Special Issue: Reduction Sequence, *Chaîne Opératoire*, and Other Methods: The Epistemologies of Different Approaches to Lithic Analysis

The History and Efficacy of the *Chaîne Opératoire* Approach to Lithic Analysis: Studying Techniques to Reveal Past Societies in an Evolutionary Perspective

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ABSTRACT

We present here a brief history of the origins and development of the concept of *chaîne opératoire*, followed by details of the theory of the technological approach (including the protocol), in order to illustrate the gradual shift in lithic analyses in France:

- from a Natural Science, and the study of the "progressive development of Prehistoric Humans,"
- to Anthropology, and the use of techniques to investigate societies through an evolutionary perspective.

We also elaborate/provide insights on the limits, advantages, and potential future directions for the technological approach. Throughout this paper, we focus on the technological approach developed in France and give examples taken mainly from the Middle Paleolithic, our main area of expertise.

This special issue is guest edited by Gilbert B. Tostevin (Department of Anthropology, University of Minnesota). This is article #5 of 7.

A BRIEF HISTORY OF THE ORIGINS AND DEVELOPMENT OF THE *CHAÎNE OPÉRATOIRE* APPROACH IN FRANCE

BEFORE THE *CHAÎNE OPÉRATOIRE*

The Progressive History of Prehistoric Humans

During the second half of the 19th century and the early 20th century, the analysis of lithic technology was based on the personal ability of scholars to comprehend the entire range of prehistoric stone tool variability, and then to synthesize the differences across time in order to unravel the progressive or "*positive*" steps toward humanity. Ancient societies were thus viewed mainly as evidence of the different steps through which human beings evolved, whether these steps were unique (Mortillet 1883) or parallel (Peyrony 1920, 1930; Breuil 1932a, b) (the journal founded in 1864 by G. de Mortillet was entitled "Matériaux pour l'histoire positive et philosophique de l'homme"[1]).

Because there was no precise and explicit typology, the same tool could be designated in different ways by different scholars, and sometimes in different ways by the same scholar throughout his or her lifetime (see Monnier, 2006)[2]. The lack of emphasis on methodology was likely a consequence of the "management" of prehistoric archaeology by a few scholars who based their interpretations on their own extensive experience. The only exception to this rule might be the emphasis placed on the explanation of the "techniques of intentional chipping" (Breuil and Lantier 1951, 1965), which, interestingly, may have been driven by the need to train less experienced archaeologists (including amateur archaeologists who by then constituted the majority of archaeologists) to distinguish artifacts from geofacts.

Prehistoric Humans Through Their Stone Tools

It was not until the 1950's that French scholars clearly emphasized the need to explicitly describe their methodology ((Bordes 1950; Bordes and Bourgon 1951; Bourgon 1957)). This is illustrated, for example, by F. Bordes' book on the typology of Lower and Middle Paleolithic tools (Bordes 1961), D. de Sonneville-Bordes' and J. Perrot's typology of the Upper Paleolithic (Sonneville Bordes and Perrot, 1954, 1955, 1956a, b) and G. Laplace's own analytical typology (Laplace 1966). This new approach was guided by new

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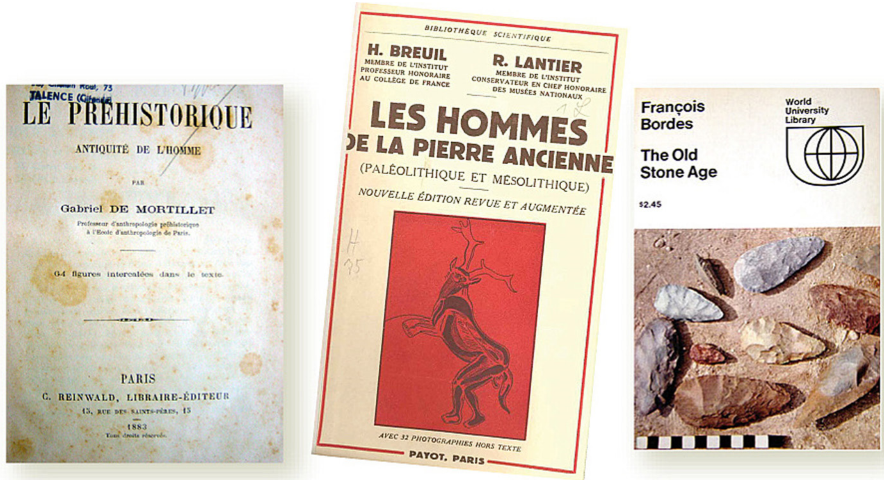

Figure 1. Book covers illustrating how the focus of scholars shifted from understanding the linear and progressive framework of "Prehistoric Man" (Mortillet 1883) to the understanding of "Men of the Old Stone Age" (Breuil and Lantier 1951) to the stone tools of the "Old Stone Age" (Bordes 1968).

questions concerning the fine-scale variability of large chrono-cultural entities such as the Mousterian (Bordes 1953). Using these newly defined typologies, and also quantifying his observations for the first time, F. Bordes subsequently subdivided the Mousterian into four sub-types, which to his surprise, seemed to correspond to the traditions of different groups living in the same territories, more or less at the same time (Bordes 1953: 465).

These new tools, consisting of a clearly defined typology and the use of quantitative methods, shed new light on the synchronic variability of Mousterian assemblages. There was a clear shift in the perspectives of scholars that was expressed in the titles of their books, changing from "Prehistoric Man" (Mortillet 1883) to "Men of the Old Stone Age" (Breuil and Lantier 1951) to "The Old Stone Age" (Bordes 1968) (Figure 1). The focus shifted from a general understanding of diachronic changes within a "*positive*," and thus linear and progressive framework of Man, to the understanding of prehistoric humans (who became plural, multiple, and variable) and the stone tools through which they could be comprehended.

Bordes' innovative and rigorous classificatory approach was widely adopted in the 1960's and 70's and was exported all over Europe and Asia (e.g., Bordes, 1968), with the result that the Quina Mousterian was identified in the Caucasus Mountains and on the Siberian plains, some 6000km away from the eponymous site! Yet, by focusing mainly on Paleolithic stone tools, F. Bordes and his followers risked isolating themselves (which they actually did) from scholars in other disciplines, especially ethnography and the philosophy of science and techniques (we will return to F. Bordes's relations with A. Leroi-Gourhan and A.-G. Haudricourt below).

The "New Archaeology" school quickly rejected the cultural interpretation of Mousterian variability, asserting that contemporaneous and neighboring groups cannot avoid influencing each other (Binford 1973). The Parisian school, led by A. Leroi-Gourhan, advocated a more heuristic approach focusing on a shorter time depth, especially within the Upper Paleolithic, taking into account habitat structures and the spatial distribution of remains on living floors (Leroi-Gourhan and Brezillon 1983).

From Stone Tools to Prehistoric Life

Meanwhile, Bordes' capacity to reformulate his questions as a function of new input is clear in a paper he published in 1972 in collaboration with J.-Ph. Rigaud and D. de Sonneville-Bordes (Bordes et al. 1972). This paper was entitled "Goals, Problems and Limits in Palaeolithic Archaeology." F. Bordes and his co-authors asked how we can better understand "Palaeolithic life", and they spoke about "a return to one's roots" after 10 or 15 years spent focusing on the variability of Mousterian stone tools through the magnifying glass of typology. They promoted an integrated study of synchronic sites occupied by prehistoric nomadic groups at different periods of the year and for different purposes. One key to reconstructing Paleolithic life would thus be to integrate the results of lithic analysis, faunal analysis, and spatial analysis of the distribution of remains. They even mentioned the influence of raw material availability on site function. However, though F. Bordes encouraged (at the University of Bordeaux I) the development of new approaches such as use-wear analysis (Anderson-Gerfaud 1981; Kantman 1971) and raw-material analysis (Demars 1982), the true formulation and development of the *chaîne opératoire* approach occurred in Paris in the late 1970's.

