Metalwork Wear Analysis: The Loss of Innocence

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Abstract

Metalwork wear-analysis has now been practised for over two decades. In this paper the authors present the achievements of the discipline and critically assess the methodologies currently applied by practitioners. Whilst the achievements and contributions of the discipline to the wider study of archaeology, and to European prehistory in particular, are numerous, it is argued that an increase in scientific rigour and a focus on addressing limitations and open problems is required if metalwork wear-analysis is to flourish as a scientific field of research. Experimentation with higher magnifications and novel microscopic techniques is encouraged, alongside more standardised and explicit analytical protocols for analysis. More details and targeted descriptions of analytical protocols for experimental work are required: experiments must be designed to answer specific questions and address lacunas in knowledge. While at present the majority of practitioners focus their analyses on copper alloys from European prehistory, and most specifically from the Bronze Age, the authors suggest that a far wider range of materials are suitable for analysis including copper alloys from the Americas and iron alloys from historic and ethnographic collections. Expanding the range of materials studied would open the field up and give it far wider relevance to archaeology and material culture studies. Finally, it is argued that the discipline will advance more quickly if practitioners share their reference collections and databases of experimental marks digitally. The authors suggest that the creation of digital reference collections, open to all, would provide metalwork analysts with the opportunity to lead related fields of research such as lithic microwear and residue analysis, where individual reference collections are the norm and cross-comparability of analysis is therefore hindered.

Keywords

metalwork wear analysis; use-wear analysis; microwear analysis; traceology; metallurgy; copper-alloy; experimental archaeology

1.1 Introduction

After nearly two decades of sustained research and experimentation, the wear analysis of archaeological metals is close to becoming a full-grown field of archaeological science. The subject initially emerged at the disciplinary nexus between lithic microwear studies and archaeometallurgy, and soon acquired its own distinctive goals, methods, and approaches. As new classes of bronze objects were examined microscopically and new traces were identified, however, new problems also emerged, which have exposed the limits of the discipline. In particular, a disconnection of sorts has emerged between metalwork and lithic wear studies owing to the oft-diverging research interests of their practitioners, the practical and material differences between the objects of study, and the lack of formal training in microwear analysis by many a metalwork specialist. As this position appears increasingly untenable, it is now urgent to reassess the developmental trajectory, methodology, and limitations of metalwork wear analysis in order to ensure its steadfast growth for years to come.

The aim of this article is to conduct this reassessment. The authors firmly believe that metalwork wear analysis is close to outgrowing the exciting, if rather disorderly, stage that characterises all pioneering fields of research, and is now coming of age. However, to mature as an independent branch of archaeological science, the discipline needs to lose its early innocence (*sensu* Clark, 1973). This minimally involves the development of a more reflexive approach to artefact experimentation and analysis, a broadly agreed strategy for filling its knowledge gaps, and a self-conscious decision as to where the subject is to stand in relation to lithic microwear analysis, archaeometallurgy, and experimental archaeology. In this article we explain how these goals may be achieved. After discussing issues of definition, we outline a brief history of the discipline, review its analytical methods, and present a number of key suggestions for its future development. We sincerely hope that our work will initiate a broader debate concerning the future of metalwork wear analysis, and how it can reach disciplinary maturity.

2.1 Issues of Definition

Various terms have been employed to define the branch of wear studies dealing with metalwork. *Use-wear* (or usewear) *analysis* is the one used most widely in the literature (e.g. Dolfini, 2011; Gordon, 1985; Kampaus, 2006; Kienlin and Ottaway, 1998). The term, borrowed from lithic microwear studies, refers to the wear visible on the edges and surfaces of an object, which is caused by use (1) (Hayden, 1979; Marreiros et al., 2015; Odell, 2004). The limits of this definition become apparent upon considering that many of the traces observed on metals are not linked to artefact utilisation, but to manufacturing and post-depositional processes (Gutiérrez-Sáez and Martín-Lerma, 2015; Li et al., 2011; Roberts and Ottaway, 2003). *Traceology*, a term similarly borrowed from lithic wear research, refers to the study of any traces visible on ancient tools (Fullagar and Matheson, 2014: 7063). Its use would avoid the implication that wear was only generated by use, or is solely found on the 'working parts' of the objects. The term, however, is normally used in lithic studies to encompass residue analysis, and is therefore too broad at present as residue analysis is wholly marginal within metalwork studies. *Functional analysis* has some currency in lithic wear research, but has rarely been employed outside it. Although used synonymously with use-wear analysis, it may in fact imply the application of methods and approaches lying outside the discipline (e.g. artefact classification and experimental archaeology). Furthermore, as with the term use-wear, it does not encompass the range of production and post-depositional marks observed on objects, and is also rather vague (Donahue, 1994: 156).

We propose here that the discipline be renamed *metalwork wear analysis*. Although this term has never been used in the context of metal traceology, it presents a number of distinctive advantages. Firstly, it does not solely focus on the analysis of use-related traces, and does not imply that certain portions of the object may carry a higher informative value than others. Yet it is close enough to the now-prevalent 'use-wear analysis' to be recognisable by both practitioners and the wider research community. Secondly, it explicitly refers to the methods and approaches of archaeological wear research while also capturing the specificities of the subject, e.g. the prevailing utilisation of low-power microscopy (see 3.1 and 4.2.3). Thirdly, it suggests that the general principles of the discipline are experimentally based and broadly derived from two areas of engineering research: tribology and fracture mechanics (Donahue, 1994). Presently, this is the term that best captures the distinctiveness of the subject whilst explicating its close relationship with lithic microwear studies.

