

Towards a systematic analysis of grain processing technologies

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1. Introduction

Since the early days of prehistoric research it has been widely accepted that the rise of animal and plant domestication brought about a significant change in stone tool technology, or, as John Lubbock defined it in 1865, a *Neo-lithic* age. Rather than a new form of flaked artefacts, it is supposed that the introduction of agriculture led to a broadening of the available toolkit, through the use of a greater variety of rock types and the development of new ways of transforming them. While the archaeological tradition in Western Europe has mainly focused on a particular variety of polished stone tools, the axes, which are considered indispensable for the clearing of the landscape, it was equally clear that a cereal crop agriculture was only feasible if an adequate grain processing technology existed. Surprisingly, this topic has received much less attention, probably because grinding implements are often considered a simple and unchanging tool type and therefore of little use in chrono-typological studies, which still play an important role in European archaeology. Moreover, alternative research strategies that try to understand and explain these artefacts in relation to the productive processes and economic structures to which they belonged have only recently

started to be developed.

Empirical studies carried out in some sites and regions (e.g., Zimmermann 1988; Risch 1995; Böhner 1997; Starnini and Voytek 1997; Castro *et al.* 1999; Adams 2002; Dubreuil 2002; Hammon 2006), as well as ethnographic data (e.g., Hayden 1987; Beaune 1989; Zurro, Risch and Clemente 2005; Baudais and Lundström-Baudais 2002) have shown an unexpected variety of stone tools, employed not only in cereal grinding activities, but also in the processing of other plants, meat or skin, in pottery production, metal working, mining, etc. In many cases, these artefacts are the only material evidence left of certain grinding, pounding, polishing, burnishing, hammering, cutting, sharpening or casting activities. Consequently, it should be expected that they represent a crucial material for any investigation concerned with the economic organisation of a society.

Given their geological, morphological and functional variability, it is difficult to find a single category that includes all these tools and, at the same time, differentiates them from the flaked stone industry. The frequently used terms *ground stone* and *polished stone* are problematic, as many artefacts are obtained by employing other working techniques, such as hammering, flaking or sawing, or present no work traces at all, when adequate cobbles are available. The fact that flaking techniques can also be used for the shaping of some rock and artefact types implies that these group of tools can not be set apart from flaked industries either. Similar difficulties appear if we adopt a functional perspective. While flaked artefacts are

primarily cutting and scraping instruments, some of the artefacts we wish to address can carry out identical actions, as in the case of axes, adzes or chisels. A different approach is offered by the German term *Grobsteinwerkzeuge*, which makes reference to the “bulky” aspect of these stone tools. Yet, such subjective qualification of artefacts makes little sense for a definition of labour instruments. Possibly the most appropriate criteria is the overall metric differences existing between these instruments and flaked artefacts. Thus, if it is deemed necessary to discriminate between these tools, the term *macro-lithic artefacts* can be used to comprise a large variety of labour instruments used for different types of activities, and which are not produced exclusively with flaking techniques. Otherwise the term *lithic artefact* would be sufficiently explicit, as long as it is no longer used in a restrictive sense, referring only to flaked instruments.

The systematic studies of macro-lithic artefacts carried out during the last years in different parts of the world not only begin to show a regional and chronological variability of grain processing instruments, in terms of geology, size, shape and use, but also make evident that the technological conditions implied by this activity are much more complex than previously expected. One observation, for example, is that understanding the transformation of cereal from plain grain into consumable flour implies looking at the grinding implements as well as at other material elements of the archaeological record. Several elements of the grinding process have particular importance (fig. 1):

- Undoubtedly, the paleobotanical identification of the cereal species and its processing prior to grinding is one crucial aspect in the technical layout of this task.
- Specific percussion and polishing stones are frequently used to prepare and maintain effective tools. These activities leave substantial amounts of pulverised rock or small fragments, which again can be identified, for example, in the sediment resulting from wet sieving and provide important information on the spatial organisation of the working process.
- Containers made out of pottery or other materials are indispensable for the storage, transport, measurement and distribution of the grain and the final product. Wear traces observable on large vessels and bowls, or residue analysis allow one to approach the handling/circulation of the product immediately before and after the grinding process.
- Grinding tools also require a stable position and a specific space in order to be effectively handled. Tables, platforms and other devices form a part of the technological context of the grain processing activity.
- Finally, one also has to ask about the labour force responsible for the whole process, which, according to ethnographic accounts, takes up a substantial part of the working day in agricultural societies, especially for its female members. The repetitive movement and strength needed to transform the grain can easily leave “skeletal markers” or so-called markers of occupational stress on the human skeleton. Given that it is usually women who carry out this arduous task in most known societies, paleoanthropological studies in this direction are of great value for the discussion of the

development of sexual division of labour from the early Neolithic

onwards.

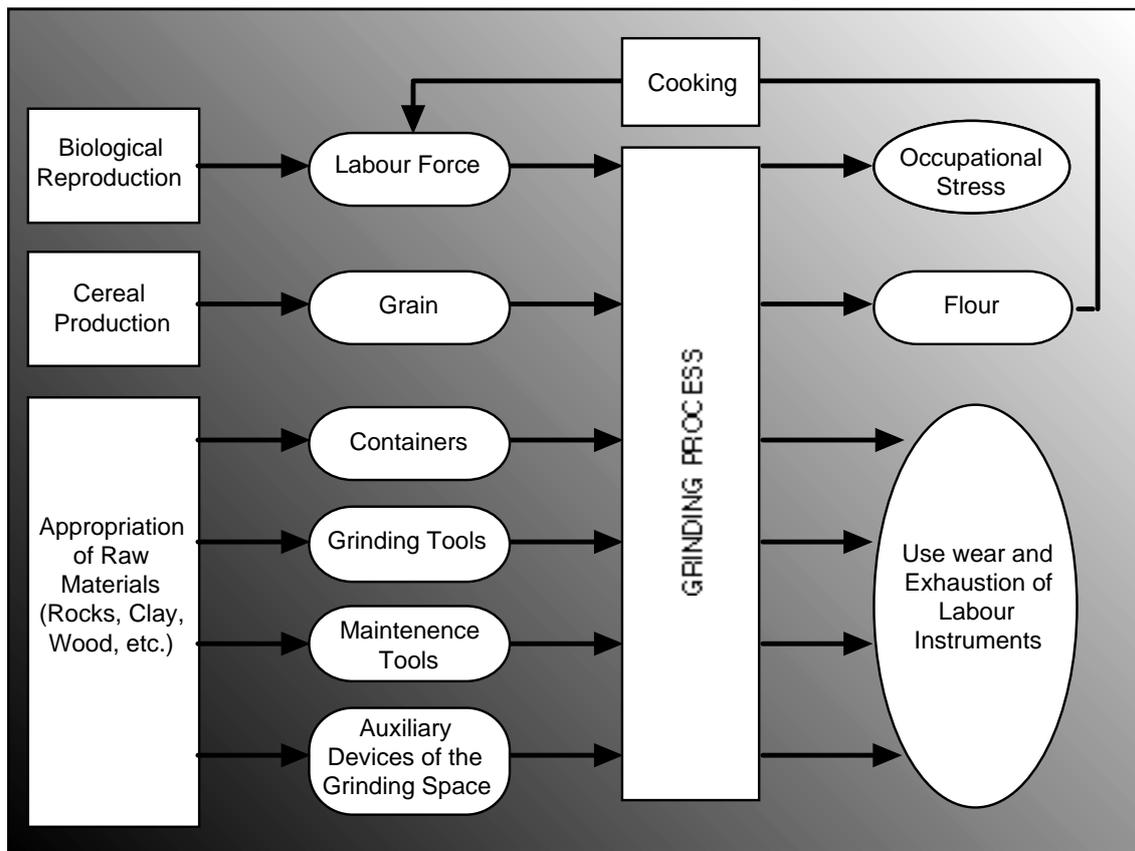


Figure 1: Structure and principal material variables of the grinding process.

