Use-wear Analysis on Quartzite Flaked Tools

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The Experimental Development of a Method

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CHAPTER ONE

INTRODUCTION

Questions about how stone tools were used, what types of activities took place, and how settlements functioned in past cultural systems have led to a variety of studies whose main aim was to develop an innovative analytical method to respond to those questions. *Traceology, use-wear analysis, micro-wear analysis* and *functional studies* are some of the terms used to name the discipline which investigates the function of past tools. This work represents a contribution to this broad discipline and focuses on a sole lithic raw material: quartzite. Quartzite, as with other coarse-grained raw materials, has been poorly studied from a functional perspective and to date, no extensive experimental frameworks have been published. In fact, research focused on micro-wear on quartzite has been rather unsystematic and often lacked strong experimental references.

Because of these factors, it was vital to constitute a robust set of experimental data in order to be able to deal with the archaeological assemblages made of this rock type. For example, there are entire regions in the world, such as the Iberian Peninsula in Europe and large areas in Africa and India, and long chronological periods, such as the Lower Palaeolithic, where the use of quartzite was extremely widespread. In such cases, quartzite embodies unique information which might be lost if the knowledge of this raw material's properties is only superficial. Often, the chances of reaching a thorough understanding of the subsistence strategies of prehistoric hunter-gatherers are linked exclusively to this type of rock.

The second part of this book is a presentation of the two archaeological case studies where the methodology proposed here was applied. As the main goal of any experimental research is to ultimately apply a methodology designed in laboratory conditions to archaeological assemblages, two Middle Pleistocene sites yielding abundant quartzite material were selected. Therefore, I analysed quartzite assemblages collected at both the Gran Dolina site in Northern Spain and the Payre site in Southern France.

The main reason why these two assemblages were selected, beside their similar chronology (GD-TD10.1 = MIS 9–11, Payre = MIS 5–8), is that it was important to understand the functional significance of quartzite in both assemblages. In the case of GD-TD10.1, the poor conditions of chert normally impede the preservation of wear. Chemical damage to chert mostly affects one of the varieties present at Atapuerca (Neogene chert) (Sala, 1997; Font, 2009; Font et al., 2010). Although some chert artefacts were successfully found bearing use-wear evidence, it was not feasible to apply use-wear analysis on the chert assemblage to a large degree. Therefore, quartzite is the second-most abundant raw material at GD-TD10.1 and it is the sole material whose microscopic study might provide significant functional information about the human occupations at the site.

Regarding Payre, the main archaeological question was to understand the functional role of quartzite throughout the entire sequence of the site (MIS 5–6, MIS 7–8) and its relationship with the other raw materials (quartz, flint, basalt and limestone).

1.1 Use-wear studies of quartzite assemblages

Quartzite or metaquartzite is a metamorphic rock very rich in quartz content originating from quartz-arenites, which are sandstones containing less than 15% of matrix (the finer fraction) and at least 95% quartz grains (Tucker, 2001). Frequently, the term quartzite is used by non-specialists as a broad category to include all coarse-grained rocks with high quartz content (such as quartz-arenites and silica cemented sandstones). This may cause confusion, assuming that the raw material type is a crucial variable in the formation of use-wear and therefore in its visual aspect. As a consequence, the term quartzite, at least within the use-wear domain, should only be employed to define metamorphic rocks having a well-sorted granulometry. Quartzite is generally characterised by conchoidal fracture behaviour and fractures happen through grains and not around them (as in the case of sandstones). Different varieties of quartzite can be characterised by different degrees of metamorphism, depending on maximum temperature and deformation phases experienced. Although a generally crystalline structure is achieved, relict features of the protoliths (such as banded structures, replaced porosity) might survive after these processes. Moreover, the presence of different accessory minerals gives additional clues to distinguish different varieties (and raw material sources).

In use-wear analysis, it is important to first assess the intra-variability of fracture behaviour of any rock type. Since different rocks, as with any other material, have specific physical properties and therefore respond differently to the same external conditions (force, pressure, velocity, worked material hardness), it is crucial to have at least a general understanding of the rock to be studied. Ideally, a micro-morphological study of the specific rock varieties involved in the research should be recommended (Pedergnana et al., 2017). Then, general tests to evaluate how different rock varieties fracture and how macro and microwear forms on them will provide interesting insights about the mechanical behaviour of the rocks studied. This is particularly true for quartzite, since each crystalline phase gives different varieties of quartzite different mechanical characteristics.

Within use-wear studies, it is generally agreed that out of all crystalline lithic materials, quartz is the most problematic because it does not seem to be susceptible to polishing, smoothing or striating under most conditions (Hayden and Kamminga, 1979:8). In fact, no striations were normally observed in previous studies. The main features documented were only worn edges and general surface abrasion (Hayden, 1979:299). Quartz was not understood as a coherent material in the field of traceology until the first solid investigations entirely focusing on this topic filled in the gap (e.g. Knutsson, 1988a, 1988b; Sussman, 1988). This is even more evident for quartzite, as fewer studies are traceable back to the beginning of the discipline.

