The Oldowan-Acheulian Transition: Is there a "Developed Oldowan" Artifact Tradition?

Sileshi Semaw, Michael Rogers, and Dietrich Stout

Abstract The phrase "Developed Oldowan" (DO) was originally coined by M. Leakey to describe a technologically "advanced Oldowan" artifact tradition, that preceded the Acheulian Industry. M. Leakey further identified three stages of the DO which she labeled as the DOA, DOB and DOC. The DO (*sensu lato*) has been generally recognized as transitional to the Acheulian, but the status of the DOB and the DOC remains unclear. In addition to a lack of clarity in terms of classification, the DO also suffers from a lack of secure radiometric dates, even at Olduvai where it was first identified. Despite such shortcomings, archaeologists still assign assemblages into the DO, as supposedly "intermediate" or transitional between the Oldowan and the Acheulian. However, a closer look at the DO assemblages from Olduvai Gorge and other sites in Africa and the Middle East shows that the artifacts assigned into this tradition are not technologically drastically different from the preceding Oldowan. Probably the flaking characteristics of the raw material types (e.g., quartzite and limestone, and to a lesser extent basalt) and the original shape of the cobbles used by hominins may have played a major role in the final shape of the "distinctive" artifact types (such as spheroids/subspheroids) used for assigning assemblages into the DO. Further, both the DOB and the Acheulian appeared ~1.7 million years ago (Ma) in the archaeological record, making it unlikely that the DO is a transitional artifact tradition that preceded the Acheulian. Our preliminary evaluation of the archaeological record at Gona, Ethiopia and elsewhere suggests a fairly abrupt appearance of the Acheulian after a temporally rapid transition from the Oldowan.

Keywords Oldowan • Developed Oldowan • Oldowan-Acheulian transition • Early Acheulian

The Oldowan and Acheulian entities appear to have been separated by a comparatively rapid change dependent on a single technical step which by its very nature could not have been taken gradually (G. Ll. Isaac 1969, 21).

Introduction

The appearance of Acheulian (or Mode II [Clarke 1969]) handaxes in the archaeological record is often heralded as a significant development in human cultural/technological evolution, relative to the preceding Oldowan industry. While the earliest appearance of the Acheulian has long been considered to occur 1.7–1.5 Ma (e.g., Clark 1970; Klein 1999), until recently the earliest *in situ* occurrence has been difficult to document securely. Although details have yet to be published, Konso in Southern Ethiopia (Beyene 2003, 2004, 2008; Beyene et al. 1997) and probably Kokiselei in West Turkana, Kenya (Roche 2005; Roche et al. 2003) document

S. Semaw (✉)
Stone Age Institute and CRAFT Research Center, Indiana University, Gosport, IN, USA

M. Camps, P. Chauhan (eds.), *Sourcebook of Paleolithic Transitions*, DOI 10.1007/978-0-387-76487-0_10,
© Springer Science+Business Media, LLC 2009

the earliest Acheulian occurrences dated to ~1.7 Ma. At Gona we have recently excavated Early Acheulian artifacts estimated to at least 1.6 Ma, but details of the associated geology/geochronology have yet to be worked out (Quade et al. 2004, 2008; Semaw et al. 2008 [in prep]).

Based on current investigations, the Oldowan, the earliest ancestral hominin stone tool tradition, appeared in the geological record by ~2.6 Ma, although it is possible that the use of flaked stones may have begun as early as 2.9 Ma (Quade et al. 2004; Rogers and Semaw [this volume]; Semaw et al. 1997, 2003 [in press]). This simple core-flake technology persisted in the archaeological record with little change until the emergence of the Acheulian Industry by ~1.7 Ma (Beyene 2008, 2004, 2003; Roche 2005). What was the nature of the Oldowan-Acheulian transition, and are there clear transitional artifacts in the archaeological record? Several Early Pleistocene artifact assemblages have been categorized as belonging to a transitional industry called the "Developed Oldowan," often based on a subjective typology. One result of the uncertain chronology, as well as the use of subjective "transitional" tool types, is that the Oldowan-Acheulian transition is, paradoxically, poorly understood. We hope to clarify some of these issues in this paper.

It is widely held among Paleolithic archaeologists that the Developed Oldowan, the stone tool tradition coined by M. Leakey (1971), marks a significant transition between the Oldowan and the Acheulian industries (e.g., Clark 1970; Klein 1999). Based on analysis of the Early Pleistocene lithic assemblages from Olduvai Gorge Bed I–Bed IV, M. Leakey proposed three stages of the Developed Oldowan, which she labeled from the oldest to the youngest, as the Developed Oldowan A, B, and C (DOA, DOB, and DOC, for short). The assemblages classified into the DOA (~1.7–1.6 Ma) contain cores/choppers and flakes, major elements of the Oldowan tradition, but are differentiated mainly by the preponderance of spheroids/subspheroids, and artifacts identified as "protobifaces." The DOB (~1.5–1.4 Ma) contains crudely-worked small bifaces (the majority made on cobbles) along with "light duty tools" including "awls, burins, and *outils écaillés*," (tool types also identified within the Oldowan and the DOA, but in much smaller numbers). Well-made large bifaces (on large flakes) that are similar to the Early Acheulian were also found in the DOB, but in smaller proportions. DOB-type assemblages are also known higher up in the Olduvai Gorge stratigraphic sequence in Bed IV, but are labeled as Developed Oldowan C simply by virtue of their more recent date (but see Jones 1994). Therefore, we will henceforth include the DOC into the DOB for the purpose of our discussion.

Following M. Leakey, the so-called "Developed Oldowan" (also sometimes referred to as "Evolved Oldowan") was widely accepted, and archaeologists have assigned Early Pleistocene assemblages from Africa and the Levant to this tradition (e.g., Bar-Yosef 1994; Chavaillon et al. 1979; Clark and Kurashina 1979; Piperno et al. 2004a, 2004b). Subsequently, Stiles (1991, 1979a, 1979b, 1979c) questioned M. Leakey's interpretations, and addressed the Developed Oldowan/Early Acheulian dichotomy in a series of papers (see also Jones 1994), and the same issue was recently discussed by de la Torre and Mora (2005), who express uncertainty by criticizing the status of the DO as a valid artifact tradition. Based on the study of some of the excavated assemblages from Olduvai Gorge, Stiles concluded that the DOB should be dropped as a valid category, because the variations seen in the bifaces of the two assemblages were mainly a result of differences in the flaking quality of the raw materials used. Although Jones' analyses showed his uncertainty about the status of the DOA and the DOB, he seems to favor the validity of the DOC in Beds III and IV.

Although archaeologists have classified some Early Pleistocene lithic assemblages into the "Developed Oldowan," it is often unclear or unstated as to which stage (A or B) of this tradition the materials should be assigned. Further, it is unclear in the archaeological literature whether the DOA or DOB (or both) should be considered transitional between the Oldowan and the Acheulian industries. Thus, it is important to have a closer look at lithic assemblages from Olduvai Gorge to assess the validity of the DOA and the DOB as justifiable artifact traditions, and to evaluate whether the two stages can be accommodated in either the Oldowan or the Acheulian industries. To that end, this paper examines earlier studies

Olduvai Gorge Bed I and Bed II assemblages, as well as other Early Pleistocene lithic assemblages in Africa, in order to determine whether or not artifact tradition(s) existed that can be unambiguously characterized as intermediate between the Oldowan and the Acheulian, and to what extent the term "Developed Oldowan" helps in understanding cultural/technological changes during the course of human evolution (see also de la Torre and Mora [2005] for detailed discussions of their revisions of the Olduvai Gorge Bed I and II materials).

Part of the inspiration behind this paper comes from our years of survey and excavations of Plio-Pleistocene archaeological sites at Gona, Ethiopia. At Gona, we have not found lithic assemblages that can be assigned to the Developed Oldowan, even though there are deposits dated to 1.7–1.5 Ma. It was interesting to us that this "artifact tradition" existed at some sites (e.g., Olduvai Gorge, Ain Hanech, and Melka Kunture, etc.) but not at Gona or other well-investigated Plio-Pleistocene archaeological sites.

Based on our investigations at Gona, experimental work conducted by other researchers (e.g., Sahnouni et al. 1997; Jones 1994; Schick and Toth 1994), and assessment of the existing Early Pleistocene archaeological literature, we argue here that the DOA appears to be technologically similar to (if not the same as) the Oldowan. While the "DOA" includes a variety of heavily-worked artifacts identified as spheroids/subspheroids and "protobifaces," the techniques employed for the manufacture of these artifacts do not show drastic departures from earlier practices, either conceptually or in craftsmanship. Hence, we do not see a need to posit a different stone tool tradition for such assemblages other than the Oldowan (e.g., Sahnouni et al. 2002; Sahnouni and de Heinzelin 1998). In addition, we do not see anything "transitional" in the DOA, and therefore suggest that the DOA be subsumed within the Oldowan Industry (see also de la Torre and Mora 2005).

Although by no means exhaustive, our assessment also supports Stiles' conclusion that the DOB should be dropped, and be subsumed under the Early Acheulian because the lithic assemblages identified into both "traditions" consist of artifacts that are clearly Early Acheulian in character. Further, both lithic industries appeared at the same time (~1.7–1.6 Ma), and overlapped for at least a million years up to ~0.5 Ma. The variations seen between the DOB and the Early Acheulian assemblages at Olduvai Gorge, particularly the workmanship of the bifaces, could have resulted from differences in the raw materials used, and their flaking quality (Stiles 1991, 1979a, 1979b, 1979c, 1981; see also Jones 1994). The makers of the "DOB" appear to be skilled and capable of making large bifaces (on large flakes) identical to some of those excavated at Early Acheulian sites. Further, the presence of bifaces made on large flakes in the Developed Oldowan (although in much smaller proportion compared to the Early Acheulian) is indicative that the same hominin species may have been responsible for the two traditions.

One further result of our review is that the Oldowan-Acheulian transition may in fact mark several interrelated transitions, and that the traditional notion of the Acheulian beginning with the first appearance of handaxes may be too simplistic. During this transition we may see some variability depending upon paleogeography; availability, size, and type of raw materials used; and possible hominin "experimentation," i.e., alternative technological responses to a range of selective pressures.

The Oldowan, a Brief Overview

In the 1930s Louis Leakey began archaeological surveys of the deposits exposed at Olduvai Gorge, in Tanzania, and discovered stone artifacts characterized by cores/choppers and flakes, which he named the Oldowan after Olduvai Gorge (Leakey 1934; see Gowlett [1990] for details on the history of early explorations). During the following decades, M. Leakey undertook systematic archaeological investigations and excavations at Olduvai Gorge. She conducted large scale excavations and carried out years of meticulous work analyzing the Olduvai Gorge materials, thereby revealing a wealth of information on the stone tool behavior of Early Pleistocene hominins in Africa.

The Olduvai Gorge Bed I stone artifacts were dated to 1.9–1.8 Ma, and at the time represented the earliest stone artifacts documented in the world (Leakey 1971). Bed I was the focus of much of the geological investigations because of the archaeological

riches and important hominin fossil discoveries made in the late 1950s and the 1960s; hence, Bed I is the best dated section of the entire sequence (Hay 1976; Tamrat et al. 1995; Walter et al. 1991). At Olduvai Gorge, upper Bed I and lower Bed II contain artifacts attributed to the classic Oldowan, i.e., assemblages characterized primarily by cores/choppers, and flakes and flaking debris, the hallmark of the Oldowan Industry or Mode I of Clarke (1969). M. Leakey believed that the cores/choppers were the actual tools that the hominins sought, and she named tool types based on their shape and assumed functions. She identified a variety of choppers (side, end, pointed, etc.), as well as specimens identified as discoids, polyhedrons, spheroids, awls, burins, and so forth (Leakey 1971, 1976a). Additional specimens included stones with pitting marks identified as hammerstones, and "manuports," i.e., unmodified cobbles that hominins transported to the sites (but see also the recent revisions by de la Torre and Mora [2005]). Even though Louis Leakey named the earliest lithic industry, it was M. Leakey, the archaeologist, who excavated, described, and clearly defined the Oldowan stone tool tradition.

