ARTICLES

On Stony Ground: Lithic Technology, Human Evolution, and the Emergence of Culture

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Culture is the central concept of anthropology. Its centrality comes from the fact that all branches of the discipline use it, that it is in a way a shorthand for what makes humans unique, and therefore defines anthropology as a separate discipline. In recent years the major contributions to an evolutionary approach to culture have come either from primatologists mapping the range of behaviors, among chimpanzees in particular, that can be referred to as cultural or "protocultural"[1,2] or from evolutionary theorists who have developed models to account for the pattern and process of human cultural diversification and its impact on human adaptation.[3–5]

Theoretically and empirically, paleoanthropology has played a less prominent role, but remains central to the problem of the evolution of culture. The gap between a species that includes Shakespeare and Darwin among its members and one in which a particular type of hand-clasp plays a major social role has to be significant. However, that gap is an arbitrary one, filled by the extinction of hominin species other than *Homo sapiens*. Paleoanthropology has the potential to fill that gap, and thus provide more of a continuum between humans and other animals. Furthermore, it provides the context, and hence the selective environment, in which cultural capabilities evolved, and so may provide insights into the costs and benefits involved in evolving cultural adaptations.

In this paper we focus on the role that paleoanthropology can play in the development of the science of cultural evolution. In particular, we want to consider the way in which information from stone-tool technology can be used to map the pattern of cultural evolution and thus throw light on the nature of the apparent gap that lies between humans and chimpanzees. First, we discuss the various meanings of the culture concept and the role of paleoanthropology in its use. Second, we look at how stone-tool technology can be used to map cultural evolution and provide insights into the cultural capacities of different hominin species. Third, we consider the inferences that can be made from stone-tool technology for the timing of major events in cultural evolution.

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EVOLUTION, CULTURE AND ANTHROPOLOGY

Culture in Anthropology

Culture is the jam in the sandwich of anthropology. It is all-pervasive. It is used to distinguish humans from apes ("everything that man does that the monkeys do not" (Lord Raglan)) and to characterize evolutionarily derived behaviors in both living apes and humans. It is often both the explanation of what it is that has made human evolution different and what it is that it is necessary to explain. It is at once part of our biology and the thing that sets the limits on biological approaches and explanations. Just to add further confusion to the subject, it is also that which is universally shared by all humans and, at the same time, the word used to demarcate differences between human societies and groups. As if this were not enough for any hard-worked concept, it is both a trait itself and also a process. When treated as a trait, culture can be considered to be the trait or the means by which that trait is acquired, transmitted, changed, and used (that is, learned, taught, and socially passed on). It exists in the heads of humans and is manifested in the products of actions. To add one further dimension, culture is seen by some as the equivalent of the gene, and hence a particulate unit (the meme) that can be added together in endless permutations and combinations, while to others it is as a large and indivisible whole that it takes on its significance. In other words, culture is everything to anthropology, and it could be argued that in the process it has also become nothing.[3,5–10]

The pervasive nature of the culture concept means that evolutionary anthropology must also tackle the problems it throws up. This is not the place either to argue that the concept should be abandoned as of little or no analytical utility (one of us attempted this several years ago, to no noticeable effect[11]) nor to come up with a cutting-edge redefinition that will clear away a century of obfuscation (we leave that in the capable hands of the Editor of Evolutionary Anthropology). Rather, we wish to consider how

TABLE 1. Cultural Capacity Is Cognitively Based, but Is Correlated With a Number of Manifestations in the Realms of Learning, Social Organization, Symbolic Expression, and Patterns of Tradition. These Expressions May in Turn Be Visible in the Archeological and Fossil Record

Broad Correlative Components of Culture	Potential Paleobiological Manifestations
Learning capacity	Technology and technological variation
	Brain size?
Social organization and structure	Archeological density, structure and distribution
	Sexual dimorphism in fossil hominins
	Nonecologically functional elements of material culture
Traits associated with symbolic thought	Brain size?
	Anatomical basis for language
	Variation in material culture
Tradition maintenance and change	Regional variation and longevity of archeological components

those aspects of anthropology that deal with the deep past of the human lineage—paleoanthropology—might throw light on the evolution of culture and the role it may have played in human evolution.[12]

The problem in attempting this is that the sources of such evidence are limited, especially if little recourse is made either to analogical or phylogenetic inferences from chimpanzees and other primates or extrapolation back from ethnography and psychology. Paleoanthropology is limited to the archeological record for the evidence it throws either on hominin cognition, and hence culture, or else on the cultural manifestations of behavior. In practice, this means using the record of stone tools, the primary source of information about the behavior of prehuman hominins.

Culture and Paleoanthropology

There are two reasons why both evolution and paleoanthropology are central to any discussion of culture. The first is that the distinction between humans and other species is usually drawn in some way around the concept of culture—put simply, we have it and they do not. Chimpanzees chipping away at the margins of tool making or grappling with the rudiments of American sign language do not really change this state of affairs. Given the fact that humans must have evolved from an acultural organism to one that possesses such capacities means that the evolution of culture is a major challenge to evolutionary theory. The second, related, aspect is that the evolution of culture must therefore be a diachronic process. Comparisons between two living species, humans and chimpanzees, can only examine outcomes, not the actual process of transition. This must be inferred. The actual development of more and more culture-bearing hominins must have occurred among species that are now extinct, to whom our only access is through the fossil and archeological record.

To search for something in the fossil and archeological records requires knowing what one is looking for, so that a consideration of definitions of culture cannot be entirely avoided. Definitions of culture largely fall into two broad groups. Either they involve the actual end products of behaviors that are inherently human (technology, for example) or they focus on the processes that produce these outcomes—that is, the cognitive underpinnings. Most recent approaches have concentrated on the latter or, in other words, trying to get into the minds of extinct species and populations. This can only be done in terms of correlates. Most definitions of culture involve three core elements: those associated with learning, its depth and extent, or the ability to acquire new information independent of a tightly constrained genetic basis; those associated with social organization and complexity; and those associated with symbolic thought, both its underlying cognitive basis and its communication. In addition to these core elements is the extent to which the behaviors derived from these capacities are either capable of change and variability (a characteristic of cultural systems) and have a means of being maintained as traditions (persistence through time). The possible paleobiological correlates of these are shown in Table 1.[12]

EVOLUTIONARY HISTORY IN THE STONES: WHAT CAN THEY TELL US?

We can now turn to stone technology. From over two million years lithic artifacts provide a rich and durable source of information about the behavior of extinct hominins, and thus greatly expand on the anatomical fossil evidence. The question to ask is what sort of information can be derived from stone tools?

Archeologists have basically come up with two answers to this question. On one hand, patterns in technology have been used to reconstruct population histories, in a sense to construct phylogenies of species and populations (cultures, in other words). Stone tools were, in effect, treated as population markers. This may be considered the phylogenetic and historical approach. On the other hand, stone tools can be and have been interpreted as adaptive markers, often with little or no phylogenetic signal, because they are endlessly thrown up convergently by the demands of the environment and social organization, which thus reflect variability in behavioral response. This can be termed the adaptive function approach.

