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Laser scanning confocal microscopy: a potential technique for the study of lithic microwear

Adrian A. Evans*, Randolph E. Donahue[1]

Division of Archaeological Geographical, and Environmental Sciences (AGES), University of Bradford, Bradford BD7 1DP, UK

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Abstract

The key problem restricting lithic microwear analysis is the lack of quantitative analysis to support qualitative assessments of different wear traces. This paper presents the reflective laser scanning confocal microscope (LSCM) as a new technique for the study of lithic microwear that has the potential to resolve this problem. Firstly, an example is presented that shows how the LSCM compares with conventional reflected light microscopy and scanning electron microscopy. This shows that images, rivalling that of the SEM, can be produced in similar timescales to conventional photomicrography and with no need for casting or sample preparation. The LSCM is also used to measure surface roughness of use-wear produced from working hide (dry, fresh and greasy), woodworking and antler working. This analysis demonstrates clear differences between the different wear polishes and the potential of the LSCM as a quantitative approach in lithic microwear research.

Keywords: Lithics; Use-wear; Lithic Microwear; LSCM; Confocal microscopy; SEM; Quantification

1. Introduction

The study of prehistoric stone tool use remains a key device in the examination and interpretation of archaeological site function and the small scale behavioural operations of hominine and early human societies. Lithic microwear analysis, along with residue analysis, has been fundamental to addressing these questions (Cahen et al., 1979; Donahue et al., 2002; Hardy, 2004; Keeley and Toth, 1981) and is a technique that relies principally on the use of reflected light microscopy at a range of magnifications; from what is termed low-power approaches (up to 100×), which target principally fracture damage (Tringham et al., 1974), to 'high-power' approaches (100–400×), which examine striations and changes in surface morphology in addition to fractures (Keeley, 1980). Scanning electron microscopy (SEM) is also used at magnifications principally ranging between 25 and 800 (Debert and Sherriff, 2007; Mansur-Franchomme, 1983). In all types of lithic microwear analysis data and images derived from experiments using stone tools to work, a range of materials are compared to wear traces observed on archaeological tools.

There are four commonly encountered problems inherent in these approaches: first, the formation processes of wear are still not well understood within the field. Previously, the results of a collection of research projects led Grace to summarise 'it would now seem conclusive that the (wear) process is abrasive' (c.f. Grace, 1993). Research using chemical analysis has shown that simple abrasion is unlikely to be the only wear process in operation (Christensen et al., 1998; Evans and Donahue, 2005; Šmit et al., 1999). Alongside this, comments and data presented in Anderson et al. (2006) show persistence of the silica dissolution models. Second, processes in the burial environment produce an array of wear traces that often interfere with the interpretability of wear traces resulting from tool use (Levi Sala, 1986). This remains a significant problem but it has been turned to its advantage and used as a means to improve understanding about site formation processes

* Corresponding author. Tel.: +44 1274 233557; fax: +44 1274 235190.
E-mail addresses: a.a.evans@bradford.ac.uk (A.A. Evans), r.e.donahue@bradford.ac.uk (R.E. Donahue).
[1] Tel.: +44 1274 235531; fax: +44 1274 235190.

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(Burroni et al., 2002). Third, wear accrues and appears in different ways on the various types of raw material used for tools (Lerner et al., 2007). This problem has been addressed by analysts through the use of comparative experimental assemblages produced on the different types of raw materials encountered. Fourth, and the focus of this paper, microwear analysis relies on interpretation of primarily subjective observations.

It has always been acknowledged by proponents of the technique that a move towards more quantitative analyses is needed (Keeley, 1980; MacDonald and Sanger, 1968; Semenov, 1964). Numerous blind test studies over the past three decades have had variable 'success' (Bamforth et al., 1990; Gendel and Pirnay, 1982; Grace et al., 1988; Newcomer et al., 1986, 1987; Newcomer and Keeley, 1979; Rots et al., 2006; Shea, 1987; Shea and Klenck, 1993). Whilst there have been several questions as to the adequacy of the experimental design of such studies and how results may therefore have been skewed (Bamforth, 1988; Hurcombe, 1988; Moss, 1983; Newcomer et al., 1988), these tests indicate the potential for improvement and highlight the need for more objective and reliable methods.

