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The application of focus variation microscopy for lithic use-wear quantification

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ABSTRACT

As the field of use-wear analysis has developed, the number of different methodologies that address tool function has increased. Multiple new methods have been published in recent years, both in qualitative and quantitative approaches. This paper focuses on a recent development in quantitative microscopy, specifically focus variation microscopy. This microscope characterizes surface features and has the ability to generate measurements of surface roughness, particularly useful for lithic use-wear studies. This paper presents the results of some preliminary measurements taken on experimental tools, highlighting the strengths and weaknesses of this new method and how it can contribute to the growing field of use-wear quantification. Finally, it presents some of the new challenges facing archaeologists interested in the quantification of use-wear and future directions of research.

1. Introduction

Understanding lithic tool function is integral to interpreting behaviors and actions of past peoples. Lithic use-wear analysis allows researchers insight into tool function through the study of fractures, polish, and striations found on tool surfaces (Grace, 1989, 1996; Hayden, 1979; Keeley, 1980; Semenov, 1964; Tringham et al., 1974; Vaughan, 1985). This analytical technique has traditionally relied on the qualitative observations of specialists who identify wear patterns microscopically. These observations are made with low- and high-powered microscopy, and the combination of these approaches provides a more holistic picture of tool function than the use of a single method alone (e.g., Lemorini et al., 2006; Richter, 2007; Rots, 2008; van Gijn, 2010). The ability to recognize visual differences between types of wear is a highly specialized field, requiring the use of experimental reference collections to interpret archaeological assemblages.

However, the qualitative nature of use-wear analysis leaves open the possibility for error and conflict of interpretation between individuals. Blind tests have been conducted by numerous researchers, with variable degrees of reliability and reproducibility (e.g., Bamforth, 1988; Moss, 1987; Newcomer et al., 1986, 1988; Odell and Odell-Vereecken, 1980; Rots et al., 2006). Some of these tests have reported positive results, while others have shown a high degree of variability between different use-wear analysts' interpretations of wear features (see Evans, this volume). As a result, the subjective interpretations of different researchers can greatly influence and impact research outcomes. This causes difficulties when attempting to compare results from assemblages analyzed by different researchers. The identification of contact material is more problematic than the identification of tool motion; an average of 43% of contact materials were correctly identified in aggregated scores from published blind test results (Evans and Macdonald, 2011). Thus, the current qualitative method of contact material identification needs refinement to increase the success rate of material identification. It is this aspect of use-wear analysis where quantification can contribute to the development of use-wear methodology.

To address issues inherent in qualitative methods, recent studies have been taking a quantitative approach to lithic use-wear analysis, using new technologies that generate measurements of surface topography, polish texture, and profile paths across surface features (e.g., Anderson et al., 2006; Evans and Donahue, 2008; González-Urquijo and Ibáñez-Estévez, 2003; Kimball et al., 1995; Stemp and Stemp, 2001; Stevens et al., 2010). Early papers on use-wear quantification focused on image analysis, evaluating gray scale levels to understand polish brightness produced by different contact materials (e.g., González-Urquijo and Ibáñez-Estévez, 2003; Grace, 1989; Grace et al., 1985; Knutsson, 1988a, 1988b; Rees et al., 1991; Vila and Gallart, 1993). Recent image analysis research has built upon these early studies to understand how polish can be characterized between different lithic raw material types (Lerner,

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2009; Lerner et al., 2007). In addition to image analysis, several early studies attempted to quantify use-wear by measuring the surface texture of tools using a variety of instrumentation including optical interferometres (Dumont, 1982) and rugosimeters (Anderson et al., 1998; Beyries et al., 1988).

Recent research into lithic use-wear has turned to the field of surface metrology to measure surfaces, using microscopes manufactured for machining and industrial purposes. Attempts to characterize worn surface texture include laser-scanning confocal microscopy (Evans and Donahue, 2008; Evans and Macdonald, 2011; Giusca et al., 2012; Stemp and Chung, 2011; Stevens et al., 2010), laser profilometry (Stemp et al., 2009; Stemp and Stemp, 2001, 2003), interferometry (Anderson et al., 2006), and atomic force microscopy (Faulks et al., 2011; Kimball et al., 1998, 1995). These microscopy technologies measure surface texture, providing the user with quantitative information about surface features.

In many of these studies, the authors focus specifically on the analysis of worn surfaces, operating under the hypothesis that the worn surfaces produced from contact with different materials (e.g., hide, wood, antler) have surface textures that are distinguishable from each other on a microscopic scale. These worn surfaces are visible under high powered magnifications, ranging from 100× − 500× (Keeley, 1980; Vaughan, 1985). When these contact materials interact with the tool they impact the lithic's surface causing characteristic wear. This wear will have different textures based on the contact material, as each material has a different surface texture and material hardness. Use-wear quantification allows the researcher to measure the surface of the stone tool directly, quantifying the surface texture of worn areas to identify the type of contact material that produced the wear.