By and large, these two approaches have been seen as alternatives, and to be in conflict with one another. Furthermore, from a historical perspective, the adaptive function approach has generally supplanted and succeeded the phylogenetic and historical approach, and has become the consensus on which most Palaeolithic archeology operates. However, it is worth considering briefly the strengths and weaknesses of each approach.

Phylogeny and History: Human Evolutionary History From Stone Tools

The idea that human evolutionary history might be reflected in stone-tool typology is one of the oldest in the discipline and, in one form or another, has been a persistent theme over the last one hundred and fifty years or more. When Frere recognized the stone tools discovered in the eighteenth century as the product of humans, and at the same time recognized that they were very "primitive," he was drawing the first of many such conclusions. Stone-tool typology could be seen to reflect the stages of human history, from the first simple flakes and cores through to the Solutrean points. During the first part of the twentieth century, this became formalized in the schemes of Breuil, Burkitt, and Bordes.[13]

The phylogenetic and historical approach generally encapsulated two basic components. The first was that if stone tools were similar, then they were made by the same sort of people, usually taken to mean people belonging to the same culture, with greater or lesser implications for ethnic groups, depending on the time scale involved. The second was that the level of sophistication or complexity of the tools reflected the cognitive or cultural status of the population concerned, usually more or less advanced within the framework of the time. When these two components are put together, one has a model for explaining prehistoric change in terms of the movements of peoples through their particular set of tools with a process of evolution toward greater cultural and, by implication, cognitive complexity.

The idea of stone tools as the markers of chronology gradually fell into disrepute, especially as it was recognized that globally it was hard to maintain the model of universal stages and that there was not necessarily any chronological consistency to the pattern of change. Nonetheless, stone tools were still seen as markers of peoples as they ebbed and flowed across the Palaeolithic landscape. The high tide of the phylogenetic and historical approach occurred when it was possible to draw simple boundaries around typological and technological clusters and to associate them with cultural history and narrative. Thus, the cultures of the Upper Palaeolithic, for example, were essentially analogous to ethnographic units, an analogy that was sometimes drawn all too explicitly.[14]

This "from technology to culture to people to history" approach has been subject to many criticisms, and is largely associated with work by archeologists in the first half of the twentieth century. The move to a greater emphasis on adaptation and, more recently, raw-material constraints, has greatly altered the way Palaeolithic archeology has been done and how the past is interpreted.

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Adaptation and Function: Information From Design

The alternative to the idea that stone tools reflect population and thus evolutionary history is that of adaptive function, and is the consensus view of archeologists today.[15,16] Variability in stone tools, rather than reflecting the social and cultural groupings of the populations who made them, reflects the demands of the environment and the responses of the populations to those demands within the constraints of raw-material availability.

The switch in emphasis was encapsulated in the Mousterian debate of the 1970s, when Binford argued that the variation in the frequencies of tool types in the rock shelters of the Dordogne and the Levant reflected different activities being carried out, rather than the movements of different people. The form of stone tools and their frequencies in assemblages have been seen increasingly as the result of environmental and ecological demands and opportunities. Concomitant with this view is the corollary that if the signal in the shapes of stone is function, it could not at the same time be phylogenetic and historical.

To this strongly ecological approach has been added an additional element, that of the constraints of stone as a raw material and the process of knapping itself. It is clear that in some parts of the world good lithic materials are abundant, and in others scarce. The strategies of stone tool manufacture would therefore be expected to reflect this. The classic example of this view has been the increasingly popular interpretation of the Movius Line as a raw material boundary within the Old World.[17,18] The way in which stone tools are made—through a process of core and flake reduction—is also important. It has been argued that the differences among typological elements are the product of different degrees of reduction, and that, for example, a few more blows and one type is transformed into another. Tool-type frequency thus reflects use and the need to retouch more or less. From an evolutionary perspective, the adaptive function approach sees homoplasies (convergent evolution brought about through a combination of selection and constraints) as being rife, and therefore the phylogenetic signal of stone tools as being very low.

Back to Population History

In recent years, however, there has been a resurgence of interest in the interpretation of archeological materials in an evolutionary, in the sense of phylogenetic, perspective.[19] This can be seen in areas of direct interest to human evolution. One example is the association of the Aurignacian industries with the dispersals of modern humans into Europe and, conversely, the issue of whether there is a link between Neanderthal populations and the Mousterian in general and the Chatelperronean in particular.[20,21] A further example is the suggestion by Klein[22] that the dispersal of *Homo heidelbergensis* into Europe is associated with the Acheulean. We have also proposed that stone tools are markers of hominin geographical patterns,[23] both in the long-term persistence of the Movius line and in the spread of Mode 3 or prepared core technologies in Africa and Europe as part of a dispersal of later archaic populations, as well as modern humans.[24]

The Evolution of Culture Through Stone Tools: Which Approach?

Given these two contrasting approaches to the information potentially locked in the stone tools, we ask which one can give the most useful insights into the problem of the evolution of culture, and thus make use of the archeological record within the field of anthropology more generally. Perhaps the common-sense answer is the adaptive functional approach. This would certainly be the preferred option for most archeologists, as it represents the prevailing paradigm for the analysis of stone tool variation. More importantly, as culture is presumably an adaptation, then it is only natural to use an adaptive approach to identify it in the past. The extent to which hominins might have possessed a greater or lesser degree of cultural capacity might be expected to be reflected in the extent to which we can see a good fit between the environment and technology. Here the proxy for culture is thus taken to be those aspects of the various definitions that emphasize the behavioral manifestations of culture, variability, and a high rate of change.

If, on the other hand, culture is seen as a cognitive state reflecting the ability of the mind to generate new behaviors, then this can be something that might be expected to reside in the characteristics of the various species and not to exhibit a great deal of sensitivity in relation to the environment. This allows us to consider whether stone-tool technology covaries with phylogeny and taxonomic status or with the environment, and thus provides an empirical route into the problem.

In summary, therefore, we need to consider stone tools both in an environmental context and in the context of phylogeny. Both history and ecology are important, as is the case in most evolutionary problems. Testing the various possibilities requires a dualistic approach.

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STONE TOOL TECHNOLOGY AND HUMAN EVOLUTION

Against this historical background, we propose that embedded in the Palaeolithic record are the signals of both adaptation and phylogeny. The ideas we will develop here are one attempt at disentangling these signals. First we look for the presence or absence of a correlation between biological evolution, based on morphological affinities, and technological change, based on the distribution of technological modes. Second, we use this derived relationship to consider whether there is an association between cultural output and the species involved, and where technological change occurs in relation to biological change. Finally, we consider how these might relate to inferred cognition. Central to our argument is that while environment is shaping the technological demands, the nature of hominins' behavioral response is circumscribed by their cognitive abilities. Thus, the link between technology and phylogeny is crucial for determining the pattern of cultural evolution.

