The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia

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The Acheulean technological tradition, characterized by a large (>10 cm) flake-based component, represents a significant technological advance over the Oldowan. Although stone tool assemblages attributed to the Acheulean have been reported from as early as circa 1.6–1.75 Ma, the characteristics of these earliest occurrences and comparisons with later assemblages have not been reported in detail. Here, we provide a newly established chronometric calibration for the Acheulean assemblages of the Konso Formation, southern Ethiopia, which span the time period ∼1.75 to <1.0 Ma. The earliest Konso Acheulean is chronologically indistinguishable from the assemblage recently published as the world's earliest with an age of ∼1.75 Ma at Kokiselei, west of Lake Turkana, Kenya. This Konso assemblage is characterized by a combination of large picks and crude bifaces/unifaces made predominantly on large flake blanks. An increase in the number of flake scars was observed within the Konso Formation handaxe assemblages through time, but this was less so with picks. The Konso evidence suggests that both picks and handaxes were essential components of the Acheulean from its initial stages and that the two probably differed in function. The temporal refinement seen, especially in the handaxe forms at Konso, implies enhanced function through time, perhaps in processing carcasses with long and stable cutting edges. The documentation of the earliest Acheulean at ∼1.75 Ma in both northern Kenya and southern Ethiopia suggests that behavioral novelties were being established in a regional scale at that time, paralleling the emergence of *Homo erectus*-like hominid morphology.

chronostratigraphy | Early Pleistocene | lithic technology development

The Acheulean technological tradition has long been characterized by the occurrence of large bifacial tools such as handaxes, cleavers, and picks (1–5). Symmetry or its tendency seen in the Acheulean tools implies imposition of form (4, 6, 7), perhaps associated with advanced spatial cognition (7). Semaw et al. (8) emphasized that the Acheulean represents a significant and discontinuous innovation over the Oldowan, not only in technological but also in cognitive and adaptive terms. Semaw et al. (8) argued that, whereas the Oldowan is characterized by small flakes and cores made by handheld percussion or bipolar techniques, the creation of large-sized (>10 cm) blanks and subsequent flaking in the Acheulean was possible only with both increased motor skill and advanced hierarchical cognition. This advance was inferred from (*i*) the complexity of the operational sequence and decision-making processes involved in producing bifaces from large flake blanks struck from giant cores (9–12) and (*ii*) neurofunctional observations in experimental modern human knapping (8, 10). A variety of functions have been suggested for Acheulean bifaces, including woodworking and carcass processing (13, 14), usually interpreted as a part of an advanced subsistence strategy coincident with or postdating the emergence of *Homo erectus/ergaster*.

Following the informed opinion of Isaac (15), Semaw et al. (8) considered the occurrence of large flake-based bifaces as the hallmark of the early Acheulean. Semaw et al. (8) summarized the Acheulean technology as characterized by (*i*) the ability to knock off large flakes, (*ii*) standardization of tool shape and/or technique, and (*iii*) the ability to flake invasively and shape tools purposefully with predetermination or preconception of form (8). Semaw et al. (8) hypothesized the emergence of the Acheulean to have been rapid and reported an abundance of early Acheulean "crudely made bifaces and picks" from the ∼1.6-Ma horizons at Gona, Ethiopia (8).

Roche et al. (16), Texier et al. (17), and Lepre et al. (18) described an isolated occurrence of an early Acheulean assemblage from west of Lake Turkana, Kenya, in a sedimentary sequence containing examples of Oldowan assemblages. This assemblage occurs at locality Kokiselei 4, stratigraphically 4.5 m above the top of the Olduvai Subchron (1.78 Ma). It consists of trihedral/quadruangular picks and unifacial or bifacial crude handaxes. However, the details of assemblage composition and technological characteristics have not been published. A nonlinear interpolated age of the tool horizon has been reported as 1.76 Ma, whereas a linear interpolation based on average depositional rate confined to the immediately subjacent strata resulted in an estimate of 1.72 Ma (18). This ∼1.75-Ma assemblage was introduced as the world's earliest known example of the Acheulean.

The Konso Formation, first discovered by the Paleoanthropological Inventory of Ethiopia (19), crops out in the southwestern end of the Main Ethiopian Rift and was found to contain ∼1.4-Ma *H. erectus* fossils and early Acheulean artifacts. Field research and laboratory analysis thereafter established that the formation spans the time period >1.9 to ∼0.8 Ma (20–22). Abundant lithic assemblages and vertebrate fossils have been recovered (23–25), including fossil remains of *Australopithecus boisei* (∼1.43 Ma) and *H. erectus* (∼1.45 to ∼1.25 Ma) (19, 26, 27).

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However, only brief descriptions of the Konso archaeology have so far been reported (23, 24, 28). Here, we provide an overview of the time-successive Acheulean assemblages recovered from the Konso Formation in light of a newly established chronometric framework of the geological sequence. In particular, we describe the Konso Acheulean by focusing on two aspects: (*i*) the timing and characteristics of its first occurrence, and (*ii*) temporal trends within the time interval of ~2 to <1 Ma. The Konso Formation, with its abundant and temporally controlled assemblages, provides us with a unique opportunity to assess the tempo and mode of early Acheulean technological development.