THE *CHAÎNE OPÉRATOIRE*: AN ANTHROPOLOGICAL APPROACH TO PREHISTORIC SOCIETIES THROUGH THEIR TECHNIQUES

The concept of technology as the science of human activities was proposed in France by A. Leroi-Gourhan when he was still working mostly in the field of ethnology (see

Figure 2. Book covers illustrating the original separation of the disciplines of Ethnology (Leroi-Gourhan 1943 (recent edition), the History of Sciences (Haudricourt 1987), and prehistoric Archaeology (Tixier, Inizan, and Roche 1980), which were ultimately integrated (Latour and Lemonnier 1994).

Leroi-Gourhan 1943: "l'Homme et la matière," first volume of Evolution et Techniques, and Soulier 2003), and later by the historian of science A.-G. Haudricourt in the 1960's (Haudricourt 1964; 1987). Both were former students of M. Mauss who had earlier recognized the benefits of understanding a society through its techniques (Mauss 1927, 1947, 2006; Schlanger 1991). The term *chaîne opératoire* was first used by A. Leroi-Gourhan (1964: 164, 1993), who did not formalize it (Desrosiers 1991; Schlanger 2004), but opened the path for its future use in ethnology and archaeology through his publications, teaching at the University of Sorbonne (Paris) and through his leadership of the "*Ethnologie préhistorique*" research team.

From the late 1970's to the early 1990's, J. Tixier[3], M.-L. Inizan, H. Roche and their colleagues defended a new approach to prehistoric societies through the study of stone artifacts, which they qualified as a technological approach, i.e. not only a typological one designed to classify, but one that could result in a deeper understanding of the social significance of the techniques used in the past (Tixier 1978, 1979, Tixie et al. 1980). This approach shifted focus from the study of prehistoric humans through their stone tools to the study of prehistoric societies through their techniques. From this perspective, a technique is understood as a social product, as well as a founding element of the society, which "constitutes the technique, conditions it, reproduces it and shapes it" (Schlanger 1991: 2). Consequently, the study of the technique—or Technology—enables us to understand the society in which the technique originated. Tixier and his colleagues renamed their CNRS[4] department: Prehistory and Technology.

Through time, Tixier and his colleagues introduced into archaeology the concepts of technical system, production processes, and technical intention, all of which had been recently formulated by French ethnographers studying material culture (see Balfet 1975; Cresswell 1983; Lemonnier 1976; also, at about the same time, R. Cresswell and his team founded the journal "Techniques et cultures"). They debated how these concepts could be useful in describing and interpreting the variability observed in Paleolithic industries in cultural terms. It took them around 15 years to make their approach explicit, as we can see in the changes made between the two major versions of their textbook "*Préhistoire de la Pierre Taillée*" (1995; Inizan et al. 1992; Tixier et al. 1980), and in the papers published by their students and colleagues (e.g. Boëda 1986, 1994; Geneste 1985; Pelegrin 1986, 1995; Perlès 1989). The 1995 version of their textbook (Inizan et al. 1995, 1999: 13 for the English translation) starts with a citation from A.-G. Haudricourt that justifies the French technological approach: "while the same object can be studied from different viewpoints, that which consists in defining the laws of creation and of transformation[5] of an object is undeniably the most essential of all viewpoints" (Haudricourt 1964 in Haudricourt 1987: 38). With this introduction, J. Tixier and his colleagues clearly single out one approach, that of the *chaîne opératoire*. However, this citation does not appear until the 1995 version of the book, showing that the integration of the work of Tixier and his collaborators with that of Ethnologists and Historians of Science did not occur before the early 1990's. Additionally, the idea that a technique is evidence of the society by which it was produced became a standard topic explicitly shared by prehistoric archaeology, the history of science, and cultural anthropology at about the same time (see, for example, the association of B. Latour, historian of Sciences, and P. Lemonier, ethnologist, for a book entitled "The Social Intelligence of Techniques" published in 1994) (Latour and Lemonnier 1994) (Figure 2).

THEORY OF THE TECHNOLOGICAL APPROACH TO LITHIC INDUSTRIES

Proponents of the technological approach in France have been more concerned with providing an analytical tool than with making a theoretical statement (Sellet 1993).

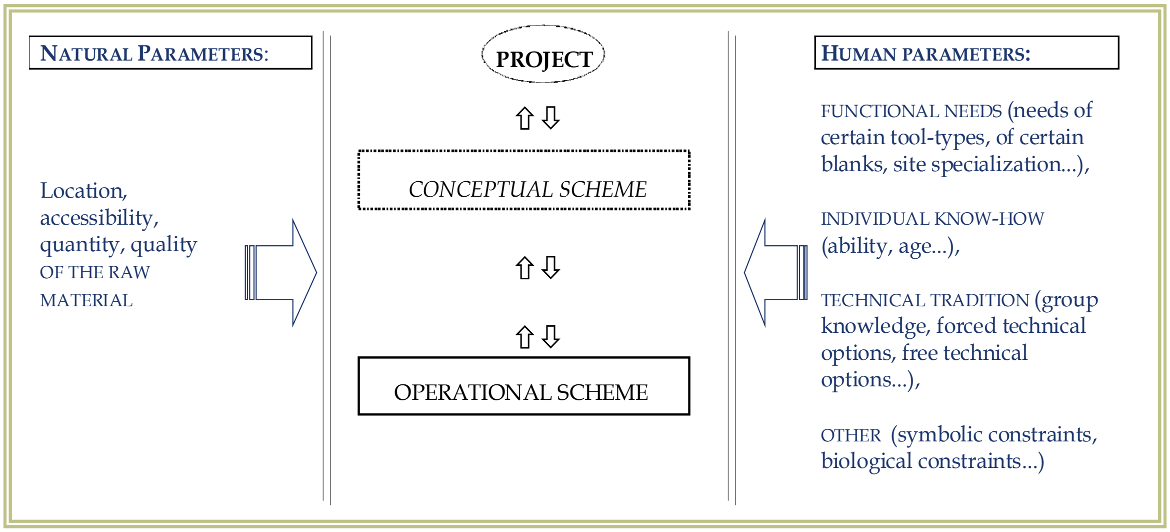

Figure 3. Relationship between the project, conceptual scheme, and operational scheme from the knapper's point of view (after Inizan et al. 1995 [Pigeot 1991]).

Nonetheless, several papers and books address the theoretical background of the technological approach.

METHODOLOGICAL FOUNDATIONS

The claim for a technology of knapped stone, through a *chaîne opératoire* approach, had, in effect, to incorporate stone tool studies within the general context of Paleolithic society. Consequently, the context in which the stone tool was produced was recognized as being as important as the process of manufacture and use itself. Every stone tool is a product of the technical system of a society, and more precisely, a product of the lithic sub-system (Inizan et al. 1995), which interacts with the bone tool sub-system, or with the wooden tool sub-system for instance, within the larger technical system of the group.

From a cognitive point of view, the approach envisioned lithic production as being managed first by a cognitive project, which was then translated into a conceptual scheme that would be made concrete through an operational scheme[6] (Inizan, et al. 1995: 15). Each of these steps are dependent on several natural and human parameters (Inizan et al. 1995; Pelegrin 1991, 1995; Pigeot 1991), which are summarized in Figure 3.

