

The Invention of Technology.

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The Invention of Technology

Prehistory and Cognition[1]

by Sophie A. de Beaune

Technical study of tools made from unknapped stone from early times to the Neolithic has allowed the identification of marks found on these tools and inferences from them about the actions they involved. On the basis of this analysis, a schema is proposed for the evolution of technical actions. It seems that we have here a concrete example of a mechanism of technical innovation and that this mechanism may be simply an illustration of a more general schema of the evolution of technology. Comparing these results with those of cognitive psychology on problem solving, it seems possible to propose several hypotheses about the cognitive content of major technical innovations by *Homo sapiens sapiens* and their less sapient predecessors. If these hypotheses are confirmed, then the cognitive processes that trigger invention must have appeared as early as the Lower Paleolithic.

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From the study of very primitive Paleolithic tools made from stone blocks, cobbles, or plaquettes and their functions, I have attempted to identify the actions associated with them and the activities to which they were linked. Aside from the fact that they were discovered in an archeological context, the sole noteworthy characteristic of these tools was that they bore traces of use (impact scars, striations, polish). It goes without saying that in this context the term "tools" cannot be restricted to shaped tools. The existence of a tool, shaped or unshaped, implies an intended action, and therefore the idea of the tool precedes the tool itself. Employing Leroi-Gourhan's (1971 (1943)) typology of percussion, which has the advantage of focusing on the description of an action on a material rather than prejudging the nature of the activity (fig. 1), I was able through micro- and macroscopic observations of the appearance and orientation of the traces of use on these tools to link them with particular types of action applied to materials. Use-wear analysis has never been performed on this type of material, research in this area having focused on shaped tools (see Semenov 1964 [1957] and Keeley 1980). Variables such as the position of the marks, the shape of the object, its size, the raw material used, and its weight had to be taken into consideration, and the results of the analysis had to be cross-checked with experimentation and ethnographic observation.

A detailed description of each of the tools identified (anvil, hammerstone, grindstone, grinder, mulling stone, mortar, pestle) has appeared elsewhere (Beaune 2000). Starting with as exhaustive as possible an inventory of these tools, I have been able to identify the probable dates of appearance of these various tools and to propose an overall view of their evolution in the course of prehistory. Finally, I have developed a schema for the evolution of technical actions as revealed by these tools in the form of a "phylotechnical tree."

This schema is based on the hypothesis that the various types of percussion evolved from a common origin in the cracking seen today in our contemporaries, an action familiar to the australopithecines and employed by certain of the apes to crack the shells of hard fruits (fig. 2). In fact, the early tools called spheroids, subspheroids, and polyhedrons necessarily preceded cutting tools, knapped cobbles and flakes, which could not be produced without a hammerstone. These tools are found in great quantities in Early and Middle Stone Age African sites (Willoughby 1987), and the fact that they are not limited to humans is consistent with their primitive nature.

From Cracking to Knapping

Chimpanzees use a hammerstone to shell and crack hard fruits against an anvil made of a cobble or a piece of wood (fig. 3). Given the similarity between early percussion tools—anvils and hammerstones—and those of chimpanzees (Joulian 1996), this cracking action was probably familiar to the early hominids (fig. 4). The presence of these tools has been widely observed in the oldest

1. Translated by Simone Monnier Clay.

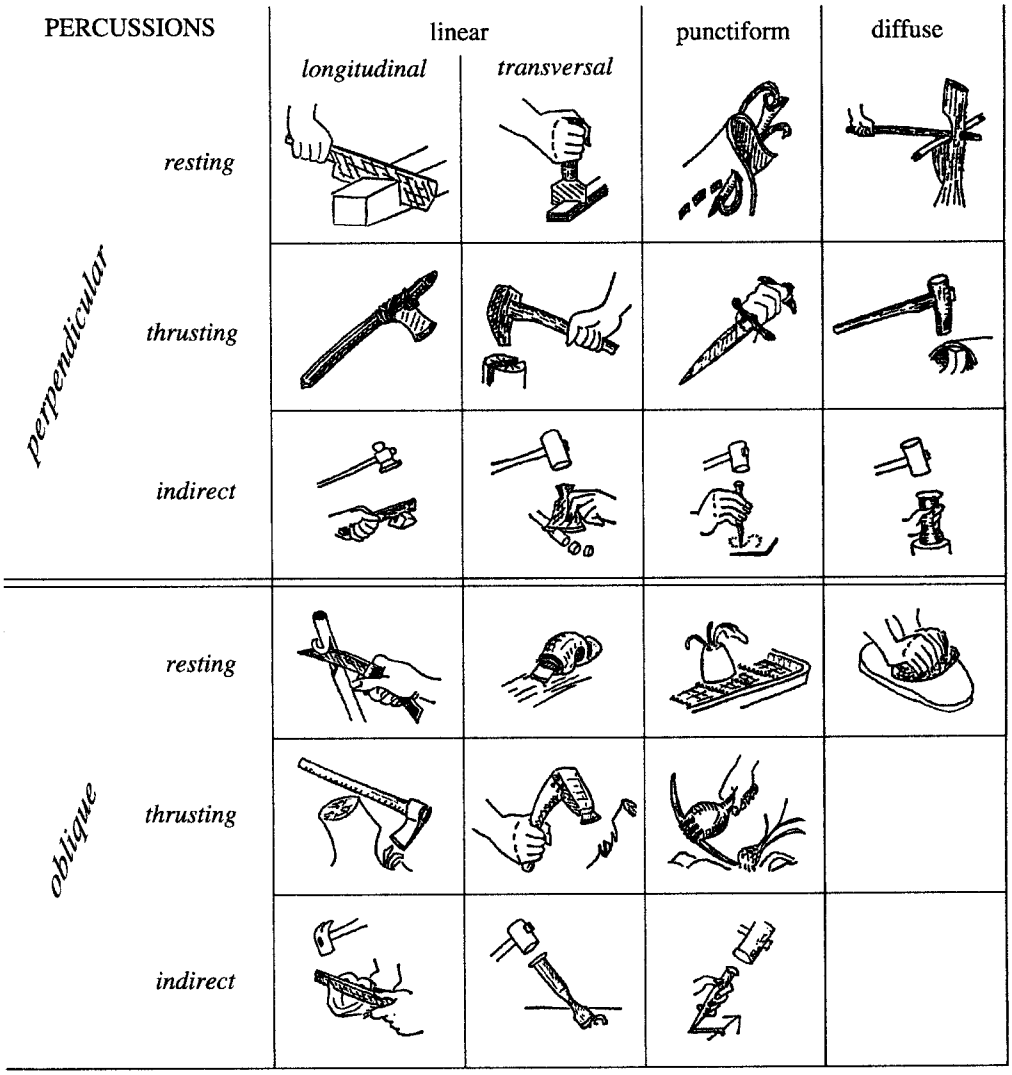


FIG. 1. *Typology of percussion (Leroi-Gourhan 1971 [1943]:58–59, reprinted by permission of the publisher).*

hominid sites in Africa. For example, lava, basalt, and quartzite blocks are particularly numerous at Olduvai (Bed IV and the Masek Beds), in Tanzania, at Melka-Kunturé (especially Gomboré IB), in Ethiopia, and in the Oldowan and the Acheulean (Chavaillon 1979; Leakey 1971, 1976*a*, 1976*b*, 1994). The pits created in them by use are usually well marked—25–45 mm in diameter and 8–14 mm in depth (Chavaillon and Chavaillon 1976). Called "pitted anvils," they are often associated with large hammerstones or pitted cobbles interpreted as hammers. According to Willoughby (1987), these two types of tools may have been used together.

Goren-Inbar et al. (2002) have recently announced the discovery of a series of pitted stones at the Acheulean site of Gesher Benot Ya'aqov in Israel, where the same layer yielded seven types of nuts still perfectly identifiable because of the damp environment that had preserved them. The association of nuts and pitted stones is evidence that these tools were used for nut cracking. Moreover, the fact that these rudimentary tools were found at a site dated to 780,000 years ago and that more sophisticated tools (material knapped according to the Kombewa and Levallois methods) have since been found there shows that these tools belong to a common tool kit and have existed for thousands of years.

Along with Joulian, Wynn and McGrew (1989) have pointed to numerous analogies between the techniques employed by the existing apes and what we know about those of the makers of the Oldowan industry, which they consider closer to today's apes than to modern humans. McGrew (1992:205) does not exclude the possibility that these makers may have been apes rather than australopithecines or representatives of the genus *Homo*. However, the Oldowan witnessed a major innovation; formerly used for the cracking of hard fruits, thrusting percussion began to be used in the fabrication of stone

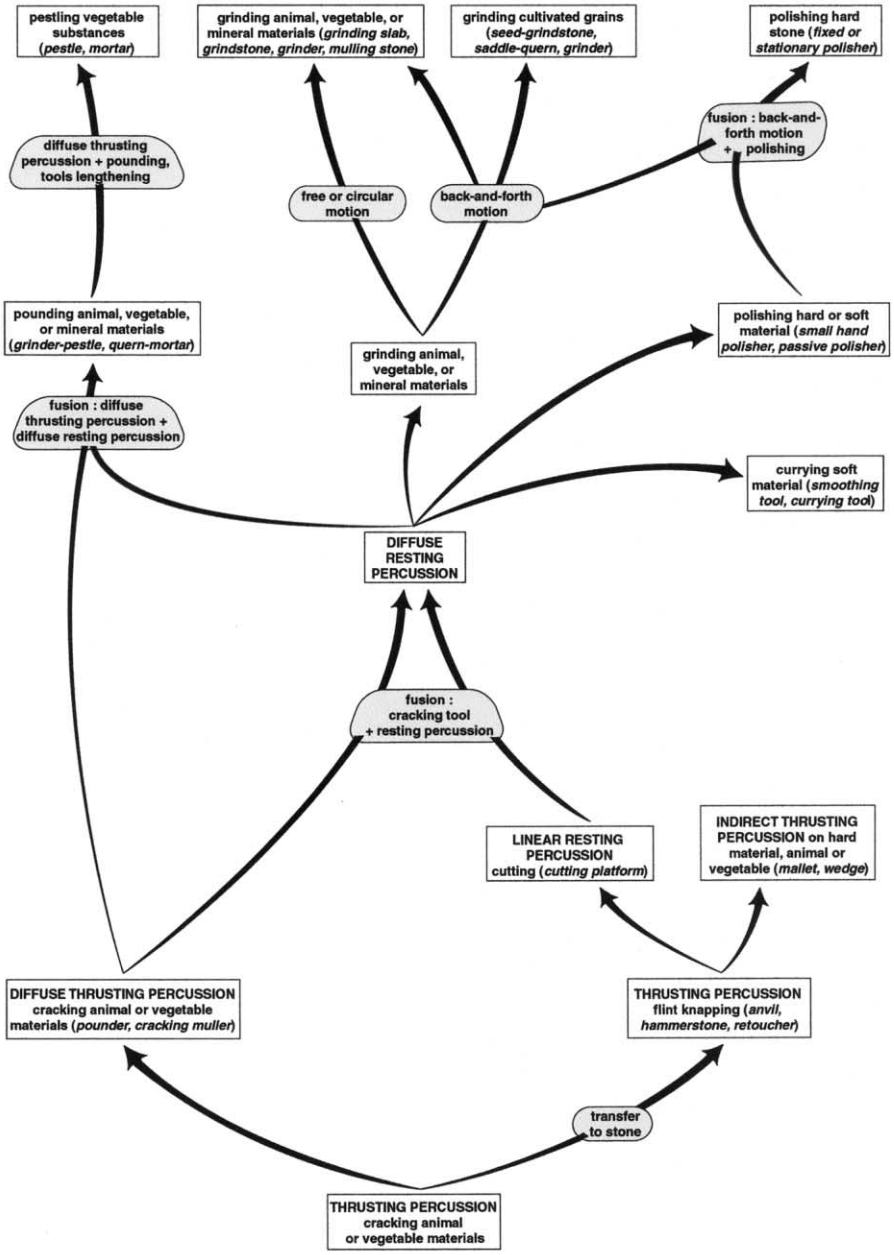


FIG. 2. *The evolution of percussion and of the associated tools.*

cutting tools.[2] That this innovation may have been the product of australopithecines is suggested by the recent discovery of shaped tools at Hadar (Ethiopia), where the sites of Kada Gona and Kada Hadar have yielded the oldest known tools, dated to 2.7 million and 2.4 million years ago (Semaw et al. 1997, Wood 1997). Similarly, the lithic collection from the site of Lokalelei in Kenya is dated to 2.3 million years ago (Roche and Delagnes n.d.).