Chronostratigraphy of the Konso Formation

Previous Studies. The overall chronostratigraphy of the Konso Formation has been presented in some detail (20–22). These previous reports established the base and top of the Konso Formation at >1.9 and <1.3 Ma, respectively. Major element composition of glass shards suggested two key correlations with the Turkana Basin tephra, the Konso Turoha Tuff (TRT) (~1.9 Ma) and Bright White Tuff (BWT) (~1.4 Ma) with the Turkana Basin KBS and Chari Tuffs, respectively (20). Analysis of major and minor element compositions of a wider range of Konso tephra corroborated the above interpretations and suggested additional interbasin correlations (22). This new set of suggested correlations included recognition of the Konso Hope Tuff (HPT), Ivory Tuff (IVT), Boleshe Tuff (BOT), Piso Tuff-1, (PST1), and Piso Tuff-2 (PST2) as probable correlatives of the Turkana Basin Akait, Lokapetamoi, and Lower, Middle, and Upper Nariokotome Tuffs, respectively. The Konso Handaxe Tuff (HAT), an important tephra at Konso that underlies an early Acheulean assemblage (site KGA4-A2, ref. 24), was considered similar to either the Koobi Fora/Upper Okote Tuffs (1.45–1.5 Ma) or the Shungura Formation Tuff J6 (1.55–1.6 Ma) (22).

Concurrent with our 2005 publication of the Konso tuff analysis (22), an updated tephrostratigraphy and chronology of the Turkana Basin time interval of 1.9–1.2 Ma was reported by Brown et al. (29) and McDougall and Brown (30). At the time of these publications, both Konso and Turkana Basin research teams (22, 29) apparently were unaware of the data and interpretations that were being reported by each other. When these data are considered, some additional interpretative revisions are necessary. We here first summarize these revisions and then present results of our newly expanded chronological analysis.

Some of the post-2005 interpretations that potentially affect the Konso chronology are as follows.

i) Based on the slightly older $^{40}Ar/^{39}Ar$ age of the TRT (1.92 ± 0.04 Ma) (20) than the KBS Tuff (1.88 ± 0.02 Ma; for data equivalence, the Konso and Turkana Basin tuff ages are converted to correspond to a Fish Canyon sanidine (FCs) age of 28.2 Ma, and uncertainties are expressed by the population SD; see below), it was suggested that the two tuffs are not strictly correlative but may represent closely spaced eruptions of the same volcanic source (29). We consider this suggestion unlikely. Only the major element dataset of the Konso TRT was available at that time (29), but the additional minor element analysis (22) further strengthens the initially suggested correlation. Because there are no instances of more than one horizon of a tuff this similar in elemental composition around this time interval at any section studied at Konso or reported from Turkana, it is probable that the two tuffs are correlative. The slight difference in the $^{40}Ar/^{39}Ar$ ages may represent the combined uncertainties stemming from factors such as grain population heterogeneity and analytical system biases.

ii) Both the Konso and Turkana Basin research teams suggested the IVT–Lokapetamoi and HPT–Akait interbasin correlations (22, 29). In addition, several potential correlations have been suggested. One important correlation is between the Konso Trail Bottom Tuff (TBT) and Turkana Basin Etirr Tuff (29). We previously considered this correlation (22) but rejected it from the then available stratigraphic placement of the Etirr Tuff in the Turkana Basin sequence below the Lower Koobi Fora Tuff. However, the Etirr Tuff is now placed higher in the sequence, above the Lower Koobi Fora and Ebei Tuffs (both ~1.48 Ma) and close to the Akait Tuff (29, 30). Because the relative positions of the Etirr and Akait Tuffs are not clearly resolved (29), this uncertainty makes the IVT–Lokapetamoi, TBT–Etirr, and HPT–Akait correlations all probable.

iii) Brown et al. (29) suggested that the Konso HAT was a correlative of an unnamed tuff of the Turkana Basin, stratigraphically constrained to ~1.51 Ma. This suggestion was based on major element composition and perhaps, our preliminary notation of an ~1.5-Ma age of the HAT (20). However, the subsequently available minor element data (22, 29) refutes this correlation. Furthermore, there are many tuffs with similar major element compositions in the time period of 1.6 to 1.45 Ma at both Konso (see below) and Turkana. The stratigraphic and chronologic position of the HAT is a major focus of our recent studies and will be discussed in more detail below.

iv) Revised $^{40}Ar/^{39}Ar$ ages of the Nariokotome Tuff series were reported (1.24 ± 0.02, 1.31 ± 0.03, and 1.30 ± 0.03 Ma, respectively, for the Upper, Middle, and Lower Nariokotome Tuffs) (30), which we previously considered correlative to some of the upper Konso Formation tuffs (BOT, PST1, and PST2) (22). According to these dates, some of the major fossiliferous and archeological horizons of the upper part of the Konso Formation are slightly younger (1.2–1.35 Ma) than formerly thought (25).

v) We formerly noted that the Turkana Basin Orange Tuff was chemically similar to the Konso Kayle Tuff-1 (KYT1) (22). However, we did not consider the two tuffs as correlatives because of the then published stratigraphic position of the Orange Tuff within the Olduvai Subchron. However, the Orange Tuff is now dated to 1.76 ± 0.03 Ma (31) and considered correlative of Shungura Formation Tuff J that is 5 m above the top of the Olduvai Subchron. We agree that the Turkana Basin Orange Tuff and KYT1 are probable correlatives (31), an interpretation further corroborated by our own analyses (see below).