This paper presents the application of focus variation microscopy to lithic use-wear analysis. Focus variation microscopy is specifically designed for surface metrology and can be used to characterize surface texture. These microscopes have the ability to generate measurements of surface roughness, which have been shown useful for lithic use-wear studies in previous research (e.g., Evans and Donahue, 2008; Faulks et al., 2011; Kimball et al., 1995). Currently only a small pilot study has been published using this instrumentation for lithic use-wear analysis (Evans and Macdonald, 2011), however there have been a number of studies conducted using the microscope for the analysis of faunal and human remains that have shown very promising results (Bello et al., 2009; Bello and Soligo, 2008; Bello, 2011; Bello et al., 2011a, 2011b; Bocaege et al., 2010; Hillson et al., 2010). In this paper, the application of focus variation microscopy to the quantification of lithic use-wear is explored through the analysis of an experimental collection of lithic tools used on known materials. The results suggest that focus variation microscopy is a promising technology that can contribute to the further development of use-wear methods. The development of quantitative analysis has the potential to allow for greater comparability between tools, assemblages, and between the results of different researchers. In combination with qualitative research, quantitative analysis can provide a robust understanding of lithic tool function.

2. Focus variation microscopy and surface metrology

Many of the new microscopy technologies employed by archaeologists for use-wear quantification, including focus variation microscopy, were designed for applications in the field of surface metrology. Surface metrology is the study of surface texture, or deviations (Whitehouse, 2011), characterizing texture in a quantifiable way. Traditionally this field has focused on the study of machined and engineered surfaces, evaluating deviations produced through manufacturing processes and wear; however it has recently branched into more interdisciplinary fields such as anthropology, archaeology, forensic science, food science, and art conservation (e.g., Evans and Macdonald, 2011; Gambino et al., 2011; Moreno et al., 2010; Schulz et al., 2010; Stemp et al., 2012).

Early surface metrology studies focused on measuring surface texture on a two-dimensional plane by measuring the surface profile. However, these profile measurements are highly sensitive to the placement of the measured line. As the field developed, techniques were developed to measure areal surface texture, or texture of an area, providing a more realistic representation of the surface (Leach, 2010). The field of surface metrology is currently undergoing changes and standardization in areal definitions (three-dimensional parameters), including the development of a new ISO standard (ISO25178-2, 2011). This standard defines the parameters of three-dimensional surfaces, including parameters useful for characterization of lithic use-wear (Table 1). Microscopes currently being used for archaeological applications, such as laser-scanning confocal microscopy and focus variation microscopy, adhere to these ISO standards of surface characterization. In addition, new developments in the field of nanometrology are greatly contributing to the traceability and calibration of these instrumentation types (Leach, 2010). The integration of knowledge from both surface metrology and nanometrology, in conjunction with the practice of qualitative use-wear analysis, will help propel the study of use-wear analysis forward.

As mentioned previously, focus variation microscopy has the ability to take both profile and areal measurements useful for a variety of surface metrology applications. Included in the areal measurements is average roughness, or *Sa*, defined as the mean height of a selected area, and *Sq*, the root mean square of the mean height (ISO25178-2, 2011). The measurement of mean height (*Sa*) is based on the calculations of *Ra*, which is the average roughness on a two-dimensional plane and is used in profilometry measurements. Average roughness (*Ra*) represents the arithmetic mean of the surface texture, with the valleys inverted to obtain a positive value (Fig. 1). In contrast to this measurement, *Sa* calculates average roughness in three-dimensions. This areal measurement is useful for the quantification of wear features, as it is less sensitive to small variations in surface texture. The parameter *Sq* is the root-mean-square of average roughness in three-dimensions and is better for describing data that can be both positive and negative, making it a more robust calculation for surface texture.

Previous studies using different microscopy technologies such as laser-scanning confocal microscopy have been successful in distinguishing different contact materials from the *Sa* and *Sq* parameters (Evans and Donahue, 2008; Evans and Macdonald, 2011; Giusca et al., 2012). These studies showed that the *Sq* parameter is sensitive to worn surfaces from different contact materials. For

Table 1
Areal surface parameters (ISO25178-2, 2011).

