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A Methodological Research

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Functional Studies of Prehistoric Grindingstones: a Methodological Research[1]

Grindstones differ from other stone tools because they represent, to use Leroi-Gourhan's[2] terms, a specific mode of action on material, aimed at crushing, pulverizing, grinding, or more generally reducing into particles or powder. This category of tools basically covers lower grindingstones, handstones, pestles and mortars. I will use this definition rather than following Anglo-Saxon scholars, who tend to include these tools in a broader category (ground stone tools) comprising all the objects transformed by pecking, hammering, abrasion and polishing.

Although grinding technology appears in early prehistory[3], its development is quite late and seems to be associated with contexts of transition from hunter-gatherer to farming cultures. The attested morphological evolution and diversity of shapes raise the question of the function of these tools. Some have suggested that grinding first developed as part of work on pigments, and was then used to transform vegetable matter. In the Middle East, the rise and diversification of this technology during the Natufian is considered proof of extensive use of plants at periods predating the establishment of the first farming communities. Analyses of grinding tools are often restricted to typological classifications. The need for a functional analysis has however long been stressed as a means of validating or refining the hypotheses mentioned above. Beyond determining the nature of the

[1]This research was supported by the TMR and "Aires Culturelles" programs of the EU, a Lavoisier grant from the Foreign Ministry and the CRFJ "researcher-month".

[2] Leroi-Gourhan, A. *L'Homme et la matière*. Paris : Albin Michel, 1971 (2nd), 348 p.

[3]In particular : De Beaune S. Essai d'une classification typologique des galets et plaquettes utilisés au Paléolithique. *Gallia Préhistoire*, 1989, t. 31, p. 27-64 ; Nonflint Stone Tools of the Early Upper Paleolithic. In Knetch, H., Pike-Tay, A. et White, R. (Eds.) *Before Lascaux*. Florida : CRC Press. 1993 : p.163-191 ; Kraybill, N. Pre-agricultural tools for the preparation of foods in the Old World. In Reed, C. (Ed.) *Origins of Agriculture*. The Hague : Mouton, 1977. p.485-521 ; Wright, I.K. The origins and development of ground stone assemblages in late Pleistocene Southwest Asia. *Paléorient*, 1991, v. 17/2, p. 19-41 ; *Ground Stone Assemblages Variation and Subsistence Strategies in the Levant, 22 000 - 5 500 BP*. Department of Anthropology, Yale University, 1992. 417 p. Ph.D ; Ground-Stone Tools and Hunter-Gatherer Subsistence in Southwest Asia : Implications for the Transition to Farming. *American Antiquity*, 1994, v. 59(2), p. 238-263.

processed material, the interest also lies in understanding choice of raw material, changes in tool shape, processing techniques, and "chaînes opératoires".

The aim of this paper is to give an overview of the functional approaches proposed in recent years, and focuses on the methodological aspects. The potential of Use-Wear analysis in particular will be illustrated through experimental results obtained by the author within the framework of ongoing research on Natufian grinding stones.

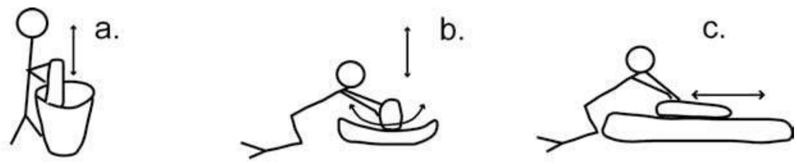
Functional studies of grinding stone tools: an overview

Before focusing on the methodologies themselves, we should first detail the questions functional analyses need to define as well as the data that can be used to determine the function of a tool.

What does it mean to diagnose a function?

Adopting Sigaut's[4] definition, and Leroi-Gourhan (op.cit) percussion movement classification, determining the function of a grinding implement comes down to responding to a series of questions:

Determining how the tool worked: one of the particularities of grinding tools is the morphology of the working parts, which are in general broad surfaces. These artifacts are assigned, according to Leroi-Gourhan's classification (op.cit.) to the category of tools that operate by "diffuse" percussion (i.e.,the working part is a surface). The way the tool was used can be characterized by: - the active or passive nature of the tool; the mode of percussion: pounding (lancée), grinding (posée), or a combination of both, - the direction of motion and incidence on the material: back-and-forth, circular, random, oblique, perpendicular or parallel. In addition, the way the tool is held (one hand or two hands), the position of the body, possible use of complementary instruments affecting means of grasping, holding of the lower tool, and the gathering of the finished product are also critical factors.



Examples of percussion modes : a. pounding, perpendicular direction; b pounding/ perpendicular and grinding / circular; c. grinding / back and forth.

[4] Sigaut, F. Un couteau ne sert pas à couper mais en coupant. Structure, fonctionnement et fonction dans l'analyse des objets. In *25 ans d'études technologiques en Préhistoire. Bilan et perspectives. Actes des rencontres 18-19-20 Octobre 1990.* Juan-les-Pins : APDCA, 1991. p.21-34.