Wynn and McGrew (1989:389) play down this innovation, insisting that apes are capable of making cutting tools when taught and that if they do not produce any it is because they do not need them, their canines and incisors playing a role similar to that of the cutting edge resulting from knapping. The researchers who taught stone knapping to the bonobo Kanzi appear to agree (Toth et al. 1993), but the ape does not seem to have calculated the striking angles or to have known exactly what he was expected to accomplish. According to Leroi-Gour-

2. Most prehistorians consider prehistoric tools as characterized by knapping. For them the first tools are the choppers and flakes of 2.5 million years ago. However, there were already "natural" tools, simple unshaped cobbles used for percussion. In both natural and shaped tools there is anticipation of the result of the action, and both should be considered tools.



FIG. 3. *Thrusting percussion: nut cracking. Diorite or ophite cobble possibly used as a pounder, Isturitz Cave, Pyrénées-Atlantiques, Gravettian, 8 cm long (de Beaune 1999:54* © Pour la Science*).*

han (1993 [1964]:92), thrusting percussion—hitting a cobble with another stone in order to produce a cutting edge—consisted of a single movement not very different from "simple percussion, the same action as would serve equally to split a bone, crack a nut, or bludgeon an animal." While these activities involved related movements, that of intentionally splitting a cobble to produce a cutting tool, although "exceedingly simple," was in his view eminently human in that it "implied a *real* state of technical consciousness." Joulian (1996:187) agrees that the actions of chimpanzees cracking nuts and pre-Acheulean hominids knapping choppers or producing flakes are not qualitatively different and that controlling the speed and the force of the action is equally important for a positive result in the two cases. He admits, however, that producing a flake requires a choice by the maker with regard to the angle of the core (pp. 184–85). If I understand him, for him as for Leroi-Gourhan the actions are virtually the same but the mental processes differ.

Prehistorians now agree that flint knapping is not simply a matter of striking a cobble against an anvil but also a matter of producing a conchoidal fracture. This presupposes the choice of an area of impact on the basis of the mass and shape of the block and requires precision in the force and direction of the blow (Pelegrin n.d.). The controversy among researchers and the doubts of some are well founded because, while a mental breakthrough is undeniable, the new *activity* stemming from it is the product of the combination of a new value and function with *an action that remained basically the same* (fig. 5). Wynn and McGrew may not be wrong in pointing out that apes can produce cutting edges, but they overlook the fact that this is because humans have taught them how to do so, which amounts to saying that the mental breakthrough is beyond their reach.

The moment when a hominin or one of its immediate ancestors produced a cutting tool by using a thrusting percussion that until then had been used by its companions only to crack organic materials marks a break between our predecessors and the specifically human. Only tools made from shaped stone are capable of linear resting percussion, that is, use for cutting and chopping. Joulian (n.d.) appropriately asks, "Does the action of 'cutting' that lies behind the tool reflect or induce the capacities and competences that are decisive for hominization?" In other words, which is the contribution that most clearly identifies hominization—the conception of tools not found in nature (which is within the reach of chimpanzees) or the steps allowing the resolution of the problem of cutting by the production of cutting edges?

In any case, once the step was taken, two different sequences of operations began to evolve separately, each using its own set of tools. The older of these sets, which seems to form a sort of common basis for the tool kit, is made up of hammerstones, spheroids, anvils, pitted cobbles, and pitted blocks. These tools are used by chimpanzees, australopithecines, and the earliest *Homo* as well as by modern humans in Australia, the Americas,

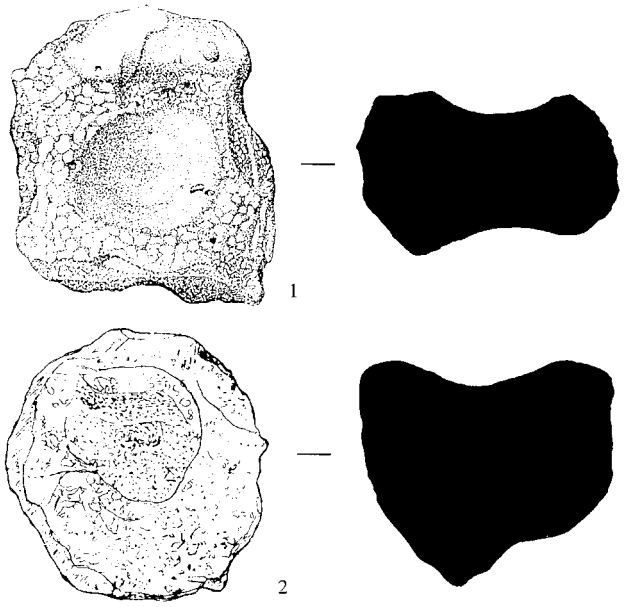


FIG. 4. *Chimpanzee tools and prehistoric human analogues. Basalt hammers with pitted depressions produced by use from (1) the Monogaga Forest, Ivory Coast, 1989, and (2) Olduvai, Tanzania, 1.74 million years B.P. (Joulian 1996:180, reprinted by permission of the McDonald Institute for Achaeological Research).*



FIG. 5. *Thrusting percussion: flint knapping. Quartzite hammerstone, Pair-non-Pair Cave, Gironde, Gravettian, 10.5 cm long (de Beaune 1999:56* © Pour la Science*).*

Africa, and even Europe (de Beaune 2000:65–70). The surfaces of these anvils (called *quebra-côcos* in Brazil [Moura and Prous 1989]), upon which shells and nuts were cracked, are covered with so many pits that they end up forming small irregular depressions. Comparable tools, called "nut-cracking stones," were important among the !Kung of South Africa, for whom the mongongo nut was a staple (Yellen 1977:88, 95–96). These anvils may also be compared to the Australian tool called the *kulki*, on each side of which there is a pitted depression caused, at least in some cases, by its use as an anvil for the crushing of hard ligneous grains with a hammerstone (McCarthy 1976:59). McGrew (1992:205–6) insists upon the identity of various palm-nut-cracking techniques employed by Tanzanian people and by chimpanzees in Guinea, asserting that the work areas used by humans to crack nuts are indistinguishable from those used by chimpanzees. It seems, therefore, that we share with our hominid ancestors and our closest chimpanzee cousins the capacity for performing the simplest form of thrusting percussion—the use of a cobble to break a bone or crack a nutshell. This activity was common to the apes and the makers of the Oldowan industry (whether australopithecines or *Homo*) and persists to this day. However, we will see that this activity, in turn, was transformed, step by step, into pounding and grinding.

The second set of tools, shaped tools, was perfected slowly, giving rise to various forms of knapping and retouch that, although still well known, are no longer much practiced because metal has replaced blades made of flint and other sharp stones. The evolution of these specifically human techniques is the virtually exclusive concern of present-day prehistorians. This is not new, however, since as early as 1964 Leroi-Gourhan had linked technical evolution among the early hominids and the first representatives of the genus *Homo* with biological evolution. (He saw this technical and biological evolution as having four major stages corresponding to as many qualitative advances [1993 (1964)], but I shall leave discussion of them to the specialists.)

With regard to the evolution of the first of these sequences, from cracking to pounding and grinding, and the second, resulting in very sophisticated knapping techniques, only the human genus managed to progress through the stages. It seems that, never having discovered cutting, the apes were unable to master the actions required for cutting, rubbing, grating, and grinding. It is possible to conclude, then, that the simplest form of thrusting percussion gave rise to three sets of actions: (1) the cracking of organic materials, which is common to the apes, the early hominids, and modern humans, (2) stone knapping, which is a human characteristic but one that may have been invented by the australopithecines, and (3) pounding, a specifically human trait.

Pounding

Parallel with the development and spread of stone knapping all over the Old World, traditional cracking techniques have reached us without much change, and we might ask whether, just as in the case of the first cutting tools, the first tools for pounding rather than cracking were not derived from these techniques, resulting from a transfer or rather a fusion. In contrast to the innovation discussed above, this time the novelty would have been the action, diffuse thrusting percussion sometimes accompanied by diffuse resting percussion (fig. 6). In fact, there is little difference between some of the "cracking hammerstones" and the first "grinder-pestle" that com-

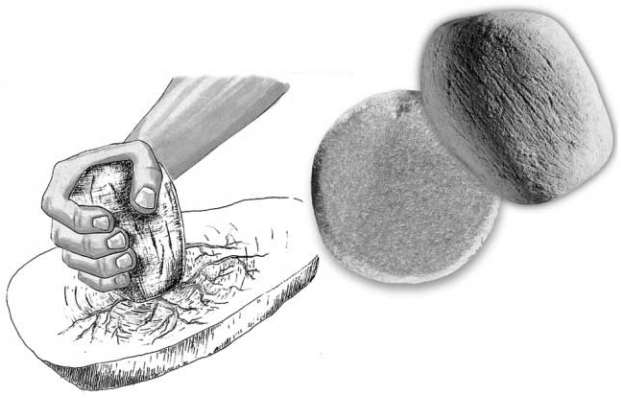


FIG. 6. *Diffuse resting percussion: grinding of plant materials.* Left, *quartzite cobble probably used as a mulling stone, Isturitz Cave, Pyrénées-Atlantiques, Gravettian, 6.5 cm in diameter.* Right, *volcanic cobble probably used as a grinder, Petit Abri de Laussel, Dordogne, Mousterian, 7.5 cm long (de Beaune 1999:52* © Pour la Science*).*

bined diffuse thrusting and resting percussion. Just as when humans began to make the first cutting tools, the purpose of the task was new; it was no longer a matter of breaking a shell or bone to gain access to its contents but one of reducing to powder or paste a material that was much softer—whether mineral (ochre), vegetable (leaves, roots, or fruit kernels), or animal (tendons, fat, or meat).