Parameter	Description
Sa	Arithmetical mean height
Sq	Root mean square of mean height
Sv	Maximum pit depth
Sz	Maximum height of the scale limited surface
Sdq	Root mean square gradient of the scale limited surface
Sdr	Developed interfacial area ratio of the scale limited surface
Smr(c)	Area material ratio of the scale limited surface
Sdc (mr)	Inverse areal material ratio of the scale limited surface
Sxp	Peak extreme height
Vv (mr)	Void volume
Vvc	Core void volume of the scale limited surface
Vmc	Core material volume of the scale limited surface

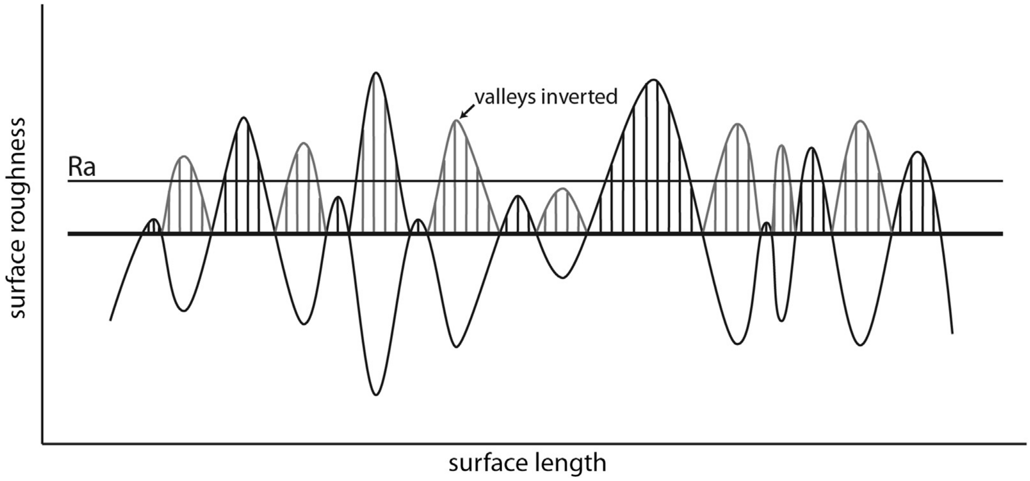

Fig. 1. Schematic of *Ra* (mean roughness) calculation across a surface profile path (surface length). Average roughness is calculated by finding the average deviation of the peaks and valleys, indicated in the shaded areas. The valleys are then inverted to obtain a positive value. The horizontal mid-line represents the average roughness, *Ra*, of this surface.

this study, the differences in *Sq* between contact materials will be evaluated due to the previous success of this parameter in lithic use-wear quantification studies, making this current research comparable with the published literature. The goal of this analysis is to identify whether polish created by different contact materials produce different *Sq* measurement values.

The Alicona InfiniteFocus microscope was used for this study (Fig. 2), which is based on the principle of focus variation (Danzl et al., 2009; Helmli, 2011). To create a three-dimensional image, the microscope searches for the best focus related to a known distance from the sample. The image is acquired by moving the microscope objectives vertically in relation to the object, bringing the object in and out of focus. The sensor within the microscope identifies and measures where the object was best in focus, a process that is repeated at sequential lateral positions to build an image. The sensor then evaluates the region around each pixel to calculate the standard deviation of the gray levels of the local region, thereby measuring the focus. If the focus is very low or very high, the gray values are almost identical with a low standard deviation. Thus, the surface topography is calculated through the in-focus depth of each plane and a composite image is generated from the in-focus slices (Helmli, 2011). Currently, the Alicona is one of the few commercial focus variation microscopes on the market that is calibrated to ISO standards for the acquisition of surface texture data.

An Alicona microscope has a motorized stage that moves in the *xy* direction, while the microscope objectives move in the *z* direction. It has a vertical range of 100 mm making it excellent for highly variable surfaces. The microscope is non-contact and any surface can be studied with no sample preparation. This is particularity useful for archaeological materials, as the technique is non-destructive. The available objectives range from 2.5× − 100× magnification and have a vertical resolution of up to 10 nm at 100× magnification, however increasing the vertical resolution also increases the scan time. Lower magnifications offer less vertical resolution, so it is important to choose the correct magnification necessary to obtain enough resolution to measure the surface texture. Scan time can be variable and experience has shown that a scan can take between a few seconds and 30 min, depending on the resolution and the vertical scan distance. In addition to coaxial illumination used by techniques such as image confocal microscopy, focus variation can use different light sources to collect information. Light sources available for this system include ring light, dark field illumination, diffuse illumination, point light source, and coaxial illumination. These different illumination types allow for different sample types to be imaged.