Determining the type of material processed: apart from identifying the material itself, and the specific or multifunctional use of the tool, the preparatory work on the material before processing needs to be defined, and whether an additive was used.

Determining the function of the tool: according to Sigaut (op. cit) this not only requires defining its action and the material processed but also the socioeconomic context of use (when, by whom, for whom and why). We also need an understanding of the full cycle of processing of the material, and to determine at which point in this process the grinding tool was used.

Functional analyses applied to grinding tools have focused primarily on determining their motion and the type of material worked.

Archaeological data and methodologies developed

Various types of data relating to external and internal tool characteristics can be used to diagnose its function:

External characteristics: spatial distribution of archeological remains can provide information on the context of use (position of a tool during its use, use of complementary instruments, social context) as well as the history of the object (reuse and recycling).

Internal characteristics: raw material, morphology, use wear and residue are generally studied to identify tool motion and the material worked.

Recent methodological research emphasizes the need to take all these data into account to formulate a functional hypothesis. I turn first to a study of the latter characteristics by presenting a rapid overview of approaches proposed. Use-wear analysis will be explored more fully in the second section.

The Raw Material

The properties of the raw material are crucial to the way a grinding tool works. Shoumacker[5] provides compelling evidence in her study of the manufacture of industrial grindingstones. She shows that characteristics of the raw material have a major impact on the efficiency of the tool; i.e the quality of the finished product, the rate at which the tool wears out and the frequency of resharpening. In an industrial context, these characteristics mainly include the type of abrasive, agglomerate, the amount of tamping and the "grade". For paired tools, efficiency is also linked to the interaction between the two stones. In a functional perspective, the study of raw materials provides information for determining the type of end product (for instance, fine polishing, a more or less fine ground), the pollution of the ground material, the frequency of tool resharpening, and tool management in general. However, the choice of raw materials should be considered as a compromise involving criteria not only related to the grinding process, but also to

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[5] Shoumacker, A. Apports de la technologie et de la pétrographie pour la caractérisation des meules. In Anderson, P.C., Beyries, S., Otte, M., and Plisson, H. (Eds.) *Traces et fonction, les gestes retrouvés. Actes du colloque international de Liège, 8-9-10 décembre 1990.* 1993 : p.165-176.

accessibility, quality of blocks, how easily they can be shaped, tools available for working stone and/or esthetic considerations.

Understanding choice of raw material in archeological contexts, and defining its functional meaning, hence implies assessing the potential sources of raw material, their availability, accessibility, knapping abilities, defining the properties of the stones and understanding their behavior during the grinding process.This approach has been put forward by Shoumacker (op.cit) and H. Procopiou.[6] It is based on surveys, petrographic analyses and experiments.

Morphological studies:

Morphological studies are probably the oldest approaches and remain the most common ones today. They generally use typological classifications or detailed descriptions according to a variety of characteristics (for the latter see for instance Nierle.[7]). When adopting a functional perspective, these studies relate observed morphological variations (between two categories of tools; i.e mortar / grindingstone or within a category) to differences in motion or in worked material. They rely on what I view as key features: tool morphology, type and distribution of traces which allow, at least partially, to characterize the way the tool worked. But to what extent do morphological variations really express differences in motions, type of materials processed, or, as proposed by some scholars changes in tool morphology during use?

Ethnological or ethno-archaeological studies can help answer these questions. By comparing these data, no systematic associations between a particular type of tool (or morphology) and a material worked (for instance grindingstone and cereal processing) have been found. Rather, the morphological differences between categories of tools or within a given category only seem to be relevant in a specific assemblage, i.e the "grinding toolkit" of a human group. For instance, Gould et al.[8] describing the Australian Western Desert Aborigines' grinding tool assemblages, point out that each specific use of handstones produces characteristic use-wear identifiable at a macroscopic level. Different motions employed to process the various materials lead to the formation of a different working surface morphology. According to V. Roux[9], for the Tichitt grindstone

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[6] Procopiou, H. *L'outillage de mouture et de broyage en Crète Minoenne*. Université de Paris I - Sorbonne, 1998. Thèse de Doctorat ; Procopiou, H., Jautee, E., Vargiolu, R., et al. Petrographic and use-wear analysis of a quern from Syvritos Kephala. In Facchini, F., Palma di Cesnola, A., Piperno, M., et al. (Eds.) *Actes du XIIème Congrés de l'UISPP, Forli 8-14 septembre 1996. Workshop 17 : Analyse fonctionnelle des pièces lithiques : situation actuelle de la recherche*, *Tome II, Vol 6*. Forli, 1998. p.1183-1192

[7] Nierle, M.C. Mureybet et Cheik Hassan (Syrie) : Outillage de mouture et de broyage (9e et 8e millénaires) *Cahiers de l'Euphrate*, 1983, t. 3, p. 177-216.

