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Non-Flint Raw Material Use in Prehistory

Old prejudices and new directions

L'utilisation préhistorique de matières premières lithiques alternatives

Anciens préjugés, nouvelles perspectives

Edited by

Farina Sternke, Lotte Eigeland
and Laurent-Jacques Costa

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FUNCTIONAL ANALYSIS OF MACRO-LITHIC ARTEFACTS: A FOCUS ON WORKING SURFACES

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Abstract: Macro-lithic tools are among the most abundant artefact categories in the archaeological record. They are made from a wide range of rocks, worked through various techniques and served to carry out a large array of tasks, beginning in the Palaeolithic and continuing to early historic times. Despite their relevance to the economic and social organisation of past societies, it is only recently that archaeologists have begun to develop specific research methodologies for the study of macro-lithic artefacts.

One aspect that deserves increasing attention is the description and analysis of traces on stone surfaces specific to production, maintenance and use. The aim of this paper is to compare the different approaches to functional analyses of macro-lithic tools and to achieve a consensus about terms and analytical categories. Issues discussed include the factors governing the formation of wear traces, the manifestation of wear on surfaces of various rock types, comparisons between macroscopic and microscopic approaches and the possibilities for photographically documenting observations. The final objective is to standardize methods for functional analyses, thereby facilitating a better technological understanding of the means of production used by pre-industrial societies.

Keywords: Functional analysis, Macro-lithic tools (ground stone tools, Felsgesteingeräte, instrumentos macrolíticos), Methodology, Terminology, Use-wear, Technology, Experimental Archaeology

Résumé: Les outils macrolithiques comptent parmi les vestiges les plus abondants mis au jour sur les sites archéologiques. Ils sont réalisés sur une grande variété de matières premières, façonnés par des techniques variées et ont été utilisés pour de nombreux usages depuis le Paléolithique jusqu'aux périodes antiques. L'étude du macro-outillage apparaît de première importance pour notre compréhension des organisations économiques et sociales passées. Pourtant, les archéologues ont longtemps limité leur étude à de simples descriptions ou classifications typologiques et n'ont que très récemment développé des méthodes spécifiques pour leur étude. L'étude des traces relatives à la mise en forme, l'entretien et l'usage des macro-outils a en particulier reçu une attention croissante ces dernières années. L'objectif de cet article est de comparer différentes approches tracéologiques appliquées aux macro-outils et d'arriver à un consensus quant aux termes et catégories analytiques employées. Les questions abordées comprennent également les processus de formation des traces en fonction des matières premières, l'apport respectif des échelles d'observation macroscopique et microscopique et l'obtention d'une documentation photographique adéquate. Ce travail vise finalement à homogénéiser les méthodes d'étude fonctionnelle des macro-outils et devrait permettre une meilleure compréhension des moyens de production des sociétés pré-industrielles.

Mots clés: Analyse fonctionnelle, macro-outillage lithique (outils de broyage et mouture, Felsgesteingeräte, instrumentos macrolíticos), méthodologie, terminologie, tracéologie, technologie, archéologie expérimentale

INTRODUCTION

This paper focuses on a varied category of stone artefacts that we propose to label “macro-lithic artefacts”. They could be called “non-flint implements”, “non-flaked tools” or “ground stone tools”; however, none of these labels are adequate for items that cannot be categorized by specific geological types, manufacturing processes or activity associations. Macro-lithic artefacts tend to be

larger and heavier than most flaked tools and in general were designed for rather heavy duty tasks such as percussion, abrasion, polishing, grinding and chopping. The category of macro-lithic tools includes, among others, abraders, polishers, shaft straighteners, mortars, pestles, grinding slabs, handstones, netherstones, hammerstones and axes. We propose that functional analyses of macro-lithic artefacts will greatly enhance what can be learned about prehistoric manufacture, use

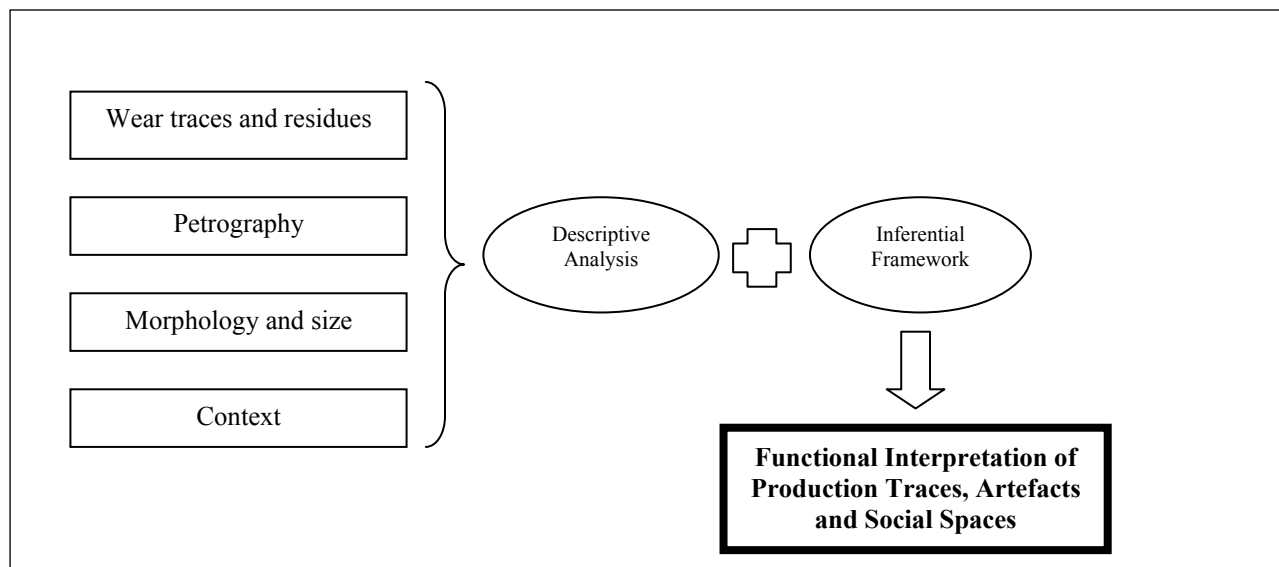


Fig. 6.1. Analytical steps for a functional interpretation of macro-lithic artefacts

and discard behaviours. These stones have been too long neglected in archaeological studies, impeding a more complete understanding of the economic organisation of many prehistoric societies.

Most commonly, macro-lithic implements were made from various igneous, sedimentary and metamorphic rocks that are more granular than the easily flaked flint, chert, chalcedony, obsidian and other cryptocrystalline rocks chosen for flaked artefacts. Granularity and the weight of the rock are significant to the action performed. When rocks of adequate size and shape were available, modification before use was not necessary. When modification was needed, they were manufactured with varying techniques, such as flaking, pecking, grinding, sawing and perforating.

The working zone of macro-lithic tools corresponds most often to a surface, but edges can also come into the analysis, especially for axes, anvils and other percussion tools. Macro-lithic tools were used in a wide variety of tasks such as working skin, bone, wood and fibre, flint knapping, pottery production, metallurgy, stone trimming and wood chopping as well as food processing. In addition to the type of activities performed, macro-lithic tools convey information about the intensity of given tasks, their technical constraints and spatial organisation. Their heuristic potential turns them into crucial archaeological evidence for the analysis of the economic organisation of past societies.

Functional analysis plays a central role in gaining a better understanding of this generally neglected category of artefacts (Fig. 6.1) by recognizing different stages in artefact life history. Design factors are reflected in the choices of rock type, size, shape and weight, while manufacture, use and maintenance factors are reflected in different wear traces and residues from the processed

material used (regarding use-wear traces see Appendix 2; regarding residues analysis see Jones 1990; Fullagar and Field 1997; Atchison and Fullagar 1998; Formenti and Procopiou 1998; Procopiou 1998; Christensen and Valla 1999; Procopiou and Formenti 2000; Procopiou *et al.* 2002; Fullagar and Jones 2004; Pearsall *et al.* 2004; Perry 2004; Zurro *et al.* 2005). The archaeological context of the tool provides additional information about how they were used.

The aim of this paper is to establish a baseline method for analysing use-wear on macro-lithic artefacts. The analytical description of the modifications resulting from wear is seen as a necessary step towards the definition of *production traces* (Risch 2008). From a socio-economic perspective, production has a twofold meaning. It means to manufacture or maintain an object as well as to use or consume it. As society re-produces itself through a continuous cycle of elaboration and consumption of goods, *production traces* can be understood as all physical and chemical transformations that have taken place during the circulation of any subject or object in society. Epistemologically, the concept of *production traces* goes beyond the identification of use-wear traces and encourages us to search for their relationship with particular activities.

Functional analysis of macro-lithic artefacts has been addressed by only a few archaeologists working independently in different countries, on various contexts and publishing in different languages (for example Semenov 1964:134-142, 1969/2005b; Gorman 1979; Adams 1988, 1989a, 1989b, 1993, 2002a and b; Fratt and Biancaniello 1993; Fujimoto 1993; Ibáñez and González 1994; Korobkova and Sharovkaya 1994; Risch 1995, 2002; Mansur 1997; Fullagar and Field 1997; Procopiou 1998; Procopiou *et al.* 1998; Dubreuil 2002, 2004; González and Ibáñez, 2002; Menasanch *et al.* 2002; Zurro

et al. 2005; Hamon 2006; Hamon and Plisson, 2008; Delgado Raack 2008; and see also A. Lunardi and A. Sajnerová-Dušková *et al.* this volume). At this point, it has become critically important that recording procedures and terminology be standardized to further communication and to facilitate replication of the analysis in view of the growing interest in the study of macro-lithic implements.