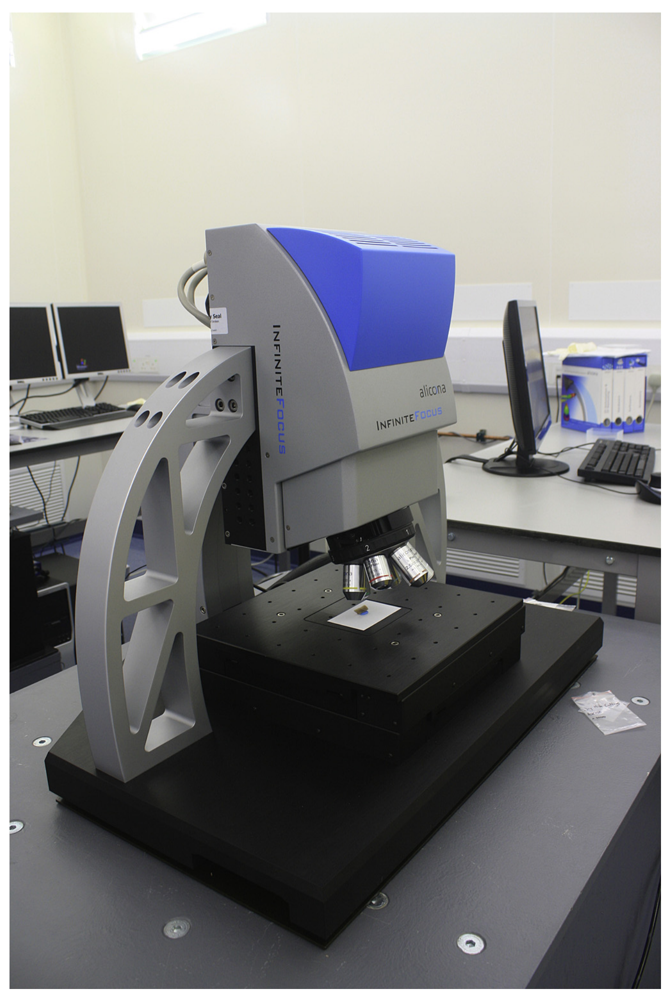

Fig. 2. The Alicona InfiniteFocus microscope (focus variation microscope) with lithic sample on the stage.

Although focus variation microscopy has a lot of strengths, the technology also has limitations in comparison to other techniques. Translucent materials cause significant problems when acquiring a focus variation measurement. This has been noted for bone and teeth samples, where the translucent and highly reflective surfaces do not allow the microscope to properly capture the an image (Bello et al., 2011b). Although replicas or coatings can be used to counteract this problem (Bello et al., 2011b), it is not always possible to replicate or modify the object. As well, because the differences in surface texture can be at the nanoscale, the resolution of the casting material must be sufficient to capture this variability. Because the microscope measures a range of focuses, there needs to be sufficient contrast on the sample's surface to obtain a measurement. Thus, the microscope has difficulties obtaining measurements from highly polished or very smooth surfaces. The surface must have a level of surface roughness >15 nm to obtain a measurement (Helmli, 2011).

3. Methods

Experimental tools used on five different contact materials were analyzed, totaling eight experimental pieces (Table 2). The number of strokes was recorded, rather than duration of use, to mitigate user fatigue and maintain a consistent amount of contact between the tool and the worked material. The tools were manufactured on high-quality chert collected from the Negev, Israel, and were knapped by Dodi Ben Ami. The lithics were modeled on Middle Epipalaeolithic trapeze-rectangle geometric microliths; each tool is approximately 2.5 × 1.5 × 0.5 cm in size, with straight, abrupt backing and a straight cutting edge (Fig. 3). All tools, except the wheat harvesting tool, were handheld with a piece of hide for protection and were used by the author. The wheat harvesting tool was part of a larger experimental harvesting project directed by Patricia Anderson (CNRS) and was hafted in a wooden handle replicated by Dan Rahimi (Royal Ontario Museum) with five additional microliths. These microliths are from the same replicated set used in the other experiments. The harvesting experiment was designed to test microliths as cereal cutting tools and the tool was used continuously for three days to test their effectiveness. As a result, the inset microliths in the harvesting tool were used more intensely than the other analyzed microliths. It is important to note that the resulting measurements for the wheat cutting tool could be impacted by the use-duration as well as the contact material. Further work is needed to identify the effects of use duration on surface roughness measurements, although preliminary studies suggest that surface texture produced by certain contact materials plateaus after minimal use (Giusca et al., 2012).

The contact materials used in the experiments were antler, wood, dry hide, meat, and wheat. Unworked surface measurements were also included in the analysis to create a control sample. Two different experimental tools for antler, hide, and meat were included in the analysis. Tools were either used in a longitudinal motion (cutting) or a transverse motion (scraping). Unfortunately due to limitations in accessing the microscope, only one experimental tool was included for wood and wheat.