[8] Gould, R.A., Koster, D.A. et Sontz, A.H. The Lithic Assemblage of the Western Desert Aborigines of Australia. *American Antiquity*, 1971, v. 36, n°2, p. 149-169.

[9] Roux, V. *Le matériel de broyage. Etude ethnoarchéologique à Tichitt (R.I Mauritanie), vol. "mémoire" n°58.* : Editions Recherche sur les Civilisations, 1986.

assemblage (Mauritania), several criteria serve to differentiate grindingstones, handstones and grinders used to make flour, crush date nuts, pulverize tobacco and incense as well as for processing hides and vegetable matter used in basket making: overall morphology, sizes, morphology or characteristics of the working surfaces (for instance traces of resharpening). To sum up, the various materials processed by a given human group may require different modes of grinding and the tool can be adapted to carry out this work in different ways as evidenced by the choice of raw material, its morphology, and the motion. Thus, morphological variations observed within a given archeological assemblage can reflect the presence of tools used for different purposes, suggesting work on different types of material. However, the impact of several factors must also be assessed in order to understand morphological variations observed in the archaeological record: the raw material availability, shaping techniques, use/reshapening cycle, recycling, post-depositional processes.

The approach proposed here consists of characterizing objects by morphological criteria, reconstructing their taphonomic history and then determining which morphological variations are relevant with regard to the way the object was used. This analysis serves to formulate hypotheses as to the presence of tools with different functions, which can then be tested through use-wear or residue analyses.

The Use-Wear Approach

Current research

Only a few use-wear studies have been carried out for grinding stone material. They benefit from previous methodologies and techniques developed for use-wear analyses of cutting edges. Like them, they are based on 'actualism', using natural or experimental reference collections, and on observation at various magnifications.

The reference collections cover grinding, abrasion and polishing processes using raw blocks or transformed tools and the shaping of stones by polishing, hammering or pecking. Different kinds of sedimentary, metamorphic and basalt stones have been used. Two types of protocols can be differentiated; either different stones are used for the same process or a specific stone is used for processing different materials[10]. To the best of my knowledge, J. Adams has

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[10] This overview is based on the following works :

Adams, L.J. Use-Wear Analysis on Manos and Hide-Processing Stones. *Journal of Field Archaeology*, 1988, v. 15, n.3, p. 307-315 ; Adams, L.J. Methods for improving ground stone artefact analysis : experiments in mano wear patterns. In Amick, D.S. et Maudlin, R.P. (Eds.) *Experiments in Lithic Technology*. :, 1989. p.259-274 ; De Beaune, S. Approches expérimentale de techniques paléolithiques de façonnage des roches peu aptes à la taille. *Paléo*, t. 5, 1993, p. 155-174.

Fullagar, R. and Field, J. 1997. Pleistocene seed-grinding implements from the Australian arid zone. *Antiquity*, 1997, v. 71, p. 300-307 ; Hamon, C. *De l'utilisation des outils de mouture, broyage et polissage au Néolithique en Bassin Parisien*. Université de Paris I, 56p. mémoire de developed the most elaborate reference collection for grinding implements using sandstone tools. Different observation techniques are used: macroscopic, low and high magnifications, image analysis and rugosimetry. The technique used affects the way traces are defined.

To summarize these findings, the traces produced in the grinding process can be characterized as follows. Use leads to the formation of flat areas or plateaus on the asperities of the surface (Procopiou *et al*, op.cit) resulting from the leveling of areas of higher elevation. According to Adam's experiments, use may also lead to the flattening of the entire surface. These two studies view this surface modification mainly as the result of a mechanical process. This is congruent with Mansur et alii's work (op.cit) on polishing. Researchers using low magnification tend to describe the observed use-wear according to the alteration of the grains that compose the stone. This procedure, used in particular by Adams, indicates that the most relevant criteria to describe the observed differences are the type of grain alterations (crushing, leveling, rounded), their spread and distribution on the surface. Adams shows that low power magnification observation on sandstone can differentiate polishing/ abrasion from the grinding process as well as the types of worked material as a function of their general properties (abrasive, presence of fatty substances). Several researchers have pointed out that the mineralogical composition of the stone influences the development of use-wear. Some minerals, in particular quartz, develop more pronounced use-wear than others. Mansur and Fullagar and Field (op.cit) note that traces are less visible or absent on certain raw materials. Their studies also indicate that micro-wear polish can be identified. To date, there are few quantitative analyses of wear. Gray levels and luminosity graphs produced by Mansur and Serhnisky (op. cit) can, in my opinion, complement photographic illustrations of use wear in a compelling manner. At present, they do not really serve to quantify wear. Rugosimetry studies carried out by H. Procopiou and her team are more advanced in this field. For the time being, they have not been applied for identifying worked materials; however the author intends to test laser rugosimetry for the study of micropolish. A chemical characterization of microwear, as developed for flint tools, has not yet been attempted. However two studies associate use-wear and residue analyses .