The Leakeys' work brought unparalleled enthusiasm and attention to the prehistory of East Africa. Following their success, a number of international projects began systematic fieldwork during the 1960s and 1970s, primarily in Kenya and Ethiopia. The multidisciplinary research initiated and pioneered by the late F.C. Howell was instrumental for the discovery of Late Pliocene stone artifacts at Omo in Southern Ethiopia. American and French teams undertook years of excavations at Omo, and recovered stone artifacts (mainly made of quartz) within the Shungura Formation in the deposits dated to 2.4–2.3 Ma, almost 0.5 Ma older than the artifacts earlier excavated from Olduvai Gorge (Chavaillon 1976; Howell et al. 1987; Merrick 1976; Merrick and Merrick 1976). In the 1980s and 1990s, field investigations at Lokalalei, in Kenya, revealed the presence of stone artifacts made of basalt and phonolite dated to 2.4–2.3 Ma (Delagnes and Roche 2005; Kibunjia 1994; Kibunjia et al. 1992; Roche et al. 1999). Archaeological work at Kanjera South, also in Kenya, has led to the recovery of Late Pliocene stone artifacts estimated to ~2.0 Ma (primarily based on paleomagnetic profiles) (Bishop et al. 2006; Plummer 2004).

In Ethiopia, geological work by Maurice Taieb in the 1960s and 1970s opened up the venue in the Afar, an unexplored paleoanthropologically-rich area with ancient fossils and stone artifacts exposed in the deposits straddling the Awash River (Johanson et al. 1982; Taieb and Coppens 1975; Taieb et al. 1972). Systematic field investigations carried out later in the 1990s, and subsequent research by the Gona Palaeoanthropological Research Project, resulted in the discovery of 2.6-Ma excavated stone artifacts at East Gona (mainly made on trachyte and rhyolite), and cut-marked bones and a hominin named *Australopithecus garhi* in the Middle Awash (Asfaw et al. 1999; de Heinzelin et al. 1999; Semaw 2000, 2005, 2006; Semaw et al. 2003, 1997 [in press]). Continued investigations of the Late Pliocene deposits exposed at Ounda Gona to the south have yielded stone artifacts and associated fragmented fossil fauna (with cut-marked bones also found on the surface) that were also radiometrically dated to 2.6 Ma (Domínguez-Rodrigo et al. 2005; Semaw et al. 2003). At Hadar, Oldowan stone artifacts (made on trachyte and ignimbrite) associated with an early *Homo* maxilla and dated to 2.3 Ma were excavated in the early 1990s (Kimbel et al. 1996). To date, the Late Pliocene sites in both Ethiopia and Kenya have not yielded artifacts identified as spheroids/subspheroids, protobifaces, awls, burins, etc. All of these sites contain cores/choppers and flakes that are typical of the Oldowan Industry.

During the Early Pleistocene (~1.9–1.5 Ma) a large number of archaeological sites were documented all across Africa, including Melka Kunture, Gadeb, Middle Awash, Konso, and Fejej in Ethiopia (Asfaw et al. 1992, 1991; Chavaillon et al. 1979; Clark and Kurashina 1979; Clark et al. 1994; de Lumley et al. 2004; Kurashina 1987; Piperno et al. 2004a, 2004b); Koobi Fora in Kenya (e.g., Isaac and Harris 1997); Nyabusosi in Uganda (Texier 1995); Olduvai Gorge and Peninj in Tanzania (de la Torre et al. 2008; Domínguez-Rodrigo et al. 2001 [in press]; Isaac et al. 1974; Leakey 1971); Ain Hanech and El Kherba in Algeria (Sahnouni et al. 2002; Sahnouni and de Heinzelin 1998); Sterkfontein, Kromdraai, and Swartkrans in South Africa (Brain et al. 1988; Field 1999; Kuman 1994a, 1994b, 1998; Kuman et al. 1997). Spheroids/subspheroids were identified at some of the sites, such as Ain Hanech, Melka Kunture, Gadeb, and Sterkfontein.

Of these sites, Melka Kunture, Gadeb, and Sterkfontein were reported to contain artifacts assigned to the Developed Oldowan. Interestingly, the artifacts from a majority of the other Early Pleistocene sites were classified into the Oldowan Industry or its "variants."

The evidence from all of these sites indicates that Oldowan artifacts were simple cores and flakes, made mainly with the hand-held percussion technique (sometimes with the bipolar technique). At about 2.6 Ma, the hominin toolmakers had a superb understanding of conchoidal fracture on stones, and they selected relatively high quality and fine-grained raw materials that were suitable for making sharp-edged implements (Rogers and Semaw [this volume]; Semaw 2006, 2000; Semaw et al. 2003, 1997; see also Stout et al. [2005]). Evidence of cut-marked fossil bones from Gona and the Middle Awash indicate that ancestral hominins at 2.6 Ma had already begun incorporating meat into their diet (de Heinzelin et al. 1999; Domínguez-Rodrigo et al. 2005). From our conservative perspective, the technology of Late Pliocene/Early Pleistocene stone tool manufacture—both conceptually as well as in workmanship—remained the same until the advent of the Acheulian Industry, described below.

The Developed Oldowan A

At Olduvai Gorge, artifacts assigned to the "DOA" come from Lower and Middle Bed II (including FLK North and HWK East), where spheroids/subspheroids and light duty tools (primarily made of chert) become more abundant compared to Bed I. Also, "protobifaces" and heavy duty tools become relatively numerous here. M. Leakey believed that the preponderance of spheroids/subspheroids and the light duty components within the Lower and Middle Bed II assemblages signaled the appearance of an advanced stone tool tradition that she labeled the "Developed Oldowan," and later modified to the Developed Oldowan A ("DOA"). Although Bed II contains important archaeology as well as hominin fossils, it is poorly dated and still awaiting refinement on the age of the tuffs. Based on a combination of $^{40}Ar/^{39}Ar$ (including K/Ar) and paleomagnetic calibrations, the lower part of Bed II is dated to ~1.71 Ma, and the topmost Bed II to approximately 1.1 Ma (Hay 1976; Manega 1993; Stollhofen et al. 2008; Tamrat et al. 1995; Walter et al. 1991). Thus, the ages of the materials assigned to the DOA are estimated to 1.7–1.6 Ma.

It is important here to briefly examine some of the elaborate artifact types identified by M. Leakey, all of which formed the basis for classifying the Lower-Middle Bed II assemblages into the "DOA" tradition.

Spheroids/Subspheroids

Artifact forms labeled as spheroids/subspheroids, sometimes also referred to as "bolas," have been recovered from several Lower Paleolithic sites such as Olduvai Gorge, Ain Hanech, Gadeb, Melka Kunture, Chesowanja, and relatively younger sites such as Isimila, Isenya, and Olorgesailie, all from East and North Africa (Chavaillon et al. 1979; Clark and Kurashina 1979; Gowlett et al. 1981; Howell 1961; Isaac 1977; Kurashina 1987; Leakey 1971; Roche 2000; Sahnouni 2006, 2005, 1993; Sahnouni et al. 2002, 1997; Sahnouni and de Heinzelin 1998; Willoughby 1985); and from "Ubeidiya" in Israel (Bar-Yosef 1994; Bar-Yosef and Goren-Inbar 1993). Since the primary artifacts of the Oldowan tradition were simple cores and flakes, experimental replication studies have shown that hominins were mainly after sharp-edged cutting implements (Bunn 1981; Bunn et al. 1980; Keeley and Toth 1981; Potts and Shipman 1981; Toth 1987, 1985). However, archaeologists have long wondered about the function of spheroids and subspheroids and how they were made (Sahnouni et al. 1997; Schick and Toth 1994; Willoughby 1985).

Roche and Texier (1995, see also Roche [2000]) suggest that spheroids and (polyhedrons) show more sophistication in technology due to the deliberate shaping and consecutive flaking technique necessary to produce these forms. This contrasts with the simple and contiguous flaking seen in other Oldowan core types. Willoughby (1985) suggests that they could have been used for pounding/processing plant foods or as missiles, but does not rule out that they were simply the natural result of quartz being used as hammerstones/percussors. Schick and Toth

(1994; see also Sahnouni et al. [1997]) tested this idea by conducting experiments demonstrating how the Olduvai Gorge spheroids/subspheroids may have been produced. The experimental knapping study of quartz by Schick and Toth (1994, 446) indicated "that the simplest explanation for the artifact classes of subspheroids and spheroids is that these forms are hammerstones that have been used for an extended length of time for flaking cores." Thus, among the most plausible explanations for the preponderance of spheroids/subspheroids from Bed II times are "early hominins shifting their preference of raw materials from lava to quartz over time" (Schick and Toth 1994, 446; see also Jones 1994). Schick and Toth (1994) concluded that "repeated use of quartz chunks or exhausted cores as percussors would naturally produce battered artifacts that would formally be classed as subspheroids and spheroids without any necessary intent or premeditation on the part of the hominids to produce these forms" (Schick and Toth 1994, 442). Experimental study conducted on limestones also showed that continuous heavy flaking of this raw material results in forms identified as spheroids/subspheroids, similar to several of the artifacts known from Ain Hanech dated to 1.8 Ma (Sahnouni et al. 1997; see also Sahnouni 1993). Thus, it is likely that the spheroids/subspheroids at Olduvai Gorge were derived from increased hominin use of quartz as the preferred raw material, both for cores as well as hammerstones. Also, Jones' (1994) analysis indicated that the pieces identified as spheroids/subspheroids at Olduvai Gorge were consistently made on quartz. However, Schick and Toth do not rule out the possibility that such specimens could have been used for other functions once the spherical shapes were attained through extensive percussion.

Are spheroids/subspheroids, then, really evolved forms compared to the core/choppers, discoids, etc., of the Oldowan tradition? Do they show technological sophistication demanding more skill for making them? It depends on what we interpret as being intentional, which is difficult to demonstrate from the archaeological record. The simplest explanation is that these forms were probably a byproduct of simple flaking, made by the hand-held percussion technique similar to earlier artifacts of the Oldowan tradition, and were conditioned by the raw materials used (e.g., quartz at Olduvai Gorge, limestones at Ain Hanech). Therefore, for now, the workmanship does not appear to be related to an advanced technical skill drastically different from the techniques of manufacture employed for making Oldowan artifacts. In this regard, it is interesting to note that the lithic assemblages at Ain Hanech contain relatively numerous spheroids/subspheroids, and the site is dated to ~1.8 Ma, but the materials are still classified into the Oldowan rather than the "Developed Oldowan" (see Sahnouni et al. 2002; Sahnouni and de Heinzelin 1998).