The economic relevance of grinding technology becomes clear if one considers the dominant role cereal plays among subsistence resources in agricultural societies (as well as many hunter gatherer communities), and the fact that this sort of food inevitably has to be channelled through these means of production in order to become consumable. Grinding tools not only give information about the technical and spatial aspects of the production process, but also provide one of the few archaeological indicators about the volume of subsistence production within a community. Consequently, grinding artefacts represent primary and indispensable evidence in any archaeological approach about the economic and social organisation of agricultural production, as well as

consumption. Yet, as this brief overview suggests, such approach can not restrict itself to an analysis of stone tools alone, but rather has to be aimed towards establishing the relations between the different technical components of the production process (fig. 2).

The implicit or explicit acknowledgement of the potential contribution of macro-lithic artefacts for the explanation of prehistoric economic organisation has led to some advances in the last few years in the methodological foundations needed for the analysis of this largely neglected category of archaeological materials (Beaune 2000; Adams 2002; Dubreuil 2002; Procopiou and Treuil 2002; Risch 2002; Hamon 2006; Delgado 2008). Certainly more work has to be carried

out at a theoretical level, as well as in relation to analytical procedures such as functional analysis. Yet, it is still surprising how scant the available information is for macro-lithic artefacts, even at the descriptive level (measurements, geological identification, shapes, drawings, etc.).

For example, systematic studies carried out in the Old World only cover certain periods and areas or specific sites, while the overall development of grain processing technologies, or the means of production of macro-lithic objects in general, remains an unwritten chapter of later prehistory.

Labour Object + Labour Force + L. Instrument → Product + Residue				
<ul style="list-style-type: none"> • Cereal type • Previous processing of the cereal 	<ul style="list-style-type: none"> • Markers of occupational stress 	<ul style="list-style-type: none"> • Grinding tools: <ul style="list-style-type: none"> a. geological, morphometrical and functional characteristics of the grinding tools b. Volume of grinding implements per socio-economic unit • Preparation and maintenance tools • Containers to store LO and P • Auxiliary devices and grinding spaces 	<ul style="list-style-type: none"> • Conservation of food remains only under exceptional conditions • Palaeonutrition 	<ul style="list-style-type: none"> • Fragments of tools • Residues of grain (e.g., starch) • Residues of pulverised rock related to production and maintenance of grinding stones
<ul style="list-style-type: none"> • Palaeo-ethnobotany 	<ul style="list-style-type: none"> • Anthropology 	<ul style="list-style-type: none"> • Archaeology 	<ul style="list-style-type: none"> • Palaeo-ethnobotany • Isotopic and trace element analysis 	<ul style="list-style-type: none"> • Residue analysis • Archaeology

Figure 2: Economic model and principal archaeological implications of the grinding process.

The aim of this paper is to lay out a general framework for the technological analysis of grinding tools that contributes to an understanding of the economic structure of agricultural societies. The primary empirical difficulty in this respect is the identification of grinding artefacts in the archaeological record. The functional character of large abrasive slabs is expressed in their shape, size and geology, as well as wear traces or, rather, in the combination of these

physical traits. A closer look at these aspects in the archaeological material usually reveals a much larger variability than expected and than expressed in conventional classifications based on *a priori* categories such as “metates”, “manos”, “mortar”, “pestle”, etc.

2. Cereal grinding instruments: the grinding slab/handstone and mortar/pestle technological sets

The transformation of grain into

consumable flour or meal can be accomplished by a set of alternative technological devices. Therefore, the first task in any archaeological approach for these activities is to identify which artefacts encountered in a particular context were actually involved in this production process. Frequently this becomes a more difficult question to answer than expected, especially if no functional or residue analyses have been carried out. In practice, this means that most archaeological classifications of macro-lithic materials are based on little more than certain ethnographic preconceptions or mere speculation. Contextual data on the position of stone implements within the settlements and their relation with other artefacts and botanical or faunal remains are seldom recorded, although this information would offer a straightforward possibility to approach the function of the tools and the organisation of this activity.

The ethno-archaeological research carried out by Hayden (1987) and Horsfall (1987), together with Adam's (1989a; 2002) use-wear analyses and archaeological investigations have provided a general model for the grinding technology developed in Central and North America. These studies have also proved that similar artefacts or even the same grinding tools can be used for working hides, crushing minerals, grinding coffee, washing clothes, and a series of other activities. Although in farming societies such uses will generally be of minor importance in comparison to grain processing activities, it still is important to carefully evaluate such alternative functions through functional, typological and contextual analysis.

During our ongoing work in Ghana and Mali it has been possible to identify distinctive types of abrasive stone slabs used for different purposes, such as the processing of millet, sorghum, spices, shea butter nuts or glass beads. At the same time, cereal grinding with stone artefacts can be complemented with or even substituted by pounding in wooden mortars. The use of one and/or the other tool set often depends on the texture and taste of the flour and, hence, of food or drink that one wishes to prepare. Mortars can also be employed to increase the return obtained from the stalk. Moreover, these functional and instrumental differences interact with regional and historical variables, resulting in a complex technological picture.

Nepalese wooden mortars and pestles are reported to be used for husking, crushing or pounding of millet, corn, barley and rice (Baudais and Lundström-Baudais 2002). As observed in Africa, these tools can be complemented or substituted by grinding stones at the different stages of the grain processing. The relevance of husking in mortars has also been tested experimentally in relation to einkorn (*Triticum monococcum*) and emmer (*Triticum dicoccum*) (Meurers-Balke and Lüning 1992). On the other hand, experimental work carried out with grinding stones demonstrated that a previous pounding of the free-threshing wheat (*Triticum aestivum*) and hulled barley (*Hordeum vulgare*) was not necessary nor convenient in order to reach higher levels of labour efficiency (Menasanch, Risch and Soldevilla 2002; Risch 2002). Contextual observations made in El Argar

settlements of cereal remains and ceramic vessels with carbonised hulled grain situated next to grinding slabs further supports the idea that these were the only artefacts used in this process.

3. Technological conditions of cereal grinding artefacts

Grinding slabs (*metates*) refer to large, more or less oval stone slabs with an abrasive work surface present on the ventral face. The analyses of large collections from prehistoric settlements of the western Mediterranean show a statistically significant threshold at 250 cm² between the active surfaces of grinding slabs and other abrasive artefacts (Risch 1995; Delgado 2008). Handstones (*manos*) have a similar shape and the same active surfaces as grinding slabs, but are significantly smaller. However, in particular cases it may not be easy to establish the limit between each type of artefact on metrical criteria alone, as the transition can be continuous. Moreover, not all artefacts with abrasive surfaces smaller than 250 cm² can be considered

grinding tools either. Rather, a large variety of tasks, ranging from metallurgical production to the processing of a variety of plants, are carried out by means of different abrasive stone artefacts (for an ethnographic example, see e.g. Beaune 1989). In this case the main discriminating criteria is the technically complementary functions of the mano and the metate.

