

CHAPTER 8

What does Oldowan technology represent in terms of hominin behavior?

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For the past 2.6 million years, humans and their ancestors have left behind traces of their behavior that record the variation in biological and cultural changes throughout our evolutionary history. Most of our understanding of the behavior of hominins is derived from evidence from stone artifacts. The study of Early Stone Age stone artifacts has a long history that is intimately intertwined with evolving ideas of what material culture represents and the ways in which this information can be interpreted. This has included a generalized focus on cultural historical changes through to more process-oriented approaches to ancient behavior. The last decade of research on the Oldowan has opened analysts' eyes to greater diversity of behaviors expressed in the Oldowan. Unfortunately there is not a lot of consensus about how the evidence informs our perception of hominin behavior (De la Torre and Mora 2009). Here we will discuss various aspects of artifact manufacture and use in the early Pleistocene. We will investigate the current debates regarding the behavioral meaning behind stone artifact manufacture and review current approaches. In particular, this chapter reviews the current dual approaches to the study of the earliest archaeological traces. We describe the strengths and weaknesses of these perspectives and consider how it might be possible to combine these techniques in a way that provides a greater understanding of the earliest toolmakers.

Most scientist currently studying Oldowan behavior agree that the cultural historical approaches of the 1970s focused too heavily on description and did not include enough explanation of variation. Attempts to simplify these descriptions to allow for greater comparison across assemblages (Isaac 1977; Toth 1985) has provided some insights to behavioral adaptations associated with early hominin behavior. Some have suggested that these simplifications overlook the detailed aspects of artifact production,

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however, and therefore are not useful indicators of the full scope of technological behaviors that Oldowan hominins possessed (De la Torre and Mora 2009). Investigations of stone artifacts cover a broad spectrum from formal analogies between tool forms and psychological states (Wynn and McGrew 1989) through to extremely detailed investigations of fracture mechanics that might have very little to do with hominin behavior (Braun et al. 2009b). It is vital that Oldowan archaeologists begin to approach tool use in the Pleistocene in ways that are firmly linked to the empirical data but yet still applicable to higher-order inferences (Torrence 1989).

Different methodologies for the analysis of Oldowan stone artifacts have paralleled competing ideological approaches to the study of the earliest material culture. These different strains of thought are mirrored by similar ideological differences in the study of stone artifacts in general (Geneste et al. 1990; Shott 2003; Van Peer and Bar-Yosef 2009). Some have even suggested that the two approaches are so diametrically opposed as to completely prevent comparison between data sets derived using different methodologies. This has resulted in somewhat of a stalemate in Oldowan studies. There are many debates regarding what Oldowan tools mean for the behavior of their makers; however, none of these debates are likely to be settled given the current framework of investigation.

What do we want to know about Oldowan behavior? Why should anyone care?

Although there are certainly disputes among Oldowan archaeologists, all would most certainly agree that a unifying basis behind studies of these early industries is insight into the evolution of our earliest ancestors. Almost all studies of Pleistocene technology use models of evolutionary change as a basic framework (de la Torre et al. 2003; Delagnes and Roche 2005; Kimura 1999). At a very basic level, we want to know why early hominins started making stone tools. We also want to know if the variation that we see in the archaeological record represents adaptive shifts that were important in the evolution of our ancestors. For these questions to be answered we must accept the possibility of a null model in which evolution plays a very small role in Oldowan stone artifact manufacture. Although the null model is a plausible hypothesis, it seems unlikely that hominins invested time and energy in the development of a complex series of behaviors that had no impact on their eventual genetic fitness.

Thus, if we begin with an assumption that the artifacts found in these early sites do represent evolutionarily significant adaptations of our earliest

ancestors, then perhaps we can investigate the evolutionary pressures that shape Oldowan behavior. Unfortunately, different schools of thought part ways here. Some approaches to the study of the Oldowan conceptualize artifacts as part of a subsistence system that requires stone artifacts for the acquisition of resources (Blumenschine et al. 2008; Tactikos 2005). These approaches often invoke environmental variation to explain differences. In many behavioral ecological approaches, the evolution of behaviors is in some way related to the capabilities of hominins to access certain resources (Stout et al. 2010). Artifacts become an extra-somatic parallel to biological evolution. Natural selection controls certain behaviors that guide the decisions that hominins make about when and how to manufacture artifacts and when to discard them (Kelly 1988, 1995; Nelson 1991). The exact method of how natural selection effects these decisions is not well understood, however the details of this are beginning to be addressed (Mesoudi and Lycett 2009; Shennan 2009). This approach seems to oversimplify the forces that shape cultural variation if artifacts are viewed as purely a phenotypic expression of hominin behavioral genotypes. Hominins that produced Oldowan technology were not driven only by requirements to produce sharp edges from cobbles. Studies of Oldowan behaviors could be enhanced when they integrate the social framework with which all tool use is associated (Stout 2002). Indeed, it is exactly this social framework that is the basis behind approaches to the Oldowan that are usually associated with Leroi-Gourhan's emphasis on technical actions (Leroi-Gourhan 1964). These models incorporate mechanisms of cognition as well as transmission of skilled behaviors, and thus they are directly applicable to models of cultural evolution that emphasize transmission processes (Mesoudi et al. 2006). Followers of this approach envision natural selection acting on the details of individual cognition and the role that this plays in a social context (de la Torre et al. 2003). This perspective does not disregard the ecological and economic constraints but sees the cultural aspects of technical production as equally as important. By isolating individual variation as the smallest unit of analysis, this approach has many advantages over behavioral ecological approaches. Behavioral ecological approaches largely investigate patterns at the assemblage level and rarely investigate patterns at the level of the individual knapper. Investigation of evolutionary mechanisms, using techniques often described as *chaîne opératoire*, have equal difficulties, however. This perspective places an emphasis on understanding the intentions of the knapper. It is obviously impossible to independently test whether these intentions were correctly identified. In fact, the *chaîne opératoire* method often directly rejects the concept of hypothesis testing

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and instead depends on the details of the collection to direct the analysis (Pelegrin et al. 1988). The focus of these socially bound models is on the cognitive requirements of different knapping methods. These are usually expressed in poorly defined terms of elaboration, degrees of utilization, and acquisition of techniques (Roche 2005). The direct application of these concepts to models of biological evolution is very difficult (how do you define when a technique is “elaborate” enough to affect the genetic fitness of an individual person?).