Mainly following the methodology created for flint with a few adaptations, researchers analysed quartzite assemblages (Plisson 1986; Pereira 1993, 1996; Alonso and Mansur, 1990; Carbonell et al., 1999b; Igreja et al. 2007; Hroníková et al. 2008; Igreja, 2008; Aubry and Igreja 2009; Cristiani et al., 2009; Lemorini et al. 2014). In few cases, detailed studies have also been carried out considering the specificities of this rock (Beyries 1982; Gibaja et al. 2002; Leipus and Mansur 2007; Clemente-Conte and Gibaja-Bao 2009).

The High-power approach (transmitted light optical microscopes) was thought to be insufficient to provide reliable use-wear results on highly reflective materials like quartzite (Grace 1989, 1990). Even if the employment of the DIC (Differential Interference Contrast) can be useful to avoid light reflection of reflective materials (Igreja 2008, 2009; Knutsson et al. 2015), it does not always provide satisfactory results (Pedergnana and Ollé, 2017: Fig. 22).

Almost all available functional studies on quartzite describe use-wear found on crystals and on the matrix differently. Specific features (e.g. rough, domed, and flat polish) are said to be only found either on quartz crystals or on the matrix between them (e.g. Alonso and Mansur, 1990; Mansur, 1999; Hroniková et al., 2008; Clemente-Conte and Gibaja-Bao, 2009; Lemorini et al., 2014; Berruti et al., 2016). Based on geological definitions, the matrix cannot be found in quartzites and therefore no use-wear can form on it. If the smallest fraction of quartz grains on quartzite is interpreted to be the matrix, our results can be compared to those published elsewhere.

Quartz grains in quartzite have a diameter of *ca.* 50–100 µr and they are formed by several faces having different orientations. Different crystal faces are the main cause of the high reflectance of quartzite surfaces when scanned with optical microscopy. Therefore, at times it is impossible to obtain in-focus images of all faces composing a crystal. Moreover, sometimes some faces are so reflective that they cannot be observed even with the aid of the DIC. In such cases, wear possibly present on these surfaces is not detectable.

This is why alternative solutions should be pursued. Scanning electron microscopy has successfully been applied to the study of use-wear on quartzite during the past few decades (Sala, 1997; Ollé, 2003; Vergès, 2003; Pedergnana and Ollé, 2017). SEM proved to have major advantages over optical microscopes because it naturally avoids light reflection and generally has a higher depth of field which can be further improved (Boyde, 2004; Borel et al., 2014).

1.2 Functional studies on Lower and early Middle Palaeolithic assemblages

Although one of the founders of use-wear analysis focused his research on Lower Palaeolithic lithic assemblages in England (Keeley, 1980), it is unusual to apply this method to ancient material. This is basically due to two reasons. First, the generally poor preservation of the surfaces of lithics in older assemblages that are often recovered from lacustrine or fluvial environment contexts, where the incidence of post-depositional processes may be very high. Second, with a few exceptions (France, England), these assemblages are almost entirely composed of coarse-grained rocks (e.g. quartz, quartzite, basalt). As use-wear analysts have mostly focused their efforts on the development of a solid method through the analysis of finegrained lithologies (e.g. chert), the minor interest in ancient assemblages is easily understood.

However, parallel to the most well-known and comparable studies of the 1970s and 1980s, some sporadic works considered extremely ancient chronologies, such as the Oldowan sample from the Koobi Fora region (Kenya) analysed by Keeley and Toth (1981). Further studies followed these first trials on ancient materials (Longo, 1994; Peretto et al., 1998; Vergès, 1996, 2003; Sahnouni et al., 2013). Although minor research focused on the initial phases of the Lower Palaeolithic, most of the studies have considered significantly more recent lithic industries, ascribed to the Middle Pleistocene. Flint handaxes from the Lower Palaeolithic site of Boxgrove (*ca.* 500 ka) in England were microscopically analysed by Mitchell (1998), who concluded that they were usually used for short periods of time and then abandoned without re-sharpening.

Donahue and Evans (2012) attempted to analyse the Lower Palaeolithic assemblage of Linford Quarry in England. The analysis did not provide significant functional results due to the poor preservation of the surfaces. Out of 109 samples, only two displayed evidence of use-wear. Post-depositional modifications were very abundant and widespread. Several kinds of post-depositional alterations were described (e.g. mild polishing, metal traces, natural severe wear, bright spots) and categorised into different degrees of development. Coudoulous in France, dated to *ca.* 300 ka, is another Middle Pleistocene site whose collections were submitted to use-wear analysis (Jaubert et al., 2005; Venditti 2014). Quartz is the most abundant material in this assemblage and its high reflective index has rendered use-wear analysis quite difficult.

Use-wear analysis applied to limited lithic samples recovered in association with large animals has provided interesting insights into the ways that small flakes were used in butchery activities during the early Middle Pleistocene (Lemorini, 2001; Aureli et al., 2015; Mosquera et al., 2016). The sample analysed from the Ficoncella site (Italy) is particularly interesting for the analysis of limestone implements, given the fact that this raw material has generally not been studied in the past from a functional point of view (Aureli et al., 2015:16). In fact, the first systematic study of limestone comprising an extensive experimental reference collection has recently been made available from the analysis of the Lower Palaeolithic assemblage of the Bolomor site in Spain (MIS 9) (Hortelano-Piqueras, 2016).