Results. The newly investigated sections at the Konso-Gardula (KGA) localities KGA19 and -21 include the entire East Kayle Beds interval (21), with minimal gaps spanning the time period ~1.75 to ~1.45 Ma (Fig. 1). Three of the KGA19 tuffs are probable correlatives of the Turkana Basin tuffs. One of these tuffs, the KGA19-Bench Tuff (NBT), has very similar elemental chemistry (Table S1) and concordant $^{40}Ar/^{39}Ar$ ages (see below) with the Turkana Basin Morutot Tuff. The stratigraphically next lowest tuff at KGA19, the Doublet Tuff (DBT), and the overlying KGA19-HAT (19HAT) and Konso Brown Tuff (BRT) are all similar in major and minor element chemistry with the type section Okote Tuff of the Turkana Basin (29). The 19HAT and KGA4-HAT (4HAT) are indistinguishable in their elemental composition but differ in glass shard morphology. Although the 19HAT is dominated by bubble wall shards, this condition is not the case with the 4HAT, suggesting different modes of eruption. Combined with the magnetostratigraphic evidence (see below), the geochemical and petrological analysis suggests that the 19HAT and 4HAT represent close successive eruptions of the same volcanic source.

Magnetostratigraphy of the circum HAT levels provides additional constraints on the chronostratigraphy of the Konso tuffs. Although the entire KGA19 stratigraphic interval under consideration is within the reverse Matuyama Chron, well above the normal Olduvai Subchron, we observed two short normal polarity intervals. One of these intervals occurs just below the NBT,