Although we can see that an evolutionary background guides both of these approaches, the pragmatic application of these methods is less straightforward. We still have not answered the question of why the study of human evolution as a whole should be concerned with these different methods. It is increasingly apparent that the unique condition of humankind is directly linked to our social mechanisms and cultural capabilities. In that sense, material culture records a series of cultural adaptations that humans have made over the course of the last 2.6 million years. These behavioral adaptations have modified the context of our biological adaptations. They have done this through a manner in which selective environments of hominins are modified by the behaviors of the hominins themselves (Laland and O'Brien 2010). The most obvious case is the use of stone tools to gain access to resources that were otherwise inaccessible. The best evidence we have of this comes from the zooarchaeological record (de Heinzelin et al. 1999; Domínguez-Rodrigo et al. 2005). Access to key resources like fat and protein were clearly important factors in the biological evolution of our species. Current narratives of the evolution of the genus *Homo* often point to these adaptations as vital to the expansion of the brain and expanded social networks (Reader and Laland 2002; Wood and Collard 1999). We may need to rethink the relationship between brain size and tool use, based on new evidence suggesting that smaller-brained hominins used tools and had access to higher-quality dietary resources (Brown et al. 2004; McPherron et al. 2010). We clearly need further research on this topic, considering the vociferous debate surrounding these issues (Domínguez-Rodrigo et al. 2010). More quantitative methods of identifying the earliest tool use are necessary. However, the general pattern throughout the Pleistocene is one of increasing dependence on stone tools for the acquisition of key resources (Ambrose 2001). Although tools clearly played some role in the subsistence adaptations of Oldowan hominins, the possibility certainly exists that tool production played some role in the cognitive evolution of Oldowan hominins. Although stone tool production in the Oldowan seems relatively simple, it involves a complex series of behaviors (e.g., collection

and transport of appropriate materials, reduction that is guided by technical rules) that may have placed selective pressures on hominin cognition. Determining exactly which aspects of the archaeological record testify to the advanced cognitive capabilities will be difficult (McPherron 2000). It might be possible to understand these cognitive capabilities by investigating different methods of learning and social transmission in these early technologies (Nonaka et al. 2010; Whiten et al. 2009).

What do we know about Oldowan hominins' behavior?

1. *Oldowan hominins selected stones based on their mechanical properties*

There is an increasing body of evidence that hominin selection of stone for artifact manufacture included a detailed understanding of fracture mechanics. The earliest evidence of stone manufacture comes from the Gona sites in Afar region of Ethiopia. The earliest description of these excavated materials remarked at how the specimens appeared to have many of the hallmarks usually associated with later time frames. Flakes and cores showed multiple series of small removals, and platforms were relatively thin (Semaw et al. 1997). Another interesting aspect of these materials was the fact that they were made on very fine-grained rock types, including rhyolites and cherts (Semaw 2000). Recent analysis shows that these materials are not actually very abundant in the landscapes on which the Gona hominins lived. Stout and colleagues have shown that the Gona hominins specifically selected these fine-grained materials to make stone artifacts (Stout et al. 2005). In fact, the selection bias of hominins appears to be directly related to the grain size of the materials. Hominins therefore were not selecting particular types of rocks but were actually selecting individual stones based on the grain size of these materials. This means that at the very dawn of artifact manufacture, hominins understood that fracture could be more easily controlled in rocks that were made of smaller crystal sizes (Brantingham et al. 2000). Further evidence from the West Turkana materials suggested that hominins recognized the lithological features of stone that were important for artifact manufacture. Hominins also used this information to guide decisions about artifact manufacture (Harmand 2009). These decisions can be seen in the differences in reduction techniques seen at Lokalalei 1 and 2C. Hominins used simple flaking methods to reduce stones that were made on more intractable materials. This was especially the case on stones that could be found only as round cobbles (Delagnes and Roche 2005). These

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behaviors appeared to vary across sites, however. Hominins at the site of Kanjera South used a selection process that specifically identified certain features of stone (Braun et al. 2009b). Studies of the material properties of these stones suggest that hominins specifically selected stones that had durable edges. Although most of the rock types that were selected for artifact manufacture were also fine grained, some were not. For example, medium-grained granites were difficult to knap, yet hominins from Kanjera selected these materials for manufacture. These stones were not available near the Kanjera site.

2. *Hominins transported stones around the landscape*

The earliest studies of the Olduvai and Koobi Fora material emphasized description of the variation in Oldowan assemblages (Isaac 1972; Leakey 1971); however, subsequent studies of these collections that included an experimental referential framework determined that transport of stone was a key feature of Oldowan behavior (Potts 1991; Toth 1987). The most detailed description of this was based on the description of relatively short refit sequences from Koobi Fora. These showed that hominins arrived at archaeological sites with cores that had already been flaked, and most likely they left sites with flakes and possibly with cores they had collected from the sites (Schick 1987). These studies allow us to understand an Oldowan technological organization whereby stones are routinely transported around the landscape. Admittedly, many of the earliest Oldowan industries are found within meters of conglomerates (Goldman and Hovers 2009; Harmand 2009; Stout et al. 2005). Previous models had actually suggested that the early phases of the Oldowan represented a period when hominins were tethered to resources of stone (Rogers et al. 1994). This hypothesis has been mostly substantiated by evidence from many of the earliest sites that have shown that relatively early Oldowan sites are always found near conglomerates (Braun et al. 2010; Kimbel et al. 1996). New data from various sites now suggest that hominins even as early as 2 million years ago transported stone over relatively long distances. Data from the Kanjera South site shows that hominins transported 28% of the assemblage over distances that were greater than 10 km. Furthermore, it appears that hominins chose to transport specific materials based on their mechanical properties (see earlier discussion). Later there is extensive evidence that hominins transported stone over greater distances. At Olduvai, raw materials were transported at distances similar to that seen at Kanjera (Hay 1976). Provenience studies in the Koobi Fora Formation suggest that transport of stone over 25 km took

place at least periodically (Braun et al. 2008a). Transport patterns of certain aspects of the Oldowan record are well documented later. At Olduvai the transport of materials was guided by the availability of stone raw material as well as other factors, such as carnivore competition (Blumenschine et al. 2008). Rogers' (Rogers 1996; Rogers and Harris 1992) comprehensive landscape study of the Okote member materials described a detailed account of the means by which hominins transported materials from raw material sources to proximal floodplain contexts. This pattern was further supported by a later investigation of large scraper forms (Braun et al. 2008c). This study showed that not only did hominins consistently transport materials into floodplain contexts but also demonstrated that the largest scraper forms were systematically chosen for transport to those contexts where raw material was scarce. This suggests that hominins did not just collect and discard materials at random; instead it appears that hominins had at least a rudimentary understanding of the arrangement of resources around their landscape. This understanding guided decisions about transport and discard.

3. *Hominin artifact manufacture was guided by specific technical rules*

The classic description of Oldowan behavior is that it is a "least-effort solution to a sharp edge" (Isaac and Harris 1997). This description still stands as a basic tenet of Oldowan tool manufacture. Oldowan hominins were likely trying to create sharp edges in a way that cost them the least amount of energy and time; however, there does appear to be substantial variation within this conceptual framework. Sometimes the costs of transport or replenishment of raw material sources was high enough to modify the way in which hominins made stone artifacts. The maintenance of striking platform surfaces might have prevented hominins from having to procure further resources. These technical rules could have guided Oldowan tool manufacture. Some of these technical rules do not appear to have been constant throughout East Africa. Much variation exists in the types of technical rules that were adopted by Oldowan hominins, but some have been well documented:

- A) *Angles less than 90 degrees are exploited when available.* This is a general rule of fracture mechanics and has been documented in replicative flintknapping (Pelegrin and Texier 2004) as well as controlled experimentation (Dibble and Rezek 2009). Although hominins did not always follow this pattern (Delagnes and Roche 2005; Sahnouni et al. 1997), it is a generalized feature of most knapping techniques.