Protobifaces

According to M. Leakey, "protobifaces" are specimens that are "intermediate between a biface and a chopper" (M. Leakey 1971, 5). These specimens "are always rare and are restricted in time span from Upper Bed I to the Sandy Conglomerate, the lowest horizon of Middle Bed II. They do not conform to any particular pattern or technique of manufacture but appear to represent attempts to achieve a rudimentary handaxe by whatever means was possible" (M. Leakey 1971, 266). A closer look at some of the specimens identified as "protobifaces" shows that these are cores/choppers that are heavily-reduced through intensive bifacial flaking. As clearly shown in the illustrations provided in M. Leakey's volume (1971, 79, 80), the specimens identified as "protobifaces" from FLK North, Lower Bed II, are actually heavily-worked cores/choppers (Fig. 1). Such specimens are rare even at Olduvai Gorge, and are among the tool types unlikely to have been deliberately designed with a template of a biface in mind (see also de la Torre and Mora 2005). Therefore, it is difficult to envision that hominins manufactured such tool forms in the anticipation of creating future proper bifaces. One can argue that the hominins could have made bifaces if they desired to do so, but the idea of a proto-form/pre-form at this stage appears to be unlikely. Interestingly, there are also instances of artifact types that could be identified as "protobifaces" even among the excavated specimens from Gona dated to 2.6 Ma, although smaller in size (see Fig. 2), but the identification of such heavily-worked pieces as "protobifaces" at this early date

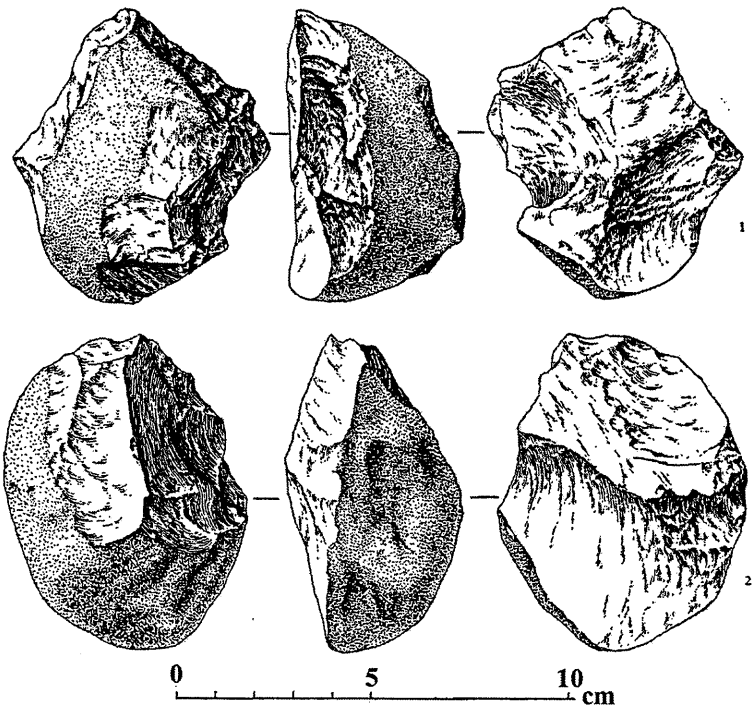

Fig. 1 FLK North, "protobifaces" on lava, levels 1–2, after M. Leakey (1971)

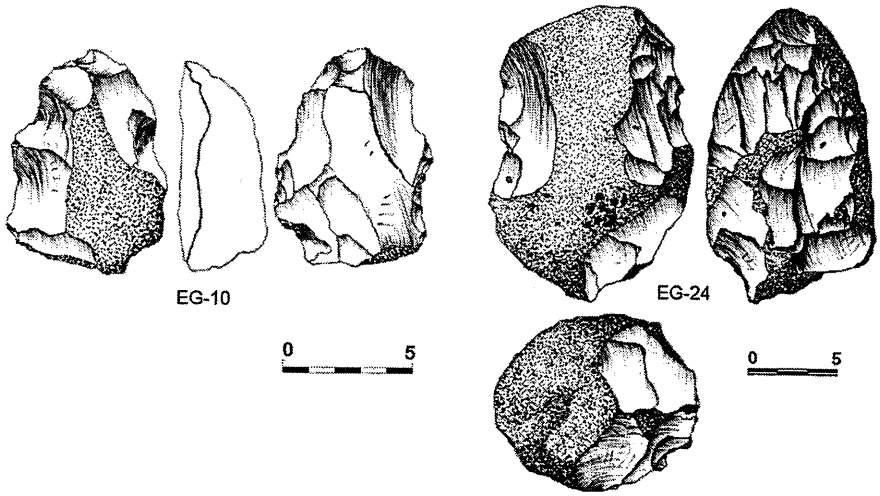

Fig. 2 Heavily-flaked cores, EG & EG24, Gona, 2.6 Ma

cannot be meaningful. It seems that those were heavily-worked cores/choppers that have attained such shape through continuous bifacial flaking, and most likely not made, as suggested by M. Leakey (1971), through the intentional shaping by hominins to produce "protobifaces" by any means possible.

Awls and Burins

Like the "protobifaces," the so-called "awls" and "burins" are probably accidental (Potts 1991), and according to de la Torre and Mora (2005, 43) some of the pieces identified as burins are actually

"knapping fractures." It seems hard to justify that these pieces were made intentionally by Early Pleistocene hominins to be used as "awls" and "burins" (*sensu stricto*), as their names imply. Further, the number of such artifacts was insignificant even at Olduvai Gorge, and difficult to grasp if the "tools" were indeed part of the tool repertoire of Early Pleistocene hominins. Therefore, the pieces identified as "awls" and "burins" probably were not deliberately made to be used for elaborate functions as implied. It is also interesting to note that such elaborate tool types did not make the list of artifacts recovered from any other Early Pleistocene sites in Africa.

Choppers

As archaeologists, we tend to associate assemblages that primarily consist of choppers and flakes with the Oldowan industry (Mode I). Observations in the field at Gona (and elsewhere, e.g., Koobi Fora) have shown that crudely made cores/choppers and flakes, the hallmark of the Oldowan, actually are ubiquitous during the Early and Middle Stone Age, and persisted well into the Late Pleistocene. Hominins probably made crude-looking choppers/cores throughout the Paleolithic to produce sharp-edged flakes used as "expedient tools." Choppers/cores were produced in large numbers during the Oldowan, and continued to be made, although in fewer numbers, well into the Acheulian and later times (e.g., Clark et al. 1994). Researchers place much emphasis on "artifact types" and "tool frequency" to determine the technological/cultural affinity of archaeological materials, and usually without due regard to the role that the variable flaking qualities of different raw materials (not to mention initial raw material sizes and shapes) may have played in influencing artifact forms, as discussed above (see Jones 1994; also Stiles 1979a, 1979b, 1979c). Also, different activities (e.g., carcass processing vs. plant processing) probably had a significant impact on Early Stone Age assemblage composition. Therefore, the naming of a variety of artifact traditions based solely on "tool frequency" (for example, based on the proportion of choppers vs. spheroids/subspheroids), without due consideration to the role that raw material variability may have played in assemblage composition, may not carry much weight, particularly for the Early Pleistocene. Studies have clearly shown the effect of access (or lack thereof) to good quality raw materials impacting artifact forms (e.g., Stout et al. 2008). Therefore, investigations of the paleogeographic and paleoenvironmental settings of Early Pleistocene sites are critical for understanding ancestral human stone tool manufacture and use behavior, as are studies of the flaking quality and influence of raw materials (for example, their proximity and availability), before assigning assemblages into different "cultural traditions." M. Leakey (1971) initially believed that the various "chopper" forms were the desired tools, but knapping and butchery experiments have shown that these were probably byproducts generated as a result of the production of sharp-edged cutting flakes (Isaac 1984; Toth 1987, 1985).

The Developed Oldowan B

At Olduvai Gorge, assemblages assigned to the "DOB" began in Middle Bed II, and the earliest occurrences may date to ~1.5–1.4 Ma. Here, hominins continued making the same classic Oldowan artifacts (cores/choppers, *débitage,* and manuports), but also some crude bifaces, signaling the emergence of a more "advanced" stone tool tradition. The light duty tools including scrapers, burins, awls, *outils écaillés*, and laterally trimmed flakes were also present in the "DOB" throughout Bed II up to Bed III. This same lithic tradition also persisted, with some additions, into Bed IV times, and was named the "Developed Oldowan C," although it is unclear to us how it differs from the assemblages assigned to the "DOB." Nevertheless, both the DOB and the Early Acheulian are found in Beds II–IV and the Masek Beds, and were penecontemporaneous for over 1.0 million years.

M. Leakey noted that the bifaces found in the Developed Oldowan show "unskilled workmanship," whereas Early Acheulian bifaces were larger in size and well-struck, and the makers

appeared to have "full mastery of their materials." Thus she argued that those two traditions should be separated. According to M. Leakey, the "Developed Oldowan" is contemporary with, but distinct from, the Acheulian: "...the factor that distinguishes the two traditions is an inability to detach large flakes in the Developed Oldowan—as in the Oldowan itself—whereas from Bed II onwards the Acheulean bifaces were generally made on large flakes" (M. Leakey 1975, 484–486). It is our impression that in the past a majority of archaeologists have generally agreed with M. Leakey's observations on the differences between "Developed Oldowan" and the "Early Acheulian" (e.g., Barham 1997; Klein 1999).

The Early Acheulian

M. Leakey (1971) excavated, discovered, and described the Acheulian at Olduvai Gorge, but Kleindienst (1962) set the criterion that an assemblage should contain 40–60% bifaces to be classified as Acheulian. Although Leakey did not oppose Kleindienst's definition, she pointed out that the term "Acheulian" should also be applied to the contemporary assemblages where a low percentage of bifaces is found in an industry otherwise characteristic of the "Developed Oldowan" (1976a, 447). According to M. Leakey, Early Acheulian bifaces tend to be larger and more numerous compared to those in the "DOB." Further, the spheroids/subspheroids that dominated the DOA assemblages become relatively few in the Acheulian.

It can be argued that M. Leakey (1971) did not clearly define the differences/similarities between the DOB and the Early Acheulian. Initially she classified some of the Bed II Assemblages (MNK and the Lower Floor at TK) to the Developed Oldowan, and later reclassified them into the Acheulian.

> It now seems possible that the industries from two sites in Bed II (MNK and the Lower Floor at TK), that were first classed as Developed Oldowan, should probably be included in the Acheulean, since the bifacial tools are Acheulean in character and technique of manufacture, although they are exceedingly rare. These two industries were originally classified as Developed Oldowan on the basis that a proportionate abundance of bifaces was a diagnostic character of the Acheulean (Kleindienst 1962), and that an industry should have 40% or more to qualify as Acheulean. More detailed work on the Acheulean and Developed Oldowan indicates that other features are perhaps more important, in particular the technique of manufacture evident in the bifaces. (M. Leakey 1976b, 31)

Part of Leakey's difficulty with the Oldowan-Acheulian transition was the initial acceptance of Kleindienst's arbitrary 40% threshold (and later reconsideration), but other problems had to do with uncertain dating and vague ideas of what exactly is changing during this transition, summed up in the somewhat subjective type of "biface." In their revision of the Olduvai Gorge artifacts, de la Torre and Mora (2005) illustrate that some of the so-called "bifaces" are not even artifactual. Thus, we are still uncertain of the answers to such simple questions as: What exactly marks the end of the Oldowan and signals the beginning of the Acheulian? When did the Oldowan end and the Acheulian begin? How long did the transition last? Why is the Developed Oldowan considered to be transitional? Further research is needed, especially on the functions of the Acheulian stone tools and their paleoenvironmental settings to be able to answer some of these questions conclusively.

Discussion

The Developed Oldowan A

Did the Oldowan evolve into the "Developed Oldowan"? Why do we have artifacts classified as "Developed Oldowan" at some sites but not others? Despite years of extensive and systematic field surveys undertaken in the Early Pleistocene Gona deposits, the archaeology team has found no artifacts that can be identified as protobifaces, spheroids/subspheroids, awls, burins, etc., the hallmark of the "Developed Oldowan" tradition. In addition, no other Late Pliocene site in East Africa has yielded artifacts identified as these types. Crudely made handaxes and cleavers found from Early Pleistocene deposits at Gona have been associated

with Oldowan (Mode I) choppers and flakes. Gona is not an exception in this regard, and several other sites in Africa that contain Oldowan artifacts (either Late Pliocene or Early Pleistocene) have not yielded lithic assemblages that can be identified as Developed Oldowan (*sensu stricto*). For example, artifact forms such as spheroids are unknown at Koobi Fora, Lokalalei, Omo, etc.

Spheroids and subspheroids have been found at Ain Hanech, Algeria, and date to 1.95–1.77 Ma (Sahnouni et al. 2002; Sahnouni and de Heinzelin 1998). The site is contemporary with Olduvai Gorge Bed I, and is certainly older than the Developed Oldowan levels at Olduvai Gorge. Sahnouni believes that artifact manufacture here follows the norms of Oldowan technology, and he has classified the Ain Hanech artifacts into the Oldowan. The spheroids/subspheroids, the main artifact types of the DOA, were not universal during the Early Pleistocene, and existed only at sites where quartz and limestone were the raw materials accessible for ancestral toolmakers (e.g., Sahnouni et al. 2002, 1997; Sahnouni and de Heinzelin 1998; Willoughby 1985).

