Статті

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SCALES OF ANALYSIS: THE USAGE OF APPROPRIATE MAGNIFICATION IN USE-WEAR STUDIES

The interpretative potential of microscopic use-wear polishes is a factor of the scale of analysis. Observational surface area decreases in inverse proportion to magnification. In this paper I present the results of polishes on bone tools that have developed from fricative contact with nine different materials. Microwear polish is viewed at five different magnifications. I show that 50x—200x magnification, or observational areas of 0.4—2.0 mm², is the most appropriate scale of analysis of use-wear polishes regardless of whether one is conducting morphological identifications or relying on surface texture analysis software. The images presented here are meant to serve as an online reference collection to allow use-wear analysts to visualise how polish appearances change at different levels of magnification.

Key words: use-wear; microscopy, scales of analysis, magnification, texture analysis.

Introduction

Use-wear analysis has come a long way since its development by Serhii Semenov (1964) in the 1950's. Initially restricted to low-power microscopy (defined here as less than 100x magnification), the benefits of high-power magnification to visualise the microscopic details of polished surfaces soon became apparent (Keeley 1974). Most use-wear analysts now routinely make use of both low and high-powered microscopy in their examinations of tool surfaces, with "low" typically starting at around 30x—50x and "high" typically reaching between 400x—500x magnification. The consensus seems to be that low-power magnification is most profitably used for the initial observation of polish distribution, while higher magnifications are used to describe specific features of the polish. The most useful magnification range for studying use-wear polishes seems to be around 100x to 200x (e.g. Keeley, Newcomer 1977; Griffitts 2001; Fullagar 2006; Scott et al. 2005; Gates St-Pierre 2007; Bradfield 2015; Evora 2015; Marreiros et al. 2015; Chabot et al. 2017; Falci et al. 2019; Hohenstein et al. 2020). Polishes are perhaps the most relevant use-wear feature for identifying the nature of contact materials — that is whether the contact material was hard or soft, course-textured or fine (Vaughn 1985; Ibáñez, Mazzucco 2021). Although polish may form due to a variety of causes unrelated to usage (Grace 1990), it is generally understood that its formation on stone and bone artefacts is a dynamic process that differs from one type of contact material to another (Ibáñez, Mazzucco 2021). It is this dynamic nature of polish accrual that allows analysts to distinguish between different types of contact materials, whether it is in a general sense of hard and soft materials, or more specifically such as between fresh hide, wood and iron (Christadou 2008; Stone 2013; Bradfield 2015: table 2).

Although it is seldom explicitly acknowledged, the scale of analysis is a critical aspect in the interpretation of use-wear features. Different magnifications are used depending on the type of use-wear features in which an analyst is interested. The interpretative potential and accuracy changes at each level of magnification (Andrefsky 2008). For example, analysts interested in how a tool was made (either through scraping with a blade or grinding against an abrasive surface) or the type of activity a tool was involved in (whether it was used in a cutting, slicing or chopping motion), would generally use lower magnifications, as these features are best viewed with a wider perspective. Magnifications that are too high risk losing the forest from the trees (contextual and associative information is lost). Mag-

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nifications that are too low risk losing the trees from the forest (detail necessary to identify contact material is sacrificed). Surfaces that appear smooth under low magnification may appear rough and deformed under higher ones (Scott et al. 2005). It therefore stands to reason that the terminology we use to describe microwear features is dependent on the particular magnification being used. However, despite this seemingly obvious fact, I am aware of only one publication that attempts a systematic description of the changes in polish microwear appearance at different magnifications. Alexandra Legrand and Isabelle Sidéra (2007) presented a description of microfeatures at 32x, 100x and 200x that developed on experimental bone awls used to perforate fresh hide and wet bark. Yet, as has recently been pointed out (Desmond et al. 2018), use-wear studies that employ different methods often present their micrographs at different magnifications and either present their magnifications differently (either as a scale bar or as a stipulated magnification) or do not provide a scale or magnification at all. This can make trying to compare micrographs and use-wear descriptions between studies challenging, if not impossible.

In an attempt to address this issue, I present here a descriptive and visual assessment at varying levels of magnification (32x, 50x, 100x, 200x and 500x) of use-wear polishes that have been produced on bone tools with nine different contact materials. By doing so, I hope to show that the scale of analysis (inclusive of magnification and observational area) is as important as the particular technique (light microscopy, interferometry, surface texture analysis, etc.) used to obtain an image of the polished surface, and that our descriptions and measurements of particular micro-features must be cognisant of the scale of analysis. If nothing else, the presentation at graded increments of use-wear polish of different materials should provide the aspiring use-wear analyst a useful set of comparative material on which to draw.

Magnifications in use-wear studies

Low-power magnification is usually used for an initial examination of artefacts thought to have use-wear. Low-power, stereo-microscopes are readily accessible, provide a good depth of field for larger areas and provide an appropriate scale at which to observe the distribution and extent of polishes and the boundaries between zones of contact (Rots 2005; Buc, Loponte 2007; Gates St-Pierre 2007; Evans, Donahue 2008; Buc 2011; Van Gijn 2014). Contrary to what some authors have suggested (e.g., Odell, Vereecken 1980; Choyke, Daróczi-Szabó 2010; Akhmetgaleeva 2017; Zhilin 2017; Halett et al. 2021), most analysts, including myself, have found magnifications much below 100x insufficient to identify contact materials, except perhaps at a generic level of hard *vs* soft. Indeed, the low-power micrographs provided by some of the above-referenced authors do not show sufficient detail to be able to confidently identify the contact material responsible for polish formation (cf. Akhmetgaleeva 2017; Zhilin 2017; Halett et al. 2021). Macro-scale damage, such as manufacturing wear, edge chipping, hafting damage and various taphonomic signatures are, however, best viewed at low-magnification (Lyman 1994; Fisher 1995; Griffitt, Bonsall 2001; Li, Shen 2010; Evora 2015).