Among the studies available on Lower Palaeolithic material, research on the Sierra de Atapuerca's sites in Spain stands out. For example, studies carried out on the Galería site's material have underlined the presence of woodworking and butchering activities, despite the occasional poor preservation of some lithologies (mainly chert) (Ollé, 1996, 2003; Sala, 1997; Márquez, 1998; Carbonell et al., 1999b). Also, the same activities are described for samples analysed from the Gran Dolina site (TD6, TD10 units) (Márquez et al., 2001).

A recent work combining use-wear and residue analyses at two different locations at the Middle Pleistocene site of Shöningen in Germany highlighted the presence of mainly woodworking and butchering activities, with some uncertainties about evidence for hafting on two samples (Rots et al., 2015).

More frequently, use-wear analysis has been successfully applied to assemblages dating from MIS 9 onwards (e.g. Martínez et al., 2003; Lazuén et al., 2011; Lazuén, 2012; Clemente-Conte et al., 2014). Middle Palaeolithic sites are thought to be characterised by less weathered assemblages compared to those with more ancient chronologies, such as Acheulean and Oldowan industries. The most abundantly documented activities are generally woodworking and butchery. The site of Biache-St-Vaast (MIS 7) in France is an example of a successful functional study providing very interesting insights. Activities linked to butchery and woodworking were recorded, and more recently, hafting technologies and spear throwing have also been documented (e.g. Beyries, 1988; Claud et al., 2013; Rots, 2013, 2015). A preliminary study of the collection of Maastricht-Belvédère (Netherlands) (MIS 7) has also recently been performed and at least one spear tip was identified in the assemblage (Rots, 2015). Functional data is also available for the Payre site (France) (MIS 7–8; MIS 5–6), for which use-wear and residue data were published (Moncel et al., 2009; Hardy and Moncel, 2011). Use-wear traces on a sample of convergent flint tools revealed that they were used by applying longitudinal and transversal actions. However, it is unclear what materials were worked due to the poor development of the wear. Residues also play an important role in defining site function. Specifically, the identification of animal and vegetal fragments has contributed to the reconstruction of a Neanderthal diet at the site (Hardy and Moncel, 2001). Within the same chronological framework, studies of the artefacts from San Quirce in Spain (MIS 5) revealed that wood and vegetal fibres were commonly worked materials at this site (Clemente-Conte et al., 2014).

Handaxes have also been important objects of investigation in recent years. Non-exhaustive experimental programmes focusing on the use of handaxes are available in the literature (e.g. Jones, 1980; Mitchell, 1995; Ollé, 2003; Claud et al., 2009; Viallet, 2016). A low-power approach (stereo-microscopes) is generally preferred for handaxe analysis, since the main parameter considered is that of macro-scars. Thus, the morphology and distribution of scars are generally documented (Claud, 2009; Viallet, 2016). Functional data concerning handaxes is still relatively rare and results usually relate them to woodworking and butchery activities (Keeley, 1980; Binneman and Beaumont, 1992; Ollé, 2003; Soressi and Hays, 2003; García-Medrano et al., 2014). Percussive activities have also been documented on them, although comprehensive experimental programmes have never been performed on a large scale (Moncel, 1995; Mitchell, 1998; Domínguez-Rodrigo et al., 2001; Rots and Van Peer, 2006; Claud et al., 2013).

The attempts of the first use-wear studies at analysing early African assemblages have been followed by recent research focusing on Oldowan quartz and quartzite assemblages (Lemorini et al., 2014). Moreover, sites with early chronologies have recently yielded interesting functional data in the Levant (Lemorini et al., 2015). Residues have also rarely been documented on ancient material. Evidence of the most ancient residues recorded so far comes from the Acheulean assemblage of Peninj, analysed by Domínguez-Rodriguez et al. (2001), where remnants of phytoliths were attributed to woodworking activities.

However, functional studies of very old assemblages are still quite rare, mainly due to problems relating to the preservation of the artefacts. In fact, we should not underestimate the fact that post-depositional alterations, especially when presenting high degrees of development, are capable of obliterating wear related to use by compromising its original appearance as well as its spatial patterning. Residues have hardly been preserved at all on the surfaces of stone tools with ancient chronologies, although they can be found in extraordinary circumstances.

CHAPTER TWO

USEFUL CONCEPTS IN THE STUDY OF STONE TOOL FUNCTION

> *Techniques are to be defined as traditional actions combined in order to produce a mechanical, physical, or chemical effect, these actions being recognised to have that effect* (Mauss, 1967:24).

2.1 Stone tool's lifecycle

The lifecycle of a stone tool is defined as the transposition of moments from its manufacture until its abandonment. Based on this definition, it comprises all phases of technical production, use, curation and even abandonment. A subsequent phase may be present, which refers to its post-depositional exposure to external agents (trampling, soil movements, etc.). After burial, the lifecycle of a stone tool is momentarily interrupted until it is unearthed either by ancestral human groups (who might have re-used it) or by archaeologists. If a tool is re-used, it may display newly-formed traces. Archaeologists may also modify stone tool surfaces by adopting careless handling protocols. In early excavations, archaeological material was often assembled into large bags for storage, and this obviously provoked extensive damage to the lithics (e.g. friction traces, gloss, linear streaks of polish, rounding of ridges).

The sequence of a tool's life is initiated when it is made or selected, usually to fulfil a particular need to modify matter. Surface modifications as well as residues may be accumulated on a tool during practically all the stages of its life. Use-wear studies aim to differentiate the modifications caused by the use of the tools from those having other causes.