3.1 Metalwork Wear Analysis: History and Research Advances

Metalwork wear studies developed much later than lithic microwear research despite Semenov's early foray into metal tools (Semenov, 1964). Such a late development has been ascribed to a number of reasons including the fear that recycling, manipulation, re-sharpening and corrosion would seriously limit the potential of metalwork wear analysis (Roberts and Ottaway, 2003: 120). It has also been attributed to long-standing preoccupations with typology as the chief avenue for assessing the functionality of ancient bronzes (Gutiérrez-Sáez and Martín-Lerma, 2015: 171). It may perhaps be added that researchers, and especially the students of the European Bronze Age, were for a long time reluctant to consider that our prehistoric past might have been a violent one (Keeley, 1996); hence their hesitation to search bronze weapons for combat marks or to test their use-value experimentally. The combined influence of these factors was ultimately responsible for the delayed emergence of metalwork wear analysis *vis-à-vis* lithic traceology.

The examination of use-related marks on prehistoric and historic copper alloys was pioneered from the late 1970s by a small number of European and American scholars, some of whom appear to have been unaware of each other's work. In Europe, Kristiansen (1978; 1984; 2002) assessed the functionality of Bronze Age swords using interdisciplinary approaches that encompassed, but were not limited to, the microscopy-enhanced observation of large assemblages of objects, while Schauer (1979) trialled the investigation of use marks on spear-heads. In America, Penman (1977) tested the potential of wear analysis on artefacts from the Old Copper culture, while Gordon (1985) studied indigenous bronze tools from Machu Picchu using a novel combination of microscopy and metallurgical analysis. These early studies may be commonly defined by (a) the non-specialist background of the scholars, none of whom had any formal training in lithic microwear analysis; (b) a certain lack of methodological sophistication, evident for example in the absence of experimentation with replica objects; and (c) their eclectic approaches, which employed optical microscopy within a broader spectrum of archaeological and analytical methods.

Pioneering studies of this kind were carried out until the late 1990s (e.g. Bridgford, 1997; 2000; Wall, 1987), when Kienlin and Ottaway (1998) first proposed a rigorous methodology for the wear analysis of copper-alloy objects, which deliberately drew on lithic microwear research. Their ground-breaking investigation of prehistoric axe-heads encompassed the following steps:

(1) field tests with replica axes in order to understand wear formation processes;

(2) taking dental casts of the cutting edges of experimental and prehistoric axe-heads;

(3) examining the dental casts using a low-power stereo-microscope in order to interpret ancient wear patterns by comparison with the experimental ones.

Kienlin and Ottaway's research marked the birth of modern metalwork wear analysis, and their 'classic' three-step approach has since been widely employed, albeit with some adaptations (see 4.1).

As most researchers were interested in prehistoric copper alloys from Europe, the new discipline made significant inroads into Copper Age and Bronze Age studies. In particular, four classes of artefact were afforded the greatest attention: swords, shields, spears, and halberds. Kristiansen and Bridgford's early work on swords was taken forward by Molloy (2007; 2008; 2010; 2011), who advocated a martial-arts approach to the study of these iconic prehistoric weapons. This was based on integrated wear analysis of archaeological objects and field experiments with replica swords, in which he tested the combat potential of the weapons in staged duels (Fig. 1). He was able to show that the alleged division between Middle Bronze Age 'rapiers' and Late Bronze Age 'cut-and-thrust' swords, which had long dominated Bronze Age studies, is incorrect as both types of weapon are suitable for thrusting and slashing attacks, and both display similar combat marks on their cutting edges. Other researchers concentrated on different problems. For example, Quilliec (2008) investigated both combat and destruction marks on a sample of swords from Atlantic Europe, paying special attention to any contextual differences which could shed light on codified practices of use and deposition. In a similar vein, Mödlinger (2011) integrated the wear analysis of central European swords with chemical analysis, x-raying, and 3D computer tomography – an approach that allowed her to unlock the complete life-cycle of the objects from production to deposition. Overall, these scholars revealed that Bronze Age swords had complex object biographies (*sensu* Gosden and Marshall, 1999), which often included use in combat encounters.

The innovative results obtained by sword wear analysis were further supported by the study of prehistoric bronze shields. These objects had universally been thought to be unfit for practical use since Coles' early experiments with replicas (Coles, 1962). However, the new research showed that not only were accurate replica shields effective in withstanding sword and spear attacks, but that the actual Bronze Age shields often display combat marks inflicted by swords, spears, and projectile points (Molloy, 2009; Uckelmann, 2011). Similar points were underscored by spear research, which revealed that these weapons might have been used in hybrid fighting styles that combined throwing, thrusting, and slashing moves (Anderson, 2011; Horn, 2013).

One of the most significant advances brought about by prehistoric weapon analysis concerns halberds (Fig. 2). This is a class of Early Bronze Age implements that had long be regarded as ceremonial due to supposed hafting weaknesses as well as a presumed clumsiness in the hand (O'Kelly, 1989: 164-5; Ó Ríordáin, 1937: 241). However, field tests with an Irish replica halberd disproved this view, since the weapon was shown to effectively pierce twenty sheep skulls without suffering any damage to its point, cutting edges, or hafting rivets (O'Flaherty, 2007a; 2007b). These results were further confirmed by the use-wear analysis of archaeological Irish, British, and continental halberds, which yielded plentiful evidence of blade-on-blade impact and other combat damage (Brandherm, 2003; 2004; 2011; Dolfini 2011; Horn 2014; O'Flaherty et al., 2011). Copper-alloy arrow points from Iberia were also investigated using a similar method, which led to broadly similar results (Gutiérrez-Sáez et al., 2010; 2014). Overall, the wear analysis of Bronze Age weapons and armour, backed by a new generation of laboratory and field tests, has had a fundamental role in overturning undemonstrated assumptions regarding the poor functional qualities of these objects, and has ushered in a new era in the study of prehistoric interpersonal violence.

