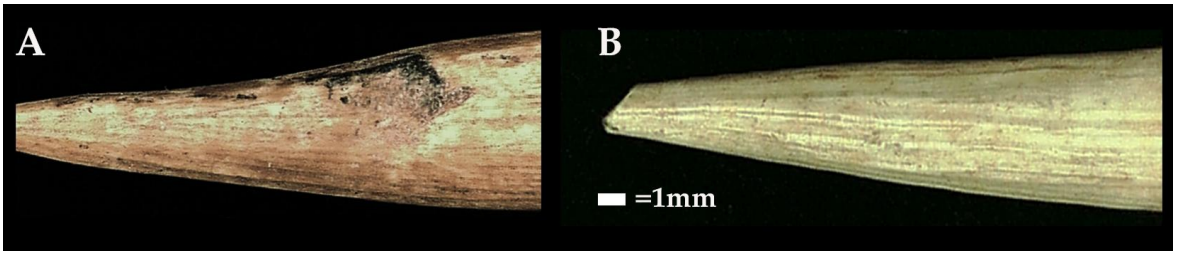


Figure 5.4: Early *chaîne opératoire* stages showing longitudinal lithic striations on small, thin pointed tools from Taforalt, 20x

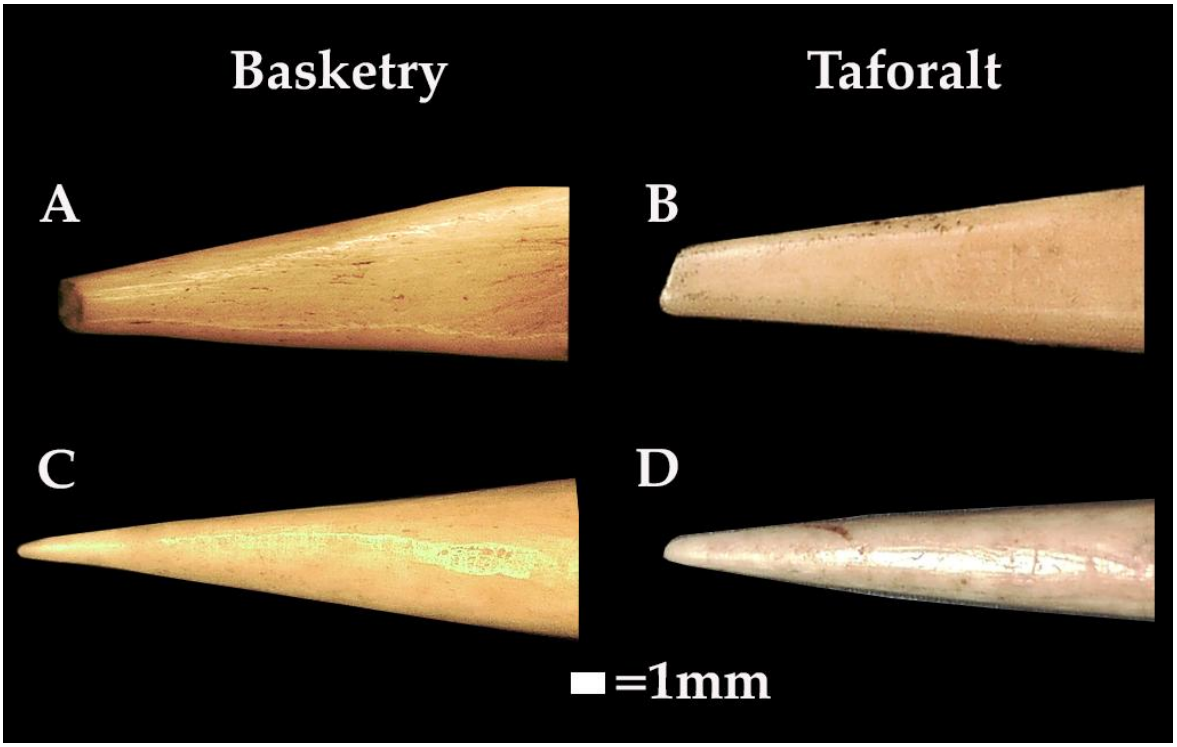


Figure 5.5: Consistencies in highly-smoothed surfaces on ethnographic basketry tools (A, C) and on bone tools from Taforalt (B, D) at 20x

Conversely, tools recovered at a more advanced *chaîne opératoire* stage appear smoothed, and such smoothing occurs atop and obliterates any lithic formation striations. In cases where the tool has been used for a long enough duration to sufficiently homogenise the tool's surface, a glossy polish can be seen covering the entire tip and shaft of the tool (**Fig. 5.5, Table 5.2: Advanced basketry use stage**). This kind of polish formation is consistent with basketry processes in which working portions of the tool are repeatedly abraded against silicate rich vegetal material (**Table 1),** which over time homogenises the bone surface topography (Campana 1989, LeGrand and Radi 2008).

As a result, tools which are most diagnostic of basketry use-wear are those in an intermediate use-stage within their *chaîne opératoire* **(Fig. 5.6, Table 5.2)**. These tools have been used long enough to have developed microtopographic changes where they came into contact with the worked plant material, but not so long that all surface features have

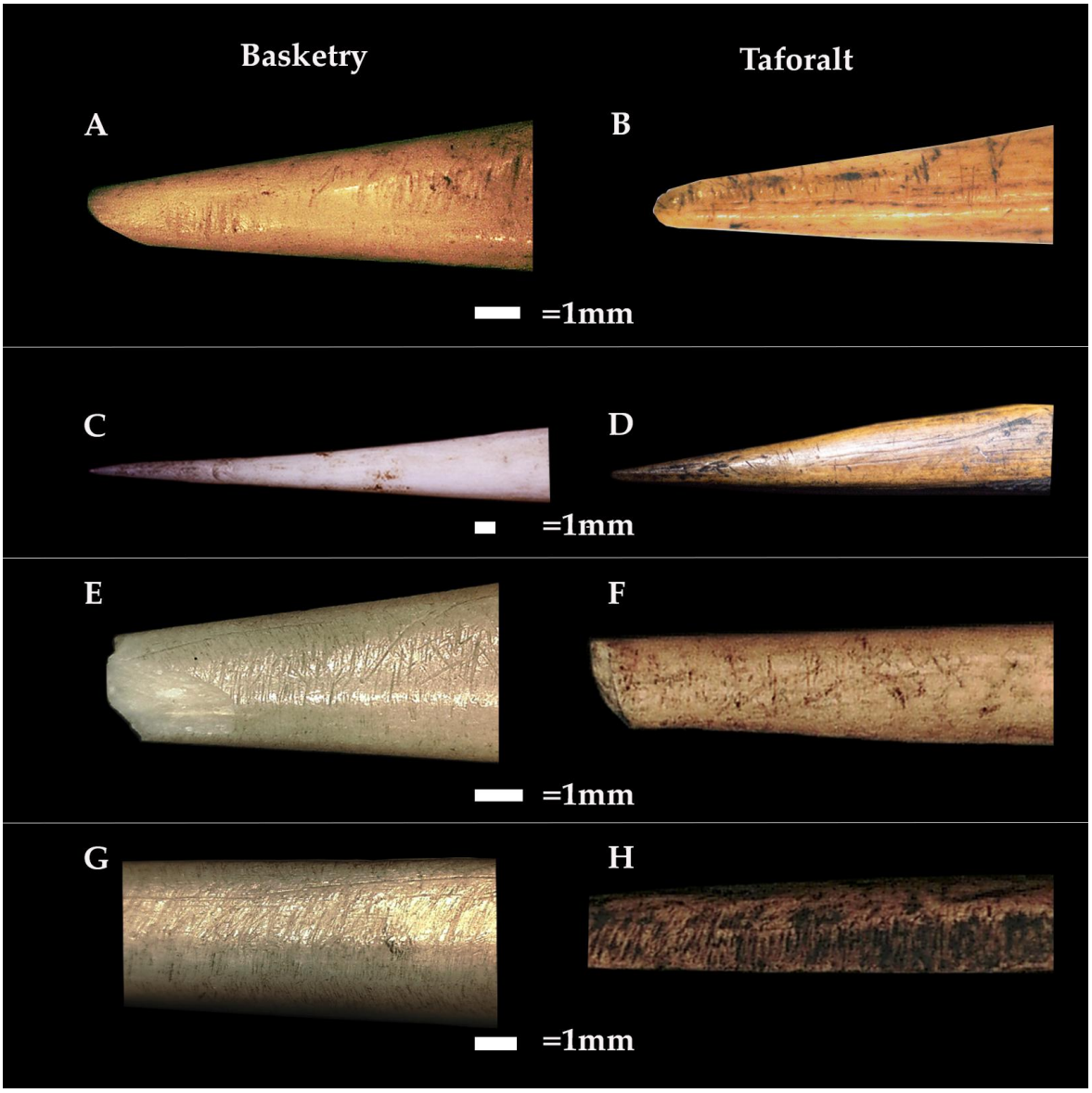


Figure 5.6: Correspondences between basketry use-wear at 20-50x on ethnographic bone tools used to make coiled baskets (A, C, E, and G)) and on bone tools from Taforalt (B, D, F, and H)

been homogenised and obliterated through continuous abrasion (**Table 5.2: Intermediate basketry use-stage**). While it is possible that these patterns represent different crafting processes and/or materials worked, this seems unlikely for the following reasons. First, ethnographic basketry tools show similar *chaîne opératoire* use-trace development among

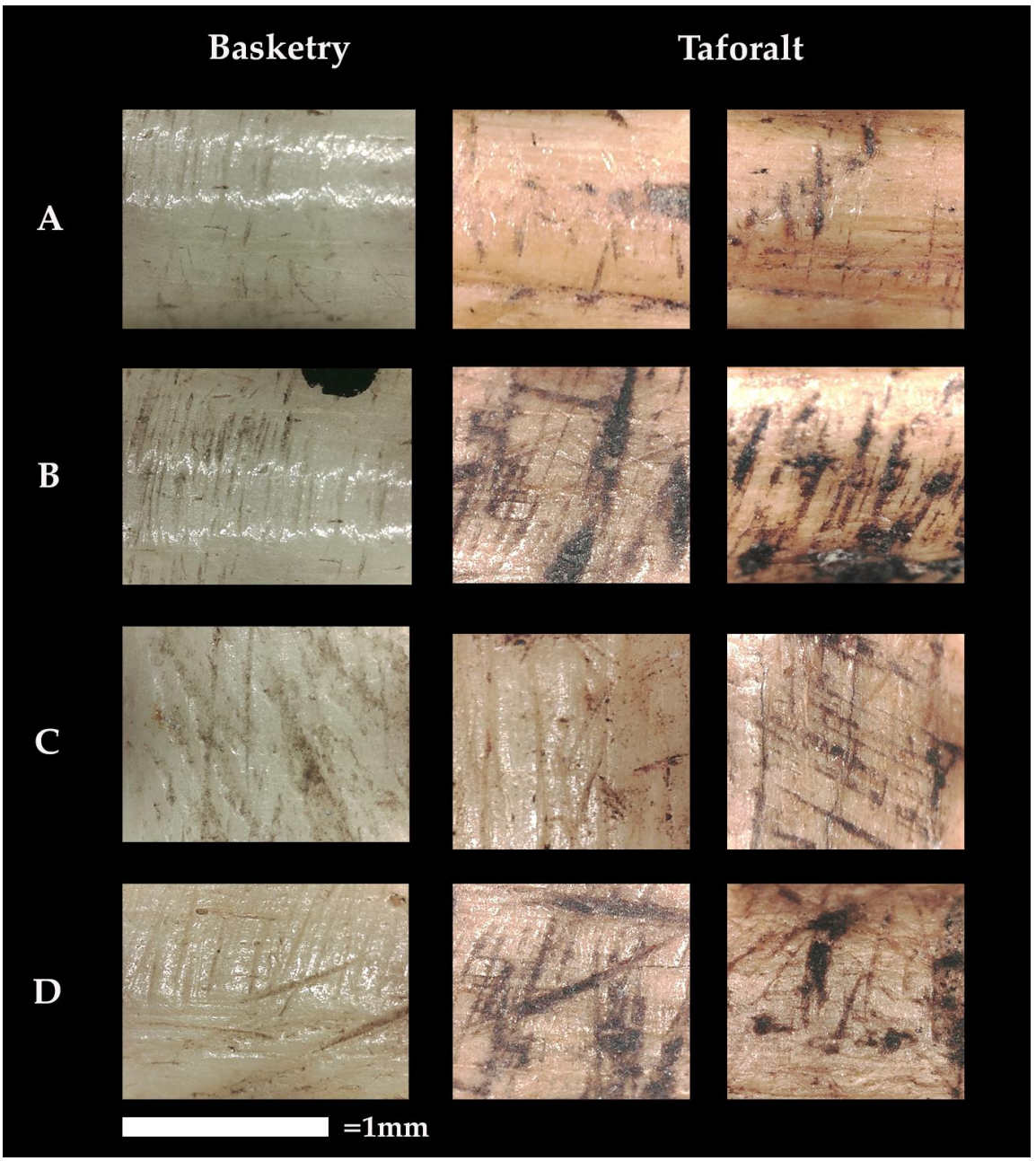


Figure 5.7: Short clustered parallel striations (A-B) and overlapping transverse striations (C-D) at 230x on ethnographic basketry tools (left) and on bone tools from Taforalt (right)

tools used for the same purpose (e.g., **Figs. 5.4 and 5.5**). Second, as *chaîne opératoire* stages are largely heuristic-and continuous rather than discrete-tools with features 'between stages' exist in both the Taforalt subset and among the ethnographic basketry tools. Finally, granular inclusions (such as pigments) which could cause different abrasive patterns are present in similar volumes on tools at all *chaîne opératoire* stages (**Fig. 5.8,**

discussed later). It is therefore suggested that this differential patterning is representative of a *chaîne opératoire* use-wear continuum, rather than evidence for different uses.