The Pattern of Hominin Evolution

To provide a framework, we can briefly outline the pattern of hominin evolution from the origins of the genus *Homo*. Figure 1 shows the distribution of proposed genus *Homo* taxa by time and geography. The earliest *Homo,* as well as the australopithecines, are excluded: Although there is clear evidence that they did make stone tools,[25–27] this primarily suggests either that Mode 1 technologies are plesiomorphies of *Homo,* being developed among one or more australopithecine lineages, or else an apomorphy at the base of *Homo.* The subsequent distribution of Mode 1 technologies shows the diversification and geographical radiation of the descendants of *Homo ergaster* or possibly earlier members of *Homo.* Among these geographically widespread members of *Homo* there appears to be considerable diversity, with a distinctive pattern to be found in Eastern Asia that has led some authorities to distinguish between an African lineage (*H. ergaster*) and an Asian one (*H. erectus*).[28,29]

Newer finds, such as those from Dmanisi,[30] Ceprano,[31,32] and Buia[33] support this perspective, although others such as the material from Baka[34] have been employed to question such a distinction. The evolutionary changes that occur from a little

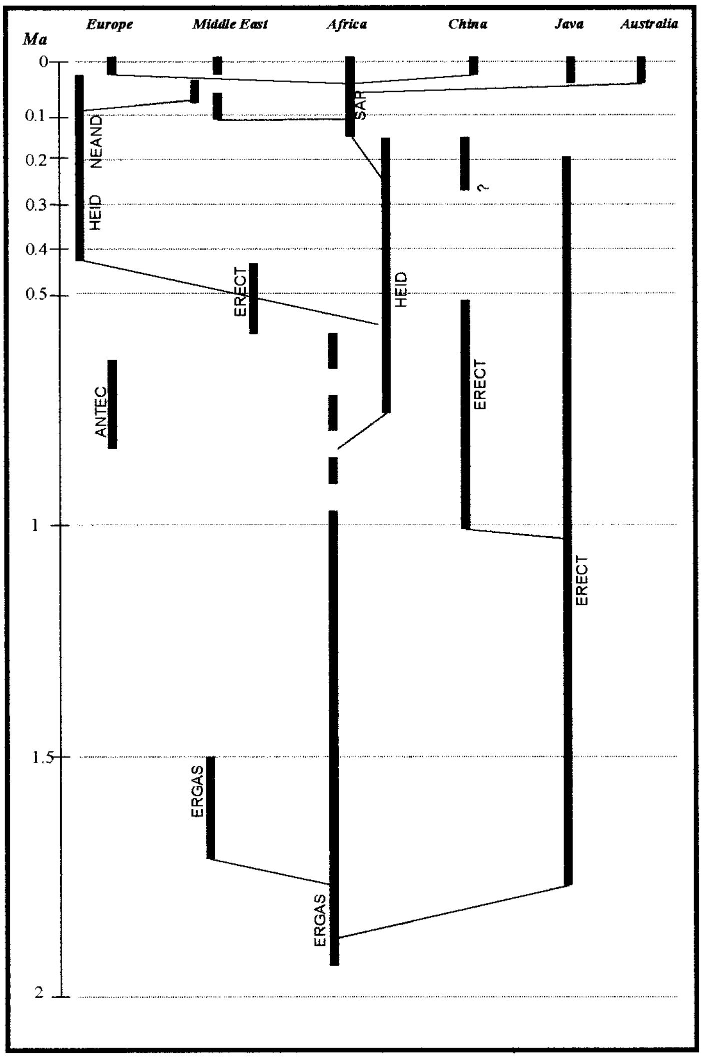


Figure 1. Chronological and geographical distribution of recognized taxa of *Homo.*

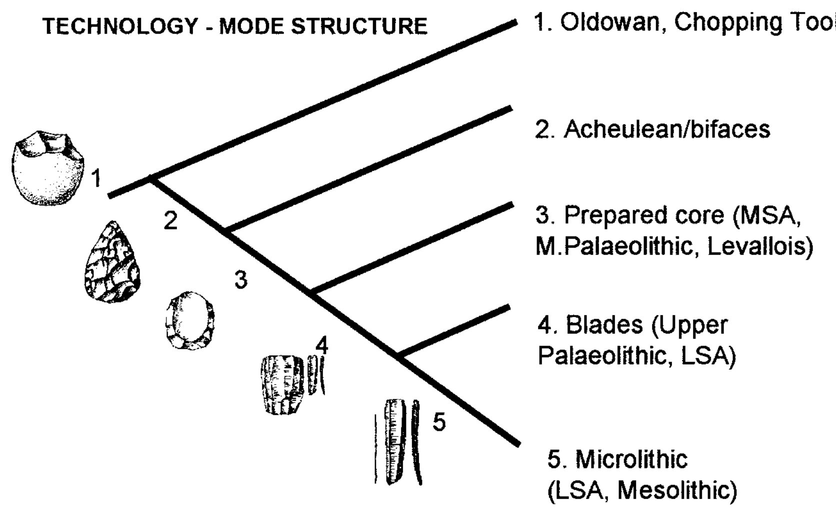
more than 0.6 Myr have led to the view that there is a new taxon, *H. heidelbergensis,* which had a larger cranial vault and a generally more modern appearance, although retaining the extreme robusticity of the Lower Pleistocene *Homo* species.[35] This taxon is found in Africa and Europe, and to some it may also be present in East Asia. A further element of diversity can be added to this essentially Middle Pleistocene pattern with *H. antecessor,* known from Spain.[36] Finally, the terminal Middle Pleistocene and the earlier parts of the Upper Pleistocene show the evolution of two highly encephalized and derived forms of hominin, Neanderthals in Eurasia and modern humans in Africa.[37] The latter, *H. sapiens,* are present in Africa probably from 150,000 years ago, but occur, presumably through population expansions, in other parts of the world considerably later: 100,000 years ago in Western Asia, 60,000 years ago in Australia, and around 40,000 years ago in Mediterranean Europe and Eurasia.[38]

Technological Modes, Hominin Phylogeny, and the Scale of Environmental Variation

How do stone tools map on to a phylogeny of the genus *Homo?* This raises the question of how we "measure" technological diversity. There is no generally agreed means of doing this, as different approaches emphasize different traits, including means of flake production, typological forms and frequencies, metrical variation, core reduction sequences, and microwear patterns. The geographical and chronological scale of variation in each of these is very variable, and many show high levels of local, small-scale diversity rather than the large-scale one that we associate with hominin phylogeny biologically. We argue that in terms of mapping the general patterns of change and stability, what is needed is a scheme that operates on a global scale and reflects broad-scale change rather than local site variation. To make a biological comparison, we need a system that has high interpopulation variation relative to intrapopulation variation. Against this criterion, the most appropriate classification system is that of technological modes, the major forms of lithic production (see Box 1).

The principles have been developed elsewhere,[23,24,39] but in brief consist in recognizing general technological traits and treating them cladistically. These traits refer to the basic means by which the stone tools were made and the broad nature of the artifactual outputs. Using Clark's modes,[40] five basic technologies have been recognized: Mode 1 being chopping tool and flake industries; Mode 2 being the production of bifaces and bifacially worked handaxes; Mode 3 being prepared core technology; Mode 4 being lamellar or blade technology; and Mode 5 being microliths. Although there are continuities between them, they express more complex ways of making stone tools, leading toward greater control and a more effective use of raw material to produce particular end products. They are particularly suitable to be considered cladistically and so phylogenetically, because they are built upon each other, and incorporate some of the elements of "descent" that are essential to an evolutionary approach. It is important to emphasize that one of the reasons that the technological modes are appropriate for evolutionary analysis is that they stress the most derived elements in an assemblage, for it is well-known that even after the development of more derived modes, more "primitive" ones, in the cladistic sense, persist.