Kurashina (1987) compared the Developed Oldowan assemblages from Gadeb, Ethiopia, with 64 Oldowan, Developed Oldowan, and Acheulian assemblages from sub-Saharan Africa. The results of his analyses, based on the "tool frequency," showed that the Developed Oldowan clusters well with the Oldowan, and Kurashina concluded that the Developed Oldowan represents an activity facies within the Oldowan. Gowlett (1988) sees the DOA as "simply a somewhat evolved form of Oldowan, in which bifacial working is increased, but in which there are no radical new departures" (p.14). Following a more detailed study of the Olduvai Gorge archaeological materials, de la Torre and Mora (2005, 228) conclude that "...there is no such thing as the Developed Oldowan."

So, is there an artifact tradition attributable to the Oldowan-Acheulian transition? As far as Leakey's DOA is concerned, the answer is no. The Olduvai Gorge spheroids/subspheroids are simply a result of extensive flaking and/or use of quartz as percussors/hammerstones, and the so-called "protobifaces" probably have very little (if anything) to do with a plan of making bifaces. Instead, Leakey's "protobifaces" are actually pieces that would be identified as exhaustively reduced cores (bifacially-worked side-choppers following M. Leakey's typology, see Fig. 1). The existence of burins and awls during the Early Pleistocene (Oldowan and the DOA) is also hard to justify (see de la Torre and Mora 2005; Potts 1991). While some of these pieces may formally be assigned to these types (based on their shape), it is difficult to conceive of the need by Early Pleistocene hominins for such tools, and if indeed those pieces were used as such. In sum, the DOA is not technologically different enough from the Oldowan to merit a different tradition. Therefore, it seems appropriate for the DOA to be dropped, and be subsumed within the Oldowan Industry.

The Developed Oldowan B

Why were the DOB and the Acheulian penecontemporaneous for almost one million years? M. Leakey argues that the two represent different cultural traditions or the assemblages were crafted by two different hominin groups (species?). Clark (1970) suggests that the two contemporary traditions may represent activity variants, i.e., artifacts made for differing functions. Gowlett (1988) also seems to favor the idea that differences in function may explain the variations in the Developed Oldowan/Acheulian. Isaac (1984) indicated preferred hominin habitats, with the Bed I and Bed II Oldowan sites located close to the lake, whereas the Acheulian toolmakers ranged widely away from the lakeside floodplain, a point which is also elaborated upon by Hay (1990).

Stiles (1979b) argued that the use of different raw materials was responsible for the variations seen in the DOB and the Early Acheulian. He carried out statistical tests on bifaces and large flakes recovered from two Early Acheulian (EFHR and TK Lower Floor [TKLF]) and two DOB (TK Upper Floor [TKUF] and FC West Floor [FCWF]) sites from Olduvai Gorge. His results showed that there were indeed statistical differences in the bifaces and the whole flakes of the two "traditions," and that the DOB assemblages had significantly higher frequencies of quartz compared to lava (see also Jones

1994). Stiles argued that "raw material rather than cultural tradition accounts for the differences between the bifaces of the two industries" (1979b, 129), and concluded that "... the observed differences can be explained by differences in the raw materials and primary form of the bifaces, there being no need to call on separate cultural traditions as an explanation" (p. 29). Hence, Stiles (1979b) urged that the DOB be dropped. Davis (1980) argues against the raw material explanation provided by Stiles, but offers no plausible explanation for the differences in the two assemblages.

According to Jones:

> ...there is a small but definite overlap between the two types of collection in that 5 to 10 per cent of the Developed Oldowan samples consist of bifaces that are identical to the majority at many Acheulean sites, and less than 5 per cent of several Acheulean collections consist of small bifaces which are morphologically and technologically similar to the majority at Developed Oldowan sites. (Jones 1994, 272)

It is problematic to accept Kleindienst's criterion that an assemblage should contain at least 40% handaxes to be classified into the Acheulian tradition. It is clear that the hominins responsible for the DOB assemblages already had the technological competence and the capability to make bifaces. Therefore, other factors may explain why the "tool frequencies" in the two assemblages differed. The most plausible explanation is that the differences in the flaking-quality, proximity, size, shape, and availability of raw materials may have influenced assemblage composition of the artifacts of the two "traditions" (Jones 1994; Stiles 1979a, 1979b).

> Other differences include the very variable morphology of the Developed Oldowan biface sample, as compared to the general consistency of the Acheulean samples. The sample sizes of the Developed Oldowan occurrences are generally lower than most Acheulean samples; and while the Acheulean collections from any one site will tend to be dominated by one maybe two materials, the Developed Oldowan collections will preserve roughly equal numbers of each material. Quartzite, however, has a notably lower occurrence at Developed Oldowan sites than at Acheulean sites, where it tends to be the dominant raw material for bifaces. (Jones 1994, 273)

Other explanations for the differences between the DOB and the Acheulian include the use of different paleohabitats by the makers of the two assemblages. R. Hay (1976) pointed out that the Developed Oldowan sites were located within 1 km of paleo-lake Olduvai Gorge, whereas the Acheulian sites were >1 km from the lake. Compared to the Oldowan, we see more or less similar habitats (mainly open grasslands/stream channels) occupied by the makers of the DOB and Early Acheulian artifacts. Most of the DOB and Early Acheulian sites are found in more open settings and located near channels. According to Jones (1994), the sources for both phonolite and quartzite were localized, and hominins (both DOB and Early Acheulian toolmakers) would have had equal access to stone resources for creating blanks on which to make large bifaces. Thus, the makers of both the DOB and Early Acheulian probably started with the same blank sizes. Jones (1994, 296) states that there are "...two very important similarities between these two samples of bifaces: first, both samples are made in roughly the same manner, i.e. using the same basic set of techniques, to the same basic plan shape. Second, both samples are made in the same range of raw materials."

Jones (1994) also points out a number of possible explanations for the differences between the DOB and Early Acheulian, and he seems to think

> ...that the bulk of the Developed Oldowan bifaces started out as typical Acheulean handaxes, but through use and the need to renew edges, or a general need to produce small flakes, they were flaked to their present shapes and discarded. This applies well to the phonolite and quartzite samples, but not to the basalt and trachy and esite collections. There is no evidence that the blanks for the Developed Oldowan quartzite and phonolite bifaces started out small; the bifaces in these two materials started out at the same size. This is further borne out by re-sharpening experiments on typical Acheulean bifaces. After three or four phases of re-sharpening, I was left with what could only be classified as a typical Developed Oldowan handaxe. (Jones 1994, 274)

According to Jones, "the majority of the Developed Oldowan sample consists of re-sharpened and re-flaked Acheulean handaxes" (Jones 1994, 296). Compared to the Acheulian, the DOB contains more variety of tool types and a higher percentage of *débitage*, and Jones concluded that the DOB sites represent activity areas for maintaining artifacts, whereas the Acheulian sites represent discard areas after use. In sum, the DOB seems technically similar

and appears to be contemporary with the Early Acheulian, and such assemblages with crudely made Acheulian handaxes, choppers, heavy duty tools, and *débitage* should be subsumed under the Early Acheulian.

Is There a Transitional Industry Between the Oldowan and the Acheulian?

The main task of Oldowan toolmakers was selecting fine-grained cobbles with good flaking quality for making sharp-edged flakes needed for processing carcasses and other cutting needs. The flakes were struck from cores with the hand-held percussion technique. In contrast, Early Acheulian toolmakers were concerned with selecting large cobble blanks and/or boulder cores of sufficient size for the removal of large flake blanks (>10 cm). Ethnographic (Stout 2002; Toth et al. 1992) and experimental (Toth 2001) evidence strongly suggests that the latter would have been done with the core supported on an anvil or the ground, rather than in the hand. Large flake production in the Early Acheulian thus involves different objectives, different raw materials, and different means of support, as well as much greater force, possibly involving different percussive techniques such as throwing (Toth 2001). This mode of flaking is qualitatively different from the production of Oldowan flakes and clearly represents a novel technological invention. The challenges of properly positioning and supporting larger cores, and of delivering larger amounts of percussive force to precise targets further reflect an increase in required motor skill over Oldowan flaking.

Early Acheulian toolmaking further differs from the Oldowan in the subsequent shaping of the flake or cobble blank. This introduces an additional stage in tool production as well as an additional level of hierarchical action organization. Flake removals must be organized with respect to an overarching goal, and properly related to one another on this larger spatiotemporal scale if success is to be achieved. Early Acheulian bifaces are quite crude compared to later forms, yet examples from Gona clearly show the deliberate creation of bifacial cutting edges and shaping of distinct points. This is true of bifaces on large cobbles as well as flake blanks, and reflects invariance at a higher level of hierarchical organization.

Whereas the neural demands of Oldowan toolmaking pertain primarily to sensorimotor coordination (Stout and Chaminade 2007; Stout et al. 2008), the higher-level organization of Acheulian toolmaking places demands on the prefrontal cortex (Stout et al. 2008), a region generally thought to play a central role in coordinating flexible and goal-directed behavior (Ridderinkhof et al. 2004). Late Acheulian toolmaking in particular is associated with activation of the right hemisphere homologue of Broca's area, a region implicated in language processing as well as the more general coordination of actions as subordinate elements within ongoing, hierarchically-structured action sequences (Koechlin and Jubault 2006). Broca's area has been a focus for hypotheses relating to manual object combination, hierarchical action organization, and language evolution (Greenfield 1991). The earliest paleoneurological evidence of expansion in this region comes from KNM-ER 1470 (Holloway 1999), dating to ~1.9 Ma.

In sum, qualitative technological, behavioral, and cognitive differences between the industries make a "transitional" industry difficult to envision. Essential neural, somatic, and behavioral preconditions must have been in place to afford the invention of this new technology; however, the technology itself represents a clear discontinuity. In addition, at Olduvai Gorge, the "Developed Oldowan" persisted side-by-side with the Acheulian industry for about one million years (1.5–0.5 Ma). The contemporaneity of the Developed Oldowan and the Acheulian itself casts doubt on the validity of the Developed Oldowan as a transitional industry.

Outside of Olduvai Gorge, the Karari Industry at Koobi Fora has been described as similar to the DOA (Isaac and Harris 1997). Emerging at about 1.6 Ma, the "Karari" is a distinctive artifact tradition with a preponderance of single platform cores that overlapped with the "Developed Oldowan" at Olduvai Gorge, Early Acheulian at West Turkana, and other sites. Given its standardized form and technique of manufacture, "...it would seem probable that the idiosyncratic features of the Karari industry are best regarded as due to stone-working *habits* that were adjusted to local raw material

forms" (Isaac 1984, 164–165 [original emphasis]). In the final analysis, it seems likely that the Karari Industry will prove to be an alternative technological response to some of the same behavioral changes (e.g., different habitats, increased mobility [Braun and Harris 2003; Rogers et al. 1994]) that prompted the invention of the Acheulian, rather than a "transitional" industry in the conventional sense.

It is probable that hominin behavior does change in the Early Pleistocene, but it is difficult to equate these changes to a transitional stone tool industry. For example, compared to the Late Pliocene, stone tool use became more "habitual" and sites were repeatedly occupied during the Early Pleistocene. By 1.8 Ma, intensive flaking of cores, a larger number of retouched pieces, and high density concentrations of artifacts were documented across many sites in Africa, as well as more cutmarked bones in the archaeological record (Toth et al. 2006). However, the same techniques of Oldowan artifact manufacture (hand-held/bipolar technique) lasted for about a million years (2.6–~1.7 Ma). Major changes in the hominin plan and aim of stone tool manufacture, i.e., the conceptual and physical ability to remove large flakes from boulder cores and impose form and symmetry—tasks that demand complex operational sequences—emerged with the Early Acheulian ~1.7 Ma.

Isaac, years ago, suggested that:

> ...the seemingly abrupt initiation of the early Acheulian may relate to the discovery of how to strike large flakes consistently. What is not yet clear is whether bifaces at the moment of innovation represented *new tools* for performing long lasting tasks (such as butchery) or whether *new tasks* were added to the behavioural, adaptive repertoire. To resolve this we will need better information on function before, during, and after the beginning of the Acheulian. (Isaac 1984, 50 [original emphasis])

Better information is now accumulating, albeit slowly, as discussed below.