Use-traces diagnostic of basketry production in an intermediate use-stage occur in the form of small, short, shallow, parallel, clustered transverse striations, generally originating at and/or below the point tip (Buc 2011, Campana and Crabtree 2018, Griffits 2001, Legrand and Radi 2008, Medina et al. 2018, Soffer 2004, Stone 2009). These are visible at 20-50x magnification, and their specific locations on the tool, direction, orientation, and density are consistent between a subset of ethnographic basketry tools and the pointed tools from Taforalt (**Figure 4**). These correspondences remained consistent at 230x magnification. Specifically, both the Taforalt tools and some basketry tools exhibited short clustered parallel striations occurring just below point-tip (**Fig. 5.6 A-B**), and overlapping transverse striations occurring on the tool shaft just below tip (**Fig. 5.6 E-F).** No ethnographic tool functions other than basketry displayed use-traces occurring in this pattern.

Emergent features of this Taforalt tool subset include the presence of pigment on most of the tools analysed. Pigments were found embedded within fossa, in crevices, on tools' tips and bases, and within use-wear striations. Colourant was always found to occur beneath all other matrices (**Fig. 5.8),** indicating that colourant on tools was not the result of a passive accumulation or post-depositional transfer. Whether these pigments were used specifically to colour baskets or had some other purpose at Taforalt, the presence of colourants deeply ingrained in some use-traces indicates that at least some of the worked material (i.e., grasses/basketry) came into direct contact with pigments.

Pigment colours include ochre in reds, purples and oranges, as well as a striking silvery grey 'glittery' mineral pigment. This has yet to be formally identified but is

consistent with manuports consisting of lead and galena found elsewhere on site (Collcutt 2019b).



Figure 5.8: Pigment traces on small pointed tools from Taforalt (230x)

5.4 Discussion

Given congruences in use-wear with a consistent subset of Indigenous Californian ethnographic basketry tools, and the lack of similarity in use-wear with all other tool types investigated, it is probable that small, thin, pointed tools found at Taforalt were likely used to create basketry. Since use-traces on Taforalt tools are a match with some, but not all, Indigenous Californian basketry tools, it is necessary to determine what factors explain these correspondences and differences. To begin with, basketry making among Indigenous Californian groups was not a monolithic practice but rather incredibly diverse, with a number of different 'technocomplexes,' or regional traditions of similarity

in practice (Bates and Bernstein 1982, Jordan and Shennan 2003, Kroeber 1922). Because these areas of practice are relatively well documented, it is possible to track what kind of basketry was being made in each ethnographic region, and which plant materials were favoured for use. It must be noted that tribal entities as conceived by anthropologists do not always have a basis in Indigenous concepts of relatedness, and for the sake of clarity and reproducibility, this study retains the spelling and wording under which the artefact or cultural group was recorded in the relevant museum collections or literature. Where possible the Indigenous names for plants and objects have been listed alongside their Latin taxonomic or English counterparts. Finally, because ethnographic materials studied here originated in the late 19th and early 20th Centuries the past tense is used for the sake of consistency, but should not be taken to imply that basket making or other Indigenous cultural practises are things of the past (Bates and Bernstein 1982).

Among all tools examined in this study, use-traces on tools from Taforalt are nearly identical to those found on basketry tools produced by Cahuilla, Eastern Miwok, and an unnamed central Californian people (**Fig. 5.9**, Cahuilla 'wish' [Mason 1904] and Miwok 'tculla' [Barrett and Gifford 1933]) (**Table 5.3**). Though Cahuilla and Eastern Miwok tools represented only a small subset (n=15) of those analysed in this study, these tools were used specifically to create single- and three-rod coiled baskets, which likely accounts for the relative homogeneity in use-trace development. These consistent correspondences in use-wear track with coiled basketry as a production complex among southern and central Californian groups (Kroeber 1905, Mason 1904).

Some groups created both coiled and twined basketry forms, such as the Pomo peoples of central California. A number of Pomo coiled basketry awls were examined, and though these showed some similarity in use-traces to the Taforalt tools, the use-trace

correspondences were not as precise as those found on Cahuilla, Miwok, and the central Californian basketry tools. This is likely because Pomo peoples produced baskets using not only single and three-rod coiling, but also splint-foundation, two-stem foundation, four-stem foundation, and half-hitch coiling techniques, as well as seven forms of twined basket (Mason 1904). Performing a wider variety of basketry techniques with these awls caused different and more complex use-wear patterns to develop on the tools, when compared to the Taforalt tools and ethnographic tools used in one or two techniques.



Figure 5.9: Coiled basketry awls from central and southern California with use-traces matching those found on the Taforalt tools

Finally, there were no use-trace correspondences evident between the Taforalt tools and tools used to make twined baskets. These include bone basketry tools used by northwestern Californian, Pacific Northwestern, and Alaskan groups who exclusively created twined baskets (Kroeber 1905, Merrill 1923). This suggests that use-wear on

Taforalt tools corresponds not with 'basket making' in general, but only with use-wear developed through a limited number of coiled basketry techniques, and are potentially specific to single and three-rod coiling.

Tool number	**PAHMA catalogue information**	**Culture**	**Baskets produced**
1-11115 **Fig. 5.9F**	'Basketry awl of deer leg bone.'	Cahuilla	Coiled Basketry (Mason 1904:423)
1-10125 **Fig. 5.9A**	'Used in [basketry] sewing and weaving. With a sharp point. This is made from the proximal end of posterior cannon bone (fused metatarsal) of Odocoileus (deer). Split from foreleg of deer and polished off.	Eastern Miwok	Single or three-rod coiling [Kroeber 1922:264, Barrett and Gifford 1933 :90]), Plate XXXIX (Barrett and Gifford 1933)
1-11028	'Basketry awl of deer leg bone.'	Cahuilla	Coiled Basketry (Mason 1904:423)
1-10072 **Fig. 5.9E**	'Old sharp pointed bone [basketry] awl'	Eastern Miwok	Single or three-rod coiling [Kroeber 1922:264, Barrett and Gifford 1933 :90]), Plate XXXIX (Barrett and Gifford 1933)
1-11097	'Basketry awl of deer leg bone.'	Cahuilla	Coiled Basketry (Mason 1904:423)
1-10241 **Fig. 5.9B**	'Used in [basketry] sewing and weaving. Native name: ‘tculla’ '	Eastern Miwok	Single or three-rod coiling [Kroeber 1922:264, Barrett and Gifford 1933 :90]), Plate XXXIX (Barrett and Gifford 1933)
1-216989 **Fig. 5.9D**	'Bone, tip broken. Made of deer cannon bone, polished. Used in making coiled basketry.'	'Central California'	Coiled basketry (cataloged provenance, Kroeber 1922:274)

1-216991 **Fig. 5.9C**	'Bone, tip intact, unfinished at handle end with dried residue attached. Used in making coiled basketry.'	'Central California'	Coiled basketry (cataloged provenance, Kroeber 1922:274)

Table 5.3: Ethnographic basketry tools which best correspond with Taforalt use-wear

In Cahuilla basketry, *Epicampes rigens*, *Muhlenbergia rigens* (deer grass, Cahuilla 'suulem'), or *Washingtonia filiferia* (palm) was used for the weft, and either *Juncus robustus, Juncus lesenerii (*rushes, Cahuilla 'seily') or *Rhus tribolata (*sumac*)* was used for the coils (Kroeber 1908, Lando and Modesto 1977, Mason 1904, Pearlstein et al. 2008). Basket making among the Cahuilla was traditionally performed by girls and women, and a description of the coiling process follows:

> The basket is begun at the center of the bottom, the thickness of the coil of grass depending upon the size of basket to be made. A bone pricker [awl, **Fig. 5.9F**] is used. The coil is begun by laying one end of the filament [weft] upon the bunch of grass and taking a few wraps about it to hold it down. This is bent double, and the sewing progresses by catching the filament [weft] over the bunch of grass through the coil of the sewing filament made at the last turn (Mason 1904:424).

In Miwok basketry, the method of production is single- or three-rod coiling (Kroeber 1922, Barrett and Gifford 1933). Preferential coil materials were *Epicampes rigens* (deer grass) and *Rhus trilobata* (sumac, Miwok 'ta'ma'), and *Cercis occidentalis* (redbud, Miwok 'tapátapa') was generally used for the weft (Barrett and Gifford 1933). Basket weaving was also done by women, and coiled basket making proceeded as follows:

> These various materials were manipulated and woven with the hands. The only tool was the bone awl [**Fig. 5.9 A, B, and E**] which was used to pierce the finished part of the basket, to make an opening through which to pass the sewing material... The starting knot ([Miwok} 'sayu') in many coiled baskets is a small, tightly bound coil of fine maple or sedge splints, or of the leaf of *Iris hartwegii* ([Miwok] 'yotowina'). These must be very fine to permit bending at a very sharp curve (Barrett and Gifford 1933:86).

Correspondingly, the use-traces which develop on the bone tools (evident in the form of parallel and crossing linear striations **[Fig. 5.7 A-D]**) show the direction-of-movement of the tool when in use. These traces develop on the portion of the tool (the tip and shaft) which is repeatedly coming into abrasive contact with the coils as the weft is sewn through the coils of grass or rushes. Use-traces indicative of this gesture develop transversely or diagonal to the tools' shaft, depending on the angle of the tool as it is pushed through the coils (**Fig. 5.7**). In Cahuilla basketry the coil direction is clockwise (from left to right), except in the case of small, globular baskets which are coiled counterclockwise (Kroeber 1908). Miwok peoples likewise used both clockwise and counterclockwise coiling techniques (Barrett and Gifford 1933), which may account for the presence of overlapping transverse striations (**Fig. 5.7 C-D**).

In addition to use-wear patterning, Cahuilla, Miwok, and Taforalt tools show analogous *chaîne opératoire* use-trace development. Specifically, later stage tools exhibit highly polished surfaces as a result of repeated abrasion as the tool passes tightly through the silicate rich basketry coils (**Fig. 5.5**) (Legrand and Radi 2008). Use-wear in the form of rounding to the tools' point-tips has been observed to be beneficial in the creation of coiled basketry (**Fig. 5.5 C-D; Fig. 5.6 A-B**). Pointed bone tools with slightly rounded tips were able to effectively split the basketry coils in order to insert the weft without splitting the fibers, an advantage over sharply pointed or metal tools (Campana 1989, Mason 1904). Matches in use-trace patterning on small, thin, pointed tools at Taforalt are therefore interpreted as diagnostic of the production of coiled basketry using silicate rich plants in the coils, and potentially as a result of both clockwise and counterclockwise coiling.

ZooMS research into preferential bone tool raw material selection at Taforalt has shown that these tools (and by extension, their products) were embedded within long

term culturally mediated strategies (Desmond 2018). In order to understand these cultural strategies in a holistic way, it is necessary to examine how the use of coiled baskets interdigitates with other lines of archaeological evidence at Taforalt. Basketry, alongside other technologies, appears to have facilitated an intensification in specific food resources among the Iberomaurusians. Here we can use ethnographic analogy to understand how different cultures used similar technologies to collect and process the same resources which were important at Taforalt. Finally, we will consider how basketry could have connected with emergent cultural forms, such as increased population size and craft specialisation.

A first consideration is the spatial organisation of basketry production within the cave. Given the preferential distribution of pointed bone tools in well lighted areas of the cave, and the abundance of pointed forms recovered from the small, brightly lit area near the northerly cave entrance, it is probable that this last area represents a 'workshop' for the production of coiled baskets (Desmond et al. 2019). All recorded Indigenous Californian coiled basketry techniques involve the strategic selection of basketry materials, including extensive planning in seasonal harvesting and pre-processing (Barrett and Gifford 1933, Mason 1904, Merrill 1923, Pearlstein et al. 2008). Once materials are collected and prepared, plants constituting the coils need to be soaked in order to be pliable enough to work into the desired shape (Merrill 1923). These conditions underscore the need for fixed, spatially organised, and well lighted production areas, and explain the concentration of tools in corresponding areas on site. The coils were likely constructed from *Stipa teccanisima* (esparto grass, Arabic '(h)alfa(h)' and Amazighe 'awri/ari/iwri' [Barton et al. 2019c]), as inedible esparto stalks were uprooted with the root systems intact and transported into the cave in great numbers (Humphrey et al 2014, Morales 2019).

Previous to this study, esparto has been hypothesised to have served as basketry material in the North African Palaeolithic, and at Taforalt specifically (Barton et al. 2019c, Carrión et al., 2018, Desmond et al. 2018, Gassin et al. 2020, Humphrey et al. 2014, Morales, 2018, Morales et al. 2015). Traditional Moroccan esparto crafting has a known history dating to the late Pleistocene and continues into the ethnographic present (Barton et al. 2019c, Gassin et al. 2020). Esparto also has a long history as a crafting material elsewhere in the Mediterranean. Clay impressions, as well as artefacts in the form of clothes, hats, shoes, baskets, and rope crafted from esparto are evident since the Neolithic in Spain (Fajrado et al. 2015). Because of its high silica content, esparto would produce analogous use-trace development to the polish seen in later *chaîne opératoire* stage tools when used as basketry coils (Maghchiche et al. 2013).