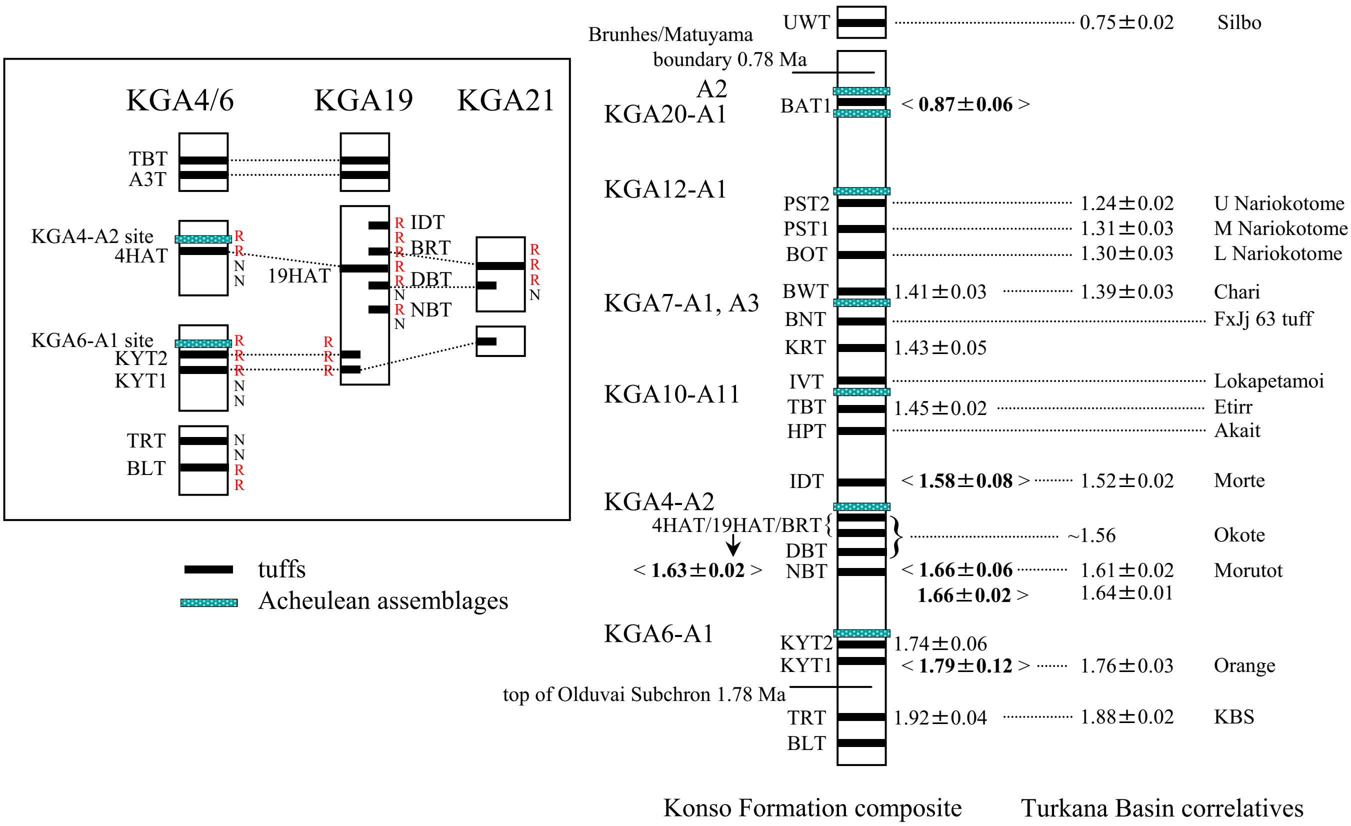

Fig. 1. Chronostratigraphic summary of the early Acheulean-bearing Konso Formation and correlation with the Turkana Basin tuffs. The geographic location of the Konso research area and locality positions are depicted in Suwa et al. (25). Dates in < > indicate new $^{40}Ar/^{39}Ar$ dates. Other dates are from Katoh et al. (20), McDougall and Brown (30), and McDougall et al. (31). All dates are weighted means adjusted to correspond to an FCs age of 28.2 Ma. Error margins are represented by population SDs. *Left* shows the schematic stratigraphy of the newly investigated KGA19 and -21 localities that enables a better chronological resolution of the Konso Formation time interval of ~1.45 to ~1.75 Ma. R and N indicate reverse and normal polarity intervals, respectively.

and the other is stratigraphically above the NBT and subjacent to the DBT. It is probable that either or both of these intervals correspond to what has been documented as the Gilsá and/or Stage 54 event(s) at ~1.57 Ma (32). However, recent radioisotopic dates of lava flows in Iceland and the Hawaiian Islands suggest an age of ~1.6 Ma or slightly older for the Gilsá event or excursion (33, 34). The reported $^{40}Ar/^{39}Ar$ isochron age of 1.60 ± 0.08 Ma (34) corresponds to an age range of ~1.62–1.64 Ma if alternative age estimates of the Taylor Creek sanidine standard (35, 36) are applied. Both 4HAT and 19HAT are just above the upper short normal polarity interval documented at Konso, suggesting an age either just younger than 1.57 Ma or more broadly ~1.6 Ma. Farther down in the Konso stratigraphy, a normal to reverse polarity transition was identified 4–5 m below the KYT1 tuff. This transition is interpreted as the top of the Olduvai Subchron.

Our newly acquired $^{40}Ar/^{39}Ar$ ages of the relevant Konso tuffs are concordant with the above chronological indicators within uncertainty limits. The Iyanda Tuff (IDT) crops out above the BRT and 19HAT. Our $^{40}Ar/^{39}Ar$ age of the IDT is 1.58 ± 0.08 Ma (values here and below are the weighted mean ± population SD), somewhat older but not significantly different from the chemically similar Morte Tuff (1.52 ± 0.02 Ma) (Table S1). However, the geochemical similarity of this comparison is not as strong as it is with the NBT–Morutot pair. The 19HAT analysis resulted in two distinct age populations: 1.63 ± 0.02 and 1.76 ± 0.01 Ma (Table S2). The latter age is incongruent with the totality of the evidence and probably represents upward reworking of grains from an underlying tuff (such as the ~1.75-Ma KYT1 or -2 tuffs). The age estimate of 1.63 ± 0.02 Ma of the 19HAT is somewhat older than but compatible with the interpolated Okote Tuff age of 1.56 ± 0.05 Ma (30). Our $^{40}Ar/^{39}Ar$ ages of 1.66 ± 0.06 and 1.66 ± 0.02 Ma (Table S2) of the NBT are older than the recently suggested Morutot Tuff age of 1.61 ± 0.02 Ma (30) but not significantly different from the Morutot's plateau age of

Fig. 2. The ~1.75-Ma KGA6-A1 picks made on large flake blanks. *Upper* and *Lower* show dorsal and ventral views, respectively. The largest pick (fourth from left) is 229 mm long with a trihedral section 90 mm thick.

1.64 ± 0.01 Ma obtained by step heating analysis (30). Additional analyses are needed to more precisely constrain both Morutot and NBT geochronologies. Our poorly constrained $^{40}Ar/^{39}Ar$ age of 1.79 ± 0.12 Ma for KYT1 is compatible with its stratigraphic position ~4 to ~5 m above the top of the Olduvai Subchron and corroborates the Turkana Basin Orange Tuff age of 1.76 ± 0.03 Ma. Additional details of our $^{40}Ar/^{39}Ar$ analysis are presented in *SI Text*.

Acheulean Assemblages of the Konso Formation

Overview and Chronology of the Earliest Acheulean at Konso. We consider an assemblage to represent the early Acheulean technology when the following attributes are present: the production of large flake blanks (>10 cm and frequently exceeding ~20 cm) and modification of these large blanks and similar-sized cobbles into tools with some degree of shape consistency to typologically qualify as picks, handaxes, and cleavers (tool terminology as in refs. 1, 37). Semaw et al. (8) noted that, although a stray occurrence of a typological handaxe or pick can occur within a large sample of Oldowan core tools, these tools are modified cores and tend to be smaller in size. They are not made on large flake blanks, and they are not recurrent items of an assemblage.

Although bifacially worked handaxes are often considered the hallmark of the Acheulean, we emphasize here that handaxes and picks of the early Acheulean tend to be predominantly (or literally) unifacially worked (i.e., the ventral face is little worked or unworked). Therefore, we consider the early Acheulean technology to include both large cutting tools (handaxes, cleavers, and knives) and heavy-duty tools (picks and core-axes) that are bifacially or unifacially worked.