In this paper, we will concentrate principally on the use-wear produced through friction. The inferential background used to analyze use-wear is primarily based on experiments and comparisons with archaeological material (for a discussion see Plisson 1991). The experiments carried out so far concern mainly the utilization of grinding or abrading implements made of different varieties of sandstone, vesicular basalt, schist and limestone. Nevertheless, the experiments with quartzite pebbles, compact basalt, and gabbro hammerstones, basalt picks and various types of axes should be noted (for example de Beaune 1993, 1997, 2000; Hayden 1987: 85-98; Mills 1993; Risch 2002: 129-132; see also Dodd 1979 and contributions in this volume). Appendix 1 gives an overview of the main experimental analyses published so far in relation to macro-lithic tools used for grinding and abrading activities.

CHARACTERISATION OF ARCHAEOLOGICAL MATERIALS

An initial requirement of any functional analysis is a detailed petrographic description of the rock. After all, the development of wear on a surface, as well as ultimate implement shape, depends in part on rock type, composition and texture and in part on the activities in which the implement was used. Prior to any observation of use-wear, it is important to become familiar with the natural or unworked surfaces of the rock types studied. At first glance, this gives an idea of the structure of the stone, including mineral composition, granularity, porosity, cementation as well as an expectation of the behaviour of the stone's surface during work. Against this "natural" pattern the alterations produced through different work processes can be evaluated.

The terms used to describe the petrologic and mineralogical characteristics of the rocks have been recently discussed by different authors (see for example Shoumacker 1993; Risch 1995:52-55; Adams 2002a; Santallier *et al.* 2002; Schneider 2002). Each publication includes a discussion about the relationship between the rock's properties and the damage caused by grinding. Based on these studies, four levels of classification and rock description are suggested which can be supplemented by thin sections of a sample of artefacts to confirm and complement the surface observations.

1. *General classification* of the various types of igneous, sedimentary and metamorphic rocks.

2. Description of the *fabric* or structure of the rock including the physical arrangement of the constituent grains and minerals. The following types of fabric can be distinguished macroscopically:
 - a. Isotropic: random grain orientation.
 - b. Planar: grain particles organized along parallel surfaces.
 - c. Linear: elongated grains oriented in a single direction.
 - d. Plano-linear: combination of a planar and linear fabric.
3. Description of the rock's *texture*, including the physical aspects of the grains, expressed as granularity, cohesion and porosity. Both, *fabric* and *texture* have a real influence on the development of wear because of variability in the high and low aspects of the surface topography that become involved in the mechanics of wear. Textural terms vary by rock type with igneous, metamorphic and sedimentary rock each having specific terms (Table 6.1). The general texture of each group of rocks can be described in the following terms based primarily on microscopic observation.

Granularity refers to grain size and homogeneity. If grain sizes are the same, the texture of the rock is uniform. Unequal grain sizes create an irregular texture. Grain size can be measured by means of a scale incorporated into the eyepiece of the microscope. Grain shape and roundness are generally estimated using standardized charts. Shape charts separate grains that have axes of approximately equal dimensions (equant) versus those that are extended in one or more dimensions (prolate, bladed, oblate). Roundness charts distinguish grains along a continuum from *very angular* (no rounded edges) to *well-rounded*, with no edges at all.

Cohesion is determined by how the grains and minerals are bound together, united either by recrystallisation or by some type of matrix (detrital, micaceous) or cement. Especially with sedimentary rocks such as sandstones or conglomerates, it is important to know the type of cement (e.g. silica or carbonate) that binds the larger components of the rock. Cohesion determines a rock's durability which is its ability to withstand wear.

Porosity refers to the empty spaces between mineral components. Porosity can be estimated with relative abundance charts or measured directly using quantitative microscopy or laboratory experiments.

4. Detailed description of a rock's *mineral composition*. Because of differences in their crystalline structure, rocks respond to wear in very different ways. Soft minerals, such as muscovite, wear quite differently than hard quartz grains. The identification of the major components can be observed with a binocular microscope; however, minor inclusions require a petrographic analysis through thin section or x-ray diffraction (XRD). Charts of modal proportion (e.g.

Tab. 6.1. Characterization of rock textures represented in the three main rock families

		Rock type		
		Igneous	Metamorphic	Clastic Sedimentary
Generic name for fine and coarse fraction		Groundmass	Matrix	Matrix
		Phenocrysts	Blasts, clasts	Clasts
Grain size and homogeneity	Fine, uniform	Aphanitic (grains too fine to see) Vitreous (glassy)	Granoblastic, granular	Silt, clay, mud
	Coarse, uniform	Faneritic	Granoblastic	Sand, gravel
	Coarse, irregular	Porphyritic Strainer texture	Porphyroblastic; porphyroclastic	Conglomeratic
Oriented texture		Flow structure	Lepidoblastic (foliated); Nematoblastic (lineated); mylonized	Bedded
Highly porous		Vesicular (gas bubbles preserved in groundmass)	n/a	"Porous" followed by rock name

AGI Data sheets) currently used in petrography are helpful for an approximate quantification of the different minerals and provide a means to establish the compositional homogeneity of a rock.

TRIBOLOGICAL MECHANISMS OF WEAR

Wear is the progressive transformation of a surface as a result of the relative motion between it and another contact surface (Teer and Arnell 1975:94; Czichos 1978:98; Szeri 1980:35; Adams 1988:310, 1993:63, 2002a:25, 2002b:59; Procopiou 2004). Wear analysis is the examination of archaeological artefacts at macroscopic and microscopic levels for evidence of prehistoric manufacture, use, maintenance and handling of the item as well as for evidence of post-use damage.

The various mechanisms involved in wear formation for grinding, pounding and abrading implements have been discussed by J. Adams with specific reference to the research of tribologists (Adams 1988, 1989a, 1989b, 2002a:27-41, 2002b). Tribologists study wear in an effort to keep it from happening and have recognized the role of intermediate substances that either promote or inhibit wear (Teer and Arnell 1975:94; Czichos 1978:98; Szeri 1980:35; Adams 1988:310, 2002a:25, 2002b; Procopiou 2004). Adams (1988, 1993, 2002a, 2002b) distinguishes four mechanisms responsible for the formation of specific damage given on macro-lithic surfaces: *adhesive wear*, *abrasive wear*, *fatigue wear* and *tribochemical wear* (a combination of mechanical and chemical interaction).¹ These four mechanisms are not mutually exclusive in how they change the surface, nor is each the result of a single,

independent event. Rather, they interact and one becomes dominant over the others depending on the characteristics of the contacting surfaces and the nature of any intermediate substances. These are important concepts for macro-lithic wear analyses because they provide a means for evaluating wear patterns (Table 6.2) against those created experimentally and understood through ethnographic analogy.

Tab. 6.2. Hypothesis of relationship between tribological mechanisms and observed wear traces

TRIBOLOGICAL MECHANISMS	VISIBLE WEAR TRACES
<i>Adhesive wear</i>	Residues
<i>Fatigue wear</i>	Fractures
	Cracks
	Pits
	Frosted appearance
<i>Abrasive wear</i>	Striations and scratches
	Levelling
	Grain edge rounding
<i>Tribochemical wear</i>	Polish or sheen

When two surfaces come into contact, even if there is no movement, there are molecular interactions. These interactions create bonds that are broken when there is movement of one surface across or away from the other surface (Czichos 1978:119-123; Kragelsky *et al.* 1982:6). Movement and the subsequent breaking of bonds release energy in the form of frictional heat and loosen rock grains from one or both surfaces. This is *adhesive wear*. The loosened rock grains either remain between the

¹ For the definition of these concepts in tribology see for example Quinn 1971; Teer and Arnell 1975; Czichos 1978; Dowson 1979; Szeri 1980; Kragelsky *et al.* 1982; Blau 1989.

surfaces or become attached to the opposite surface or at another location on the original surface. In the early stages of wear, the damage may not be visible, except at very high power magnification. However as wear progresses, the damage builds up and interacts with the other mechanisms. Adhesive wear on macro-lithic surfaces is probably best seen where they are handled. The oils in our hands adhere to the stone surfaces, even if there is no active rubbing.

As pressure or the alternating stress of movement is applied to contacting surfaces, the highest elevations bear the weight and mass of the load. If the load is more than is bearable, then there is collapse and crushing of the elevations (Teer and Arnell 1975:95; Czichos 1978:105). This crushing is the result of *fatigue wear*. Damage is visible both, macroscopically and at low power magnification as cracks, fractures and pits. The effect is similar to that seen on frosted glass. Fatigue wear might destroy damage patterns created by adhesive wear, but at the same time, it opens up fresh surface area upon which new adhesive bonds can be created. These areas of fatigue are called impact fractures and are easily seen on tools that have been battered with pecking stones (Adams 2002a:30, 2002b:58).

Particles that are loosened through adhesive and fatigue wear remain between surfaces, becoming abrasive agents in the wear process. These abrasive agents create scratches and gouges across the stone's surface. Material gouged out by the agents also becomes involved in the abrasive wear process. *Abrasive wear* is also caused by the movement of a more durable asperite surface, grain or mineral across a less asperite surface, grain or mineral. The harder, rougher grains or minerals of the durable surface dig into the smoother material of the other surface. Movement displaces the softer material, creating striations and scratches in the direction of the movement (Teer and Arnell 1975:106; Czichos 1978:126).

As surfaces move against each other, the alternating stresses of movement and pressure instigate the mechanisms of adhesive wear, abrasive wear and fatigue wear. These mechanisms create superficial cracks on both contacting surfaces. Once a crack has formed, crack propagation results in the release of energy in the form of frictional heat (Czichos 1978:105-112). The release of heat is only one of the factors important in the "environment" surrounding the contacting surfaces.