Most taphonomic damage, whether it is from insects (Backwell et al. 2012; Holden et al. 2013), butchery (Bello et al. 2011), trampling (Reynard 2013) or the dissolution of the bone surface due to weathering (Martisius et al. 2020) are best viewed at <40x magnification, although certain features and fine-grained details may require higher magnifications (Backwell et al. 2012; Fernandez-Jalvo, Andrews 2016). Manufacturing traces and crude use-wear, such as such as that which developsfrom digging activities and soft-hammer percussion, is also best observed at low magnifications of between 20x―50x (Backwell, d'Errico 2001; d'Errico, Backwell 2003; Blasco et al. 2013; Bradfield, Antonites 2018; Stammers et al. 2018; Mateo-Lomba et al. 2019; Pante et al. 2020).

High-power magnification (up to 500x) is typically used for more detailed examination of a tool's surface, particularly in the characterisation of polishes and the micro-striations found therein (Knutsson 1988; d'Errico 1993; LeMoine 1994; Christensen 1999; Griffitts, Bonsall 2001; Donahue et al. 2002; Buc, Loponte 2007; Gates St-Pierre 2007; Van Gijn 2007; Buc 2010). Certain features that are important for identifying and differentiating contact materials, such as micro-striations, micro-pitting on bone, surface cracking and poorly developed volume deformations are best viewed at ~100x magnification (Griffitts 2001; Legrand, Sidéra 2007). Some course-grained and reflective materials, such as quartz, may require very high magnifications (~500x) to observe use-wear (Dubreuil et al. 2015; Chabot et al. 2017).

Analysts interested in adhesive morphological residue analysis would also typically rely on higher magnifications, starting at 200x up to perhaps 1000x (Cooper, Nugent 2006; Lombard, Wadley 2007; Medina et al. 2018).

Notwithstanding the broad consensus on the scale of magnifications necessary for use-wear analysis, the subjective nature of the inferences drawn from observations, a lack of standardised descriptive criteria and the problem of equifinality have occasioned the use an ever-growing variety of surface imaging and measurement techniques (Grace 1989; von den Dries, Van Gijn 1997; Van Gijn 2014; Marreiros et al. 2015). These techniques are intended to quantify microwear features and thereby provide a greater degree of objectivity to interpretations (Grace et al. 1985). Indeed, most of these studies have shown that polishes produced experimentally can be distinguished on the basis of various quantifiable attributes, and certain activities can be differentiated on the basis of surface roughness variables (d'Errico, Backwell 2003, 2009). However, I would argue that these techniques still need to be applied at the appropriate scale of analysis (both in terms of magnification and areal coverage) to be useful.

Interferometry (Dumont 1982), atomic force microscopy (Kimball et al. 1995), confocal microscopy (Evans, Donahue 2008) and close-range photogrammetry (Zupancich et al. 2019) are all techniques that facilitate the use of various texture analysis software (González-Urquijo, Ibáñez-Estévez 2003) designed to measure and quantify the various topographic features on a tool surface, thus allowing the differentiation of polish type, degree of wear and manner of usage. Data can also be stored and used as interpretative analogues in future studies. Depending on the type of device, availability to researchers and individual analyst preferences, effective magnifications can range from 50x to 200x, with scan areas typically being in the region of 0.1—1.0 mm^2 (González-Urquijo, Ibáñez-Estévez 2003; Scott et al. 2005; Evans, Donahue 2008; d'Errico, Backwell 2009; Martisius et al. 2020; Ibáñez, Mazzucco 2021). The trouble is that because the various surface roughness parameters are calculated from and normalised based on the scanned area it becomes difficult, if not inappropriate, to compare the results obtained at different scales of analysis. As noticed by R. Scott et al. (2005) in reference to dental microwear, and as I will show here, surface features can appear very different at different magnifications and sometimes certain diagnostic microwear features occur over a larger area than may be accommodated in the scan field. For example, even though L. R. Kimball et al. (1995) and J. Ibáñez, N. Mazzucco (2021) both employ texture analysis at 200x magnification, one cannot directly compare the results obtained across a 15 μm^2 area, in the case of the former, with measurements obtained over a 450 μm^2 area, in the case of the latter.

One way around this problem is to use digital masking techniques to filter out those areas of the surface that ought not to be included in the surface roughness calculation (Borel et al. 2021). Filtering out natural, unworked surfaces or surfaces affected by taphonomic alterations means that observational area is less important as one can select only those areas one wants to include in the calculation. However, one still needs to visually, and therefore subjectively, identify those areas that have *bone fide* use-wear and distinguish them from those areas that do not. For this reason, A. Borel and colleagues view quantification techniques as a compliment to qualitative observations rather than a replacement. I am inclined to agree.