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When hominins did not comply with this rule, they usually shattered the striking surface or produced multiple step fractures that prevented further reduction. This technical rule is rarely violated. Some manufacturing techniques apparently require the flaking of cores at very high platform angles (>90 degrees; e.g., polyhedrons; [Roche 2005]). As a corollary to this rule, stones that do not exhibit acute angles are rarely selected for artifact manufacture (Harmand 2009). In fact, rounded cobbles and large blocks are often split into pieces before they are flaked to maximize the number of acute angles (Toth 1997).

- B) *Removals are usually produced in groups that usually have parallel or subparallel technological axes.* This pattern is not exclusive to Oldowan flaking, but it does appear to occur in numerous instances of the Oldowan. This technical rule usually results in removals being grouped in multiple *series*. These series all have similar platform attributes and often have similar dorsal scar patterns (Delagnes and Roche 2005). This is documented in the Gona localities, which have relatively low levels of centripetal flaking (Stout et al. 2010). Refit sets from the Lokalalei site document the use of multiple series of removals that allowed for the maintenance of a flat flaking surface throughout the reduction of the cores (Delagnes and Roche 2005). It appears as if hominins in the Oldowan usually exploited a flaking surface that had acute angles until that part of the core was no longer viable. In highly reduced cores this technical rule usually breaks down. Heavily exhausted cores at Gona, Lokalalei, and Kanjera all show the production of multifacial removals with the alternative use of multiple flaking surfaces (Braun et al. 2009a; Delagnes and Roche 2005; Stout et al. 2010).

Other technical rules that appear to have been followed at early Oldowan sites include the use of opposed platforms to maintain flat flaking surfaces at Lokalalei 1 (Braun et al. 2009a; Delagnes and Roche 2005). At Gona there appears to be an emphasis on the removal of very large flakes early in the reduction sequence to maximize the cutting edges produced from relatively small cobbles (Stout et al. 2010). Many of these rules were focused on increasing the productivity of flake removals. Techniques for increasing productivity have been documented in the Koobi Fora sites as well (Braun and Harris 2003). At later sites, systematic technical rules appear to be associated with specific reduction strategies. Examples from Peninj show that hominins followed technical rules that divided cores into production

surfaces and preparation surfaces (centripetal hierarchical reduction technique); de la Torre et al. 2003; Texier 1995). In the developed Oldowan of Koobi Fora Formation, the production of single platform cores followed technical rules that limited the number of striking surfaces (Ludwig and Harris 1998). In the Omo collections, the use of bipolar flaking was common in small cores, although unidirectional unifacial flaking was also prevalent (de la Torre 2004). Later there is also the appearance of specific techniques of shaping that can be seen in the appearance of true polyhedrons (Roche 2000). Although these technical rules did exist, there were also apparently constraints that many early hominins could not overcome. For example, Lokalalei hominins could not produce new platform surfaces after knapping mistakes that rendered flaking surfaces unusable (Delagnes and Roche 2005).

What don't we know about Oldowan artifacts?

The list of things that we do not know about Oldowan artifacts is depressingly large. Currently the use of Oldowan artifacts for specific tasks has not been conclusively documented. Previous microwear studies have suggested that these tools were used for butchery and woodworking activities (Keeley and Toth 1981). New microwear studies have suggested that hominins might have used stone tools to process tubers (Lemorini et al. 2009). Further experimental studies have suggested that the flakes that were broken off cores were actually the most useful tools for a variety of tasks that we assume hominins engaged in (Toth 1987). Later there is some evidence that hominins engaged in particular woodworking activities (Domínguez-Rodrigo et al. 2001). The best evidence of hominin tool use is derived from bone surface modifications. Although these marks on the surfaces of bones that record the evidence of butchery activities have been studied for almost thirty years, there is still much debate over their behavioral meaning (Blumenschine et al. 2007; Domínguez-Rodrigo 1999, 2003; Domínguez-Rodrigo and Barba 2006; Domínguez-Rodrigo et al. 2007; Domínguez-Rodrigo and Pickering 2003; Domínguez-Rodrigo et al. 2005).

A more troubling gap in our knowledge of Oldowan behavior is whether variation in Oldowan tools is in any way related to the biological evolution of the hominin lineage. Although studies have suggested that almost all hominins were capable of using stone tools (and new Pliocene discoveries confirm this [McPherron et al. 2010]), there is really no way to determine that tools were linked to certain species (Panger et al. 2002; Susman 1994). The best evidence that tool use is associated with the genus *Homo* is that

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there is no apparent change in Oldowan tool use toward the end of the *Paranthropus* lineage (although the exact termination of this lineage is not well understood, and the archaeological record at around 1 Ma is sparse). New research is providing the basic knowledge of understanding how stone tool form can be modified by different behavior patterns, and this could provide the vital basic information needed for future advances (Williams et al. 2010).

Determining the role of Oldowan artifacts in the biology of our ancestors has another great hurdle, however. We currently do not know the mode and tempo of Oldowan variation through time. One theory suggests that the variation in Oldowan tool use is the result of very long period of stable adaptation that remained unchanged (Semaw 2000; Semaw et al. 1997; Semaw et al. 2003; Stout et al. 2010). Others suggest that the variation within the Oldowan represents multiple lineages of tool use that originate and extinguish in a similar fashion to that seen in the multiple lineages of hominins that existed in the Plio-Pleistocene (Delagnes and Roche 2005; Roche 2000, 2005). This debate is unlikely to be resolved in the near future, mostly because neither side has developed a model that would falsify their own hypothesis. Furthermore, each side of the debate uses completely different (yet complementary) techniques to investigate these hypotheses.

A major concern with this debate revolves around the inferential models used to investigate these hypotheses. The study of archaeological remains over the past thirty years has emphasized the importance of directly understanding each inferential step within an archaeological argument (Gifford-Gonzalez 1991). Without this type of focus we are bound to overlook possible equifinalities between higher-level inferences and the archaeological data. I believe that Oldowan studies have come to an impasse because of the lack of integration between higher-order inferences about hominin behavior and lower-level observations. Gifford-Gonzalez provided a framework for understanding the inferential connection between these inferences that she described as a *nested hierarchy* (Gifford-Gonzalez 1991). This nested hierarchy begins with the trace, which is the static archaeological object and in the case of the Oldowan is most likely a stone tool. Then the nested hierarchy builds up to causal agent that concerns actual physical activity that produces the trace. In the case of the Oldowan this is usually the propagation of force through a stone. This depends on the raw material properties of the stone and certain details of fracture mechanics. After the causal agent is the *effector*, which almost always in the case of the Oldowan is hard hammer percussion. Certainly in some cases this can be modified to include bipolar percussion or the use of different types of hammerstones (Texier et al. 2006).