DEA, 2000 ; Ibanez Estevez, J.J. and Gonzalez Urquijo, J.E. Utilización de algunos cantos rodados en Laminak II. *Kobie (Serie Paleantropología), Bilbao*, 1994, v. XXI, p. 131-155 ; Mansur, M.E. Functional analysis of polished stone-tools : some considerations about the nature of polishing. In Bustillo, M.A. et Ramos Millan, A. (Eds.) *Siliceous Rocks and Culture*. Madrid : CSIC et Université de Grenade, 1997. p.465-486 ; Mansur, M.E. et Srehnisky, R.A. El Alisador basaltico de Shamakush I : microrastos de uso mediante el analisis de imagines digitalizadas. *Relaciones, Revista de la Sociedad de Antropología*, sous presse, v. XXI, p.; Procopiou, H. 1998.*op. cit* note n°7 ; Procopiou, H., Jautee, E., Vargiolu, R., et al. 1998. *op.cit* note n°7 ; Procopiou, H. and Formenti, F. La chromotographie en phase gazeuse. Meule et molettes : à quoi ont elles servi ? *Les dossiers d'archéologie*, 2000, t. 253, p. 70-73

Reference collection developed for Natufian grinding tool use-wear analysis

Three Natufian assemblages were studied in order to test the hypothesis of preferential use of grindstones to process vegetable matter. This study combines several approaches cited above and mainly focuses on use wear analysis. For this purpose, I developed an experimental reference collection. The clarification of experimental protocols is often lacking and I would like to stress its importance for the development of complementary studies and future critical analysis.

Creation of a reference collection

Various parameters can affect the formation of use-wear, the main ones being: the raw material of the tools, the presence or absence of shaping and the type of shaping, the kind of material processed, the preparatory work on the material before processing and the eventual use of an additive, the motion, pressure, and the duration of use.

In addition, the environmental conditions; i.e. the place (laboratory or field), the temperature and relative humidity, can also affect development of wear.

A rigorous approach would require a comparative analysis of the impact of each of these factors by varying them separately. Such an exhaustive reference collection represents several years of team-work. Choices had to be made, and I opted to test the impact of processed material on use-wear. I worked exclusively on basalt, since this rock is one of the best represented in the assemblages studied. I mainly used "flat grindingstones" such as handstones and lower grindingstones. Despite these restrictions, the cases to be tested remain numerous. I will discuss each of the factors mentioned above to justify the variables that have been taken into account.

Raw material: there is high variability in basalt rocks. Study of archaeological series indicates use of crypto-crystalline basalt composed of crystals that can be observed under low magnification. Within this class, the variability remains high in terms of mineral composition, cohesion of crystals and porosity. I defined different categories of basalt within archaeological assemblages and oriented the experimental protocol partially to test variations of use wear as a function of these categories.

Shaping: the archeological material presents high morphological variability. I did not try to reproduce these shapes but rather the preparatory work of the surface before use (hammering).

Motion: most experiments deal with paired tools (handstone and grindingstone) and keep motion and mode of grasping constant (i.e. grinding back and forth, preceded by a few pounding movements where the active tool is held in one hand, the passive part held on the lap). In several cases the impact of a change in the direction of the motion was tested. In addition, work with a single tool (i.e. abrasion/polishing with back and forth motion) was also performed.

Worked material: the aim was to test a broad range of mineral, vegetable and animal matter. A list of potential materials was drawn up from archaeological, paleo-environmental, and ethnological data.

Duration of use: grinding stones are often used over a long period of time, and handed down from generation to generation. If the focus is on wear surfaces, resharpening can be defined as a return to the original surface. Ideally, the experiment should attempt to reach complete wear- out of the working surface, requiring resharpening. This stage can be defined according to observations made on archaeological artifacts and experiments. Even after the longest performed working time, 5 1/2 hours, this stage was not reached. Archaeological collections are not entirely composed of worn-out tools or resharpened ones. Use-wear was therefore documented at different stages.

The experiments carried out can be divided into four different groups. Their purpose and protocols are presented below.

Experiment 1: stone on stone contact

Purpose : characterize traces resulting from stone on stone contact without an intermediary substance

Experimental material and protocol: a lower block was divided into parallel strips corresponding to different zones. On each of these zones, a different upper block of basalt was used in grinding in a back-and-forth motion. There was no pre-shaping of the blocks. I also used an upper block of sandstone to compare use wear produced by this material with that made by basalt. The upper and lower surfaces were observed at different stages of work: 10 min, 20 min, 40 min and 1 hour.