A new technique that has recently been applied to use-wear analysis is reflectance transformation imaging (Malzbender et al. 2001; Desmond et al. 2018). Similar to close-range photogrammetry (see Zupancich et al. 2019), reflective transformation imaging uses multidirectional light sources to calculate normalised surface roughness parameters and interpolate 3D surface texture based on how light is reflected off the surface. It permits the user to generate 3D maps that allow the surface to be viewed in relief from different positions. Purportedly offering higher resolution than traditional 3D scans, it is touted as being able to avoid the incommensurability of results obtained at different magnifications, thus negating the need for qualitative descriptions. It is also considered a more objective measure than static photographs that focus on certain features felt to be important by the analyst. With magnifications ranging from 10x—50x it is unclear, however, how simply altering the light source to increase the visibility of surface topography features (which can be done with most stereo-microscopes) can improve the visualisation of diagnostic microwear features that are too small to be seen at 50x magnification. Certainly, the surface details of worked bone tools chosen for presentation by A. Desmond et al. (2018) are insufficient to allow independent verification of the authors' interpretations based on a traditional observation-based microwear analysis.

Methods

Nine bone blanks were prepared from cow and springbuck metapodials. The bone was fractured and trimmed into similar lengths. The periosteal surface was brushed with a Ryobi mechanical grinder to create a smooth, flat, homogenous-textured surface. Contact materials were selected based on ready availability and also on what is frequently identified in the archaeological record, namely bone, mercerised cotton fabric, heterogenous-grained soil, tanned leather, iron, fresh hide, soft plant material (in this case the hardened stalk of a *canna* sp.), and *acacia* sp. wood. The periosteal surface of each bone blank was manually rubbed on one contact material for 30 minutes. This period of time is generally considered sufficient for diagnostic traces to develop on bone tools (LeMoine 1994; Griffitts 1997; Buc, Loponte 2007). The motion was mostly longitudinal to the long axis of the bone, but Von Den Dries and Van Gijn (1997) have shown that the surface topography deformation and polish formation are independent of the motion applied.

Microscopic analysis was conducted at 32x using an Olympus SZX16 stereomicroscope and at higher magnifications (50x, 100x, 200x and 500x) using an Olympus BX51M reflected light microscope. Both microscopes were mounted with a DP72 camera. These increments were determined based on the microscope objective lenses and also because they are the standard magnifications under which use-wear is usually observed. Surfaces that had developed polish as a result of use formed the focal areas and, in most cases, micrographs were taken at different magnifications over the same focal point. I used Stream Essentials imaging software and the extended focus image (EFI) function to get the entire image in focus at the higher magnification range. The size of the focal area is dependent on the magnification used and is influenced by whether the specimen is observed through the eyepiece of the microscope or on the computer monitor via the mounted camera. For my purposes, Table 1 presents the effective focal or observational areas at each magnification increment as they appear in the micrographs, that is as they would appear on the computer monitor and not through the microscope eyepiece. I assume that most people doing use-wear analysis look at the computer screen and not through the microscope eyepiece.

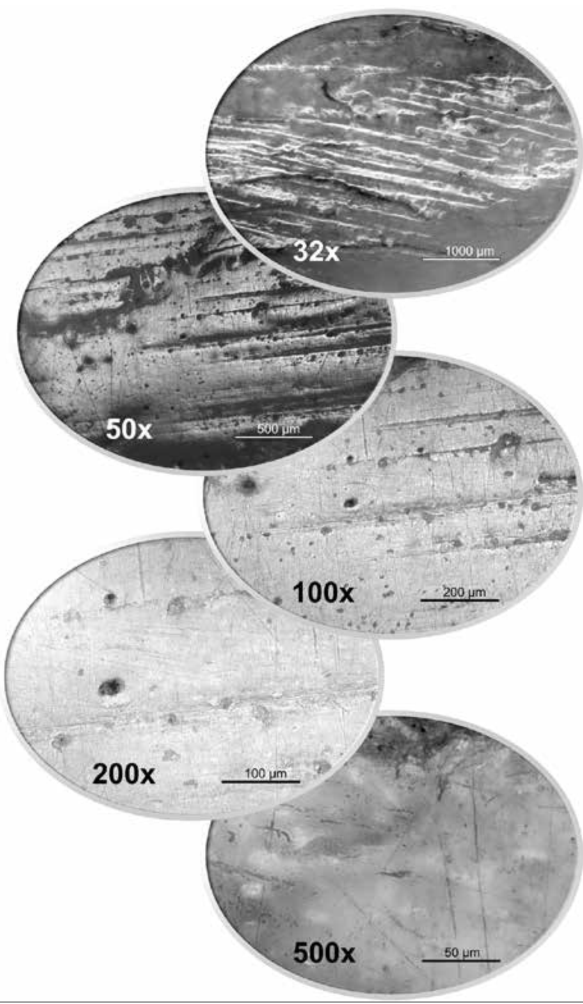

Fig. 1. Polish produced by working wet hide for 30 minutes viewed at different magnifications

Results

The appearance of the polishes that accrue from different contact materials as they appear under the five different magnifications are presented in figs. 1—9. The descriptions are my own, but largely follow those for bone use-wear as laid out in various papers of the Worked Bone Research Group proceedings (e.g., Gates St-Pierre, Walker 2007 but also see Von Den Dries, Van Gijn 1997; Bradfield 2014: table 5.1.2).