The presence of clay in the Grey Series also likely articulates with basketry production; specifically, to line baskets in order to make them waterproof (Barton and Collcutt 2019, Barton et al. 2019c). Parallel impressions of sedges or grasses are found in some clay nodules, and it is suggestive that one clay fragment was intentionally shaped into a coil (Barton and Collcutt 2019), mirroring the shape of and suited to the lining of coiled basketry. In the world archaeological record, pottery is hypothesised to have had many independent centres of development through the accidental burning of clay lined baskets, enabling the transition from clay as a lining to a stand alone form (Blinman 1993, Brown 1989, Morris 1927). The presence of clay lined baskets is suggested elsewhere in prehistoric North Africa: Early-Middle Holocene basketry fragments from Libya retain mineral traces suggestive of clay (Di Lernia et al. 2012). Above-ground clay lined baskets have previously been suggested as storage containers at Taforalt in the absence of pit-forms on site (Barton et al. 2019c). Clay lined baskets would also have been suitable

waterproof containers, and are known to have been used in hot rock heating and cooking methods from the Pleistocene onward (Speth 2015, Shyrock and Smail 2018). The presence of clay-lined baskets is further indicated by the fact that the clay fragments recovered at Taforalt were all heated, and occurred alongside non-local fire-crazed limestone throughout the Grey Series (Barton and Collcutt 2019, Collcutt 2019a). In some cases 'baked clay' has been known to replace heated stones in some acorn cooking processes (Heizer and Elsasser 1979, Mason 1992). However, owing to the overwhelming presence of fire-crazed rocks in Grey Series levels which would have served this purpose much more effectively, the use of clay as a heating element seems unlikely.

To date, the earliest evidence for hot-rock cooking comes from the late Aurignacian in France, and since the Upper Palaeolithic has appeared consistently in European, African, and Asian archaeological contexts (Movius 1966, Petraglia 2002, Thoms 2009). It was likely a component of early technological repertoires in the Americas, though modelling has suggested that less frequent use and smaller population sizes may have rendered it archaeologically invisible until the Holocene (Thoms 2009). Watertight baskets have been the preferred method for stone boiling in particular. Basketry is an ideal material for withstanding the impact of the heated stones dropped into it, by being '...a flexible fabric able to withstand repeated direct force by conforming to the force' (Nelson 2010:243). Hot rock cooking generally appears in cultures experiencing an intensification in broad spectrum foraging, land use intensification, and population packing, measured as an area's 'food-resource potential relative to its extant land-use system'; all conditions met within the Grey Series at Taforalt (Thoms 2008:588, Barton et al 2019a, Binford 2001). The broad spectrum intensification seen in Grey Series levels at Taforalt further conforms to a study of world-wide ethnographic patterns, '...when [the] percentage of time spent

gathering makes up more than 30% of the total time in subsistence activities, basketry is used for stone boiling' (Nelson 2010:246). Ethnographic techniques for waterproofing esparto baskets exist in the region surrounding Taforalt cave, and involve flattening the leaves before weaving (Barton et al. 2019c).

Based on the evidence for basketry and hot-rock cooking at Taforalt, it is possible to investigate how these technologies could have articulated with and scaffolded an intensification in the three main resources intensified in Grey Series levels; acorns, pine nuts, and land snails.

Pine nuts and acorns are both considered 'back-loaded' food resources; that is to say, relatively easy to collect and store, but energetically costly to process (Barton et al. 2019c, Tushingham and Bettinger 2013). For acorns and pine nuts, parallels in cultural strategy with Indigenous Californian groups will be investigated, following Morales et al. (2015). California's density of hunter-gatherer populations exhibiting reduced mobility, intensification in pine nuts and acorns, and social complexity more commonly associated with agricultural groups in similar climatic settings make these groups appropriate analogs with -- and effective models for -- specific cultural practises and processes at Taforalt (Buonasera 2013, Morales et al. 2015). Acorns and pine nuts have been described as the two staple foods of the Cahuilla (Lando and Modesto 1977), and were also important among the Miwok (Barrett and Gifford 1933). Burden baskets were used in foraging both acorns and pine nuts among Indigenous Californian groups, including Cahuilla and Miwok peoples, and experimental studies have shown that when filled to capacity, baskets containing pine nuts and acorns were virtually identical in weight (Bettinger et al. 1997).

Pine nuts were a commonly exploited food resource among Indigenous Californian groups throughout the Holocene, and are high in polyunsaturated fat (Bettinger 1977, Farris 1993, Gamble and Mattingly 2012). Among the Cahuilla specifically, Singleleaf (*Pinus monophylla)* and Parry pinyon pine (*Pinus quadrifolia*, Cahuilla 'tevatwic') were used as part of the 'winter diet' (Bean 1974, McCarthy 2012, Wilke and Dawson 1979). Hot-rock pine nut processing in baskets has been identified among a number of Indigenous Californian groups (Coville 1892, Gamble and Mattingly 2012). While pine nuts can be eaten raw, roasting can improve the flavour, remove the pine pitch, kill the nut embryo which enables long term storage, and open the scales of green cones for extracting the nuts (Farris 1982, McCarthy 2012). Other segments of pine were used in various ways. Among the Miwok, uses included (but were not limited to) fuel, as a basketry material, in thatch, bedding, and floor coverings, in house-coverings, for medicinal purposes, and to make pitch and mastics (Barrett and Gifford 1933). Pine pitch was used by many Indigenous Californian peoples to make baskets watertight, including the Cahuilla and Miwok (Barrett and Gifford 1933, McCarthy 2012). Ethnographic accounts from northwestern Tunisia show that pine cones were collected unripe and stored, and, when needed, the cones were sun dried or roasted in order to extract the seeds (Morales et al. 2015). The pine nuts were then ground, mixed with water, sieved, and heated at a low temperature to form a soup or broth. Empty cones were stored and used as fuel, and evidence for the same or similar collection and processing techniques is attested at Taforalt, as well as at the Early Holocene site of El Mekta in Tunisia, and the Late Pleistocene site of Haua Fteah in Morocco (Morales et al. 2015:135-136).

The use of acorns among Indigenous Californian peoples is well documented, and will be treated here only in brief. *Quercus kelloggii* was the preferred food acorn in all but

the Northwest of California, and required an extensive logistical strategy in harvesting, transportation, drying, storage, processing, and eventual preparation into food (Bettinger et al 1997, Mason 1992). Basketry or other woven vegetal material was involved in every stage of this process; burden baskets in collection and transportation, mats for drying, baskets or granaries for storage, grindstones and baskets for processing (sometimes including leaching, or the removal of tannic acid), and baskets for food preparation (Mason 1992, Tushingham and Bettinger 2013). One of the most common acorn food preparation methods was hot-rock cooking in watertight baskets, a method requiring constant stirring, and producing an acorn 'soup' or 'mush' widespread among Indigenous Californian peoples, including the Miwok (Barrett and Gifford 1933, Mason 1992). Acorns are also a traditional North African food, and as with pine-nuts, acorns were often collected unripe from trees, stored, and then processed when needed to open the nut (Morales et al. 2015). Evidence for this same acorn collection strategy is present in Late Pleistocene and Early Holocene archaeological contexts across North Africa (Morales et al. 2015). Regional North African strategies for acorn processing include boiling, roasting, drying, storage, and refining into a flour (Morales et al. 2015). Near the modern village of Tafoughalt (next to Taforalt Cave), local informants related that unprocessed acorns could be stored in esparto baskets for six months, and processed acorns presumably have an even longer 'shelf life' (Barton et al. 2019c).

Land snails are not a well attested food source in Indigenous California, but continue to be a staple resource in many African and circum-Mediterranean cultures (Adeyeye et al 2020). Snails have a high nutritional value as they are rich in protein and other essential minerals and amino acids (Adeyeye et al 2020). When snails are collected from the local environment, as in the Grey Series at Taforalt, modern best practice dictates

that they be 'purged' before they are consumed. Purging entails containing and feeding the snails for at least three days, enough time for them to expel any potentially toxic plants they may have consumed in the wild (Thompson 1996). This process would have necessitated containers for collecting and purging snails. In Spain, a particular esparto basketry form (known as 'Caracolera'') was crafted for snail collection, and involved the use of a stitching technique specific to this purpose (Farjado et al 2015). Boiling snails remains the most common method of processing to this day, and hot-rock cooking in baskets has been posited as a likely scenario for snail cooking at Taforalt (Arrébola Burgos et al. 2001, Taylor and Bell 2019). Snails spoil shortly after they die, and preservation techniques such as smoking or drying are necessary to reduce the microbial load and preserve snail meat for longer periods (Adeyeye et al 2020). In the absence of pottery containers at Taforalt, it must be assumed that collection, purging, cooking, processing (drying or smoking), and storage needs were met with the use of organic technologies. Whether from Barbary sheep or snails, the main factor in meat preservation is 'keeping it sufficiently dry, a point which recalls the advantage in hanging such materials close to a more or less continuous source of heat and smoke'(Barton et al. 2019c). Given the extensive evidence for burning in Grey Series levels, Taforalt Cave would certainly have met this criterion.

While use-trace patterning suggests that coiled basketry was being made, the presence of colourants suggests that pigment may have been intentionally applied to the baskets. All Indigenous Californian coiled basket forms considered here have deliberate coloration and design motifs, and vegetal materials were often selected for their colour and woven into patterns on the baskets (Barrett and Gifford 1933, Mason 1904, Merrill 1923, Pearlstein et al. 2008). Though dichotomous conceptions of 'utility' and 'art' are

largely modern, the use of colourants at Taforalt shows that Iberomaurusian basket makers may have incorporated deliberate stylistic or aesthetic elements into their crafting process.

5.5 Conclusion

This study underlines both the usefulness of bone tools as an artefact class, and the usefulness of appropriate ethnographic case studies in the interpretation of archaeological materials. First, it reiterates the validity of using a *chaîne opératoire* approach to bone tools. As with lithics, osseous tools can be understood using traditional artefact analyses, such as typological and whole-tool morphology studies. Unlike lithics, however, osseous tools can be subjected to tests designed for use on organic materials, such as proteomics and DNA analysis. These analyses enable an understanding of taxa raw material selection, and while in some ways are akin to lithic proveniencing studies, can also illustrate seasonal, ideological, and otherwise inaccessible cultural strategies. Since bone is softer than stone, it's surface features more readily deform during use and develop diagnostic use-traces indicative of function (Legrand and Sidera 2007, Legrand and Radi 2008). Because of the relatively rapid deformation of bone surfaces during use, it is possible to interpret the uses of archaeological osseous tools through a comparison with diagnostic use-trace matches on ethnographic osseous tools (Desmond et al. 2021). This method has been profitably applied to bone tools from southern African, Australian, North American, and European archaeological contexts (e.g., Bradfield and Antonites 2018, Bradfield 2020, Langley et al. 2016, LeMoine 1994, Olsen 1979, Soffer 2004, Stone 2009), and the current study underscores the productivity of this line of enquiry. In particular, such comparative

analyses are a useful way to obtain proxy evidence for perishable crafted forms which may not have otherwise been accounted for, or, as with Taforalt, whose presence was suggested (but not confirmed) through complementary lines of archaeological evidence (Barton et al. 2019c).

This study also shows the utility of interrogating broad scale correspondences between cultures which are geographically and temporally disparate, but which display a 'robustness of relevant similarities'' (Currie 2016). Such similarities include peoples who inhabit(ed) similar landscapes or climates, used the same food resources entailing a breadth of logistical preparation and attendant technologies, and experienced similar patterning in mobility or reduction of mobility, demographic expansions and contractions, etc.. While realising that the archaeological record itself is a contemporary phenomena, structures of inference must be based on uniformitarian principles in order to gain meaningful insight into the processes that created this record (Raab and Goodyear 1984). In other words, while the specific cultural strategies of the Iberomaurusians cannot be observed directly, it is not parsimonious to presume they would have used their technologies in vastly different ways to other cultural groups which produced these technologies in similar circumstances. However, in using ethnographic data, it is crucial to avoid pitfalls such as presupposed ancestral relationships, deterministic approaches, 'primordialism', and unwarranted inferential leaps (Bradfield 2014, Pargeter et al. 2016). Here, the tension between useful ethnographic analogy and cultural determinism can be bridged through a scientific analysis of bone tool topography, and how these tools and their products are embedded in specific, co-occurring technological and behavioural strategies. When analogies are scaled to the artefactual level, ethnographic materials are

useful tools in investigating archaeological artefacts (Stone 2013). This is particularly true of bone and fiber artefact analysis, because

> [t]he use-wear on these objects was produced in a dynamic, day-to-day context by people who actually used these objects, which reflects not only the mechanical properties of the interacting materials, but also personal variation, developed motor skills and long-term, authentic utilization. The physical and mechanical properties of bone and fibers are not greatly affected by variation in environment, and considering a wider range of possibilities in the ethnographic record may allow the recognition of unexpected patterns on archaeological artefacts (Owen 1993). (Stone 2009:229)

Though no one would suggest direct relationships between Iberomaurusian and Indigenous Californian cultures, striking technological and cultural parallels exist (Morales et al. 2015). These take the form of environmental and climatic similarities, an intensification in acorns and pine nuts coinciding with increased population density and reduced group mobility, and technological corollaries in the form of grindstones, hot-rock cooking, and basketry.

While it is much less secure to extend ethnographic analogies to the social and ideological, it is possible that comparable cultural processes, such as emergent role specialisation in craft production, also accompanied this shift at Taforalt. In the European Palaeolithic, gendered role specialisation has often been approached through perishable craft production, with a view to how people used these forms in constructing inter- and intra-group social identities (Dobres 1995, Stone 2009). In a number of Indigenous Californian contexts, the enhanced labour inherent in resource intensification (necessitated by collection, preparation, and processing) were absorbed primarily by women (Buonasera 2013, McGuire and Hildebrandt 1994, Willoughby 1963). For example, basketry making was the domain of women and girls among the Cahuilla and Miwok peoples, and tasks surrounding acorn and pine nut procurement and processing were

mostly performed by women (Barrett and Gifford 1933, Lando and Modesto 1977). While gendered division of labour with regard to these particular resources is unclear at Taforalt, studies of femoral cross-sectional strength and robusticity indicate that both men and women were highly mobile, and gendered strategies in resource procurement are not contraindicated (DeGroote and Humphrey 2019).

Evidence for perishable crafts in symbolic or ideological processes can, however, be deduced from other lines of evidence. While the cultural or individual-specific significance of colourant on the baskets at Taforalt cannot be fully understood, it is possible that stylistic, artistic, and aesthetic conventions were in place in the North African LSA. Crafted forms also appear as a part of early funerary behaviour. In particular, Individuals 1, 2, 3, 7, 13, and 14 show skeletal articulations and positioning consistent with partial decomposition in a void, a scenario met when bodies are wrapped before burial (e.g., woven material or animal skins) (Humphrey et al. 2019). These voids indicate that baskets or other organic materials were a part of Iberomaurusian mortuary practice, even among the earliest burials.