How are we to explain the progression from diffuse thrusting to resting percussion? We must keep in mind here that cutting tools had already existed for 2 million years. Some may have been used for linear thrusting percussion such as chopping, but others, closer to knives, indicate linear resting percussion in that contact must be maintained with the material that is being cut. The striations produced by defleshing that can be seen on some bones from the Early Paleolithic seem to have resulted from percussion of the latter type. In this case, the action would sometimes become a rhythmic back-and-forth movement like sawing. Among the first cutting tools there were already some that suggested resting percussion, and here too the shift that gave rise to pounding consisted of the use also for resting percussion of a tool that up until then had been employed for cracking or knapping stone. The combination of a familiar action (resting percussion, at least in its linear form) with a tool traditionally used for other purposes allowed for the emergence of a new type of tool, the grinder-pestle.

This technical event can be dated to sometime in the Middle Paleolithic in Europe and the Middle Stone Age in Africa. For example, at the Florisbad site in South Africa, dating to 49,000–38,500 years B.P., some of the tools showed signs of polished wear, which was sometimes associated with percussion pits (Meiring 1956). This pyramid-shaped tool has a very highly polished or glazed surface. Its base is smooth, with a small central pit (fig. 7). Bone tools shaped by scraping have recently been found at the entrance of Blombos Cave, South Africa, and identified as coming from a Middle Stone Age level dating to 77,000 years B.P. (This discovery went almost unnoticed because of another discovery, that of a fragment of hematite carved with a geometric design, which also reflects a major technical innovation [Henshilwood et al. 2001].) In Western Europe there are stones from the Mousterian showing polish from use and striations that may have been used for resting percussion, for example, a cobble of volcanic rock found in the Petit Abri de Laussel (Dordogne, France) and dated to between 70,000 and 40,000 years B.P. (fig. 6, *right*). Farther east, from Raj Cave, near Kielce (Poland), have come six Mousterian tools (one made of quartzite, one of sandstone, and four of granite), several of which have well-polished flat surfaces and traces of a colorant that identify them as grinders (Kozlowski 1992:34–35). These few examples show that resting percussion was acquired simultaneously by modern humans in Africa or their immediate precursors (archaic *H. sapiens*) and by the Neandertals of Europe. Thus they demonstrate that culture cannot be linked with biological development. We can surmise that, despite their differences, all existing cultures reached a stage of maturation sufficient for innovation at the same time. Technology must have evolved fairly synchronously in the two human types.

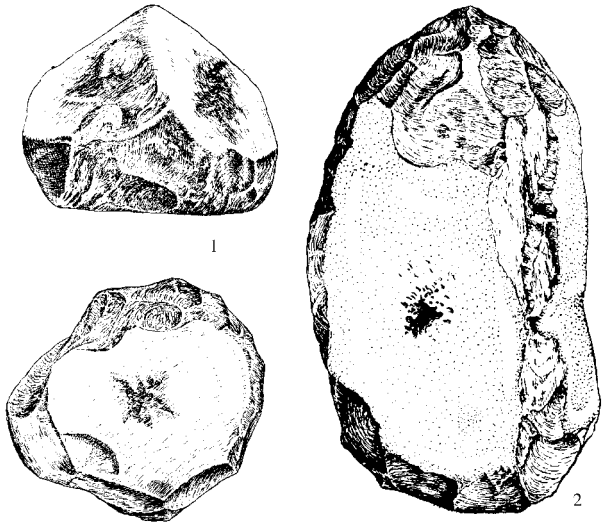


FIG. 7. *Dolerite tools from Florisbad, South Africa, Middle Stone Age, 49,000–38,500 years B.P.* 1, *combined pyramid and pit-anvil, 8 cm long;* 2, *combined pounder and pit-anvil, 16 cm long (Meiring 1956:211, 214, reprinted by permission of the National Museum of Bloemfontein).*

It was only in the Upper Paleolithic that more characteristic objects made their appearance. Alongside grinder-pestles, used interchangeably for resting and thrusting percussion (a stage in the development of true pestles), emerged new types of tools used exclusively for diffuse resting percussion. As early as the Aurignacian in Europe we observe a whole range of new tools corresponding to technical innovations emerging from specialization and adaptation to different materials. These tools are found elsewhere as well, notably in Africa, for example, in the Cave of Hearths in the Transvaal, where 15,000-year-old "grinding-stones" (active and passive) have been identified as belonging to the Middle Stone Age (Mason 1962:257–59). In addition, tools used only for resting percussion such as grinding slabs and mulling stones, dated to around 18,000 years B.P., have been identified in sites in western Arnhem Land, southwestern Western Australia, and the eastern Kimberley region (Smith 1988). Gradually, a number of other tools appeared and spread: elongated pounders, round mulling stones, smoothing tools, needle polishers, etc. (de Beaune 2000). Tools used solely for diffuse resting percussion belong to two main categories: (1) pounding tools for crushing organic matter and minerals, which evolve into grinding tools, and (2) tools for polishing and smoothing in the course of the fashioning or flattening of the surfaces of objects made of bone, ivory, stone, or soft animal or plant materials.

From Pounding to Pestling

Long present as a simple oblong cobble, especially from the Upper Paleolithic on, the grinder-pestle grew longer and began to be produced in the Near East. Beginning in the Kebaran and the Natufian, one finds it associated with the quern-mortar and the first mortars, for example, at Hefsibah, Haon III, and Ein Gev I (fig. 8) and even Wadi Hammeh 27 (Bar-Yosef and Belfer-Cohen 1989, Edwards 1991). Although this tool is often considered a pestle, in fact it combined diffuse thrusting percussion with a vertical movement and resting percussion with a circular movement (fig. 9). Such tools are found notably in Australia, where these are fist-sized water-worn cobbles about a kilogram in weight, roughly circular in outline and domed or rounded in section. These tools served two purposes associated with what M. A. Smith calls mortars (although in fact they are quern-mortars)—pounding and the grinding of hard, dry acacia seeds. Smith (1985) points out that the worn surfaces are flat or slightly convex and often have a small pecked depression in the center that seems to have been produced by the grinding of hard grains. Several have polish due to wear on their surfaces. They come from Pleistocene-age sites in central Australia and date from 18,000 to 15,000 years B.P. This intermediate technical solution

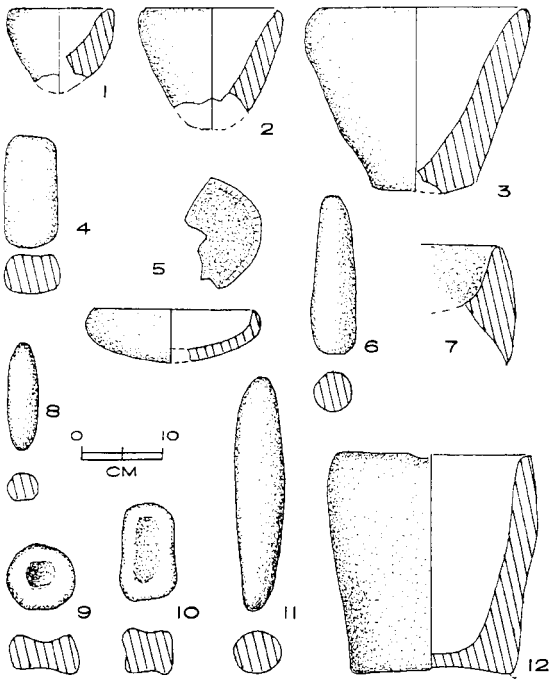


FIG. 8. *Pounding tools from the Kebarian and the Geometric Kebarian.* 1–4, *Hefsibah;* 5–8, *Haon III;* 6 and 7, *Mushiabi V and XIV;* 9–12, *Ein Gev I (Bar-Yosef and Belfer-Cohen 1989:461, reprinted by permission of the publisher).*



FIG. 9. *Diffuse thrusting and resting percussion: fruit pounding. Cobbles used as grinder-pestles, Grand Abri de Laussel, Dordogne, Gravettian.* Left, *limestone, 8.5 cm high.* Right, *quartzitic sandstone, 15.2 cm high (de Beaune 1999:57* © Pour la Science*).*

that allowed both grinding and crushing seems to have been adopted in many parts of the world. For example, it is reported from Telarmachay, in Peru, where levels dated from 9,000 to 3,800 B.P. have produced globular cobbles that show "distal facets of abrasion" and sometimes traces of impacts produced by thrusting percussion. Julien (1985:211) stresses that they were used both to pound and to grind, and thus they seem to correspond to our grinder-pestles.

These grinding tools were refined to produce what could be called a true invention—the long pestle and deep mortar still widely used in Africa. The role of the weight of these tools was certainly to link the diffuseness of the percussion with its thrusting aspect. In this type of percussion, all the handler had to do was drop the pestle. The kinetic energy necessary for the operation stemmed not from the handler but from the falling object, which therefore had to be heavy. Thus a tool that linked thrusting with resting percussion turned into a tool operating solely by diffuse thrusting percussion. The change probably occurred gradually, with the size and weight of the pestle increasing with the depth of the mortar. As the grinder-pestle's size increased, the resting aspect of its percussion gave way to its thrusting aspect. A transition took place at some point from stone to wood, probably because of the risk of the heavy stone pestles' cracking mortars of wood or stone.

From Pounding to Grinding

Pounding tools were gradually perfected to produce grinding tools. Materials were increasingly finely ground and ultimately reduced to powder. It is apparent from

the archeological data available to us that European Upper Paleolithic humans distinguished between pounding and grinding. On the one hand, they still practiced a form of pounding that linked diffuse thrusting percussion to resting percussion, as is apparent from their quern-mortars and grinder-pestles; on the other hand, they were beginning to develop rudimentary grinding techniques. In any case, it is clear that the first grinding slabs used in conjunction with grinders or mullers made their appearance at the beginning of the Upper Paleolithic among the Neandertals as well as among modern humans—as is evident from the Châtelperronian grindstones found in the Grotte du Renne at Arcy-sur-Cure (Yonne, France) and those found in several sites in southwestern France (de Beaune 2003). The motion associated with them is still free or roughly circular but rather narrow. Although the pounding and grinding of wild cereals have not been demonstrated for the beginning of the European Upper Paleolithic, there is no reason not to assume that the grinding of other plant (acorns), animal (fat), or mineral (colorants) materials was already being practiced (fig. 10). In fact, Paleolithic hunters must have consumed wild grains, tubers, and fleshy fruits (acorns, walnuts, hazelnuts) that could be ground and reduced to a paste before they were cooked. It is also likely that they used grindstones to crush blocks of colorant or vegetal or animal fibers before using them. Moreover, recent analysis has shown that the grinding of wild grains was being practiced in Australia 30,000 years ago (Fullagar and Field 1997).