Prior to analysis with the Alicona, each tool was thoroughly cleaned using methods adapted from Keeley (1980). First, each piece was cleaned with warm water and a mild detergent while being lightly brushed with a soft-bristled tooth brush. Next each piece was soaked in a bath of 10% sodium hydroxide (NaOH) for 10 min to remove organic deposits. Following this cleaning, the artifacts were soaked in a 10 min bath of 10% hydrochloric acid (HCl) to remove any mineral deposits. The NaOH and the HCl were changed between each tool to maintain the chemical effectiveness. Finally, the experimental tools were bathed in water for 10 min to remove any remaining chemical traces. Although chemical cleaning is not accepted by all use-wear analysts, it was undertaken in this study so that surfaces roughness measurements did not unintentionally include adhering materials.

Artifacts were mounted directly onto a piece of plasticine modeling clay for analysis under the microscope. Unlike other modeling clays, plasticine has low elastic properties and does not oscillate once the object has been mounted. Each piece was scanned under the focus variation microscope using the 20× objective to identify areas heavily affected by wear. Coaxial illumination was used for this study. Once an area was selected, the magnification was increased to 50×. Scans of 286 × 218 μm were acquired at this magnification level (Fig. 4). For each tool, a total of five areas were selected along the worn edge at 50× magnification, targeting areas that had the most visible modification from use. Polish does not develop evenly along the edge of the worked tool, therefore an element of subjectivity was introduced by visually choosing the sample areas to ensure worn areas of the tool's surface were measured.

Once the scans were acquired, the files were imported into Mountains Map 6.2 for analysis. This software is designed for surface metrology applications and measures areal parameters based on ISO 25178. For this study I employed the sampling methodology developed by Evans and Donahue (2008) for the quantification of lithic use-wear using a laser-scanning confocal microscope. On each 286 × 218 μm image, ten areas of 10 × 10 μm were selected for roughness analysis (*Sq*) (Fig. 5). These areas were randomly selected from the areas visibly worn on the larger surface. For each tool, fifty 10 × 10 μm scans were collected from the worn areas. Additionally, five areas of the same size were measured from the unused chert surface just below the areas that had evidence of wear. These were also selected randomly from the unworn surface and were used as a control for the contact material roughness, providing a base roughness for the original raw material.

A series of areal surface parameters, including *Sa* and *Sq*, were collected from each 10 × 10 μm scan. Additional parameters were also measured for future research but are not included in this analysis. For this study *Sq* (root-mean-square of height) was chosen as the parameter for comparison among the contact materials because it is a standard in the field of surface metrology. As mentioned previously, this parameter has also shown potential in

Table 2
Details of experimental chert microliths used in analysis.

Experiment#	Contact material	Angle	Direction of motion	# of strokes	Additional comments
EX-4a	Meat	45–90	Longitudinal	1000	Pig meat
EX-4b	Meat	45–90	Longitudinal	1000	Pig meat
EX-6	Hardwood (dry)	90	Longitudinal	1000	Dry hardwood
EX-9	Antler (dry)	45–90	Transverse	1000	Ventral surface towards the antler
EX-13	Antler (dry)	45–90	Transverse	1000	Ventral surface towards the antler
EX-10	Hide (dry)	90	Longitudinal	1000	Tanned leather
EX-11	Hide (dry)	90	Longitudinal	1000	Tanned leather
EX-14	Einkorn wheat	45–90	Longitudinal	12 150	Part of larger harvesting experiments

Fig. 3. A. Set of experimental microliths, un-hafted, used in the experiments. B. Replicated Middle Epipalaeolithic haft used for harvesting experiments with six inset microliths.

recent publications for the quantification of wear (e.g., Evans and Macdonald, 2011; Giusca et al., 2012).

4. Results

Prior to analysis of the full assemblage, t-tests were run on the tools in each contact material group to test whether Sq between the tools used on the same contact material were significantly different. This was important to test for prior to analyzing the full assemblage to confirm that each contact material produces comparable roughness measurements. For the antler working tools, a t-test for unequal variance was run between the two tools. The results of the test indicate that the means between the two tools are not significantly different (unequal variance t-test, $t = 0.671$, $p = 0.507$). The meat cutting tools also show that the means are not significantly different between the two tools (unequal variance t-test, $t = -1.4025$, $p = 0.166$). It is encouraging that the same contact materials on different tools produce average roughness measurements (Sq) that are not significantly different. However, the result between the hide working tools is not as optimistic. The t-test shows that the means between the two hide working tools are significantly different ($t = 4.037$, $p = <0.001$). This suggests that