The theory is as follows: the constant elements (regularities) of the operational scheme allow determination of the conceptual scheme driving the operational scheme. The definition of the goals of the conceptual scheme allows definition of the initial project (this will be illustrated below by Figure 9). Consequently, it is because a gesture is constant or recurrent that it can be interpreted as intentional (although it is still influenced by human and natural factors).

The natural factors and their influence on the process are understood by comparing the nature and origin of the archaeological raw materials with the current raw material location, accessibility, quantity, and quality. The human factors would be inferred from, for example, the identified goals of the process (cf. functional needs), analyses of the individual know-how of modern flintknappers (cf. prehistoric individual know-how), or the inferred methods and techniques used during the process (cf. technical tradition).

THE "*CHAÎNE OPÉRATOIRE* TOOL"

The *chaîne opératoire* approach allows archaeologists to reconstruct the time/order arrangement of the different steps used to produce an artifact (Geneste 1991b: 10). Each artifact can be situated within the process through an analysis of the technical stigmata (i.e., nature and location of large flake scars, abrasion traces, or the point of impact) of the previous operations that are preserved on the object (Pelegrin et al. 1988). The *chaîne opératoire* approach also allows an understanding of the geographical organization of the technical process, as the location of each stage of the process can be identified by the presence or the absence of its by-products at a particular site (Geneste 1985, 1991a, b). Consequently, the differential management of raw materials and/or blanks can be observed, which allows us to define the economic management of raw-material and/or blanks within a territory (Inizan 1976; Perlès 1980, 1989).

Experimental and Archaeological Frames of Reference

The efficacy of the "*chaîne opératoire* tool" is augmented by physical experiments performed by archaeologists using the raw materials employed by prehistoric groups to produce their stone tools, as well as by the growing number of analyses of archaeological assemblages using this methodology. For instance, the physical stress that occurs during the fracturing of rock has been explored (e.g., from Speth 1972 to Pelcin 1998)[7]. The gesture (action) and nature of the hammer used to fracture rocks, as well as their effects on the raw material, have also been studied (e.g., from Crabtree 1972 to Pelegrin 2000), as have uncontrolled knapping accidents, such as breaks, plunging flakes, hinge-fractures, and others (Callahan 1979; Crabtree 1972; Inizan et al. 1995; Johnson 1979; Roche and Tixier 1982: 34–38). Characteristic indications of the temporal ordering of each piece in many different processes, which were deduced and hypothesized from the study of archaeological materials, have been verified by artifact refitting and experimental reproduction[8] of these processes (e.g., from (Newcomer 1971 to Locht 2002; Mora et al. 1991)). And, of course, the archaeological database concerning the methods used during the Paleolithic in western Europe (for example) has grown a great deal over the last 20 years (e.g., Dibble and Bar-Yosef 1995; Peresani 2003).

Study Protocol

As an example, we present the protocol used in one of our manuscripts (Soressi 2002: 48–50). We do not present a protocol for taphonomic analyses of lithic assemblages, as they can be found elsewhere (e.g., Villa and Soressi 2000, and references therein). Analyzing the taphonomy of a lithic industry is of course a necessary preliminary to any study, as it allows us to define the reliability of the lithic assemblage to answer behavioral questions.

In a technological study, the first step is to separate the artifacts according to the raw material from which they were made, based on criteria that could have influenced the knapping process, such as the petrographic nature and alteration to the cortex. These aspects indicate:

- the geological bed from which the raw material was collected, and
- the primary or derived context of the outcrop.

Within each raw material category, it is useful to separate the "negative" artifacts (i.e., cores and bifaces; cf. Carbonel et al. 1983), on which the last removals are negative, from the "positive" ones (flakes), on which the last blow produced the ventral face of the artifact (retouch is not taken into account at this stage)[9]. Within these categories, the artifacts with and without cortex are then separated and among these, the artifacts are ranked according to their dimensions. This ordering can provide a preliminary indication of the order of production of each artifact because, during the knapping process, as cortex cover diminishes so should the artifact size (e.g., Ahler 1989; Dibble et al. 2005; Geneste 1985; Newcomer 1971), if all the negative artifacts were not abandoned at the same stage, and if positive artifacts, cortical and non-cortical, are present.

In the second step, the objective is to understand the "techniques" and "methods"[10] used to produce the assemblage. Within the above categories, artifacts can be separated according to techniques, knowing that it is often very difficult to accurately determine the technique used to produce each artifact (see Soressi 2002: 53–54 for a synthesis of some of the criteria that can be used to recognize techniques).

Then, by observing the organization of removals on each piece (see Soressi, 2002: 55 for a description of the criteria used to reconstruct the direction and chronology of the removal of each piece), including on its platform, it should be possible to reconstruct a short sequence of removals. These can then be arranged in sequential order to reconstruct the global sequence, or method(s), used to produce the assemblage, as in a virtual three dimensional puzzle.

Of course, some artifacts are more useful than others, as the short sequence that they illustrate may or may not be characteristic of a step in the process. Also, some steps are essential to the process and their presence or absence is thus always significant. For instance, if the method used consists of maintaining a debitage surface and a platform surface on the core, then two types of flakes are essential—flakes that maintain the surfaces by creating concavities and thus adjacent convexities, and flakes that use those convexities and "destroy" them by creating flat areas or concavities. Consequently, the first flake type will have an asymmetrical transverse section and/or an asymmetrical longitudinal section, whereas the second type will have symmetrical sections. For example, the Levallois method depends on the alternative production of an "*éclat débordant*" (core edge flake) and other types of "maintenance" flakes, and the production of true "Levallois flakes" (cf. Boëda et al. 1990; Boëda and Pelegrin 1979) (Figure 4a vs. 4b). However, symmetrical and asymmetrical flakes do not correlate with desired end product and waste.

Therefore, the <u>direction</u> of the sequence of removals, as well as its <u>internal hierarchy</u>, is reconstructed based on:

- the diminution of cortex (even if this is not very precise: if cortex is maintained on some portion of the cores all along the process—as in Levallois debitage—only highly cortical removals will attest to one particular stage, the beginning of the core reduction sequence);
- the diminution of artifact size (both absolute scalar and relative size; even if removals of the same type in a standardized production might not vary greatly in size throughout much of the process);
- the recognition of the removal types that alternatively produce and use/destroy the convexities on the core (e.g., the core edge flake and the true Levallois flake);
- the positioning of these two types of removals on the volume of the core (determined by the scars present on their upper face and their morphology) (e.g., at the intersection of two surfaces of a core edge flake, on a large surface for the Levallois flake—as indicated by the morphology of the core edge flake and of the Levallois flake, as well as the morphology of some of the cores); and,
- the chronology between these two types of removals (e.g., the core edge flake comes after a preceding Levallois flake, as indicated by the chronology of the removals on the core edge flake itself, but it will be followed by another Levallois flake, as indicated by the chronology of the removals on the exhausted cores) (Figure 4).

The goal of the third step is to reconstruct the morphological characteristics of the products of the operational sequence, which are determined by the techniques and methods used to produce them.