The action of grinding seems to have changed very little for 19,000 years, judging from the shape of the surfaces of the grindstone found at Wadi Kubbaniya and the traces of use-wear on them, which indicate a rather circular motion extending no more than an arm's length. The manos (mulling stones) found at the site confirm that a rotary action rather than a longitudinal motion was employed (Roubet 1990). These grindstones were certainly used to prepare food, since they were associated with the remains of tubers that must be ground either to extract toxins (*Cyperus rotundus*) or to remove fiber that would make them indigestible (*Scirpus maritimus*) before being consumed. Most of the other species identified—in particular fern rhizomes and doum palm fruit pith—also benefit from being ground to make them more digestible (Hillman, Madeyska, and Hather 1990:190). Mass spectrometric analyses of three grindstones has allowed the identification of organic residues rich in cellulose and poor in protein, matching the description of the four plant materials just mentioned (Jones 1990). These results show that hunter-gatherers of the Egyptian Upper Paleolithic supplemented their meat diet with roots and tubers that they crushed on grinding slabs to reduce them to powder or paste. These slabs have neither edges nor curb, which means that a basket or a pile of leaves had to be placed under them to collect the products of the grinding (Roubet 1990:488). It is known that by this time the grinding of the seeds of wild cereals was already being practiced elsewhere. Grains of barley and oats from the final Upper Paleolithic were discovered at

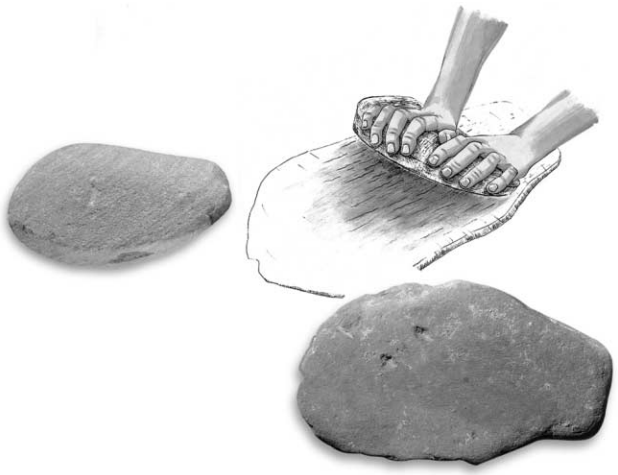


FIG. 10. *Diffuse resting percussion: grinding red ochre.* Left, *sandstone grinder, Isturitz Cave, Pyrénées-Atlantiques, Gravettian, 13.5 cm long.* Right, *schist grinding slab, Cap Blanc Rock Shelter, Dordogne, Middle Magdalenian, 28 cm long (de Beaune 1999:53* © Pour la Science*).*

Franchthi (Greece) and other Epipaleolithic sites of the Near East (Hansen 1991:166–74) and in the Kebaran of Ohalo II (Israel), dated to 19,000 years B.P. (Kislev, Nadel, and Carmi 1992:162).

It was several thousand years before there was any real change in the way grinding was practiced independent of the nature of the material ground. At Tushka, in Egyptian Nubia, a number of grinding slabs, of which the oldest are 14,550 years old (Locality C) and the most recent 12,000 years old, were found in levels attributed to the Qadian Epipaleolithic. They were used first with a free, not circular motion (Locality C) and then with a free or oval motion or, more often, a back-and-forth motion (Locality D) and then with a back-and-forth motion covering almost the entire surface of the slab (Localities E and F). The site also produced numerous lunates with lustrous edges that experiments showed were produced by the cutting of grasses or other plant materials containing silica. The remains of tall grasses that cannot be identified with precision confirm the harvesting of wild grains (Wendorf 1968). According to Wendorf, who points out that the grinding material found at Tushka is not an isolated occurrence (other Nubian sites [e.g., Kom Ombo] having produced comparable material), before plants were cultivated there was a period of "intensive collecting economy" that must have lasted between 4,000 and 5,000 years during which dependence upon ground grains increased to the point of their becoming a major source of food. The occupation of the Tushka site probably dates to the beginning of this period (pp. 944–45).

Starting with the Natufian, several types of grindstones are found together at the same sites, suggesting specialization of functions. For example, in northern

Iraq, in the Epipaleolithic level—contemporary with that of the Natufian at Zawi Chemi Shanidar, assigned to the Mlefatian, and occupied between 12,000 and 10,000 B.P.—two types of grinding stones were found that may correspond to distinct stages in the preparation of meal from wild oats. Grindstones of various depths in the form of trough querns were probably used to crack and pound wild cereal grains with an action comparable to that used with quern-mortars. The covering of wild cereal grains is harder than that of cultivated cereals, and therefore separating the kernels required vigorous action. Flat querns were specifically used for grain grinding (Solecki 1969:993). The first flat, oblong querns that seem to have been used with a back-and-forth motion have been found in the Natufian site of Abu Hureyra on the Euphrates, north of the Levant, and date from the nineteenth millennium (Moore 1991). They point to the appearance of a new action, grinding with a back-and-forth motion with both hands, and this implies a new body posture, kneeling before the grindstone.[3] This new action certainly precedes the invention of agriculture, since it is applied to the treatment of wild cereals.

According to Katherine Wright, the increase in the number of grinding slabs and querns as contrasted with mortars and pestles from the end of the Natufian to the Pre-Pottery Neolithic A does not mean that the former are "better" than the latter. She argues that mortar and pestle continued to be the most efficient way of separating the chaff from the grain, provided that the pestle was made of wood (1994:243).[4] Grinding tools in fact require more work, but they have the advantage of improving the nutritional quality of cereals by slowing their digestion (Wright 1993:97; 1994:243). Moreover, as Wright recognized, the disappearance of stone mortars after the Natufian may reflect their replacement by mortars and pestles made of wood—a hypothesis that will probably never be demonstrated (1994:257).

A new step was taken with the appearance of large, sometimes open-ended querns showing asymmetrical wear at Mureybet (phase IIIa) and Cheikh Hassan, dated to approximately 10,000 B.P. (Nierlé 1982:197), of which the sample from the final Natufian at Mallaha could be a precursor. In fact, considering its narrowness and its length (40–50 cm), one large perfectly flat quern was probably used with a back-and-forth motion (Valla et al. 1999) (fig. 11). These asymmetrical querns led to saddle querns, with concave surfaces shaped by hammering—something that seems not to have existed before the Neolithic.

Grinding with a back-and-forth motion is much more efficient than grinding in a free or rotary motion. With each forward motion the grinder crushes the grain on the whole surface of the grindstone; the return motion spreads the ground material across the work surface to be ground again in the next motion. The longer the work surface, the better the grinding. When the grindstone is open-ended, the flour produced falls regularly onto a cloth placed in front of the quern. According to Ribaux (1986: 79), the grain querns from the end of the Bronze Age have flatter work surfaces than Neolithic querns but function in the same way, with an axial movement. Ribaux claims that these flat querns represent one of the final stages in the evolution of the rotary quern. We are seeing, then, the development of querns that are more and more specialized in the treatment of cultivated grains. The size of these querns constantly increases, and, while the first querns are rough in appearance, as they are adapted to use for increasingly specific purposes querns are increasingly fashioned. The techniques for producing them also develop over time from a partial and rudimentary shaping of the circumference to a complete fashioning. Alongside of these sophisticated querns, more multipurpose ones generally persisted.

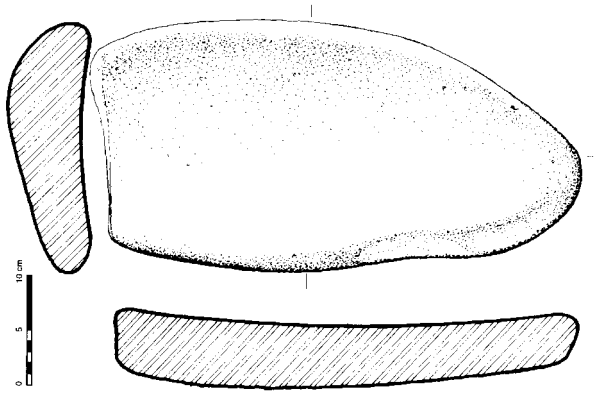


FIG. 11. *Basalt grindstone from Mallaha, Israel (level Ib), Natufian (Valla et al. 1999:164, reprinted by permission of the Israel Prehistoric Society).*

The presence of two different types of querns is attested ethnographically. At Tichitt, seed grindstones are found next to those used for fragile materials such as incense. The ones for grain are larger and have surfaces prepared by hammering; the others have surfaces polished by use. The two types differ not only in form but also in the materials associated with them and the way in which they were used—with the grain grindstones the material was pushed back and forth, whereas with the others it was moved freely or with a circular motion (Roux 1985). This shows a functional difference corresponding to Curwen's (1937, 1941) and later Storck and Teague's (1952:43–45) distinction between saddle querns and flat querns or rubbers (fig. 12).

In Australia, two types of querns can also be found among the Aborigines. One of these, a large slab with a flat surface and several long, shallow grooves resulting from use, is reserved for the wet grinding of soft grains

3. Molleson (1994) has identified in the fossil population of Abu Hureyra (Syria) osseous pathologies of the knees, the big toe, and the vertebral column attributable to prolonged and repeated kneeling in the position required for the grinding of grain.

4. Wright insists that the stone pestles dated to the Kebaran must have been used to grind other plant matter, but elsewhere she reports that at Ohalo II (Israel) these tools were associated with grains of wild cereals (1994:250).

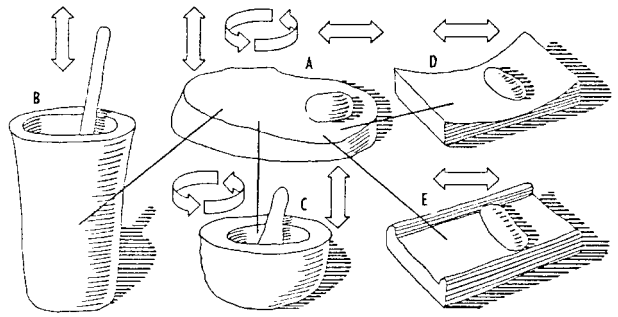


FIG. 12. *Motions used with early milling implements.* A, *pounder-rubber, free motion;* B, *tall mortar, up-and-down motion;* C, *shallow mortar, rotary motion with some pounding;* D *and* E, *saddle/quern/metate form, back-and-forth motion, showing two ways of channeling this motion (by curving the lower stone and by providing edges) (Storck and Teague 1952:44, copyright 1952 by the University of Minnesota, renewed 1980).*

or of harder grains that have been subjected to an initial dry grinding process in a mortar (Smith 1985:24; 1988: 95–97). The other, of which there are archeological examples, is an unmodified stone or slab, irregular in shape, with ground surfaces that are not well defined, and is used as an expedient tool for a variety of purposes, for example, preparing bush tobacco, pulverizing cartilage or small game, and crushing fruit (Smith 1986:34). According to McCarthy (1941), these stones were used for grinding and crushing and sometimes even as whetstones. Flat sandstone slabs with smooth, polished surfaces resulting from wear, showing traces of phytoliths and starch grains, were found at the Cuddie Springs site and are 30,000 years old. This invites thought about the origin of gathering in Australia (Fullagar and Field 1997).