The Emergence of the Acheulian

The earliest appearance of the Acheulian has long been considered to occur 1.7–1.5 Ma (e.g., Clark 1970; Klein 1999), but the earliest *in situ* occurrence has been difficult to document securely, leading to some confusion in the literature. For example, while Klein (1999) cites West Turkana as documenting the earliest Acheulian site (from Roche 1995), Clark et al. (1994) cites Konso (from Asfaw et al. 1992), Lieberman and Bar-Yosef (2005) refer to Peninj (from Domínguez-Rodrigo et al. 2001), and Klein (2006) cites Kokiselei at West Turkana (from Roche et al. 2003) and Gona (from Quade et al. 2004). Despite these various hints, full reports of the artifacts, their age, and context have yet to be published. At Konso, Early Acheulian artifacts that are ~1.7 Ma have been reported by Beyene (2008, 2004, 2003; see also Beyene et al. 1997; Suwa et al. 2007), but this should await a full report by the researchers. Roche et al.'s (2003) brief report indicates the presence of an Early Acheulian Industry at Kokiselei (KS4), West Turkana, Kenya, dated to ~1.65 Ma. The artifacts consist "of handaxes or proto-handaxes, picks, and of flakes, some of them very large, as are some of the cores" (Roche et al. 2003, 665). Some technologically complex Oldowan stone tools are also reported from Peninj dated between 1.6 and 1.4 Ma (de la Torre et al. 2003), but these assemblages lack bifaces and the large blanks known to occur at this time. Although for a long time the Early Acheulian from Peninj was believed to be ~1.4 Ma, recent publications by de la Torre et al. (2008) and Domínguez-Rodrigo et al. (in press) have reported an age around 1.2 Ma for both the Oldowan and the Early Acheulian of Peninj.

Systematic survey of the newly designated Busidima Formation at Gona (Quade et al. 2004, 2008) has yielded Early Pleistocene Oldowan, and Early-Late Acheulian, Middle Stone Age, and Late Stone Age archaeological sites (Semaw et al. [in prep.]). A number of these sites have been excavated, yielding stone tools *in situ*. The presence of a more than 100 meter-thick Plio-Pleistocene sequence in the Busidima Formation has provided an opportunity to assess whether any lithic assemblages existed to mark the Oldowan-Acheulian transition. Our recent fieldwork at Gona has shown the presence of abundant Early Acheulian crudely-made bifaces and picks estimated to be ~1.6 Ma (Quade et al. 2004, 2008; Semaw et al. 2008 [in prep.]). However, there are no lithic assemblages that are attributable to the Developed Oldowan, and the evidence from Gona appears to favor a rapid technological

transition from the Oldowan (Mode I) to the Acheulian technology (Mode II), much in the same way that the earliest sites at Gona mark an abrupt transition from no archaeological record to the presence of an archaeological record (see Rogers and Semaw [this volume]).

Our continued archaeological field investigations at Gona show that the main artifact types found in the Early Pleistocene deposits (i.e., in addition to the typical Oldowan cores/choppers and flakes) include crudely made Early Acheulian handaxes, picks, and cleavers. These are the new artifact types unknown in the Late Pliocene/Earliest Pleistocene stone assemblages of the Oldowan tradition. The Early Acheulian assemblages consist of numerous large flakes (blanks) and crude bifaces that were made on large cobbles as well as on large flakes >10 cm (e.g., Fig. 3). Interestingly, a common form at these early sites (e.g., OGS-12 and BSN-17) is a pick (sometimes trihedral) made on large cobbles, perhaps similar to the early sites at Konso.

Although the Acheulian is usually associated with *Homo erectus* (and *Homo ergaster*), their first appearance datum (FAD) not contemporaneous. Fossil hominins in Africa attributed to *Homo erectus* date from at least 1.65 Ma (see recent review in Suwa et al. [2007]), and the earliest Eurasian hominins from Dmanisi (Republic of Georgia) and Java (although with less-secure chronological placement) are also known with dates of ~1.8 Ma (Gabunia et al. 2001; Larick et al. 2001; Lordkipanidze et al. 2007, 2005), although Acheulian artifacts are absent from these localities. The relationship between the appearance of *Homo erectus* and the origin of the Acheulian tradition is unclear; from the present evidence these events may be separated by at least 100,000 years.

Hominins c. 1.7 Ma began producing crude bifaces and picks (and probably cleavers as well) from large cobbles and large flakes. The making of large flakes (>10 cm) was cognitively and technically different from the production of the simple sharp-edged cutting flakes produced during the Late Pliocene, the main purpose of which was probably for processing carcasses. As stated by Isaac (1969), the discovery of how to knock off large flakes (blanks) used for making bifaces appears to be the novel strategy that heralded the appearance of the Acheulian Industry. Substantial differences exist in the entire cognitive processes involved in the two traditions. Late Pliocene hominins were primarily after fine-grained cobbles used for the production of small sharp-edged cutting flakes. Preliminary observations indicate that during the initial stage, Early Acheulian toolmakers (e.g., at Gona) were after large size raw materials irrespective of their fine-grained nature. This does not mean that hominins were not interested in fine-grained raw

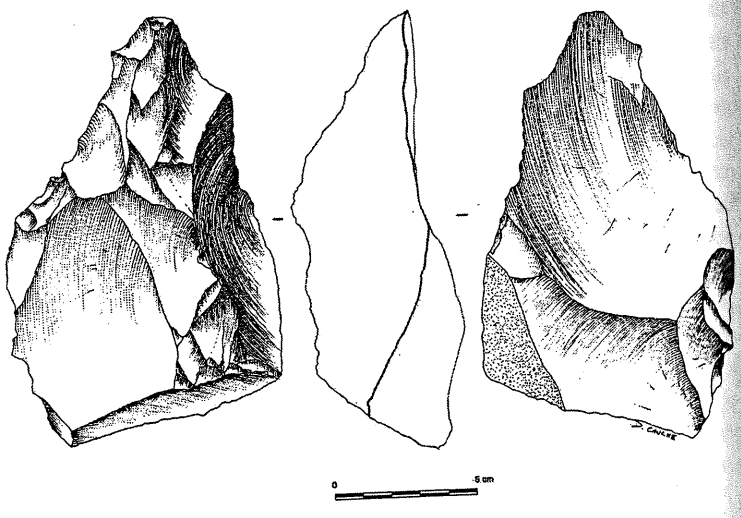

Fig. 3 Early Acheulian biface excavated from OGS-12 (Gona), ~1.6 Ma

materials, but simply that clasts that were large as well as fine-grained were quite scarce, and the hominins utilized whatever large cobbles/boulders were accessible for producing large blanks. Such considerations likely explain the recently noted (Sharon 2008) tendency for Large Flake Blank tools to be made on relatively coarse-grained materials throughout the temporal and geographic range of the Acheulian. At Olduvai Gorge, Oldowan, "Developed Oldowan," and Acheulian toolmakers occupied different paleogeographic landscapes, i.e., close to paleo-lake Olduvai Gorge during Bed I times, and more inland later; the composition of the raw materials also changed from lava during Bed I to quartzite during later times (see review in Kyara [1999]).

The case regarding the quality of raw materials used at Olduvai Gorge, according to de la Torre and Mora (2005, 209), may be different from Gona, with the hominins selecting (e.g., at TK) for "large quartz blocks without irregularities that could be turned into large cutting tools, anvils, etc." This contrasts with Bed I sites where small lava cobbles of "irregular quality" quartz fragments were used for making the Oldowan artifacts. During the Late Pliocene small, sharp-edged cutting (Oldowan) flakes were produced by hand-held percussion, throwing, or bipolar techniques, but the large blanks produced by the makers of the Early Acheulian would have been difficult to produce using these hand-held percussion methods. The large implements produced by Early Acheulian toolmakers are known to be effective for cutting, digging, and woodworking, but these tools' functions are not yet clear.

It is arguably more difficult to make a handaxe from a cobble than from a large flake; therefore, we cannot consider those made of cobbles as primitive or less advanced. Flaking and shaping a large cobble into a pick or biface may be difficult, and experimental work should throw light on this issue. Nonetheless, both types (bifaces on cobbles as well as on large flakes) were made by the makers of the Early Acheulian, and most likely hominins had figured out that first obtaining a large flake makes it easier for making handaxes and cleavers.

The timing and circumstances of the technological leap from the Oldowan to the Acheulian stone tool tradition in Africa is still among the most important but least understood questions in the field of paleoanthropology. Why the Acheulian ~1.7 Ma? While there is some evidence of African climate change about 1.8–1.7 Ma (Cerling 1992; deMenocal 2004), there is no clear link between environmental change and the origins of *Homo erectus* or the Acheulian. The Oldowan-Acheulian transition is important because it marks the first time that our ancestors created tools (handaxes, cleavers, and picks, among others) that probably required a preconception of form before their manufacture—tool forms that persisted for over 1.3 million years. This transition is poorly understood, though, because of the paucity of well-dated Acheulian archaeological sites that are older than 1.4 Ma. As we have discussed, some preliminary investigations in East Africa suggest that the Acheulian appeared in the geological record about 1.7 Ma, and probably coincided with the expansion of *Homo erectus* into areas unoccupied by earlier hominins (Beyene 2008, 2003; Beyene et al. 1997; Roche et al. 2003). However, the emergence of the Acheulian at ~ 1.6–1.7 Ma has yet to be unambiguously demonstrated both archaeologically and geologically. The timing of the appearance of the Acheulian is geologically poorly constrained by only a few sites, and the environmental background for the behavioral changes in hominins near the Pliocene/Pleistocene boundary is poorly understood.

With regards to the "transition" between the Oldowan and the Acheulian, Isaac long ago stated that

> the sharp distinction between these new Acheulean Industries and the Oldowan or Developed Oldowan is related to the appearance in the former of large flakes which formed the blanks on which tools were made. A "quantum" jump or "invention" may well have been involved in this changeover. (Isaac 1972, 409)

His suggestions still hold, and we agree with his conclusions, although we feel the "invention" may, in fact, be more complex than it sounds, as we suggest below.

Conclusion

A long held consensus view among archaeologists is that the "Developed Oldowan" is transitional between the Oldowan and the Acheulian, but this

is not apparent in the archaeological record. For Paleolithic archaeologists, having a clearly transitional stone tool tradition seems orderly and convenient, but that does not appear to be the case with the "Oldowan–Developed Oldowan–Acheulian" transition, and the relationship of these three "traditions" actually appears to be more complex. Current evidence suggests that the so-called DOA/DOB and the Early Acheulian began at about the same time, i.e., ~1.7 Ma. Hence, even if they were considered to be viable traditions, the DOA and the DOB cannot both be precursors to the Acheulian, and they cannot be transitional between the Oldowan and the Acheulian. Further, the DOB and the Acheulian at Olduvai Gorge appeared at the same time and then overlapped for about one million years (1.5–0.5); therefore, both traditions are contemporary. Further detailed research on the age and paleoenvironmental settings of these occurrences is warranted to sort out the meaning of the differences in these traditions. Most archaeologists seem to accept the validity of the "Developed Oldowan" as a stone tool tradition, but at this stage it seems to us reasonable to assign the DOA to the Oldowan, and the DOB to the Early Acheulian, as others have suggested before.