The first necessary technical condition for the grinding process is a perfect adjustment between the grinding slab and the handstone that allows the crushing and pulverising of the grain. Consequently, the active sides of both tools must present symmetric shapes. Hürlimann (1965: 78-80) was the first to point out the morphological interdependence between both grinding surfaces (fig. 3). Later, Zimmermann (1988: 725) presented a model that explained the shape of the working surfaces as a mechanical consequence of the absolute metrical relation existing between both artefacts (fig. 4).

Handstone	Grinding slab
I	VI
V	V
III	IV
????	II

Figure 3: Predicted morphological relation between the active surfaces of grinding tools according to Hürlimann (1965, p. 72 - modified).

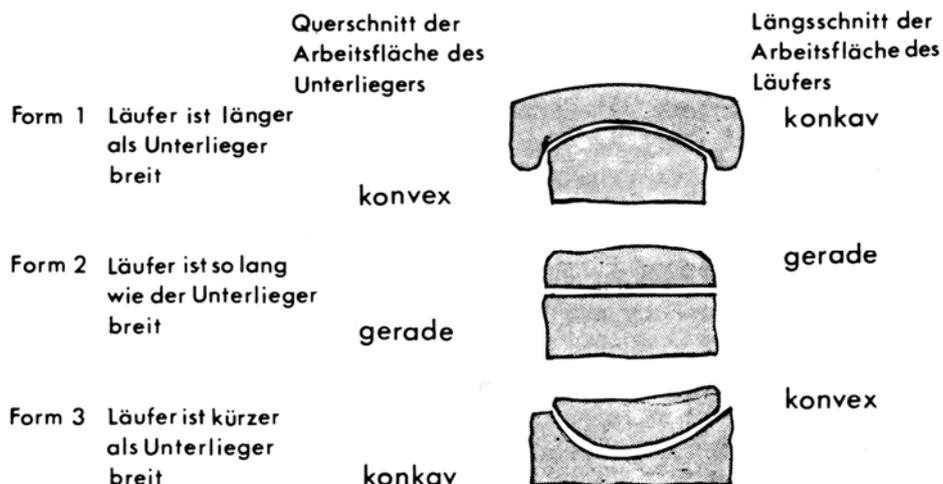


Figure 4: Predicted morphological relation between the active surfaces of grinding tools according to Zimmermann (1988, p. 725).

Ethnographic and experimental data have confirmed that a small handstone produces a concave surface on a large grinding slab (and a convex one on the handstone) and that equivalent dimensions produce flat ones (Hayden 1987; Adams 1989b, 1999). More problematic is the prediction that convex transverse shapes develop on the querns when the length of the *manos* exceeds the width of the first.

While our own observations in northern Ghana confirm this model, the *metates* used in Central America, for example, present a flat transverse section, although the *manos* are c. 10 cm longer than the width of the grinding surface (Hayden, 1987, p. 190-202). Practically the same situation has also been observed in Nepal, where the length of flat hand stones exceeds the width of the grinding slabs by 10-20 cm (Baudais and Lundström-Baudais 2002,

p. 166-167). The Swiss Bronze Age represents an archaeological case where large hand stones correlate with flat grinding surfaces (Hochuli and Maise 1998, p. 269). Consequently, the metric relation alone does not explain the different shapes of the grinding surfaces. Women in Ghana attributed the slightly convex transversal shape of their tools to the fact that the body weight is not distributed evenly between the left and the right hands during the whole grinding process, as we had also predicted based on experimental tests (Menasanch, Risch and Soldevilla 2002). How flat profiles can develop under the same technical conditions still requires further mechanical and tribological investigation, but one possibility is that such surfaces are the result of a regular maintenance of the surfaces, rather than the consequence of wear.

In general, ethnographic, experimental and archaeological information suggests that no simple correspondence between the different shapes can be established. The height of the convexity or the depth of the concavity of the grinding stones, as well as the absolute metrical relation existing between both artefacts, rather than just their morphological match, are relevant factors in the material wear and shaping of the grinding surfaces. The way hand stones are handled (e.g., in a circular or a reciprocal movement) is another factor that must be taken into account (Adams 1999). Based on the still limited amount of available experimental and ethnographic observations, the following model of correspondences has been proposed (tab. 1).

	Relative dimensions	Morphology Grinding slab	- Morphology - Handstone
1	$A_G > L_H$	CV/CV or RT/CV	CX/RT or CX/CX
2	$A_G \leq L_H$	RT/RT or CV/RT	RT/RT or RT/CX
3	$A_G \leq L_H$	CV/C T/CX	CV/RT or CV/CX or Wooden <i>Mano</i>
4	$A_G \geq L_H$	CX/CX	CV/RT or RT/RT or CV/CV

Table 1: Predictive model of morpho-metrical coupling (longitudinal profile axis/transverse profile axis) between grinding tools (AG: Width of the grinding slab; LH: length of the handstone; CV: concave, CX: convex, RT: flat). This model is based on experimental and ethnographic observations (Risch 2008: proposition 14).

The second technological condition that must be fulfilled during the grinding process depends on the

abrasive capacity of the raw materials used. Ethnographic and archaeological studies show that the tools forming the grinding set can be made from similar

or slightly differing rock types. Often, the material of one of the tools, normally the handstone, has a slightly compacter fabric and is less abrasive than the other. Such minor differences in the texture of the active surfaces allow for more efficient crushing and pulverising of the grain. Consequently, only those small size artefacts with abrasive wear marks which are made out of a raw material that adjusts to the material of the grinding slab can be interpreted as hand stones. Experimental tests have shown that extremely compact gabbro or quartz cobbles, the most frequent lithotype among the polishing tools of the southeast Iberia, provided very poor results when used on schist or conglomerate grinding slabs (Menasanch, Risch and Soldevilla 2002; Risch 2002, p. 111-119). Micaschist with a high proportion of quartz grains (c. 50-70 %) proved significantly more efficient, as the cereal grain seems to be more easily trapped between the grinding surfaces. High yields were also achieved when both tools are made out of garnet bearing micaschist, which is the dominant material among the Bronze Age *metates* in southeast Iberia. Yet, in this case the result was very impure flour. Apart from high contents of bran, which was finely ground and difficult to separate, a high amount of mineral fragments, such as quartz and garnet, formed part of the final product. Even if prehistoric communities tolerated higher levels of impurities in the food, as the paleo-anthropological studies on dentition show, the presence of very hard particles such as garnet makes this flour hardly consumable. If one reconsiders the technological situation

of Bronze Age southeast Iberia with these parameters in mind, it appears that only 30-35% of the small size abrasive tools, which potentially could be considered as handstones, are made out of a suitable type of schist (Risch 1995). This underlines that the examination of the material properties of the different rock types is a crucial aspect in the functional interpretation of abrasive artefacts.