Box 1. Clark's Technological Modes



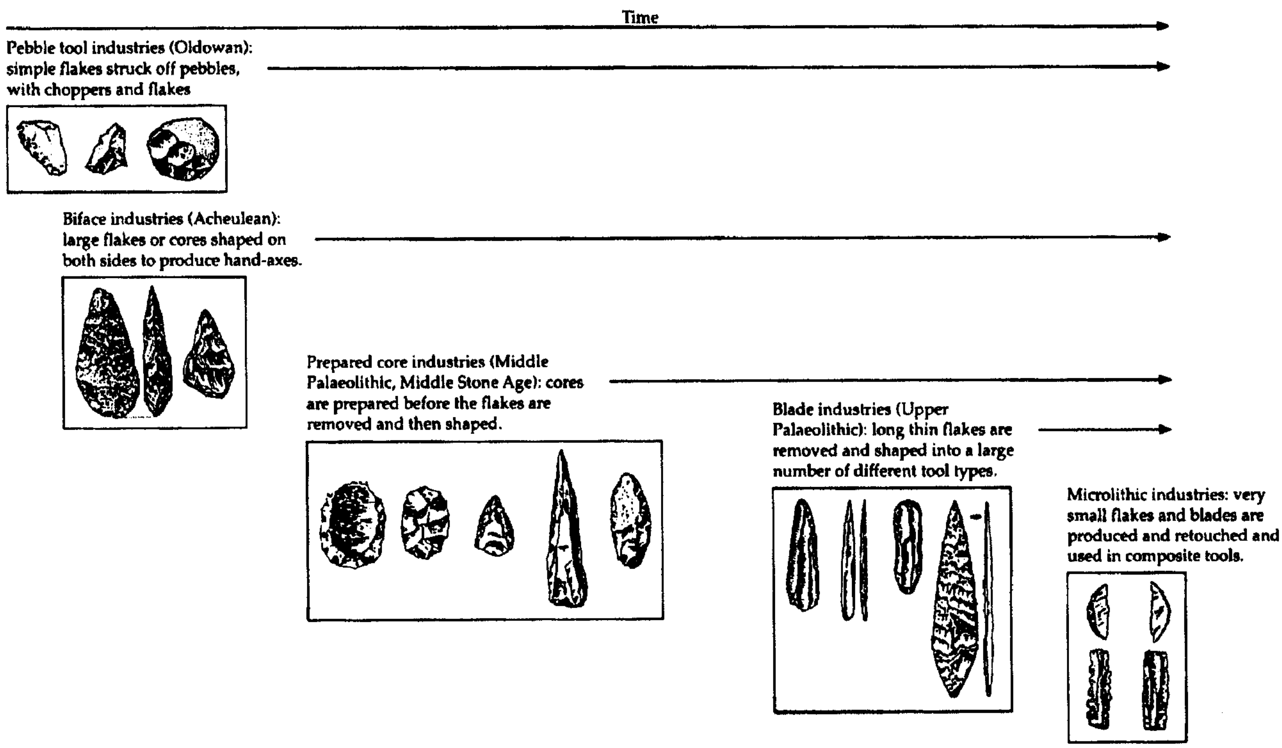
Clark, working in the context of a plethora of archeological cultures and terminological diversity, attempted to provide an overarching framework for summarizing variation in Paleolithic and Mesolithic lithics on a global scale. He suggested that across the range of lithic assemblages there could be seen some generalities that related to the way in which the stone tools were actually manufactured—hence, the term modes. Clark had in mind the technological modes of production for the Stone Age, upon which were superimposed the varieties brought about by cultural preference, economic need, and raw material availability. His modes provide a basic framework for grouping and separating stone-tool assemblages at a general rather than specific level. They are described here in outline form, with their broad geographical and temporal distribution.

Clark's modes were based essentially on the way in which the basic flake-core relationship occurred. Mode 1, comprising the Oldowan and Asian Pebble Tool and Chopping Tool Traditions, constituted the simplest mode of production, the striking of a flake off a core. The number of flakes could vary, but what held this system of production together was the simple platforms and lack of preparation involved. The flakes struck off tended to be relatively small compared to the size of the cores, and to lack, both on the cores and the flakes, significantly invasive retouch. This mode resulted in relatively little diversity of tool forms, relatively little by way of core reduction, and lack of any preparation of the striking platforms. Mode 1 occurs extensively throughout the Old World over much of the Pleistocene and well into the Pliocene in sub-Saharan Africa. The African Mode 1 industries are primarily Pliocene and Lower Pleistocene, whereas in Eastern Asia they persist until the Upper Pleistocene. They also occur in the Middle Pleistocene in Europe.

Mode 2 saw the development of two elements, although of course it would have been possible for these to occur independently. The first of these was the ability to strike off relatively large flakes so that they would have some of the size properties of cores, but with a narrower cross-sectional area, and thus be suitable for a greater amount of invasive retouch. It was this that constituted the second development, for it became possible to retouch the resulting flakes in such a way that secondary flakes were removed across the whole surface of the flake and on both sides. The result was the bifacial tradition that is represented by the Acheulean and its variants. The Acheulean is known from Africa from dates close to 1.5 million years ago, although it often is difficult to draw a line between this and the developed Oldowan Mode 1 industries. The bulk of well-documented African Acheulean sites are less than 1 million years old, and usually belong to the Middle Pleistocene. In Europe, Western Asia, and the Indian subcontinent, the dated Acheulean sites fall mostly into the Middle Pleistocene, although there may be some evidence (at Ubeidiya) that it sporadically occurred earlier. There has been prolonged controversy over the presence of true Mode 2 industries in Eastern Asia. Although there is some evidence for bifacial stone tools in that region, there is nothing truly like the recurrent Acheulean of the west. It is this distinction that is represented by the Movius Line.

Mode 3 represents a major shift in the output of lithic production, although it shares with Mode 2 elements of the way tools are produced. The key difference is that the core is prepared prior to striking off a major flake as a means of having greater control over the shape and thickness of the flake. The actual means of preparation, however, is probably similar to that used in the production of handaxes. The outcome is a much

Box 1. Clark's Technological Modes (continued)



more diverse set of finished tools, and hence a greater potential for variability and a greater emphasis on smaller items. Mode 3 constitutes the technologies of the European Middle Palaeolithic and the African and Indian Middle Stone Age. Its presence in the Middle Pleistocene of Eastern Asia is disputed, but it may have had a more extensive eastern distribution in the Upper Pleistocene.