Metal tools have also received a good deal of scholarly attention, with particular reference to copper-alloy axes (Dolfini, 2011; Kienlin and Ottaway, 1998; Moyler, 2008; Roberts and Ottaway, 2003). This research revealed that the striation patterns visible on prehistoric axe-heads may largely have been caused by tree felling, wood working, and related activities (Fig. 3). Problematically, there have been no experiments which have looked at the marks left on axe blades from working other materials including bone, stone, earth, and metal (such research is now underway by one of the authors); as such the interpretation of these marks as caused by wood-working only is provisional. Other sets of distinctive marks were also highlighted, which were caused by post-casting modifications of the objects including planishing, edge hardening, and sharpening. Overall, one of the greatest achievements of axe wear studies was to shift the research agenda towards the middle stage of the life-cycle of these objects. Previously, axe studies tended to focus on either production, with a strong emphasis on chemical analysis and metallography, or deposition, where purely archaeological narratives were prevalent. Wear analysis has now opened a window on the entire life-cycle of prehistoric axes, bringing to the fore an array of rich individualised biographies (Crellin, 2014; Crellin and Dolfini, 2013; Dolfini, 2011).

In addition to the work carried out on the surfaces of metalwork, there is a parallel and valuable field of research, which explores the marks left on other materials by metal objects. Where prehistoric wood has been discovered in good condition – often at waterlogged sites such as Flag Fen (Pryor, 2001), the timber circle at Holme-next-the-Sea (Brennand and Taylor, 2003)) and Oakbank Crannog (Sands, 1997) – analysts have been able to use the tool markings visible on the wood to infer how, and with what tools, the wood had been worked (e.g. Sands, 1997; Taylor, 1992; 2001; 2003). Similarly, there is a body of research that has studied cut-marks on bones to distinguish those caused by stone implements from those caused by metal ones (e.g. Bello and Soligo, 2008; Christidou, 2008; Greenfield, 1999; Olsen, 1988; Walker and Long, 1977). This research has been somewhat disconnected from mainstream metalwork wear analysis. It has, however, broadened our research perspectives by highlighting uses of ancient metal tools, which have not yet been (or cannot be) explored by analysts directly.

4.1 Research methodology

Although broadly based on the methodology applied to stone artefact analysis (Hayden, 1979; Keeley, 1980; Tringham et al., 1974; van Gijn, 2010; Vaughan, 1985), metalwork wear analysis has developed its own distinctive approach to research as a result of the disciplinary history and goals outlined above, and in response to the challenges posed by the material. Most of the analysts who have operated in the last fifteen years have deployed the three-stage protocol introduced by Kienlin and Ottaway (1998), which has been discussed above. This section offers a critical examination of each step while also discussing alternative approaches and practices.

4.2.1 Stage 1 – Experiments with replica objects

Conducting a meaningful experiment with replica copper-alloy objects normally involves the following steps: firstly, casting and building a complete, faithful replica of the objects to be tested; and secondly, designing a set of tests, which need to replicate as closely as possible the tasks and actions in which the archaeological objects are thought to have been used. This requires in-depth knowledge and understanding of the objects to be replicated including their chemical composition, casting process, post-casting treatment, and hafting materials and methods. It also forces researchers to make a number of educated guesses as to how long-disappeared components of the objects (e.g. the hafts) may have been built and connected to the metal blade or point, and how the complete objects may have been used, for what tasks, and with what tool and bodily motions (Fig. 4).

Kienlin and Ottaway's (1998) research on early metal axe-heads from the north-Alpine region provides a good example of the complexity of the task in hand. The authors first collated all compositional determinations of the archaeological axe-heads concerned and categorised them according to broad compositional groups. This allowed them to identify two main casting alloys (i.e. unalloyed copper and 6% tin-bronze), which they then used for their replicas. Secondly, they built sand moulds with the help of a wooden former and used them to cast the axe-heads needed for the tests. Thirdly, they collated metallographic data from the literature, which guided them through the post-casting treatment of their replicas. In this instance, half the axe-heads were left as-cast and the other half were cold-worked to increase their hardness. Fourthly, the axe-heads were hafted according to two different methods, which were devised upon researching the literature for complete prehistoric tools. Fifthly, they designed a set of field tests, which entailed a number of choices regarding the tasks to be tested, the duration of each task, how to use the tool, and how to record and quantify data whilst in the field.

As is apparent from this review, designing a meaningful experiment for the production of reference wear marks is a complex procedure that requires in-depth archaeological and metallurgical knowledge, comprehensive research into the objects to be replicated, and a great number of conscious decisions, each of which will have some bearing on the traces produced during the tests. It also necessitates a degree of 'practical knowledge' and craft skill, which can only be achieved through protracted engagement with the objects (Doonan and Dungworth 2013). The design and implementation of meaningful experiments is an area in which metalwork wear analysis shows particularly close resonance with the methods used by researchers in lithic studies, and with the questions and difficulties they face.

4.2.2. Stage 2 – Taking the dental casts

Having generated suitable wear on the replica objects, casts may be taken using dental impression material. This normally involves the application of polyvinylsiloxane or similar silicon-based substances to the used portion of the objects (e.g. the cutting edge), which are then peeled off, bagged, labelled, and taken to the laboratory for examination. Likewise, dental casts can be taken from a sample of archaeological objects (Fig. 5).

A number of issues have emerged with this seemingly unproblematic procedure, which is employed as a matter of course in lithic microwear analysis. The first problem concerns the portion of the object to be analysed in relation to the research question. If the latter required the examination of the entire object (e.g. for determining manufacturing marks), the taking of dental casts would be either impractical or extremely expensive, thus limiting the quantity of the objects that could be analysed. Secondly, it was observed that the dental impression material may leave residual marks when used on light-coloured objects, and that fragments of the patina may be unwittingly removed from objects with substantial surface corrosion (Roberts and Ottaway, 2003: 123). For these reasons, some researchers dispensed with the dental casts altogether and conducted the analysis on the objects themselves, normally at museum premises (e.g. Dolfini 2011; Horn 2013; Lowe-Fri, 2011).The issue with staining and the removal of patina fragments emerged early in the history of the discipline and is often cited as a reason not to take dental casts. The problem seems to be caused by the incomplete mixing of the two parts of the silicon-based moulding compound, which has been eradicated by the development of accurate mixing guns. Recent geological research into the use of dental casting as a means to examine fossilised teeth from museum collections has provided quantitative evidence of the safety, accuracy and precision of some silicon-based moulding media (Goodall et al., 2015). Similar tests are being carried out by the authors on prehistoric axe-heads, and it is hoped that they will conclusively prove the safety of the procedure for archaeological copper alloys.