Moreover, our discussion above and our work at Gona have led us to consider that the way the "Oldowan–Developed Oldowan–Acheulian" transition has traditionally been conceived may be conflating separate cultural/technological/ecological changes occurring in the Late Pliocene/Early Pleistocene that may or may not be interconnected, such as: (1) the ability to knock off large flakes, (2) the ability to flake invasively and shape tools purposefully with predetermination or preconception of form, (3) the standardization of tool shape and/or technique, (4) changing diet and ranging patterns, (5) possible changes in group size and/or organization, and (6) possible changes in learning styles and abilities. Early Pleistocene hominins may have "experimented" with these developments initially until all elements came together with the classic Acheulian. For example, in our opinion, the Karari Industry at 1.6–1.5 Ma definitely shows the ability to knock off large flakes and standardization, but lacks clear evidence for predetermination of form or shaping or invasive flaking (such as seen in later handaxes). Early Acheulian artifacts such as those found at OGS-12 at Gona may demonstrate all of the technical factors except invasive retouch and perhaps standardization (we would need a larger sample to identify true standardization). The evidence from Kokiselei 4 and from Konso may also be consistent with this idea, although we await full analytical reports on the Acheulian assemblages from these sites. The major point here is not that the Karari or other assemblages are transitional, but that at the very beginning of the Acheulian we expect to find some variability depending upon paleogeography, availability, and size and type of raw materials, as well as what appears to be some "experimentation" (although this "experimentation" need not have been conscious), that is, alternative technological responses to similar selective pressures. More research will be needed to discern what this variability means (what these selective pressures were) and whether or not the earliest Acheulian forms, again in Isaac's words, "represent *new tools* for performing long lasting tasks (such as butchery) or whether *new tasks* were added to the behavioral, adaptive repertoire" (Isaac 1984, 163). Given the initial variability in the Early Acheulian record, we suspect the latter.

Acknowledgments We would like to thank Parth Chauhan and Marta Camps for inviting us to contribute to this volume. We would also like to thank the ARCCH of the Ministry of Culture and Tourism, and the National Museum of Ethiopia for permits and overall assistance. The Gona research was funded by the Leakey Foundation, the Wenner-Gren Foundation, the National Science Foundation and the National Geographic Society. The work of M. Leakey has inspired archaeologists from all over the world. Her contributions to African archaeology are unparalleled, and the Olduvai Gorge archaeological volume (3) is the first seminal work on Early Pleistocene hominin stone tool manufacture and use behavior. Although some of her interpretations may be questioned, as the first individual to take such a huge responsibility she did a terrific job, and we admire her immense undertaking. SS would like to thank the Stone Age Institute and Friends of CRAFT for overall assistance to the Gona Palaeoanthropological Research Project. MJR acknowledges funding support from a Connecticut State University Research Grant. Members of the Gona Project and colleagues have contributed to our success in a number of ways, and we are grateful to Jay Quade, Naomi Levin, Leslie Harlacker, and Melanie Everett. Mila Norman assisted at the Stone Age Institute. We appreciate the support and assistance of Tim White, Berhane Asfaw, Yonas Beyene, Giday WoldeGabriel, Alemu Admassu and the late Desmond Clark. We thank Dominique Cauche for the artifact drawings. We are grateful for de la Torre's review of this

manuscript and his invaluable comments. The late Clark Howell inspired, supported and encouraged the Gona research. We are grateful for his continuous selfless support, and we dedicate this manuscript to him.

References

Asfaw, B., Beyene, Y., Semaw, S., Suwa, G., White, T., and WoldeGabriel, G., 1991, Fejej: A New Paleontological Research Area in Ethiopia. *Journal of Human Evolution* 21:137–143.

Asfaw, B., Beyene, Y., Suwa, G., Walter, R.C., White, T.D., WoldeGabriel, G., and Yemane, T., 1992, The Earliest Acheulean from Konso-Gardula. *Nature* 360:732–735.

Asfaw, B., White, T., Lovejoy, O., Latimer, B., Simpson, S., and Suwa, G., 1999, *Australopithecus garhi*: A New Species of Early Hominid from Ethiopia. *Science* 284: 629–635.

Bar-Yosef, O., 1994, The Lower Paleolithic of the Near East. *Journal of World Prehistory* 8:211–265.

Bar-Yosef, O., and Goren-Inbar, N., 1993, *The Lithic Assemblages of 'Ubeidiya'. A Lower Palaeolithic Site in the Jordan Valley*. Quedem, Monographs of the Institute of Archaeology, no 34., Jerusalem.

Barham, L., 1997, Stone Working Technology: Its Evolution. In *Encyclopedia of Precolonial Africa*, edited by J.O. Vogel, pp. 109–115. AltaMira Press, Walnut Creek, CA.

Beyene Y., 2008, The Konso Paleoanthropological Site and Its Importance. Paper presented at the International Conference on "*Transforming the Might of a Century Long Research Output into Development.*" Sponsored by the Authority for Research and Conservation of Cultural Heritage and the Ethiopian Millennium Festival National Council Secretariat Office, January 12–15, Addis Ababa, Ethiopia.

2004, The Beginning and Development of the Acheulean: as Recorded at Konso Sites (Abstract). In *Climats, Cultures et Sociétés Aux Temps Préhistoriques de l'Apparition des Hominidés jusqu'au Néolithique*. Institut De France, Colloque Inter-Académique, Académie des Inscriptions et Belles-Lettres, Academie Des Sciences, Paris.

2003, The Emergence and Development of the Acheulean at Konso. *Anthropological Science* 111: 58.

Beyene, Y., Zeleke, Y., and Uzawa, K., 1997, The Acheulean at Konso-Gardula: Results from Locality KGA4-A2. In *Ethiopia in Broader Perspective, Vol., I*, edited by K. Fukui, E. Kurimoto, and M. Shigeta, pp. 376–381. Shokado, Kyoto.

Bishop, L.C., Plummer, T.W., Ferraro, J.V., Braun, D., Ditchfield, P.W., Hertel, F., Kingston, J.D., Hicks, J., and Potts, R., 2006, Recent Research into the Oldowan Hominin Activities at Kanjera South, Western Kenya. *African Archaeological Review* 23:31–40.

Brain, C.K., Churcher, C.S., Clark, J.D., Grine, F.E., Shipman, P., Susman, R.L., Turner, A., and Watson, V., 1988, New Evidence of Early Hominids, their Culture and Environments from the Swartkrans Cave, South Africa. *South African Journal of Science* 84:828–835.

Braun, D., and Harris, J.W.K., 2003, Technological Developments in the Oldowan of Koobi Fora: Innovative Techniques for Artifact Analysis. In *Oldowan: Rather More than Smashing Stones*, edited by J. Martinez-Moreno, R. T. Mora, and I. de la Torre, pp. 117–144. Universitat Autonoma de Barcelona, Bellaterra.

Bunn, H.T., 1981, Archaeological Evidence of Meat-Eating by Plio-Pleistocene Hominids from Koobi Fora and Olduvai Gorge. *Nature* 291:574–577.

Bunn, H., Harris, J.W.K., Isaac, G., Kaufulu, Z., Kroll, E., Schick, K., Toth, N., and Behrensmeyer, A.K., 1980, FxJj50: An Early Pleistocene Site in Northern Kenya. *World Archaeology* 12:109–136.

Cerling, T. E., 1992, Development of Grasslands and Savannas in East Africa During the Neogene. *Palaeogeography, Palaeoclimatology, Palaeoecology* (Global and Planetary Change Section) 5:241–247.

Chavaillon, J., 1976, Evidence for the Technical Practices of Early Pleistocene Hominids, Shungura Formation, Lower Omo Valley, Ethiopia. In *Earliest Man and Environments in the Lake Rudolf Basin*, edited by Y. Coppens, F.C. Howell, G. Isaac, and R.E.F. Leakey, pp. 565–573. University of Chicago Press, Chicago.

Chavaillon, J., Chavaillon, N., Hours, F., and Piperno, M., 1979, From the Oldowan to the Middle Stone Age at Melka-Kunture (Ethiopia). Understanding Cultural Changes. *Quaternaria* 21:87–114.

Clark, J.D., 1970, *The Prehistory of Africa*. Thames and Hudson, London.

Clark, J.D., and Kurashina, H., 1979, Hominid Occupation of the East Central Highlands of Ethiopia in the Plio-Pleistocene. *Nature* 282:33–39.

Clark, J.D., de Heinzelin, J., Schick. K.D., Hart, W.K., White, T.D., WoldeGabriel, G., Walter, R.C., Suwa, G., Asfaw, B., Vrba, E., and H. Selassie, Y., 1994, African *Homo erectus*: Old Radiometric Ages and Young Oldowan Assemblages in the Middle Awash Valley, Ethiopia. *Science* 264:1907–1909.

Clarke, G., 1969, *World Prehistory*. Cambridge University Press, Cambridge.

Davis, D.D., 1980, Further Consideration of the Developed Oldowan at Olduvai Gorge. *Current Anthropology* 21: 840–843.

Delagnes, A., and Roche, H., 2005, Late Pliocene Hominin Knapping Skills: The Case of Lokalalei 2C, West Turkana, Kenya. *Journal of Human Evolution* 48:435–472.

de Heinzelin, J., Clark, J. D., White, T.W., Hart, W., Renne, P., WoldeGabriel, G., Beyene, Y., and Vrba, E., 1999, Environment and Behavior of 2.5 Million Year Old Bouri Hominids. *Science* 284: 625–629.

de la Torre, I., and Mora, R., 2005a, *Technological Strategies in the Lower Pleistocene at Olduvai Beds I & II*. ERAUL (112). Universiteé de Liége, Liege, France.

de la Torre, I., and Mora, R., 2005b, Unmodified Lithic Materials at Olduvai Bed I: Manuports or Ecofacts? *Journal of Archaeological Science* 32:273–285.

de la Torre, I., Mora, R., Domínguez-Rodrigo, M., Luque, L., and 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* 44:203–224.

de la Torre, I., Mora, R., and Martinez-Moreno, J., 2008, The Early Acheulean in Peninj (Lake Natron, Tanzania). *Journal of Anthropological Archaeology* 27:244–264.

de Lumley, H., Beyene, Y., Barsky, D., Byrne, L., Camara, A., Cauche, D., Celiberti, V, Fournier, A., and Pleurdeau, D., 2004, L'industrie Lithique Preoldowayenne du Site de Fejej FJ-1. In *Les Sites Préhistoriques de la Région de Fejej, Sud-Omo, Éthiopie, Dans leur Contexte Stratigraphique et Paléontologique*, edited by H. de Lumley and Y. Beyene, pp. 391–563. Editions Recherche sur les Civilisations, Paris.

de Menocal, P.B., 2004, African Climate Change and Faunal Evoultioin During the Pliocene-Pleistocene. *Earth and Planetary Sciences Letters* 220:3–24.

Domínguez-Rodrigo, M., Serrallonga, J., Juan-Tresserras, J., Alcala, L., and Luque, L., 2001, Woodworking Activities by Early Humans: A Plant Residue Analyses on Acheulian Stone Tools from Peninj (Tanzania). *Journal of Human Evolution* 40:289–299.

Domínguez-Rodrigo, M., Pickering, T.R., Semaw, S., and Rogers, M., 2005, Cutmarked Bones from Archaeological Sites at Gona, Afar, Ethiopia: Implications for the Function of the World's Oldest Stone Tools. *Journal of Human Evolution* 48:109–121.

Domínguez-Rodrigo, M., Alcala, L., and Luque, L. (in press), Peninj. A Research Project On the Archaeology of Human Origins (1995–2005). Brill, Harvard, Massachusetts.

Field, A.S., 1999, An Analytical and Comparative Study of the Earlier Stone Age Archaeology of the Sterkfontein Valley. M.A. Thesis, University of the Witwatersrand, Johannesburg.

Gabunia, L., Anton, S.C., Lordkipanidze, D., Vekua, A., Justus, A., and Swisher, C.C. III, 2001, Dmanisi and Dispersal. *Evolutionary Anthropology* 10:158–170.

Gowlett, J.A.J., 1990, Archaeological Studies of Human Origins & Early Prehistory in Africa. In *A History of African Archaeology*, edited by P. Robertshaw, pp. 13–38. James Currey, London.

1988, A Case of the Developed Oldowan in the Acheulean. *World Archaeology* 20:13–26.

Gowlett, J.A.J., Harris, J.W.K., Walton, D., and Wood, B. A., 1981, Early Archaeological Sites, Hominid Remains and Traces of Fire from Chesowanja, Kenya. *Nature* 294:125–129.

Greenfield, P.M., 1991, Language, Tools, and Brain: The Development and Evolution of Hierarchically Organized Sequential Behavior. *Behavioral and Brain Sciences* 14:531–595.

Hay, R.L., 1990, Olduvai Gorge; A Case History in the Interpretation of Hominid Paleoenvironments in East Africa. *Geological Society of America*, Special Paper 242: 23–37.