A final condition that the grain processing toolkit should fulfil, according to the principles governing the material behaviour of abrasive surfaces, is that handstones should outnumber grinding slabs in the archaeological assemblage. The wear indices obtained through experimental analysis using sandstone artefacts were five times higher for the mobile than for the stable component (Wright 1993). Information gained among American as well as African societies suggests that the mean lifespan of handstones is approximately half that of the grinding slabs (tab. 2). This would explain why the proportion of 2:1 is frequently encountered in archaeological cases where grinding slabs with flat or concave transverse profiles are predominant. This pattern is ruled by the principle that the wear of two abrasive surfaces, which are in constant contact, is inversely proportional to their size. In settlement contexts where most of the broken and discarded artefacts are not recovered, such as the case at the Los Millares sites, one should encounter at least a proportion of 1:1. Below this value, the possibility that the smaller mobile tools could also have been made out of wood should be considered.

Region	N	X	Sd	Min	Max	Geology	Reference
Maya Highlands-Grinding slab	39	32.9	19.7	5	80	vesicular basalt	Hayden 1987, p. 194
Maya Highlands-Handstone	31	21.5	19.5	3	100	vesicular basalt	Hayden 1987, p. 194
Guatemala-Grinding slab	37	35*	-	10	100	vesicular basalt	Horsfall 1987, p. 343
Guatemala-Handstone	32	20*	-	3	100	vesicular basalt	Horsfall 1987, p. 343
Sudan-Grinding slab	-	5-6	-	-	-	sandstone	Schön & Holter 1988, p. 159
Sudan-Handstone	-	1-2	-	-	-	sandstone	Schön & Holter 1988, p. 159
Ghana-Grinding slab	3	35	-	25	45	silicified sandstone	Risch (unpublished)
Ghana-Handstone	3	20	-	17	25	silicified sandstone	Risch (unpublished)

Table 2: Expected object lifespan (years) recorded in communities still using grinding tools (number of observations, mean, standard deviation and range). Variability of the values is mainly caused by differences in shape, size and raw material of the tools (Risch 2008, proposition 16).

In general, we should retain that the grinding slab/handstone set must be designed, in terms of shape, size and geology, in a way that warrants an easy pulverising of cereal grain. For example, the arrangement often encountered in European archaeological museums of a small polishing stone, made of quartz, gabbro or similar hard rocks, placed on top of a large sedimentary or metamorphic grinding slab is not a feasible combination. In this sense, the technological characterisation of the macro-lithic artefacts must be the first step of any functional analysis. For this purpose a standard recording system has been developed, which, apart from describing morphological, metrical and petrographic variables, focuses on the description of the traces observable on the surface of the tools produced by: 1. natural processes, 2. manufacture and maintenance activities carried out on the artefact and 3. use of the artefact (for details, see Risch 2002, p. 35-54).

4. A technological alternative: wooden *manos*

When these criteria were applied to the study of macrolithic artefacts recovered in systematically excavated settlements of the western Mediterranean, a puzzling observation was made: while it was relatively easy to identify the grinding slab/handstone tool sets of the Copper Age (c. 3000-2200 cal BCE), only 3-4% of the grinding tools of the Bronze Age (2200-1000 cal BCE) could be classified as handstones according to the above-mentioned criteria (Risch 1995, 2002, 2008). Moreover, the artefacts classified as grinding slabs, based on use-wear analysis as well as on contextual information, combine a convex transversal active surfaces with surprisingly narrow (mean values for different sites ranging between 167-206 mm) and long (336-417 mm) shapes (fig. 5). Following the metrical parameters established in Zimmermann's model, the length of the corresponding handstones should be greater than the width of the stable artefacts, i.e. larger than at least 17 cm. Yet, as the analysis of the stone

artefacts of the settlement of Gatas (Almería) illustrated, hardly any of the

tools with abrasive wear marks fulfil this condition (fig. 6).

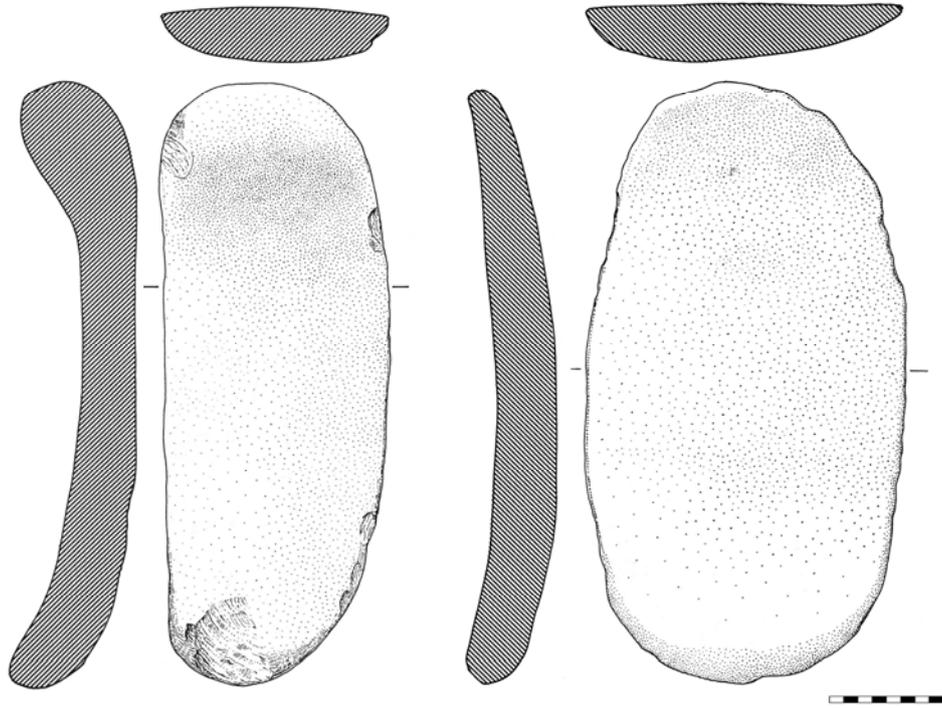


Figure 5: Argaric grinding slabs from the El Argar levels of Fuente Alamo, Almería (Risch 2002, p. 326, 327).

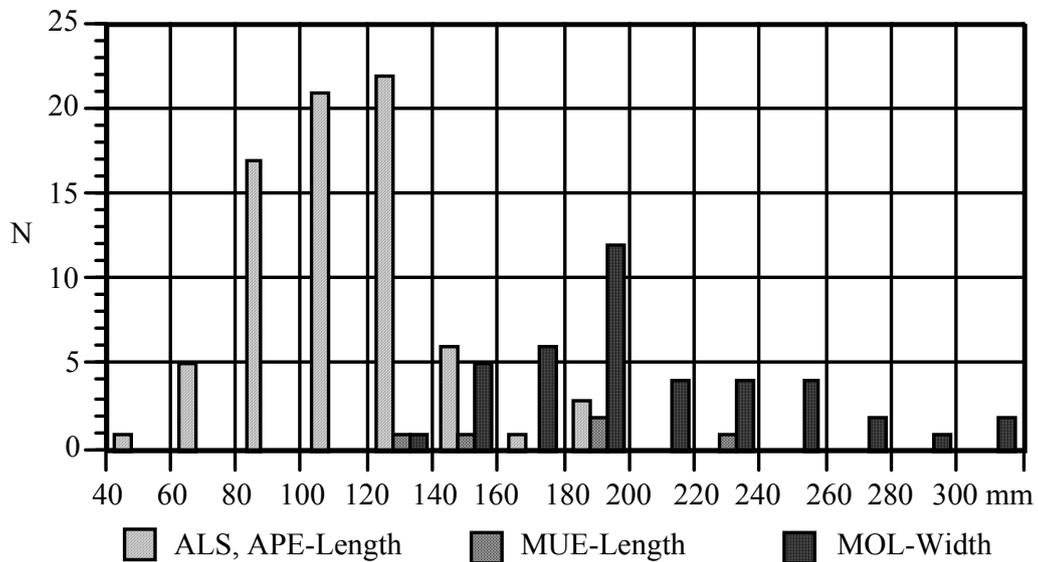


Figure 6: Comparison between the length of small abrasive tools (ALS, APE: polishing stones, MUE: handstones) and the width of the grinding slabs (MOL) from the Bronze Age settlement of Gatas (Almería) (Castro et al. 1999, p. 110).