Production

During the early phases of a stone tool's lifecycle, several types of technical traces may be produced such as striations, plastic deformations and macro-fractures. Production stages often fall into three categories:

- *Blank production:* this may require the creation of a specific shape, either by knapping it from a core or by shaping cobbles *(façonnage)*;
- *Retouching:* when blanks do not present the morphological criteria required for performing specific tasks, edges are retouched either on the active parts (the used part of edges) or on the prehensile parts (generally opposed to the active part). This is done in order to guarantee a better manual grip (e.g. by reducing the sharpness of an edge) or to make artefacts fit handles;
- *Hafting:* tools may be hafted into handles before being used. Therefore, surface modifications produced during both hafting and de-hafting practices can be present on artefacts along with those related to use (Rots, 2010).

Use

There are three main categories of interest with regards to tool use:

- *Tool use:* longitudinal, transversal, rotational gestures performed on different kinds of organic or inorganic materials (e.g. cutting meat, scraping bone, perforating skins). During this phase, fractures and surface modifications due to use are formed. Residues directly connected to the actions performed always adhere onto the surface of tools. If these residues survive burial processes, they can be used to implement functional interpretations of tool usage;
- *Re-sharpening:* edges are sometimes retouched several times during use to re-shape them in order to be effective (e.g. functional, usable). Additional technical traces may be produced at this stage;
- *Transportation:* tools can be transported from one site to another before use or in between multiple stages of use. Transportation may cause what is called 'bag wear' (e.g. polished areas, lines of polish, striations).

Abandonment

After all possible uses of a tool during its life, it is finally abandoned. The character and intensity of any further surface modifications it is subjected to depend upon several factors (environmental conditions, temperature and humidity, soil pH, sediment type, etc.). Burial phenomena generally include post-depositional movements of the soil, trampling, bioturbation and all activity which could modify the burial conditions and therefore the stratigraphy (holes, tunnels, etc.).

Extraction of tools from sediments

Tools can be unearthed at different stages of their lifecycles by both modern archaeologists and by prehistoric groups others than those who produced them. So, the extraction of tools from sediments can be:

- *Performed by prehistoric groups:* this may start a new lifecycle of tools including sub-sequential phases of use (re-sharpening, use and abandonment);
- *Performed by archaeologists:* they use specific methodological procedures aimed at the careful extraction of objects. Even in this case, some additional traces may occur (such as large polished lines due to contact with metal trowels or other tools used in the field);

Tools begin a new life when they are stored and when laboratory analyses are performed. At this moment, modern wear and residues may be accumulated. Wear can be related to improper storage of the artefacts or to accidental breakage. Residues, however, are far more likely to be produced as even minimal interaction with archaeological tools may cause deposition of modern fibres, human cells, pollens grains, etc. (Pedergnana et al., 2016).

In sum, several actions may mechanically alter stone tool surfaces in different ways. Experimentation is used to infer the possible causes of wear formation (manufacture, use, post-depositional events). To do so, archaeological evidence is systematically compared with experimentally produced data. It is important to bear in mind that use-wear connected to archaeological human occupation of sites may be overlaid with traces of subsequent use by the same or different human groups. Moreover, transportation or even deposition, excavation and further analyses may all leave traces on tools that should be distinguished from use-related wear. Changes in the surface topography, which affect the presence of both wear and residues, may constantly occur at any stage of the lifecycle of stone tools, from the time of their manufacture to final abandonment and analysis.

Hence, this issue is quite complex and functional interpretations should always take into account all the possible causes for the production of wear. The main objective is, of course, the distinction of wear caused by factors other than use and to eliminate it from final interpretations.

2.2 Experimentation in functional studies

Experimentation is an unavoidable tool in functional studies. As a branch of 'Experimental Archaeology' (Coles, 1979), it became very important in the domain of lithic micro-wear research from its onset (Semenov, 1964; 1970). In use-wear studies, stone tools are not manufactured to replicate specific morphotypes but rather to investigate the past function of tools (Coles, 1979).

Therefore, experiments involving the use of lithic tools are set up and several variables are controlled to monitor use-wear formation on different lithic raw materials. In this phase, it is crucial to keep a number of variables constant in order to correctly interpret the resulting use-wear attributes. General rules should be taken into account when starting to construct a micro-wear reference collection. First of all, all micro-wear analysts should build their own reference collection to be aware of the ways in which stone tools are handled and used.

Some basic criteria to be considered when designing experimental programmes are:

- ✓ Variables must be controlled throughout all experiments;
- ✓ All experiments need to be observed and documented;
- ✓ Experiments need to be measurable and replicable by others;
- ✓ Experimental conditions need to be described in detail;
- ✓ Subjectivity should be limited as much as possible;
- ✓ Whenever possible, data should be quantified.

Following these fundamental steps, different types of experiments can be designed. 'Emic' experiments aim to remove subjectivity by using machines to perform experiments (Knutsson, 1988a:11–12). Robotic equipment is used in this kind of experiment to gather measurable data (e.g. Iovita et al., 2014). On the other hand, 'ethic' experiments are performed at exterior locations and recreate the original conditions where prehistoric activities took place (on the ground, etc.) (Knutsson, 1988a:11–12). The same concept is expressed by the term 'replicative experiments', where the main aim is to reproduce activities that are hypothetically analogous to those that occurred in the past (e.g. Semenov, 1964; Keeley, 1980). This kind of experiment is generally characterised by poor quantitative data.