1976, *Geology of the Olduvai Gorge*. University of California Press, Berkeley and Los Angeles.

Holloway, R., 1999, Evolution of the Human Brain. In *Handbook of Human Symbolic Evolution*, edited by A. Lock and C.R. Peters, pp. 74–125. Blackwell Publishers Inc., Malden, MA.

Howell, F.C., 1961, Isimila: A Palaeolithic Site in Africa. *Scientific American* 205:118–129.

Howell, F.C., Haesaerts, P., and deHeinzelin, J., 1987, Depositional Environments, Archaeological Occurrences and Hominids from Members E and F of the Shungura Formation (Omo Basin, Ethiopia). *Journal of Human Evolution* 16:665–700.

Isaac, G.Ll., 1984, The Archaeology of Human Origins: Studies of the Lower Pleistocene in East Africa 1971–1981. In *Advances in Old World Achaeology*, Vol. 3, edited by F. Wendorf and A. Close, pp. 1–87. Academic Press, New York.

1977, *Olorgesailie*, Chicago University Press, Chicago.

1972, Chronology and the Tempo of Cultural Change during the Pleistocene. In *Calibration of Hominid Evolution*, edited by W.W. Bishop and J. Miller, pp. 381–430. Scottish Academic Press, Edinburgh.

Isaac, G.Ll., 1971, The Diet of Early Man: Aspects of Archaeological Evidence from Lower and Middle Pleistocene Sites in Africa. *World Archaeology* 2:278–299.

1969, Studies of Early Culture in East Africa. *World Archaeology* 1:1–28.

Isaac, G.Ll., and Harris, J.W.K., 1997, Sites Stratified within the KBS Tuff: Reports. In *Koobi Fora Research Project, Plio-Pleistocene Archaeology*, Vol. 5, edited by G. Ll. Isaac and B. Isaac, pp. 71–114. Clarendon Press, Oxford.

Isaac, G.Ll., and Curtis, G. H., 1974, Age of the Acheulian Industries from the Peninj Group, Tanzania. *Nature* 249:624–627.

Johanson, D.C., Taieb, M., and Coppens, Y., 1982, Pliocene Hominids from the Hadar Formation, Ethiopia (1973–1977): Stratigraphic, Chronological, and Paleoenvironmental Contexts, with Notes on Hominid Morphology and Systematics. *American Journal of Physical Anthropology* 57:373–402.

Jones, P.R., 1994, Results of Experimental Work in Relation to the Stone Industries of Olduvai Gorge. In *Olduvai Gorge- Excavations in Beds III, IV and the Masek Beds (1968–71), Vol. 5*, edited by M.D. Leakey and D. Roe, pp. 254–298. Cambridge University Press, Cambridge.

Keeley, L., and Toth, N., 1981, Microwear Polishes on Early Stone Tools from Koobi Fora, Kenya. *Nature* 293: 464–465.

Kibunjia, M., 1994, Pliocene Archaeological Occurrences in the Lake Turkana Basin. *Journal of Human Evolution* 27:159–171.

Kibunjia, M., Roche, H., Brown, F.H., and Leakey, R.E.F., 1992, Pliocene and Pleistocene Archaeological Sites of Lake Turkana, Kenya. *Journal of Human Evolution* 23:432–438.

Kimbel, W.H., Walter, R.C., Johanson, D.C., Reed, K.E., Aronson, J.L., Assefa, Z., Marean, C.W., Eck, G.G., Bobe, R., Hovers, E., Rak, Y., Vondra, C., Yemane, T., York, D., Chen,Y., Evensen, N.M., and Smith, P. E., 1996, Late Pliocene *Homo* and Oldowan Tools from the Hadar Formation (Kada Hadar Member), Ethiopia. *Journal of Human Evolution* 31:549–561.

Klein, R.G., 2006, CA Commentary on Monnier, G.F. The Lower/Middle Paleolithic Periodization in Western Europe. *Current Anthropology* 47:731–732.

Klein, R.G., 1999, *The Human Career: Human Biological and Cultural Origins,* 2nd edition. University of Chicago Press, Chicago.

Kleindienst, M., 1962, Components of the East African Acheulian Assemblages: An Analytical Approach. In *Actes du IVe Congres Panafricain de l'Etude du Quaternaire*, edited by G. Mortelmans and J. Nenquin, Vol. III, pp. 81–111, Tervuren.

Koechlin, E., and Jubault, T., 2006, Broca's Area and the Hierarchical Organization of Human Behavior. *Neuron* 50:963–974. (doi:10.1016/j.neuron.2006.05.017).

Kuman, K., 1998, The Earliest South African Industries. In *Early Human Behavior in Global Context. The rise and Diversity of the Lower Paleolithic Record*, edited by M. D. Petraglia and R. Korrisettar, pp. 151–186. Routledge, London and New York.

1996, The Oldowan Industry from Sterkfontein: Raw Materials and Core Forms. In *Aspects of African Archaeology, Papers from the 10th Congress of the Panafrican Association for Prehistory and Related Studies*, edited by G. Pwiti and R. Soper, pp. 139–148. Zimbabwe Publications, Harare.

1994a, The Archaeology of Sterkfontein: Past and Present. *Journal of Human Evolution* 27:471–495.

1994b, The Archaeology of Sterkfontein: Preliminary Findings on Site Formation and Cultural Change. *South African Journal of Science* 90:215–19.

Kuman, K., Field, A.S., and Thackeray, J.G., 1997, Discovery of New Artifacts at Kromdraai. *South African Journal of Science* 93:187–193.

Kurashina, H., 1987, Comparison of Gadeb and Other Early Stone Age Assemblages from Africa South of the Sahara. *The African Archaeological Review* 5:19–28.

Kyara, O., 1999, *Lithic Raw Materials and Their Implications on Assemblage Variation and Hominid Behavior During Bed II, Olduvai Gorge, Tanzania.* Ph.D. Thesis, Rutgers University, New Brunswick, NJ.

Larick R, Ciochon, R.L., Zaim, Y., Suminto, S., Rizal, Y., Aziz, F., Reagan, M., and Heizler, M., 2001, Early Pleistocene $^{40}Ar/^{39}Ar$ Ages for Bapang Formation Hominins, Central Java, Indonesia. *Proceedings of the National Academy of Sciences* 98:4866–4871.

Leakey, L.S.B., 1934, The Oldoway Culture Sequence. In *Proceedings of the 1st Congress of Prehistoric and Protohistoric Sciences*, pp. 73–74. Oxford University Press, London.

Leakey, M.D., 1976a, A Summary and Discussion of the Archaeological Evidence from Bed I and Bed II, Olduvai Gorge, Tanzania. In *Human Origins, Louis Leakey and the East African Evidence*, edited by G. Ll. Isaac and E.R. McCown, pp. 431–459. W.A. Benjamin Inc., Philippines.

Leakey, M.D., 1976b, The Early Stone Industries of Olduvai Gorge. In *Les plus Anciennes Industries en Afrique: The Earlier Industries of Africa.* Proceedings IX Congress of the Union Internationale Des Sciences Prehistorique et Protohistoriques, edited by J.D. Clark and G. Ll. Isaac, Coloque V, pp. 24–41, Pretriage, Nice.

Leakey, M.D., 1975, Cultural Patterns in the Olduvai Sequence. In *After the Australopithecines*, edited by K. W. Butzer and G. Ll. Isaac, pp. 476–493. Mouton Publishers, Chicago.

Leakey, M.D., 1971, *Olduvai Gorge, Vol. III. Excavations in Beds I and II, 1960–1963.* Cambridge University Press, London.

Lieberman, D., and Bar-Yosef, O., 2005, Apples and Oranges: Morphological Versus Behavioral Transitions in the Pleistocene. In *Interpreting the Past: Essays on Human, Primate, and Mammal Evolution in Honor of David Pilbeam, American School of Prehistoric Research Monograph Series*, edited by D. Lieberman, R.J. Smith and J. Kelly, pp. 275–296. Brill Academic Publishers, Boston.

Lordkipanidze, D., Jahashvili, T., Vekua, A., de Léon, M.S. P., Lollikofer, C.P.E., Rightmire, G.P., Pontzer, H., Ferring, R., Oms, O., Tappen, M., Bukhsianidze, M., Agusti, J., Kahlke, R., Kiladze, G., Martinez-navarro, B., Moushkhelishvili, A., Nioradze, M., and Rook, L., 2007, Postcranial Evidence from Dmanisi, Georgia. *Nature* 449:305–310.

Lordkipanidze, D., Vekua, A., Ferring, R., Rightmire, G.P., Agusti, J., Kiladze, G., Mouskhelishvili, A., Nioradez, M., de Lèon, M.S.P., Tappen, M., and Zollikofer, C.P. E., 2005, The Earliest Toothless Hominin Skull. *Nature* 434:717–718.

Manega, P.C., 1993. *Geochronology, Geochemistry and Isotopic Study of the Plio-Pleistocene Hominid Sites and the Ngorongoro Volcanic Highland in Northern Tanzania.* Ph. D. Thesis, University of Colorado, Boulder.

Merrick, H.V., 1976, Recent Archaeological Research in the Plio-Pleistocene Deposits of the Lower Omo, southwestern Ethiopia. In *Human Origins: Louis Leakey and the East African Evidence*, edited by G.L., Isaac and E. R. McCown, pp. 461–481. W.A. Benjamin Inc., Menlo Park.

Merrick, H.V., and Merrick, J.P.S., 1976, Recent Archaeological Occurrences of Earlier Pleistocene Age from the Shungura Formation. In *Earliest Man and Environments in the Lake Rudolf Basin*, edited by Y. Coppens, F.C. Howell, G.L., Isaac and R.E.F. Leakey, pp. 574–584. Chicago University Press, Chicago.

Piperno, M., Bulgarelli, G.M., and Gallotti, R., 2004a, Prehistoric Archaeology, the Site of Garba IV. The Lithic Industry of Level D. Débitage and Tools on Flake. In *Studies on the Early Paleolithic Site of Melka Kunture, Ethiopia*, edited by J. Chavaillon and M. Piperno, pp. 469–544. Istituto Italiana di Prestoria e Protostoria, Florence.

Piperno, M., Bulgarelli, G.M., and Gallotti, R., 2004b, Prehistoric Archaeology, the Site of Garba IV. Tools on Pebble and Percussion Material. In *Studies on the Early Paleolithic Site of Melka Kunture, Ethiopia*, edited by J. Chavaillon and M. Piperno, pp. 545–580. Istituto Italiana di Prestoria e Protostoria, Florence.

Plummer, T., 2004, Flaked Stones and Old Bones: Biological and Cultural Evolution at the Dawn of Technology. *Yearbook of Physical Anthropology* 47:118–164.

Potts, R., 1991, Why the Oldowan? Plio-Pleistocene Toolmaking and the Transport of Resources. *Journal of Anthropological Research* 47:153–176.

Potts, R, Shipman, P., 1981, Cutmarks Made by Stone Tools on Bones from Olduvai Gorge, Tanzania. *Nature* 291: 577–580.

Quade, J., Levin, N., Semaw, S., Renne, P., Rogers, M.J., Simpson S., and Stout, D., 2004, Paleoenvironments of the Earliest Stone Toolmakers, Gona, Ethiopia. *Geological Society of America Bulletin* 16(11/12): 1529–1544.

Quade, J., Levin, N., Simpson, S.W., Butler, R., McIntosh, W., Semaw, S., Kleinsasser, L., Dupont-Nivet, G., Renne, P., and Dunbar, N., 2008, The Geology of Gona, Afar, Ethiopia. *The Geological Society of America Bulletin*. Special Paper 446:1–31.

Ridderinkhof, K. R., van den Wildenberg, W.P.M., Segalowitz, S.J. and Carter, C.S., 2004, Neurocognitive Mechanisms of Cognitive Control: The Role of Prefrontal Cortex in Action Selection, Response Inhibition, Performance Monitoring, and Reward Based Learning. *Brain Cognition* 56:129–140. (doi:10.1016/j.bandc.2004.09.016).