The last step consists of determining if each step of the

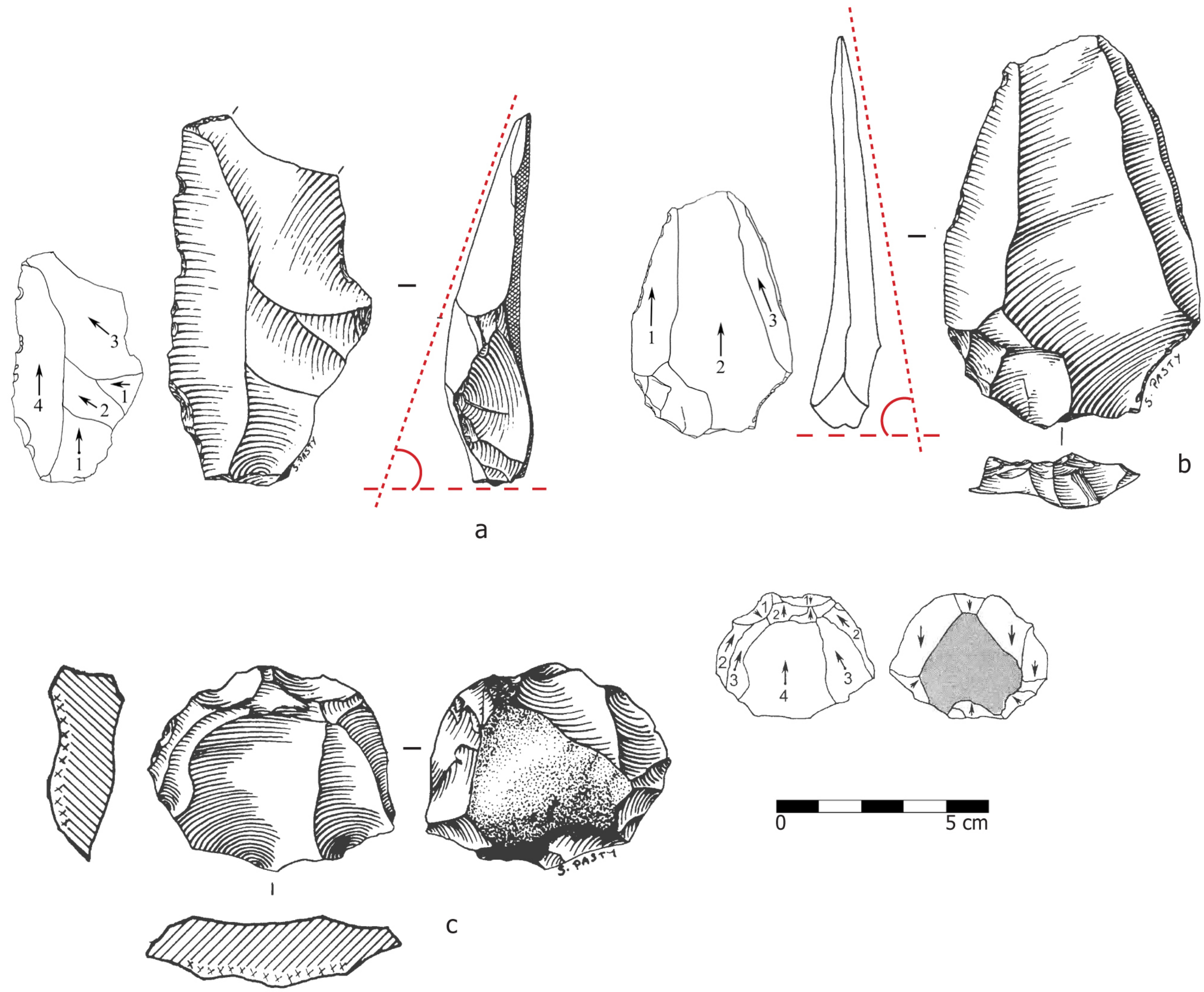

Figure 4. a) "Débordant" (core edge) Levallois flake with an asymmetrical section (its removal increases the lateral convexity of the Levallois core to the left of the flake platform but lowers the convexity to the right of the flake); b) True or "full Levallois" flake with a symmetrical section (its removal flattens the Levallois core); c) Levallois core (showing the alternating removal of "débordant" flakes and of "full Levallois" flakes (all from Le Moustier, Layer G, Soressi [1999]).

chaîne opératoire is present for each raw material in the assemblage. Each step of this procedure must be completed for each of the raw material types identified.

Observations and attribute combinations judged relevant during the physical classification of the artifacts are then quantified to allow the use of descriptive and comparative statistical tests.

LIMITS, ADVANTAGES, AND FUTURE DIRECTIONS FOR THE TECHNOLOGICAL APPROACH

CONTEXTUAL LIMITS

Quantification and Inductive/Deductive Reasoning

A "rebellion" against the use of the Bordian typology as a goal in and of itself (when interpretations went no further than assigning an assemblage to a particular Mousterian facies) and the emergence of technological approach (Tixier 1979 and see details in Endnote 4) occurred simultaneously. This likely had some methodological consequences, which by themselves are not justified by the theoretical foundations of the then-new approach. These consequences were:

- The rejection of formal quantification, which was sometimes considered as a goal in and of itself by researchers using the Bordian typology. Also, and more importantly, the first technological studies were aimed at recognizing the different methods used by prehistoric groups as indicators of cultural entities, an approach which, by itself, does not need quantification (see, for instance, the textbook written by Inizan et al. 1995 in which artifact illustration is presented as a demonstrative tool, but quantification is not).
- The rejection of the piece-by-piece study of an assemblage (probably as a consequence of the rela-

tionships that must be established between pieces when each is considered as part of a puzzle. Each piece is not meaningful by itself, but only within the context of the assemblage),
- The rejection of a pre-established input grid (or data-entry spreadsheet with attributes to be noted for each artifact), which might be a consequence of the two first phenomena.

Still, quantification and a predefined input grid have been used in some technological research (e.g., Pelegrin 1986, 1995), especially those studies focusing on the economy of the knapping process (e.g., Geneste 1985, 1988).

One hindrance to the growth of quantification has been the lack of published quantified experiments that could be used as a reference for interpreting quantified data. For instance, the only reference we have concerning the quantity of Levallois flakes of each type produced during Levallois debitage (which is very useful in order to interpret the number of artifacts exported or imported at a site) is that published by J-M. Geneste in his dissertation in 1985 (an experimental program is, however, currently in progress by L. Bourguignon, M. Brenet, and colleagues).

Furthermore, a grid cannot be established before an initial global observation of the assemblage has been made; this is usually done with the assemblage organized on tables in the manner described above in the protocol section. The input grid, which allows quantification by recording the attributes of each piece, is defined after this first superficial, visual analysis of the assemblage. In this way, only the pertinent attributes, i.e. the ones that we are able to interpret, are chosen. The use of a pre-established input grid was developed especially for the analyses of experimental work (e.g., Bourguignon 1997, 2001).Meanwhile, some recent technological analyses demonstrate that statistical analyses of quantified data (now easily manageable with the aid of computers) greatly aid in understanding and interpreting the results of technological analyses of assemblages (e.g., Soressi 2002), as well those of other types of analyses.

The "Technical Tradition" Effect

In an assessment of twenty-five years of technological studies, published in 1991 by French researchers (Collectif 1991) (Figure 5), some of the major accomplishments of the technological approach were highlighted (Perlès 1991). These are:
- the accumulation of data on prehistoric technical knowledge, i.e., evidence of the technical traditions of different societies, resulting in the identification of the major methods and techniques of most periods; and,
- relatively numerous analyses of the organization of knapping activities over prehistoric landscapes in the form of case studies investigating the economy of the flintknapping process through the selection of raw materials and tool blanks.

Meanwhile, other aspects had been less thoroughly explored, including:
- the evaluation of the cognitive capacities necessary to carry out the different operational schemes; and,
- the definition of the social and economic contexts in which the flintknapping activities were carried out, or in other words, the relationship between the social and the economic context and the dynamic of technical changes.