For those analysts who work with the original objects in various museums, the utilisation of different microscopes may lead to inconsistent results, for example in image quality. This can be overcome by carrying one's own microscope to the museums or by using a portable digital microscope, whose image quality and resolution may, however, be inferior (see Horn 2013: 22 for discussion). However, with the growing development of a wide range of new microscopes and techniques (see 5.2.1), it may be time to reconsider this problem as researchers may want to examine objects with types of microscopes not normally available at museums (Fig. 6). The bottom line here is that it has been ascertained that working with either the dental casts or the objects is practicable and safe under most circumstances; therefore it is up to the analyst to decide whether or not to take casts based on their own research goals, the objects with which they are working, and the preference of the museum curatorial staff.

4.2.3. Stage 3 – Examining wear on the dental casts or objects

The analysis of the dental casts or objects normally involves the examination of the traces under a low-power, incident-light microscope, working at magnification ranging from x5 to x50. The marks thus observed are then recorded on schematic diagrams, photographed using the microscope's mounted camera, characterised (e.g. as manufacturing, use, and post-depositional changes, or as plastic and physico-chemical deformations: Gutiérrez-Sáez and Martín-Lerma, 2015), and interpreted by reference to the experimental marks and the literature. Whilst working with the original objects, however, this protocol needs to be adjusted. For example, it is advisable to examine the objects visually and by means of a hand-held magnifier before they are put under the microscope. This allows a preliminary assessment of the wear marks including their location, nature, and visibility in relation to the object's surface corrosion. Furthermore, additional light sources may be used (e.g. halogen desk lamps placed on either side of the microscope), which can be especially useful for highlighting faint traces (Dolfini, 2011). When working with the objects it is also important to devise identification and recording procedures that allow for the accurate positioning and cross-referencing of the marks observed. In our experience, the best way to do this is to sketch the objects prior to the analysis (Fig. 7). The sketches can be used to locate the marks and identify them through letters or numbers, which will then be reported on all the diagrams and notes compiled by the analyst. It is also crucial to take high-quality photographs and micrographs of the objects and marks, and cross-reference them with the sketches. Accurate recording is especially important to make analyses and results cross-comparable as well as to allow other researchers to assess, interpret, and perhaps critique one's results.

Although the analytical procedures discussed here have provided a fundamental reference point for most research undertaken in the last fifteen years, the eclectic strategies adopted by early scholars survived well into the new millennium, and still characterise the discipline to this day. These often encompass a broad spectrum of archaeological and metallurgical methods, which are used to complement the visual or microscopic characterisation of ancient metals. Alternative approaches are often deployed for the examination of combat or deliberate destruction marks, which can normally be assessed by the naked eye. They are also favoured in the study of large samples of objects, when painstaking detailed examination may be impractical (e.g. Brandherm, 2003; York, 2002; see also several chapters in Uckelmann and Mödlinger, 2011). Other scholars attempted to quantify wear by drawing on the techniques employed by tribologists (e.g. Moyler, 2008). These approaches add to the variety of the discipline and show that its fundamental principles and methods can be adapted to specific research questions and artefact classes.

5.1 Towards a manifesto for metalwork wear analysis

As this review shows, metalwork wear analysis is a fast-growing field of research. The last few years have seen the development of a shared approach to microscopic analysis as well as the first, systematic studies of a wide range of copper-alloy artefacts including swords, axe-heads, halberds, shields, spear-heads, and arrow points. However, if it is to grow for years to come, the discipline needs a robust injection of scientific rigour as well as an open debate regarding the analytical procedures, the experimental protocols, and the recording and interpretation strategies to be adopted. We discuss here the problems that, in our opinion, are to be addressed most urgently.

5.2.1 Formalisation of analytical protocols

Firstly, we need to formalise the analytical protocols pioneered so far to make them fully comparable with each other, and perhaps develop new ones for reflected-light, SEM, and quantitative analysis techniques. Two areas sorely need our attention: terminology and trace interpretation. Conflicting lists of terms have been proposed by various analysts, based on either causation or intensity of the damage, while others discriminate between plastic and physico-chemical deformations of the metal (e.g. Dolfini, 2011; Gutiérrez-Sáez and Martín-Lerma, 2015; Horn, 2013; O'Flaherty et al., 2011). This partly reflects different objects and uses, but it is partly due to personal preferences. Worryingly, the outcome is that different people call the same marks different names, or use the same names for different marks. This state of affairs hinders communication between analysts and research groups, and the problem needs to be addressed before the different terms crystallise further: clarity and consistency are essential pre-conditions to be able to talk to each other. As for trace interpretation, designing blind tests (e.g. Newcomer et al., 1986; Newcomer and Keeley, 1979; Rots et al., 2006; Stevens et al., 2010) specifically for copper alloys will ensure that we do not just call, but also understand the traces that we see in the same way as other researchers. Blind testing marked a fundamental step in the 'loss of innocence' of lithic microwear analysis (Evans, 2014) and we strongly advocate its application to metalwork analysis as well.

5.2.2 Understanding wear formation processes and the impact of corrosion

Secondly, we need to better understand wear formation and corrosion processes. This involves research into a number of problems including establishing more precisely and rigorously how marks such as edge chipping, plastic deformation and striations form, and how their shape and size relate to duration of use. Without such work the currently established methods will continue to lack a rigorous foundation. Sequential experiments (see Ollé and Maria Vergès, 2014) would be one way to address the problem as well as closer collaboration with material scientists and tribologists, who have long studied wear development mechanisms. In addition we need to investigate polishes, which are often visible on the cutting edges of metal tools and weapons but have seldom been studied (Fig. 8). Perhaps more urgently, we must address head-on the 'elephant in the room' of metalwork wear analysis, which is understanding more precisely how post-depositional processes (and especially surface corrosion) affect the survival and visibility of wear traces (Gutiérrez-Sáez and Martín-Lerma, 2015; Horn, 2013: 35-36). As for the relationship between alloy composition and wear formation, the studies hitherto conducted must be greatly expanded as to include further alloys, more classes of artefact, and a greater variety of edge-hardening treatments (Gutiérrez-Sáez and Soriano-Llopis, 2008; Soriano-Llopis and Gutiérrez-Sáez, 2009).