A first result of the systematic recording of the macro-lithic artefacts and their active surfaces was that a technical alternative appeared at the beginning of the Bronze Age in southeast Iberia. Although, detailed descriptions of macro-lithic tools are still rare in the Mediterranean context, looking at different collections from Italy and Greece one gains the impression that the rareness of suitable handstones, especially where this type of narrow and long grinding tool with a convex transverse profile appear, is much more common than expected.

Such an archaeological anomaly raises a series of questions: How then could the grinding process take place in situations where so few hand stones existed? Could the mobile part of the toolkit be made out of a different material, which was not preserved in the archaeological record? Would it be possible to use, for example, wooden *manos*? What do the traces of wear on the prehistoric artefacts suggest? A specific experimental programme, in combination with use-wear analysis, was designed in order to answer these questions. The main objectives were to test, firstly, the suitability of wooden grinders in comparison with their lithic

equivalents, and secondly the technological behaviour of grinding stones with convex transverse shape (for a detailed description, see Menasanch, Risch and Soldevilla 2002; Risch 1995, 2002).

In order to quantify the “efficiency” of alternative technological devices two indices were proposed:

1. *labour return*, measured as grams of flour produced per minute ($LR = Fl/min$);
2. *grain yield*, expressing the proportion between flower and bran obtained from a given amount of grain in a fix period of time ($GY = Fl/Br.min$).

A third criteria, which proved to be important during and after the grinding process but was difficult to quantify is physical exhaustion.

After a series of experiments under different technological conditions were carried out, it became clear that the use of wooden *manos* represented a feasible choice. In fact, the highest values of *labour return* and *grain yield* were achieved with a semi-cylindrical *mano* made out of hard wood (fig. 7).

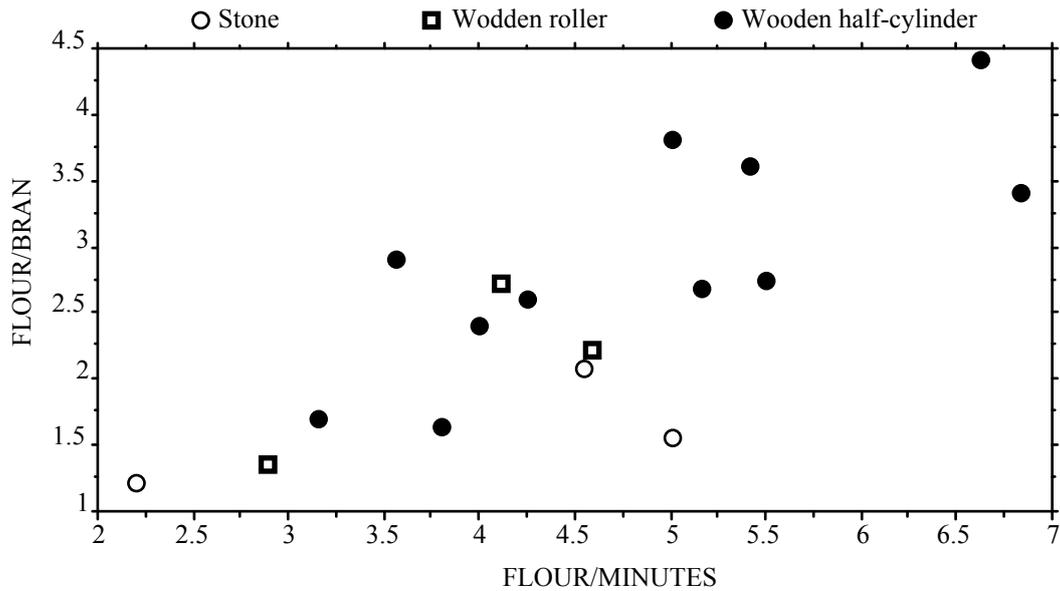


Figure 7: Indices of labour return and grain yield obtained with different types of hand stones. Several persons with different amounts of practice worked on all materials (Risch 2002, p. 119).

Especially interesting was to observe its effect on convex grinding stones. Contrary to what was expected, the grain and flour did not slide along the margins, but remained in the centre of the surface, while the bran moved down on both slopes. Lighter than the flour and grain fragments, which remained fixed in the centre, the bran slid automatically towards the margins. This effect was even more noticeable when processing barley. Each time, a new hand full of grain is placed in the centre of the surface, the vibration of the grinding stone during the reciprocal movement produces a concentration of the heavier particles towards the higher ridge, and a simultaneous separation of the lighter bran (fig. 8). In contrast, it was necessary to brush away the flour and grain fragments on flat experimental surfaces when they clogged the surface and hindered an efficient grinding. After some practice with convex artefacts, it even became possible to separate bran from flour during the grinding procedure itself, as the flour can be collected in such a way that no later sieving is necessary. This effect of concentrating the heavier particles towards the middle of the surface explains why the Bronze Age grinding stones could be very narrow (17-21 cm) in relation to their length (34-42 cm).



Figure 8: Cereal processing on an argaric grinding slab with a wooden *mano*. Bran collects at the margins and around the grinding stone while the processed flour concentrates in the centre (white).

Another important insight gained from the experimental programme was that the convex surfaces could not be the result of wear development, but rather represented intentionally prepared surfaces. It was observed that grinding areas produced only by pecking were too irregular, so that grain fragments remained trapped in the pits. Consequently, *labour return* and *grain yield* remained low. Instead, levelling c. 65% of the active side with a hard polishing stone gave the surface of the experimental tools a roughness and an appearance equivalent to that of the archaeological ones. The technical result was an increase of the abrasive contact between the lower, stationary and the upper, movable tool, which allowed a much more efficient and comfortable grinding (fig. 9). Moreover, the morpho-metric analysis showed that the convexity of the Bronze Age grinding stones is highly standardised (median = 4 mm; mode = 4 mm; $x =$

4.339 mm; $sd = 2.361$) and depended significantly on the width and thickness of the artefacts (fig. 10). This implies that narrower and thinner grinding tools, i.e. more exhausted tools, present a lower central ridge than the wider and less used artefacts. If transverse convexity was the consequence of the wear, as proposed by Zimmermann's model, then the opposite tendency would be expected. Definitely, experimental and archaeological observations have led to the conclusion that in this context a convex transverse shape is a technical feature of the grinding process, which was purposely produced and needed a regular maintenance during the lifespan of the artefacts. Many of the cobbles of hard rock such as quartzite and micro-gabbro found together with the grinding stones, exhibit the type of use wear marks expected to develop during such polishing and pecking activities.