Figs. 1—3 show polish that has developed from contact with soft, malleable, animal materials. At 32x magnification we can see the presence, and extent and distribution, of invasive, dull polished and smoothed, domed high point topography, but, we cannot see any other features that are characteristic of soft materials, such as micro pitting and fine, shallow oblique striations. These latter features are clearly visible at 50x—200x. At 500x magnification the micro pitting has disap-

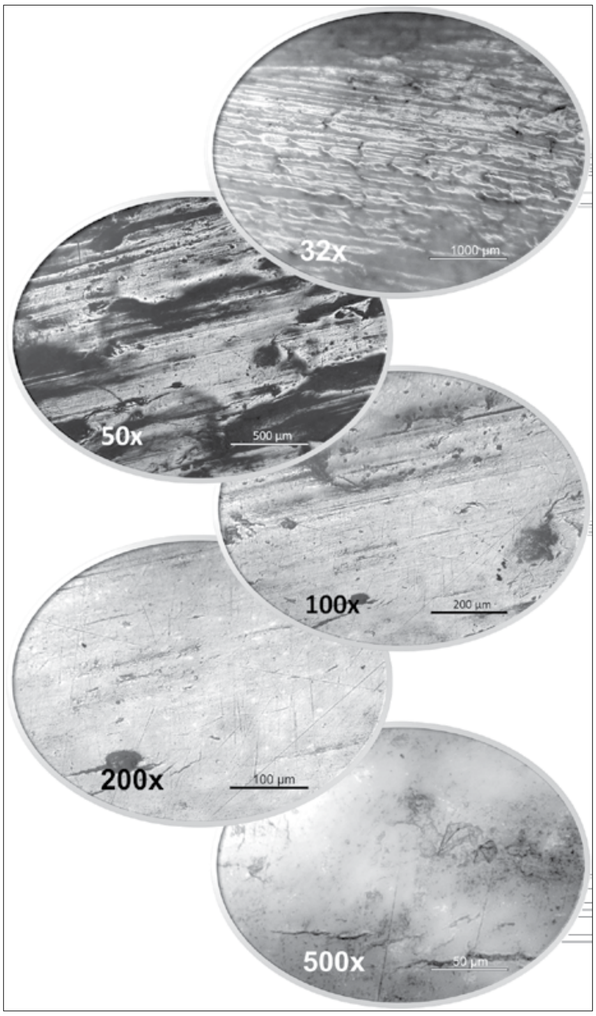

Fig. 2. Polish produced by rubbing the bone specimen between fingers for 30 minutes viewed at different magnifications

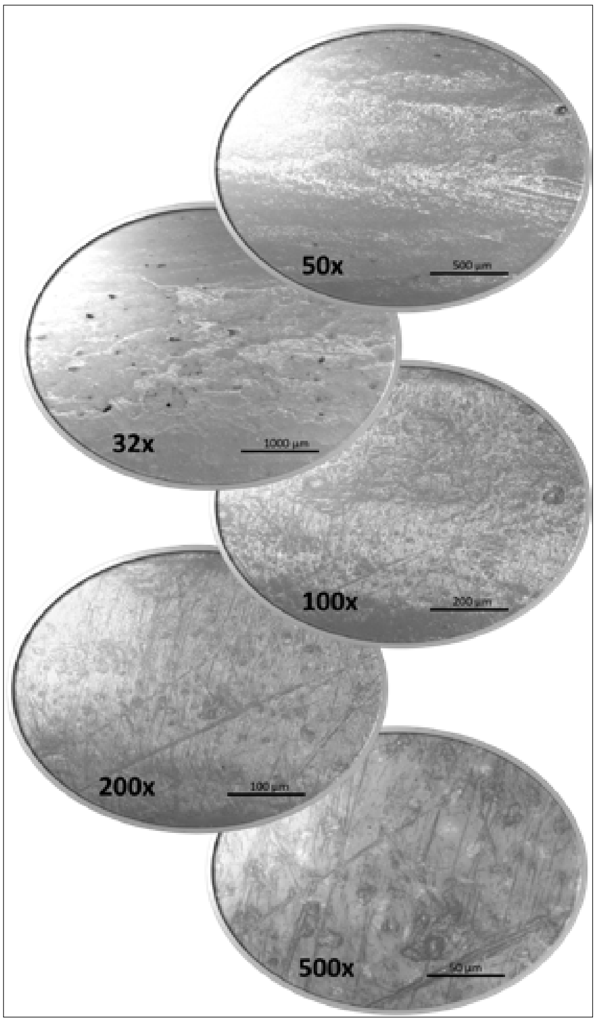

Fig. 3. Polish produced by rubbing the bone specimen against tanned leather for 30 minutes viewed at different magnifications

peared entirely, as too has a sense of the smooth, rounded surface topography. At 500x magnification the surface visible in the field of view appears flat. The micro-striations of leather polish continue to be more pronounced than their softer variants. It can also be noticed that at 32x magnification leather polish does not obscure the manufacturing traces as completely as fresh hide or hand polish.

Figs. 4—6 show a variety of hard and soft plant-based materials. Manufacturing traces and/

Table 1. **Relationship between effective magnification and visible surface area. Note that the surface area is greater when viewing specimens directly through the microscope eyepiece**

Magnification	Focal area
32x	4 mm²
50x	2 mm²
100x	0.8 mm²
200x	0.4 mm²
500x	0.2 mm²

or original natural bone surface features remain visible up to 200x magnification on the specimens that contacted softer plant materials, whereas the wood polish has obliterated all manufacturing traces at 50x magnification. The micro-striations, micro-pitting and "comet-tails" (see Von Den Dries, Van Gijn 1997) appear similar from 50x to 200x magnification across all three plant materials. Wood polish produces a very flat focal area, whereas mercerised cotton fabric produces a rounded appearance similar to that seen among the animal-based contact materials at 50x—200x. Once again, except for wood, 500x magnification provides too few, if any, identifiable features to allow an accurate assessment of contact material. The long, pronounced unidirectional micro-striations characteristic of wood working are only visible at 50x magnification and beyond.