This paper details the application and appraisal of a new device for the study of microwear traces on stone tools; the material science laser scanning confocal microscope (LSCM). This type of microscope was developed in 1950s but did not come into use until mid-1980s and, by combination with fluorescent techniques, has become well established in biomedical research (Pawley, 1999). Fluorescent LSCM has been used previously in archaeological research, where dyes have been used to highlight microcracks in stone tool surfaces (Derndarsky and Ocklind, 2001; Shanks et al., 2001). White-light confocal microscopy has been applied recently to study the texture of tooth surfaces (Scott et al., 2006, 2005). In contrast, reflected LSCM has had limited application in metrological (surface science) and tribological (wear) research (e.g. Ebersbach et al., 2006; Pohl and Stella, 2002). Here, we present results from LSCM analysis of the surfaces of experimental stone tools used on a variety of different materials: hide (fresh, greasy, and dry), antler, and wood to illustrate the imaging and surface characterisation abilities of the technique. Measurements of surface texture are presented along with micrographs demonstrating the quality of images produced by the LSCM.

2. Background

2.1. Surface characterisation in lithic microwear analysis

Early attempts at quantification involved simple measurement of striation direction, the crude recording of surface reflectivity and use of interference patterns (Dumont, 1982; Keeley, 1980; MacDonald and Sanger, 1968). Some attention has been placed on image processing as different polished surfaces have different topographies and reflect different levels of light (brightness). Grace et al. (1987) documented the comparison of greyscale histograms and others (Gonzalez-Urquijo and Ibanez-Estevez, 2003; Vila and Gallart, 1993) have attempted to develop this further. It has also been applied to validate observations of microwear traces resulting from butchery (Mitchell, 1997). However, it is clear that several ongoing issues need to be resolved with this approach before it becomes useable. These problems relate to the inability to control for orientation, lighting and material reflectivity and the ubiquitous problem of the post-depositional modification of wear features.

Chemical analysis of tool edges has also been an avenue of exploration that has also displayed some potential (Christensen et al., 1998; Evans and Donahue, 2005; Šmit et al., 1999). These studies have contributed to our understanding of lithic microwear formation processes and have identified the possibility of characterising certain wear features by studying surface chemistry.

Another promising avenue of research is highlighted by Kimball et al.'s (1998, 1995) much overlooked studies using atomic force microscopy to directly measure surface topography. This was applied to study tools used for 1 h each on meat, dry hide, wood, and antler. A series of 1×1 μm areas were selected for the measurement of surface roughness (Ra), five from 'peaks' and five from valleys from within 15×15 μm area scans of tool edges. The worn surfaces on the used tools were quantitatively distinct from each other and unused surfaces. Whilst the types of use-material studied were limited, it can be seen that harder materials smooth the more exposed parts of the tool more than softer materials. The valleys within the polished surfaces on the used tools have the same roughness of unused flint except for the tools used on wood and antler; here, these regions appear to be partially smoothed. Kimball et al. (1995) argue that this supports a model of polish formation, which incorporates silica dissolution and re-deposition. The atomic force microscope produces very good three-dimensional surface micrographs but tool size is restricted to those less than 10 mm in size and scan depth is limited, so application to true assemblages or larger areas of wear is not feasible when archaeological tool size and shapes are to be studied.

Anderson with others has experimented with optical rugosimetry (Anderson et al., 1998) and optical interferometry (Anderson et al., 2006). While these methods were only applied to plant working tools, there is a clear demonstration of potential for applying them to the problem of wear quantification. Optical interferometry has also been applied to study stone working tools (Astruc et al., 2003) and again shows a limited but positive application.

Stemp and Stemp (2001) introduced laser profilometry and experimented by measuring along 4 mm long transects at tool edges, recording surface roughness at 1 μm resolution. They showed that different stone types have different roughness and, by studying tools used to saw shell, pottery and antler, demonstrate the method's potential. Later work (Stemp and Stemp, 2003) compared tools used over different numbers of strokes to saw wood and pottery by measuring surface roughness (Rq), over different length-scales, and fractal dimension. Wood sawing showed no quantifiable difference in surface roughness between unused, little used, and heavily used tools.