'Analytic experiments' (e.g. Tringham et al., 1974; Vaughan, 1985; González and Ibáñez, 1994; Gutiérrez, 1996) include dependent and independent variables in their protocols and analyse their inter-relationships.

The concept of 'sequential experiments' is a natural development of analytic experiments (Ollé and Vergès, 2014) that is also based on the control of dependent and independent variables and responds to the need for monitoring a repetitive sequence of events. This kind of experimental approach has been specifically designed to monitor the formation of use-wear on stone tools, by observing the same surface portions after several periods of use-time.

Along with experimental data that are produced in laboratory conditions, ethnographic accounts might also add interesting information about tool use (Rots and Williamson, 2004; Xhauflair, 2014). Observations in the field have contributed to the understanding of how stone tools were produced and used by indigenous peoples (e.g. Stout, 2002; Shott and Sillitoe, 2005; Diamond, 2012). Stone tools acquired from ethnography probably have different use-wear patterns than those found on experimental tools used by researchers.

First of all, researchers do not produce and use lithic artefacts to deal with their own subsistence. Second, stone tools are not inserted into their own culture and therefore the gestures used in their manufacture are not socially established. In other words, although they might have learned from skilful knappers, researchers have not been culturally designed to perform the tasks at hand. They do not have preferences for particular sets of gestures, nor do they follow any specific sequences of actions. All of these factors could have a tremendous impact on the experimental results.

The experimenters' gestures are not inserted into any social context and therefore they lack significance from a strict anthropological point of view (Mauss, 2007). These considerations serve as a reminder about the complexity of using experimental data as direct analogies with past stone tool use, as reproductions of prehistoric activities are generally carried out under laboratory conditions.

2.3 Tribology

One of the most controversial debates ever in traceology was about the understanding of use-wear formation processes. Some of the first use-wear analysts already incorporated concepts from fracture mechanics (Cotterell and Kamminga, 1979; Kamminga, 1979) and tribology (Knutsson, 1988a; Fullagar, 1991; Levi-Sala, 1996; Burroni et al., 2002; Ollé, 2003; Vergès, 2003; Anderson et al., 2006; Ollé and Vergès, 2008, 2014; Adams, 2014) in their research with the main aim of explaining how use-wear forms.

Tribology (from the Greek *tribos*, rubbing) is defined as the study of contacting surfaces in relative motion and it deals with different aspects of a material's behaviour, such as lubrication, friction and wear (OECD, 1969). Although lubrication (i.e. when the two solids are separated by a lubricant) and friction (i.e. rubbing of one surface against another in dry conditions) intervene in the use of stone tools, the main concern of functional analysts is indeed 'wear' (Semenov, 1964), which is defined as 'the progressive loss of substance from the operating surface of a body occurring as a result of a relative motion at the surface' (OECD, 1969:64). Generally speaking, mechanical wear processes are sorted into abrasion, erosion, adhesion and surface fatigue, while corrosive wear is regarded to be a chemical process frequently acting in conjunction with mechanical processes (Hutchings, 1992; Kato, 2006; Williams, 2005). Abrasion or abrasive smoothing (Kamminga, 1979:151) has a predominant role in tribological systems, giving rise to different kinds of surface modifications (polished areas, linear features, grooves, pits, etc.). Abrasive wear occurs when there is displacement of material generating plastic deformations on one or both surfaces (Ludema, 1996). Tribological systems are made of two interactive solid bodies in relative motion. A third body may be actively present in the system in the form of external abrasive particles sliding between the two surfaces.

In experiments involving lithic implements and generally softer worked materials, the displacement of material on the lithic surfaces is caused by their protuberances or asperities (i.e. the small-scale irregularities on a surface), which may be stuck between the two surfaces and eventually accelerate wear (scratching or grooving the surface) (Hayden, 1979). When hard abrasive particles are present between the surfaces in relative motion, the intervening process is called scouring abrasion (OECD, 1969) or three-body abrasion (Williams, 2005). When those particles are incorporated in a liquid and swept along in its flow, the process implicated in the formation of wear is called abrasive erosion. It is worth remembering that the interaction between sediments and lithic fragments produces surface modifications very similar to those generated through use and sometimes it is very difficult, if not impossible, to differentiate them (Keeley, 1974; Levi-Sala, 1986, 1996; Burroni et al., 2002; Pedergnana and Rosina, 2015). If we assume that abrasion is the principal process causing wear on lithic implements during use (being aware that other processes, such as surface fatigue and adhesion, also intervene but with less impact), the nature of the two materials being part of the tribological system affects the ways in which wear develops.

Knowing that the asperities of the original surfaces of the two bodies in relative motion play an enormous role in the development of wear, one can easily understand why wear has incredibly distinct appearances on different lithologies. The rock types generally employed in knapping activity vary both in terms of chemical composition and structure, so the effects of abrasion change in both extension and intensity. This is why differences in use-wear appearance were also documented on different varieties of the same raw material (e.g. Levi-Sala, 1996; Lerner, 2014a, 2014b). In fact, different rock types as well as different varieties of the same rock are characterised by distinct surface topographies, which imply different physical properties and therefore a different way in which forces propagate onto the surfaces.