Other hard materials, like bone (fig. 7) and wrought iron (fig. 8) present similar features to

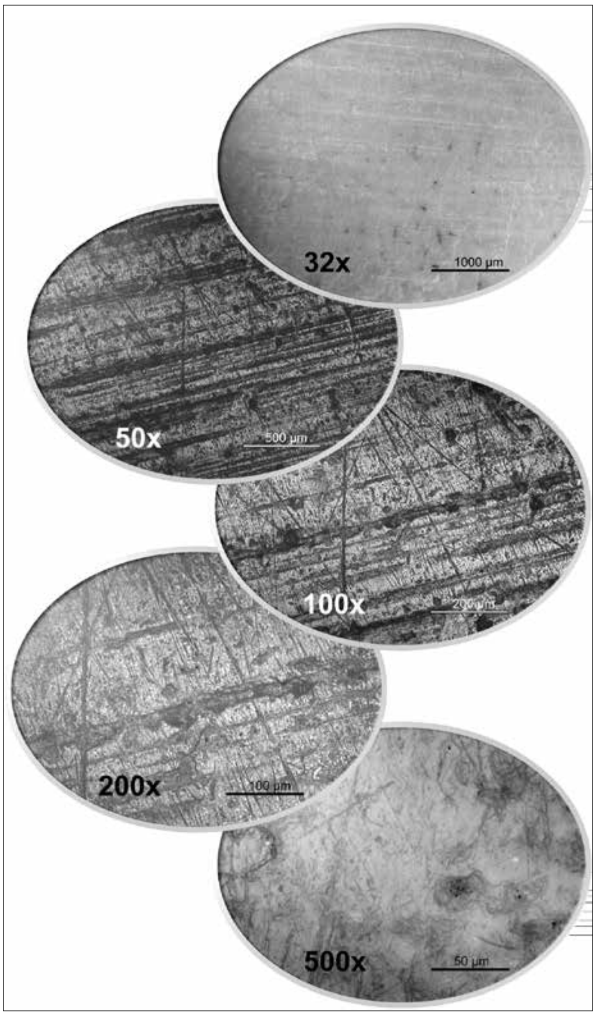

Fig. 4. Polish produced by defleshing the hardened stalk of a canna sp. for 30 minutes viewed at different magnifications

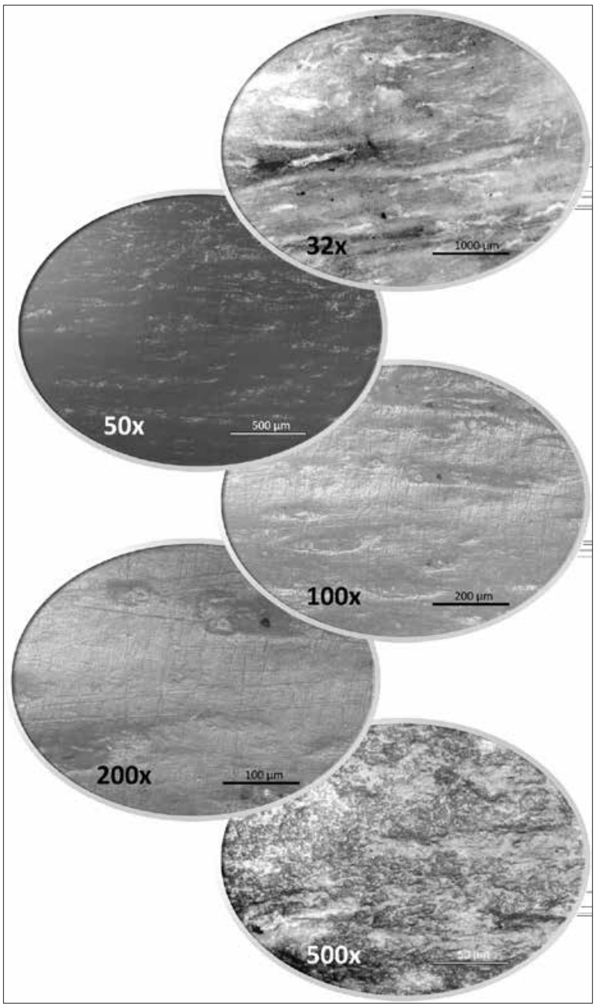

Fig. 5. Polish produced by rubbing the bone specimen against mercerised cotton fabric for 30 minutes viewed at different magnifications. Note the periosteal surface of this specimen did not undergo any manufacturing process, which is why these traces are not visible in the micrographs

wood at 500x, but are sufficiently different and distinguishable at lower magnifications. The bright polish and tightly grouped directional striations indicative of metal-imparted polish (see Christadou 2008) are visible between 50x—200x, but indistinguishable at lower and higher magnifications. Among these three hard materials only metal polish displays characteristic micro features at 32x magnification, whereas wood and bone polish are scarcely distinguishable at this low magnification range. Indeed, bone polish appears more closely related to leather polish than to wood at this magnification level.