Adhesive wear, abrasive wear and fatigue wear create an environment for the chemical interactions of the *tribochemical wear* mechanism. These chemical interactions produce *reaction products*, which are the films and oxides that build up on surfaces (Czichos 1978:123). These reaction products are visible on stone surfaces as sheen, sometimes referred to as polish by technologists studying flaked stone tools. Tribochemical interactions are constantly occurring and are enhanced by frictional energy and mechanical activation. However,

unless the reaction products are allowed to accumulate, they cannot be seen. While the other three mechanisms are constantly exposing fresh surfaces upon which interactions can occur, they are concomitantly removing any build-up of reaction products. Reaction products continue to be removed until the higher elevations of the contacting surfaces are crushed to the point that fatigue wear is no longer a factor and the asperities of the two surfaces are no longer gouging each other. Thus, reductions in surface topography and surface asperity allow the reaction products to build up enough to be macroscopically visible.

It is easy to see that the mechanisms of adhesive wear, abrasive wear and fatigue wear are reductive processes, each with distinctive damage patterns. Tribochemical wear, however, is additive. The two most important facts to remember are: 1) the visible wear is from the mechanism most recently in operation on the surface and 2) the best way to evaluate wear is to compare it either to an unused area on the tool (although taking into account subtle handling traces) or to a piece of raw material of the same type. As has been described above, the petrographic identification of the rocks is an essential part in the functional analysis of macro-lithic artefacts.

This general framework should be explored further by analyzing experimental tools and testing the behaviour of different raw materials subjected to friction and impaction. When compared, the results of various experiments highlight the different modifications caused by disparate factors such as abrasion or the presence of grease.

DESCRIPTION OF USE-WEAR

As has already been debated by flaked lithic technologists (Hayden 1979; Hayden and Kamminga 1979; Keeley 1980; Odell and Odell-Vereecken 1980; Anderson-Gerfaud 1981; Vaughan 1985), there are advantages and disadvantages in using low-power, stereoscopic binocular microscopes or high-power, metallurgical reflected light microscopes during use-wear analysis. Two of the most obvious obstacles to any magnification used during the analysis of macro-lithic artefacts are the size of the artefacts and the diversity of the mineral components that form the rock. Clearly, the creation of wear on a rock's surface depends on the crystalline structure of its minerals. Quartz, carbonates and muscovite, for example, each respond very differently to friction, creating different degrees of roughness or smoothness. Yet, what is the best way to observe use-wear on a surface? The answer is that there is no single, best way to observe worn surfaces. Different scales of observation are required, even on the same surface (Fig. 6.2). Surface descriptions range from the general morphology of the surface created by a combination of grains and minerals to the description of wear traces on individual grains and in the spaces between the grains (called interstices or vesicles depending on the stone).

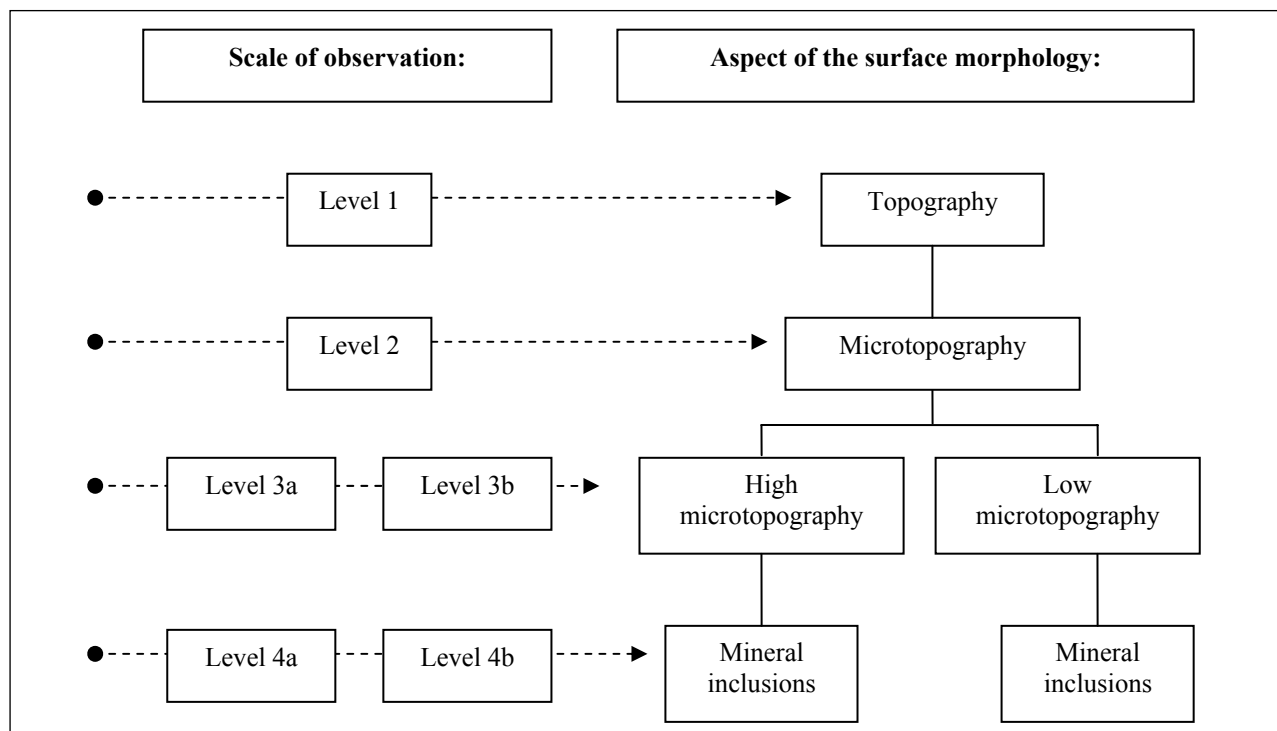


Fig. 6.2. Different levels of observation of a stone artefact's surface

All authors agree on the importance of topography as a basic criterion for describing the alterations produced by friction on a rock surface. According to Adams (2002:29), “topography” refers to the elevational differences observed on the surface and, “...the term microtopography distinguishes the topographic variation visible under magnification from the topography visible macroscopically”. The recognition of use-wear and hence the aspect of the topography, varies according to the scale of observation. A macroscopically flat topography looks extremely irregular under high-power magnification and it is important to specify those distinctions when presenting use-wear descriptions. Furthermore, the clear description of surface microtopography allows us to account for use-wear visible on the highest grain surfaces as well as in the lowest parts (e.g. interstices or vesicles between grains). Such differentiation is important for distinguishing between a stone surface worn against a soft contact surface (for example hides) and one worn against a hard contact surface (for example another stone).

The appearance of topography and microtopography can be defined in terms of shape and surface roughness or asperity (Fig. 6.3). While the first refers to the general morphology of the surface viewed macroscopically (Observation Level 1), the second criteria specifies the degree of irregularity visible microscopically among fractions of the surface (Observation Level 2). Essentially at each scale of observation, it is possible to describe the general and the particular surface shape (Photos 1, 2, 3, 13, 16). Contour gauges (*Rugosimetres*) offer the possibility to characterize topographic differences with absolute values and will expectedly become more common in the

future (Zahouani *et al.* 2004), so that we can develop measurements to quantify descriptions that are currently only qualitative.

Identifications of microtopographic alterations on the highest grains or plateaus of a worked surface, as well as in the lowest recesses, are Level 3 observations. These are the observations critical to our ability to distinguish the nature of contact surfaces. Some contact surfaces are too rigid to be worked into the lowest recesses, some are pliable enough to extend part-way into the recesses and others are soft enough to reach the bottom-most recesses. Level 4 observations are made at a smaller scale only on individual minerals or grains (figs. 6.7.g, h). At each of the observation levels, it is important to remember the nature of the unaltered rock surface to evaluate alterations produced by maintenance, use or mere handling.

Low Power Magnification

When the surfaces of macro-lithic artefacts are observed under low power magnification (for example, 10-60 power, most commonly using a stereo-microscope), it becomes clear that distinctive use-wear patterns were derived from contact with and movement across specific opposing surfaces. In this paper, our descriptions are concerned with contacting surfaces and sometimes with the role of substances between the contacting surfaces called intermediate substances. Intermediate substances can be foods such as grains, berries or tubers or non-food substances such as clay. The impact of such intermediate substances in the wear process can not be discounted (see for example Adams 1988, 1989, 2002a, 2002b; Mena-

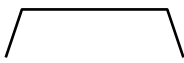
Development of topography (level 1)	Development of microtopography (level 2)	
	Regular	Irregular
FLAT 		
SINUOUS OR ROUNDED 		
UNEVEN OR RUGGED 		

Fig. 6.3. Variation of the topography and the microtopography of a macro-lithic artefact including the profile and regularity of the surface

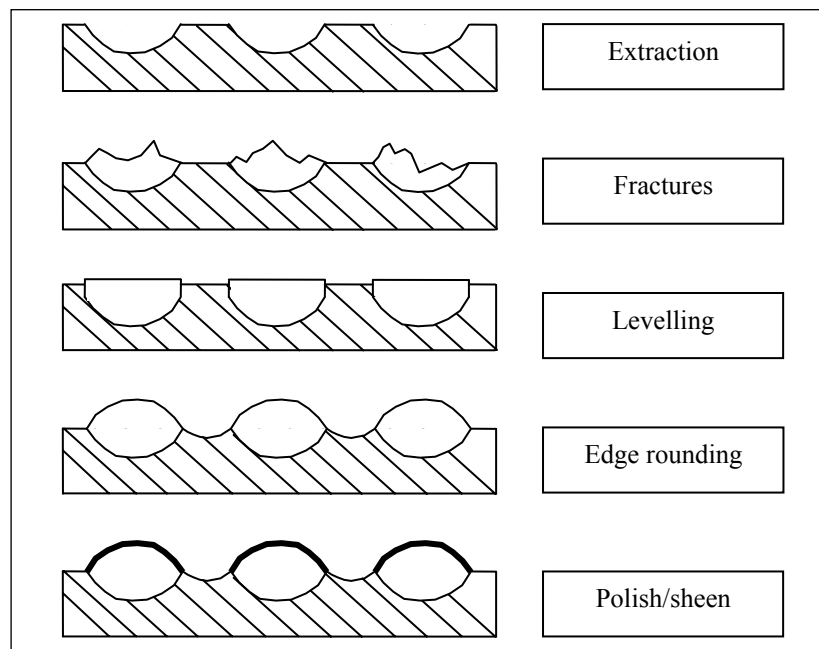


Fig. 6.4. Schematic representation of the wear traces observed on individual grains or minerals

sanch *et al.* 2002; Risch 2002; Dubreuil 2004; Hamon 2006; Hamon and Plisson 2008).