The most important properties of solid materials are toughness, resilience, ductility and malleability. Resilience is measured by the quantity of energy a material can absorb when it is deformed elastically, while ductility and malleability are values connected to the ability of a material to deform under tensile or compressive stress, respectively. Toughness is a combination of the latter two, which are both aspects of plasticity – the extent to which a solid material can be plastically deformed without fracture – and it seems to be more important than hardness in wear formation (Cardarelli, 1966). In fact, material hardness (i.e. the measurement of how resistant a solid matter is to plastic deformation or to fracture when a compressive force is applied) is basically the same for rocks mainly composed of quartz, as the value of quartz hardness in the Mohs scale is 7. What changes instead is toughness, seen as the material's resistance to fracture when stressed (Hayden, 1979; Tiryaki, 2006; Cardarelli, 2008). What defines toughness values in crystalline materials is the arrangement of grains. Thus, toughness is connected with the disposition, orientation and compaction degree of crystals and it largely defines the way those materials fracture (Lawn and Marshall, 1979). It emerges that, with the same amount of compressive stresses (e.g. during activities involving a knapped implement and a softer worked material) applied to lithic tools, the way in which different lithologies fracture changes. Different fracturing modes imply different amounts of fragmented particles (or chips), and as a consequence, more or less available abrasive material between the two surfaces (e.g. the third body in tribological systems). Thus, the less abundant the abrasive material, the slower the formation of wear. The presence of external particles embedded in residues would act as a 'third body' in the tribo-system (Hutchings, 1992; Ludema, 1996; Williams, 2005), and the quantity and size of those particles would be a crucial parameter to predict wear extension. Certainly, particle hardness bears a very important role in this context. In fact, particles must have a hardness value equal to or higher than the surface they scratch. In a tribo-system composed of lithic surfaces and lithic micro-chips, the hardness of the scratched surface and of the active particles is exactly the same.

Adhesive wear is also present within use-wear formation processes but to a much lesser extent, and it takes place when one surface removes material from the other, generally at the junction points between the two surfaces (i.e. opposing asperities that are in contact). The removed material normally adheres to the hardest surface. An example of this wear can be seen in the presence of organic residues on tools' surfaces.

Finally, surface fatigue is another process used to explain the formation of some linear features (e.g. furrows, grooves) on brittle materials such as quartz (Knutsson, 1988a), and it is defined as surface or sub-surface fracturing when a material is subjected to cyclic loading (Cardarelli, 2008). Where forces are sufficient to deform the surface layer, material may be lost in the form of thin flakes or platelets (Williams, 2005). This feature is typical of the furrow-type striation, at least on quartzite (Ollé et al., 2016b; Pedergnana and Ollé, 2017).

2.3.1 Use-wear types from a tribological point of view

Traditionally, use-wear has always been described in terms of macro- and micro-wear in functional studies. Macro-wear is normally observed with low-power equipment (stereo-microscopes), whereas micro-wear is documented with the aid of high-power microscopes (metallographic microscopes, SEMs). Macro-traces comprise edge damage (i.e. scarring), edge rounding, and long and wide striations (such as impact striations), whereas micro-wear traces generally comprise two main categories: polish and striations. While the division between macro- and micro-traces has generally been maintained in all use-wear studies, not as much effort has been made to describe the ways in which wear forms.

The main problem of ignoring or underestimating the role that the original rock topography has in the formation of wear is that functional interpretations might lack clarity. The misinterpretation of wear on the archaeological record can then lead to biased reconstructions of past human behaviour. This is why it is important to address use-wear formation processes, as pointed out by use-wear analysts gathered together at the international conference organised at the University of Simon Fraser (Canada) in 1977. As widely discussed at this conference, some concepts used in material sciences are of extreme importance to grasp the significance of archaeological use-wear (Hayden, ed., 1979). The basic principle is that all surface modifications are mainly caused by mechanical processes (fracture, scratching, abrasion, etc.) and that the interaction of stone tool surfaces and the various worked materials constitute a tribo-system (Fig. 2.1), as discussed in the previous paragraph. Moreover, when external particles (sand grains, the addition of ochre in hide-scraping activities) or fragments of the stone tools' edges are trapped in the interstitial medium formed by remnants of the softer material (i.e. the contact material), third-body abrasion takes place.

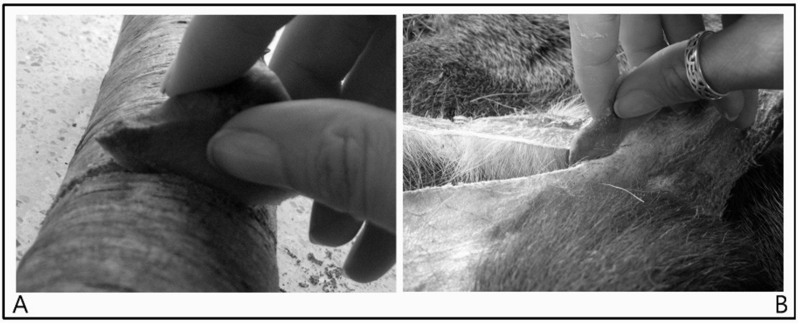

*Fig. 2.1: A) Bidirectional, longitudinal movements using a quartzite flake on a woody branch; B) Unidirectional, longitudinal movements using a quartzite flake on a dry skin (*Cervus elaphus*).*

I have documented the said particles on the experimental tools composing the reference collection presented in this work (Fig. 2.2). They are clearly distinguishable from the organic substrate through SEM analysis. Specifically, EDX analysis allows documenting the main elements composing the rock chips (e.g. silicon and oxygen), which are not present in the fragmented worked material.