As far as the European Upper Paleolithic is concerned, the extremely fragmentary state of almost all of the grindstones known to us precludes the identification of two distinct types, but the fact that there seem to be two different types of active tools may allow us to think in terms of an early differentiation of grindstones.

Polishing

Polishing consists in rubbing the surface of an object for a long time to modify or smooth it. During the European Upper Paleolithic there were probably two distinct polishing motions: (1) the polishing of small objects such as sculptures and beads, which must have been done with an active hand polisher, with the object attached to a support or held in the left hand (fig. 13), and (2) the polishing of long objects such as spears and shafts made of bone, ivory, or antler tines, which had to be done with a flat or grooved passive polisher with a back-and-forth movement, with or without an intermediate abrasive. Grooved polishers were common in the final Paleolithic and Mesolithic of Western Europe (Gob and Pirnay 1980), but grooved stones also exist elsewhere in the world. In the Near East they appear during the Natufian and persist for several millennia. Chemical analysis of the residues of the worked material wedged in the grooves of a specimen of compact volcanic rock from the Erq el-Ahmar rock shelter (Israel) confirmed that it had been used to work an object of bone or antler. If in fact the object was meant for polishing or whetting bone, the striations observed at the bottom of the groove can only be explained in terms of the presence of an intermediate abrasive element, since bone or antler, being softer than stone, could not have made them (Christensen and Valla 1999).

It is only in the Neolithic that there was a "major improvement" (to quote Simondon [1989 (1958)])—polishing on a large scale of utilitarian objects such as ax blades. Fixed polishers appeared as abrasive polishing developed and improved over time, with harder and harder stones being polished. The presence of fixed polishers on bedrock is attested ethnographically and archeologically in numerous places around the world (fig. 14). On the basis of a study of 130 polishing rocks found in French Guiana, Rostain and Wack (1987) have drawn up a typology of polishers in terms of the shape of the imprint dug into the rock—whether that of a cup, the hull of a boat, an almond, or even a spindle—depending on the section of the ax blade. Archeologically, it is not always possible to date these fixed polishers, since some people, such as the Akurio, are still using them. In Europe, most fixed polishers are thought to date to the Neolithic, but some are difficult to date. The grooved blocks found at Moigny-sur-Ecole and at Baulne (Essonne)—considered megaliths because of their size—are not linked to any



FIG. 13. *Diffuse resting percussion: bone polishing. Pumice-stone needle polisher, Isturitz Cave, Pyrénées-Atlantiques, Upper Magdalenian, 5.1 cm max. long (de Beaune 1999:56* © Pour la Science*).*



FIG. 14. *Polishing of an ax blade in the groove of a fixed polisher, Tagi Valley (Irian Jaya, New Guinea) (Pétrequin and Pétrequin 1993:190, reprinted by permission of the publisher).*

archeological environment in their immediate surroundings (Benard and Sénée 1983).

One might wonder, however, whether this "Neolithic" polishing did not derive from the fusion of the polishing of long objects practiced during the Upper Paleolithic with the back-and-forth grinding of the Epipaleolithic. In this case, it would be an example of the identification of a new purpose for a familiar action. Example of tools' being used indiscriminately as grinding stones or polishers, in particular in Australia (McCarthy 1941), support this hypothesis and confirm the relationship between these two sets of movements.

It is curious that the finest carved objects of the Upper Paleolithic were made in several stages that seem to follow the same order as the actions previously mentioned. This may not be coincidental, since in both cases we are progressing from the coarse to the more refined: shaping or rough-hewing calls for more or less forceful thrusting percussion, and this step is followed by carving properly speaking, including scraping, fine pecking (which is sometimes indirect), graving (light thrusting percussion or linear resting percussion), and finally more or less fine polishing (diffuse resting percussion).

Toward a Model of "Phylotechnical" Evolution

The major innovations described here were made possible by the modification of tools, the materials worked, or the intention of the action. They are the result of the combination of preexisting elements rather than creations *ex nihilo*. They may be summarized as follows:

1. From cracking to flint knapping, in which a preexisting motion, having acquired precision and increased control, was applied to a new raw material with a new intention.

2. From cracking and cutting to pounding, in which a tool previously used for cracking was used with a motion previously used for cutting—a fusion of diffuse thrusting percussion and linear resting percussion to produce diffuse resting percussion.

3. The emergence of pounding in a quern mortar, which involved the undifferentiated use of diffuse resting and thrusting percussion, and the refinement of this technique to produce pestling.

4. The diversification of technical applications of diffuse resting percussion, bringing about numerous technical innovations—polishing, abrasion, and smoothing—through the simple modification of the shape, the nature, or the weight of the tool being used and variation in the raw material worked.

5. The appearance of grinding, which can be dated to the first querns and must have been associated with an increase in wild plant consumption and diversification in the treatment of roots, leaves, the kernels of fruits, and eventually wild cereals. Grinding was slowly perfected through the gradual transformation of a free movement into a more or less circular or oval one. This was followed by a back-and-forth motion in which the tool was held in both hands, something that was much more profitable for the grinding of seeds that accompanied the cultivation of the first cereals.

The invention landmarks corresponding to the various sets of motions can be roughly dated as follows: The cracking of organic materials, shared by apes, early hominids, and modern humans, is evident by 2.5 million years ago, although it may have existed earlier. Stone knapping, characteristic of humans but perhaps invented by australopithecines, engendered all of the sets of actions that involve linear resting percussion and is also evident by 2.5 million years ago. Pounding, which is specifically human, seems not to have appeared prior to the Middle Paleolithic and developed among the Neandertals of Europe and *H. sapiens* of Africa. The sets of motions strictly linked to diffuse resting percussion, such as grinding and polishing, may have existed among the Neandertals and archaic *H. sapiens* but remained sporadic until the Upper Paleolithic. Thereafter they spread and developed among *H. sapiens sapiens (sensu stricto)* and underwent diversification and refinement throughout most of the world, although we have examined this development mainly from the Upper Paleolithic to the Neolithic in Europe and the Near East.

The Cognitive Approach of the Evolutionary Model

The evolution I have just described amounts to a succession of breakthroughs separated by long periods of more continuous development. All of these breakthroughs follow the same outline: a motion of a tool formerly applied to a particular raw material with a particular intent is suddenly used to handle a new raw material or with a new intent. That these breakthroughs led to lasting innovations is probably attributable to social or ethological conditions.

Of course, we must keep in mind that these breakthroughs or "catastrophes" in the mathematical sense are exceptional in the history of technical evolution, but they are of the greatest interest to prehistorians because their results are obvious even though we cannot pinpoint the moment when they took place. It is in the nature of archeological and paleontological data that we never witness the "event" itself but can observe the preceding and subsequent events and deduce from them what took place. It is not enough for an invention to exist for it to be adopted and diffused. Many researchers have examined the conditions contributing to the adoption of an innovation or an invention—conditions that are social as well as technical or psychological (see, among others, Leroi-Gourhan 1973 (1945), Gille 1978, Haudricourt 1987, Lemonnier 1993). Besides archeological discoveries being extremely discontinuous, one can assume that their widespread occurrence means that they have passed the test for adoption. Questions remain, however, about the cognitive preconditions for these breakthroughs and what we can learn from them about the comparative cognitive capacities of *H. sapiens sapiens* and their predecessors. Ultimately, what we are interested in is the cognitive processes that lead to the production of a new idea.

Having observed what occurs at the level of the elementary action and its development, I discovered that I could link these cognitive "leaps" to what cognitive psychologists see in problem-solving situations. Among the various cognitive strategies for comprehension and reasoning, one in particular attracted my attention: the analogical reasoning that plays such an important role in problem solving. The mental processes that seem to be triggered by these breakthroughs may be likened to reasoning by analogy. They are based on a capacity to perceive and use analogous facts, that is, to establish a link between two domains and transfer a familiar procedure from one situation or class of situations to a new situation that is similar though not identical (Richard 1990: 137–38).

Various researchers have studied the operations governing analogical transfer: access in long-term memory to old and analogous information, the transfer of properties, and evaluation after the transfer. Depending on the case, this may be a matter of insight or of a rapid scanning of available structures that, once the search for information in long-term memory has begun, guides the subject toward the recovery of one type of knowledge rather than another to be used as a reference in handling the current situation. This presupposes the capacity to reactivate old conceptual structures and the possession of cognitive tools such as abstraction and generalization (Gentner 1983, Holyoak 1985, Gineste 1997). Once the new situation has been perceived as analogous to a known one, a new component—subsequent experience—intervenes. New problems and their solutions are stored in the memory and later, if necessary, serve as a source of analogous situations from which to draw inferences about the current one (Holyoak and Thagard 1989, Cheng and Holyoak 1986).

In addition, for the analogical transfer to produce something new requires a mental projection—one that Boirel (1961:311) called "prospective intentionality" and Simondon (1989 (1958):57) spoke of as "a conditioning of the present by the past through what has not yet taken place" or "a conditioning reversed in time." This would be impossible, Simondon argued, without forethought and creative imagination—the ability to project from the virtual to reality.

With these brief remarks I have simply restated my conclusions in terms of cognitive psychology, but this makes it possible to make use of our current knowledge of the cognitive capabilities of humans and apes. Experimental research in child development has shown that children as young as 14–16 months are capable of transferring what they have learned to analogous problem situations: "Infants readily transfer knowledge of familiar means to novel objects and expect that some (unknown) effect will ensue" (Bushnell, Brugger, and Sidman n.d.). Research conducted by Holyoak and associates on somewhat older children (three to five years old) shows that analogical transfer requires them to develop an abstract representation of the source of the analogy (Brown, Kane, and Echols 1986, Holyoak, Junn, and Billman 1984, Gholson et al. 1989). It seems that the capacity for categorization and inference appears by the age of two (Gelman and Coley 1990). This means that the ability to appeal to analogy is acquired during the preverbal stage before becoming more reflexive. Insight—the sudden intuitive perception of a solution without going through a trial-and-error stage—occurs in children as young as 12–24 months (Piaget 1952 [1945]).

The situation concerning the apes is as follows: In ethology, analogical reasoning is known as transfer of competence. Although there is considerable research on short-term memory among animals focusing on recognition (see Vauclair 1996), research on the long-term memory that is indispensable for the recovery of situations that are similar to the situation at hand seems to be rare. The only noteworthy exception is that reported by Premack (1971, 1975) concerning the female chimpanzee Sarah, who had been the subject of experimental-language training. According to some ethologists, insight has occasionally been observed among chimpanzees (Byrne 1995, Tomasello and Call 1997). For example, the chimpanzee Sultan had the intuition that if he put several reeds together he could reach a banana placed outside his cage (Köhler 1925). His insight is quite comparable to that of a human, with its

period of incubation and the working of an unconscious part of the mind during a period of conscious neglect of the problem: He plays with the sticks after having tried in vain to reach the bait and then suddenly jumps up and produces the "clever" solution: this is a "schematic anticipation of the solution" (Byrne 1995:84–85), and it is not far removed from what Simondon is talking about. However, instances of insight and the use of long-term memory for analogical reasoning among nonhuman primates remain isolated and individual and are not transmitted to other members of the group. Sultan's insight is the only one that is regularly mentioned. The major difficulty for an invention to be produced and reproduced is located at the level of mental projection. Apes are occasionally able to come up with ideas (just as Sultan did), but in their natural environment they cannot produce an abstract mental schema of such an idea: the idea has no future, no projection in the future.