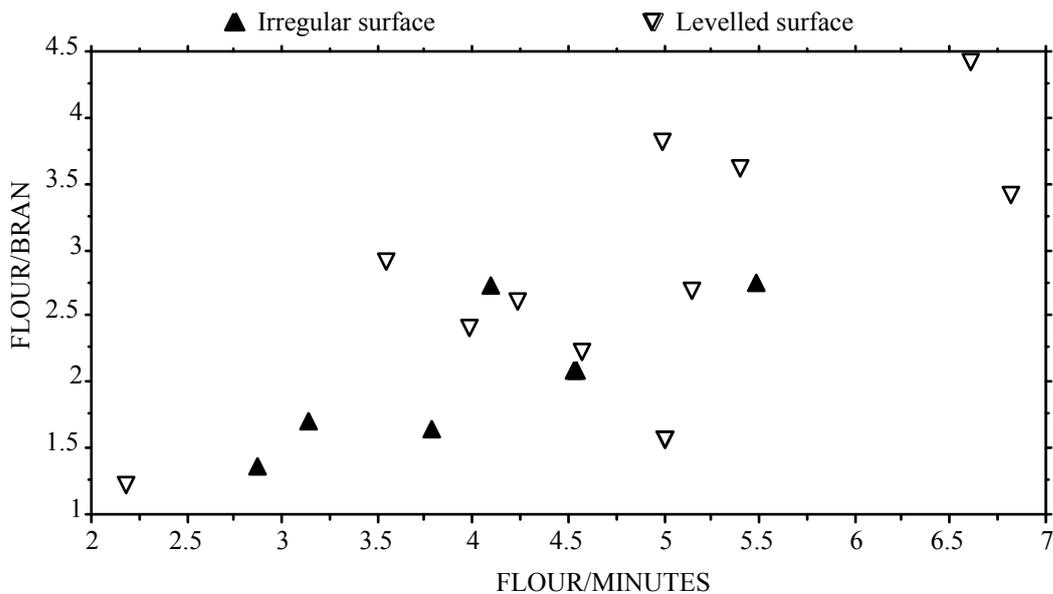


Figure 9: Indices of *labour return* and *grain yield* obtained with differently prepared grinding surfaces (Risch 2002, p. 117).

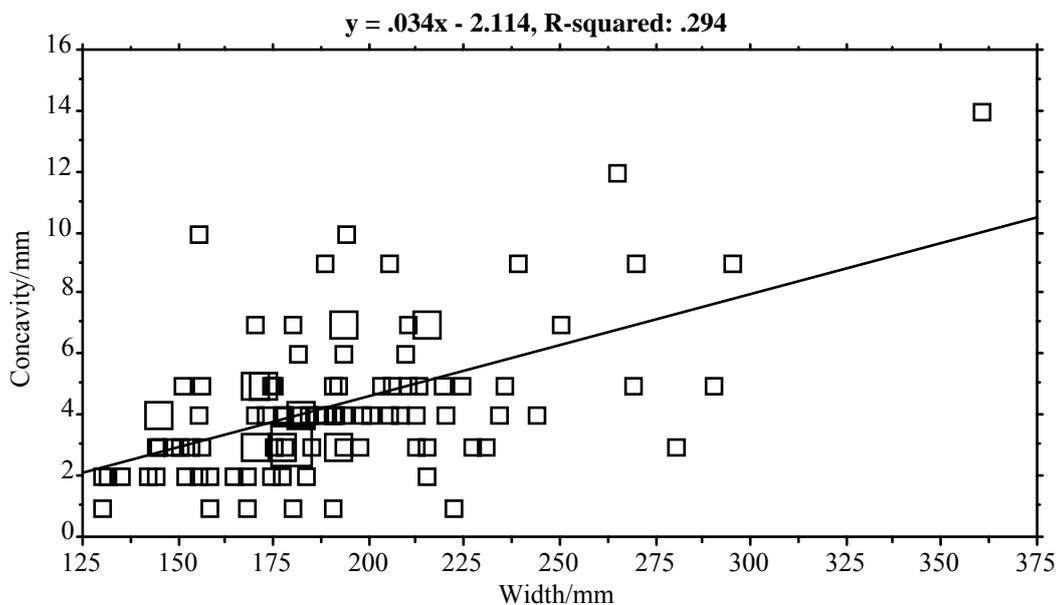


Figure 10: Relation between width and transverse convexity of grinding stones from the archaeological site of Fuente Alamo (N=124) (Menasanch, Risch and Soldevilla 2002, p. 84).

The next step consisted in the description of use wear marks on the experimental and archaeological artefacts which were used in the cereal grinding processes (Risch 1995, 2002; Delgado 2008). Among them, we found mainly two different wear patterns, depending on the material nature of the grinding equipment. The first one shows intensively levelled surfaces that are characterized by the presence of

large homogeneous zones with a levelled straight section. These zones are clearly limited and surrounded by intact interstices. On the top of the homogeneous zones, grains of the rock have been worn down till the level of the matrix and occasionally grain extraction and microfractures can also be observed. The presence of striations is another important criterion that allows the recognition of this type of wear pattern. These are almost always

located in the upper parts of the microtopography (fig. 11a-b). According to our experiments, this kind of wear must be related to contact with hard and rigid materials, that is to say, to grinding-slabs which are operated in correspondence with handstones. In the archaeological record, this kind of pattern mainly appears on grinding-slabs made out of mechanically deficient materials. The lack of morphological standardisation is also a feature that defines this kind of wear trace, whereby concave grinding-slabs seem to be predominantly associated with it as well (Delgado 2008, fig. 4.1.33 and 4.1.34).

The second wear pattern also includes levelling of the surface as the most important criterion, in association with eventual grain extraction and microfractures. We again find nearly straight homogeneous zones, although in the central part of the surface the rounding of their borders gives them a slightly convex appearance (fig. 11c-d). In contrast to the first use wear pattern, striations are absent and wear affects the slopes of the interstices. This explains why the aspect of those surfaces is much more sinuous than the latter. In experimental terms, homogeneous zones with a straight section, grain extraction and microfractures indicate a contact with hard materials, while edge rounding and no striations are related to contact with softer material.

Given that both use wear patterns coexist on the same surface, at least two simultaneous or successive wear processes must have acted on those grinding slabs. Experimental tests have allowed replication of such a complex pattern through a two-step labour process: after the initial preparation of the optimal grinding conditions (surface roughness) through percussion as well as polishing with a pebble, cereal grinding was carried out on the grinding slab with a wooden *mano*. In this way some of the older wear traces remain visible, such as the levelling of the high topography of the harder minerals, while others, like striations, seem to be eliminated during the grinding process proper.

Another technological feature that characterises these kinds of grinding slabs is a more standardised production in terms of the morphology and petrology of the tools. Most of them show convex transversal sections, a rather narrow shape and are made out of specific rock types. The roughness of the selected rocks appears to be a more important criterion than mechanical resistance and hardness of the rocks. This could be explained by the lower abrasive capacity of the wooden *manos* in comparison to lithic *handstones*, and consequently the lower potential of contamination of the flour with mineral particles (Delgado, Gómez-Gras and Risch, in press).