In the Konso Formation, more than 20 archeological sites have been identified and logged. Their chronostratographic placements range from ~1.9 to <1.0 Ma. The chronostratigraphic positions of the representative Acheulean assemblages discussed here are schematically shown in Fig. 1. At Konso, the earliest recognized Acheulean assemblage occurs at KGA6 just above the KYT2 tuff. The KYT2 is ~6 m above the top of the Olduvai Subchron and has been radioisotopically dated to 1.74 ± 0.03 Ma. We consider this Acheulean occurrence to be indistinguishable in age from the earliest Acheulean of the Turkana Basin, recently considered the world's oldest with an interpolated age of 1.72 or 1.76 Ma (18).

At Konso, a more typical early Acheulean with abundant large bifacial tools occurs at the ~1.6-Ma HAT levels of KGA4 and -19. Thereafter, Acheulean assemblages are commonly seen at many of the fossil- and artifact-bearing Konso localities. Well-preserved assemblages are known at ~1.45 Ma (KGA4 and -10), ~1.4 Ma (KGA5, -7, and -10), ~1.25 Ma (KGA8 and -12), and <1.0 Ma (KGA18 and -20). Assemblages that apparently lack large cutting tools and/or picks, and hence, attributable to the Oldowan technological complex, are known at ~1.9 Ma (KGA4 and -11), ~1.75 Ma (circum KYT1 and -2 levels at KGA6), ~1.6 Ma (KGA21), and ~1.45 Ma (KGA4).

KGA6-A1 Locus C Acheulean. The KGA6-A1 site was first recognized by surface artifacts that included crude unifacial picks made on large and thick flake blanks. Subsequent excavations were conducted, and in situ Acheulean tools were recovered on top of a silty sand layer capped by waxy clay. Together with the surface scatter immediately adjacent to the KGA6-A1 Locus C excavation area, we recovered a total of 47 large flakes, some bifacially or unifacially modified. Of these flakes, 18 are sufficiently shaped to be classified as picks, handaxes, or cleavers (Figs. 2, 3 and 4). The raw materials used were almost exclusively the locally available basalt. The larger tools exceed 20 cm in maximum dimension. Most are shaped entirely by unifacial modification. Although flake scar counts tend to be low (often <10), the dorsal face is flaked, with no cortex remaining in approximately one-half of the tool items. Picks are dominant and mostly made on thick flake blanks. Asymmetric converging sides

Fig. 3. Cleavers from KGA6-A1 (~1.75 Ma; *Left*), KGA4-A2 (~1.6 Ma; *Center*), and KGA12-A1 (~1.25 Ma; *Right*).

with a thick pointed tip were formed by abrupt flaking. One of the lateral sides often shows a concavity, sometimes accentuated into a notch-like form by percussion flaking. The opposite side edge was shaped into a long, steep, and linear to curved edge. When the notching was emphasized, it produced a characteristic bent or notched-nosed tip shape (24). Handaxes are also crudely shaped but exhibit curved to linear bilateral cutting edges that converge into a somewhat rounded to rectilinear tip. Some selected attributes and comparisons with later assemblages are summarized in Tables 1 and 2.

Based on its crude workmanship and lack of a clearly bifacial tool component, we had formerly termed the initially collected subset of the KGA6-A1 assemblage proto-Acheulean (28). However, a similar term protobiface was used by Mary Leakey to refer to rare examples of core-derived artifacts that mimicked handaxes in form (reviewed in ref. 8). At Melka Kunture Gombore I, also as a rare element of an Oldowan assemblage, similar core tool types were described as "primitive handaxes" (38). Therefore, to avoid confusion, we consider the KGA6-A1 Locus C assemblage to represent an early form of the Acheulean and not proto-Acheulean.

Konso Acheulean from ~1.6 to <1.0 Ma. The earliest typical early Acheulean assemblage at Konso is represented by the ~1.6-Ma KGA4-A2 assemblage. This assemblage and the later Konso occurrences seem broadly comparable in workmanship with the early Acheulean of Olduvai Bed II (2), best known at sites EF-HR (~1.5–1.6 Ma) and BK (~1.3–1.4 Ma). The KGA4-A2

Fig. 4. Handaxe refinement through time. *Upper*, dorsal; *Lower*, ventral. From left to right, two each are shown from KGA6-A1 (~1.75 Ma), KGA4-A2 (~1.6 Ma), KGA12-A1 (~1.25 Ma), and KGA20 (~0.85 Ma). In each pair of handaxes from the respective sites, near-unifacial (left) and more extensively bifacial (right) examples are shown (except with the KGA20 handaxes, which are both well worked bifacially).