If we grant that the process of invention that emerges from my phylotechnical tree is quite comparable to what occurs during the cognitive process of analogical reasoning, then it may be suggested that several steps are necessary for an idea to emerge:

1. A "source" situation stemming either from shared knowledge passed on from generation to generation or from the subject's individual experience is stored in long-term memory.

2. Transfer of knowledge is used to solve a technical problem, either through insight or through the scanning of possible solutions in the memory. This translates into an activation of previous knowledge or transitory representations and presupposes a mental projection of the result of the action.

3. The new solution is stored in the memory to serve later as a "source" situation. This cognitive condition contributes to the acceptance of the novelty by the group and its transmission, assuming an environment that is favorable technically, socially, and psychologically.

It would seem, then, that the development of the techniques reviewed in this article requires cognitive capabilities that are not yet within the reach of apes. If this were the extent of the results of my research, it would be trivial; we do not need to refer to prehistoric findings to evaluate the cognitive capabilities of apes. The most interesting result lies elsewhere. If we insist that the breakthroughs of this development stem from particular cognitive capacities—from conceptual sliding and mental flexibility—then these cognitive capacities date to the first technical differentiation of the treatment of raw materials—in other words, to the first bifurcation of our family tree, among the early hominids or some australopithecines.[5]

This means that although humans now seem to be the only higher primate in possession of all the cognitive capacities involved in the appeal to analogy, some of our ancestors could also have possessed these capacities. This forces us at least to moderate the assertions of prehistorians and paleoanthropologists that the early hominids were incapable of following a mental model and that intelligence cannot exist without language (see Gibson and Ingold 1993, Parker and McKinney 1999). Davidson, Noble, and Tattersall lean the farthest in this direction, being under the impression that "modern cognition" appears only with the *H. sapiens* of the Upper Paleolithic (Noble and Davidson 1996, Tattersall 2001). In reality, we see that whatever the abilities of the species responsible for the first bifurcation of our tree, they must have been superior to those of the apes of our times and comparable at some points to those of modern humans. Between "modern cognition" and animal cognition one must imagine intermediate stages upon which I hope that the present research has shed some light.

Finally, my hypothesis is not incompatible with Fodor's model of the modularity of the mind, according to which the cognition of hominids developed in a mosaic pattern. The adoption of such a modular view in an evolutionist context allows for a detailed examination of a set of cognitive characteristics that are independent of the mind, characteristics that may have their own developmental and evolutionary history (Brown 1993, Fodor 1983, Karmiloff-Smith 1992, Mithen 1996). This would help to explain how the skills required for technical behavior developed independently from the particular features necessary for the development of language.

If invention is indeed based upon known cognitive processes and if these processes are specifically human and have been for a long time, then we can understand why apes remained at the cracking stage. If my hypothesis proves wrong (and that is not impossible), its formulation will still have drawn attention to the importance of calling upon disciplines such as cognitive psychology to understand phenomena that at first seem to belong to archeology, sociology, or the history of technology. This could only advance the debates taking place in areas such as cognitive ethology. My research suggests that drawing from cognitive psychology may shed new light on the human mind without pretending to produce definitive answers. In addition, it seems to me that the genealogy of technical actions that I have described here might provide material for the investigation of behavior that could in turn contribute to cognitive studies.

5. In fact, we have seen that it is difficult to know to what species the first tools can be attributed with precision. What matters is that it was a species that existed before *H. sapiens sapiens* and even *H. sapiens neandertalensis*.

Comments

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Evolution took an ancestor we shared with other African apes and transformed it into modern humans and those

apes. Some of the changes affected the skeletal anatomy and presumably soft tissue as well. Other changes were certainly in the domain of behaviour, and archaeologists attempt to construct a narrative about those changes from an archaeological record dominated by the presence of stone tools. There are many more sites with stone tools than sites with fossil skeletal remains, so if we get our interpretations right archaeologists may be able to construct a fuller picture of that record than any other scientists of hominin and human evolution. It is a grand challenge, but it is not a straightforward one.

Despite the emergence of arguments that apes have culture (McGrew 1992, 1998, 2004; van Schaik et al. 2003; Whiten et al. 1999) and that the behaviour of the earliest stone tool makers has strong similarities to ape behaviour (Wynn and Mc Grew 1989), it is still the case that only under laboratory conditions have apes made stone tools and used them (Schick et al. 1999, Toth et al. 1993, Wright 1971). De Beaune suggests that Kanzi did not seem to calculate striking angles, and that was indeed my impression on a visit to the Language Research Centre in 1993 (Savage-Rumbaugh and Lewin 1994). She presumably bases this judgment on Kanzi's rapid adoption of the technique of producing flakes by throwing cores onto the hard concrete floor of his cage. On my second visit to the Language Research Centre in 1998, however, I observed Panbanisha, a female bonobo, making stone tools and particularly noted that she did seem to calculate angles. This is just an anecdote of a short-term visitor, but there is clearly room here for some further detailed observations of these two ape knappers.

Another way of interpreting Kanzi's attitude to knapping is that he found alternative solutions (he also throws cores against other rocks) to the problem that he was being asked to solve with sharp flakes. As I have reported elsewhere (Noble and Davidson 1996), he certainly responded readily to an unrewarded request to make flakes by isolating the core (holding it with his foot) and hitting it with a hammer stone. He then, with no encouragement or reward, spontaneously chose a flake from those he had made and thrust it through the wire of the cage to where I was standing. I find it difficult not to interpret this as his understanding a lot about the circumstances of knapping and the demonstration he had been asked to give. In a similar way, chimpanzees in the wild observed to use a small stone to balance a nut-cracking anvil may be showing that they are able to respond to more than just the immediate contingencies (Matsuzawa 1994). Whether this amounts to the sort of insight that de Beaune attributes to humans I leave for others to decide: I know that some will come down on the side of the apes.

Among the evidence from Blombos she focuses on technique of manufacture of bone points, but the importance of the Southern African Middle Stone Age sites is the combination of signs of more complex cognitive abilities, as Henshilwood and Marean (2003; see also Davidson 2003*a*) and d'Errico (2003) have shown. Although de Beaune does recognize the importance of some of the Australian evidence (particularly grindstones), she could have been more expansive. As have others, she has missed the central importance of the combination of the building of watercraft (Davidson and Noble 1992), implied fishing with nets (Balme 1995), early appearance of ground ochre (Jones and Johnson 1985) and probably early art (Watchman 1993), beads (Morse 1993), bone points (Webb and Allen 1990), and very early ground-edged hatchet heads (before 20,000 years ago) (Schrire 1982), to say nothing of burial with ritual (Bowler et al. 1970, Bowler and Thorne 1976), as indicating fully modern human behaviour by the time of first colonization of Australia about 55,000 years ago (Roberts et al. 1994). In consistently stressing this combination of evidence from Australia, Noble and I have sought to distance ourselves from the imputation from our published work (Davidson and Noble 1989), repeated by de Beaune, that the Upper Palaeolithic can be seen as some sort of paradigm for an important stage in human evolution. Let me state it as clearly as possible here: I do not think that the Middle-to-Upper-Palaeolithic transition in Europe was the most important example of the emergence of modern human cognitive abilities. The colonization of Australia demonstrates that modern human cognitive abilities had emerged 20,000 years earlier.

Finally, I welcome any attempt to provide a new perspective on stone tools. The classic sequence (which because of its Eurocentric origins emphasizes the importance of the Upper Palaeolithic) proves rather unsatisfactory as a basis for interpretation of the sequence of changes outside Europe. The Australian argument is uninfluenced by evidence from flaked-stone technology. Blades, for example, prove to be a very unreliable friend (Bar-Yosef and Kuhn 1999, Davidson 2003*b*). De Beaune's emphasis on technology rather than typology is one of the ways ahead. One of the very important insights of her approach is that "a motion or a tool formerly applied to a particular raw material with a particular intent is suddenly used to handle a new raw material or with a new intent." It is in such exaptive circumstances that many of the evolutionary changes in behaviour will be identified.

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Investigations of early hominin cognitive abilities have always been difficult because of the lack of direct evidence of prehistoric behaviors. De Beaune has attempted to address this issue by focusing on evidence for different types of use-actions and inferring the cognitive abilities represented by changes in these actions. While my expertise does not lie in the area of hominin cognitive abilities, I can comment on the investigation of stone tool function and use. Discussion of the methodology for the identification of different use-actions is limited to the statement "I was able through micro- and macroscopic observations of the appearance and orientation of the traces of use on the tools to link them with particular

types of action applied to materials." Detailed methods may have been presented elsewhere (de Beaune 2000), but a short discussion at the beginning of this paper would have lent greater credence to the author's identification of tool use-actions. Despite the lack of methodological clarity, the functional identifications discussed here can be inferred by those familiar with the use-wear literature.

In contrast to many discussions of early cognitive abilities that tend to concentrate on the western European archaeological record, this one is not limited to a particular region. De Beaune brings in examples of technological innovations from Africa, Australia, Europe, and the Middle East. While this is a strength in some respects, it also leads to the comparison of very disparate samples. The archaeological record is by nature incomplete, and therefore the identification of the "first" appearance of any behavior is potentially problematic. While it is certainly possible to compare regions to look for general trends, statements such as "These few examples show that resting percussion was acquired simultaneously by modern humans in Africa or their immediate precursors (archaic *H. sapiens*) and by the Neandertals of Europe" assume that the archaeological record is more complete than it is.

Another problem with attempting to identify the earliest appearance of different use-actions lies in the differential preservation of organic and inorganic materials. Because wooden artifacts rarely survive at archaeological sites, some tools, such as those used for polishing, may be much older than the archaeological record suggests. Functional analyses of knapped stone tools have recently suggested that intentional modification of wood occurred as early as 1.5 million years ago in East Africa (Dominguez-Rodrigo et al. 2001, Hardy and Rogers 2001). Unfortunately, the purpose of this modification remains unknown.

Despite these drawbacks, de Beaune presents hypotheses about hominin behavior that are potentially observable archaeologically. Much of the research on hominin cognitive abilities focuses on trying to reconstruct language origins or prehistoric linguistic capabilities. While these behaviors would certainly tell us much about hominin cognitive abilities, they leave no trace in the archaeological record. De Beaune's research focuses on behaviors that do leave archaeological traces and should stimulate further testable hypotheses on the development of human cognition.

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As primatologists who study living hominoids in nature, we applaud de Beaune's attempts to integrate data from nonhuman primates into her inclusive schema on the evolution of human technology. Most of our comments will focus on the material culture or elementary technology of extant monkeys and apes, as this may contribute to the reconstruction of the evolution of lithic technology in extinct taxa.