Mode 4 continues the trajectory of Mode 3 in the sense that it is concerned with producing pieces off a core with the shape of those pieces being determined by the way in which the core has been prepared. In this case, the preparation is designed to produce long flakes and results in cylindrical prismatic cores and fine, elongated blades with narrow cross-sections, which then are reworked extensively into diverse sets of subsidiary tool types. Although elongated flakes (that is, blades) are produced by the Mode 3 technologies, the Mode 4 system is different in that it is based on prismatic cores. Conventionally, Mode 4 industries are associated with the Eurasian and North African Upper Palaeolithic and occur late (after 50,000 years) in the Upper Pleistocene. Blades are also known to occur in earlier deposits, for example in the Kapturin Beds in Kenya, and in the early Upper Pleistocene of Western Asia and Northern Africa, but these are seldom prismatic.

Mode 5 involves microlithic technologies: the production of very small flakes and blades that are retouched and worked into various shapes in some contexts or are used as composite unmodified tools in others. Microliths are widely known in the later parts of prehistory. They form the basis of the African Later Stone Age from approximately 30,000 years ago. However, there may have been earlier occurrences of this mode (for example, the Howieson's Poort in southern Africa around 80,000 years ago). Microliths are also known in Southern Asia from around 30,000 years ago, more widely across Europe and Asia in the latest parts of the Pleistocene, and in the early Holocene (the Mesolithic). Mode 5 industries are also known in the mid-Holocene in Australia.

Figure 2 shows the distribution of the technological modes represented in phylogenetic terms. It is perhaps striking that the overall shape of the two trees is remarkably similar: Both show deep African/Asian clades and relatively prolonged longevity of lineages. This confirms the continental rather than local scale of variation. These are, of course, two well-known and established facts, and it would perhaps be surprising if there was no

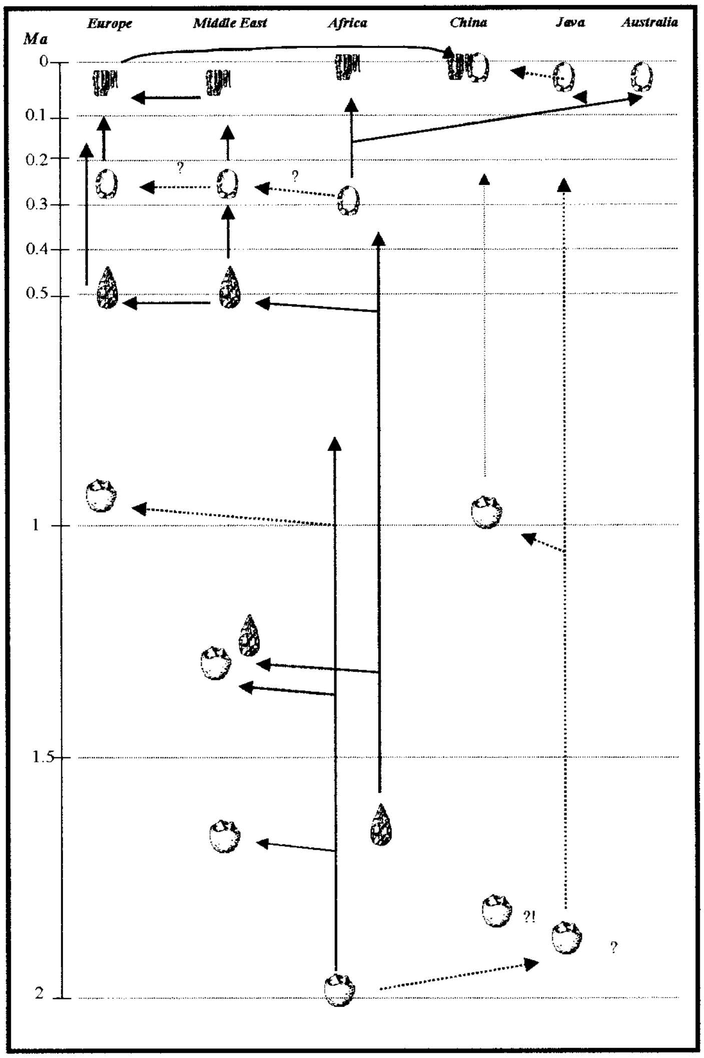


Figure 2. Chronological and geographical distribution of lithic technologies in terms of modes.

concordance given that they are supposedly the records of the same populations. How, though, does this pattern relate to the expected scale of variation? The answer to this question is that the scale observed seems to reflect long-term phylogenetic patterns more than fine-grained adaptive ones. If environment was driving Lower Paleolithic variability, one would perhaps expect a far more fragmented distribution, with, for example, frequent oscillations between Mode 1 and Mode 2 industries as habitats changed and as the availability of raw material varied from region to region. This is not what is seen. Instead, the best predictor of what an artifact is going to look like is what the earlier ones in the same region did—a measure of heritability, as it were, among (admittedly nonreproducing) artifacts. There is a fidelity of form that defies the scale of ecological variation and seems to suggest that the variation in stone tools as refuted in Clark's modes says more about the characteristics of their makers than the environments in which they were living.

There are, however, differences between the two. Where most interpretations of the fossil phylogeny suggest a divergence between European and African lineages dating back to the middle or early part of the Middle Pleistocene, the shared technology of the Neanderthals and modern humans (Mode 3) suggests a later divergence or at least a period of contact and cultural diffusion around 300 Ka. Elsewhere we have proposed that Neanderthals and modern humans may have shared a more recent Middle Pleistocene ancestor than *H. heidelbergensis,* a population we named *H. helmei.*[24] It should be noted that our use of *H. helmei* differs from that made later by McBrearty and Brooks[48] to refer to the immediate African ancestor of modern humans only.

The preceding evidence suggests that there is a strong but not entirely straightforward relationship between phylogeny and technological modes. This may seem to indicate that in terms of the two approaches discussed earlier, the phylogenetic and historical approach is the most consistent with these data. This may suggest that there is not a strongly adaptive element to technology. This is misleading in two ways. The first is that while the technology is adaptive—that is, carrying out particular functions that enhance survivorship—it is strongly mediated by the cognitive capacities of those hominins, who appear to have been limited at least in terms of their ability to innovate and vary their productions. This enhances the idea that the stone tools are providing insights into the evolution of the cognitive basis for culture. The second way in which we may be misled is if the approach through modes is insensitive to the scale of variation that is significant at an adaptive level. This has been one of the criticisms leveled at the approach and can be discussed in terms of "private histories."