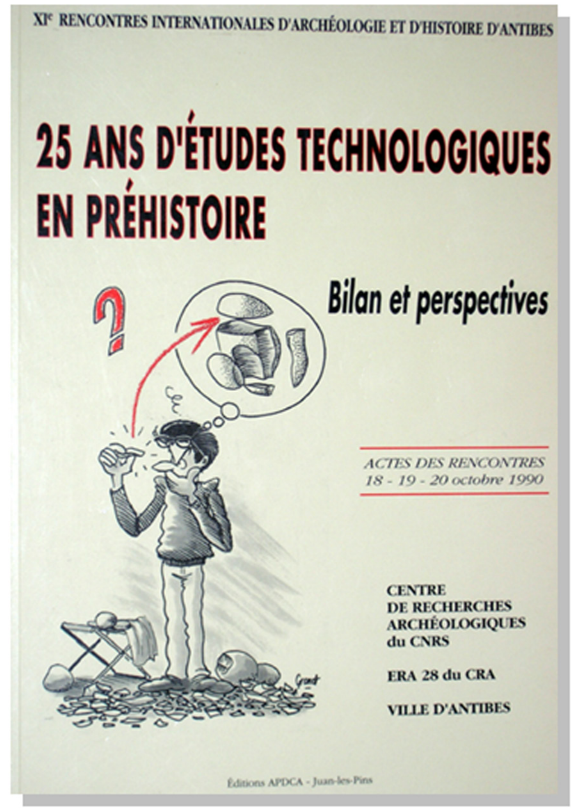

Figure 5. Cover of 25 ans d'Etudes technologiques, Bilan et Perspectives, *1991 (Collectif 1991).*

The lack of progress in these latter two aspects is due to what we might call "the technical tradition" effect. Since most of the first efforts of the pioneers of the technological approach focused on the definition of potential technical traditions (identified through the techniques and methods used in particular assemblages), the technological approach became known for this focus rather than for its broader aspirations, which originally included the investigation of the cognitive and social contexts of prehistoric life.

STRUCTURAL/INTERNAL LIMITATIONS

The Problem of Co-Occurrence

When several different and unrelated processes (from a technical or a spatial point of view) are observed within one assemblage, it is impossible to determine if this is related to the use of different processes at the same time by a single group, or to the successive occupation of the site by groups using different processes. This limitation is shared by all approaches to lithic analysis as it is related more to site formation processes than to the method and theory of artifact

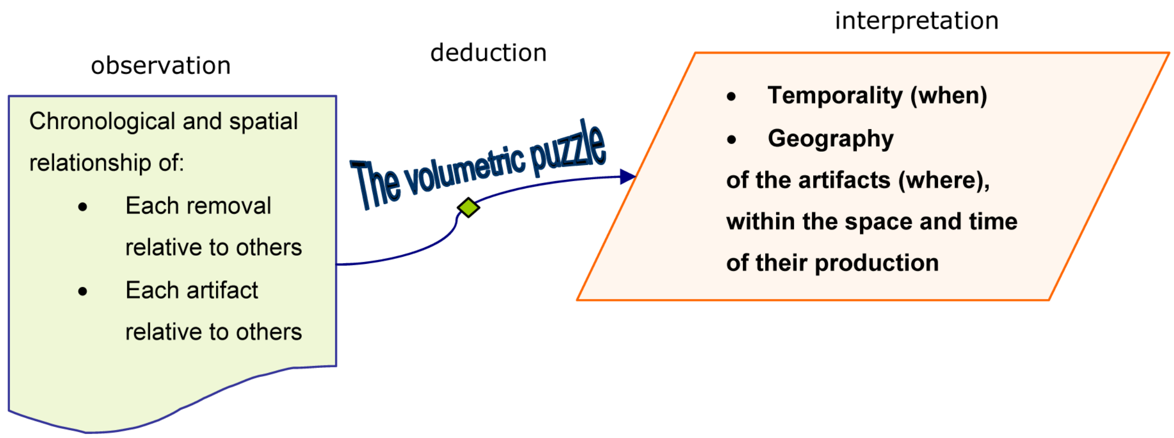

Figure 6. Reconstructing the volumetric puzzle and how the "reading" of each artifact allows the analyst to locate it within the space and time of its production process.

analysis. Extensive refitting between artifacts belonging to different *chaîne opératoires*, or different areas of the site, is usually used to discuss this problem of co-occurrence (e.g. Delagnes 1996; Tostevin and Škrdla 2006).

The Problem of Representation

The only links (steps) of the *chaîne opératoire* that are susceptible to be recognized are those that are represented in an assemblage by numerous artifacts or which are not represented by numerous artifacts, but by a few diagnostic ones that match a pattern characterized and precisely described elsewhere based on numerous artifacts[11]. This problem has been debated by A. Gallay (1986) and is not specific to the technological approach. Note, however, that this approach is more susceptible to such problems, since the methodology is not based on a piece-by-piece recognition, but rather on the establishment of the chronological and hierarchical relationship between a few individual pieces.

Of course, when one process is represented by a small number of pieces, it is impossible to determine whether this process is representative of the prehistoric group or if it is anecdotal, and thus representative of an idiosyncratic assemblage unlike others created by the same prehistoric society.

The Problem of Completeness

As a consequence of the problem of anecdotal processes, the reconstructed operational schemes are all-encompassing in essence and cannot be considered as exhaustive. In other words, other operational schemes could have been used, but they are not represented by a sufficient number of pieces to be recognized.

Technological analyses are therefore more precise if the number of pieces is greater, whereas to solve the problem of co-occurrence, the analysis would benefit from an assemblage representing the smallest time depth, which often produces a smaller assemblage. This is again a limitation shared by other methods of stone tool analysis.

ADVANTAGES

The technological approach, grounded in the use of the "*chaîne opératoire*" tool, has the capacity to guide the analyst through each step of analysis and interpretation. It has the potential to become an explicit methodology.

From the 3D Rock Puzzle to the Morphological and Economic Intentions

One of the advantages of the *chaîne opératoire* is to provide a definition of the "temporality," as well as the "geography," of each artifact within the space and the time of the flint-knapping activity. Each object can be considered in its processual context due to several attributes that have been tested through experimental replication and are thus known to be meaningful in an understanding how prehistoric people broke volumes of stone to produce useable cutting edges; we might call this the volumetric (or 3D)[12] puzzle.

The dynamic processes at the origin of each artifact are "read" at two scales:

1. The scale of the object itself: the chronology of the removals on a core allows us, for example, to determine if there was a temporal hierarchy between two surfaces during its debitage (reduction). If there was, one surface had to be used after the other, and this first surface, the platform surface, is the surface from which the last and often larger removals were removed.
2. The scale of the chronological relationship between objects within the assemblage: this analysis allows us to identify at what stage the artifacts were abandoned, whether at an initial, advanced, or exhausted stage of core reduction, for example (Figure 6).