While the appearance of advanced perishable crafting techniques at Taforalt cannot be called precocious (with baby carriers, for example, hypothesised to date to millions of years ago [Berecz et al. 2020]), they can be understood in a rarely afforded high resolution North African Palaeolithic context. Bone tools used in basketry crafting existed as elements in the technological repertoire of seasonally itinerant hunter-gatherer Iberomausurians, and these technologies were scaled up and expanded on in support of changing cultural strategies. When viewed in context, it is clear that plastic, adaptive crafting processes, including the creation of coiled basketry, scaffolded (and arguably

enabled) the shift to greater sedentism, resource intensification, and demographic expansion evident in the Grey Series Iberomaurusian at Taforalt.

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6 Paper 4: Documenting functional use-wear on bone tools: an RTI approach

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Abstract

Bone tools have a long archaeological history, and have recently been shown to retain use-traces distinctive of different perishable crafting practises. When examined in a controlled way, these diagnostic use-traces could serve as proxies for the crafted forms the bone tools were used to produce (e.g., baskets, leather goods, etc.). However, a number of methodological stumbling-blocks have hindered the sharing of bone tool use-wear results in a consistent standardised format. We suggest the application of Reflectance Transformation Imaging (RTI), and provide details for how to construct an RTI system which resolves most problems related to reproducibility in use-trace analysis.

6.1 Introduction

6.1.1 The role of bone tools in prehistoric cultures

In archaeology, any understanding of the past is based on interpreting material remains left by past peoples. We do, however, realise that not all objects and technologies used in the remote past will have survived to the present day. In particular, items made out of organic materials, including crafted forms (e.g., baskets, leather goods, etc.), are vastly underrepresented at archaeological sites (Croes 1997, Hurcombe 2008, Soffer et al. 1999). In most cases the archaeological invisibility of these crafted forms pairs with the archaeological invisibility of their producers to reveal a vast blind spot in our knowledge of how the remote past was actually lived, and by whom (Griffits 2001, Stone 2009/2013, Bradfield 2014, Stammers et al. 2017, Medina et al. 2018, Langley et al. 2021).

Of the organic materials that do survive, osseous materials are certainly the most common. Bone tools have been used by hominin species for millions of years, and are in evidence in a number of world contexts at least since the Lower Palaeolithic (e.g., Mania 1962, Yizraeli 1967, Brain 1993, Yellen et al. 1995, Backwell and D'Errico 2001, Biddittu and Celletti 2001, Bouzouggar et al. 2019, Tourloukis et al. 2019, etc.). Because the field of prehistoric archaeology has been historically dominated by the study of stone tools, the lesser attention given to bone tools has obscured understanding of their place(s) in the technological repertoire of Palaeolithic human groups (Desmond et al. 2018, Antonites et al. 2016, Soffer 2004, Stone 2009). Stone tools are virtually indestructible, and their tendency to survive has led to an over-emphasis on particular practises such as hunting and butchery. These biases can distort modern researchers' views of the scope of possible activities within prehistoric groups (Soffer 2004, Soffer et al. 1999, Stone 2009/2013).

Conversely, a lack of evidence for perishable technologies in turn elides the contributions and life histories of anyone not engaged in hunting: in other words, contributions of women (e.g., pregnant or nursing mothers), small children, the elderly, people with injuries, physical and mental disabilities, etc. (Soffer et al. 1999, Soffer 2004, Stone 2009/2013). As with bone tools, the presence of crafted products is implied very early in our evolutionary history. For example, baby carriers are hypothesised to have been in use for millions of years, since *Homo erectus* (Ehrenberg 1989, Falk 2009, Berecz et al. 2020) if not earlier (Taylor 2010, Caldwell 2013). Though crafted forms themselves may not survive, in many cases bone tools used in craft production may still exist. It is only recently that, by combining tribological principles (the study of interactions between surfaces in motion) with experimentation, archaeologists have been able to distinguish bone tool use-wear characteristic of different crafting processes. As such, bone tools can serve as a crucial proxy for otherwise archaeologically invisible activities (Langley et al. 2021, LeMoine 1994, Bradfield 2020, Desmond 2018/2019, Stone 2013, Soffer et al. 1999, Soffer 2004).

In recent years, there has been a widespread recognition that morphological and/or typo-functional descriptions alone are not trustworthy indicators of how a bone tool was actually used (many of which can appear formally similar), and that the study of microtopographic wear traces apparent on the tools themselves is the only reliable way to diagnose use (Chomko 1975, Olsen 1979, LeMoine 1994, Griffits and Bonsall 2001, Soffer 2004, Gates St-Pierre 2007, Stone 2009, Bradfield 2012/2014, Antonites et al. 2016, Arrighi et al. 2016, Langley et al. 2016, Akhmetgaleeva 2017, Desmond 2018, Medina et al. 2018, etc.). Though pioneered in the early/mid 20th Century (e.g., Tyzzer 1936, Semenov 1964), experimental studies have only recently come to dominate how osseous tools are

interpreted, through the creation and use of replica osseous tools for different tasks. Many early experiments were focused on functions of osseous tools as weapons, and there is a wealth of contemporary literature surrounding weaponry and projectile uses of osseous points (Arndt and Newcomer 1986, Bergman 1987, Rozoy 1992, Stodiek 1993, Iovita & Sano 2016, Pokines 1998, Pétillon 2005/2006/2016, Bradfield and Brand 2013, Bradfield et al. 2020, Langley et al. 2020, etc.). Here, we focus on non-weaponry functions, particularly everyday crafting practises used in a domestic context.

Determining bone tool functionality is possible through the study of microscopic abrasive changes which appear on the surface of bone tools during use. The basis for these studies is the concept of tribology (Le Moine 1994). When a tool is used repeatedly in the performance of a specific task, abrasive wear patterns are produced in the form of changes to a bone tool's surface topography (Campana 1989, LeMoine 1994). Because bone is softer than stone, it will retain traces of repeated contact with other materials as deformations to the tool's surface at the point of contact: '[t]he plasticity and softness of bone allow rapid and characteristic recording of a given action. The original volume of the active end of the tool is more or less quickly deformed depending on the way the tool is used, the nature of the material being worked, its condition, as well as the duration of use'(Legrand and Radi 2008, 306). For example, if a bone tool is drawn repeatedly across a hide with granular inclusions, both the animal's skin and any particulates on it will leave identifiable traces to the surface of the bone tool (Campana 1989, 63). These traces will differ from, say, traces developed through using a tool repeatedly to wedge wood (Campana 1989, 60-61). When examined at magnification, these traces can be distinguished from one another, even though the overall shape of the tool used in both of these processes may look nearly identical (e.g., a 'point'). Archaeologists conducting

experiments with replica osseous tools can then compare the micro-topographic patterns produced on the experimental tools with patterns found on archaeological tools.

Experimentation has successfully documented use-traces associated with a variety of specific activities, including hide and skin piercing (Campana 1989, Akhmetgaleeva 2017, Campana and Crabtree 2018, Legrand and Radi 2008, Griffits 2001, Wojtczak and Kerdy 2018, Bradfield and Brand 2013), scaling fish (Arrighi et al. 2016, LeMoine 1994), beading fish-heads and net making (Arrighi et al. 2016), use as hoes (Bradfield and Antonites 2018), in pottery smoothing (Buc 2011, Gates St. Pierre 2007, Struckmeyer 2011), termite-mound digging (Gardner 2019, Backwell and D'Errico 2001), corn-husking (Gates St-Pierre 2007), tattooing (Gates St-Pierre 2018), detaching limpets from rocks and gouging limpets out of their shells (Griffits and Bonsall 2001), as nose-bones (Langley et al. 2016), in basketry manufacture (Campana 1989, Legrand and Radi 2008, Olsen 1979, Campana and Crabtree 2018, Struckmeyer 2011), as clothing fasteners and bodkins, as implement handles, in splitting and shaving wood (Campana 1989), as hair-scrapers (LeMoine 1994), as musical instruments (Olsen 1979), in smoothing textiles while on a loom and gloss-linen polishing (Struckmeyer 2011), in sewing reeds (Arrighi et al. 2016), as billets (Olsen 1979), as hide compressors (Campana 1989, Martisius et al. 2020) and as wood wedges (Van Gijn 2005).

In other studies, use-trace analysis has focused on discerning changes associated with different worked material. Here the focus is on what the tool was used *with*, rather than what the tool was used for. These experiments include general wet and dry material working (LeMoine 1994), tanned-skin working (Campana 1989, Arrighi et al 2016, Watson and Gleason 2016), dry-skin working (Buc 2011, Van Gijn 2005) fresh skin working (Buc 2011, Legrand and Radi 2008, Watson and Gleason 2016) bending birch bark (Arrighi et al

2016), in silica-rich-plant working (Griffits 2001,Buc 2011), rush-working (Buc 2011), smoked-hide piercing, bark piercing (Gates St-Pierre 2007, Watson and Gleason 2016), non-woody plant working, plant stripping/splitting (Griffits 2001), plant-scraping (Medina et al. 2018), sweat-scraping (Olsen 1979), plant fiber manipulation (Soffer 2004, Campana and Crabtree 2018, Stone 2009), nettle-working, sinew working (Stone 2009), bark peeling (Struckmeyer 2011, Van Gijn 2005), reed-working, hemp-working, digging (Van Gijn 2015), and Yucca working (Watson and Gleason 2016).

Finally, some experimental studies have diagnosed use-wear associated with a particular motion of use or direction of force. These include longitudinal impact/pressure (Backwell et al. 2018, Bradfield 2012, Buc 2011), hafting, smoothing (Buc 2011), piercing (Campana 1989, Buc 2011, Christidou and Legrand 2005), fleshing/softening, punching/puncturing (Christidou and Legrand 2005), chiselling (Griffits 2001), indirect percussion, and rotation (Campana 1989, Legrand and Radi 2008).

The interpretation of archaeological bone tool microtopographies has successfully revealed a number of wide-scale, yet formerly imperceptible practises and processes. Such practises include evidence for termite digging associated with *P. robustus* nearly two million years ago (Backwell and D'Errico 2001, Gardner 2019), seasonality in Palaeolithic economies, such as seasonal labour practises evident in on-site hide processing (Akhmetgaleeva 2017), targeted exploitation of wetland areas for plant-based crafting material (Arrighi et al. 2016), short-term occupation of special purpose camps devoted to shellfish processing (Griffits and Bosnal 2001), evidence for an advanced 'maritime toolkit'-including fish gorges-among early California Palaeocoastal groups (Rick et al. 2001), the presence of textile weaving with a loom in Upper Palaeolithic Europe (Soffer 2004), a marked fluorescence/expansion of osseous technologies in the Late Upper

Palaeolithic (signalling diversification in craft production and changing ideologies, economy, and role-specialisation [Stone 2009]), a high density of plant-working and clothing/bedding manufacture activities, indicating the presence of women on-site at a Neolithic camp (Van Gijn 2005), tanning processes using Oak bark peelings (Struckmeyer 2011), the use of bones as garment pins/fasteners in the Chalcolithic (Campana and Crabtree 2018), very early perishable crafting, resin collecting, and/or personal ornamentation in Australia (Langley et al. 2016, Langley et al. 2021), and early musical instruments (Bradfield 2020) to name a few.

It is clear that a scientifically coherent approach to the study of bone tools -- based on tribological principles and an examination of use-trace patterning -- can reveal a great deal about human activities in deep time, and in much more detail than lithic analysis alone. A comprehensive consideration of bone tools can shed light on formerly invisible actions, actors, and artefacts. As promising as these methods are, there remain significant challenges in the experimental design, analysis, and publication of use-wear results that have impeded bone tool researchers.

6.1.2 Obstacles in bone tool analysis

One of the major difficulties facing researchers in this field is the ability to generate results of experimental studies in a reproducible way. To begin with, a standardised methodological protocol in bone tool analysis does not yet exist, and therefore analytical methods differ greatly between studies. These include scanning electron microscopy (SEM), light-microscopy, digital microscopy (e.g., Dino-Lite), metallurgical microscopes, hand-held lenses (e.g., a magnifying glass), macro photography, visual examination, etc.

Methods can vary from magnifications of 10000x in the case of SEM to 10-250x with use of a light microscope, rendering comparisons of the resultant data untenable between studies. Even among studies using similar magnifications, publications often present the magnification used in different ways (i.e., the use of scale bars vs. listing the magnification used), and differences in depth of focus relative to each method may further distort images. Both the physical examination of tools and any published illustrations of use-traces are performed and recorded under different lighting conditions (e.g., in diffuse natural light vs. under a focused spotlight), as well as different lighting directions (e.g., above versus oblique), colours (e.g., yellow vs. white), and brightnesses (i.e., lumens). Differences in these conditions can vastly impact the way changes to bone tool surface topography appear. Published images are, of course, supplemented by written descriptions of use-traces. Though there has been some work toward the standardisation of bone tool terminology (e.g., Camps-Fabrer et al. 1998, Julien 1982, Pétillon 2006, etc.), researchers may use different qualitative descriptions of use-wear. Some authors provide an index or glossary specifying terms used and their specific meanings, some broadly define descriptive terminology, and some do not.

Finally, sharing use-wear research involves the publication of two-dimensional images of bone tools, including illustrations, still captures from digital microscopes, SEM image files, photographs, etc. All of these image types are subject to further disparities in publication format, with factors such as fidelity, resolution/graininess, and the use of black and white, greyscale, or colour, which vary by publication. Any published images of tools (via whatever method) are also inherently static, capable of showing a single aspect of tools' surface topography in a single image. The use of different methods, lighting conditions, magnifications, resolutions, descriptive terms, and image fidelity in

publications can further simplify or obscure the actual dynamic wear to surfaces which can occur on the surface of a three-dimensional object such as a bone tool.