The following terms describe specific use-wear traces visible under low power magnification that result from contact and movement of heterogeneous rocks across specific surfaces. These traces (Fig. 6.4) are observable at different powers of magnification on small or large grain aggregates as well as on individual grains or minerals (Figs. 6.6d-h). To facilitate description, the same attribute terms are consistently used to locate and explain the different types of use-wear on macro-lithic surfaces.

Linear traces

Semenov (1964) used striations and polish as descriptive terms in his functional analysis of archaeological and

ethnographic artefacts. Under very low-power magnification (less than 20x), *linear traces* in the form of striations and scratches are usually visible on the high topography of a working surface. In general, striations and scratches are caused by the movement of a harder surface across a softer one (Adams 2002a:30, 2002b:58). Texture and durability of the hard surface determines the potential for the extraction of entire crystals or grains or tiny fragments of those, as it moves across the softer surface. In general, it is easier to see striations and scratches on dark, medium-hard minerals (Fig. 6.7b) and more difficult to differentiate striations on translucent and very hard or very soft minerals. The consistent description of linear traces will help communicate how they were formed and the direction of their formation (Delgado Raack 2008).

- Distribution* is the patterning of linear traces across a surface and can be described as *loose*, *covered* or *concentrated* (Fig. 6.5).

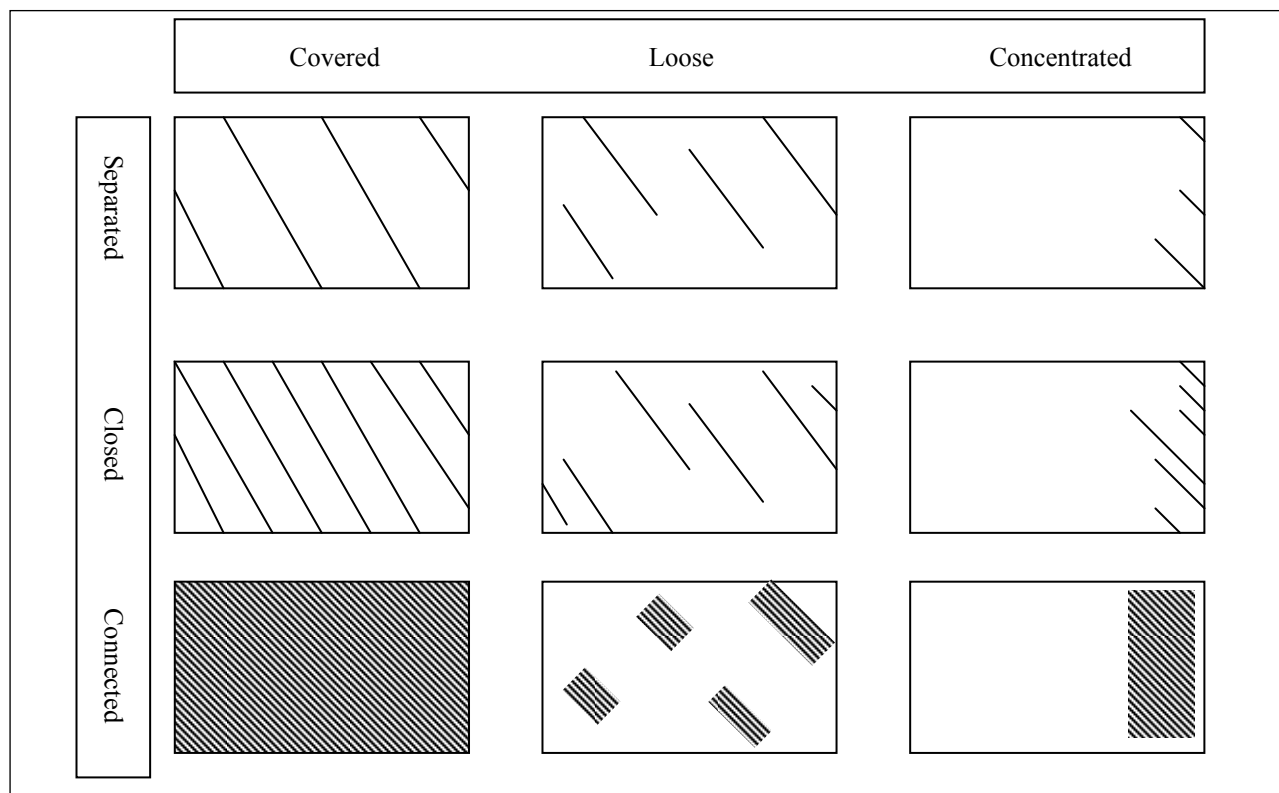


Fig. 6.5. Graphic representation of the correlation between distribution and density of traces (defined for linear traces but applicable to other use-wear types)

- b. *Density* describes the linear traces as *separated*, *close* or *connected* (Fig. 6.5).
- c. *Incidence* is the location of the striations on topographic highs or lows and their relative depth (*shallow* or *deep*).
- d. *Disposition* is the spatial arrangement of the striations in relation to each other and can be described as *random*, *concentric*, *parallel*, *oblique* or *perpendicular*.
- e. The *orientation* of striations in relation to the major axis of the surface is *longitudinal*, *transversal* or *oblique*.
- f. A width of 0.5mm or less is a *striation*. A *scratch* is more than 0.5mm.
- g. *Length* is a relative distinction between *long* traces that extend across the working surface and *short* linear traces that extend only part way.
- h. *Longitudinal morphology* is the distinction between *continuous* and *intermittent* striations.
- i. *Transverse morphology* is the shape of the linear trace in profile such as *V-* or *U-shaped*.

Polish or sheen

Polish typically describes a shiny surface. Grace (1989:38) defined it “as a visible alteration of the natural surface that increases its reflectivity”. As usual, the nature of the unmodified rock must be taken into account,

because the development and intensity of a shiny surface will depend on mineral composition and granularity of the stone as well as the worked material and the duration and intensity of use (Figs. 6.6.e, g). Polish is linked to another wear process called ‘levelling’ which is subsequently described. Flatter surfaces have greater potential for high light reflectivity. The observation and interpretation of polish is somewhat more difficult than that previously described for linear traces.

- a. *Distribution* of polish is similar to that of linear traces by referring to its distribution across a particular surface as *loose*, *covered* or *concentrated* (Fig. 6.5).
- b. Polish *density* can be described as *separated*, *closed* or *connected* in approximately the same manner as for linear traces (Fig. 6.5).
- c. *Reflectivity* is described in relative terms as *slightly* (Fig. 6.6.c), *moderately* and *highly* reflective. For now, this is a judgement that will vary among analysts until techniques become common for quantifying reflectivity.
- d. *Incidence* describes whether the polish is only on the *topographic highs* or also in the *interstices*.

Levelling

Levelling (Figs. 6.6.d, e, f, h, 6.7.a) is a wear process that works on individual grains and minerals as well as on the larger scale of surface topography. Large levelled areas

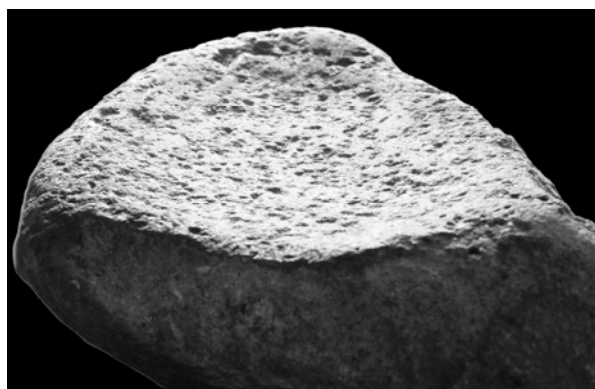


Fig. 6.6a



Fig. 6.6b



Fig. 6.6c



Fig. 6.6d



Fig. 6.6e



Fig. 6.6f



Fig. 6.6g



Fig. 6.6h

Fig. 6.6. Examples of wear traces visible on different grinding implements used to process cereal