Through experimental replication and experimental fracturing of flint, researchers have identified variables that determine the morphology and economy (how many flakes produced per kilogram) of the end-products and it thus it is possible to search for the expression of these variables in

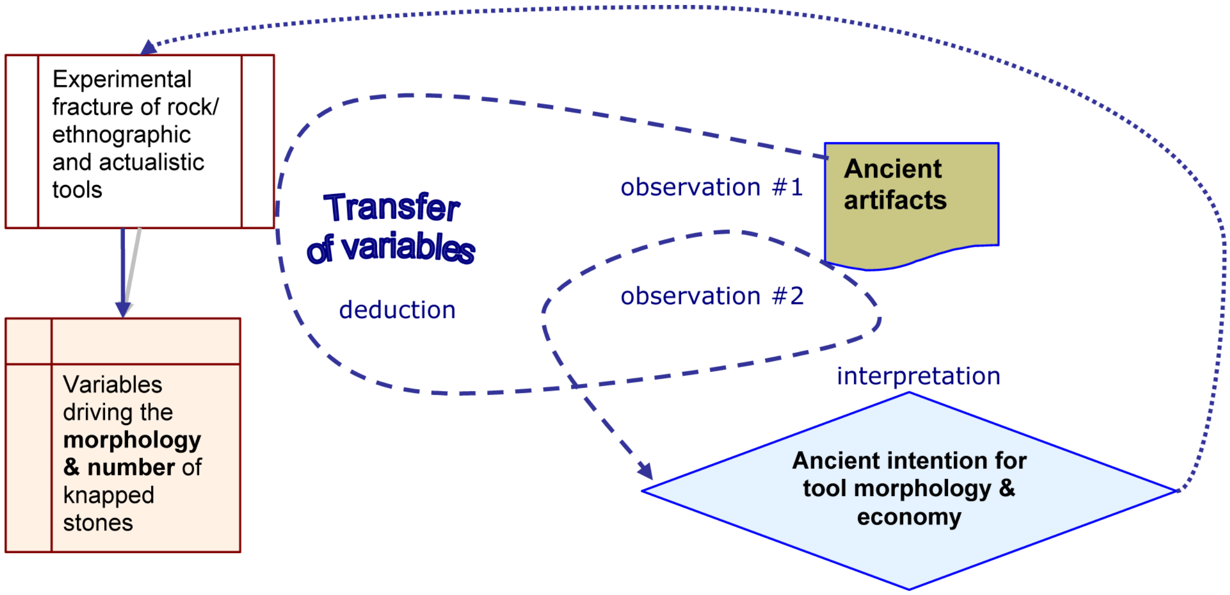

Figure 7. Transferring the effects of variables identified through the experimental rock fracturing to ancient artifacts, in order to gain insights into ancient intentions.

the archaeological record, and possibly to define the intentions of prehistoric artisans (see Soressi 2005; Figure 7).

The technological approach is not an analysis of the form or morphometric features of an object, but rather a dynamic, volumetric, and geographic analysis based on the transfer[13] of variables selected from an actualistic reference base. This interpretative background allows us to reach a global interpretation, and not only a descriptive listing of the archaeological remains. An example of the attributes recorded, the conceptual scheme deduced, and the interpreted intentions in the context of an analysis of Mousterian of Acheulian Tradition assemblages from Pech-de-l'Azé I (Figure 8) is provided in Figure 9.

A Posteriori Attribute Definition and the Importance of the Assemblage Context

Our experience with scholars using different approaches gave us the feeling that our *a posteriori* definition of attributes, which is based on hypothetico-deductive reasoning, can be one of the main practical differences between our technological approach and others. The definition of attributes recorded on each piece after a first examination of the assemblage, once it has been organized on a table, offers a major advantage—it allows the use of attributes that are more precise and more relevant because they are more specific to the actual operational scheme used. This procedure avoids *a priori* averaging of the recorded attributes to make sure they will fit every situation. Of course, the final interpretation of the expression of the attributes will be based on the next step, which is quantitative analysis. Before going further, and after discussions with the editors of this volume, we should add that the personal practice of each researcher, depending if this person is more into "descriptive" versus "explanatory" research, would certainly change their approach to the point raised here. Here, we certainly place ourselves in a position where we do not want to exhaustively analyze one lithic assemblage, but we tend to define the attribute after having looked at the collection and after having defined the interesting questions we want to ask (among the several dozens of potential questions) and the ones that the collection can actually answer.

For example, some artifacts that we now recognize as biface shaping flakes within the context of the Mousterian of Acheulian Tradition were originally classified as Levallois flakes. This is clear from F. Bordes' Pech-de-l'Azé I collection, for example, which was conserved in the museum with his original classifications (Figure 10). This difference results from a definition of Levallois flakes that was not sufficiently precise, but also because the classification of the flakes as Levallois occurred independently from the rest of the assemblage, as if each had been an individual find without context. However, there is a context showing that most of the "negative" artifacts in these assemblages are bifaces, that these bifaces were shaped with several dozens of removals that left a complicated scar pattern (a characteristic shared with Levallois cores), and that numerous attributes of the flakes themselves bespoke a different method of production. These attributes, which are all useful in distinguishing biface shaping flakes from Levallois flakes, include the angle between the platform and the distal extremities of the removal and the thinness of the platform, in particular relative to the length of the flake and to the length of the platform itself. Therefore, it is through use of the context of all of the artifacts in the assemblage that one is able to define the attributes that are useful to reconstruct the dynamic puzzle of knapped stone-tools.

In any case, we interpret only what we are able to understand. Consequently, this *a posteriori* definition of attributes is not less objective than an *a priori* attribute definition. In an *a priori* definition, attribute choice is driven by previous

Figure 8. Photos of some of the artifacts analyzed following the approach illustrated in Figure 9: a and c) scrapers on biface shaping flakes; b and d) "raclettes" on biface shaping flakes; e) Mousterian of Acheulian Tradition biface (all from Pech-de-l'Azé I, after Soressi et al. [2008]).