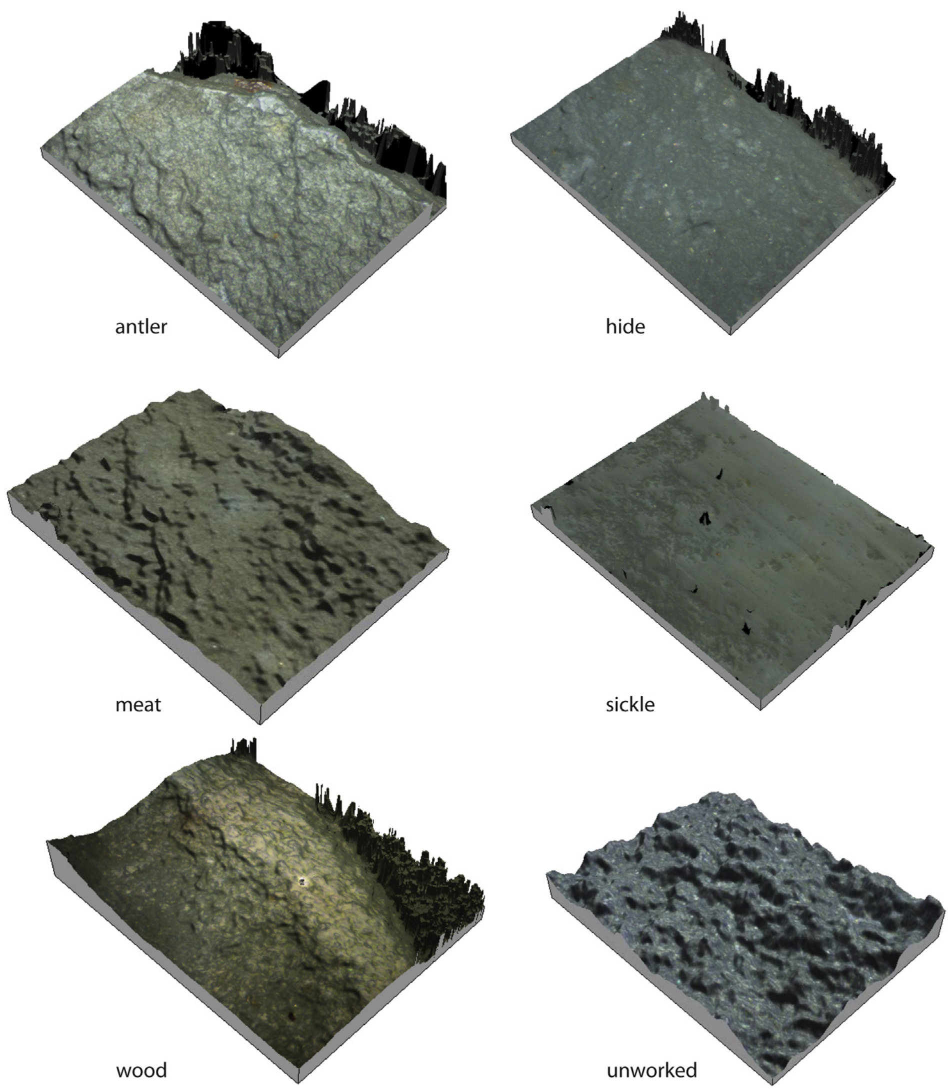

Fig. 4. Examples of the images produced by the focus variation microscope for each contact material. The edge of the tool is to the upper right side of the image (black spikes are scans off of the tool's edge).

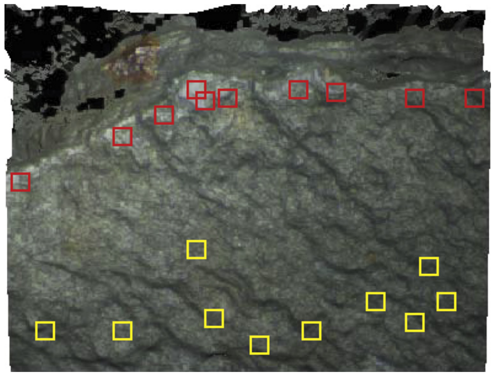

Fig. 5. Example of sampling method of 10 × 10 μm squares from the lithic surface (antler working tool). Red (upper) squares are sampled from the polished area and yellow (lower) squares are sampled from the un-polished area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

there is more variability in the measurements for hide working tools. The polish from the hide tools is less developed than the harder materials and the variability in measurements may be the result of the less developed polish. It may also be the result of sampling error, where the unworked surface was also sampled due to difficulties in distinguishing polished from un-polished areas (see Stemp, this volume for other examples).

The results of analysis between all contact materials indicate that there is a difference in average roughness between each of the contact materials (Table 3, Fig. 6). The contact material that produced the smoothest surface was wheat, with a mean *Sq* of 0.415 μm. It is important to note that this tool was used more intensely than the other tools. Therefore the smoother surface might be the result of duration rather than differences in the contact material. The antler-working surface roughness was 0.472 μm (mean), with the meat producing a slightly rougher signature at 0.545 μm (mean). The two roughest contact materials were the wood working tool at 0.982 μm (mean) and the hide cutting tools at 0.982 μm (mean).