Roche, H., 2005, From Simple Flaking to Shaping: Stone Knapping Evolution Among Early Hominids. In *Stone Knapping: The Necessary Conditions for a Uniquely Hominid Behavior*, edited by V. Roux and B. Bril, pp. 35–48. Mc Donald Institute Monograph Series, Cambridge.

Roche, H., 2000. Variability of Pliocene Lithic Productions in East Africa. *Acta Anthropologica Sinica* 19:98–103.

1995, Les Industries de la Limite Plio-Pléistocène et du Plésitocène Ancient en Afrique. In *Congreso Internacional de Paleontologia Humana (Orce, September 1995), 3a Circular*, p. 93. Orce, Spain.

Roche, H., and Texier, P.-J., 1995, Polyèdre, Sub-Sphéroïde, Sphéroïde et Bola: des Segments Plus ou Moins Longs d'une Même Chaîne Opératoire. *Cahier Noir* 7:31–40.

Roche, H., Delagnes, A., Brugal, J.-P., Feibel, C., Kibunjia, M., Mourre, V., and Texier, P.-J., 1999, Early Hominid Stone Tool Production and Technical Skill 2.34 Myr ago in West Turkana, Kenya. *Nature* 399:57–60.

Roche, H., Delagnes, A., Feibel, C.S., Harmand, S., Kibunjia, M., Prat, S., and Texier, P.-J., 2003, Les Sites Archéologiques Plio-Pléistocènes de la Formation de Nachukui (Ouest Turkana, Kenya): Bilan Préliminaire 1996–2000. *Comptes Rendus Palévol* 2(8): 663–673.

Rogers, M.J., Feibel, C.S., and Harris, J.W.K., 1994, Changing Patterns of Land Use by Plio-Pleistocene Hominids in the Lake Turkana Basin. *Journal of Human Evolution* 27:139–158.

Sahnouni, M., 2006, The North African Early Stone Age and the Sites at Ain Hanech, Algeria. In *The Oldowan: Case Studies into the Earliest Stone Age*, edited by N. Toth and K. Schick, pp. 77–111. Stone Age Institute Press, Bloomington, IN.

Sahnouni, M., 2005, Point des Connaissances du Paléolithique Ancien d'Afrique du Nord et la Question de la Premiére Occupation Humaine au Maghreb. In *Le Paléolithique en Afrique. L'histoire la plus longue*, edited by M. Sahnouni, pp. 99–128. Artcom/Errance, Paris.

Sahnouni, M., 1993, Étude Comparative des Galets Tailles Polyedriques, Subspherques et Spheriques des Gisements d'Ain Hanech (Algerie Orientale) et d'Olduvai (Tanzanie). *L'Anthropologie* 97:51–67.

Sahnouni, M., and de Heinzelin, J., 1998, The site of Ain Hanech revisited: New investigations at this Lower Pleistocene site in Northern Algeria. *Journal of Archaeological Science* 25:1083–1101.

Sahnouni, M., Schick, K., and Toth, N., 1997, An Experimental Investigation into the Nature of Facetted Limestone "Spheroids" in the Early Palaeolithic. *Journal of Archaeological Science* 24:701–713.

Sahnouni, M., Hadjoulis, D., van der Made, J., Derradji, A., Canals, A., Medig, M., Belahrech, H., Harichane, Z., and Rabhi, M., 2002, Further Research at the Oldowan Site of Ain Hanech, North-Eastern Algeria. *Journal of Human Evolution* 43:925–937.

Schick, K. and Toth, N., 1994, Early Stone Age Technology in Africa: A Review and Case Study into the Nature and Function of Spheroids and Subspheroids. In *Integrative Paths to the Past*, edited by R.S. Corruccini and R. Ciochon, Advances in Human Evolution Series, pp. 429–449. Englewood Cliffs, NJ.

Semaw, S., Rogers, M.J., Stout, D., Quade, J., Levin, N., Renne, P.R., Butler, R., Simpson, S.W., and Kidane, T., 2008, The Oldowan-Acheulian Transition: New Insights from Gona, Ethiopia. Paper Presented at the Paleoanthropology Society Annual Meeting (Abstract), 25–26 March, Vancouver, BC, Canada.

Semaw, S., 2006, The Oldest Stone Artifacts from Gona (2.6–2.5 Ma), Afar, Ethiopia: Implications for Understanding the Earliest Stages of Stone Knapping. In *The Origins of Human Technology: Studies into the Early Stone Age (Oldowan)*, edited by N. Toth and K. Schick, pp. 43–75. CRAFT Press, Bloomington, IN.

Semaw S., 2005, Les Plus Anciens Artefacts Lithiques (2.6–2.5 Millions d'Années) des Sites Archéologiques du Pliocène Final de EG-10 et EG-12 à Gona Est, Afar, Ethiopie. 2005. In *Le Paléolithique en Afrique: L'histoire la Plus Longue*, edited by M. Sahnouni, pp 13–52. Artcome/Errance, Paris.

Semaw, S., 2000, The World's Oldest Stone Artifacts from Gona, Ethiopia: Their Implications for Understanding Stone Technology and Patterns of Human Evolution Between 2.6–2.5 Million Years Ago. *Journal of Archaeological Science* 27:1197–1214.

Semaw, S., Rogers, M.J., Quade, J., Renne, P.R., Butler, R. F., Domínguez-Rodrigo, M., Stout, D., Hart, W.S., Pickering, T.R., and Simpson, S.W., 2003, 2.6 Million Year Old Stone Artifacts and Associated Bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. *Journal of Human Evolution* 45:169–177.

Semaw, S., Renne, P., Harris, J.W.K., Feibel, C.S., Bernor, R.L., Fesseha, N., and Mowbray, K., 1997, 2.5 Million Year Old Stone Tools from Gona, Ethiopia. *Nature* 385:333–336.

Semaw, S., Rogers, M.J., Stout, D., (in press), The East Gona and Ounda Gona South Oldowan Archaeology (2.6 Million Years Ago), Afar, Ethiopia: Insights into Late Pliocene Lithic Assemblage Variability. In *The Cutting edge: New Approaches to the Archaeology of Human Origins*, edited by K. Schick and N. Toth, N. Stone Age Institute Press, Series Number 3, Bloomington, IN.

Semaw, S., Rogers, M.J., Stout, D., Simpson, S.W., Quade, J., Levin, N., Renne, P.R., McIntosh, W., Dunbar, N., Kidane, T., and Butler, R., (in prep.), Archaeological and Hominid Discoveries (1999–2007) from the Gona Palaeoanthropological Research Project Study Area, Afar, Ethiopia. A Manuscript to be Submitted to the Proceedings of the International Conference on

Paleoanthropology, Paleontology and Archaeology in Ethiopia, *"Transforming the Might of a Century-Long Research Output into Development"*. A Symposium Organized by the Authority for Research and Conservation of Cultural Heritage and the Ethiopian Millennium Festival National Council Secretary Office. January 2008, Addis Ababa, Ethiopia.

Sharon, G., 2008, The Impact of Raw Material on Acheulian Large Flake Production. *Journal of Archaeological* Science 35:1329–1344.

Stiles, D., 1991, Early Hominid Behaviour and Culture Tradition: Raw Material Studies in Bed II, Olduvai Gorge. *The African Archaeological Review* 9 :1–19.

1981, On the Developed Oldowan and Acheulian: Problems in Lithic Taxonomy. *Current Anthropology* 22 :185–188.

1979a, Paleolithic Culture and Culture Change: Experiment in Theory and Method. *Current Anthropology* 20:1–21.

1979b, Early Acheulian and Developed Oldowan. *Current Anthropology* 20:126–129.

1979c, Recent Archaeological Findings at the Sterkfontein site. *Nature* 277:381–382.

Stollhofen, H., Stanistreet, I.G., McHenry, L.J., Mollel, G. F., Blumenschine, R.J., and Masao, F.T., 2008, Fingerprinting Facies of the Tuff IF Marker, with Implications for Ealy Hominin Palaeoecology, Olduvai Gorge, Tanzania. *Palaeogeography, Palaeoclimatology, Palaeoecology* 259 :382–409.

Stout, D., 2002, Skill and Cognition in Stone Tool Production: An Ethnographic Case Study from Irian Jaya. *Current Anthropology* 45:693–722.

Stout, D., and Chaminade, T., 2007, The Evolutionary Neuroscience of Toolmaking. *Neuropsychologia* 45:1091–1100.

Stout, D., Quade, J., Semaw, S., and Rogers, M., 2005, Raw Material Selectivity of the Earliest Toolmakers at Gona, Afar, Ethiopia. *Journal of Human Evolution* 48: 365–380.

Stout, D., Toth, N., Schick, K., and Chaminade, T., 2008, Neural Correlates of Early Stone Age Toolmaking: Technology, Language and Cognition in Human Evolution. *Philosophical Transactions of the Royal Society of London.* Published online (doi:10.1098/rstb.2008.0001).

Stout, D., Semaw, S., and Rogers, M., 2008, Technological Variation in the Oldowan (2.6 Ma) from Gona, Afar, Ethiopia. Paper Presented at the Paleoanthropology Society Annual Meeting (Abstract), 25–26 March, Vancouver, B.C., Canada.

Suwa, G., Asfaw, B., Haile-Selassie, Y., White, T., Katoh, S., WoldeGarbriel, G., Hart, W.K., Nakaya, H., and Beyene, Y., 2007, Early Pleistocene *Homo erectus* Fossils from Konso, Southern Ethiopia. *Anthropological Science* 11:133–151.

Taieb, M., Coppens, Y., Johanson, D.C., and Kalb, J., 1972, Dépôts Sedimentairs et Faunes du Plio-Pléistocène de la Basse Vallée de l'Awash (Afar Centrale, Ethiopie), *Compte Rendues des Seances de l'Academie des Sciences* 275:819–822.

Taieb, M., and Coppens, Y., 1975, Expédition Internationale de l'Afar, Ethiopie (3e Campage 1974); Découverte d'Hominidés Plio-Pléistocène a Hadar. *Compte Rendues des Seances de l'Academie des Sciences* 275D:1297–1300.

Tamrat, E., Thouveny, N., Taieb, M., and Opdyke, N.D., 1995, Revised Magnetostratigraphy of the Plio-Pleistocene Sedimentary Sequence of the Olduvai Formation (Tanzania). *Palaeogeography, Palaeoclimatology, Palaeoecology* 114:273–283.

Texier, P.-J., 1995, The Oldowan Assemblage from NY18 Site at Nyabusosi (Toro-Uganda). *Compte Rendues des Seances de l'Academie des Sciences* 320 IIa:647–653.

Toth, N., 2001. Experiments in Quarrying Large Flake Blanks at Kalambo Falls. In *Kalmbo Falls Prehistoric site, Vol. III*, edited by J.D. Clark, pp. 600–604. Cambridge University Press, Cambridge.

1987, Behavioral Inferences from Early Stone Age Assemblages: An Experimental Model. *Journal of Human Evolution* 16:763–787.

1985, The Oldowan Reassessed: A Close Look at Early Stone Artifacts. *Journal of Archaeological Science* 12:101–120.

Toth, N., Clark, J.D., and Ligabue, G., 1992, The Last Stone Ax Makers. *Scientific American* 267:88–93.

Toth, N., Schick, K., and Semaw, S., 2006, A Technological Comparison of the Stone Toolmaking Capabilities of *Australopithecus*/early *Homo*, *Pan paniscus*, and *Homo sapiens*, and Possible Evolutionary Implications. In *The Origins of Human Technology: Studies into the Early Stone Age (Oldowan)*, edited by N. Toth, and K. Schick, pp. 155–222. CRAFT Press, Bloomington, IN.

Walter, R.C., Manega, P.C., Hay, R.L., Drake, R.E., and Curtis, G.H., 1991, Laser-fusion $^{40}Ar/^{39}Ar$ Dating of Bed I, Olduvai Gorge, Tanzania. Nature 354:145–149.

Willoughby, P.R., 1985, Spheroids and Battered Stones in the African Early Stone Age. *World Archaeology* 17:44–60.