Private Histories

There are many caveats to the broad interpretation of the archeological record presented, of which the most important one is that the modes clearly reflect only a small part of the variability in stone tools, and it could be argued that they are the only ones that reflect this scale of variation. Typology, assemblage structure, and microwear analysis might well display diversity at either more general scales or more local ones. This in itself would not be surprising or necessarily a problem with this evolutionary history model. Microwear,[41] for example, might well be expected to map onto a very large scale of variability, as it is probably the case that different stone tools were used for the same purposes by different populations. In other words, there is only one way to skin a dead cat, but many tools that can be used to do it. At the other extreme, the detailed typological shape of the end-product artifacts may well be expected to display local variation, as these will be influenced both by the availability of raw materials and small-scale cultural tradition, the Paleolithic equivalent of the different ways of hand-clasping or nest-building found among chimpanzees. A prehistoric human example would be the differences in detailed bone harpoon shape found among the epi-Paleolithic populations of northern Europe, which shared the same basic stone-tool technology, and which Clark used to identify social territories.[42]

We argue that although the modes do not tell the whole story, they do tell an important one. This might perhaps be a pointer to the way in which we think about integrative approaches to human evolution. There are many sources of information about the evolutionary past, from fossils to archeology to genetics. While ultimately each must be the product of a single series of historical events, nonetheless each may have to some extent a private history. Genes may record events that are completely invisible archeologically—indeed, one would expect them to—while the stone tools might be highly sensitive to changes that are not seen in cranial morphology. Indeed, as the number of genetic systems studied increases, it is becoming clear that while they tell the same basic story, each one does have a private history: the Y chromosome compared to mtDNA, beta-globin compared to Alu insertions, and so on. Different elements of stone-tool technology may well also have their own private histories, and these histories may be regionally and chronologically specific. For this reason, technology may well not provide a single line of evidence and information, but separate ones relating to different evolutionary events—some to speciation, some to dispersals, some to behavioral grade shifts, some to cognition, some to ecology.

THE EVOLUTION OF CULTURE THROUGH HOMININ EVOLUTION

Technology and Evolution: Correlation and Causality

We can put this notion into practice by considering the relationship between the major changes in modes and the appearance of new taxa as shown in the fossil record.[23,24,39] In Figure 3 a phylogeny for *Homo* is shown, with the appearance and disappearance of the technological modes superimposed. It can be seen that the relationship is far from straightforward (Fig. 4). It may be that this complexity is at least partly due to imprecise dating, but it may also reflect to some extent the fact that while both the stones and the fossils tell the same story they are sensitive to different parts of it. For example, we can see that the emergence of stone-tool technology predates the current evidence for the origins of *Homo*. In contrast, the earliest evidence for *Homo ergaster* does not relate to any significant change in technology, but rather technological change occurs considerably later, when Mode 2 appears, after 1.4 Myr. It is also the case that *Homo heidelbergensis*, which is known from about 600,000 years ago, is not associated with a new technological mode, although there is some evidence to suggest that at this time there is an intensification of biface production. Finally, when we look at the later parts of human evolution, there is some tentative reason for suggesting that the emergence of Mode 3 technologies in Africa may be associated with a new morphology—what we have referred to elsewhere as *Homo helmei*. However, both *H. sapiens* and *H. neanderthalensis* make their appearance in the context of Mode 3 technologies, with Mode 4/5 only occurring tens of thousands of years after the first anatomical evidence for modernity.

. . . although the modes do not tell the whole story, they do tell an important one. This might perhaps be a pointer to the way in which we think about integrative approaches to human evolution. There are many sources of information about the evolutionary past, from fossils to archeology to genetics. While ultimately each must be the product of a single series of historical events, nonetheless each may have to some extent a private history.

To many, the complexities of the relationship between hominin lineages and technology might lead to the view that there is no relationship at all. Certainly there is no simple causal relationship between the development of new technologies and speciation. There is not even a consistent relationship, in the sense that technological change always precedes anatomical change or vice versa. There is, nonetheless, an important pattern that requires explanation. What is likely is that different elements are related to different events. Speciation or, more prosaically, the date of first appearances, is a demographic process, usually arising from the occurrence of small isolated populations. It is not inherent in this process that there should be a technological or behavioral or adaptive change. Rather, this process relates to genetic divergence, either through drift or selection. The major behavioral changes that might be associated with any new species could arise on either side of that geographical boundary. Major adaptive changes, in other words, are not necessarily related to speciation. What they may be associated with are dispersals. That is, where technology confers a major adaptive advantage it

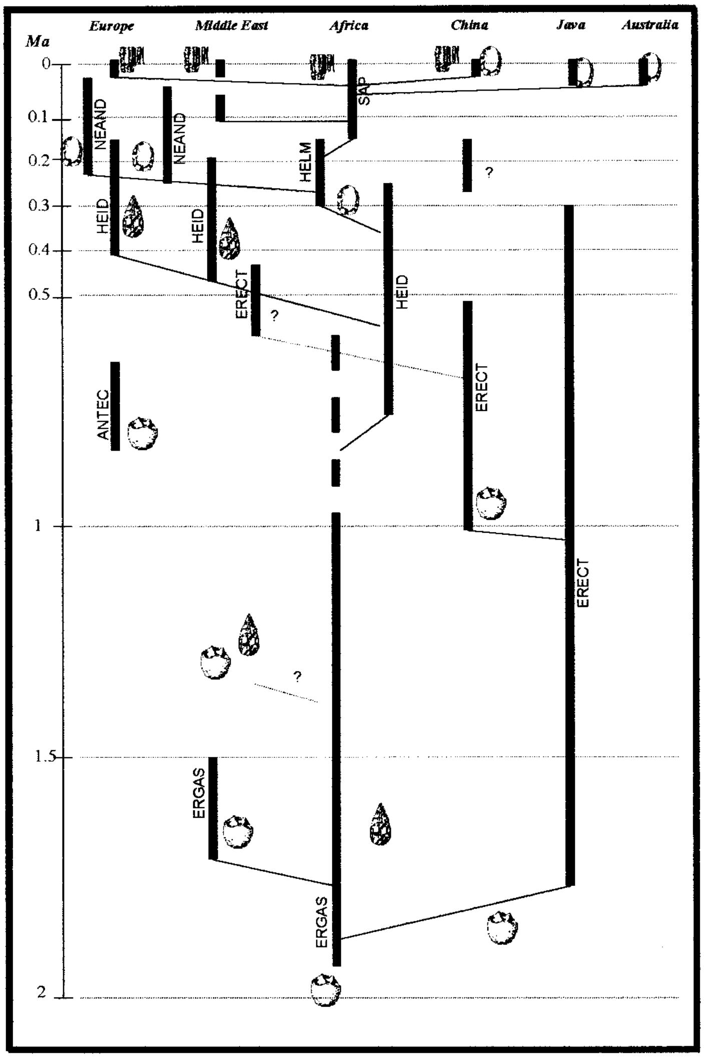


Figure 3. Comparison of chronological and geographical distribution of lithic modes and *Homo* taxa.

leads to a geographical range expansion, and this will be visible: Hence the often apparently rapid widespread distributions of novel technologies.[43] This may explain why the appearance of modern humans in Europe is associated with a new technology, the Aurignacian or Upper Paleolithic, but the anatomical features associated with these populations have been present in Africa for as much as 150,000 years.[44]

The Evolution of Culture: Inferences From Technology

What, though, can we learn about cultural evolution from modes? The most obvious point is that these technological systems of fossil hominins are deeply stable. Despite minor typological variation and raw-material constraints, there is little doubt that the Mode 2 industries, even subdivided into flake-based and nodule-based, are characteristic of particular periods and continents, and that they do not change much. It is perhaps a forgotten wonder of the archeological world that a French-trained archeologist who knows of nothing but the Dordogne could go to the Cape of Good Hope and recognize the artifacts and mode of production. What does this tell us about culture? Two things come to mind. The first is that across time there is clearly an increase in the complexity of the means by which tools are made, involving both more careful material selection, more forethought in the approach to production, and the potential for a greater diversity of outcomes. Unfashionable as it may be, this can be described as a progressive trend. However, the question to ask is where across this trend are significant changes occurring. This is not just "chronological" variation. The modes persist much longer in some places than others (for example in Eastern Asia with Mode 1), suggesting that the evolution of the underlying cognitive capacities of the hominins was not uniform across the world. If the modes reflect culture or cultural capacity, then culture is not evolving uniformly across the world's hominin population. At present there is insufficient data across Asia to understand the details of this and whether it is a case of isolation or local selection, but as a problem it emphasizes the need to situate the archeological record on the hominin phylogeny. It is no longer possible to refer to generalized evolu-