5.2.3 Higher magnifications and novel microscopic techniques

Thirdly, we need to test the potential of new types of microscopes and work at higher magnifications. At present, most practitioners start their analyses with hand lenses and then put the objects or dental casts under bi-focal low-power microscopes, whose magnifications rarely exceed x50 (but see Li et al., 2011 for a notable exception). This procedure mirrors the early stages of lithic microwear analysis, until Keeley (1980) introduced a high-power approach (up to x400 magnification) based on reflected-light microscopy. Today both approaches are employed side by side by most lithic analysts as each has its own strengths and limitations (Marreiros et al., 2015). The time has now come for metalwork researchers to do the same, and test the potential of high-power microscopy including Scanning Electron Microscopes (e.g. Borel et al., 2014, Tumung et al., 2015), Focal Variation Microscopes/3-Dimensional Microscopes (e.g. Bello, et al., 2009; Bello et al., 2011; Bello et al., 2013 Macdonald, 2014), and Laser Scanning Confocal Microscopes (e.g. Evans and Donahue, 2008; Ibáñez et al., 2014) on copper alloys. In particular, we need to understand what new traces can be identified with high-power microscopes and if the latter allow a better resolution of wear, e.g. distinguishing between traces caused by different materials. Given the fundamental role that high-power microscopy has had in addressing these problems in lithic microwear analysis, one could presume that significant gains can be made in metalwork studies as well.

5.2.4 Formalised experimental protocols

Fourthly, there is a real and pressing need to develop formalised experimental protocols for our tests with replica objects. Two contrasting approaches have been tried so far: laboratory tests and field tests. Conducting laboratory tests with rigs or robotic devices offers the distinctive advantage of a controlled environment, in which all factors contributing to wear formation can more easily be monitored, recorded, and understood. Yet the drawback is that the complexity of human behaviour can rarely be reproduced by a robot or a rig. On the contrary, field tests provide us with an opportunity to experiment with objects in seemingly 'authentic' conditions (Kampaus, 2006: 121), but control of wear formation processes can be poor. Moreover, reproducing 'authentic' use conditions may be trickier than it first appears. Objects often give us some indication as to how they might be used insofar as their style inheres in their function (Shanks and Tilley 1987: 92); in the case of a pen, for instance, it is obvious which end is for writing. Yet the use of an object is predicated upon a relational synergy between a particular knowing body and the particular object at a given moment in time. Muscle memories and structures emerge in conjunction with our interactions with things and come to shape how we relate to the material world more broadly. One may use an object in a manner that was unthought-of during production, or with a novel bodily technique: consider those who write and paint with the pen in their mouths. Even though an object may imply how it is best used, nuances within that use (e.g. left and right handedness) and the creativity that emerges from the relational nexus of people and objects may be especially hard to grasp under certain circumstances, or when dealing with long-disappeared objects. It follows that reconstructing socially specific 'techniques of the body' (Mauss, 1973) may prove difficult; the past, as Lowenthal (1985) perceptively put it, is a foreign country. A way out of the problem is offered by multivocal approaches to experimentation, in which the conditions and factors underpinning the tests are meaningfully varied (Bell, 2015; Hurcombe, 2008). This is, for example, the approach chosen for the ongoing Newcastle Bronze Age Combat Project (Fig. 9), which combines two different sets of tests with replica weapons (one 'authentic' and one breaking down the fluidity of the combat sequence into discrete, individually recordable actions) in order to assess the formation of combat marks in varied circumstances (Crellin et al., 2015). Whatever pathway to experimentation one may select, it is important that tests with replica objects are at once more reflexive and more formalised. As with all archaeological experiments, our tests must address specific research questions, lay out a clear methodology in which all variables should be discussed (and possibly controlled), and enable us to critically evaluate the results against the archaeological record (Cunningham et al., 2008; Outram, 2008).

5.2.5 Expanding the range of materials and objects

Fifthly, we need to extend wear analysis beyond copper alloys and prehistoric tools and weapons from Europe. These materials and objects have hitherto dominated the subject but there is ample scope for expansion beyond them. The pioneering work of Li et al. (2011) on the bronze weapons found with the Terracotta Army is an excellent example of the potential of metalwork wear-analysis beyond prehistoric Europe, and there is great potential for similar works focusing on the Americas. Moreover, there are existing studies that consider wear on iron weapons such as Gebühr (1977; 1980) and, more recently, Blakenfeld and Rau (2009). Corrosion, however, is a major issue for work on prehistoric iron and steel, and the method needs substantial adaptation if we are to make any significant progress in this area. Undoubtedly, well-preserved historic and ethnographic iron and steel objects can be examined to address research problems concerning their manufacture, use, and artefact biographies including repairs and conservation. As for the more corroded archaeological iron and steel artefacts, these could afford quantitative approaches to analysis of the kind used in tribology (Moyler, 2008). One also has to consider the untapped potential of residue analysis as mineralised organic residues often survive on the oxidised surface of copper alloys. Mineralised residues have yielded vital information concerning prehistoric textiles and tools' and weapons' hafts (Gutiérrez-Sáez and Martín-Lerma, 2015: 184). Curiously, however, these studies have mostly been conducted disjointed from wear analysis, and greater integration between disciplines is called for here. As our knowledge of wear formation as well as our analytical methods become increasingly formalised and rigorous, there is a genuine opportunity to expand the discipline beyond European prehistoric research and to have a far wider impact on global archaeology.