The unworked material roughness produced a significantly rougher signature than the worked chert, with a mean *Sq* of 1.230 μm. The standard deviation on the unworked surface measurements is also very high (1.011) suggesting that chert raw material is a highly variable surface. The unworked surfaces from the tools were analyzed separately to ensure that the surface roughness variability witnessed in the aggregated 'unworked' group was not the result of raw material variability among the samples. The resulting graph (Fig. 7) indicates that, with the exception of tool 1, there is a high degree of variability within each sample. Furthermore, the tools overlap in this range of variability. Thus, the range surface texture is the result of a highly textured raw material and not variability between the tools.

The Shapiro–Wilk normality test was run on each distribution. The results of the tests indicated that the distributions are significantly different from normal ($p < 0.05$), therefore the Kruskal–Wallis test was chosen to evaluate whether the means of the six different groups are significantly different. This test is equivalent to the one-way ANOVA for non-parametric data and allows for the comparison of more than two means.

The results of the Kruskal–Wallis test indicate that many of the contact material means are significantly different (Table 4). However, the differences between antler, meat, and wheat are not significant, nor are the differences between wood, hide and unworked surfaces. The difference between antler and meat is very close to significant, suggesting that the relationship between these two contact materials might be better understood with an increase in sample size. Overall, the results of the analysis indicate some contact materials result in different mean *Sq* values and the Alicona InfiniteFocus microscope is capable of measuring *Sq* on the surface

Table 3
Mean *Sq* for the worn surface produced by each contact material.

Contact material	No. scans	Min (μm)	Max (μm)	Std. dev.	Mean *Sq*
Antler	100	0.082	1.610	0.268	0.472 μm
Wood	50	0.278	2.870	0.555	0.982 μm
Hide	100	0.186	2.860	0.498	0.929 μm
Meat	100	0.140	1.840	0.310	0.545 μm
Wheat	50	0.088	1.040	0.239	0.415 μm
Unworked	400	0.088	7.950	1.011	1.230 μm

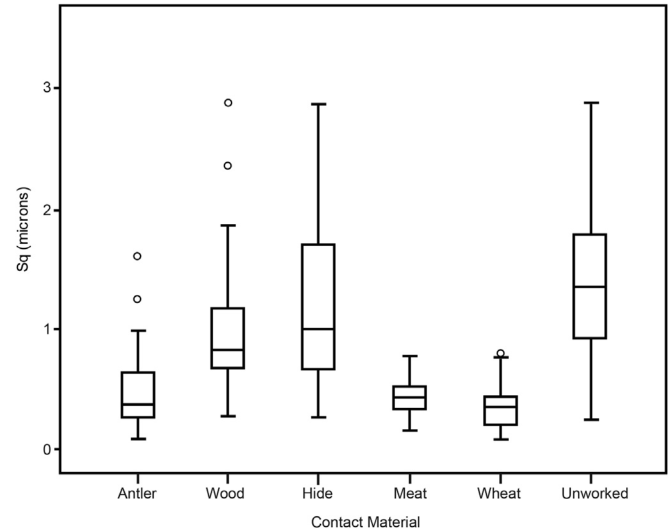

Fig. 6. Box-plot showing the spread and mean of *Sq* values for the worn surface produced by each contact material.

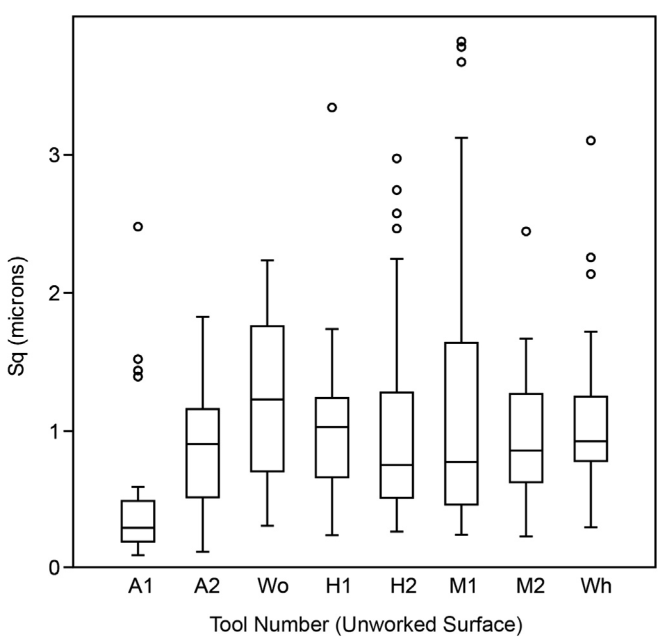

Fig. 7. Box-plot showing the spread and mean of *Sq* values for the unworked surfaces of the experiment tools (A = antler working tool, Wo = wood working tool, H = hide working tool, M = meat working tool, Wh = wheat working tool).