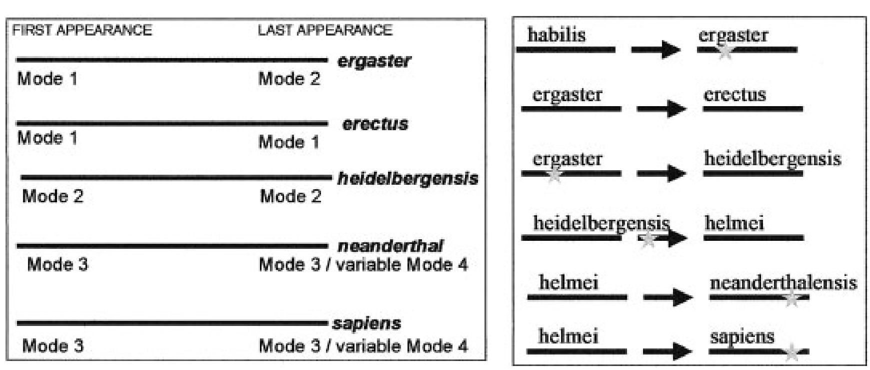


Figure 4. Relationship between technological change and lineage change among hominins. The left diagram shows the major lineages of *Homo* and where Mode changes occur within them, while the right diagram shows how mode changes relate to "species" changes.

tion of cultural capacities within the genus *Homo*.

The second cultural aspect is the stability of the modes across the Pleistocene, which has been extensively discussed here and elsewhere. In one sense this stability mirrors a condition of culture—faithful replication of systems—but it does so on a scale that is manifestly very different from that of modern technologies. This argues either for a remarkable cultural template beyond the capacities of modern humans or for the absence of another cultural trait, the ability to innovate and make modifications. This latter possibility seems the more likely, with a sense that one part of the cultural program, imitation, was far more dominant in earlier hominins than it is in modern humans. As Byrne[45] has shown for gorillas, imitation is quite a complex cognitive process, so this does not mean that these creatures were not considerably more intelligent and culturally competent than living apes.

Finally, with regard to modes, we can ask whether the points at which they change are significant events in the evolution of culture or are what has been referred to earlier as private histories acting independently of the rest of the hominin evolutionary record. The mode change that has attracted the most attention recently is that of Mode 4, the blade technology associated with the Upper Palaeolithic.[22,44,46] This has been strongly associated with the appearance of modern human behavior and the Out-of-Africa model of recent human evolution. However, as various authors have pointed out,[24,47,48] it is difficult to pinpoint a direct cognitive change with this Mode. First, it is too regionally specific, essentially being confined to Eurasia. Second, it is too late, having occurred well after the first appearance of modern humans and after the diversification of the human population. If it was a cognitively and biologically based cultural shift, then it occurred only after the major populations of the world had separated, and therefore could not be a universal trait of humanity. Mode 4 and, we argue, Mode 5 as well, are important, not as markers of major cognitive evolution, but of the processes of demographic expansion into various environments, and probably reflect the processes described in Shennan's density model of cultural explosions.[49]

At the other end of the technological spectrum, the development of Mode 1 technologies has been seen as a significant cultural evolutionary event, distinguishing more advanced hominins from apes.[16] Although there is some experimental evidence that chimpanzees are capable of stone fracture techniques, these appear to be achieved with difficulty. *Homo habilis,* or whichever Pliocene hominin first made stone tools, was clearly able to replicate the process consistently. This does probably represent a significant change in the process of cultural evolution. Strout and coworkers have used PET scans of people carrying out stone knapping to explore the cognitive processes involved and shown that these do share similarities with cognitive responses to tasks of a cultural nature in the extent to which they coordinate motor control with other aspects of cognition, especially spatial processing.

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Between these two extremes lie Modes 2 and 3. The development of Mode 2 at one level seems to show a major change: the ability to strike off large flakes and invasively retouch them in a controlled way, with a perception of the importance of final shape.[16,50] This shift occurs during the span of *Homo ergaster*. However, it is worth noting several points about the development of Mode 2. It does not appear with *H. ergaster* (1.8 Myr), but several hundred thousand years later; while the end product (the Acheulean) is distinctive, it does merge more gradually with the Developed Oldowan (Mode 1); and there is a considerable contrast between the earlier forms and the later modern derived Mode 2 that is associated with *H. heidelbergensis,* where there appears to be a much greater emphasis on symmetry and regular form, especially once access was gained to the flint sources of Europe. From the perspective of cultural evolution, Mode 2 does represent a major cognitive shift, but its full impact is a gradual process, not a sudden punctuated event followed by prolonged equilibrium. This seems to suggest that although the rate of change is glacial in comparison to modern cultural change, it does show a pattern of development that can be interpreted in terms of the refinement of a practice.

Mode 3 represents a different situation. It can be cogently argued that the basic technique of Mode 3, the preparation of the core prior to flaking, is inherent in the Mode 2 technologies, and a "Levallois component" has long been recognized as a part of many Acheulean assemblages. This has led some to suggest that the distinction between the two is insignificant. However, although the actual technological aspects of change may be continuous, the outcomes are radically different. Rather than the repetitive and monomorphic production of handaxes, instead there is the diversity of flake forms. The shift represents a major change in the way stone cores (even if the cores are large flakes) are used and developed: They become the template from which diversity can be produced rather than the end product themselves. This can be seen in the increase in variation that occurs in the Middle Stone Age and Middle Palaeolithic, both within and between assemblages.[51,52] With Mode 3 we see something that begins to approach the variation we would associate with modern cultural behavior, and its appearance may be related to other substantive changes in behavior.[53]

Cultural Status of Extinct Hominins

On the basis of the preceding discussion, we could argue that the technological modes do provide useful insights into the evolution of culture, but for this to be strengthened it needs to be more firmly rooted into other aspects of human evolution. We have shown (Figs. 1–3) that there is considerable congruence in the broad distribution of modes and hominin populations, but this is far from simple, and that not all mode transitions show the same pattern in relation to biological evolution. This is summarized in Table 2.

From this two major points emerge. The first is that there is no simple relationship between modes and hominin species. For example, most technology-using hominins made Mode 1, itself an interesting insight into the evolution of culture, suggesting a deep plesiomorphic conservatism for most of human evolution. It is likely that the origins of each mode lie in one lineage: Mode 1, an australopithecine?; Mode 2, *H. ergaster;* Mode 3, *H. helmei;* Modes 4 and 5, *Homo sapiens*. It is clear, however, that these lineages all diversified into a number of descendent populations that persisted in making the same stone tools. If these are species, then speciation was not the product of any technologically induced development. Indeed, in terms of evolutionary process, it seems that technologies change during the course of a lineage's existence.