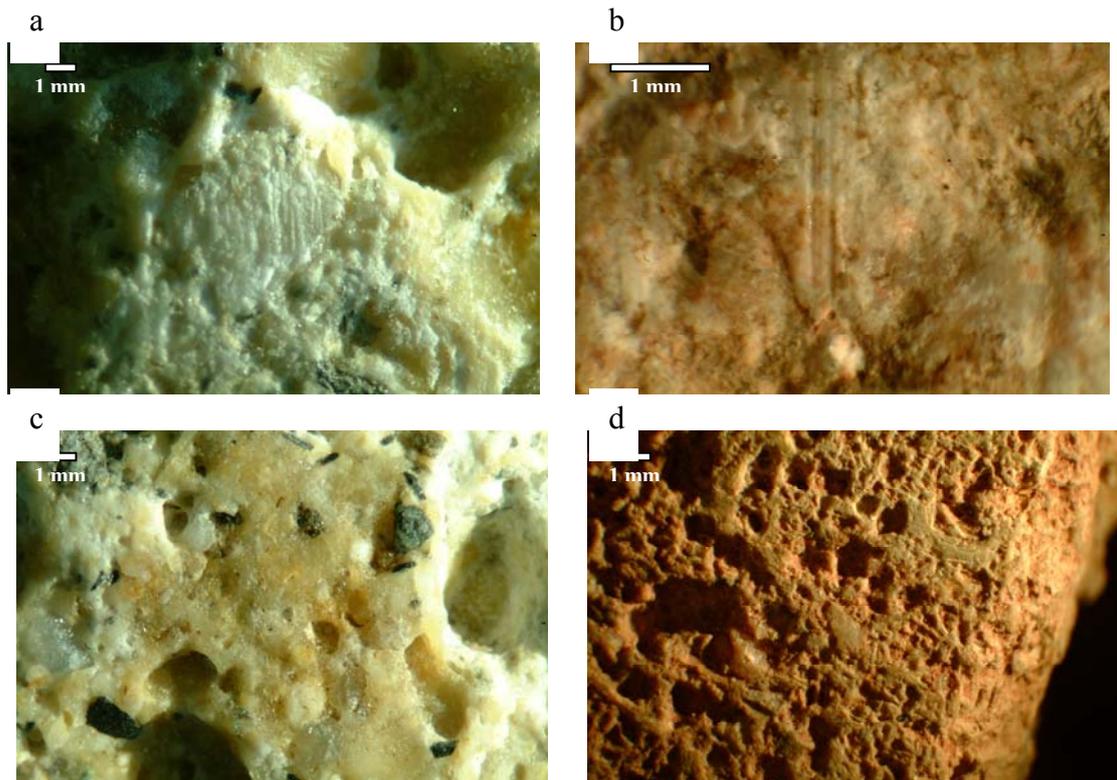


Figure 11: Examples of experimental grinding surfaces used in abrasive contact with stone (a) and wooden (c) *manos*, and archaeological surfaces used in contact with stone (b) and wooden (d) *manos*. Note the presence of surface levelling and striations in images a and b, and the more sinuous aspect of the surfaces in cases c and d, due to abrasion against a softer material.

After the morpho-technical and functional analysis of the archaeological grinding tools, it can be concluded that only a small amount of the grinding slabs from Bronze Age settlements of the western Mediterranean (c. 2200-1000 cal BCE) show use wear patterns produced by a grinding process with stone *manos*, while most of them are more related to patterns obtained through the use of wooden artefacts (fig. 12; for a full description of the experimental work and functional analysis see, Risch 2002, p. 122-145 and Delgado 2008, p. 330-341). Taking into account that most of the cereal grinding equipment used during the Copper Age seem to have been utilised stone *manos*, the dominance of wooden *manos* in the Early Bronze Age must have represented an important technical

innovation. The grinding experiments carried out so far confirm that wooden *manos* allow an increase in the *grinding efficiency* (combination of labour return and grain yield) and produce a more refined flour.

Although detailed accounts of grinding processes in non-industrial contexts are still rare, the use of wooden grinding tools is documented among some contemporary societies. For example, the Fang from Equatorial Guinea prefer wooden *manos* or *metates* in order to grind different crop types (Panyella and Sabater 1957). Also in southeastern Mali, around Koulikoro, shea butter nuts are crushed and ground into a fine paste with long wooden grinders operated in a typical reciprocal movement on large stone slabs (Pailler and Garin, personal communication).

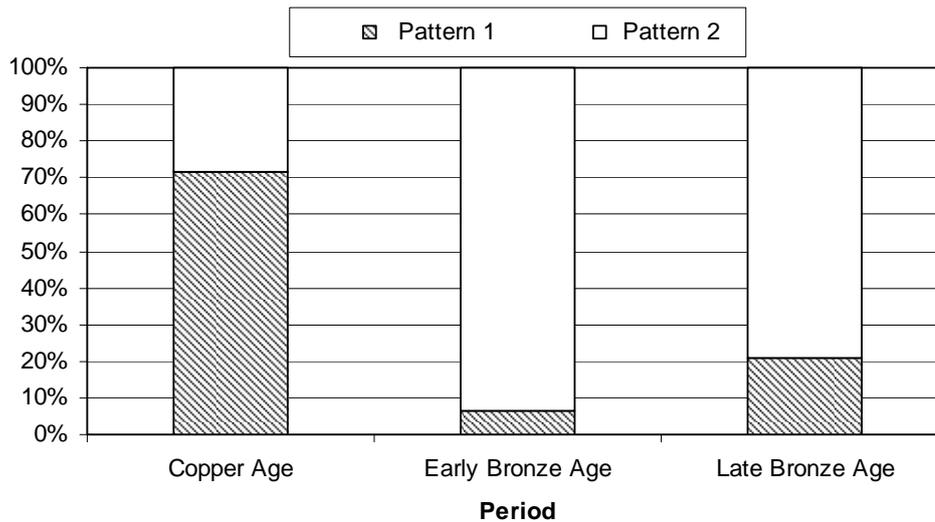


Figure 12 Frequencies of wear patterns for the Copper and the Bronze Age of Southeast Iberia, showing grinding surfaces in contact with stone *manos* (pattern 1) and with wooden *manos* (pattern 2).

The hundreds of grinding stones registered in the El Argar hilltop settlements show an intensification and a centralization of the grain production, especially during the last 350 years of their development (c. 1900-1550 cal BCE) of this first state-like society of the western Mediterranean. This massive accumulation of means of production and the increase of flour production obtained through the use of wooden *manos* seems to have played a crucial role in the emergence of the first state-like society of the western Mediterranean and the maintenance of class differences through a restricted access to raw materials, labour instruments and subsistence goods.

4. Conclusion

Hopefully it has been shown with the above example that the identification of the actual grinding instruments in the archaeological record is more complicated and can imply a larger variety of aspects than is usually considered. Therefore, from a methodological point of view, it is important for macro-lithic analyses to

explicitly define the criteria used to classify artefacts into the different functional and typological categories. It becomes equally clear that a larger corpus of archaeological studies and artefact descriptions, as well as more experimental and functional analysis are necessary, if we wish to achieve solid reference bases that allow a better understanding of the technical factors governing the large variety of productive activities in which macro-lithic tools played a part. Only then will it be possible to profit from the heuristic potential of the archaeological artefacts in relation to productive forces and social relations of production.