Table 4
Resulting Kruskall-Wallace *p*-values for the experimental collection of tools. Using a 95% confidence interval, the *p*-values that are significantly different are highlighted.

	Antler	Wood	Hide	Meat	Wheat	Unworked
Antler	x	<0.001	<0.001	0.052	0.131	<0.001
Wood		x	0.551	<0.001	<0.001	0.657
Hide			x	<0.001	<0.001	0.159
Meat				x	0.002	<0.001
Wheat					x	<0.001
Unworked						x

of worked stone tools to help distinguish different contact materials. Similar results have been shown in other quantification studies. Using profilometry, Stemp et al. (2008) showed that some contact materials have distinguishable *Rq* values while other contact materials are more ambiguous. The ability to distinguish some, but not all, of the contact materials might also reflect the scale of analysis. Evans and Donahue (2008) show that some contact materials, such as greasy and dry hide, are statistically distinguishable at larger scales of analysis, while other contact materials, such as fresh hide and greasy hide are quantitatively different at smaller scales. Thus, further investigation into the scale of the sampling areas is needed for individual contact materials to determine the most appropriate scale of analysis.

5. Discussion

The quantification of use-wear is an important step in moving towards new comparative approaches. Focus variation microscopy is a new tool for archaeological research that can contribute to use-wear quantification through the identification and separation of different polish types. This study showed that significant differences are present in the mean roughness measurements (*Sq*) between antler and wood, antler and hide, antler and unworked, wood and meat, wood and wheat, hide and meat, hide and wheat, meat and wheat, meat and unworked, and finally wheat and unworked. However, the differences between antler and meat or wheat polishes are ambiguous, as are the differences between wood and hide polish or an unworked surface. The difference between antler and meat polish is very close to significant ($p = 0.052$), suggesting that the relationship between these two contact materials might be better understood with an increase in sample size. Overall, the results of the analysis indicate that the Alicona InfiniteFocus microscope is able to distinguish some polish textures produced by different contact materials, adding to the growing types of methods useful for lithic use-wear quantification.

As the development of use-wear quantification continues there are some important avenues of research that need exploration to standardize the method. One of the most important issues that analysts need to address is how to determine the scan area. For this study, each 10×10 µm zone was randomly selected from an area where the wear was most developed. This area was determined through observations of the tool surface. However, further work is needed to determine the best areas of analysis. Are the results more meaningful on the areas completely modified by wear? Or areas where the original tool surface can be contrasted with the texture produced through use? In addition, the appropriate scale of the sampling area needs to be determined for each contact material.

The assessment that the surface roughness of the worn areas is a useful parameter for determining contact material is based on previous studies, but this does not mean that it is the only useful surface parameter. The ISO standard includes measurements of volume analysis, maximum peaks, maximum valleys, along with numerous other measurements. A recent study conducted with the National Physical Laboratories, UK, evaluated the evolution of wear as lithic tools were used over increasing periods of time (Giusca et al., 2012). Included in this study was a secondary aim of finding suitable areal surface texture parameters (ISO25178-2, 2011) that can differential between use duration. The results of this experiment showed that in addition to *Sa* and *Sq*, the parameters *Sz*, *Smr*, *Smc*, *Sdq*, *Sdr* and *Vvc* (Table 1) also were useful in accessing use duration. More research is required to understand the nature of these parameters in relation to the identification of contact material.

Finally, there are multiple microscopes on the market that have the ability to measure surface texture. However, it is not known how the measurements from these microscopes are comparable with each other. A recent study tested the comparability between the Alicona InfiniteFocus microscope and the Olympus LEXT laser-scanning confocal microscope (Evans and Macdonald, 2011). The results of the preliminary experiment showed that average roughness was comparable between the two microscopes when measuring an antler working tool, but there were some unexplained differences in the *Sq* value. Further testing and experimentation is required, including other types of microscopy such as interferometry and atomic force microscopy, to understanding the comparability of results as new studies are being published. Understanding how the results from different types of instrumentation relate to each other is imperative to moving quantitative use-wear analysis forward.

6. Conclusion

In conclusion, quantitative methods have the potential to contribute to the growing field of lithic use-wear analysis. Focus variation microscopy can contribute to the continued development of surface quantification. While this appears to be a very useful endeavor, it is important to move towards developing best-practice methods for quantitative analysis, including how to choose the area of analysis and the best parameters for characterizing surface features. Finally, the use of qualitative methods of use-wear analysis cannot be divorced from quantitative methods. Choosing the location for analysis and the interpretations made from the results are built upon the traditional use-wear methods. Quantitative methods are not replacements for low and high-powered microscopy; they are new methodologies to be used in tandem with qualitative research to gain a robust view of lithic tool function.

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