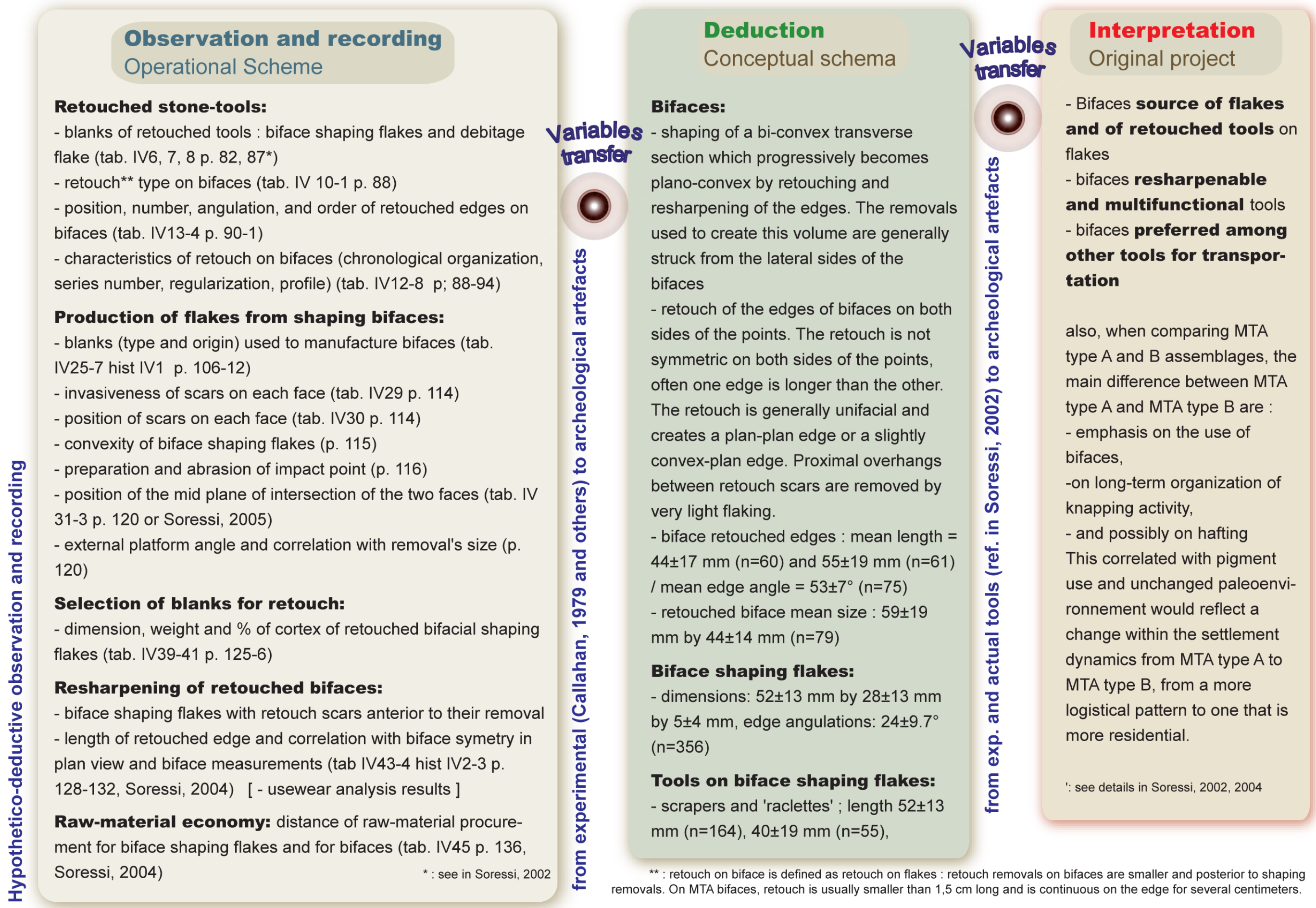

Figure 9. Example of data collection and reasoning applied to Mousterian of Acheulian Tradition biface assemblages from Pech-de-l'Azé I (France) (references to tables and pages refer to figures in Soressi [2002]).

experience, so the only difference with an *a posteriori* definition is that, in the latter approach, the attribute definition is based on a first understanding of the assemblage as well. Therefore, an *a posteriori* definition of attributes is more efficient because it is more precise and saves time. We do not imply here that approaches other than *chaîne opératoire* are not flexible; modern attribute analysis also uses a flexible definition of attributes. This might be a consequence of the current mastering of research methods by a myriad of researchers building on each other's work, and no longer by a few scholars relying mostly on their own experience.

CURRENT AND FUTURE DIRECTIONS FOR THE TECHNOLOGICAL APPROACH

Current and future directions for the technological approach may be oriented toward the evolutionary and historical significance of stone tool production and the dynamics of the changes in stone tool technology through time. Scholars would thus focus more on cognitive archaeology, on understanding the functions and economy of artifacts, and on further explorations of the "phylogeny" of artifacts.

Cognitive Archaeology

Supporters of the technological approach probably still did not sufficiently explore the evolutionary significance of the use of one manufacturing process *versus* another one. Questions in this realm might include the implications of the number of operations in a knapping process, the hierarchy between them, the cognitive skill (including language ability), and the manual skill implied in each operation. All of these issues appear to have been underestimated until now.

This topic was addressed by J. Pelegrin in particular (1985, 1993, 1995, 2005). Individual ability and questions related to craft specialization in recent periods of prehistory (e.g., Karlin et al. 1993; Pigeot 2004; Ploux 1984: 260–266) have perhaps been addressed more thoroughly than questions concerning the cognitive and motor skills of the different human species and sub-species throughout human evolution (but see Roche and Texier 1996; Roche et al. 19This orientation is currently being developed, however, as illustrated by the recent volume edited by V. Roux and B. Bril (Roux and Bril 2005; see also Roux 2000), which includes archaeologists and researchers specializing in the

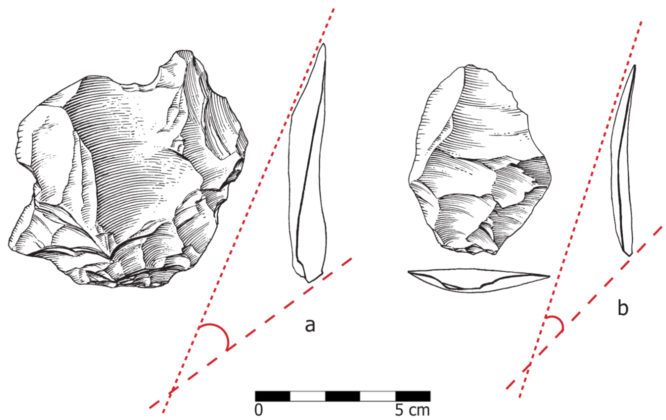

Figure 10. Biface shaping flakes from Pech-de-l'Azé I (the one on the left had been classified as a Levallois flake by F. Bordes) (drawings J.-G. Marcillaud). Compare the angle between the platform and the distal extremities of these biface shaping flakes and the Levallois flakes illustrated in Figure 4.

science of movement, neuroscience, and psychology. It also worth noting a recent attempt to revitalize Piaget's work with new data to discuss the emergence of language and the evolution of knapping activities (Airvaux, 2009).

Once again, prehistoric archaeology would likely benefit from more contact and collaboration with researchers in the fields of developmental, comparative, or cognitive psychology, as well as the neurosciences.

Context and Understanding Function

Greater knowledge of the context in which stone tool manufacture occurred would help us to understand the processes of the invention of artifacts (see, for example, the theory developed by Simondon 1958; Simondon and Chateau 2005). In addition, relationships with the other technical sub-systems (food collection/hunting, food processing, social cooperation for each task) should be determined since they potentially influence each other.

For instance, some recent research has focused on the functional significance of the morphology of stone-tools, postulating that function is driven at least in part by morphology, which in turn is driven by the processes used to manufacture the stone tools (Boëda 1991; Bourguignon 1997; Geneste 1991b; Geneste and Plisson 1996; Lepot 1993; Plisson 1988, 1993; Soressi 2002; Soriano 2000). This approach focuses on determining the potential range of uses of a stone tool from its morphology. For example, a knife is conceived to be used as a cutting tool ("*en coupant*" cf. Sigaut 1991), but it can also occasionally be used as a screw driver (!). Still, its range of use, defined by its manufacturing process, is for cutting, as it is better adapted to this specific use, and it is through analyses of its morphology that this can be determined. For example, this type of analysis applied to bifaces of the Mousterian of Acheulian Tradition showed that these bifaces were made in a way that allowed their use as multifunctional tools, which may explain (added to the fact that they could be used as both tools and cores due to their particular manufacturing process) why they were preferentially chosen by this group as traveling tools (Soressi 2002: 136–158; Soressi 2004a). This approach complements use-wear analyses that usually focus on the last use(s) of stone tools.

Also, Boëda (2005) recently tried to formalize how changes in the gestures used during the use of an object influence the dynamic of technological change through time (here we see a re-exploration of M. Mauss' idea of the importance of "*Techniques du corps*" (1936) in human societies).

Context and Understanding Economy

In 1991, C. Perlès proposed a model to interpret changes in the economic strategies of prehistoric groups. She suggested that the dynamics of change in an economic strategy (defined from the economy of raw materials and the economy of "debitage") might be related to two major factors:

- the intensity of tool use and the amount of risk associated with manufacturing defects in tools (see also Bleed, 1986), and
- group mobility, changing between logistical and residential.

This model is, of course, especially useful when it is possible to compare different sites used by the same group during its seasonal movements across a territory. Due to the uncertainties of the currently available methods, radiometric dates are often unreliable for determining the contemporaneity of different sites. For example, for the Mousterian of Acheulian Tradition in southwestern France, most sites have the same mean age of approximately 50,000 BP ±5000 years (at a 65% confidence level; i.e. ±10,000 years at a 95% confidence level; e.g., Soressi 2005a), which means that there is a strong possibility that the MTA (A+B) episode lasted less than the 1 sigma confidence interval of the age measurement (i.e., less than 10,000 years). However, to be sure of site contemporaneity, we should have a dating method with 2 sigma uncertainties smaller than the total duration of the events (!) (this is true only with ^{14}C ages starting from the Neolithic, beyond the problem of the calibration plateau).