Fig. 6.7a



Fig. 6.7b



Fig. 6.7c

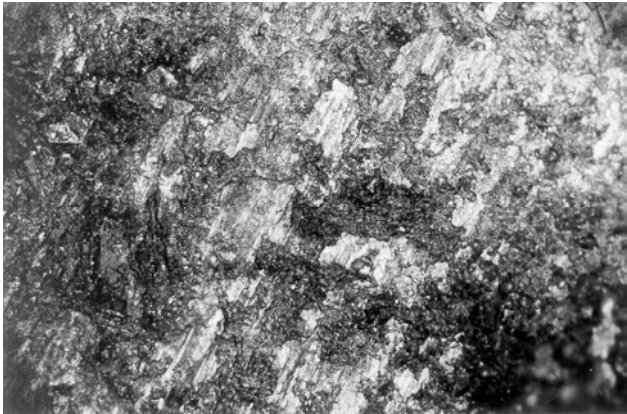


Fig. 6.7d



Fig. 6.7e

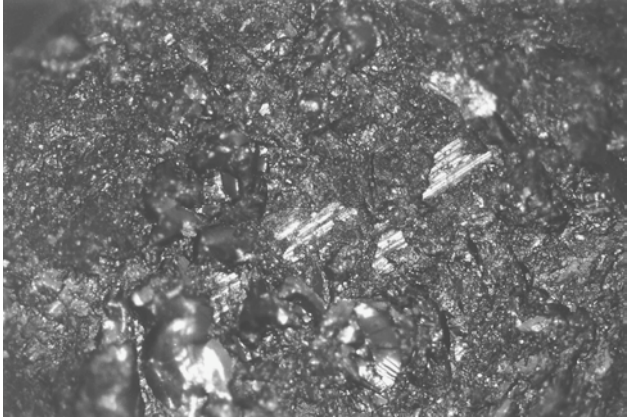


Fig. 6.7f

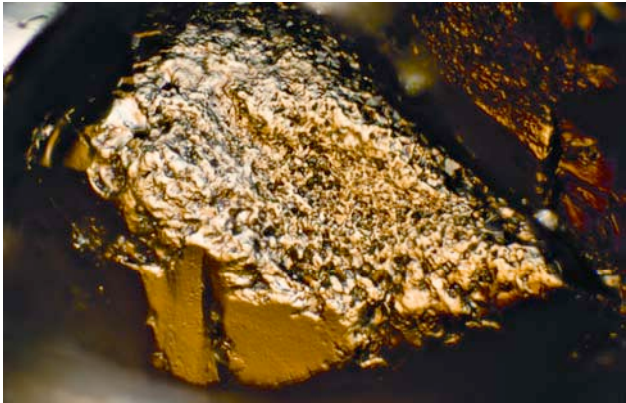


Fig. 6.7g

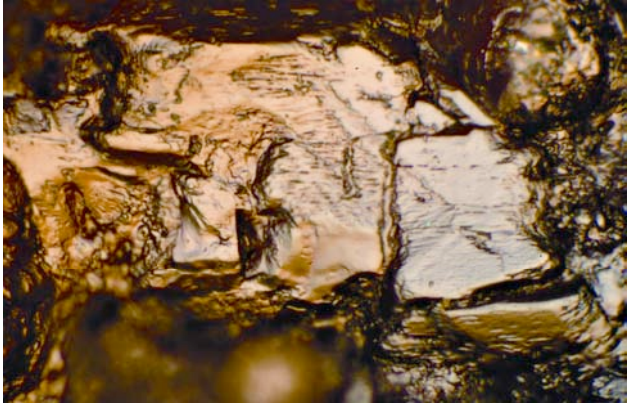


Fig. 6.7h

Fig. 6.7. Examples of wear traces visible on different grinding implements used to process cereal

on the surface are sometimes referred to as ‘homogeneous zones’. Levelling is most visible on durable rocks composed of well cemented grains that remain affixed long enough for the grains to be worn level with the matrix. Because levelling is a very visible and characteristic use-wear pattern on many abraders, polishers and grinding implements, the following terms are used similarly to those defined for linear traces and polish, but with different morphological and spatial criteria (Dubreuil 2002:209-210). Again, mineral composition and grain size of the rocks need to be taken into account when evaluating the process of levelling.

- a. *Distribution* of levelling can be described as *loose*, *covering* or *concentrated* (Fig. 6.5).
- b. *Density* describes the pattern of levelled relief or grains as *separated*, *close* or *connected* (Fig. 6.5).
- c. *Incidence* describes the location of levelling as on *high* or *low topography*.
- d. *Morphology* of the levelled topography may appear *flat*, *sinuous* or *rounded* at the Level 1 scale of observation.
- e. *Texture* of the levelled topography is described in relative terms as *rough* or *smooth*.

Pits and grain extraction

The formation of pits is directly related to granularity and cohesion. Rocks with poorly cemented grains develop pits in their surfaces due to grain extraction. The pits are the places vacated by the grains. Fine grained, durable rocks are less affected by grain extraction than poorly cemented rocks with large grains. Pits are also formed through fatigue wear, causing the removal of grain aggregates from the tool surface. The hardness of the minerals or grains is important in this process, influencing the propensity of a grain or mineral to break under pressure. Comparison with unmodified rocks is necessary to differentiate use-wear pits from the rock’s natural asperity. Grain levelling increases the high topography of a working surface, pitting increases low topography and consequently, enhances roughness (Figs. 6.6c and f). Quantitative differences between levelling and pitting are helpful in the functional interpretation of working surfaces distinguishing abrading or abraded surfaces from hammering or hammered surfaces (e.g. Procopiou 2004).

- a. *Distribution* of pits is described similarly to other patterns as *loose*, *covering* or *concentrated* (Fig. 6.5).
- b. *Density* of pits can be described as a *loose scattering* of pits across the surface, as a *closed* or *dense pattern* of pits that do not overlap or as a *connected pattern* of overlapping pits (Fig. 6.5).
- c. *Orientation* is described as *longitudinal*, *transverse* or *oblique* positioning of pits on the worked surface. Such descriptions provide information about the kinetics of a tool against the contact surface.
- d. *Depth* can be a relative description of pit dimension such as *fine* or *superficial* and *wide* or *deep*.

- e. *Pit shape* in plan view can be described as *irregular*, *circular*, *triangular*, *starlike* or *comet* shaped. Such observations help distinguish the nature of the contact surface and of the movements or kinetics of the tool.
- f. *Pit shape* in cross-section can be described as *U-* or *V-shaped*.

Fractures

Fractures and cracks can be observed across stone surfaces, across aggregates of grains or on individual grains and minerals. *Step fractures* are more commonly observed than concoidal ones on macro-lithic tools, because most of the rocks are too coarse-grained to fracture concoidally. Concentrations of fractures and cracks across the surfaces of some rock types produce what is described as a ‘*frosted appearance*’ (Fig. 6.6d) similar to that on frosted glass (Adams 2002a:30, 2002:58).

- a. *Distribution* of fractures is described similarly to other patterns as *loose*, *covering* or *concentrated* (Fig. 6.5).
- b. *Density* of fractures can be described as a *loose scattering* across the surface, as a *closed* or *dense pattern* or as a *connected pattern* of overlapping fractures (Fig. 6.5).
- c. *Orientation* is described as *longitudinal*, *transverse* or *oblique* positioning of fractures on the worked surface. Such descriptions provide information about the kinetics of a tool against the contact surface.
- d. *Depth* can be a relative description of fracture dimension such as *fine* or *superficial* and *wide* or *deep*.

Grain edge rounding

Grain edge rounding occurs when soft contact surfaces are elastic enough to completely envelop the irregularities of the rock surface and work into the interstices around grains and minerals. A slow mechanical alteration occurs that gradually eliminates edges on the grains or minerals. Grain edge rounding is described as *present* or *absent* (Figs. 6.6c,g and Fig. 6.7a).

Each of the described traces is the result of specific wear mechanisms (Table 6.3, see also Table 6.2). Nevertheless, one has to take into account that in dynamic or successive activities, wear patterns can blur each other or appear combined. The observation and systematic description of use-wear (see Fig. 6.3) allows us to identify recurrent patterns on experimental tools of different rock types, understand the principles ruling their formation and establish links with particular motions and activities.

High-power Magnification

Analyses at higher magnifications, for example with a metallographic microscope, have been less common than

Tab. 6.3. Main criteria for description of the different traces on macro-lithic artefacts

	Distribution	Density	Incidence	Longitudinal morphology	Disposition	Orientation	Metric dimensions	Reflectivity
Linear traces	x	x	x	x	x	x	x	
Polish/sheen	x	x	x					x
Levelled relief	x	x	x	x				x
Levelled grains		x	x					
Pits	x	x		x		x	x	
Fractures/Cracks							x	

analyses with low power, stereoscopic microscopes. The primary problem is a practical one. The artefacts are generally too large to fit under the higher-power microscopes. One solution has been the preparation of surface casts. Various types of casts can be used, as was practiced for example by H. Plisson (1983, 1984) studying micropolish on flint implements and by L. Dubreuil (2002, 2004), who applied casts to the study of micropolish on macro-lithic tools.

Of all the techniques tested, casts made of silicone and acetate yielded the best quality by accurately replicating the microtopography. Even though there is a tendency for casts not to capture the deepest interstices (especially with acetate), they are still useful for the study of use-wear. It is particularly important to note that colour and specific optical properties of the different crystals are not replicated by casts. Consequently, the casts facilitate observations at high-power magnification, because they reduce light dispersion and then enhance contrast.

To date, analyses using high-power magnification have primarily focused on the formation of micropolish on grinding implements (see for example Fullagar and Field 1997; Mansur 1997; Dubreuil 2002, 2004; Zurro *et al.* 2005). Micropolish is regarded as particularly diagnostic in flint use-wear analysis (see for example Semenov 1964; Keeley 1977; Keeley and Newcomer 1977; Shchelinskij 1977; Anderson-Gerfaud 1981; Plisson 1985; Vaughan 1985; Levi-Sala 1986, 1993; Mansur-Franchomme 1986; Plisson and Mauger 1988; Plisson and Van Gijn, 1989). Micropolish is defined here, following H. Plisson (1985), as a modification of the microtopography of a tool's surface taking the form of a smooth and even sheen that reflects light differently than the unmodified rock. Whatever its formation process (mechanical and/or chemical), micropolish forms most visibly where the grains are not distinct, but rather

coalesced as if welded together. Within the micropolish, the coalescence corresponds to the areas where the grains are not distinct, but welded together by smoothing or coating. The location, distribution, density and incidence of the coalescence are the constituent features of micropolish morphology (Plisson 1985).

Observations and comparison of various experimental tools, as well as casts of the working surfaces, have been carried out by one of us (L. Dubreuil). One of the results is that the contrast between the micropolishes and the natural surface is enhanced by the non-polarized transmitted lighting of semi-transparent casts. But it has also been noticed that with the transmitted light microscope, observations can be hindered by a less accurate rendering of the micropolish textures. For this reason, the reflected-light microscope appears more versatile.