Table 1. Major tool types of the Konso Formation Acheulean

Site	Age (Ma)	Total tools	Relative frequency of tool types				Percent made on flake/cobble			Percent unifacial		
			Cleaver	Handaxe	Pick	Others	Cleaver	Handaxe	Pick	Cleaver	Handaxe	Pick
KGA6-A1 Locus C	∼1.75	28	0.11	0.14	0.39	0.36	100/0	88/12	100/0	100	75	91
KGA4-A2	∼1.6	71	0.11	0.27	0.48	0.14	88/0	62/0	44/6	50	37	26
KGA10-A11	∼1.45	46	0.13	0.35	0.26	0.26	100/0	56/6	17/33	33	56	8
KGA7-A1, A2, A3	∼1.4	72	0.18	0.24	0.56	0.03	69/8	53/12	10/73	38	31	5
KGA12-A1	∼1.25	110	0.24	0.27	0.25	0.25	81/8	67/9	26/22	42	30	15
KGA20-A1, A2	∼0.85	27	0.15	0.70	0.15	0.00	50/0	37/11	25/50	0	5	25

archeological horizon occurs in a ferruginous reddish-brown sandy layer ∼1 m above the 4HAT. Acheulean artifacts were made predominantly on basalt, represented by an abundance of trihedral to quadruangular picks of varied sizes made mostly on large flakes with a few made on cobbles. A function-based and/or stylistic continuity of pick form can be inferred from similarities between the older KGA6-A1 and the more abundant KGA4-A2 examples (Figs. 2 and 5). However, differences between the KGA6-A1 and KGA4-A2 assemblages are also marked. Many of the KGA4-A2 picks are bifacially flaked and somewhat more modified than the KGA6-A1 counterparts (Table 1). The KGA4-A2 handaxes tend to be better shaped than those handaxes of KGA6-A1; many exhibit “near-symmetry” (39), at least in some portions of the tool, and edge thinning to the tip (Fig. 4). However, because of predominance of little/no ventral flaking in the bifaces, total flake scar counts remain low and modally lower than in picks (Fig. 6 and Table 2).

More diverse Acheulean assemblages derive from sediments dated to between 1.5 and 1.2 Ma. Considerable interassemblage variation is seen in raw material use, preferred blank types, relative frequency of tool types and sizes, and related tool shapes. Such aspects of the collection will be presented elsewhere. Here, we concentrate on some tendencies that characterize the aggregate of the Konso early Acheulean during this time period. Between ∼1.6 and ∼1.2 Ma, an increase of workmanship is seen in handaxe form, resulting in better tip shape and plan form symmetry (Fig. 4). This shape refinement is based on more intensive edge flaking, which is numerically reflected in an increase of flake scar count (Fig. 6 and Table 2). However, despite this refinement, the handaxes remain thick, with sinusoidal cutting edges characteristic of the early Acheulean.

The Konso picks of this time interval are diverse, but flake scar counts do not increase through time as they do in the handaxes. Instead, a common shape tradition can be inferred to persist through time (Fig. 5). Although edge modification of the picks is neither universal nor standardized, the recurring tendency for a notched tip shape does suggest either functional and/or stylistic intent. The occurrence of diminutive examples corroborates the hypothesis that there was imposition of shape and that this imposition was, at least in part, stylistic.

Infrequently worked bone pieces are known from the Konso Formation, some of which we have described elsewhere (40). From the ∼1.4-Ma time horizon, there is a striking example of a large mammal long bone shaft fragment shaped into handaxe form by extensive flaking (Fig. S1). Although such bone modification was evidently rare, it shows that shape imposition occurred across distinct raw materials.

Finally, Acheulean assemblages higher in the Konso sequence, close to the Brunhes/Matuyama boundary, occur at KGA18 and -20. Here, the thick trihedral/quadruangular picks, characteristic of the >1.2-Ma Konso Acheulean, are absent from the current small samples, and the handaxes are now considerably more refined. Symmetry of form is substantially advanced in some of these handaxes, with circumferential flaking accompanied by advanced plan symmetry and substantial thinning (Fig. 4 and Fig. S2). Quantitatively, we observed a significant increase in flake scar count and a decrease of relative thickness (Fig. 6 and Table 2). Qualitatively, the flake scars are both shallow and invasive, implying some degree of soft hammer use.

Discussion

As is the case at west of Lake Turkana (18), the earliest Konso Acheulean occurs at ∼1.75 Ma within an otherwise Oldowan sequence of archeological occurrences (*Methods*). Lepre et al. (18) suggested that the rare co-occurrence of the Acheulean within the landscape of more common Oldowan assemblages might indicate different groups of hominids with different tool-making behaviors. However, the obvious alternative is that the Acheulean large cutting tools and picks represent new activities or new solutions to existing activities within the same biological species/population lineage (8). The Konso evidence now suggests that, at ∼1.75 Ma, activities that required large early Acheulean tools were an important aspect of the behavioral repertoire of hominids in both the Turkana and Konso basins.

Until recently, the earliest definite and well-provenienced *H. erectus* specimen, KNM-ER 3733, was attributed an age of 1.78 Ma (41) and considered to possibly predate the Acheulean by several hundred thousand years. However, a recently refined chronology suggests an age of 1.65–1.7 Ma for the KNM-ER 3733 cranium (27, 31, 42), and the combined west Turkana and