Experiment 2: shaping surfaces

Purpose: describe surface resulting from the pecking and hammering

Experimental material and protocol: the working surface of tools used to grind various materials was first shaped - for the lower grindingstones, the neocortex was removed, a concave part was shaped to maintain the ground material and eliminate surface irregularities; - for the upper tools, the neo-cortex was removed,

Type of worked material	*Number of experiments and working time*	*Comments, variations tested*
Minerals		
Grinding of ochre	Paired tools, maximum time 3.30 hours	
Plants		
Wheat	Conducted on 3 pairs of tools, maximum grinding time 5.30 hours	Variation in type of basalt
Husking and grinding of wild barley	Conducted on 2 pairs of tools, maximum grinding time 2 hours	Husking, grinding with and without water
Grinding acorns	Conducted on 3 pairs of tools; maximum time 5.30 hours	Grinding on fresh and dried material
Grinding nuts	Conducted on paired tools, max time 3.30 hours	
Grinding mustard seeds	Conducted on paired tools, max	Ground after drying

	time 5.30 hours	
Grinding of fenugreek	On paired tools, max time 5.30 hours	Ground after drying
Grinding feva beans	On paired tools, max time 5.30 hours	Ground after drying
Animal matter		
Grinding of dried meat	On paired tools, max time 5 and _ hours	Test of pounding meat
Grinding of dried fish	On two pairs of tools, max time 5 and _ hours	Grinding of boneless more or less fatty fish

Table 1

Type of worked material	*Number of experiments and working time*	*Comments, variations tested*
Minerals		
Abrasion of ochre	One experiment, abrasion for 1 hour	
Abrasion of shells	One experiment, 3 and 1/2 hours	Surface abrasion and perforation
Plants		
Work on wood	One experiment, 5 and 1/2 hours	Abrasion of the surface, shaping into a point
Animal matter		
Work on bone	Two experiments, max time 3 hours	Work on dry and fresh bone, abrasion of surface and shaping into a point
Work on hide	Two experiments, max time 3 hours	Cleaning and softening with and without water

Table2

the surface was regularized and the working part was shaped to provide maximal contact with the passive tool. In addition, a motion which combines pecking and abrasion in varying order was also tested. Hammerstones of different rocks including basalt, quartz and flint were used. A total of 17 blocks or zones were examined in detail and submitted to a comparative analysis. Fifteen others were studied more rapidly in order to verify the results.

Experiment 3: grinding various types of material with handstone and grinding stone

Purpose: test the impact of various worked materials on use wear.

Experimental material and protocol: experiment 1 showed a low variability of use wear depending on the type of basalt; therefore the raw material parameter was not systematically taken into account. *(Table 1)*

Experiment 4: work with a single tool (Table 2)

Purpose: extend the range of material processed and test whether there are significant differences in use wear between paired tools and a single tool.

Experimental material and protocol: most of the blocks were used as a lower tool, the material was rubbed by a back and forth movement. Only work on hide was carried out using an upper tool, the hide was held on a wooden plank.

Main results

Surface analysis procedure

I mainly worked using a low power microscope (magnification up to 80x). Examination of archaeological artifacts and preliminary observations of experimental materials prompted me to use the criteria proposed by J. Adams for the surface description which I completed by data descriptions from other studies (in particular H. Procopiou).

The principles and the descriptive terms used in this study are presented below.

Macroscopic observation serves to describe the overall topography of the working surface: this refers to the presence or absence of a contrast between interstices and "leveled off" asperities (i.e regularized areas known as plateaus when they have a flat morphology in profile, "rounded out wear areas" when they are not entirely flat). The surface can also present an all-over regularization without being organized into peaks/hollows. Striations and shiny surfaces visible to the naked eye are also described.

With the low power microscope, the description of the micro-topography includes identification of altered zones, their morphology and distribution. These altered zones are characterized on the basis of grain surface modifications described by Adams: leveling of grain, rounded or sharp edges, chipping or crushing marks. Another criterion used by Adams to describe wear is the presence or absence of interstices between grains. In this paper, I will use the term "homogeneous zones" when the grains do not show interstices and form uniform surfaces. Areas of leveling without interstices refer to cases where grains are still recognizable. In the opposite case, the grains are said to be "dug out" or "in relief". For each type of alteration, its extent on the grain itself is defined (for instance, a rounded part can be overall or only developed on the top of the grains) as well as its distribution on the surface in general. These observations also aim to describe the types of striations and distribution of sheens. The description of striations refers basically to the length, depth, orientation, presence singly or in groups, and distribution.

Results of low power microscope analyses

The experimental protocols serves to document several points concerning the various factors involved in the wear formation process:

- ❖ impact of the raw material
- ❖ impact of shaping techniques
- ❖ tool use: paired or singly
- ❖ impact of the worked material
- ❖ motion

The fourth point was investigated more fully and will be developed in greater detail.