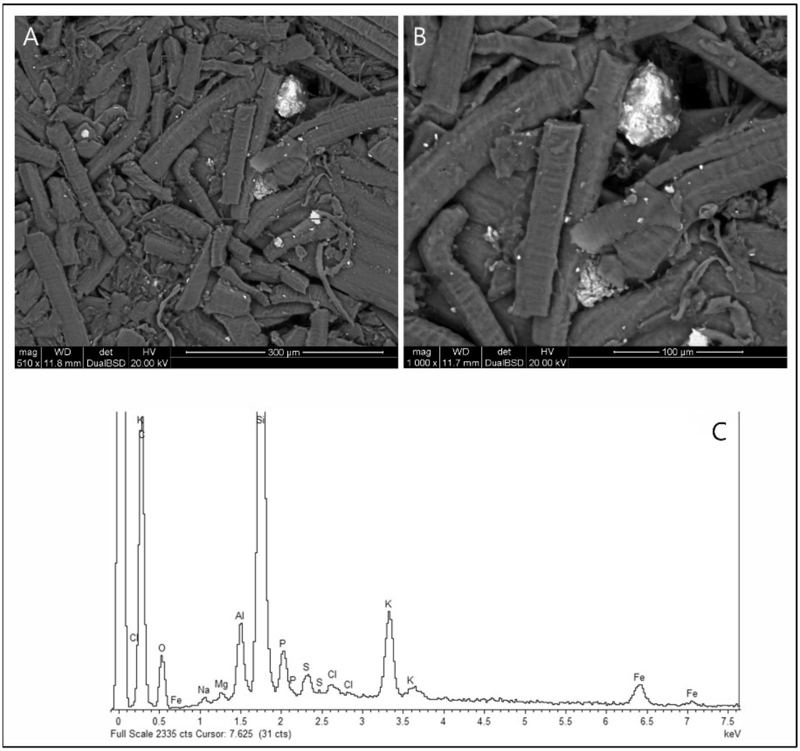

Fig. 2.2: The interstitial medium present in the third-body tribological system composed of a lithic tool and fragments of the worked material observed with a SEM. Microscopic chips of quartzite detached during friction are found within hide fibres.

Edge damage

Edge damage is generally described as severe rounding of edges, as well as the presence of several scars organised in specific patterns. It is thought to be indicative of the general hardness of the contact material, of the kinematics (deduced from the location of scars on ventral or dorsal surfaces), and of impact fractures. In traceology, edge damage (considered as scarring) is any retouch on stone artefacts that is not the result of deliberate effort by man to modify the morphology of blanks (Tringham et al., 1974; Moss, 1983). One of the main issues of considering edge scarring as a valuable indicator of use is the equifinality with other causes (mainly retouch and post-depositional events, such as trampling).

In tribology, spalling and flaking are defined as the separation of particles from a surface in the form of flakes; usually it is the result of sub-surface fatigue (OECD, 1969). The resulting scars are the negative concavities of the micro-flakes detached from the surfaces. Spalling is usually the result of sub-surface fatigue, and it is more extensive than pitting. Pitting is also defined as any removal or displacement of material resulting in the formation of surface cavities (OECD, 1969).

Generally, functional interpretations are not based on the macro-wear evidence alone, as it has been demonstrated that the same scar morphologies can be the result of several other events, such as trampling and soil movements.

Polish

In traceology, polished surfaces are described as worn-out surfaces usually being shiny under the optical microscope (Keeley, 1980). The appearance of polished areas can be described in terms of their brightness or dullness (that is, how much light the polish reflects) and their roughness or smoothness (Keeley, 1980:22). Two big issues emerge if this definition is fully accepted. First, if brightness intensity has to be measured, then optical microscopes have to be employed. If polished areas are observed with other equipment which does not use light to magnify surfaces (e.g. SEMs, confocal microscopes), then the definition provided by Keeley and traditionally accepted by traceologists is not entirely valid. Moreover, Keeley defined different polishes, diagnostic for common materials worked in prehistory ('wood polish', 'bone polish' and so on) (Keeley, 1980). The second methodological issue is that all descriptions of polished areas (roughness, smoothness, invasiveness, etc.) are subjectively formulated and therefore not quantified. Unfortunately, the same problems of equifinality described for edge damage are found when observing polishes. Polishes can equally derive from use and soil movements as well as from other causes involving the manipulation of the lithics. When stone tools are hafted and de-hafted, for example, scars can form. Also, when stone tools are stored and transported in the same bag, polish can form on edges or ridges of the tools.