Problems in reproducibility can be further compounded when archaeological osseous tools are compared to vastly different materials and documentary media within a single study. Comparative datasets may include experimentally produced and used tools, taphonomic reference collections (physical or published), ethnographic data (varying in substance from written descriptions to photographs to access to physical reference collections), and the published results of other bone tool analyses. This latter category alone can include studies that foreground use-wear patterning, as well as studies from a time when use-trace analyses were far less developed, and when morphological identifications were still the 'gold standard' in assessing bone tool function. Comparing use-wear on experimentally produced tools, which are available to the researcher in real time, to images in (or descriptions of tools in) published studies can lead both to false-positive matches, or to erroneously discarding use-wear congruences due to obscure or different descriptive terms, perceived dissimilarities based on magnification, lighting angle, etc.. Clearly, the use of all these different comparative datasets and methods together can result in a scientifically incoherent analysis, through the unwitting use of dissimilar, vague, or incommensurate comparative data.

6.2 Methods

6.2.1 Developing a protocol that addresses these obstacles

The themes discussed here are broadly pervasive and, taken together, such methods are far from the tightly controlled parameters necessary to accurately determine past bone

tool function. We therefore suggest a systematic protocol in assessing bone tool microtopography. First, we need to choose a scale of analysis. Magnification between 10-50x has broadly been established as a methodological standard for recording use-traces (Soffer 2004, Legrand and Sidera 2007, Legrand and Radi 2008, Bradfield and Brand 2013, Bradfield 2014, Akhmetgaleeva 2017). At these magnifications whole-tool features are visible, there is less potential for image flattening or distortion which occurs at higher magnifications, colour, polish (reflectiveness) and shape can be more accurately conveyed, and microscopes which work at these magnifications are widely available. We believe that most use-traces are best visualised at an observational and relational scale, best suited to understanding the relationships between 'zones of wear' (e.g., a polished base indicating a hand-held use or a fixed haft, and an asymmetrically rounded tip indicating resharpening [Campana 1989]). Particular research questions can certainly be investigated by using other techniques, and the use of higher magnifications is possible with Micro RTI (Reilly et al. 2021).

The need to examine bone tool topography at 10-50x, in colour, and under controlled magnification and lighting parameters, using portable, easy-to-find equipment which is not prohibitively expensive, and then to be able to share results with other researchers in an interactive yet easily transmissible way allowed us to converge on a single technology; Reflectance Transformation Imaging, or RTI.

RTI was first developed at Hewlett Packard Laboratories in 2001 by Tom Malzbender and Dan Gelb. RTI is an imaging method which '...requires only images to generate high quality photorealistic renderings of a textured surface' (Malzbender et al. 2001). The basic premise of RTI involves lighting an object from a number of different directions, while a photo is taken at a fixed position above the object. Open-source

software is then used to calculate 'surface normals,' or vectors perpendicular to the object's surface, to interpolate how light is reflected off the object's surface at different lighting positions. These images are then synthesised into an output known as an RTI file. The resultant RTI file allows the viewer to interactively move a light source around a mathematical 3D map of the object, allowing even minute surface topography to be viewed in relief from a number of different positions (**Fig. 6.1**).

RTI is done at very high resolution, as the surface detail is preserved on a per-pixel basis (Malzbender et al. 2001, Kinsman 2016a, Falcetano 2017, Duffy et al. 2018). The RTI file can be used to further enhance surface topography for use-trace interpretation using specialised viewing applications, such as RTIViewer (Cultural Heritage Imaging 2013). The RTI viewer allows lighting positions to be further manipulated by applying a variety of rendering modes, and creating visualisations which can enhance surface inspection of objects. For example, rendering modes such as multi-light enhancement produce extreme raking-oblique light on the tools' surface, without the loss of shadow detail (which is problematic in conventional object photography lighting). Additionally, applying a surface normals rendering mode allows for further critical examination of a surface at a pixel level.

RTI has a number of benefits over other imaging techniques. To begin with, RTI offers advantages over conventional photography. While using advances in camera technology, RTI allows for 'computational photography' and surmounts the limitations of photographs as static images of an object (Fornaro and Chiquet 2019). With conventional archaeological object photography, the photographer chooses the spectral quality of lighting and edits the lighting position before camera capture to enhance diagnostic features seen on a subject from the camera position. Here, the photographer chooses to

show (or is restricted to reveal) details given by lighting opportunities. The final publication photograph is then presented as objective, though it is arguably subjective. With RTI photography the relationship between the human eye and camera position is infinite and surpasses the limitations of the human eye, camera, and lighting of conventional photographs; it captures a multitude of views and can be critically understood to be a scientific image. When compared with photogrammetry, RTI works much better on reflective, smooth, or polished surfaces, which tend to make point-tracking in photogrammetry very difficult. This is crucial as many bone tools will exhibit use-wear in the form of smoothed areas of high-gloss or polish. When compared with GIGAmacro, RTI capture times are much quicker, and retain more information per-pixel as a result of multiple lighting angles (Falcetano 2017). RTI also offers a much higher resolution and better visual representation of an object's surface than does 3D scanning, and is far more portable, less expensive, and works on a scale better for most interpretive analyses than does an SEM. Further, RTI captures are non-contact, and do not require covering the object in gold as with an SEM. When compared with traditional microscopy, RTI can capture dynamic images of objects as opposed to viewing them in isolation from a single perspective (Newman 2015). Of course we do not suggest that photos, microscope stills, written descriptions, etc. be eliminated from use-wear studies; rather we suggest that they be used in concert with RTI, in order to show and describe use-wear as fully as possible and to best advantage.

RTI files are stored digitally, and a working model of the tool/feature under discussion can easily be shared among researchers. Many javascript based viewers are available (now a ubiquitous technology with a low entry level), meaning these files can be easily shared via a web browser. Standardisation in imaging conditions and ease in

file-sharing allow researchers to avoid the incommensurability of results at different magnifications, different lighting positions, different quality of photographic reproductions etc. currently present in publications, and refer directly to a dynamic model of the tool. RTI also obviates the need for often confusing qualitative descriptions; for example, use-wear deemed 'scratching' is no longer subject to interpretation, but would refer to topographies which are directly appreciable to any other researcher with access to the file. RTI therefore provides a remote web-based platform for reproducible bone tool analysis.

RTI has a proven record in successfully tracking subtle changes in objects' surface topography. For example, it has been used to find minute damage to the surface of paintings (Manfredi et al. 2014), to isolate and read ink on carbonised papyri (Piquette 2014), and for viewing original designs on degraded metal artefacts (Roberts Thompson & Williams 2016). RTI has already proven useful in viewing modified bone surfaces, such as identifying butchery marks on bone and antler artefacts (Mytum and Peterson 2018). It has also been used in legal/forensic contexts, to analyse and distinguish specific trauma and tool marks occurring on the surface of bones (Clarke and Christensen 2016). Images produced by RTI clearly meet a high/evidentiary standard of fidelity to the bone analysed, as the authors suggest it for legal use in laboratory, courtroom, and forensic environments (Clarke and Christensen 2016).

There are two main methods for RTI capture: H-RTI and dome RTI. The most common of these is the highlight method (H-RTI), wherein a hand-held light source (such as a flashlight) is moved into different hemispherical positions around an object in a darkened room, and a photograph is taken at each lighting position (Mytum and Peterson 2018). A fixed distance between the object and flashlight can be determined by use of a

string cut to a specific length (Mytum & Peterson 2018). Small reflective ball bearings are placed in-frame with the object, and the position of lighting for each capture is recorded by calculating the position of the light reflection on the three-dimensional sphere. Software is then used to calculate the position of the light relative to the object, allowing for a seemingly three-dimensional topographic rendering of the object's surface (Kinsman 2016a, Macdonald 2017, Duffy et al. 2018).

In contrast to H-RTI, dome RTI captures are performed with use of a prefabricated dome structure which is placed over the object. Dome RTI is generally done in museums and other settings where the portability of an H-RTI set-up is not important. This dome contains a number of lights affixed at different locations over the object in a hemispheric position, and are automated to turn on individually with each camera capture (Duffy et al. 2018). This set-up obviates the need for a darkened room, a flashlight, and ball bearings, as the dome itself blocks any other light source. As the positions of the lights are pre-determined, the images can be automatically synthesised into an RTI file.

Each of these RTI methods has benefits and drawbacks. For example, the elements of an H-RTI kit are inherently portable, consisting primarily of camera equipment and a light. H-RTI can be used to document artefacts on site; it is particularly well-suited for capturing objects *in situ* (providing the lighting conditions can be met), and has even been used underwater (Selmo et al. 2017). Portability is crucial in situations where artefacts or collections are delicate, in remote locations, in precarious geopolitical situations, or non-exportable, and creates a viable working model when the object being recorded is physically absent (Hunziker-Rodewald & Fornaro 2019). However, H-RTI can be time consuming, and if the object moves during capture the process has to be started all over again. To date, the single published application of RTI to archaeological bone tools used a

H-RTI capture method consisting of 36 photographs taken with a flashlight at different positions around the object, using a standard camera set-up. Though the dynamic nature of RTI files was found to be very useful, here the utility of H-RTI was limited to pre-selecting artefacts which would merit further analysis via other methods, time-consuming when compared to other methods, and only able to capture details already visible to the naked eye (Newman 2015).

Dome RTI capture is far less tedious and time consuming with it's automated lighting and image processing. Dome RTI controls for many of the variables which have hampered comparability in other studies, as there is an automatic control over the lighting distance, colour, direction, and intensity (brightness). Dome RTI also eliminates the need for a string in checking the distance between the object and the hand-held light source, making captures far less tedious, and reducing inadvertent bumping or moving of the object, which renders the capture sequence unusable. The object is protected by the dome during image capture, and post-processing can be easily automated without the need for reflective ball-bearings. This procedure, however, does not allow for editing photos to maximum advantage prior to processing. Additionally, the non-portability of most RTI domes limit its use outside of static museum and/or conservation settings. In view of the limitations of RTI presented by each method of capture, we chose to tailor our own system to use the benefits of H-RTI and dome RTI, at the scale best suited for rendering bone tool use-wear.

6.2.2 Our design

Foremost, we realised that a standard camera lens would not capture the level of bone tool surface detail necessary for comparative analysis, but replacing a standard camera lens with a macro lens would allow us to capture images at the necessary magnification and resolution. Due to the smaller sensor used and larger image captured with the macro lens, the image is easily scalable. Macro lenses also provide a fixed focal length, which is perfect for use in a lighting dome and can be used in a number of other imaging techniques (photogrammetry for example). Macro lenses are also useful in conventional photography as they can focus to infinity. When using a macro lens, focal length influences how close one needs to be to the subject: this is known as working distance. With a greater focal length, it is possible to be farther from the subject and still achieve the effect of extreme closeness. Smaller focal lengths allow a very close working distance while easy focus acquisition is maintained, and has benefits over the use of a microscope, with which a very small area is covered during image capture. Areas outside the central view are often out of focus, unless computational focus depth stacking is utilised. For this project we chose a Nikon 60mm Micro Nikkor lens with manual focus giving a 1:1 reproduction, and a high MTF performance (Modulation Transfer Function or 'MTF' is a measurement of the optical performance potential of a lens), enabling minimum distortion and accuracy of colour value recording of fine details on the camera sensor.

Since documenting bone tool microtopography happens both on-site and in museum collections, we wished to develop a technology which was both robust and portable enough to use in all settings, while also allowing for the best possible capture outcomes. This seemed most achievable through use of a portable lighting dome (**Fig. 1**),

which would eliminate the time-consuming nature of the H-RTI capture, while simultaneously allowing for more lighting positions (50+) to construct a more detailed final RTI file. We combined the systematic and thorough lighting conditions provided by a dome (in addition to the object being completely protected and eliminating ambient light) with the benefits of H-RTI, which include portability, cheapness, etc.. In field settings it is not always possible to find circumstances akin to the 'darkened room' necessary for standard H-RTI. Furthermore, we needed a dome which did not require an electrical outlet as its power source, and which was not likely to be damaged by excavation conditions such as dust or debris (at least not any more than standard camera equipment). However, we did wish to retain the use of ball bearings as an aspect H-RTI, allowing us more control in editing photos before they are compiled into an RTI file. Capturing these photos in RAW crucially allowed us to lighten/darken images to best advantage before using the PTM fitter to run them through the RTI builder (available at CulturalHeritageImaging.org), an advantage over most domes' standard automatic processing. Since it is the RAW data which is captured by the camera sensor, it is possible to repeatedly change and reformat; JPEG captures, for example, don't allow for this degree of choice and control. Capturing in RAW is absolutely necessary for high fidelity reproduction of true colour, and also editing exposure, shadows, highlights etc.

Though there are a number of open source RTI designs available (Falcetano 2017, Pawlowicz 2016), our design (**Fig. 1**) was based on Kinsman 2016b, with a number of modifications. The dome contains a total of 72 lighting positions, with four rows of 18 lights each. Each row points the LEDs at the approximate angles of 15°, 30°, 45°, and 60° (degrees) above the centre of the dome. Instead of a 16 x 8 LED driver, we made use of a charliplexing LED array known as the Lots of LEDs Shield (LoL Shield) in order to

provide more mechanical strength, and to make wiring more straightforward (Rodgers 2015). Our use of a shield meant that there was no secondary module that could get damaged, and the wiring was also less likely to get damaged; rather, the wiring plugs directly into the headers of the arduino board. We used all the same size LED bulbs in a white light for best colour fidelity, and used cable crimpers to rapidly add dupont style sockets to pre-wired LEDs, and allowed us to rapidly manufacture them without soldering. In terms of software to run the dome capture sequence, we developed a lightweight Python based terminal application to send different switch commands to the arduino (**Fig. 1a**), which allowed us to control our own lighting settings from a laptop. Because we use the USB/Serial cable, the entire dome can be powered from the laptop, with the added possibility of using a 9V battery in future. Instead of a reed switch we used an infrared LED with a timed pulse to trigger the camera; this in theory could be programmed to include other camera pulses, but at the moment it only works with Nikons. We also added a 30 second pause before beginning the capture sequence, to allow any vibrations from the camera set-up to abate (**Fig. 6.1b**).