Tools working as a pair: examination of the natural surfaces, experiments conducted on rubbing stone against stone and study of pecked surfaces serve as a reference to assess the role of the worked material in the use-wear formation. Although conducted for relatively short periods of time, these experiments indicate that direct contact of stone on stone is highly abrasive and creates crushing and breaking off of the grains as well as the formation of small wear zones on the asperities, sometimes visible to the naked eye, although better under the low power microscope. They form elevated homogeneous zones, which are generally not smooth but rather are irregular, dark in color, and bearing striations (Plate 1, a and b). These alterations are recurrent and appear to be diagnostic of stone-stone contact as they were only produced in this specific context.

When material is placed between the two stones, the use-wears are different both at the macroscopic level as well as under low power magnification. The areas of leveling on the asperities are in general more pronounced and larger, the grains show a greater range of alterations including, among others but not systematically, the development of homogeneous zones different from the ones produced by stone-to-stone contact.

Turning now to the different worked materials, several groups can be distinguished.

The clearest differences can be seen between work on minerals and the other ground materials. The abrasive properties of ochre cause an overall leveling of the relief visible at a macroscopic level and the formation of specific wear zones visible at low magnification (small homogeneous zones). The entire surface is affected by chipping and micro crushing of the grains (Plate 1, c and d).

As for the other grounded materials, major differences emerge between those containing oil or fat, and those which do not. Cereals and leguminous plants can be contrasted with animal matter, nuts, mustard seeds and fresh acorns (the features were less apparent for dry acorns). For the latter, wear is much more pronounced and leads to the formation of flat areas of various size. In these areas, wear is characterized by a leveling of the grain and rounding of its edges. These alterations are associated with the development of highly reflective sheens and deep striations, the former often develop in the interstices. For cereals, regardless of the type of work, the leveled areas are less pronounced, and have a generally rounded profile. The alterations on these areas cover a broad spectrum, the surface has less sheen, the striations are associated with the development of homogeneous zones (Plate 1 g and h). Leguminous plants appear to form a

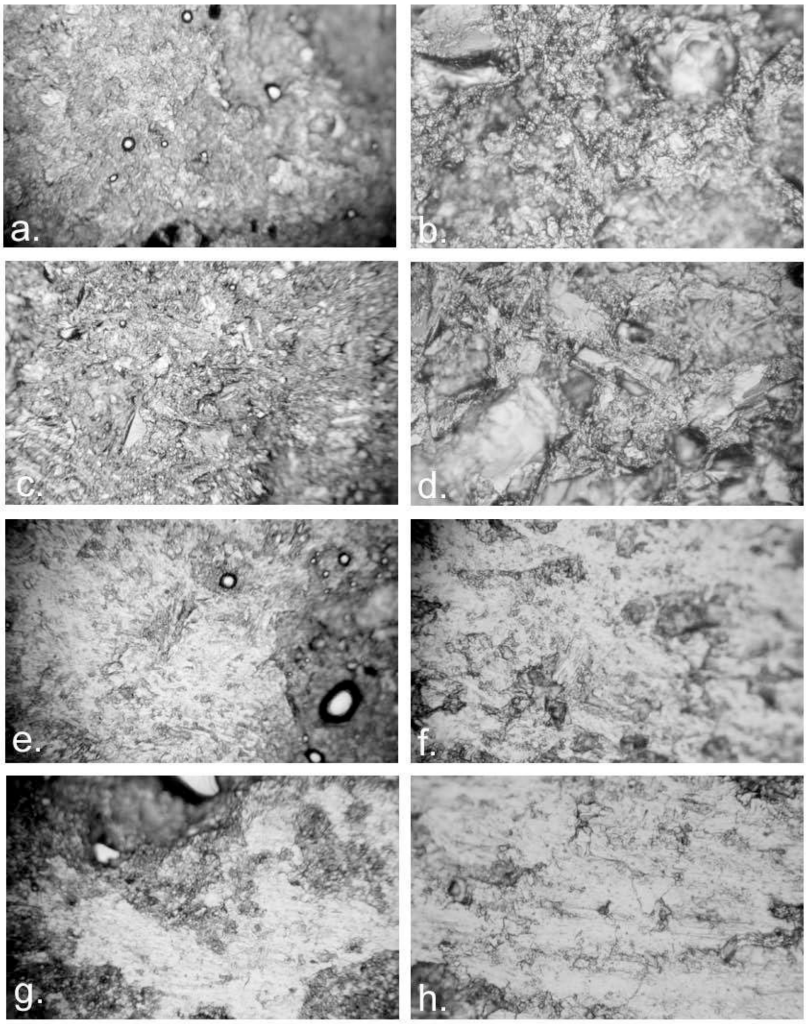

Plate 1 : Observations under lower magnification : stone against stone, surface of an upper block a. X6, b. X40 ; grinding ochre, surface of the lower grindingstone c. X6, d. X40 ; grinding nuts, surface of the lower grindingstone e. X6, f. X40 ; grinding wheat, surface of a lower grindingstone g. X6 and h. X40.

separate category, with traces of grain removals and micro crushing dominating the leveled asperities.

