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

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A R T I C L E I N F O

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A B S T R A C T

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

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