The second point is that if the strongest evidence for the evolution of enhanced cultural capacities and their underlying cognition comes with freedom from the constraints of the environment (and, in the case of technology, this is presumably raw-material constraints), then this occurs in a series of stages during the development of later Mode 2, more fully in Mode 3, and certainly with the elaboration of Modes 4 and 5. Certainly, it seems that there is a strong contrast in behavior and apparent cognitive flexibility between hominins prior to *H. heidelbergensis* and those after. It is perhaps significant that this is also the period when brain-size evolution accelerated.

Who Has Culture, Whatever That Is?

We are aware that compared to the rich tapestry of culture in the other papers in this issue, our version is somewhat stony and bare. There is no web of kinship or devious monkeys, no language, and no symbolic thought. In a way, our intent has been to trace the most basic of patterns in as broad a comparative context as possible, so that we can see how cognitive state might map on to the radiation of hominins as seen in the fossil record. This has meant confining ourselves to a single source of information, stone tools, and a large-scale approach, technological modes. Given this limited approach, we can see that the similarities between the fossil record and the technological one suggest that the latter has a strong phylogenetic signal, and that this can be interpreted as showing that the ability to generate technological solutions to adaptive problems was limited in many species.

If we return to the larger questions relating to the evolution of culture from the common ancestor with chimpanzees to modern humans, we can consider which among the many species of hominins can be said to have possessed culture or, more accurately, how they compared in their cultural capacities with either chimpanzees or modern humans. The cultural capacities of those hominins making Mode 1 alone (early *Homo,* early *H. ergaster,* and *H. erectus*) could be seen as very close to that of chimpanzees in terms of their limited control and formalization of functional output, although the ability to generate standardized stone tools seems to represent some sort of shift (perhaps shared with some australopithecines?). Those making Mode 2 (*H. ergaster* and *H. heidelbergensis*) show in the standardization of form and the remarkable stability of tradition a considerable difference from the chimpanzee and the earlier hominins. Furthermore, the fact that these changes occur across the time of the lineages concerned suggests that this is not a case of behavioral or cognitive stability. The development of Mode 3 (*H. helmei, H. neanderthalensis,* and *H. sapiens*) represents an even greater shift, with both standardization of form and diversification of end product. Comparison across Modes 2 and 3 suggests that there is an earlier cognitive shift related to the ability to imitate and to maintain content and form (tradition?), and a later one associated with innovation. This latter change, when viewed in the context of the evolution of modern humans and the amazing accretion of diversity of material culture that occurs through the last 100,000 years, suggests that the evolution of these cultural capabilities was not a single event, but cumulative. Perhaps the most important conclusion is one that stresses the importance of looking at evolution diachronically: The evolution of culture is not a single step. Rather, the gap between humans and chimpanzees, between a few termites for lunch and Beethoven, is filled with incremental steps.

While it has been possible to gain insights into the cognitive states of extinct hominins via the relationship between technological modes and morphological affinities, it may be questioned how far we have demonstrated the absence or existence of culture. On one hand, it may be argued that as all the hominins make and use stone tools, they are culture-bearing; on the other hand, some might say that as we have no access to symbolic thought or language, there is no evidence for culture. In other words, the final interpretation depends on the definition of culture. The problem is how to proceed out of the definitional problem.

One way is to recognize that culture is neither an absolute, present-or-absent trait nor an indivisible whole. It is made up of a series of potentialities, largely resting in cognition, and depending on different mental thoughts. We can differentiate, for example, between imitation and copying as one element, which forms the basis for social transmission, social learning, and the maintenance of traditions, and innovation and elaboration, which forms the basis for cultural diversifi-

TABLE 2. Nature and Implications of Changes in Technological Modes

Transition	Nature of change	Nature of output	Change through time	Cultural inferences	Associated hominins
Mode 0 ↓ Mode 1	Extension from stone-tool use to stone-tool modification, or extension of nonstone tool modification to stone	Relatively few different forms, with little formal shape Regional variation probably just raw-material related	Little, although the Developed Oldowan can be seen as a move toward Mode 2 and greater control, but the rate of change (100,000s of years) is very slow	Hominins probably not very dissimilar from apes, but control and foresight involved in consistent fracturing, choosing raw materials, and deploying tools shows a difference from the capabilities of living apes	*robustus?* *garhi?* *habilis* *rudolfensis* *ergaster* *erectus* *antecessor*
Mode 1 ↓ Mode 2	Ability to strike off large flake blanks from cobbles or to use large nodules in ways that allow invasive retouch on both sides	Relatively few forms, but these show signs of a preferred shape, and often exhibit symmetry Regional variation is probably largely determined by raw materials (flakes versus nodules)	Considerable change through time that may be related both to technical competence and the demand for particular preferred shapes (symmetry)	The emphasis in Mode 2 technology is on greater planning and goal-directed behavior associated with demand for particular shapes Some evidence for cultural variation on a large geographical scale (cleavers in Africa and India)	*ergaster* *heidelbergensis*
Mode 2 ↓ Mode 3	Transformation of the planning involved in Mode 2 toward the preparation of the core to allow greater control of flake production	Diverse, predetermined flakes, often very thin, with potential for modifying extensively into different tools (especially points) Regional variation may be increasingly associated with cultural patterns rather than raw materials	Some directional change from early generalized MSA to later, but most of the interassemblage variation is the development of local styles (MTS, Stillbay, Chatelperronean) Final Mode 3 in Europe undergoes major change	Clear evidence for cultural variants regionally. Evidence for greater planning and awareness of indirect outputs	*helmei* *neanderthalensis* *sapiens*
Mode 3 ↓ Mode 4/5	Continuation of the strategy of emphasis on flake rather than core production, and predetermination of shape. But with emphasis on narrow flakes (blades), very thin flakes, and miniaturization (Mode 5, microliths)	Blade blanks for use as composite tools and for secondary shaping Major regional variation goes beyond raw material constraints, and probably reflects active strategies of use and cultural preference	Major change through time, although not in any unidirectional way toward greater technical competence or refinement	Evidence for ethnic marking by technology and other elements of material culture Localized cultural traditions and variants are endemic	*sapiens*

cation. Each of these, and many others, can be considered as a more finely graded scale. Whiten, in this volume, has proposed that culture be tackled through the search for contrasting features, which would include such things as the existence or absence of traditions. Perhaps what the paleoanthropological perspective adds to this is that these contrasts are extremes on a continuous scale and, furthermore, that they can vary independently. In this sense, we return to the position that while culture as the end product of evolution may be a qualitatively different "whole," its evolution is best treated in a more reductionist and piecemeal manner.[11,12] In this way we can track a series of different trajectories, each of which contributes to the final outcome. Thus, although we may never be able to speak in absolute terms about the cultural status of extinct hominins, we may be able to scale them relative to humans and chimpanzees, and also gain insights into the process. For this to occur, however, it is necessary for archeologists to work more closely with the biological record that lies at the heart of human evolutionary history.

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