In the category of material containing fat or oil, a difference can be seen between animal and vegetable matter. Grinding of fish and meat leads to use wear which appears to be recurrent and can be defined as follows. Although some grains stay in relief and are rounded, most of them are truncated, present no interstice but remain identifiable. These zones are covered by a highly reflective sheen and striations, intersected with small interstices that correspond to grain removal. For vegetable matter although grains are highly worn down locally, most remain slightly in relief and rounded. The reflective sheen appears much more opaque and dark (Plate 1, e and f).

Differences were also observed between the various types of vegetable matter containing oil. As for wheat and wild barley, despite the variety of processes tested (husking, grinding with and without water in the case of barley), grinding leads to the formation of quite similar use-wear.

Work with a single stone

The range of experiments carried out was less extensive (ochre, shells, hides, bones, wood). Each type of material produces specific use wear. Differences are more apparent than on paired tools. There could be two explanations for this. First of all, is the more limited range and higher disparity of worked materials in comparison to experiments on paired tools. Second, the abrasive contact between the stones in paired work probably creates "interferences" and makes the use wear traces more uniform.

Hence each type of worked material in this series of experiments produced specific traces. Wood, bone, shell and ochre can be grouped together because they all produce surface alterations by micro crushing and grain truncation (more pronounced for ochre and shells). Sheen areas correspond to dark homogeneous zones for bone, shell and ochre, and to irregular zones where grains still can be individualized for wood. Work on shell shows two forms of homogeneous zones. For ochre, homogeneous zones show a striated morphology, are orange, have a high sheen, and some grains still appear in relief. During work on hide, non-leveled, discontinuous shiny surfaces developed (intersected with small interstices) and correspond to opaque, black homogeneous zones.

For each series of experiments, casts of small zones of the working surface were made at different stages in order to sample the development of wear and to enable analysis of the surface using other techniques.

Analysis under high power magnification

The results of a preliminary analysis of the casts under high power magnification, using direct and transmitted light, are summarized here. The purpose was to test whether use would lead to the development of micro-polish. Although micro-polish has given rise to numerous debates, it is considered by many use-wear analysts as the most diagnostic feature of the worked material.

Micro-polish can be defined, according to H. Plisson[11], as smooth surface structures caused by a modification of the original micro-relief, whether this is the result of a removal or

[11] Plisson, H. *Etude fonctionnelle d'outillages lithiques préhistoriques par l'analyse des micro-usures : recherche méthodologique et archéologique*. Paris : Université de Paris I, 357 p. Thèse : Lettres, 1985.