5.2.6 Sharing databases of experimental marks

Finally, there is a real need for practitioners in the field to share the research methods and results more broadly than has been done so far. One of the obvious ways of doing so is to develop reference databases of archaeological and experimental traces, which could be made available to all practitioners online (e.g. via the UK-based Archaeology Data Services: http://archaeologydataservice.ac.uk/). This is an area in which metalwork analysis could lead the way within broader wear studies. The current practice of developing a personal research reference collection, widespread in lithic traceology, is frankly wasteful and unwittingly diminishes the scientific worth of individual research by reducing comparability. If reference collections were available online it would be much easier for analysts to compare their results and to check that they are calling the same marks the same names. The issue is all the more important for metalwork wear analysis as replicas tend to be expensive. Sharing our results and the data behind our interpretations is good science as it leaves space for others to truly understand, critique, and debate our results and explanations.

6.1 Conclusion

As recently as 2006, Kampaus (2006: 119-20) wrote that "the future of archaeometallurgical usewear is not certain, as it is being conducted by a small group of scholars, associated with a limited number of universities". The wealth of research undertaken since shows that the future of metalwork wear analysis no longer hangs in the balance. The discipline has taken root at several universities across Europe, is practised by a growing number of scholars, and has developed its own distinctive approaches to research. It is also taught in a Master's course at Newcastle University (UK), which provides formal training for the next generation of scholars. However, the subject has yet to see the growing pains that lithic microwear analysis once suffered, which marked its coming of age. This article has highlighted the problems on which metalwork wear analysis needs to focus so that it too can lose its early innocence. Importantly, these problems straddle and intersect the fields of microwear analysis, archaeometallurgy, and experimental archaeology. It logically follows that researchers must achieve a good knowledge and understanding of all three subjects, without necessarily being specialists in any of them. Hence, we maintain that metalwork wear analysis ought to position itself at the nexus between microwear analysis, archaeometallurgy, and experimental archaeology, since all three subjects contribute to it in equal proportion (Fig. 10). As most current practitioners have a background in metallurgical studies and European prehistory, reaching this ideal balance point involves a collective journey towards the fields of microwear analysis and experimental archaeology. Here lies what is perhaps the greatest challenge for the next decade. For it is only by completing this journey that metalwork wear analysis can fulfil its potential of enlivening an entire category of objects from our past, not only by answering some of the 'big' questions of archaeology, but also by asking new and exciting ones.

Word count: 5,475

End notes

(1) We are not considering here the wealth of information that can be gleaned from the analysis of the internal structure of the object by means of x-raying, 3D computer tomography, metallography, and other techniques of structural and crystallographic analysis.

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Fig. 1 – Combat tests with replica Bronze Age swords and shields. Experiential tests of this kind have led to a wholesale reappraisal of the fighting potential and uses of prehistoric metal weaponry (from Molloy 2009).

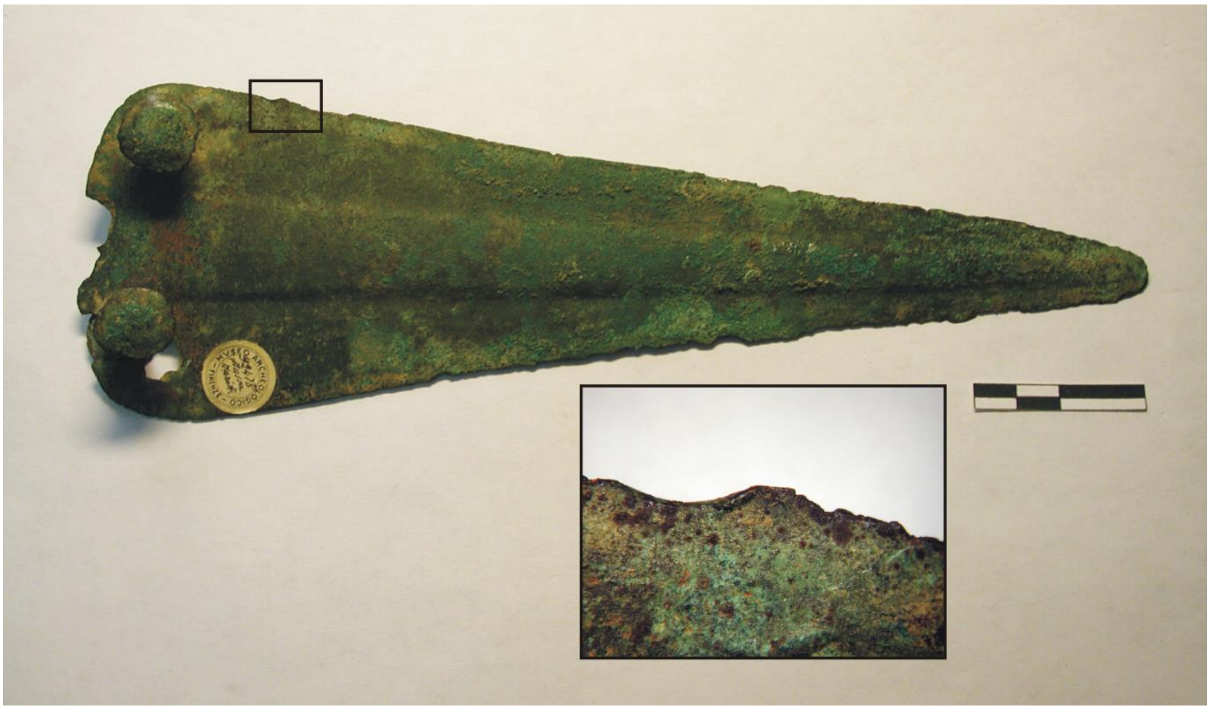

Fig. 2 – Prehistoric halberd blade from Italy. Prehistoric halberds from Europe often display distinctive marks on the cutting edges (see inset, x12 magnification), which are interpreted as evidence of blade-on-blade strike in combat encounters (photo: A. Dolfini, with permission of the Soprintendenza per i Beni Archeologici della Toscana).