One step up from the causal agent is the actor. In Oldowan studies we are on very shaky ground here. We cannot know the exact species that produced these tools, but we can be reasonably sure that it was a hominin that was bipedal, had a relatively small body size, and a wrist/hand architecture that was archaic (Tocheri 2007; Tocheri et al. 2003; Tocheri et al. 2008). In addition, we also know this hominin was likely omnivorous, and for the latter parts of the Oldowan (after 1.4 Ma) we can be sure that the hominins had a brain size that was much larger than chimpanzees or earlier hominins (Lee and Wolpoff 2003; Wood and Collard 1999). One inferential step up from the actor is the behavioral context, which would involve the production and use of chipped stone tools. This would also include details of the reason for the production of tools (e.g., butchery, woodworking, tuber processing). Again we have limited knowledge about what use hominins had for their tools, but we can be certain that the production of multiple sharp edges played at least some role in this process. This behavioral context would also include the social aspect of tool production (Roux and Bril 2005). There is a possibility that Oldowan hominins taught each other to make stone tools; however, there is currently no good referential model for determining what teaching looks like in the Oldowan archaeological record (Nonaka et al. 2010). Alternatively, a single hominin within a group could have been largely responsible for much of the tool production. Currently these types of questions remain unanswered, except that we can be sure that tools were made within a social context (Lemmonnier 1990). The final inferential step, between the behavioral context and the ecological context, is where the major paleoanthropological questions can be answered. The way in which hominins interact with their environment is almost certainly responsible for evolutionary changes in hominin behavior.

Too often studies of Oldowan research are concerned with only part of this nested hierarchy. I view most Oldowan research as either focused on the nested hierarchy from the perspective of the actor and below (*chaîne opératoire* approach) or from the actor up to the behavioral context (behavioral ecological approach). Bridging the gap that links the full range of the nested hierarchy is rarely accomplished. Approaches that focus on the detailed aspects of stone tool production (e.g., Delagnes and Roche 2005) have the advantage of providing detailed descriptions of the way in which tools are made. They fall short of providing any type of link between these behaviors and the behavioral or ecological context of hominins, however. Conversely, studies that explicitly state the hypothesized details of the behavioral context (Kimura 1999, 2002) of tool production can often apply “decontextualized lithic attributes” in a “rigid and mechanistic way”

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without attention to the details of the methods and technical strategies of Pleistocene knappers (De la Torre and Mora 2009). Will it ever be possible to bridge the gap between these two methods and their shared inability to link the traces of Oldowan behavior (i.e., artifacts) to the behavioral context of Pleistocene hominins?

One of the ways to begin to bridge these gaps is by first describing the assumptions that are implicit in each of the two approaches, which can provide room for understanding how linking these two methods will afford a more detailed approach to hominin behavior.

The chaîne opératoire approach: The use of detailed description of stone artifact manufacture has a very long history but has really reached its pinnacle in the study of Oldowan research in the past few years. This approach sees the cognitive setting as an essential part of the organization of hominin activities. Pelegrin's (Pelegrin et al. 1988) description of this approach details its three major foci. First, *chaîne opératoire* provides a mechanism for linking aspects of concrete technical activities. Second, moving up an inferential step, the approach then links these technical activities with assemblage level distinctions, which Pelegrin describes as technical systems. Finally, these technical systems are linked to aspects of social organization. This description is very similar to Gifford-Gonzalez's linkage between causal agents (technical activities) and the behavioral context (social organization). The *chaîne opératoire* approach views artifacts as expressions of a shared system of templates and combined knowledge. This knowledge not only testifies to the social make-up of the group but also to the cognitive capabilities of each individual knapper (Hovers 2009). An implicit assumption of this approach, however, is that the toolmakers have shared ideology that borders on modern ideas of culture. In later periods there is no doubt that this is the case; however, in Oldowan contexts this should be stated as a hypothesis to be tested. Data from nonhuman primate material culture strongly suggests that shared ideologies in the production of material culture are frequently part of ape behavior (Whiten et al. 2003; Whiten et al. 2005; Whiten et al. 2009). A further assumption of the *chaîne opératoire* approach is that technology cannot be separated from its social context. This requires the analyst to understand fully the social context of the early hominins. Since we do not understand the social systems of early hominins, this is a difficult prospect (Foley and Gamble 2009). This is made even more difficult as many researchers doubt whether tool production systems were shared by groups in the Oldowan: "... Inter-group transmission of technical knowledge was [not] yet an established practice" (Delagnes and Roche 2005). Does the identification of technical practices really require a priori

assumptions about the infrastructure of culture and society (Hovers 2007, 2009)? It might be possible to use a combination of detailed technological analyses and ecological contexts to understand hominin behavior.

Behavioral ecological approach: This approach to hominin behavior is based largely on the processual models initially devised early in the 1960s that also termed this *behavioral archaeology* (Binford 1977; Schiffer 1976). The approach sees hominins as producing stone tools as a method of solving ecological problems (i.e., procurement of food). Those who conform to this approach assume that ultimate explanations of behavioral variability will be found in adaptive explanations. These adaptive explanations usually incorporate some form of environmental determinism (Stout et al. 2010). The real strength of these models is their direct applicability to models of evolutionary change. In these models, the currency of natural selection is genetic fitness and is directly correlated to adaptive success through improvements in the acquisition of resources aided by stone artifacts. The assumption is that methods of artifact production vary according to their benefits, and these methods are heritable (Ferraro 2007). These models often equate to linear models of evolution that assume progressive, directed change through time (Roche 2005). This is not necessarily the case and environmental explanations for variation in Oldowan behaviors allow for flexible adaptations to varied environments (Braun et al. 2009a). Behavioral ecological models do carry major assumptions about hominin behavior, however. The most basic is that all stone tools in the archaeological record represent adaptive responses to the environment in which the hominins lived. Behavioral ecology models assume that hominins are rational actors and follow patterns that are the “most” adaptive. There is certainly reason to believe that hominins were rational in their decisions to produce one tool over another. However, the likelihood that every single artifact in the Oldowan archaeological record represents an adaptive response seems naive. Some have suggested that the production of tools might have provided the kind of buffer between hominins and environmental pressures that allowed for variation to be more closely aligned with social norms (Hovers 2009). How much of the Oldowan hominin archaeological record reflects social constraints on artifact production? Considering the impact of social mechanisms on the material culture of chimpanzees, it would seem difficult to relegate social variation to the “left over” variation after environmental variables had been fully explored (Boesch and Boesch 1993; Whiten et al. 2009). Recent investigations into the material culture of chimpanzees has shown that social mechanisms are vitally important (Haslam et al. 2009). Furthermore, holistic descriptions of chimpanzees’ tool use that include both *chaîne opératoire* approaches as

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well as behavioral ecological information have been extremely successful at characterizing these behaviors (Biro et al.; Carvalho et al. 2009; Carvalho et al. 2008). By seeing Oldowan assemblages as a palimpsest of multiple knapping events and looking for probabilistic inferences based on modal trends of attribute variation, we might lose sight of individual variation. Natural selection acts on the level of the individual, and so it would likely be important to understand tool use at this level.