The use of existing typologies (e.g., Leroi-Gourhan 1971 [1943]) as a basis for novel extension, elaboration, and clarification is a useful heuristic device. However, making the starting point a hammerstone and anvil omits an earlier stage of percussive technology, that of the anvil alone (Mc Grew 1992, Marchant and Mc Grew n.d.). Several nonhominoid species, both birds and mammals (e.g., capuchin monkeys [*Cebus* spp.] [Boinski, Quatrone, and Swarts 2000, Westergaard 1998]), batter plant food items directly against a hard surface in order to crack them open. At the very least, this shows that elementary percussive technology need not require a large brain or complex cognitive abilities.

As do Wynn and Mc Grew (1989), Leroi-Gourhan (1993 [1964]), and Joulian (1996), de Beaune interprets wild chimpanzees' use of hammer and anvil to crack nuts to mean that living great apes show the motor patterns necessary to produce cutting edges. She then suggests that they do not do so, but this ignores recent archaeological evidence to the contrary (Mercader, Panger, and Boesch 2002). Whether the nut-cracking wild apes of Taï Forest made use of the flakes that they produced is another question requiring further analysis, but Mercader et al.'s findings in nature seem to falsify de Beaune's hypothesis that apes will produce cutting-edge stone objects only when taught by humans to do so.

De Beaune plays down studies of lithic technology done on nonhuman primates in captivity, stating that human tuition to do so invalidates their performance and shows that nonhumans lack the cognitive capacity ("mental breakthrough") needed. This is a curious argument, for if it were applied to living *Homo sapiens* most of us would fail the test, as anyone who has naively tried to knap stone will know. Humans are taught knapping, so why not apes? Thus, it is disappointing to find no reference to studies of capuchin monkeys (e.g., Westergaard 1995) or more recent studies of bonobos (Schick et al. 1999). Further, studies of capuchin monkeys in nature now show that such behavioral performances are not limited to captivity: as do chimpanzees, *Cebus apella* in dry forests in Brazil use stones as hammers to crack nuts, producing pitted anvils (Oxford 2003).

Pounding (reducing an animal, plant, or mineral material to powder or paste) is said to be an advanced, specifically human trait. A similar assertion of human uniqueness is made about using a mortar and pestle. Yamakoshi and Sugiyama (1995) have reported that a population of wild chimpanzees at Bossou in Guinea does both. The chimpanzees detach a frond of the oil palm (*Elaeis guineensis*) and modify it to make a pestle. This they use to pound the "heart" (apical growth point or meristem) of the palm to a pulp, using the end of the upright trunk of the palm as a mortar. The forceful up-and-down action of the pestle converts the tough, fibrous material to an edible mass. This technique is known to

some but not all chimpanzee groups in the region (Humle and Matsuzawa n.d.).

Given these ethnographic findings from recent primatological research, it is far less clear which cognitive capacities can be inferred to be present or absent in early hominines. To talk about "breakthroughs" or "cognitive leaps" in the evolution of cognition seems premature. To say, as de Beaune does, that "in their natural environment, they [apes] cannot produce an abstract mental schema of such an idea [clever solution to a problem]" seems overreaching. To conclude, given the evidence from primatology, that apes "remained at the cracking stage" in the typological sequence seems no longer tenable, and this casts doubt on her inferences about earlier hominines or panines (Marchant and McGrew n.d.).

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Many animals innovate and use tools (Reader and Laland 2003). Thus studies of animal innovation and tool use can help determine the cognitive processes underlying innovation, to what extent these capacities are shared by humans and other animals, the ecological and social circumstances favoring innovation and diffusion, and the evolutionary history of innovatory and technological capacities. For example, comparative analyses reveal a link between brain volume, innovativeness, and tool use in both primates and birds (Lefebvre, Nicolakakis, and Boire 2002, Reader and Laland 2002)—a link of long-standing interest to archeologists (Wynn 2002).

De Beaune (personal communication) notes that in hominids the technological cultural evolution she addresses is dissociated from genetic evolution. For example, resting percussion was acquired simultaneously by modern humans in Africa and the Neanderthals of Europe. However, the (genetic) evolution of the cognitive capacities underlying innovation in tool use remains largely an open question. De Beaune makes the case that innovation in tool use is different from animal innovation, relying on cognitive processes particular to hominids such as analogical reasoning. The kind of cumulative cultural evolution she describes is almost certainly unique to hominids, though there are instances in which animal innovation results from the combined efforts of several individuals or is consequent on the acquisition of another innovation, and cumulative cultural evolution of tools has been suggested (Kawai 1965, Paquette 1992, Laland 1999, Hunt and Gray 2003). Moreover, many processes may be involved in the creation of a particular innovation in animals and humans (Reader and Laland 2003). These processes, now receiving increased empirical attention, include attentiveness to novelty, exploration, asocial learning, insight, creativity, the capacity to inhibit existing behavior patterns, and reasoning by analogy (Reader and Laland 2003). Several of these processes may be cognitively simple and are by no means unique to humans.

Hammer (cracking) tool use has been observed in wild animals other than apes and hominids, among them capuchin monkeys and five bird species (Tomasello and Call 1997, Lefebvre, Nicolakakis, and Boire 2002). This finding, combined with extensive reports of extractive foraging in many species, suggests that several taxa may possess the cognitive capacities necessary for such tool use. Moreover, experiments demonstrating that individuals can acquire tool use independently question the common idea, with regard to humans and animals, that social transmission is necessary for the maintenance of tool use within a population (Tebbich et al. 2001). In nonhuman primates it appears that many innovations fail to spread throughout social groups (Reader and Laland 2003), allowing the possibility that repeated local inventions of a particular behavior pattern may be quite common.

The proportion of innovative tool use potentially preserved in the archeological record can be estimated by examination of the materials used in animal innovation and tool use, on the basis that stone artifacts survive well but vegetable matter does not (Wynn 2002). Such estimates will obviously be subject to bias. For instance, stone tool use may be more likely to be reported or observed than the use of vegetative matter (for example, chimpanzee nut cracking with stones is a noisy activity). It is also unclear to what extent nonhominid artifacts will bear the signs of use and be recognizable, though in at least one case common chimpanzee (*Pan troglodytes*) stone tools have been excavated and identified (Mercader, Panger, and Boesch 2002).

I examined the available data for instances of innovation and tool use, excluding captive studies, experimental studies, and behaviors involving man-made or unnamed objects. Of 140 reports of primate foraging tools and proto-tools, 18% involved stones or rocks and 78% vegetation such as leaves or sticks (Reader, unpublished data: see Reader and Laland 2002). Similarly, stones were mentioned in 21% of 14 categories of monkey and ape tool use (Tomasello and Call 1997). Of 162 reports of primate foraging innovation, 4% involved stones, 28% vegetation, and 51% new dietary items (Reader, unpublished data). Fifty-one of the primate tool or proto-tool cases were innovative, 14% involving stones and 82% vegetation. In birds, 19% of 39 foraging tool use cases involved stones or shells (and 18% of 86 proto-tool use cases, such as anvil use [Lefebvre, Nicolakakis, and Boire 2002]). Of the 65 common chimpanzee behavioral variants examined in Whiten et al.'s (1999) synthesis of long-term field studies, 11% involved stones and 83% vegetation. In contrast, no stone use was recorded for 36 behavioral variants surveyed in a similar study of the orangutan *Pongo pygmaeus* (van Schaik et al. 2003). A broadly consistent pattern emerges, with 15–20% of primate and bird tool/proto-tool use involving stones or rocks but lower percentages for innovative and population-specific behaviors. Thus the vast majority of inno-

vations may be missing from the archeological record of tool use in hominids.

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De Beaune provides a useful summary of archaeological evidence regarding prehistoric pounding and grinding technologies, but there are some important problems with her broader theoretical interpretations. Before discussing these problems, however, I feel obliged to point out some inaccuracies regarding the dates of the earliest known tools, which de Beaune lists as "2.7 and 2.4 million years ago" from "the sites of Kada Gona and Kada Hadar" in Ethiopia. In fact, the Gona tools are well dated to between 2.5 and 2.6 million years on the basis of radioisotopic ($^{40}Ar/^{39}Ar$) and magnetostratigraphic evidence (Semaw et al. 1997, 2003). Stone tools from Hadar have a radioisotopic minimum age of 2.33 ± 0.07 million years and a loosely constrained *maximum* age of 2.4 million years based on the presence of *Theropithecus oswaldi* (Kimbel et al. 1996). It is also worth noting in this context that the 2.3-million-year age for the Lokalelei site 2C referred to by de Beaune has recently been questioned and may actually be closer to 2.2 million (Brown and Gathogo 2002).

Putting these dating issues aside, there are positive and negative aspects to de Beaune's "phylotechnical" argument. Her basic point that new technologies do not simply appear but must be actively invented is an important one that does not always figure in evolutionary accounts of human technology. The same may be said about her emphasis on the actual motions and processes involved in tool manufacture and use rather than the static morphology of finished artifacts. Unfortunately, these important points are not carried far enough. In particular, de Beaune's use of Leroi-Gourhan's typology of percussion to construct her evolutionary argument repeats the fallacy of misplaced concreteness (Whitehead 1929) that has been such a problem for more traditional typological approaches to stone tools.

Conventional descriptive typologies are as essential in archaeology as in any scientific endeavor. However, it is a mistake to forget the level of abstraction involved and to treat such classificatory systems as if they were themselves the concrete objects of study. In the present case this has led to a superficial treatment of technological change as nothing more than the recombination of abstract movement types and the consequent neglect of the detailed physical reality of the movements as goal-directed activities by real individuals in concrete ecological and social settings.

For example, de Beaune follows Leroi-Gourhan in asserting that the physical action of flaking stone is essentially equivalent to nut cracking because both may be classified as thrusting percussion. This hypothetical equivalence glosses over potential differences in required force and accuracy, among other things, and should be tested rather than simply asserted on authority. Differences in the perceptual-motor demands of particular forms of percussion are not part of Leroi-Gourhan's typology but may have important social and cognitive implications when the issue of skill acquisition is considered (Stout 2002, n.d. *a*). I agree with de Beaune that Oldowan technology was a "major innovation" but feel that more detailed studies of the bodily movements (Roux, Bril, and Dietrich 1995, Bril, Roux, and Dietrich 2000), neural activity (Stout et al. 2000, Stout n.d. *b*), and social interactions (Stout 2002) involved in stone knapping will be required to assess the true dimensions of this invention.

By narrowly defining technological invention as the transfer of a motion or tool to a new material or intent, de Beaune equates such invention with analogical reasoning. This once again assumes the concrete reality of the abstract categories created by Leroi-Gourhan—this time as concepts in the minds of ancient tool makers. According to this scheme, innovation is said to proceed through the cognitive manipulation and/or recombination of these concepts. Mental capacities such as abstraction, generalization, and "prospective intentionality" are then implicated. Not considered is the kind of concrete experimentation or tinkering that often leads to invention in the real world. Many animals produce innovative behaviors in this fashion, from birds learning to open milk bottles (Fisher and Hinde 1949) to monkey potato-washing (Kawai 1965) and the various tool-assisted foraging techniques of chimpanzee populations (Whiten et al. 1999). If we are to attribute capacities for "conceptual sliding and mental flexibility" on the basis of such innovation, then these capacities are widespread indeed.