Fig. 3 – Early Bronze Age Flat Axe from the Manx Museum on the Isle of Man. The photo and micrograph showing striations from both wear and re-sharpening to the blade. (photo: R. Crellin, with permission of Manx National Heritage).

Fig. 4 – Newcastle student Joshua Desrosier fells a birch tree with a replica Middle Bronze Age palstave. Designing meaningful experiments with replicas forces researchers to make educated guesses regarding construction technology and the uses of prehistoric objects (photo: A. Dolfini).

Fig. 5 – Taking a cast of an experimental axe blade using high-precision impression material (photo: A. Dolfini).

Fig. 6 – Wear marks on a range of copper-alloy objects. *Top left*: Use-wear marks on the surface of a Late Bronze Age sword from the Yorkshire Museum of Archaeology (bar length – 10mm, photo: R. Hermann). *Top right*: Spear stab mark on the surface of a replica bronze shield (bar length – 2mm; photo: R. Crellin). *Lower left*: Bending and notching to the blade of a flanged Early Bronze Age axe from the Manx Museum, Isle of Man (bar length – 2cm, photo: R. Crellin, with permission of Manx National Heritage). *Lower right*: Notch to the blade of a replica spearhead caused by a sword blade (bar length – 2mm, photo: R. Crellin).

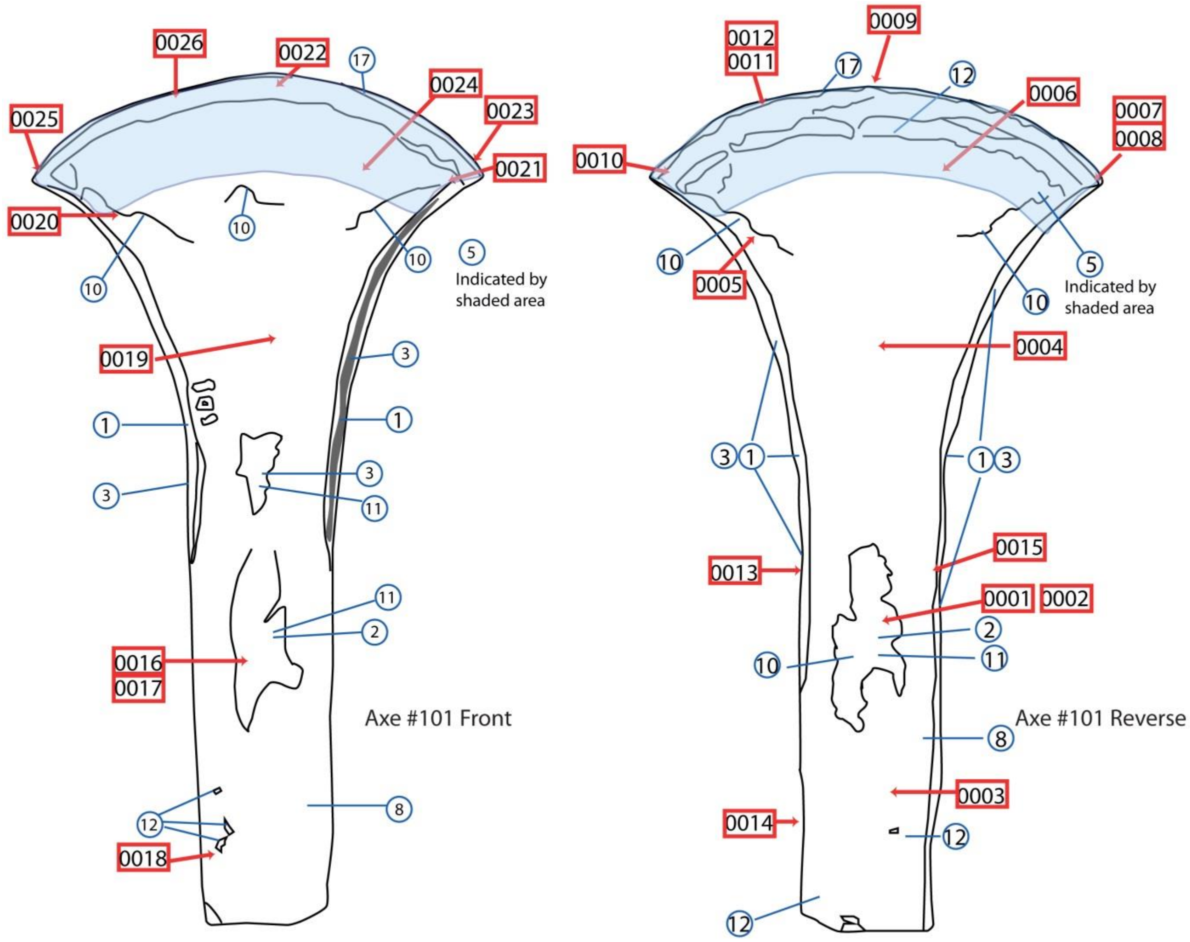

Fig. 7 – Annotated digitised sketch of a replica axe. Figures in blue circles relate to observed wear marks, figures in red boxes indicate the position and number of associated micrographs (illustration: R. Crellin).