Other comparisons of various experimental basalt implements resulted in the conclusion that micropolish tends to be more developed on abraders and polishers (Dubreuil 2002, 2004) than on grinding implements. On polishers, the sheen is well developed across a rather large area on the highest part of the microtopography. Furthermore, significant micropolish variations are observable with different contact surfaces.

Experiments with handstones and grinding slabs showed that the abrasive wear caused by two stones grinding against each other represent one of the most distinctive use-wear pattern developed on the surface. Indeed, at high magnification, the working surface of most of the experimental grinding stones appears slightly shiny, levelled but rough (Fig. 6.7e). The formation of striated shiny areas on the highest parts of the microtopography was also noticed in several instances (Fig. 6.7f). The same type of wear has been observed in experiments involving

abrading a basalt implement with another basalt tool (Fig. 6.7c) or with sandstone (Fig. 6.7d) without using intermediary substances. Such features seem to be characteristic of abrasive contact.

Additional analyses carried out recently by L. Dubreuil and H. Plisson, using a metallographic microscope at higher magnification, indicate that more diagnostic use-wear patterns should be looked for in the intermediate areas between the topographic highs and the depths of the interstices. Essentially, the intermediate area is not affected by the abrasive wear of two stones grinding against each other, but is affected by the resources ground between the stones. Use-wear in the intermediate area has been observed on the experimental sandstone and basalt implements (see for example Figs. 6.7g and h). The intermediate area can be as small as part of a grain and is observable at the higher-power magnifications (200 power and higher) generally used for the analysis of flint tools.

These observations suggest the importance of using two levels of analysis: one focusing on the highest parts of the microtopography and the other on the intermediate areas. Undoubtedly, the use of high-power magnification (up to 500x) is required for analyzing micropolish located in the intermediate area. This also has implications for success at identifying the kinetics of the tools, because diagnostic micropolishes do not seem to develop at the same location on the microtopography for grinding implements and for abraders/polishers. The development of analytical methods using high-power magnification will help refine this framework.

Another important avenue of research is to better characterize the differences in micropolish morphology according to the type of resource processed. Descriptions of micropolish variation can be adapted from those used for flint implements (for example Plisson 1985) as suggested by Dubreuil (2002). For example, descriptions of micropolish on the surface should include distribution, density, disposition, dimension and microtopographic context. Furthermore, micropolish structure should be described in terms described previously such as morphology (in cross-section, rough, smooth or flat), texture (for example, the coalescence can be generally flat but grainy), contours (limits between areas of coalesced grains and distinct grains) and the presence of special features (striations or pits).

PHOTOGRAPHIC DOCUMENTATION OF WEAR TRACES

Good photographs are crucial for documentation and comparison of use-wear. Irregular topography and heterogeneous mineral composition pose serious difficulties for taking sharp photomicrographs that represent all the details observed during a dynamic microscopic analysis.

A technique commonly used for photomicrographs is to fix a compact digital camera to a low-power microscope using an intermediate optical adapter. However, because adapters are not universal, it is necessary to choose them in accordance with the specific optical formula of the microscope. A better solution involving less equipment is the single lens reflex (SLR) digital camera with a 50 mm macro lens. The images captured by such a camera/lens configuration are sharper because of a fundamentally better optical geometry and because of a large sensor that captures more subtle, visual information.

This system is particularly useful when the macro-lithic artefact can not be transported due to its weight or because it is part of the natural bedrock (e.g. grinding basins in Africa or India). For photographing permanent features, field equipment has been developed consisting of a light and a 30 cm high, metal tripod mounted with the digital camera/50 mm macro lens on a bellows. For illumination, a flash is placed horizontally on the rock next to the bellows, so that a very oblique light enhances the differences in surface microtopography. Because magnification is altered by adjusting the distance between the camera and the photographed surface and not by additional optical devices, the images are particularly clear for documentation and comparison of use-wear patterns.

These examples illustrate the fact that occasionally a simple, albeit infrequently used technique can provide a reliable way to document use-wear patterns observed at low-power magnification. Such techniques offer real alternatives to photography through a binocular stereomicroscope which is primarily designed for three-dimensional direct observation, but requires high-end optical formulas for producing sharp photographs (Plisson and Lompré 2008).

Lighting is another important parameter for good quality photographs of magnified three-dimensional surfaces. Light direction and diffusion must be manipulated to highlight the important topographic features where use-wear is visible, such as on the grain tops, in the intermediate areas and in the bottoms of the interstices. The best camera with poor lighting can not compete with a more common camera and optimal lighting. The control of light is quite problematic when the rock is partly translucent, as is common with sandstones and quartzites. At low-power magnification, the grainy structure gives enough contrast for general overview; however, as magnification increases, the glare off of micro crystals makes direct observation and photography unsatisfactory. Even with sharp objectives and polarizing filters, this cannot be improved without coating or casts.

The desire to have photomicrographs taken at high-power magnification presents different challenges than for low-power observations. For example, the artefacts are generally too large to be placed under conventional, high-power microscopes and the heterogeneous mineral

structure of the rocks makes it difficult to focus, because depth of field decreases with magnification. A solution has been found with the combination of two techniques from classic metallurgical and new digital technology. The use of acetate casts enhances contrast and the computer compilation of successive views increases the focused depth of field with high resolution objectives (Plisson and Lompré 2008). A high quality of image is easily produced that allows the perception of subtle use-wear details such as wear from handling and a better distinction of use-wear from different worked materials.

High-power photomicrographic views are standardized by the technology of the microscope which fixes the lighting, scale, resolution and centring of the image, thereby facilitating the exchange and comparison of data between specialists. With low-power photomicrographs, the frame is much more open with lighting, scale and centring not standardized and some features insufficiently documented such as the curvature of the working surfaces (Fig. 6.6a). Methodological standardization depends on our ability to reach a collective agreement. The equipment in use today varies widely, giving different types and qualities of images and making comparisons difficult. Until standardization is achieved, it is suggested that each microphoto-graph is tagged with reference to the type of microscope, level of magnification, lighting and camera used.

CONCLUSION

Because of the heterogeneous mineralogy of macro-lithic artefacts, the methods of use-wear analysis developed for fine-grained rocks such as flint needed to be reevaluated and adapted. Significant advances toward this end have been made during the last decade with research focusing primarily on abraders, polishers and grinding implements. Most scholars agree that low-power magnification is an appropriate approach for studying use-wear on macro-lithic tools. At this level, it is possible to see important modifications to surface topography, the grains, and the matrix. Yet, most scholars also recognize the necessity to develop analyses at higher power magnification for fine-tuning their interpretations.

The appeal of low-power magnification can be explained by the characteristics of abrading, polishing and grinding implements. Macro-lithic artefacts are generally used long enough for use-wear patterns to be visible without magnification. Topographic variation among working surfaces is partly related to the way in which the tools were used, but most importantly to the properties of the processed resources, be they abrasive, smooth, dry, oily, hard or soft. Despite the fact that macro-lithic tools are made from relatively coarse rock types, it is possible to distinguish the various techniques of tool production, manipulation and discard. As has been reiterated, a detailed description of the rock's petrographic properties and natural surfaces are crucial in order to account for the

impacts of wear mechanisms and to recognize manufacture and use-wear patterns.

The objective of this paper has been to outline the basis for a standardized procedure to describe wear patterns on macro-lithic artefacts. This should improve the comparability of analyses and help identify general trends in the formation of use-wear on abrasive tools made from particular rocks. Experiments, as well as analyses of archaeological and ethnographic materials, provide evidence that it is possible to distinguish abraders, polishers and grinding tools based on the analysis of their use-wear patterns. Furthermore, broad categories of resources can be distinguished that were ground between two stones. Generally, the grinding of minerals, various types of vegetal and animal resources can be recognized. It is hoped that additional experiments will help to refine the diagnostic criteria for a more precise differentiation of use-wear patterns on different rock types. High-power magnification analyses hold promise for achieving this goal.

The development of micropolish has been observed on macro-lithic tools by several scholars, demonstrating that minute traces of a tool's life history are also preserved. So far, significant advances have been made in the differentiation of micropolishes, in understanding their development and in defining the appropriate observation techniques. The criteria used for the interpretation of micropolish on flint implements, in our opinion, can not be used unconditionally for the study of macro-lithic tools. Detailed comparisons of experimental materials are required to characterize the variation of micropolish morphology according to not only the type of processed resources, but also to tool designs.

A final comment about future research on macro-lithic tools is toward broadening our tribological perspective. The development of tribological models of wear mechanisms would help us understand more precisely how wear is mapped not only onto working surfaces, but also onto other aspects of an artefact altered by maintenance, handling or ageing. Furthermore, we could begin to address issues such as the duration and intensity of use. Understanding these aspects, together with tool function and the spatial organisation of tool use and activity locations, are central to any sociologically oriented research. Macro-lithic artefacts allow us to identify (e.g. leather working) and often also to quantify (e.g. cereal production) many productive activities which otherwise are difficult to detect in the archaeological record. Moreover, their good preservation in settlements makes it possible to determine the spatial and temporal variability of these activities, thereby providing direct insight into the social organisation of production (questions relating to centralization of production and social division of labour) as well as into economic change or stability (questions relating to specialisation, technological innovation, productivity and occupation duration). Progress in functional analysis, together with careful collecting and recording of macro-lithic artefacts during

excavation, should help the archaeological community to see beyond the uninteresting *aspects* of macro-lithic artefacts and, following Semenov (1961/2005a), to recognize their historical *value*.

Fig. 6.6a. Experimental basalt slab (porphyritic basalt with plagioclase and olivine-iddingsite) used for 5 hours 30 minutes while grinding husked wheat with a basalt handstone worked in a reciprocal, rocking stroke. Direction of the stroke is perpendicular to the image length. At a macroscopic scale (level 1 observation), the most visible traces are: a) the concavity of the working surface which can be related to the rocking motion and to the fact that the width of the grinding-slab is larger than the length of the handstone (for a discussion see Adams 1993); b) a levelling of the highest surface topography is visible. The levelled areas are slightly convex in cross-section. The pits (the dark areas between the levelled areas) are from tool manufacture, where the surface was pecked with a quartz pebble hammerstone. Photograph by H. Plisson; SLR 5.3 Mo pixels digital camera with a 55mm macro objective.