At this stage, provided that we follow certain rules, we believe it is reasonable to rely on technical processes to determine the contemporaneity between sites sharing the same technical tradition, even for ancient periods of prehistory such as the Middle Paleolithic. These rules focus on:

- facies with a specific geographic distribution;
- facies with a specific time depth (reasonably small compared to other contemporaneous facies); and,
- sites belonging to these facies that are located within a territory that is of reasonable size compared with ethnographic references, and compared with the territory from which most of the raw materials originate.

For instance, within the Middle Paleolithic, the Mousterian of Acheulian Tradition (MTA) type A, as well as the MTA type B, would be good candidates as they have a geographic distribution and temporal span much smaller than the rest of the Middle Paleolithic in Europe, in comparison to preceding and contemporaneous facies. MTA (type A) artifacts from one site could be compared to artifacts from other sites sharing the same technical tradition within the reasonably sized territory of the Périgord area in southwestern France, in order to define patterns of mobility organization throughout the year (see for example one attempt in Soressi 2002: 259–269, 2004).

The behavioral hypotheses generated on the above grounds require testing through the use of other lines of evidence from archaeological remains belonging to other technical sub-systems, such as faunal remains, which can provide information about the seasonality of site occupation (throughout the year or only during specific seasons) or hunting strategies (see Rendu 2010 and Soressi et al. 2008 on the MTA model), as well as climate or environment.

Artifact Phylogeny and the Theory of the Genesis of Artifacts

A greater integration of research conducted in the Philosophy of Techniques (Stiegler 1994; Simondon and Chateau 2005) might be useful in interpretations of the technology of knapped stone in terms of artifact phylogeny or convergence and invention processes. This approach was recently proposed by Boëda (1987, 2005). From this perspective, the technique is understood as the "medium of a non genetic memory which is cumulative and transmitted" (Stiegler 1994). According to Simondon (Simondon 1958; Simondon and Chateau 2005), for example, within a technical lineage, tools would pass through different stages from a syncretic one (when several functions would be assumed by the same tools but would be juxtaposed and in concurrence with each other while using the tool), to an analytical one (when functions would be linked together), to finish with a synthetic one (where several functions would be completely assumed within one structure). Following Simondon's theory, the evolutionary processes of objects would increasingly tend toward a greater integration of the function within its structure (cf. for example the boiler came before the steam engine, which came before the transportable steam engine; another example is the history of the door latch, which eventually became completely integrated within the door). This theoretical framework inherited from the Philosophy of Techniques would be helpful in distinguishing between the migration of populations and technological convergence, or in explaining the shift from one lineage using the Levallois method to another using blade production (Boëda 2005).

CONCLUSION

Lithic analyses in France have passed through several stages in their history. Through time, their theoretical grounds have been enlarged and their methodology more clearly explicated. They have shifted from an orientation as a natural science of prehistoric man to a social anthropology of the techniques of prehistoric societies. Following this path, lithic analyses have been improved by the integration of other disciplines that are part of anthropology, as well as from the discipline of human biology. A complete anthropology of techniques (cf. Lemonnier 1986) will rely on the study of not only the object, but its context as well, meaning the actions and cognition by which it is accompanied. The current direction for the technological approach has already partly integrated this goal.

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ENDNOTES

1 "Materials for a progressive and philosophical history of humans beings"

2 For example, Peyrony first used the terms "couteau-racloir" and 'knife-scaper" for scrapers (Peyrony 1914l.: 37–38), but later used "couteau-racloir" only for what we call today backed knives or cortical backed knives (Peyrony 1942, see no. 6 on Figure 3; or Peyrony 1943, Figure 3, nos. 4 and 9). But he also distinguished a sub-type of backed knives named "pointe triangulaire (couteaux) du type de l'abri Audit" (e.g,. Peyrony 1932, 1948.). Yet, it is not clear if what H. Breuil calls "couteaux à dos de type Audit" is the same sub-type as the one used by Peyrony, or if it actually encompasses some of Peyrony's "couteau-racloirs."

3 Since his first publication on northern Africa (Tixier 1967), J. Tixier insisted on the need to go beyond typological classifications. In his introduction to a conference report published in 1979, he wrote that he disliked the fact "that prehistoric man is often reduced to numbers and a label" (Tixier 1979: 5). Classifications through typology become "sclerosing if we don't re-evaluate them," typology must "exist, but its role had been "hypertrophied" (greatly exaggerated) (Tixier 1979: 7)

4 CNRS (*Centre national de la recherche scientifique* or National Center for Scientific Research) is a government-funded research organization, under the administrative authority of France's Ministry of Research

5 "Transformation" is understood here in a synchronic manner only, not in an evolutionary perspective through time. This point of view was nonetheless taken by other historians of science such as G. Simondon. We will return to this subject later on.

6 It is often the case that "operational scheme" is understood as the equivalent of "*chaîne opératoire*." Yet, we prefer to use operational scheme for a process that happened (in the past, for the archeological operational scheme) and to restrict "*chaîne opératoire*" to name the approach we use to understand operational scheme.

7 For more exhaustive citations of the appropriate references, see Soressi 2002: 47.

8 Experiments do not provide analogous data and should not be interpreted as analogies of prehistoric behaviors. They only provide data to aid in understanding the physical laws of the raw material and of its fracture mechanics. It is the understanding of these physical laws and how they affect the knapping process, which is represented by several variables, that is then transferred to the archaeological context, as we assume that the raw materials would have had the same

physical properties during prehistory as they do now. This then necessitates refined analyses of the expression of these variables within the archaeological material to understand the choices made by the prehistoric knapper. It is usually necessary to go back and forth between the archaeological material and experiments, and a continuous verification/falsification of the hypothesis constructed from the archaeological material through experiments (Pelegrin 1991).

[9] We prefer to use the terms positive and negative artifacts instead of "detached" versus "objective" (Andrefsky 2005) in order to include cores and bifaces within the same significant category (a biface usually being a core and a tool at the same time in Mousterian assemblages, e.g., Soressi 2004a; 2004b).

[10] "Technique" (Tixier 1967) refers here to the physical means of the transfer of energy in the removal of flakes, e.g., percussion with or without an anvil, the shape and raw material of the tool(s) employed, how the piece being worked is held, and other aspects of the body position (Pelegrin 1995: 24). "Method" refers to the intellectual steps followed throughout the knapping process, expressed by the volumetric and sequential organization of the blows on the core (i.e., the reduction process) (cf. Tixier 1967; Pelegrin 2000, 2005). The knapping process is sequential by nature, but can have "*ramifications*" (Bourguignon et al. 2004), when flakes are selected to be used as cores, for example.

[11] A few Mousterian of Acheulian Tradition bifaces or a few Levallois cores testify by themselves that the knowledge and the know-how to make these bifaces or to use Levallois technology were shared by the makers of the assemblage. However, one isolated discoid (radial) core or a few isolated Levallois flakes are certainly insufficient to avoid the problem of equifinality, as they could have been produced by several distinct *chaîne opératoires* (e.g., Chazan and Kolska 2007).

[12] Actually, there is a fourth dimension, which is time.

[13] These are not based on analogies (see Whallon 1995: 452) between the actual and the ancient processes.

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