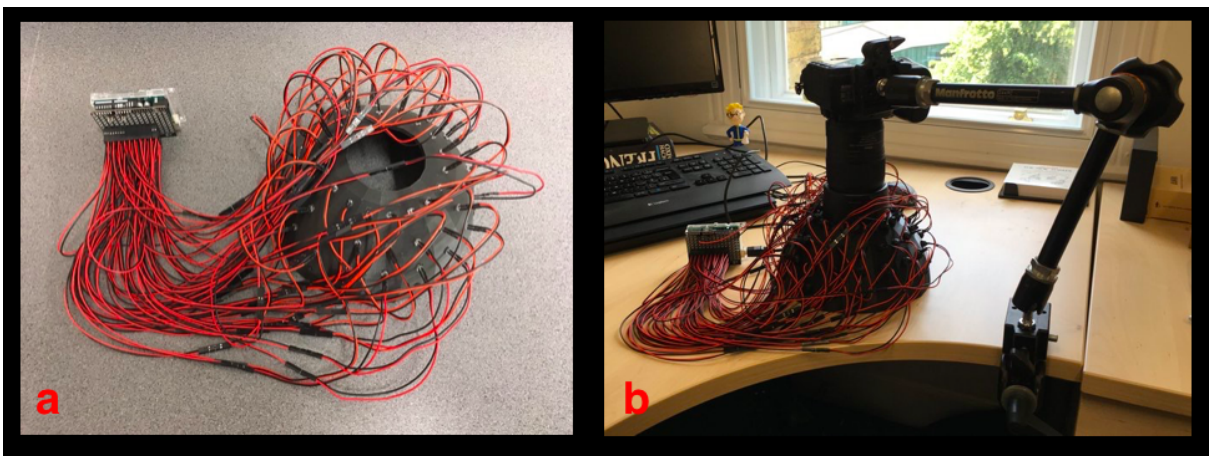


Figure 6.1: Our 3D printed RTI Dome

The flexibility of our design showcases the modularity of RTI as a method. Because the LED's are not soldered into the dome, we can run any number of lighting positions (e.g., 30 rather than 72) for a quicker capture. We can also swap out our white LEDs for ones which emit different wavelengths of light. Here we have an in-built capacity to make our RTI capture multi-spectral by changing the LEDs and using a modified camera/lens. Further, because we use an H-RTI technique within a lighting dome, it is theoretically possible to 3D print multiple setups and try new things very quickly by altering our virtual dome design. Should a researcher have questions relating to smaller magnification-specific microtopographies, a dome could be printed to fit a small light microscope (such as a Dino-Lite) rather than a camera. The 3D printed dome is lightweight and portable, and can be placed against non-level surfaces by using a magic arm on the camera. Adding a lens clip would allow one to actually attach the dome to the end of the macro lens, and different domes could be printed to accommodate different lens widths, particularly useful in field settings where artefacts and features do not always occur at level planes.

6.2.3 Our protocol

Tools were first examined visually, photographed using a Nikon D7100 camera and a Nikon 60 mm Micro Nikkor lens, then examined and photographed with a Dino-Lite digital microscope (AM3113T) before running RTI captures. We use a modified version of Duffy et al. (2018) for our basic RTI protocols (supplementary materials).

Rather than choosing archaeological or experimental tools, we have chosen a selection of ethnographic bone tools with known uses and articulations. These artefacts

represent tools used in a variety of 'real world' scenarios, and will have developed microtopographic use-wear throughout their life history. A selection of tools was chosen from the Phoebe A. Hearst Museum of Anthropology (PAHMA) collections at UC Berkeley, and are representative of different non-weapon perishable crafting use-trace pattern development. We chose tools with a variety of uses in order to test whether RTI could effectively record microtopographic patterning related to the tools' functions.

6.3 Results

In order to illustrate bone tool surface detail captured by RTI, we have included conventional photographs, digital microscope images, and stills from RTI files which show different features at a number of magnifications. We also discuss filters which can be applied to RTI files, and examples of their specific utility in interpreting bone tool use-wear.

First, we wish to show the dynamic nature of the RTI file, and how it can be manipulated to reveal different features through subtle changes in lighting position (**Fig. 6.2**). In order to show how the virtual light source is manipulated through the RTI viewer (Cultural Heritage Imaging 2013), we show four views of an antler tool used in woodwork-finishing; specifically, in polishing projecting edges and angles of carved wooden items. These views illustrate how changes in the direction of lighting illuminate different surface features, including the presence of rough/smooth areas, longitudinal and diagonal use-trace striations, concretions, etc. (**Fig. 6.2 a-d**). Were any one of these photos to represent the tool in a publication, the reader would have a different (and incomplete) representation of how the tool's surface actually looks.

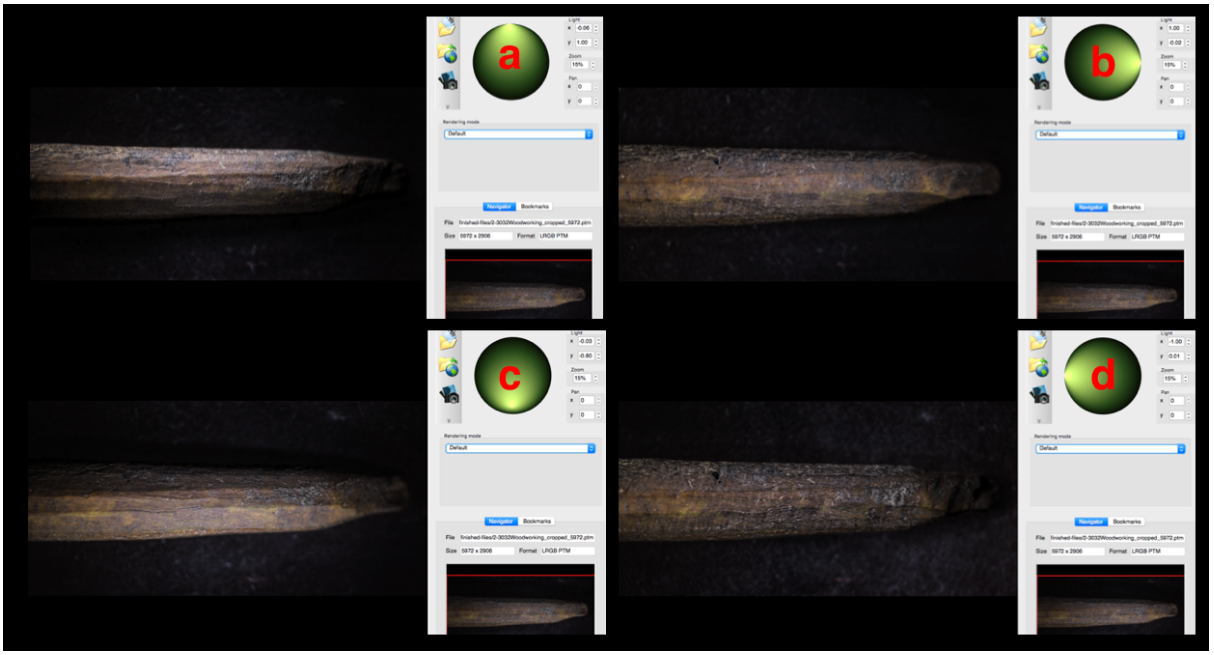


Figure 6.2: 2-3032 RTI stills of an Inupiat/Yuit (catalogued as 'Alaskan Eskimo') bone tool used in woodworking (Please see supplementary materials for RTI file)

Next, we can see how RTI captures compare with standard macro photos and digital microscope stills. **Fig. 6.3** shows a bone tool made from a deer metatarsal which was used in making coiled baskets (Native name: 'tculla'). Image **Fig. 6.3 a** is a standard macro photo with a scale bar, and **Fig. 6.3 b-c** show digital microscope captures at 50x and 230x. **Fig. 6.3 d-e** show the same object's RTI capture viewed with a 15% zoom, **Fig. 6.3 e-f** with a 28% zoom, and **Fig. 6.3 h-i** with a 41% zoom. Because of the greater degree of control in image processing provided through our design, we were able to enhance the uncompiled images' exposure and contrast before running them through the RTI builder (**Fig. 6.3: d-g**). This filter allowed us to make fine surface topographies more readily visible by enhancing the contrast between areas of different elevation on the tools' surface by modifying white balance, clarity, and exposure settings, enabling a clear visual representation of use-traces not possible with standard microscopy and still photos (**Fig. 6.3: a-c**). There is also a clear benefit in using RTI in conjunction with other methods.

While **Fig. 6.3 a-c** are useful in showing static images of surface topography, RTI (**Fig. 6.3: d-i)** allows for the examination of these use-traces in seeming three dimensions from a number of different lighting positions, in relationship to one another, at a wide variety of magnifications (zooms), across a broad portion of the tool's surface in a single image file. Interesting use-wear captured by a still photo or microscope can be more fully examined with RTI, viewed in relation to other use-wear and tool features, and shared with other researchers without a loss of fidelity.

We also show how RTI can document bone tools which exhibit a high degree of polish developed through use. As previously mentioned, highly reflective areas can be difficult to document using point-tracking in photogrammetry. Polish is also difficult to capture using flash photography and light microscopy, as the light source which illuminates the object can reflect back into the lens, causing flares and extremely bright 'blown out' images. The object considered here is a skin scraper: repeated contact with skins and hides has developed a high-polish to the working edge of the tool. **Fig. 6.4a** shows a conventional photograph; note how the polish to the tool's lower right edge is not evident, as the object was photographed in darker conditions to exclude flare from this highly polished surface. **Fig. 6.4b** shows a Dino-Lite still of the object's blade taken at 50x magnification.

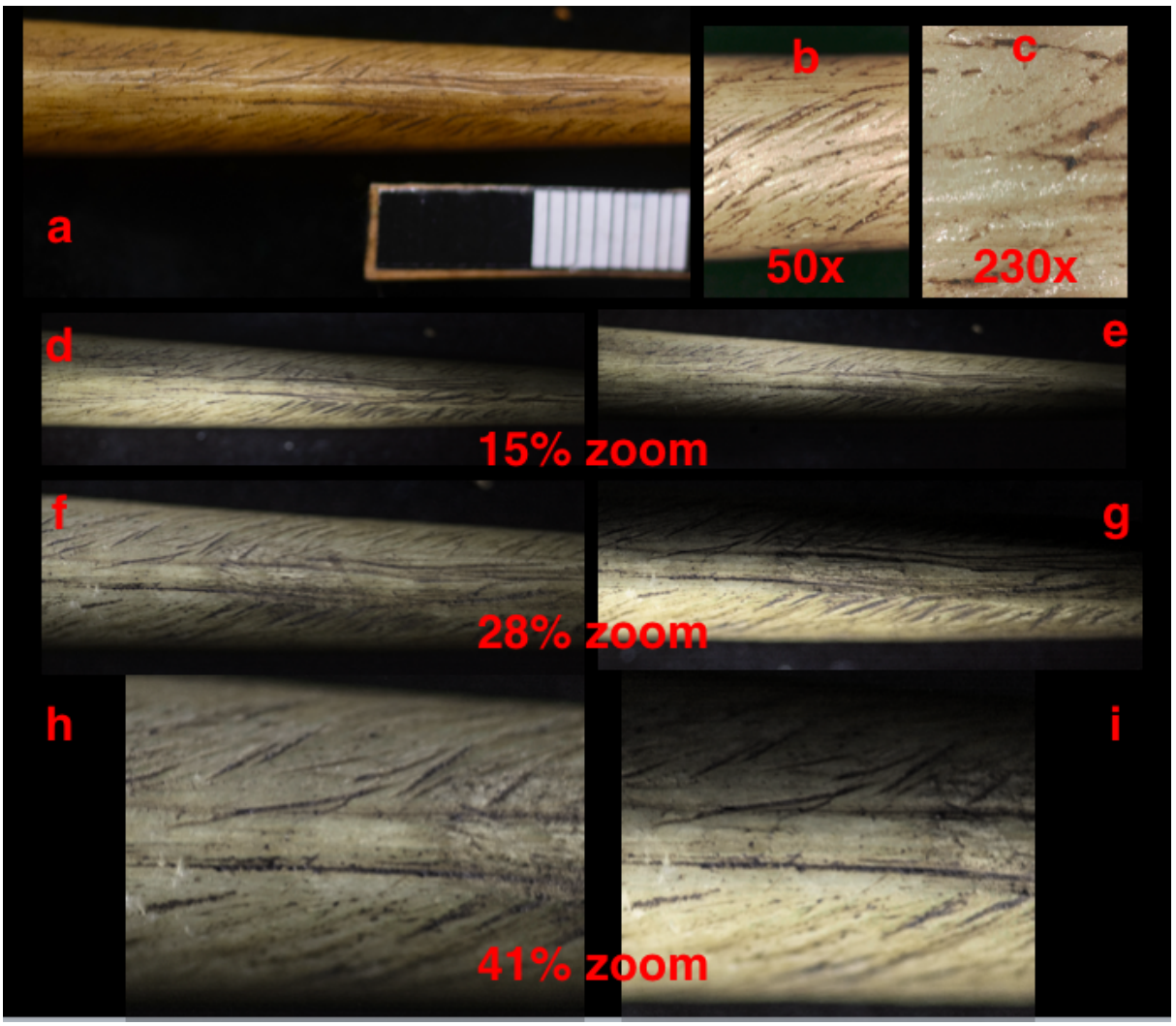


Figure 6.3: 1-10125 Eastern Miwok bone tool ('tculla') used in coiled basketry making (Please see supplementary materials for RTI file)

Here the tool appears much lighter in colour, and in places the image has been washed-out owing to glare from the light source on the reflective surface. A still from the RTI file's standard view at 40% zoom (**Fig. 6.4c**) show how RTI is able to capture the object's colour with greater fidelity, and to show areas of high gloss/polish, smoothness, and faint striations clearly and without glare or colour-distortion. Here we show how the 'diffuse grain' filter can be applied to bone tools: **Fig. 6.4d** shows the same portion of the tool (at 40x zoom), with an increased representation of height and depth on the tool's surface. This tool allows researchers to view topography in the form of peaks/depressions, and 'enhances the perception of surface shape features of the subject for interpretive

purposes' (Cultural Heritage Imaging 2013). This is also a valuable tool in use-wear interpretation: when the part of the tool being analysed is similar in colour but has differences in surface topography (e.g., **Fig 6.4c**), this rendering mode can be applied to better understand the topography or surface features and use-wear, where a polished area (indicating a surface of repeated contact) ends and a non-worked surface begins (e.g., **Fig. 6.4d**).