In tribology, the process which leads to the formation of polish (worn-out areas) is defined as polishing. Polishing is a surface-finishing process utilising different grades of abrasion which leads to an improvement in surface smoothness (OECD, 1969; Williams, 2005). Within polishing, abrasion or abrasive wear is a wear type which sees the displacement of material caused by hard particles or hard protuberances (OECD, 1969). Scouring abrasion is then caused by the presence of hard particles between two surfaces in relative motion, or by the presence of hard protuberances on one or both of the relatively moving surfaces. The abrasive particles may be embedded in one of the surfaces (OECD, 1969). When only stone tools and softer contact materials are involved, the actual abrasives are the micro-chips detached from the edges of the tools. Abrasives may also be added, like ochre when working hides (e.g. Mansur, 1983).

If polishing leads to smoother surfaces, the quantification of smoothness of the worn-out surfaces on stone tools (polishes) may be a valuable method to deduce the contact material responsible for the generation of the polish. Since the beginning of the 21st century, efforts have been made to overcome the subjectivity of traditional descriptions of polished areas by focusing on measuring polish originating from contact with different materials (among others, Evans and Donahue, 2008). Results are promising and quantitative methods are seen as a viable way to slowly overcome subjectivity in use-wear studies.

Striations

Striations are synonymous with linear features. There are different types of striations which can be sub-divided according to their width and depth (narrow deep, narrow shallow, broad deep, broad shallow) (Keeley, 1980). Again, these descriptions are mostly subjective and therefore results provided by different researchers are hardly comparable. Unlike striations, abrasion tracks (e.g. furrows) are usually short and quite broad (10 microns), often show multiple parallel-running deep tracks, and sometimes have the appearance of ‘being gouged out of the flint surface’ (Keeley, 1980) (Fig. 2.3).

There are many different definitions of the same features available in the literature on traceology. Broadly speaking, two main categories within striations can be found: sleeks and furrows. Sleeks are described as tiny, streaky scratches (Semenov, 1964:115); linear features caused by plastic deformation (Kamminga, 1979:148; Levi-Sala, 1996:12–13); linear features with a smooth-bottom (Mansur, 1982; Sussman, 1988: 13–14); and linear features having a smooth cross-section (Fullagar, 2006:222).

Furrows are defined as being partial Hertzian cracks (Lawn and Marshall, 1979:72); abrasion tracks (Keeley, 1980:23); rough-bottomed through (Mansur, 1982); grooves in the polished surface (Levi-Sala, 1996:68);

irregular striations (Knutsson et al., 1988); gouges (Susmann, 1988:13–14); and crescent cracks (Hurcombe, 1992:58).

While sleeks are frequently described as being plastic deformations of the surface, abrasion tracks or furrows do not seem to be resultant of such a process. Furrows are characterised by loss of material, which seems to be due to surface fatigue (i.e. removal of particles detached by fatigue arising from cyclic stress variations) (Fig. 2.3). They can be related to pre-existing surface cracks or to the intense forces of attrition between the particles dragged across the surface and the surface itself.

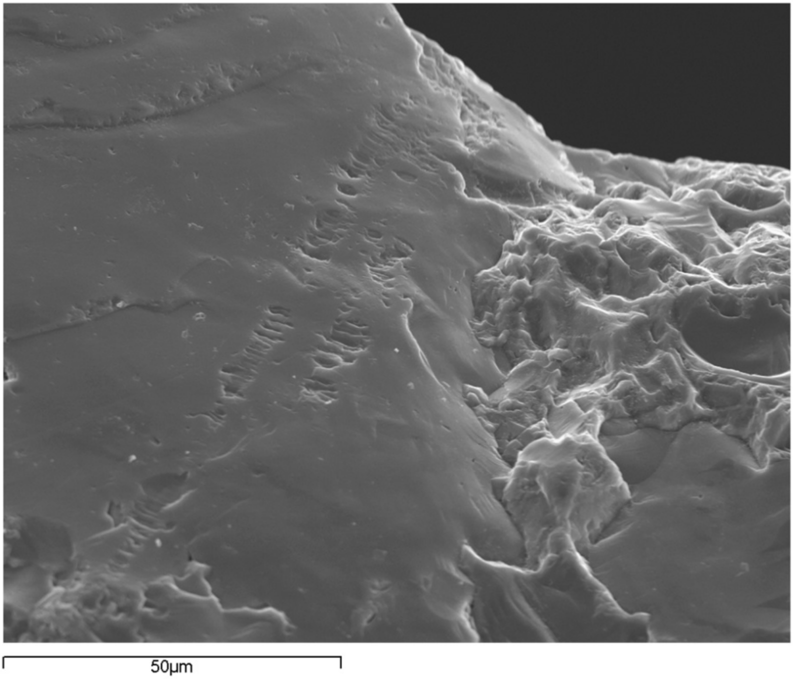

Fig. 2.3: Two long furrows, perpendicular to the used edge, probably caused by surface fatigue on an experimental quartzite tool (orig. magn.: 1000x).

In tribology, scratching is the formation of fine scratches in the direction of sliding and may be due either to asperities on the harder slider or to hard particles between the surfaces or embedded in one of them. Ridging is a deep form of scratching in parallel ridges usually caused by plastic flow of the sub-surface layer, while ploughing is the formation of grooves by plastic deformation of the softer of the two surfaces in relative motion (OECD, 1969).

It can be important to distinguish different categories of striations, as different types appear with variable degrees on raw materials. In the case of quartzite, furrows are by all means the most recurrent type appearing as a consequence of use.