As a matter of speculation, it is entirely possible that nut cracking inspired the first stone knappers. Even more plausible is the idea that the use of stones to crack bones for marrow incidentally assembled the various requisites of an adventitious discovery. Perhaps both scenarios occurred one or more times. It is unclear how such ideas might be tested. What researchers *can* do is pursue a more complete understanding of the technological actions preserved in the archaeological record. De Beaune's review of prehistoric pounding and grinding technologies contributes to this enterprise, but it does not adequately support the "phylotechnical" and cognitive conclusions that she reaches.

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De Beaune presents an interesting schema of the evolution of technical actions from the split between apes and hominids to *H. sapiens* and relies on cognitive mod-

els for elucidating the changes leading to "the invention of technology."

For de Beaune, the cognitive breakthroughs that occurred during technological evolution can be understood in terms of problem-solving strategies and particularly analogical reasoning. I am not disputing the role played by analogy in solving problems, but these cognitive skills are not the sole appanage of hominids. In fact, abstract relational judgments in the forms of inferential reasoning and analogy have been shown for example, in Sarah, a language-trained chimpanzee (Gillan, Premack, and Woodruff 1981), but also in other untrained apes (Thompson, Oden, and Boysen 1997), in monkeys (Bovet and Vauclair 2001, Fagot, Wasserman, and Young 2001), and even in marine mammals (Schusterman and Kastak 1998). Therefore analogical reasoning and other complex cognitive processes (e.g., categorizing abilities) may not be sufficient to explain the advances made by our hominid ancestors. I would suggest that technological inventions imply more than changes in problem-solving abilities. De Beaune suggests that during the course of human evolution cognitive characteristics independent of language may have evolved. She does not spell out what these features are. I would like to point to two likely candidates, namely, division of labor between hands and visuospatial abilities.

Manipulative abilities reflected in patterns of asymmetric coordination between the hands can occasionally be observed in nonhuman primates (see Van Schaik, Deaner, and Merrill 1999). They require the use of the hands to perform different but complementary actions on a detached object (e.g., grasping a fruit with one hand and peeling it with the other). However, most of nonhuman primates' hand uses are unimanual, and when movements are bimanual they are bilateral—that is, the two hands act together in parallel (see Hannah and McGrew 1987 for an example related to nut cracking by wild chimpanzees). By contrast, most human actions on objects and notably on tools imply serial assemblage of the hands (Vauclair 1993)—a true division of labor between the hands in which the action of one hand produces a frame of reference within which the second hand will act. This division of labor between the hands appears early in ontogeny. For example, by six months of age the human infant reaches for objects with bimanual coordination: one hand lands on the support near the object and then the other hand comes into contact and grasps it. This bimanual behavior (in right-handers) is conceived of as one hand (the left) providing the spatial conditions necessary for reaching by the other hand (de Schonen 1977). It is important to realize that such coordination, rare in nonhuman species, appears to be at work quite early in human evolution (see fig. 5 for an example involving flint knapping).

A possible by-product of these coordinated hand actions concerns the capacity to envision possible alternatives or to use frames of reference that do not exist *in situ*. Such competencies, requiring highly elaborate spatial representations, can be observed in the visuospatial gestures utilized, for example, in making loops and knots and in weaving (Vauclair 2003). Interestingly enough, these abilities can be neither reduced to language nor explained by it. In these behaviors, hand movement coordinations in space do not rest on concrete supports but are framed by the complementary roles of the two hands, where one hand (the left hand in right-handers) provides the spatial conditions necessary for the manipulations performed by the other. The chain of manual coordinations required by these complex spatial activities develops and is taught in a way that is, to a great extent, independent of language, namely, via direct observation and/or motor imitation (Bresson 1976, Ingold 2001), although verbal commentaries can be useful in attracting attention or scanning the operations involved in these tasks. These activities are absent from the repertoires of animal species. For example, no reliable report is available showing that chimpanzees can be trained to tie knots (an ability found in two-to-three-year-old human children).

Reply

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My aim was to present a hypothesis that might be put to the test of criticism not only by prehistorians but also by ethologists and cognitive scientists. I appreciate the commentators' constructive critiques. All except Stout agree with me that examining technology through the study of lithic materials is a promising approach to an understanding of the stages of human cognitive development. Stout rejects the idea that technological analysis of material other than knapped stone can tell us something about this development. He frames the discussion as if the discovery of stone knapping were the sole criterion for humanness, which seems to me debatable. He defends the idea of the adventitious discovery of stone knapping, but invention implies the capacity to organize scattered elements with a view to establishing their coherence in a milieu that exists only once the object is constituted; this "conditioning reversed in time" cannot take place without foresight and creative imagination, the capacity for projecting from the virtual to the real (Simondon 1989 [1958]:57–58). Accidents may happen, but they are null and void if the mind is incapable of perceiving their potential.

Hardy is disappointed that I have not explained how I identified use wear. For obvious reasons of space, I could hardly develop here what has appeared in detail elsewhere (de Beaune 2000). Similarly, Stout charges me with relapsing into the errors of descriptive typologies, doubtless because I neglected to clarify the basis for my tool types. The typology is a dynamic one based on the nature of traces of use, their location on the piece, and the raw material, morphometric data being relegated to the background.

Hardy stresses that, archeological data being by nature incomplete, one can never identify the "first" appearance of a behavior. I share his view and have also pointed out that "it is in the nature of archeological and paleontological data that we never witness the 'event' itself but can observe the preceding and subsequent events and deduce from them what took place." Reader also points to the incompleteness of archeological data, and both he and Hardy remind us that we lack the plant materials that must have made up no small part of the diet and perhaps also the "tool kit" of early hominids. I entirely agree. This implies that certain technical actions and perhaps certain "plant tools," especially for foraging, existed before stone tools, but this cannot be demonstrated. Reader distinguishes tools and proto-tools, and I admit not having recognized this distinction: an object *is* a tool or *is not*.

Davidson reproaches me with not having taken the Australian data into account with regard to the Upper Paleolithic behavior already in place at the time of the first colonization of the continent around 55,000 years ago. It is true that I concentrate on the Middle-to-Upper-Paleolithic transition in Europe, which is somewhat later, but I do not think that this affects my phylotechnical tree very much.

Most of the commentators focus on the split between apes and hominids and especially on their technical and cognitive capacities, whereas my intention was to explain the emergence of invention not only among early hominids but also in *Homo sapiens sapiens*. First, as Reader points out, I have never denied that primates and other animals use tools, and I have repeatedly spoken of nut cracking as common to chimpanzees, early hominids, and contemporary humans. I have also never argued, as Stout says I have, that stone knapping and nut cracking are equivalent. Although both involve thrusting percussion, there is a cognitive leap between them that no one would dream of denying. As Leroi-Gourhan has argued, stone knapping is eminently human in that it "implies a real state of technical consciousness" (1993 [1964]:92). It is precisely this cognitive leap—the process whereby one technical activity evolves to give rise to another—that continues to interest me, and it does not seem to me that ethology provides examples of these types of behavior even though insight and "transfer of competence" have occasionally been observed.

With regard to the technical and cognitive capacities of apes, the commentators disagree among themselves. For McGrew and Marchant, there is no doubt that chimpanzees are capable of stone knapping. I have said that they are capable of it provided that they are taught to do it. I recognize that humans also require apprenticeship to develop this capacity, but there is a fundamental difference: an ape strikes one stone against another without knowing why. In other words, there is no intention behind the action, and its apprenticeship can be considered training. In addition, one need only observe Kanzi knapping for a moment to recognize that he strikes the stone anywhere at all, without choosing a point or an angle of percussion on the core and without anticipating the form of the flake that he is going to obtain. Mercader, Panger, and Boesch (2002) are very clear that the flakes recovered from the site of chimpanzee nut cracking that they excavated were obtained by chance. Therefore, even if apes are capable of stone knapping, they do not do it with the intention of producing a cutting edge, and that makes all the difference. It occurs to me that one of McGrew and Marchant's objections may be the result of a misunderstanding: I did not call into question the apes' use of hammers to crack nuts and the associated production of pitted anvils. I simply said that, while they used sharp stones in thrusting percussion and accidentally produced cutting edges, they did not use the latter for linear resting percussion (in Leroi-Gourhan's terms), for cutting.

Whereas the flakes produced by chimpanzees and those found in early hominid sites can be compared morphologically as McGrew and Marchant, following Mercader et al., have done, one must bear in mind that the former were made accidentally and we know nothing about the conditions of production of the latter. It is possible that early hominids engaged in nut cracking and produced flakes unintentionally as chimpanzees do. This would make the appearance of the first genuine, deliberately made tools a little more recent, the oldest known being those of Lokalelei and Gona. It would not much affect my phylotechnical tree but would indicate that the ancestors of present-day apes and early hominids shared nut-cracking techniques and doubtless had the same cognitive capacities. From the cognitive point of view this would imply a differentiation perhaps a little more recent than the one I have suggested. On this subject, Stout slightly corrects the dates I indicated, which is useful but does not fundamentally alter my argument.

The unpublished data reported by McGrew and Marchant (Humle and Matsuzawa n.d.) indicating that some chimpanzees are capable of pounding the heart of the palm using the end of the upright trunk of the palm as a mortar may mean, from the cognitive point of view, that apes—or at least some of them—have cognitive capacities equivalent to those of hominids but for unknown reasons use them rarely. On this subject, Vauclair proposes an interesting hypothesis. In contrast to McGrew and Marchant, he considers apes incapable of knapping and suggests that the reason may be their inability to divide labor between their two hands and their visuospatial limitations. He points out that most nonhuman-primate hand uses are unimanual and that when they are bimanual the two hands act together in parallel. This interesting idea takes into account the laterality that has also been the object of much recent discussion (see Corbetta n.d., Steele n.d., and Holder n.d.). The question of laterality brings us back to that of neurological capacities in that if the hands are specialized, so is the brain, and neurobiological studies seem to indicate that the ape brain is less complex than ours (Maier et al. n.d.). This approach seems to me incapable of explaining the emergence of invention in biologically modern man.

While there are cognitive parameters underlying invention, as I have tried to show, it is clear that one must take into account the fact that an invention is not just

the product of an individual but rather that of a group by which is adopted. If one agrees with Reader, Mc Grew, Vauclair, and Stout that certain animals are individually capable of innovation, creativity, and insight, one must also recognize that these innovative behaviors are sporadic and do not usually become generalized within the group or do so only in a limited way (macaques that wash sweet potatoes, birds that open bottles of milk—although in the latter case it is not a matter of invention but one of applying familiar activities in a different context [see Vauclair 1996:108]). But if someday it were to be demonstrated that apes possessed in latent form the same cognitive capacities as modern humans (inferential reasoning, analogy), one would then have to explain why they use these capacities so rarely and why the innovations they produce are so rarely and so slowly adopted by the group. This would be a problem of social transmission. Without the adoption of the innovation by the group, there can be no technical evolution.

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