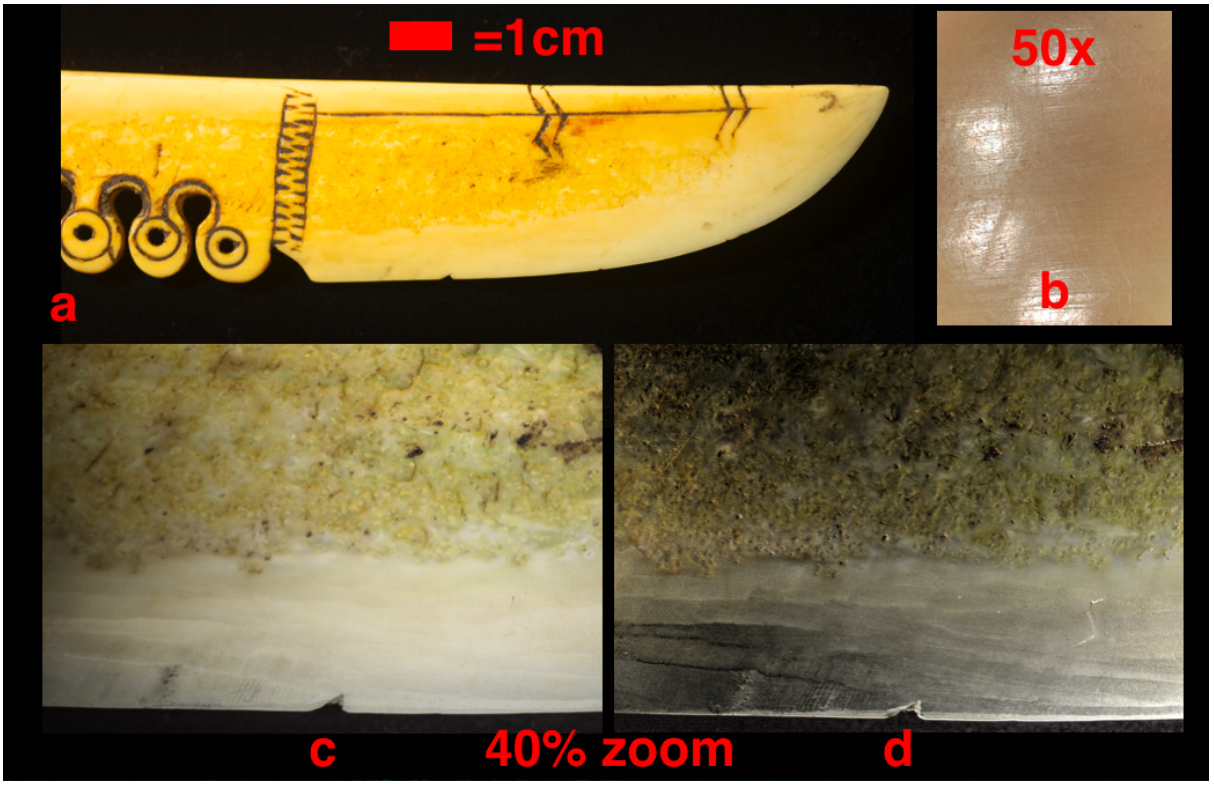


Figure 6.4: 2-1343 Inupiat/Yuit (catalogued as 'Alaskan Eskimo') bone tool used in skin-scraping (Please see supplementary materials for RTI file)

Next we show a tool which possesses multiple attributes that are difficult to document; specifically, high-polish and small, extremely fine use-traces present on the same part of the tool. This tool is a bone awl made from a deer ulna and used for making basketry. Similar to the skin-scraper, the photo of the basketry tool does not effectively capture areas of high polish (**Fig. 6.5a**), and the reflectivity of the polish makes accurately capturing microscopic striations difficult at 20x magnification (**Fig. 6.5b**). The RTI file,

however, shows both the smoothness of the polished area and the microscopic diagonal striations clustered atop it along the axis of the tool, first at a 15% zoom (**Fig. 6.5c**) and then at a 36% zoom (**Fig. 6.5d**).

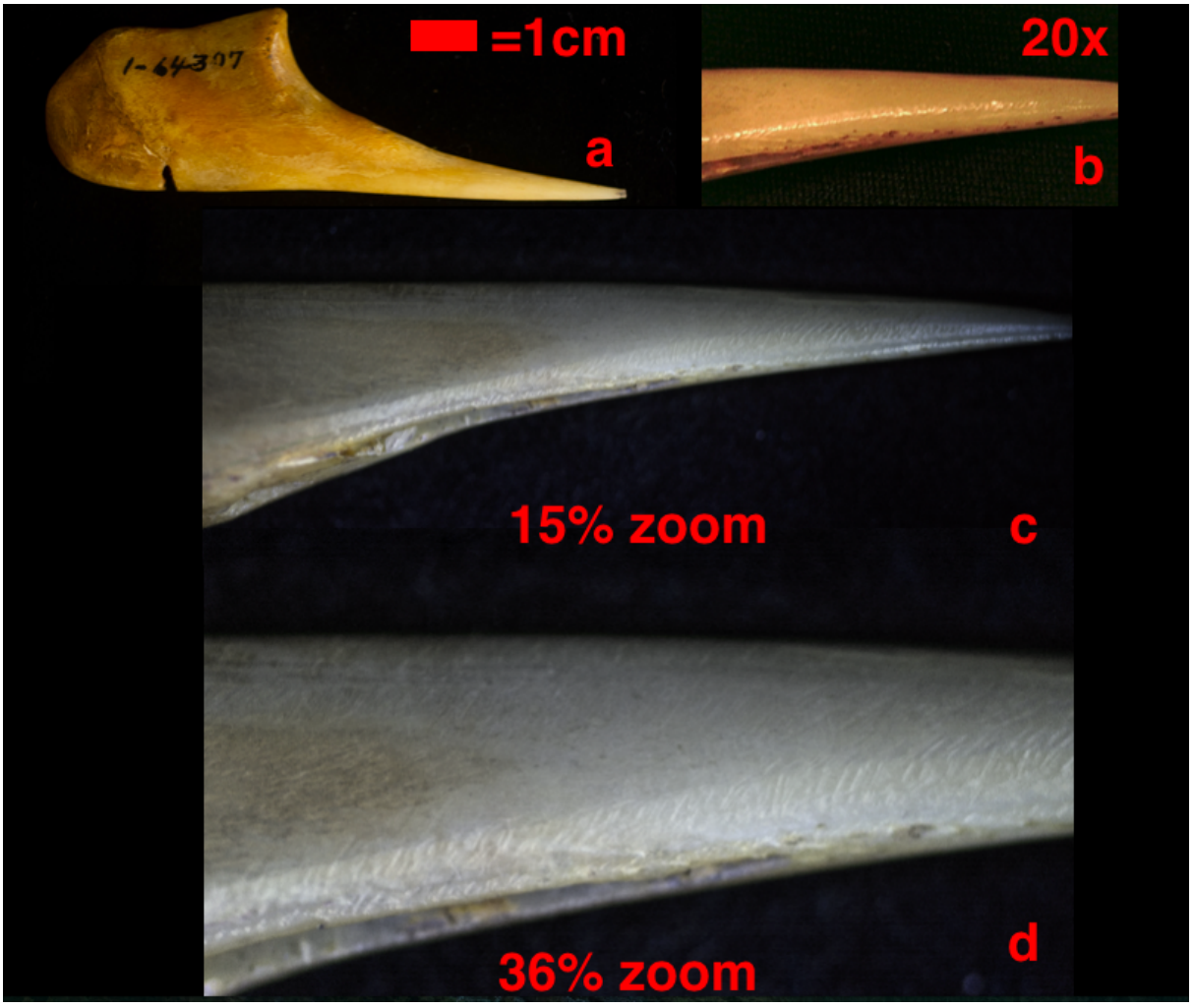


Figure 6.5: 1-64307 Pomo bone tool used in basketry making
(Please see supplementary materials for RTI file)

Finally, we show how use of the 'specular enhancement' filter allows for the viewing of surface shape/topography, and enhances the reflectiveness of smooth surfaces. **Fig. 6.6a** illustrates how the default view in the RTI viewer shows a true-colour dynamic rendering of the surface topography, including decorative incisions, concretions, etc.. **Fig. 6.6b** shows how using the 'specular enhancement' filter provides an enhanced visualization of

the lower portion of the tool's blade. This is useful for identifying/discerning areas of high polish/smoothing, and contrasting them with adjacent areas with more varied surface topography; this is a crucial step in identifying use-trace patterning, as areas of higher polish occur on portions of the tool which repeatedly came into articulation with the hand or worked materials. By using the specular enhancement filter, researchers are easily able to identify wear-foci in ways not possible with standard image capture methods.

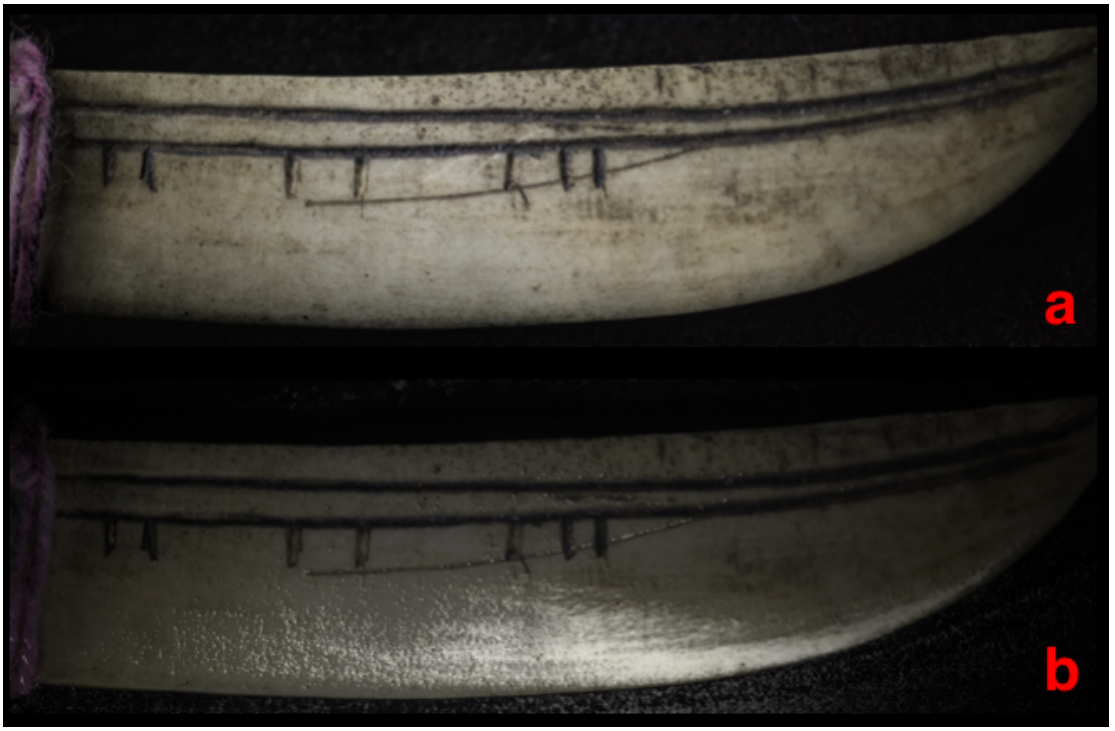


Figure 6.6: Inupiat/Yuit (catalogued as 'Alaskan Eskimo') bone tool used in skin-scraping (Please see supplementary materials for RTI file)

6.4 Discussion

RTI clearly offers advantages in representing minute surface topographies on bone tools used in perishable crafting. While specific use-wear analyses are beyond the scope of the present study, it is possible not only to see minute surface topography in three-dimensions from multiple angles, but also to track the ordinal nature of changes (e.g., polish overlain by scratching). This is important in distinguishing tool formation

strategies (i.e., initial shaping/re-sharpening) from use-wear, and from any post-depositional damage. Additionally, researchers can apply a number of filters within the RTI viewer to provide an enhanced view of topographical features. 'Diffuse grain' visually enhances changes in height and depth, while 'specular enhancement' enhances surface topography and reflectiveness, and are both valuable for identifying use-wear foci. Because RTI uses a camera lens it can capture a larger area than microscope stills, which makes it possible to see the relationships between 'zones of wear' on a tool (e.g., polish to the base indicating hand-held or hafted use and tip-striations indicating direction-of-use). A greater degree of flexibility in image post-processing allows researchers to enhance the visibility of use-wear by modifying images' sharpness, exposure, white balance, contrast, etc. before they are compiled into an RTI file. Because of the modularity of the RTI design we present here, it is further possible for researchers to choose their preferred scale of analysis (e.g., macro photography, use of a light microscope in image capture, etc.) in order to address specific research questions or objectives. RTI can also be combined with other methods in order to yield the most thorough record of a surface: in particular, newly published applications of RTI with photogrammetry are very promising (Solem and Nau 2020). Perhaps most importantly, researchers can compare diagnostic use-traces between bone tools in 'real-time' without having to have the objects physically present. RTI allows researchers to interpret bone tool use-wear in a scientific way, with a greater degree of control over variables in capture than perhaps any other currently available method of record, and to share these captures without loss of fidelity.