Use-wear that develops on bone as a result of digging in heterogenous-grained soil presents as compact sets of wide, corrugated, wavy striations (although the appearance is very much dependant of the specific soil composition). This particular soil composition lacked the tiny quartz crystals responsible for typical perpendicular cracking sometimes seen inside individual striations. While these features are more or less visible throughout the magnification range, at 500x only four striations appear in the focus area hampering an accurate identification.

Discussion

What I hope is immediately apparent even from just a cursory look over all the figures is that the surface features displayed at 32x magnification and those displayed at 500x look vastly different both from one another and from those at the intermediate magnification range. Across all contact materials micro-feature comparability is present at 50x, 100x and 200x, but not at lower or higher magnifications. Indeed, the features that are considered most indicative of contact material are most easily identifiable and distinguishable between 50x and 200x magnification. In their study of bone awls, A. Legrand,

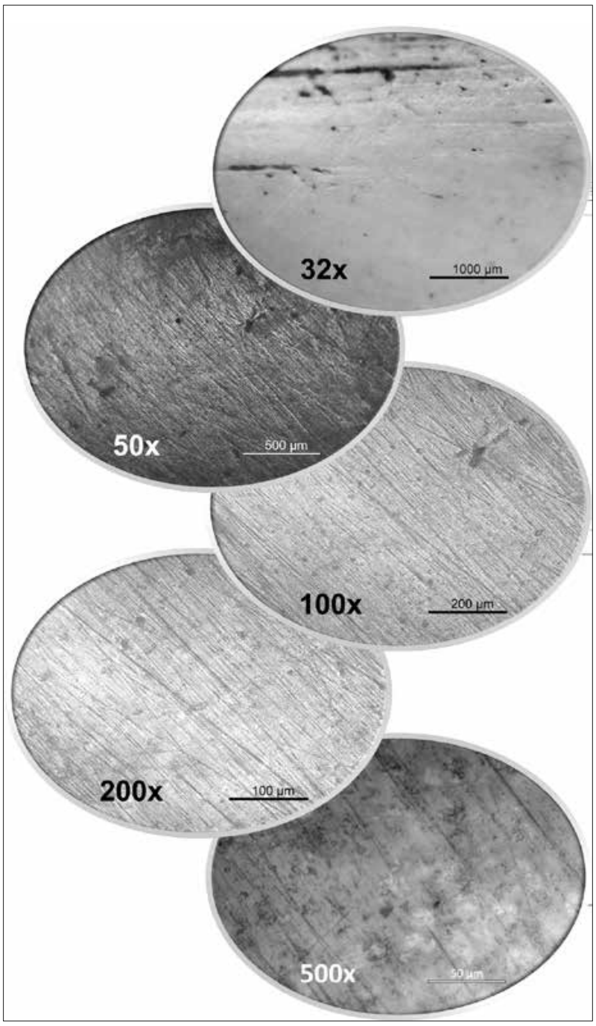

Fig. 6. Polish produced by rubbing the bone specimen against a block of fresh acacia sp. wood for 30 minutes viewed at different magnifications

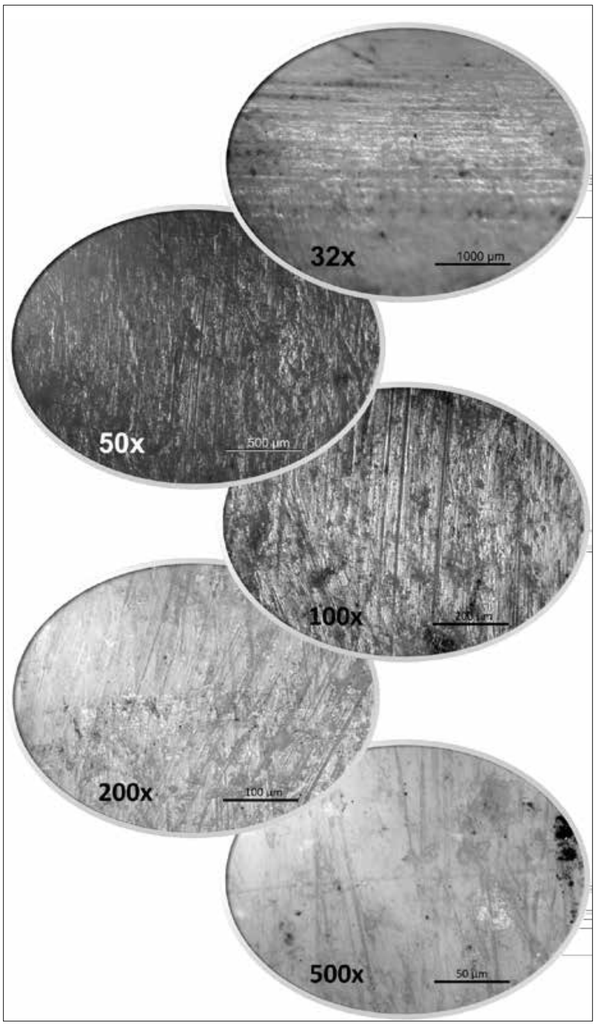

Fig. 7. Polish produced by rubbing the bone specimen against another piece of unworked bone for 30 minutes viewed at different magnifications

I. Sidéra (2007) remarked that only at 100x magnification did differences in use-wear patterns between contact materials become discernible. This is why in the literature most micrographs of use-wear are presented at 100x magnification, which equates to a 0.8 mm^2 observational area. At 32x magnification, manufacturing striations remain clearly visible on all bone surfaces (except where iron was used as a contact material) and microscopic details of polish textures are not visible. The most noticeable informational loss at 500x magnification is surface topography. This is partly due to the artificial flattening of the EFI function, but also to the reduced focal area. The latter problem is most noticeable in figs. 1 and 2 where the rounded high point topography, diagnostic of contact with soft, malleable materials, may be entirely absent from view beyond 100x magnification.