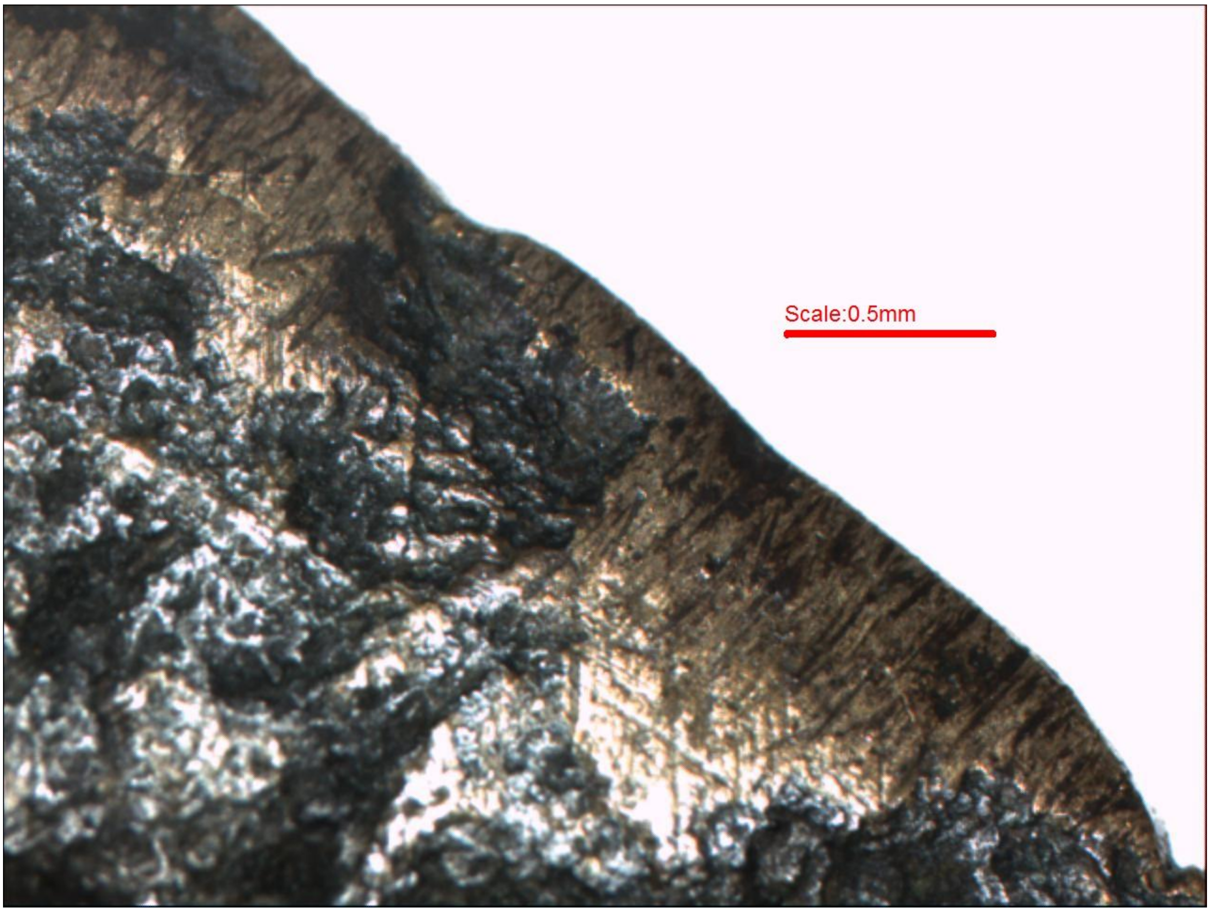

Fig. 8 – Short perpendicular striations associated with localised polish on the cutting edge of a copper-alloy axe-heads from the Tyne and Wear Archives and Museums collections, Newcastle upon Tyne. Although frequently observed, the use-related polish found on ancient metalwork has hitherto received little attention from analysts (bar length: 0.5mm; photo: J. Desrosier, with permission of the Society of Antiquaries of Newcastle upon Tyne).

Fig. 9 – Field tests with replica swords within the Newcastle Bronze Age Combat project. Problem-oriented test design and a clear methodology are essential components of any experiments aiming to understand wear formation processes (photo: D. Horan).

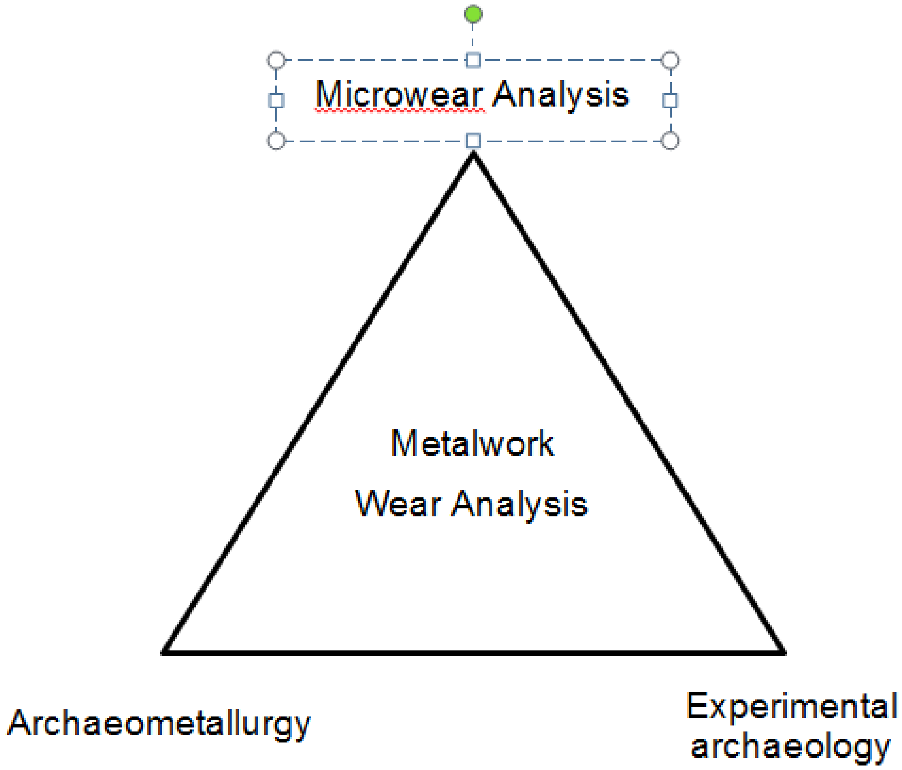

Fig. 10 – It is maintained in this article that metalwork wear analysis ought to position itself at the disciplinary intersection between microwear analysis, archaeometallurgy, and experimental archaeology (drawing: A. Dolfini).