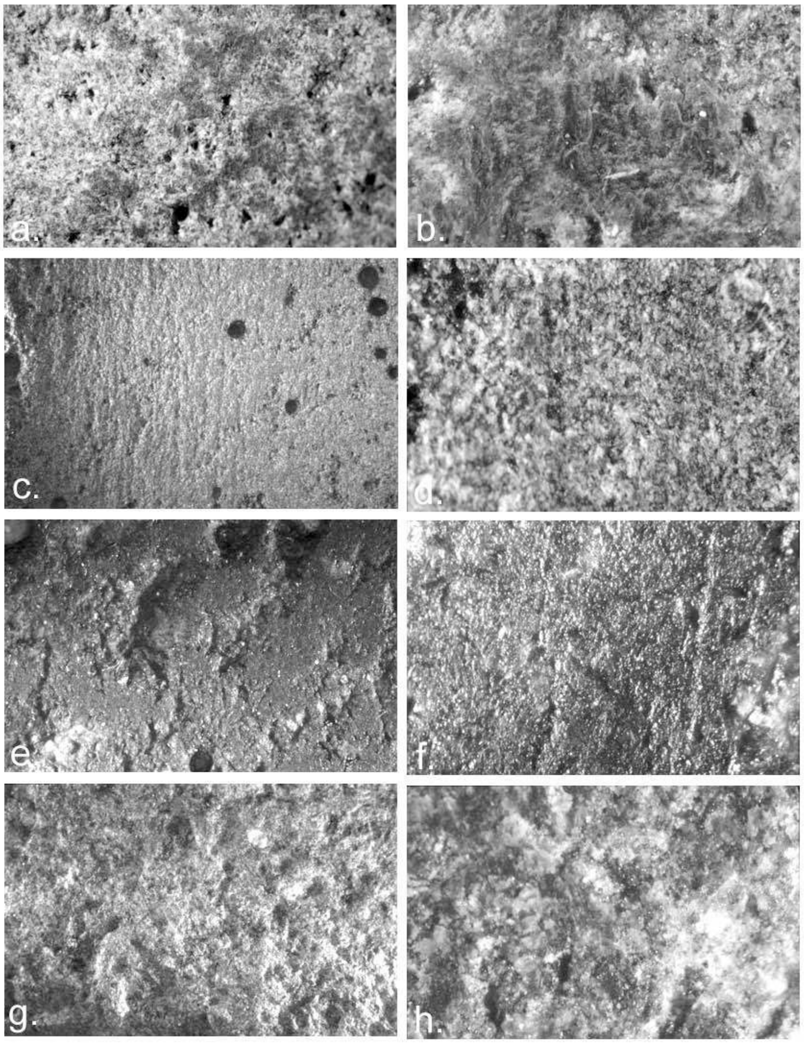

Plate 2 : Observation under high magnification (transmitted light microscope) : surface of an upper block shaped by pecking and abrasion a. X40, b. X100 ; grinding leguminous plants (fenugreek) surface of a lower grindingstone c. X40, d. X100 ; grinding nuts, surface of a lower grindingstone e. X40, f. X100 ; bone abrasion g. X40 and f. X100.

addition of material caused by a physical or chemical process (natural or artificial).

The size of archaeological objects often precludes direct observation of the grinding tools under the microscope. Several types of silicon as well as casts in acetate have been tested to reproduce samples of the working surfaces. Generally casts are made of dental elastomere (Provil L) and the replica of resin. I tested and compared observations on the cast, semi-transparent and opaque (the resin is tinted with powdered or liquid dyes) replicas, and for few cases only, on the items themselves. Three microscopes were used, Leica, Wild M20, and Olympus BH3 for the transmitted light observations. This analysis is currently in progress and I will only mention the results of the study using the transmission light microscope.

First of all, out of all the techniques tested, the casts in dental elastomere (Provil L) and acetate film yielded the best quality, and enabled, as was shown for flint and other materials, an accurate reproduction of the surface. In both cases however part of the amplitude of the relief is lost, since the products do not penetrate into the deepest interstices. Observations on different types of casts and replicas show that the coalescence zones appear most clearly in transmitted light (non-polarized) on semi-transparent replicas. This procedure could be less relevant for characterizing micro-polish such as carried out in use wear analysis, since observations are hindered by a loss of depth of field and a less accurate rendering of their texture. The contrasts between the coalescent zone and micro-relief unaffected by this alteration thus appear particularly visible in transmitted light. Further study will help refine the following conclusions. The development of these zones is most pronounced on tools used singly (see Plate 2 g and h: bone abrasion). On paired tools, there is a kind of "noise" created by the abrasive contact of the two stone surfaces. Most of the surface shows regularized but granulated areas and are only slightly reflective. This characterizes a very abrasive contact such as in the case of stone-to-stone abrasion (for instance compare Plate 2 a et b: surface of an upper bloc shaped by pecking / abrasion; Plate 2 c and d : grinding fenugreek). A significant development of coalescence zones was however found for work with materials containing lubricants, such as nuts, meat, fish and fresh acorns (for instance Plate 2 e and f grinding nuts). In this category, differences in the distribution and the texture of the coalescence zones were observed. Further studies aim to characterize the micro-polish as a function of the worked material.

Discussion and Conclusion

Recent advances in functional studies on grinding stone material have led to the development of analysis procedures which today appear to be well established at least on the theoretical level. The application to archaeological material remains restricted but will probably help refine the methodologies proposed. In general, these approaches encourage the integration of different foci of analysis to build a functional diagnosis for the study of raw material, morphologies, use wear and residues. My study basically consisted of exploring the potential of use wear analyses. In this field, some studies have demonstrated the relevancy of this approach and proposed observation and descriptive systems for use-wear. The hypothesis of a significant variation in use wear as a function of materials processed with basalt tools remained to be tested. The experimental referential testifies to the possibilities for differentiating large categories of worked materials. It confirms in addition the relevance of low power observations and its complementarity with higher magnification studies. In addition, this referential enabled me to contribute to our understanding of the development of traces, and the influence of various factors such as raw material, the type of shaping, and the way the tool was used. At this stage of the research, it seems crucial to complete the experimental work as different points emerge as priorities; namely, increase the duration of use, develop processes of a given material prepared in different ways, grind with various additives, and more generally integrate these into the complete chaîne opératoire of processing, to test for multifunctional uses, and the preservation of use wear after exposure to mechanical or chemical agents. This latter point is particularly important to enable the interpretation of archeological collections.

The experimental collection also provides a robust basis for testing different techniques for observation and surface analysis. In particular, a quantitative approach should be attempted. I believe that it is above all through the development of experiments, team-work and comparing studies carried out by different researchers that we can give a solid foundation to interpretations.

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