BIBLIOGRAPHY

ADAMS, J.L. (1989a) - Methods for improving ground stone artifacts analysis: experiments in mano wear patterns. In AMICK, D.S.; MAULDIN, R.P. eds. - *Experiments in Lithic Technology*. Oxford: B.A.R., International Series. 528, p. 259-81.

ADAMS, J.L. (1989b) - Experimental study of the shaping of ground stone

tools. *KIVA*. 54: 3, p. 261-271.

ADAMS, J.L. (1999) - Refocusing the role of food-grinding tools as correlates for subsistence strategies in the U.S. Southwest. *American Antiquity*. 64: 3, p. 475-498.

ADAMS, J. L. (2002) - *Ground stone analysis, A technological approach*. Salt Lake City: University of Utah Press.

BAUDAIS, D.; LUNDSTRÖM-BAUDAIS, K. (2002) - Enquête ethnoarchéologique dans un village du nord-ouest du Népal: les instruments de mouture et de broyage. In PROCOPIOU, H.; TREUIL, R. eds. - *Moudre et Broyer*. Paris: Publications du CNRS, p. 155-180.

BEAUNE, S.A. de (1989) - Exemple ethnographique de l'usage plurifonctionnel d'un galet de quartz. *Bull.Soc.Pré.Fran.* 86:2, p. 61-65.

BEAUNE, S.A. de (2000) - *Per une arqueologie du gest. Broyer, moudre, piler. Des premiers chasseurs aux premiers agriculteurs*. Paris: Publications du CNRS.

BÖHNER, U. (1997) - *Die Felssteingeräte der endneolithischen Siedlung von Dietfurt a. d. Altmühl, Lkr. Neumarkt i. d. Opf*, Archäologie am Main-Donau Kanal, 10, Marie Leidorf, Espelkamp.

CASTRO MARTÍNEZ, P.V. ; CHAPMAN, R. W. ; GILI I SURIÑACH, S. ; LULL, V. ; MICÓ, R. ; RIHUETE HERRADA, C. ; RISCH, R.; SANAHUJA YLL, M. E. (1999) - *Proyecto Gatas, 2: La dinámica arqueoecológica de la ocupación prehistórica*. Sevilla: Junta de Andalucía.

DELGADO RAACK, S. (2008) - Prácticas económicas y gestión social de recursos

(macro)líticos en la prehistoria reciente (III-I milenios AC) del Mediterráneo occidental. Bellaterra: PhD, Universitat Autònoma de Barcelona.

DELGADO RAACK, S.; GÓMEZ-GRAS, D.; RISCH, R. (in press) - Las propiedades mecánicas de los artefactos macrolíticos: una base metodológica para el análisis funcional. In *Proceedings of the VII Congreso Ibérico de Arqueometría (October 2007)*. Madrid.

DUBREUIL, L. (2002) - *Etude fonctionnelle des outils de broyage natoufiens: nouvelle perspectives sur l'émergence de l'agriculture au Proche-Orient*. Bordeaux: PhD, Université Bordeaux I,.

HAMON, C. (2006) - *Broyage et abrasion au Néolithique ancien. Caractérisation technique et fonctionnelle des outillages en grès du Bassin parisien*. Oxford: B.A.R., International Series, 1551.

HAYDEN, B., ed. (1987) - *Lithic studies among the contemporary Highland Maya*. Arizona: University of Arizona Press.

HOCHULI, S.; MAISE, Ch. (1998) - Geräte und Schmuck aus Stein. In *Die Schweiz vom Paläolithikum bis zum frühen Mittelalter: Bronzezeit*. Basel: Schweizerische Gesellschaft für Ur- und Frühgeschichte, p. 269-273.

HORSFALL, G.A. (1987) - Design Theory and grinding stones. In HAYDEN, B. ed. - *Lithic studies among the contemporary Highland Maya*. Arizona: University of Arizona Press, p. 323-377.

HÜRLIMANN, F. (1965) - Neolithische Reibmühlen von einer Ufersiedlung am

Greifensee. *Jahrbuch der Schweizerischen Gesellschaft für Urgeschichte*. 52, p. 72-86.

MENASANCH, M.; RISCH, R.; SOLDEVILLA, J.A. (2002) - Las tecnologías del procesado de cereal en el sudeste de la Península Ibérica durante el III y II milenio ANE. In PROCOPIOU, H.; TREUIL, R. eds. - *Mouldre et Broyer*. Paris: Publications du CNRS, p. 81-110.

MEURERS-BALKE, J.; LÜNING, J. (1992) - Some Aspects and Experiments Concerning the Processing of Glume Wheats. In ANDERSON, P. C. ed. - *Préhistoire de l'agriculture. Nouvelles approches expérimentales et ethnographiques*. Paris: Monogr. Centre Rech. Arch. 6, p. 341-362.

PANYELLA, A.; SABATER, A. (1959) - El pulimento de la piedra en un pueblo bantú, los fang ntumu de la Guinea Española y su valoración cultural. In V C.N.A. (Zaragoza 1957), p.79-86.

PROCOPIOU, H.; TREUIL, R., eds. (2002) - *Mouldre et Broyer*. Paris: Publications du CNRS.

RISCH, R. (1995) - *Recursos naturales y sistemas de producción en el Sudeste de la Península Ibérica entre 3000 y 1000 ANE*. Bellaterra: PhD Universitat Autònoma de Barcelona (www.tesisenxarxa.net/TDX-0507108-164458/).

RISCH, R. (2002) - *Recursos naturales, medios de producción y explotación social. Un análisis económico de la industria lítica de Fuente Álamo (Almería), 2250-1400 antes de nuestra era*. Mainz : P. von Zabern.

RISCH, R. (2008), "Grain processing technologies and economic organisation: a case study from the south-east of the Iberian Peninsula during the Copper Age", *The Arkeotek Journal*, vol.2, n°2 (www.thearkeotekjournal.org).

SCHÖN, W.; HOLTER, U. (1988) - Zum Gebrauch von Reib- und Mahlsteinen in der Ostsahara. *Archäologische Informationen*. 11, p. 156-160.

STARNINI, E.; VOYTEK, B. (1997) - *New light on old stones: the ground stone assemblage from the Bernabò Brea excavation at Arene Candide*. *Memorie dell'Istituto Italiano di Paleontologia Umana*. 5, p. 427-511.

WRIGHT M.K. 1993. "Simulated use of experimental maize grinding tools from southwestern Colorado". *KIVA*, 58, p. 345-355.

ZIMMERMANN, A. (1988) - Steine. In BOELICKE, U., BRANDT, D. V., LÜNING, J., STEHLI, P., ZIMMERMANN, A.. eds. - *Der bandkeramische Siedlungsplatz Langweiler 8, Gemeinde Aldenhoven, Kr. Düren*. Bonn: Rhein.Ausgrab. 28, p. 569-787.

ZURRO, D.; RISCH, R.; CLEMENTE, I. (2005) - Analysis of an ethnological mill: what to do with archaeological items. In TERRADAS, X., ed.), *L'outillage lithique en contextes ethnoarchéologiques – Proceedings of the XIVth U.I.S.P.P. Congrès*. Oxford: B.A.R., International Series. 1370.