Fig. 6.6b. Same experimental basalt slab as in Photograph 1. Observations at level 2 show that the microtopography is irregular in the levelled areas. This irregularity is the result of microfractures and grain removal (the dark spots) in the formation of use-wear. Photograph by H. Plisson; SLR 5.3 Mo pixels digital camera with a 55mm macro objective at 1:1.

Fig. 6.6c. Same experimental basalt slab as photographs 1 and 2, magnified (15x) with a metallographic microscope using a very low-power objective (1.5x/0.04) and a lateral external light. At the next level of observation (level 3), various types of alteration are observed on the phenocrysts in the levelled areas, such as edge rounding, slightly reflective polish and grain extraction, which are the most visible alterations on the photo, but also including microfractures and levelling the tops of grains. Photograph by L. Dubreuil; SLR 5.3 Mo pixels digital camera.

Fig. 6.6d. Grinding slab of granite (quartz, feldspar and a minor proportion of biotite and clorite) from Bellari, India that was used at least once a week for over 20 years, mainly for grinding rice (previously soaked in water) with a large gabbro handstone worked in a rolling motion across the slab. Direction of the movement is parallel to the length of the image. At a macroscopic scale (level 1 observation), most of the surface has been levelled, while at a smaller scale (level 2 observation), the topography is rough and irregular. The deep pits (areas in shadow) are from tool manufacture, where it was pecked with an iron tool. At the next level of observation (level 3), quartz grains appear covered by a dense pattern of fine pits and microfractures (V-shaped). Pitting and grain extraction is particularly intense on the biotite surfaces (black

minerals). Because of the numerous microfractures, the surface has a frosted appearance. Photograph by J.A. Soldevilla; 8.2 Mo pixels SLR digital camera mounted on bellow with 50 mm enlarger lens at 3.3:1; see detailed description in text.

Fig. 6.6e. Experimental slab in quartzitic sandstone used 4 hours 30 minutes for wheat grinding, magnified (5x) with a zoom stereoscopic microscope (0.5x lens). The levelling of the surface began with the highest asperities during the first stages of wear development. As wear progressed, the individual grains are levelled and no longer individually visible. The pits pecked during manufacture are still deep, because the topography is slightly, but not completely altered. Note the lack of sheen in the levelled areas. Photograph by C. Hamon; 1.4 Mo digital video camera.

Fig. 6.6f. A levelled surface of another experimental sandstone slab in compact sandstone used 13 hours 30 minutes for husked wheat grinding, magnified (5x) with a zoom stereoscopic microscope (0.5x lens). The levelling action has slowly “erased” the pits pecked during preparation of the working surface (centre of photograph). Note the difference in surface texture and topography between the polished and unpolished areas and the covering levelling of the surface. Photograph by C. Hamon; 1.4 Mo digital video camera.

Fig. 6.6g. Experimental conglomerate grinding slab used for processing 500gr of barley for 1 hour 30 minutes, magnified (10x) with a zoom stereoscopic microscope (1x lens). The basic mineralogical components are quartz and other rock fragments, mainly schist and limestone, all surrounded by cement. The wooden mano used against the slab was worked with a reciprocal stroke in a direction parallel to the length of the picture. At observation level 1, the irregularities (grain extractions and large pits) on the surfaces are the result of surface preparation with a gabbro hammerstone (worked for 15 minutes). The other visible wear pattern is the levelling of the topography. At observation level 2, the high parts of the microtopography are levelled, creating smooth areas. Wear penetrates into the interstices and affects the matrix too, which is visible with level 3 observations. Grains and the margins of the remaining pits have rounded edges. Only the harder quartz grains remain intact or covered by old fractures from surface preparation. Photograph by S. Delgado; 8.2 Mo pixels SLR digital camera.

Fig. 6.6h. Experimental metapsammite handstone used to process 500 g of barley for 1 hour 45 minutes on a grinding slab of micaschist with garnet, magnified (10x) with a zoom stereoscopic microscope (1x lens). Metapsammite is a quartz rich metamorphic rock which has the same mineralogical composition as sandstone. Some minerals were altered into micas. The movement of the mano is parallel to the short axis of the image. Level 1 observation shows a very smooth surface where grains have been levelled. At level 2, it is obvious that the extraction of

grains has formed linear traces (striations), indicating the direction of the stroke. The linear traces are irregularly scattered and intermittent across the surface. Levelling is so intense in some places that individual grains are not distinctive. At higher magnification (level 3 and 4, hardly visible in the image), all grains are covered with fractures and/or are levelled. Wear is not visible in the interstices. Photograph by S. Delgado; 8.2 Mo pixels SLR digital camera.

Fig. 6.7a. Experimental grinding slab of garnetiferous micaschist (c. 75% quartz; 20% muscovite; 5% garnet) used to grind barley for 20 hours with a wooden mano worked in a rocking reciprocal stroke. Prior to grinding, the surface had been prepared by regular pecking and smoothing with a gabbro handstone. The stroke direction is perpendicular to the maximal axis of the image. At a macroscopic scale (level 1 observation), most of the surface is obviously levelled. The deep pits (areas with shadows) are from surface preparation by pecking with a hammerstone. The levelled quartz grains in the topographic high areas have sheen and no striations. Several of the garnet grains are levelled, but their surfaces are more irregular because of pits and microfractures. Often (see centre and lower part of the image), the originally sharp crests of garnet grains are rounded. Grain-edge rounding is also visible on quartz grains in topographic low areas. The thin and softer mica (muscovite) plates are worn down on the topographic high areas, obliterating their naturally linear features and leaving behind small pits between the harder quartz and garnet grains. Mica is visually much more dominant within topographic low areas or on the natural surface of the rock. Functional analysis linked to an experimental programme has shown that the levelling and crushing of quartz and garnet grains originates from the preparation of the surface with a handstone. Grain-edge rounding of hard minerals and the wearing down of the mica is the result of grinding with wooden manos (for details see Risch 2002). Photograph by J.A. Soldevilla; 8.2 Mo pixels SLR digital camera mounted on bellow with 50 mm enlarger lens at 3.4:1 (see detailed description in text).

Fig. 6.7b. The natural surface of a garnetiferous micaschist. The linear features are the natural orientation of the mica (very shiny particles). Other rock components are not very distinctive. Photograph by J.A. Soldevilla; 8.2 Mo pixels SLR digital camera mounted on bellow with 50 mm enlarger lens at 3.4:1 (see detailed description in text).

Fig. 6.7c. Damage caused by stone-against-stone contact, shown with a positive cast of the surface of a basalt implement abraded by another basalt implement for 1 hour with a reciprocal stroke (cast made of semi-translucent resin from a dental elastomere negative and is of an area where use-wear is most visible macroscopically). The stroke direction is perpendicular to the image length. The working surface is magnified to what is considered high-power (100 X) (10x/0.25

objective) with a transmitted light microscope. The microtopography has been levelled in some areas (compare the left-top, unaffected area to the rest), but the surface remains rough and slightly shiny. The sheen seems to extend into the interstices. Photograph by L. Dubreuil; SLR camera with 25 iso black and white film.

Fig. 6.7d. Damage caused by stone-against-stone contact on the same basalt tool in Photograph 2c (but abraded with a sandstone implement), shown with a positive cast of the area abraded by a sandstone implement for 1 hour with a reciprocal stroke (cast made of semi-translucent resin from a dental elastomere negative and is of an area where use-wear is most visible macroscopically). The stroke direction is perpendicular to the image length. The working surface is magnified to what is considered high-power magnification (100 X) (10x/0.25 objective) with a transmitted light microscope. Macroscopically, the abrasion on the slab surface seems more intense with a sandstone implement than with one of basalt (compare to Fig. 6.7c). At high-power magnification, highly reflective, yet striated shiny areas are most visible on the highest microtopography. Photograph by L. Dubreuil; SLR camera with 25 iso black and white film.

Fig. 6.7e. Positive cast of a basalt grinding slab surface used to process barley for 5 hours 30 minutes with a basalt handstone in a reciprocal, rocking stroke (cast made of semi-translucent resin from a dental elastomere negative and is of an area where use-wear is more visible macroscopically). The stroke direction is perpendicular to image length. The working surface is magnified to what is considered high-power magnification (100 X) (10x/0.25 objective) with a transmitted light microscope. The use-wear observed at high-power magnification is similar to that in Fig. 6.7c in that the microtopography has been levelled, yet the shiny areas are only slightly shiny, remaining rough in places. The sheen on the slab surface has also spread to the interstices. Photograph by L. Dubreuil; SLR camera with 25 iso black and white film.

Fig. 6.7f. Positive cast of the surface of a basalt grinding slab used to process fava beans for 5 hours 30 minutes with a basalt handstone in a reciprocal, rocking motion (cast made of semi-translucent resin from a dental elastomere negative and is of an area where use-wear is more visible macroscopically). The stroke direction is perpendicular to image length. The working surface is magnified to what is considered high-power magnification (100 X) (10x/0.25 objective) with a transmitted light microscope. The use-wear resulting from fava bean grinding is similar to that on the basalt slab abraded by a sandstone implement (Fig. 6.7d) with striated shiny areas on the highest part of the microtopography. Photograph by L. Dubreuil; SLR camera with 25 iso black and white film.

Fig. 6.7g. Micropolish on an intermediate area of a sandstone grinding implement (same as shown at lower magnification on Fig. 6.6e) used to process wheat. Stroke

direction is perpendicular to the image length. The top of the quartz crystal is abraded and a polish extends down the sides, where the contact has been softer. Photograph by H. Plisson; digitally compiled shots taken at 500X (50x/0.50 objective) from an acetate print, with a 5.3 Mo pixels SLR digital camera on an episcopic DIC bright field microscope.