Table 2. Metric attributes of the Konso Acheulean handaxes and picks

Site	Age (Ma)	*n* (pick/handaxe)	Mean length in mm (SD)		Mean breadth/length (SD)		Mean thickness/breadth (SD)		Mean flake count (SD)	
			Pick	Handaxe	Pick	Handaxe	Pick	Handaxe	Pick	Handaxe
KGA6-A1 Locus C	∼1.75	11/4	179.5 (40.0)	161.0 (37.2)	0.56 (0.09)	0.71 (0.08)	0.58 (0.11)	0.41 (0.13)	10.2 (3.9)	12.3 (5.7)
KGA4-A2	∼1.6	34/19	171.4 (41.2)	159.8 (25.2)	0.52 (0.11)	0.58 (0.07)	0.65 (0.15)	0.55 (0.13)	14.7 (6.7)	12.3 (7.5)
KGA10-A11	∼1.45	12/16	154.4 (26.4)	164.6 (42.9)	0.62 (0.09)	0.64 (0.13)	0.68 (0.10)	0.53 (0.10)	13.3 (4.1)	10.6 (5.7)
KGA7-A1, A2, A3	∼1.4	40/17	134.0 (33.3)	142.4 (25.8)	0.60 (0.12)	0.62 (0.09)	0.72 (0.13)	0.58 (0.11)	17.1 (7.4)	17.1 (7.7)
KGA12-A1	∼1.25	27/30	171.4 (23.9)	174.2 (24.0)	0.54 (0.06)	0.60 (0.06)	0.74 (0.17)	0.54 (0.15)	17.6 (6.3)	18.2 (7.3)
KGA20-A1, A2	∼0.85	4/19	147.8 (11.6)	169.9 (47.8)	0.62 (0.06)	0.61 (0.07)	0.56 (0.21)	0.47 (0.08)	16.3 (4.6)	30.4 (10.9)

Fig. 5. Picks with notched tips throughout the Konso early Acheulean sequence. From left to right, KGA6-A1 (~1.75 Ma), KGA4-A2 (~1.6 Ma), KGA12-A1 (small and large; ~1.25 Ma), and KGA7-A3 (large and small; ~1.4 Ma).

Konso evidence now indicates that the earliest known crude Acheulean technology was somewhat widespread by at least ~1.75 Ma. Thus, it now seems that the emergence of the large flake-based Acheulean technology must have broadly coincided with, or closely preceded, the emergence of a *H. erectus*-like morphology within the early *Homo* lineage.

The ~1.75-Ma Konso Acheulean assemblage is characterized by a dominance of large flake-based picks and cutting tools, indicating advanced motor skill and cognition (as discussed in ref. 8). Modification that produced tool types categorized as handaxes, cleavers, and picks suggests imposition of form. The Konso assemblage shows that emphasis of the ~1.75-Ma Acheulean was on obtaining both thick pointed tips and long and durable cutting edges. Although characterization of the west Turkana assemblage is so far limited, that assemblage also seems to share these characteristics (16–18). Some of the tasks must have needed tools with substantial bulk and weight, as seen in the larger picks, whereas others needed the stable cutting edges easily obtained from the thinner large flake blanks.

Within the Konso sequence before ~1.2 Ma, both picks and handaxes remained crude in retaining a modally thick cross-section (Fig. 6 and Table 2) and little shape standardization. These attributes can be considered characteristic of early Acheulean assemblages in general (2, 8, 43). However, temporal changes are observed within the Konso sequence, but picks and handaxes show distinct trajectories. Whereas pick shapes and their flake scar counts remained comparatively consistent, handaxes show a clearer increase of refinement through time. Comparing the Konso handaxe assemblages of ~1.75, ~1.6, and ~1.25 Ma, a clear increase of workmanship can be seen in edge modification and tip thinning. This sophistication resulted in larger flake scar counts, increase of plan form symmetry, and perhaps, some standardization of edge and tip shape/form. Such functionally relevant changes seem to be less conspicuous in picks. This difference between handaxes and picks suggests that, whereas the pick functions were already predominantly fulfilled by the earlier ~1.75- to ~1.6-Ma shape and technologies, such a situation was not the case with handaxes; that is, handaxe functions were enhanced through time. Although one can only speculate on function from morphological analysis such as what we discuss here, experimental work (13, 14) suggests that, within a multipurpose functional requirement, picks may have functioned more in woodworking and/or digging and handaxes may have functioned more in cutting as in carcass processing (44, 45).

In contradistinction to the >1.2-Ma assemblages, the younger ~0.85-Ma Konso Acheulean is characterized by considerably refined handaxes. Some of these handaxes are refined to the extent that they would qualify as approaching "three-dimensional symmetry" (7) (i.e., symmetric not only in plan view but also in cross-section form) (Fig. 4 and Fig. S2). Some suggest that manufacturing 3D symmetric tools is possible only with advanced mental imaging capacities (7) and that such tools might have emerged in association with advanced spatial and navigational cognition, perhaps related to an enhanced mode of hunting adaptation. It has been pointed out that purposeful thinning of large bifacial tools is technologically difficult, even in modern human ethnographic settings (9). In modern humans, acquisition and transmission of such skills occur within a complex social context that enables sustained motivation during long-term (>5 y) practice and learning (9).