Where do we go from here?

Is it possible to integrate these two approaches in a way that (1) allows for detailed understanding of artifact manufacture in its social context, yet still (2) provides answers that can be linked to major evolutionary forces that are no doubt integrated with environmental variation? The way forward will not be easy, the *chaîne opératoire* approach requires the primacy of social interaction in an analysis of artifacts and systematically rejects quantitative approaches. The behavioral ecological approach similarly calls for an emphasis on environmental variables and is very often quantitative.

What would a mixture of these approaches look like? Stout and colleagues (2010) have made the first attempt to bridge this gap by providing a detailed analysis of the Gona material, using concepts that derive from both schools of thought. Their analysis emphasized the importance of certain knapping strategies (unifacial, unidirectional) in the East Gona sites and documented the presence of significant variation in technology between localities. Although their analysis did not include the in-depth description of knapping techniques seen in the analysis of the Lokalalei materials (Delagnes and Roche 2005), this is to be expected given the unique situation of entire refitting sequences that were preserved at Lokalalei. The combination of the detailed technological analysis and the comprehensive study of the raw materials allows detailed inspection of hominin competence in knapping behaviors (Harmand 2009). The analysis at Gona was able to provide some insights into the sources of variation within this area. The archaeological sites within the Gona region span a diversity of habitats allowing for the inspection of the relationship between environmental variation and technological diversity. Stout and colleagues were able to show that the variation seen at Gona could be explained by environmental differences rather than cognitive variation within the hominins that made these tools (Stout et al. 2010). At Kanjera South, a detailed behavioral ecological study has shown that it is possible to explain the selection process for certain raw materials (Braun et al. 2008b). These varied raw materials

are also knapped differently (Braun et al. 2009a). A detailed technological study shows that different raw materials appear to reflect different technical competences, when in fact they can be explained by different raw material frameworks (high availability of low-quality materials and low availability of high-quality materials).

Although Oldowan hominins appear to follow certain technical rules, these rules are not universal. One possible step toward integrating these approaches is to identify the presence of certain technical rules and abilities at several sites. If it is possible to isolate the variation in technical actions that cannot be explained by environmental diversity, we may be documenting real differences in traditions (Whiten et al. 2009). Diachronic patterns could be tested against evolutionary models to see if they conform to the models of natural selection acting on behavioral attributes (Boyd and Richerson 1985, 1993; Boyd and Richerson 2005; Lyman and O'Brien 1998; O'Brien et al. 2008). There is certainly the possibility that much of the variation that characterizes the Oldowan could be the result of random drift of behaviors within somewhat isolated groups of hominins (Bentley et al. 2004; Cavalli-Sforza and Feldman 1981; Henrich 2004).

Conclusion

The study of Oldowan behavior is derived from rather meager evidence. Bits and pieces of shattered stone are all we have to gain insight into behaviors that really have no modern analog. The closest representations we have for analogical reasoning are chimpanzees and modern hunter-gatherers, and both of these models pose significant analogical difficulties. In the past twenty years, however, archaeologists have deduced a series of important aspects of the Oldowan behavioral repertoire. We now know that from the very beginning of Oldowan tool use, hominins understood detailed aspects of rock fracture patterns and selected these materials specifically for certain attributes. Furthermore, hominins appeared to transport stone systematically over relatively large distances (especially given the diminutive stature of these hominins). Finally, hominins seem to have followed certain technical rules in the production of artifacts. These rules guided the manufacture of Oldowan cores and appear to be focused on increasing the productivity of cores. Experimental studies have also given us insights into those features of the hominin brain that are associated with Oldowan tool manufacture (Stout et al. 2008; Stout et al. 2000) and provided baseline functional explanations for different tool forms (Tactikos 2005; Toth 1985, 1991). All of these insights together serve to support the idea that hominins

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likely invested a significant amount of time and effort to learn aspects of tool manufacture and subsequently invested time into maintaining their own personal toolkits.

Further insights into the behavioral variation of the earliest tool users probably will require an integration of the two major approaches to Oldowan studies. There is much that we still must learn about Oldowan behavior. Right now we cannot know whether the strategies we see in the archaeological record represent the same type of structured behavioral patterns that characterize modern human culture (Hill et al. 2009). Semaw and colleagues see the Oldowan as a period of stasis (Semaw 2000; Semaw et al. 2003), but what does this stasis really reflect? Does this stasis represent cognitive capacities of learning in Oldowan hominins (Bettinger et al. 2006; McElreath and Henrich 2007). How can we know more about the evolution of behavior in these earliest of cultural systems? These are the types of questions that archaeologists interested in the Oldowan will pursue in the future. The answers will require more fieldwork, more experimentation, and a greater inclusion of a variety of inputs from fields as diverse as engineering through ethology.

References

- Ambrose SH (2001) Paleolithic technology and human evolution. *Science* 291(5509):1748–1753.
- Bentley RA, Hahn MW, Shennan SJ (2004) Random drift and culture change. *Proceedings of the Royal Society of London Series B: Biological Sciences* 271(1547):1443.
- Bettinger RL, Winterhalder B, McElreath R (2006) A simple model of technological intensification. *Journal of Archaeological Science* 33:538–545.
- Binford LR (ed) (1977) *For Theory Building in Archaeology*. Academic Press, New York.
- Biro D, Carvalho S, Matsuzawa T (2010) Tools, Traditions, and Technologies: Interdisciplinary approaches to chimpanzee nut cracking. In Lonsdorf, EV, Ross, SR, and Matsuzawa, T (eds.) *The Mind of the Chimpanzee: Ecological and Experimental Perspectives* pp. 141–154.
- Blumenschine R, Masao FT, Tactikos J, Ebert J (2008) Effects of distance from stone source on landscape-scale variation in Oldowan artifact assemblages in the Paleo-Olduvai Basin, Tanzania. *Journal of Archaeological Science* 35(1):76–86.
- Blumenschine RJ, Prassack KA, Kreger CD, Pante MC (2007) Carnivore toothmarks, microbial bioerosion, and the invalidation of Domínguez-Rodrigo and Barba's (2006) test of Oldowan hominin scavenging behavior. *Journal of Human Evolution* 53(4):420–433.
- Boesch C, Boesch H (1993) Diversity of tool use and tool-making in wild chimpanzees. In: Berthelet A, Chavaillon J (eds) *Use of Tools by Human and Non-human Primates*. Clarendon Press, Oxford, pp. 158–168.