Fig. 6.7h. Micropolish on an intermediate area of a basalt grinding implement (same as shown at lower magnification on Figs. 6.6a, b, c) used to process wheat. Stroke direction is perpendicular to the image length. The crystal is smooth and striated, with polish discernible by the particular undulation of its coalescence on the crystal surface. Photograph by H. Plisson; digitally compiled shots taken at 500X (50x/0.50 objective) from an acetate print, with a 5.3 Mo pixels SLR digital camera on an episcopic DIC bright field microscope.

Note of caution: magnification is not calculated the same for a microscope and for a SLR camera with a macro lens. With the camera alone, it is the size of the subject on the film (or sensor) that is measured. With the binocular microscope, it is a theoretical calculation (objective power X eyepiece power) given for a direct observation, that is far from the final size of the subject on the film or camera sensor (generally 4 or 5 times less magnified). In any case, the resolution is given by the objective.

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Appendix 1. Glossary of the descriptive terms in English, French and Spanish

ENGLISH	FRANÇAIS	ESPAÑOL
abrasive wear	abrasion	desgaste abrasivo
asperities	aspérités	asperezas
adhesive wear	usure adhésive	desgaste adhesivo
chipping and crushing marks/microfractures	microfractures	microfracturas
cracks	fissures	fisuras
fabric (of rocks)	structure ou fabrique	fábrica, estructura
fatigue wear	fatigue	desgaste de fatiga
fracture (conchoidal, step)	fracture (conchoïdale, scalariforme)	fractura (concoïdal, escalonada)
grain edge rounding	grain émousé	redondeamiento de grano
grains extraction	arrachement de grains	extracción de grano
grain levelling	arusement	nivelación
grain surface modification	altération des grains	alteración de los granos
granularity	granulométrie	granulometría
interstices	anfractuosités	intersticios
levelled relief	relief arasé	superficie nivelada
levelling	arusement	nivelación
matrix, cement	matrice, ciment	matriz, cemento
micro-topography	micro-relief	microtopografía
pit	fosse	fosilla
polish/ lustrous sheen /shiny surface / sheen	lustre, surface réfléchive	pulido, lustre
residue	résidu	residuo
rock grain	grain composant la roche	grano de la roca
scratches	rayures	rascadas
striations	stries	estrías
texture (of rocks)	texture	textura
topography	relief, topographie	topografía
tribochemical wear	usure tribo-chimique	desgaste triboquímico
use surface or active surface	surface d'usure, surface active	superficie de uso, superficie activa

Appendix 2. List and references of experiments combined with functional analysis of macro-lithic tools carried out by different authors.

Activity carried out	Material of the active tool	Material of the passive tool	Reference
<i>Grinding and pounding implement –maize</i>			
Grinding maize kernels, dried	Medium-grained quartzite	Granitic	Adams 1999
Grinding maize kernels, dried	Medium-grained quartzite	Sandstone	Adams 1999
Grinding maize kernels, dried	Vesicular Basalt	Vesicular Basalt	Adams 1999
Grinding maize kernels, dried	Vesicular Basalt	Vesicular Basalt	Adams 1999
Grinding maize kernels, dried	Medium-grained quartzite	Medium-grained quartzite	Adams 1989
Grinding maize kernels, dried	Sandstone	Sandstone	Wright 1993
<i>Grinding and pounding implement – cereals</i>			
Grinding wheat	Garnetiferous micaschist & Conglomerate	Gabbro, Garnetiferous micaschist	Menasanch <i>et al.</i> 2002; Risch 2002
Grinding wheat	Garnetiferous micaschist & Conglomerate	Wood (olive, oak, almond)	Menasanch <i>et al.</i> 2002; Risch 2002
Grinding wheat	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding wheat	Compact sandstone	Compact sandstone	Hamon 2006
Grinding wheat	Compact sandstone	Compact sandstone	Hamon & Plisson 2008
Pounding wheat	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil, in prep.
Grinding barley	Garnetiferous micaschist & Conglomerate	Gabbro, Garnetiferous micaschist	Menasanch <i>et al.</i> 2002; Risch 2002
Grinding barley	Garnetiferous micaschist & Conglomerate	Wood (olive, oak, almond)	Menasanch <i>et al.</i> 2002; Risch 2002
Grinding barley	Garnetiferous micaschist & Conglomerate	Wood (olive)	Delgado Raack 2008
Grinding barley	Garnetiferous micaschist & Conglomerate	Metapsammite	Delgado Raack 2008
Grinding barley	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding barley	Compact sandstone	Compact sandstone	Hamon 2006
Grinding millet	Sandstone	Fine grained Sandstone	Zurro <i>et al.</i> 2005
Spelt grinding	Compact sandstone	Compact sandstone	Hamon 2006
<i>Grinding and pounding implement – oily vegetal matter</i>			
Grinding sunflower seeds	Medium-grained quartzite	Granitic	Adams 1999
Grinding sunflower seeds	Medium-grained quartzite	Sandstone	Adams 1999
Grinding sunflower seeds	Vesicular Basalt	Vesicular Basalt	Adams 1999
Grinding amaranth seeds	Medium-grained quartzite	Granitic	Adams 1999
Grinding amaranth seeds	Medium-grained quartzite	Sandstone	Adams 1999
Grinding amaranth seeds	Vesicular Basalt	Vesicular Basalt	Adams 1999
Grinding sunflower seeds	Medium-grained quartzite	Medium-grained quartzite	Adams 1989
Grinding nuts	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding acorns	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding mustard seeds	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002

Activity carried out	Material of the active tool	Material of the passive tool	Reference
Pounding acorns	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil, in prep.
Acorn grinding	Quartzitic sandstone	Quartzitic sandstone	Hamon & Plisson 2008
<i>Grinding and pounding implement – legumes</i>			
Grinding fenugreek	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding feva beans	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding lentils	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Pounding lentils	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil, in prep.
<i>Grinding and pounding implement – aromatic plants</i>			
Pounding rosemary	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil, in prep.
<i>Grinding and pounding implement – animal flesh</i>			
Grinding dried meat	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Pounding dried meat	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil, in prep.
Grinding dried fish	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Pounding pork meat	Quartzitic sandstone	Compact sandstone	Hamon & Plisson 2008
Crushing fresh bone, cartilage and marrow	Compact altered sandstone	quartzitic sandstone	Hamon & Plisson 2008
Crushing beef bone (boiled and dried)	Quartzitic sandstone	Calcareous sandstone	Hamon & Plisson 2008
<i>Grinding – pounding mineral matter</i>			
Pottery Clay Grinding	Medium-grained quartzite	Medium-grained quartzite	Adams 1989
Pot Sherd Grinding	Medium-grained quartzite	Medium-grained quartzite	Adams 1989
Temper grinding (chamotte, cooked bone and flint)	Compact sandstone	Compact sandstone	Hamon 2006
Grinding calcite	Compact sandstone	Calcareous sandstone	Hamon & Plisson 2008
Clay grinding and mixing	Compact sandstone	Compact sandstone	Hamon 2006
Grinding Ochre	Cryptocrystalline basalt	Cryptocrystalline basalt	Dubreuil 2002
Grinding Ochre	Compact sandstone	Compact sandstone	Hamon 2006
Pigment Processing	Medium-grained sandstone	Medium-grained sandstone	Logan and Fratt 1993
<i>Abrading – working bone and antler</i>			
Bone Sharpening	Sheep metapodial	Fine-grained Sandstone	Adams 1989a, 1989b, 1993
Bone tool polishing		Quartzitic sandstone	Hamon 2006
Bone abrasion		Cryptocrystalline basalt	Dubreuil 2002
Antler tool polishing	Quartzitic sandstone	Quartzitic sandstone	Hamon 2006
<i>Abrading – working wood</i>			
Wood Smoothing	Greasewood	Medium-grained quartzite	Adams 1989a, 1989b, 1993
Wood abrasion		Cryptocrystalline basalt	Dubreuil 2002
Wood abrasion		Quartzitic sandstone	Hamon 2006

Activity carried out	Material of the active tool	Material of the passive tool	Reference
<i>Abrading – working mineral matter</i>			
Stone against stone, abrasion	Cryptocrystalline basalts and fine-grained sandstone	Cryptocrystalline basalt	Dubreuil 2002
Clay pots modeling	Quartzitic sandstone	Quartzitic sandstone	Hamon 2006
Sandstone shaping	Compact sandstone	Compact sandstone	Hamon 2006
Schist bracelet polishing		Quartzitic sandstone	Hamon 2006
Limestone pearl polishing		Quartzitic sandstone	Hamon 2006
Ochre abrasion		Cryptocrystalline basalt	Dubreuil 2002
Flint axe polishing		Quartzitic sandstone	Hamon 2006
<i>Abrading – working shell</i>			
Shell Working	Medium-grained quartzite	Olivella shells	Adams 1989a, 1989b, 1993
Shell abrasion		Cryptocrystalline basalt	Dubreuil 2002
Shell polishing		Compact sandstone	Hamon 2006
<i>Abrader – polisher – Hide processing</i>			
Hide Processing	Medium-grained quartzite	Medium-grained Quartzite	Adams 1988, 1993
Hide processing	Cryptocrystalline basalt		Dubreuil 2002
Hide processing	Compact sandstone		Hamon 2006
Hide processing	Quartzitic sandstone		Hamon & Plisson 2008
Hide processing	Sandstone	sandstone	Gonzalez <i>et al.</i> 2002
<i>Abrader – polisher – Metal processing</i>			
Metal forging	Copper	Gabbro	Delgado & Risch 2006
Metal sharpening	Iron	Quartzitic sandstone	Delgado & Risch 2006
<i>Other</i>			
Axe Use	Silicified Siltstone	Wood and Sediment	Mills 1993