Another aspect worth mentioning, wich is seldom acknowledged in studies of experimentally replicated use-wear polishes, is that bone and stone tools recovered from archaeological contexts seldom occur in the absence of taphonomic surface alterations (but see Martisius in press). One of the challenges of use-wear analysis of archaeological material is to disentangle what is use-related from what is taphonomic. Taphonomic marks are typically identified visually, at much lower magnifications based on their specific morphology (Fernande-Jalvo, Andrews 2016), although recent studies have made an attempt to characterise non-specific taphonomic alterations by their surface roughness parameters using a 0.8 mm^2 observational area (Martisius et al. 2020). Nevertheless, the sheer range of possible taphonomic alterations, their equifinality (Lyman 2004) and the different scales at which they occur mean that it is not yet a straight-forward process of subtracting surface roughness values of taphonomically altered surfaces from tools to arrive at their unadulterated values that could indicate their past function (Malburg

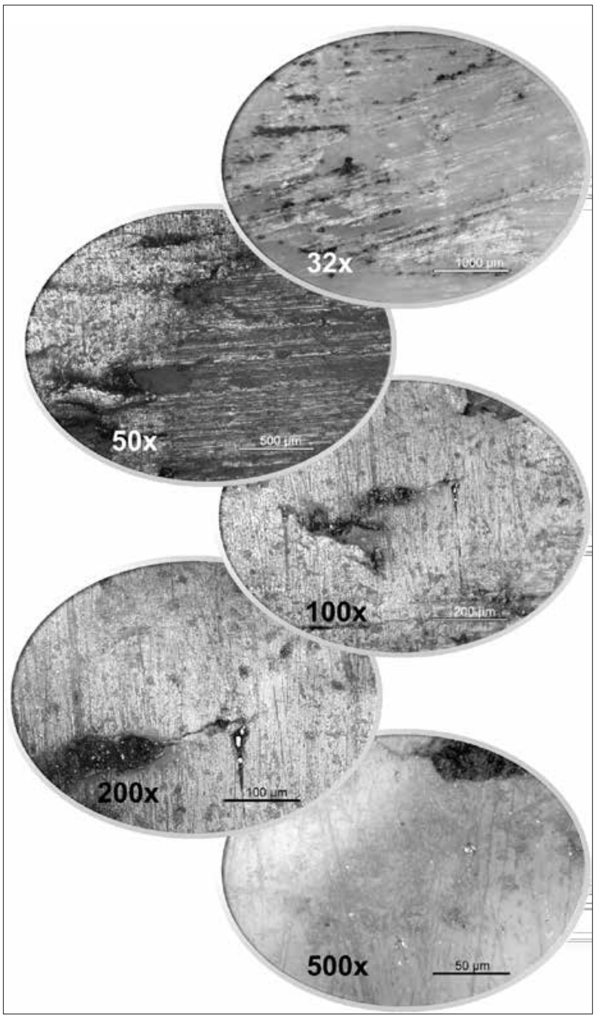

Fig. 8. Polish produced by rubbing the bone specimen against a piece of wrought iron for 30 minutes viewed at different magnifications

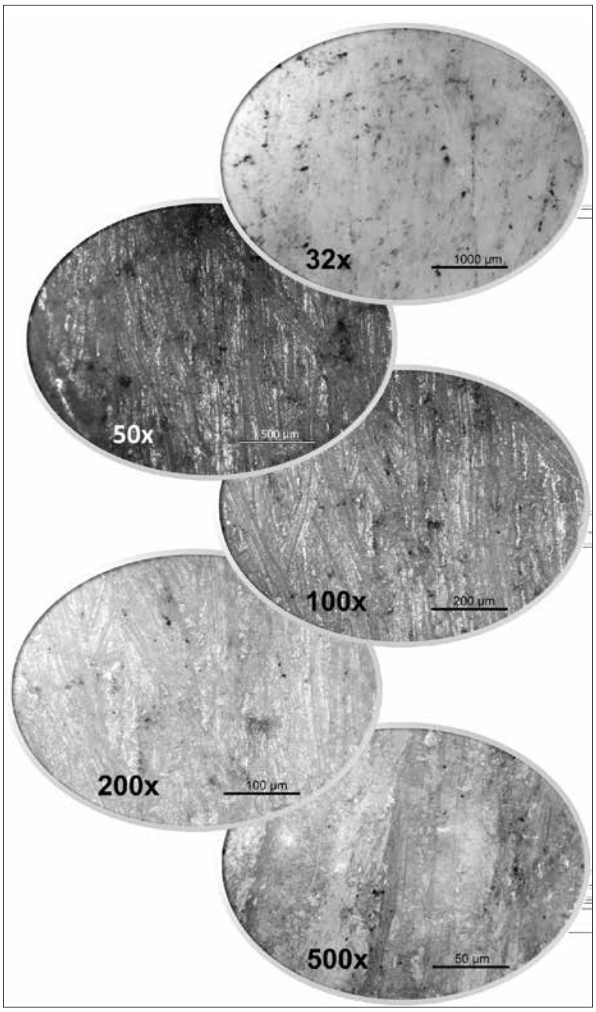

Fig. 9. Use-wear produced by digging in heterogenous-grained soil for 30 minutes viewed at different magnifications