- Boyd R, Richerson PJ (1985) *Culture and the Evolutionary Process*. University of Chicago Press, Chicago.
- Boyd R, Richerson PJ (1993) Culture and Human Evolution. In: Rasmussen DT (ed) *The Origin and Evolution of Humans and Humanness*. Jones and Bartlett, Boston, pp. 119–134.
- Boyd R, Richerson PJ (eds) (2005) *The origin and evolution of cultures*. Oxford University Press, Oxford.
- Brantingham PJ, Olsen JW, Rech JA, Krivoshapkin IA (2000) Raw material quality and prepared core technologies in Northeast Asia. *Journal of Archaeological Science* 27(3):255–271.
- Braun DR, Harris J, Maina D (2008a) Oldowan raw material procurement and use: Evidence from the Koobi Fora Formation. *Archaeometry* 51(1):26–42.
- Braun DR, Harris JWK (2003) Technological developments in the Oldowan of Koobi Fora: Innovative techniques of artifact analysis. In: Moreno JM, Torcal RM, Sainz IT (eds) *Oldowan: Rather more than smashing stones*. University of Barcelona Press, Barcelona, pp. 117–144.
- Braun DR, Harris JWK, Levin NE, McCoy JT, Herries AIR, Bamford MK, Bishop LC, Richmond BG, Kibunjia M (2010) Early hominin diet included diverse terrestrial and aquatic animals 1.95 Ma in East Turkana, Kenya. *Proceedings of the National Academy of Sciences* 107(22):10002.
- Braun DR, Plummer T, Ditchfield P, Bishop L, Ferraro J (2009a) Oldowan technology and raw material variability at Kanjera South. In: Hovers E, Braun DR (eds) *Interdisciplinary Approaches to the Oldowan*. Springer-Verlag, New York, pp. 99–110.
- Braun DR, Plummer T, Ditchfield P, Ferraro JV, Maina D, Bishop LC, Potts R (2008b) Oldowan behavior and raw material transport: perspectives from the Kanjera Formation. *Journal of Archaeological Science* 35:2329–2345.
- Braun DR, Plummer TW, Ferraro J, Ditchfield P, Bishop L (2009b) Raw Material Quality and Oldowan Hominin Toolstone Preferences: Evidence from Kanjera South, Kenya. *Journal of Archaeological Science* 36(7):1605–1614.
- Braun DR, Rogers MJ, Harris JWK, Walker SJ (2008c) Landscape scale variation in hominin tool use: Evidence from the developed Oldowan. *Journal of Human Evolution* 55:1053–1063.
- Brown P, Sutikna T, Morwood MJ, Soejono RP (2004) A new small-bodied hominin from the Late Pleistocene of Flores, Indonesia. *Nature* 431(7012):1055–1061.
- Carvalho S, Biro D, McGrew WC, Matsuzawa T (2009) Tool-composite reuse in wild chimpanzees (*Pan troglodytes*): archaeologically invisible steps in the technological evolution of early hominins? *Animal Cognition* 12:103–114.
- Carvalho S, Cunha E, Sousa C, Matsuzawa T (2008) Chaînes opératoires and resource-exploitation strategies in chimpanzee (*Pan troglodytes*) nut cracking. *Journal of Human Evolution* 55(1):148–163.
- Cavalli-Sforza LL, Feldman MW (1981) *Cultural transmission and evolution: A quantitative approach*. Princeton University Press.
- de Heinzelin J, Clark JD, White TD, Hart WS, Renne PR, Woldegabriel G, Beyene Y, Vrba ES (1999) Environment and behavior of 2.5-million-year-old Bouri hominids. *Science* 284(5414):625–629.

What does Oldowan technology represent in terms of hominin behavior? 239

- de la Torre I (2004) Omo revisited – Evaluating the technological skills of Pliocene hominids. *Current Anthropology* 45(4):439–465.
- de la Torre I, Mora R (2009) Remarks on the current theoretical and methodological approaches to the study of early technological strategies in Eastern Africa. In: Hovers E, Braun DR (eds) *Interdisciplinary Approaches to the Oldowan*. Springer Science and Business Media B.V., Dordrecht, pp. 15–24.
- de la Torre I, Mora R, Domínguez-Rodrigo M, de Luque L, Alcalá L (2003) The Oldowan industry of Peninj and its bearing on the reconstruction of the technological skills of Lower Pleistocene hominids. *Journal of Human Evolution* 44(2):203–224.
- Delagnes A, Roche H (2005) Late Pliocene hominid knapping skills: The case of Lokalalei 2C, West Turkana, Kenya. *Journal of Human Evolution* 48(5):435–472.
- Dibble HL, Rezek Z (2009) Introducing a new experimental design for controlled studies of flake formation: results for exterior platform angle, platform depth, angle of blow, velocity, and force. *Journal of Archaeological Science* 36(9):1945–1954.
- Domínguez-Rodrigo M (1999) Distinguishing between apples and oranges: the application of modern cut-mark studies to the Plio-Pleistocene (a reply to Monahan). *Journal of Human Evolution* 37(5):793–800.
- Domínguez-Rodrigo M (2003) On cut marks and statistical inferences: Methodological comments on Lupo & O'Connell (2002). *Journal of Archaeological Science* 30(3):381–386.
- Domínguez-Rodrigo M, Barba R (2006) New estimates of tooth mark and percussion mark frequencies at the FLK Zinj site: the carnivore-hominid-carnivore hypothesis falsified. *Journal of Human Evolution* 50(2):170–194.
- Domínguez-Rodrigo M, Barba R, Egido RB, Egeland CP (2007) *Deconstructing Olduvai: A Taphonomic Study of the Bed I Sites.*, Springer Verlag, Dordrecht (The Netherlands).
- Domínguez-Rodrigo M, Pickering TR (2003) Early hominid hunting and scavenging: A zooarcheological review. *Evolutionary Anthropology* 12(6):275–282.
- Domínguez-Rodrigo M, Pickering TR, Semaw S, Rogers MJ (2005) Cutmarked bones from Pliocene archaeological sites, at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. *Journal of Human Evolution* 48(2):109–121.
- Domínguez-Rodrigo M, Serrallonga J, Juan-Tresserras J, Alcalá L, Luque L (2001) Woodworking activities by early humans: a plant residue analysis on Acheulian stone tools from Peninj (Tanzania). *Journal of Human Evolution* 40(4):289–299.
- Ferraro J (2007) Broken bones and smashed stones. *On the Foraging Ecology of Oldowan Hominins*. PhD dissertation. University of California, Los Angeles
- Foley R, Gamble C (2009) The ecology of social transitions in human evolution. *Philosophical Transactions B* 364(1533):3267.
- Geneste J-M, Boëda E, Meignen L (1990) Identification des chaînes opératoires lithiques du Paléolithique ancien et moyen. *Paléo* 2:43–87.
- Gifford-Gonzalez D (1991) Bones are not enough: analogues, knowledge, and interpretive strategies in zooarchaeology. *Journal of Anthropological Archaeology* 10(3):215–254.