6.5 Conclusion

RTI provides a virtual working model of microtopographic surface features related to bone tool use. RTI captures provide a dynamic, scaleable view of minute use-wear not possible with standard photography or microscopy. It is a technology which is open-source, easy to modify, inexpensive, portable, and non-invasive. Because of its control over variables in capture, ability to capture use-wear not easily recorded by other techniques, and the dynamism of the images produced, RTI can be used to document minute use-trace patterning on bone tools under tightly controlled parameters. Since well-documented ethnographic collections and experimental bone tools are not always physically accessible, RTI files of these tools shared via a web platform can serve as a remotely accessible dataset. These files can then be compared with archaeological bone tools to determine best-fit use scenarios. In this way, RTI enables researchers to move toward bone tools as a proxy for otherwise invisible crafting practises and organic products (such as weaving, basket making, netting, etc.), through identifying diagnostic use-wear patterning on archaeological bone tools.

Understanding the role of perishable crafting can tell us a great deal about a group's technological aptitudes, and provides a much more comprehensive framework for understanding the breadth of people's activities, roles, and customs in prehistoric archaeological contexts. As the archaeological record is taphonomically biased toward stone tools and hunting-related activities, understanding bone tool use-wear is crucial in developing a more accurate picture of how the remote past was actually lived, and by whom.

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7 Conclusion

Together, these papers comprise a multi-method *chaîne opératoire* protocol, developed in order to better understand bone tools from prehistoric archaeological contexts. In this section, I will reflect on specific challenges and future directions in developing and using each of these methods.

With regard to ZooMS analysis, it is clear that ZooMS is a highly suitable method for understanding initial taxa selection strategies among bone tools at Taforalt Cave. This study suggests that ZooMS can profitably be applied to osseous tools from a number of prehistoric archaeological contexts, as, given the right preservational conditions, peptide preservation can remain robust in warm, dry, North African environmental conditions, even at this time-scale. While there have been some methodological developments in ZooMS since these first applications, taking small samples of the bone tools themselves remains the best approach in this context. ZooMS analyses have successfully used smaller sample sizes in other studies, though not with Palaeolithic bone. For example, researchers have had success in determining the taxon from which Mediaeval vellum manuscripts originated based on swab-samples (Fiddyment et al. 2015). However, given the age of the artefacts from Taforalt, and the fact that bone tools generally consist of dense or compact cortical bone, it is likely that surface swabs would not be sufficient to yield a suitable sample-size for analysis. Studies have shown that acid-based digestion methods yield best results when applied to bones with low to medium collagen preservation, and generally require a larger sample (Naihui et al. 2021). Additionally, given that most of the bone tools in the existing museum collections were not individually bagged but housed with

other artefacts and originated in a matrix rich with other organic materials, the opportunity for contamination of the sample in the absence of drilling seems high.

Future ZooMS analysis has the potential to reveal longer-term patterning in strategic selection of animals for bone tool raw material. Taxa selection strategies, in turn, may indicate why some bones were preferentially selected over others. Strategic selection patterning could shed light on otherwise inaccessible ideological and technological themes, both at Taforalt and in other prehistoric contexts. For example, do bones created from less common or 'special' taxa cluster near burial areas, indicating their presence as grave goods? Could the histological properties of specific taxa (or specific bones from specific taxa) be better suited to specific crafting purposes? Bones which are better able to absorb impact without brittleness or splintering, or bones which remain flexible under torsive forces would be ideally suited to tasks with these forces in their gesture of use. When deployed on a larger scale, ZooMS also has the potential to reveal longer-term changes in bone tool construction strategies. In the case of Taforalt, one could examine whether the same animal species were preferentially selected throughout the deposits, or whether emphasis shifted to other species in younger archaeological levels. It would then be possible to examine whether such shifts were related to less-visible cultural strategies such as seasonality in hunting, a changing environment wherein certain species became more prevalent over time, or dynamic ideological relationships with different taxa. For example, the Capsian culture succeeded the Iberomaurusian in many parts of North Africa, and the Capsians were known to use human bones as tools (Haverkort and Lubell 1999, Jackes and Lubell 2014). Were we to find tools made from human bones in younger Iberomaurusian archaeological deposits at Taforalt, it might indicate an affinity or corollary between Iberomaurusian and Capsian cultures. As mentioned previously, a

larger ZooMS research programme is currently ongoing, which will hopefully provide more data to determine whether less common animals were repeatedly selected for the construction of specific tool types through time at Taforalt.

With regard to typology, using a feature-based method allowed me to examine themes in bone tool construction without recourse to presumptive use categorisations. These assessments allowed for emergent suites of features to be accounted for in a holistic way. For example, by using both discrete and inclusive types, I was able to account for more intra-assemblage variability than with a standard typology. Here, tools with more than one feature could be counted as members of more than one type (e.g., a spatulate pointed tool could be classed among both spatulate tools and pointed tools). Size-patterning was assessed on an intra-assemblage basis, and so arbitrary determinations of size (e.g., 'big tools') could be avoided. By considering individual tool features and comparing them to the assemblage overall, it was easier to see morphological patterns related to use. Because most tools had asymmetrical shafts, tip-wear, and base-wear, and no tools with these features showed evidence for hafting, a non-projectile-focused industry was indicated. Describing the tools via this typology at an early stage made it easier to isolate collections which displayed similar morphological features to the Taforalt tools, as well as 'control' collections consisting of differently shaped tools. Though typological features can eliminate certain functional possibilities, and be suggestive of use, use-trace analysis must serve as the ultimate basis of understanding bone tool functionality.

Throughout this study, it became increasingly clear that many differences accounted for typologically (e.g., differences in 'tip type') could be seen on ethnographic crafting tools used for identical purposes. This discrepancy underlines the utility of using

ethnographic collections as a comparative basis; had I attempted to 'reverse engineer' the suite of features visible on the bone tools from Taforalt, I may have overestimated their original functional diversity and attempted to replicate formally meaningless tool attributes. By examining a breadth of ethnographic collections, it became clear that there exists a great deal of typological variability even within a single method of use, and that morphological features such as 'tip type' by themselves were not suitably diagnostic of use. Further, it became evident during the study that isolating tools in a 'middle stage' of their *chaîne opératoire* (i.e., not newly formed but not in an advanced stage of curation) was a good way to account for diagnostic use-trace patterning. It also became clear that while size measurements can be good indicators of a particular tool 'form' within a single culture, different cultures may have tools varying in size (and to a certain extent, shape) for basically identical functions (e.g. **Paper 3, Fig. 5.9**). For this reason I did not pursue statistical analyses of the size patterning and other classifications described in this study. Were I to repeat this study, I would simplify and/or eliminate many of these categories.

For these reasons, ethnographic collections are critical resources for assessing actualistic use-trace development. Ethnographic collections effectively show the diversity and breadth of wear and breakage patterns associated with use, which can then be contextualised through experimental programmes. It is evident that neither whole-tool morphology, patterning in typological features, nor simplistic experimental programmes can serve as accurate comparative datasets for prehistoric osseous tools. Rather, use-determinations must be based on microtopographic use-wear patterning developed through real-world use processes. Finally, though coiled basketry production is attested to at Taforalt, it is necessary to consider that not all crafting practises will leave diagnostic use-traces on bone tools. Coiled basket making entails passing the bone tool through

tightly coiled bunches of silicate rich plants, which repeatedly abrade the tool's surface and provide working direction-of-movement indications. When creating open-work matting using looser stitches, for example, one cannot expect diagnostic use-traces to occur in the same way. Examining technological strategies among groups with meaningfully similar cultural modes (i.e., climatic, technological, demographic, food resources, etc.) could help model how archaeological tools without diagnostic traces were used.

In many cases, ethnographic analogy has been avoided by prehistoric archaeologists as an approach fraught with difficulty, providing a contentious inroad to understanding archaeological cultures (e.g., Bednarik 2011, Cruz Berrocal 2011, Hiscock 2007, etc.). However, given the considerable time-depth of humans' proximity to animal skeletons as raw materials, it would follow that cultures worldwide will have discovered and taken advantage of specific properties of bone in order to effectively create osseous tools, themselves suited to the creation of specific crafted forms. While these strategies will not be identical in time and space, we can reasonably expect emergent and repeated similarities between bone tool technologies to occur. In future research, such strategies can perhaps be understood with a view to initial taxa selection, with specific histological properties of bone from different animals suited to different gestures of use. While ethnographic analogies should not be considered as exact models for how archaeological cultures did things, broad over-determinations can be avoided by scaling comparisons away from 'universal' cultural or ideological themes, avoiding 'primordialization,' and acknowledging that similarities between cultures are not necessarily the result of direct contact, cultural continuity, or ancestor-descendant relationships. Ethnographic analogies are useful when they occur at a smaller scale and can be falsifiable: for example, by

comparing use-traces which develop as the result of specific physical and mechanical processes.

In future work, ethnographic collections consisting of tools made from wood, horn, antler, ivory, and teeth could also be examined for use-wear. Because of the relative 'softness' of wood and horn, these materials may provide useful comparative data for use-trace development on bone tools. Teeth can also be a useful tool-material. The hardness and durability of animal teeth may have been suited to specific functions, such as hard-wood working, lithic retouching, etc. Ethnographic collections also provide a wealth of examples of composite tools. Composite tools usually consist of one or more organic materials (such as a wooden handle and twine haft), and can be exemplary of what archaeological tools may have looked like in their original form. By 'deconstructing' ethnographic composite tools into their constituent components, it is possible to determine what the most taphonomically robust portions of composite tools look like in isolation, and therefore what these would look like when found archaeologically. By doing this, features on archaeological osseous tools can be better contextualised. For example, notching or scoring to the base of a tool may have prevented a twine haft from slipping, but absent composite tools as a comparative dataset these may be interpreted as 'notational' or 'symbolic' in nature.

As with any new method, using our RTI set-up to best advantage entailed a steep learning curve. For example, through trial and error it became clear that ball bearings must be exactly level with the portion of the tool which is in-focus during capture, that even slightly dented or 'dirty' ball bearings will render a capture sequence unusable, and that it is necessary to place the ball bearings as close as possible to the tool, but at a height which will not cast a shadow on the tool's surface during capture. Even certain table

materials and/or locations are better suited to RTI capture; when the dome was placed on thin metal tables, for example, these produced too much vibration as the photos were taken, and attempting RTI capture in buildings which have a lot of ambient vibration (e.g., next to a freeway) can also interfere with capture. If available, anti-vibration tables would be useful in ensuring still captures under these conditions. The element of the tool under consideration needs to be completely level to maintain focus during capture, and tools with weathering and/or concretions can produce a shadow on the tool's surface during capture at oblique lighting positions. All of these issues are/were surmountable, however, and it is through this iterative trial and error process that I was able to streamline captures and produce results quickly and with the best possible outcomes. Because the design of the dome is easy to modify, I believe there is great potential for modification based on specific research questions; for example, 3D-printing a slightly smaller dome and using a digital microscope to conduct micro-RTI at even higher magnifications.

The potential for future work with RTI is substantial, as RTI enables researchers to share use-traces in an open-source, transparent, and reproducible format. Most promisingly, RTI can be used to create a remotely accessible database of bone tool use-wear, with which researchers can interpret use-wear on archaeological bone tools. An RTI-based online reference collection can be used to document bone, wood, horn, and other tool media, interactively displaying microtopography developed through different uses. Taphonomic and anthropogenic control collections can also be included, allowing researchers to more effectively differentiate chattermarks, rodent-gnawing, digestive etching, etc. from use-wear. Because RTI files serve as proxies for physical tools, researchers can document and share collections remotely, in many cases eliminating the

need to travel to museums or field locations in order to physically examine tools. In this way, RTI is particularly useful in documenting and preserving difficult-to-access collections, and/or collections housed in in geopolitically precarious circumstances.

When considered together, the use of ZooMS, non-presuppositional typologies, use-trace comparisons with ethnographic tools, and RTI to document and share diagnostic use-traces provide a holistic *chaîne opératoire* approach to understanding prehistoric bone tools. When these methods are used in conjunction, bone tools from prehistoric cultures can reveal a wealth of archaeological data and context which is not accessible through the study of lithic technologies and animal hunting and processing strategies alone. Accurately understanding the roles of bone tools in prehistoric societies is akin to understanding the roles and lives of a much greater segment of the population, and in doing so we are able to account for formerly invisible archaeological actors, processes, and technologies. Specifically, bone tools are closely linked with perishable crafting processes, and such

> [p]erishable fiber technologies - objects made from plant and animal soft tissues - may comprise up to 95% of the material culture made and used by contemporary foragers but are rarely found archaeologically (Barber 1991; Croes 1997; Hurcombe 2008b; Tuross, Fogel 1994). Fiber technologies, then, are frequently archaeologically invisible in two ways: 1) physically, they are perishable and are thus recovered less frequently from the archaeological record; 2) intellectually, even when they are present, these technologies are often associated with the labor of women, children, and the elderly, who are frequently omitted from our reconstructions of the past. These two factors are interrelated and each feeds the other in the development of a gap in our knowledge about ancient perishable technologies: lack of interest in less powerful members of society – in the past and the present – limits the investigation of these individuals in the past, the difficulty of recovering this evidence minimizes the attention paid to these material classes. (Stone 2013:25)

The aim of this work has been to identify and deploy a series of methods for understanding the role(s) of prehistoric bone tools. Together these methods build upon or

improve extant approaches to prehistoric bone tool analysis, provide a diachronic high-resolution approach to bone tools as objects of use, and enable the researcher to 'maintain a dynamic focus on tools as objects of use, providing a discursive and relational approach to material culture...wherein tasks and technologies together form a mutually constitutive culture of material and practice' (Desmond et al. 2018:150).

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