2019). While digital masking applications may provide a way, they presuppose a visual distinction between use-wear features and taphonomic alterations (Borel et al. 2021). Nor has the extent to which automated processes like RTI can distinguish between natural and anthropogenic alterations been demonstrated (see Desmond et al. 2018). Nor are we yet at the stage where these surface texture analysis techniques can disentangle multi-purpose tools any better than visual identification. It is worth mentioning here that different devices calculate magnifications differently (Dubreuil et al. 2015; Plisson 2018). A 100x magnification on a microscope is not necessarily directly comparable to an equivalent magnification indicated on a digital camera. Digital magnifications merely enlarge an image rather than increase the actual sensor plane. Such incommensurability between techniques also needs to be taken into account.

There is no doubting the benefits derived from microwear quantification techniques. It is undeniable that this avenue is the future of use-wear studies. However, we should not forget that even the most sophisticated surface roughness quantification technique is not wholly objective. The analyst must still choose which areas to analyse and at what magnification, or over what surface area (see Martisius in press). This is partly a choice and partly dictated by the measurement parameters of the specific instrument one uses. Because the observational area is inversely proportional to the magnification, we can see that the number of surface features decreases at each level of magnification as the observational area narrows. At 500x magnification (or 0.2 mm^2), too few features are incorporated within the field of view and it is difficult to distinguish between even course categories of contact material such as hard *vs* soft. Even a surface roughness measurement of such a small area risks missing the forest from the trees. Conversely, scans performed over larger areas must necessarily incorporate more surface features, meaning that use-wear determinations will be more robust. Yet, by increasing the observational area we also increase the opportunity for the inclusion of taphonomic alterations. Texture analysis is not yet at the stage where it can reliably differentiate the variety of taphonomic alterations from use-wear — but hopefully it will get to this point.

For now, the visual observation of use-wear features and polish quality remains the most widely used approach to functional analysis (e.g., Andrefsky 2008; Sáez, Lerma 2015; Bejenaru 2018; Bradfield et al. 2020). Irrespective of the non-standardised descriptive nomenclature inherent in this approach, a visual comparison at different scales of analysis of polishes produced by different contact materials does not exist outside of individual laboratory reference collections. Van Gijn (2014) suggested that to mitigate concerns over use-wear subjectivity we need larger samples, improved micrograph quality and more experimental and ethnohistorical databases. This study in part attempts to answer that call by making available this comparative collection of use-wear polish observed at different scales of analysis, and highlights the importance of basing functional interpretations, whether they be visually derived or based on surface texture measurements, at comparable and appropriate scales of analysis.

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ШКАЛА АНАЛІЗУ: ВИКОРИСТАННЯ ВІДПОВІДНОГО ЗБІЛЬШЕННЯ В ДОСЛІДЖЕННЯХ СПРАЦЬОВАНОСТІ МАТЕРІАЛУ

Більшість аналітиків, які вивчають спрацьованість артефактів, зазвичай використовують як малопотужну, так і високопотужну мікроскопію при дослідженні поверхонь знарядь; при цьому «малопотужна» починається приблизно від 30х—50х, а «високопотужна» сягає переважно 400х—500х збільшення. Потенціал інтерпретації мікроскопічних полірувань для спрацьованості є фактором масштабу аналізу. Площа поверхні спостережень зменшується в оберненій пропорції до збільшення. У цій роботі представлено результати полірування кістяних знарядь, які утворилися внаслідок фрикативного контакту з дев'ятьма різними матеріалами. Мікрозношувальне полірування розглядається з п'ятьма різними збільшеннями. Показано, що збільшення 50х—200х або ділянки спостереження 0,4—2,0 мм^2 є найбільш відповідною шкалою аналізу полірувань, що зношуються незалежно від того, чи проводите ви морфологічні ідентифікації, чи покладаєтесь на програмне забезпечення для аналізу текстури поверхні. Аналіз текстури поверхні пропагується як більш об'єктивна міра зносу, однак аналітик все одно повинен обрати ділянки для сканування та збільшення чи площу поверхні. Роблячи цей вибір, дослідник, по суті, повідомляє програмному забезпеченню, що він/вона вважає використанням-зношенням, а що він/вона вважає тафономічними змінами. Величезний діапазон можливих тафономічних змін і різні масштаби, на яких вони відбуваються, означають, що мова ще не йде про прямий процес віднімання значень шорсткості поверхні тафономічно змінених поверхонь зі знарядь для отримання їхніх чистих значень, які могли б указувати на їхню колишню функцію. Ми ще не на тій стадії, коли аналіз текстури поверхні дозволяє зрозуміти багатофункціональні знаряддя краще, ніж візуальне визначення. При 32-кратному збільшенні виробничі смуги залишаються чітко помітними на всіх поверхнях кісток (за винятком випадків, коли залізо використовувалося як контактний матеріал), а мікроскопічні деталі полірованої текстури не видно. Найбільш помітною втратою інформації при 500-кратному збільшенні є рельєф поверхні. Подано цілий спектр зображень, які слугуватимуть як довідкова онлайн-колекція, щоб спеціалісти з вивчення спрацьованості матеріалів могли уявити, як змінюється зовнішній вигляд полірування на різних рівнях збільшення.

Ключові слова: спрацьованість, мікроскопія, шкала аналізу, збільшення, аналіз текстури.

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