- Goldman T, Hovers E (2009) Methodological considerations in the study of Oldowan raw material selectivity: Insights from A.L. 894 (Hadar, Ethiopia). In: Hovers E, Braun DR (eds) *Interdisciplinary Approaches to the Oldowan*. Springer, Dordrecht, pp. 71–84.
- Harmand S. (2009) Variability in raw material selectivity at the Late Pliocene sites of Lokalalei, West Turkana, Kenya. In: Hovers E, Braun DR (eds) *Interdisciplinary Approaches to the Oldowan*. Springer, Dordrecht, pp. 85–97.
- Haslam M, Hernandez-Aguilar A, Ling V, Carvalho S, De la Torre I, DeStefano A, Du A, Hardy B, Harris JWK, Marchant L, Matsuzawa T, McGrew WC, Mercader J, Mora R, Petraglia M, Roche H, Visalberghi E, Warren R (2009) Primate archaeology. *Nature* 460:339–344.
- Hay RL (1976) Geology of the Olduvai Gorge. *A study of sedimentation in a semi-arid basin*. University of California Press, Berkeley.
- Henrich J (2004) Demography and cultural evolution: how adaptive cultural processes can produce maladaptive losses: the Tasmanian case. *American Antiquity*: 69: 197–214.
- Hill K, Barton CM, Hurtado AM (2009) The emergence of human uniqueness: Characters underlying behavioral modernity. *Evolutionary Anthropology* 18:187–200.
- Hovers E (2007) Technological Strategies in the Lower Pleistocene at Olduvai Beds I and II. *PaleoAnthropology* 53:57.
- Hovers E (2009) *The lithic assemblages of Qafzeh Cave*. Oxford University Press, New York.
- Isaac GL (1972) Early phases of human behaviour: models in Lower Palaeolithic archaeology. In: Clarke DL (ed) *Models in Archaeology*. Methuen & Co. Ltd., London, pp. 167–199.
- Isaac GL (1977) Early stone tools – an adaptive threshold? In: Sievking GdG, Longworth IH, Wilson KE (eds) *Problems in Economic Prehistory and Social Archaeology*. Duckworth, London, pp. 39–47.
- Isaac GL, Harris JWK (1997) The stone artifact assemblages: A comparative study. In: Isaac GL (ed) *Koobi Fora Research Project*. Clarendon Press, Oxford, pp. 262–362.
- Keeley LH, Toth N (1981) Microwear polishes on early stone tools from Koobi Fora, Kenya. *Nature* 293:464–465.
- Kelly RL (1988) Hunter-gatherer land use and regional geomorphology: implications for archeological survey. *American Archaeology* 7(1):49–57.
- Kelly RL (1995) *The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways*. Smithsonian Institution Press, Washington D.C.
- Kimbel WH, Walter RC, Johanson DC, Reed KE, Aronson JL, Assefa Z, Marean CW, Eck GG, Robe R, Hovers E, Rak Y, Vondra C, Yemane T, York D, Chen Y, Evensen NM, Smith PE (1996) Late Pliocene Homo and Oldowan tools from the Hadar Formation (Kada Hadar member), Ethiopia. *Journal of Human Evolution* 31(6):549–561.
- Kimura Y (1999) Tool-using strategies by early hominids at Bed II, Olduvai Gorge, Tanzania. *Journal of Human Evolution* 37(6):807–831.
- Kimura Y (2002) Examining time, trends in the Oldowan technology at Beds I and II, Olduvai Gorge. *Journal of Human Evolution* 43(3):291–321.

What does Oldowan technology represent in terms of hominin behavior? 241

- Laland KN, O'Brien MJ (2010) Niche construction theory and archaeology. *Journal of Archaeological Method and Theory* 17: 303–322.
- Leakey MD (1971) *Olduvai Gorge*. Cambridge University Press, Cambridge.
- Lee SH, Wolpoff MH (2003) The pattern of evolution in Pleistocene human brain size. *Paleobiology* 29(2):186.
- Lemmonnier P (1990) Topsy-turvy techniques. Remarks on social representation of techniques. *Cambridge Archaeological Review* 9:27–37.
- Lemorini C, Plummer T, Braun DR, Crittenden A, Marlowe F, Schoeninger MJ, Ditchfield PW (2009) Functional interpretation by use-wear analysis of 2-million year old Oldowan tools from Kanjera South, Kenya. *PaleoAnthropology* 2009:A22.
- Leroi-Gourhan A (1964) *Le geste et la parole. I – Technique et langage. II – La mémoire et les rythmes*. Albin Michel, Paris.
- Ludwig BV, Harris JWK (1998) Towards a technological reassessment of East African Plio-Pleistocene lithic assemblages. In: Petraglia M, Paddaya K (eds) *The Rise and Diversity of the Lower Paleolithic*. Academic Press, New York, pp. 84–106.
- Lyman RL, O'Brien MJ (1998) The goals of evolutionary archaeology. *Current Anthropology* 39(5):615–652.
- McElreath R, Henrich J (2007) Modeling cultural evolution. In Dunbar, R, Barret, B. (eds.) *Oxford Handbook of Evolutionary Psychology*, Oxford University Press, Oxford, pp. 571–585.
- McPherron S, Alemseged Z, Marean C, Wynn JG, Reed D, Geraads D, Bobe R, Bearat HA (2010) Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. *Nature* 466:857–860.
- McPherron SP (2000) Handaxes as a measure of the mental capabilities of early hominids. *Journal of Archaeological Science* 27(8):655–663.
- Mesoudi A, Lycett SJ (2009) Random copying, frequency-dependent copying and culture change. *Evolution and Human Behavior* 30(1):41–48.
- Mesoudi A, Whiten A, Laland KN (2006) Towards a unified science of cultural evolution. *Behavioral and Brain Sciences* 29(04):329–347.
- Nelson MC (1991) The study of technological organization. *Archaeological Method and Theory* 3:57–100.
- Nonaka T, Bril B, Rein R (2010) How do stone knappers predict and control the outcome of flaking? Implications for understanding early stone tool technology. *Journal of Human Evolution* 59: 155–167.
- O'Brien MJ, Lyman RL, Collard M, Holden CJ, Gray RD, Shennan S (2008) Transmission, phylogenetics, and the evolution of cultural diversity. In: O'Brien MJ (ed) *Cultural Transmission and Archaeology: Issues and Case studies*. Society for American Archaeology Press, Washington, D.C., pp. 39–58.
- Panger MA, Brooks AS, Richmond BC, Wood B (2002) Older than the Oldowan? Rethinking the emergence of hominin tool use. *Evolutionary Anthropology* 11(6):235–245.
- Pelegriin J, Karlin C, Bodu P (1988) Chaines Operatoires: un outil pour le préhistorique. *Technologie Préhistorique*. Editions du CNRS, Paris, pp. 55–63.
- Pelegriin J, Texier J-P (2004) *Les techniques de taille de la pierre préhistoriques Dossier de l'Archeologie* 290:26–35.
- Potts R (1991) Why the Oldowan? Plio-Pleistocene toolmaking and the transport of resources. *Journal of Anthropological Research* 47(2):153–176.

- Reader SM, Laland KN (2002) Social intelligence, innovation, and enhanced brain size in primates. *Proceedings of the National Academy of Sciences of the United States of America* 99(7):4436.
- Roche H (2000) Variability of Pliocene Lithic Productions in East Africa. *ACTA Anthropologica Sinica* 19(supplement):98–103.
- Roche H (2005) From simple flaking to shaping: Stone-knapping evolution among early hominins. In: Roux V, Bril B (eds) *Stone knapping: the necessary conditions for a uniquely hominin behavior*. McDonald Institute for Archaeological Research, Cambridge, pp. 35–53.
- Rogers MJ (1996) Lithic analysis in landscape archaeology: evidence from East Turkana. In: Pwiti G, Soper R (eds) *Aspects of African Archaeology*. University of Zimbabwe Publications, Harare, pp. 15–22.
- Rogers MJ, Harris JWK (1992) Recent investigations in landscape archaeology at East Turkana. *Nyame Akuma* 38: 41–47.
- Rogers MJ, Harris JWK, Feibel CS (1994) Changing Patterns of Land-Use by Plio-Pleistocene Hominids in the Lake Turkana Basin. *Journal of Human Evolution* 27(1–3):139–158.
- Roux V, Bril B (eds) (2005) *Stone knapping: the necessary conditions for a uniquely hominin behaviour*. McDonald Institute for Archaeological Research, Cambridge.
- Sahnouni M, Schick KD, Toth N (1997) An experimental investigation into the nature of faceted limestone “spheroids” in the Early Palaeolithic. *Journal of Archaeological Science* 24(8):701–713.
- Schiffer MB (1976) *Behavioral Archaeology*. Academic Press, New York.
- Semaw S (2000) The world’s oldest stone artefacts from Gona, Ethiopia: Their implications for understanding stone technology and patterns of human evolution between 2.6–1.5 million years ago. *Journal of Archaeological Science* 27(12):1197–1214.
- Semaw S, Renne P, Harris JWK, Feibel CS, Bernor RL, Fesseha N, Mowbray KM (1997) 2.5-million-year-old stone tools from Gona, Ethiopia. *Nature* 385(6614):333–336.
- Semaw S, Rogers MJ, Quade J, Renne PR, Butler RF, Domínguez-Rodrigo M, Stout D, Hart WS, Pickering T, Simpson SW (2003) 2.6-million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. *Journal of Human Evolution* 45(2):169–177.
- Shennan S (2009) *Pattern and process in cultural evolution*. University of California Press, Berkeley.
- Shott MJ (2003) Chaîne opératoire and reduction sequence. *Lithic Technology* 28(2):95–105.
- Stout D (2002) Skill and cognition in stone tool production – An ethnographic case study from Irian Jaya. *Current Anthropology* 43(5):693–722.
- Stout D, Quade J, Semaw S, Rogers MJ, Levin NE (2005) Raw material selectivity of the earliest stone toolmakers at Gona, Afar, Ethiopia. *Journal of Human Evolution* 48(4):365–380.
- Stout D, Semaw S, Rogers MJ, Cauche D (2010) Technological variation in the earliest Oldowan from Gona, Afar, Ethiopia. *Journal of Human Evolution* 58:474–491.

What does Oldowan technology represent in terms of hominin behavior? 243

- Stout D, Toth N, Schick K, Chaminade T (2008) Neural correlates of Early Stone Age toolmaking: technology, language and cognition in human evolution. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1499):1939.
- Stout D, Toth N, Schick KD, Stout J, Hutchins G (2000) Stone tool-making and brain activation: Position emission tomography (PET) studies. *Journal of Archaeological Science* 27(12):1215–1223.
- Susman RL (1994) Fossil evidence for early hominid tool use. *Science* 265(5178):1570–1573.
- Tactikos JC (2005) A Landscape Perspective on the Oldowan from Olduvai Gorge, Tanzania. Phd dissertation, Anthropology. Rutgers, the State University of New Jersey, New Brunswick.
- Texier PJ (1995) The Oldowan assemblage from NY 18 site at Nyabusosi (Toro-Uganda). *Comptes Rendus de l'Académie des Sciences* 320:647–653.
- Texier PJ, Roche H, Harmand S (2006) Kokiselei 5, formation de Nachukui, West Turkana (Kenya): un témoignage de la variabilité ou de l'évolution des comportements techniques au Pléistocène ancien. *Préhistoire et Technologie: CNRS: UMR7055-Université de Paris-Nanterre*.
- Tocheri MW (2007) Three-dimensional riddles of the radial wrist: Derived carpal and carpometacarpal joint morphology in the genus Homo and the implications for understanding the evolution of stone tool-related behaviors in hominins. PhD dissertation, Arizona State University, Phoenix.
- Tocheri MW, Marzke MW, Liu D, Bae M, Jones GP, Williams RC, Razdan A (2003) Functional capabilities of modern and fossil hominid hands: three-dimensional analysis of trapezia. *American Journal of Physical Anthropology* 122(2):101–112.
- Tocheri MW, Orr CM, Jacofsky MC, Marzke MW (2008) The evolutionary history of the hominin hand since the last common ancestor of Pan and Homo. *Journal of Anatomy* 212(4):544–562.
- Torrence R (1989) Retooling: towards a behavioral theory of stone tools. In: Torrence R (ed) *Time, Energy, and Stone Tools*. Cambridge University Press, Cambridge, pp. 57–66.
- Toth N (1985) Oldowan reassessed: a close look at early stone artifacts. *Journal of Archaeological Science* 12(2):101–120.
- Toth N (1987) Behavioral inferences from Early Stone artifact assemblages: an experimental model. *Journal of Human Evolution* 16(7):763–787.
- Toth N (1991) Importance of experimental replicative and functional studies in Palaeolithic archaeology. In: Clark JD (ed) *Cultural Beginnings: Approaches to Understanding Early Hominid Life-ways in the African Savanna*. Rudolf Habelt Verlag, Bonn, pp. 109–124.
- Toth N (1997) The artefact assemblages in the light of experimental studies. In: Isaac GL (ed) *Koobi Fora Research Project*. Clarendon Press, Oxford, pp. 363–401.
- Van Peer P, Bar-Yosef O (2009) The Chaîne Operatoire Approach in Middle Paleolithic Archaeology. *Current Anthropology* 50(1):103–131.
- Whiten A, Goodall J, McGrew WC, Nishida T, Reynolds V, Sugiyama Y, Tutin CEG, Wrangham RW, Boesch C (1999) Cultures in chimpanzees. *Nature* 399: 682–685.
- Whiten A, Horner V, De Waal FBM (2005) Conformity to cultural norms of tool use in chimpanzees. *Nature* 437(7059):737–740.

- Whiten A, Schick K, Toth N (2009) The evolution and cultural transmission of percussive technology: integrating evidence from palaeoanthropology and primatology. *Journal of Human Evolution* 57(4):420–435.
- Williams EM, Gordon AD, Richmond BG (2010) Upper limb kinematics and the role of the wrist during stone tool production. *American Journal of Physical Anthropology* 143:134–145.
- Wood B, Collard M (1999) The human genus. *Science* 284(5411):65–71.
- Wynn T, McGrew WC (1989) An ape's view of the Oldowan. *Man* 24(3):383–398.