In light of the above information, it is of interest that our metric analysis shows that there may be a fundamental difference between the handaxe technologies of >1.2 and ~0.85 Ma. Whereas

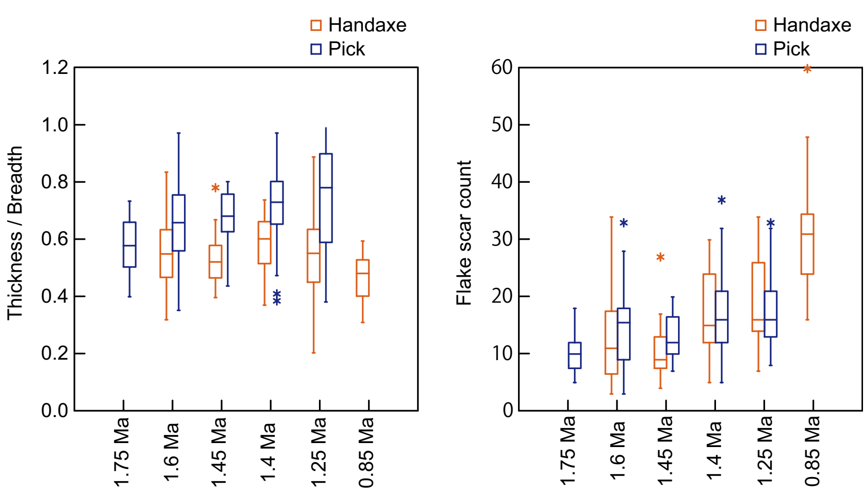

Fig. 6. Box plots of relative thickness (*Left*) and flake scar counts (*Right*) in handaxes and picks. From left to right, KGA6-A1, KGA4-A2, KGA10-A11, KGA7-A1~3, KGA12-A1, and KGA20-A1~2 are shown. KGA6 handaxes and KGA20 picks are not plotted because of small sample sizes (less than five). In both handaxes and picks, thickness/breadth ratios do not differ significantly among the 1.6- to 1.2-Ma assemblages, although a weak tendency is seen in picks getting thicker through time. In handaxes, the ~0.85-Ma KGA20 assemblage tends to be thinner than in KGA12-A1 ($P = 0.105$). In picks, flake scar count is low in KGA6-A1 compared with KGA4-A2 ($P = 0.038$) but does not differ significantly among the 1.6- to 1.2-Ma assemblages. In handaxes, flake scar count starts low (~10), significantly increases at ~1.4 Ma (~15), and culminates in the extreme ~0.85-Ma condition (>20). The box plots show the median (horizontal line), central 50% range (box margins), range (vertical line) within inner fences (1.5 times box range from box margins), and outliers (asterisks).

refinement of handaxe shape did occur from ∼1.6 to ∼1.2 Ma, this refinement did not result in tool thinning and advanced 3D symmetry. In fact, as do picks, these earlier handaxes tend to be thicker with increased trimming (Fig. 6 and Fig. S2). This tendency is most likely because of edge modification that involved steeper flaking that does not result in thinning. Contrary to this condition, the ∼0.85-Ma handaxes exhibit an increase of flake scar count that was negatively associated with handaxe thickness (Fig. S2). Thus, at Konso, the ∼0.85-Ma Acheulean technology involves a novel 3D standardization component not observed in the >1.2-Ma early Acheulean. Elsewhere in Ethiopia, similarly advanced-shaped handaxes, some with broken symmetry (7), have been reported at the Melka Kunture Gombore II site with an age of ∼0.8 Ma (46). However, this is not the case with the known ∼0.95-Ma Acheulean assemblages of Bouri, Ethiopia (37). Kenyan sites in the time range of ∼0.7 to <1.0 Ma are also known to variably exhibit handaxes with refined form (3, 4, 6, 47, 48). It would be of interest to pursue more exactly when, where, and how this technological advance emerged (49).

Finally, within the Konso Acheulean sequence, the technologically less dynamic pick succession seems to exhibit evidence for subtle but actual stylistic tradition (as discussed in ref. 50). Perhaps a slower pace of function-related change enables easier detection of nonfunctional idiosyncratic factors. This may also be taken as additional corroborative evidence for a functional difference between the early Acheulean handaxes and picks. Unraveling the functional significance of the two tool types is needed to further our understanding of the behavioral and/or biological significance of the emergence and development of the Acheulean technology.

Methods

Because of the importance of determining the age of the early Acheulean occurrences at Konso, in particular the KGA6-A1 site (Fig. S3), we scrutinized the stratigraphic sections that span the time interval of ∼1.5 to ∼1.75 Ma. At Konso, sedimentary exposures of this time interval are limited in extent, but we were able to establish five new tephra units from two previously undescribed localities, KGA19 and -21 (Fig. 1). Four of the newly recognized tuffs are similar in major element composition to the KGA4-HAT (4HAT) and the Koobi Fora/Okote Tuff complexes, making even intralocality correlations sometimes difficult. Therefore, we investigated minor and trace element compositions of glass shards to both confirm the local stratigraphy and better establish possible interbasin correlations with the Turkana sequence tuffs. The methods used are spelled out in our previous publications (20, 22). The details of the tephrochemistry analysis will be presented elsewhere.

Magnetostratigraphic profiles were made of the sections that contain tuffs that are possibly correlative of the 4HAT, which was found to be immediately above a normal to reverse polarity transition. Oriented samples were taken from soft sediments using specific tools (51) in intervals of 20 cm to <1 m to enable detection of short polarity intervals. Block samples were also collected from consolidated but fragile sediments following the information in ref. 52. Alternating field and stepwise thermal demagnetization of the natural remanent magnetization were conducted in 12–17 steps using a 2G cryogenic magnetometer and a Bartington MS2 susceptibility meter at Kobe University. Characteristic remanent magnetization directions were determined using principle component analysis (53). The details of the magnetostratigraphic analysis will be presented elsewhere.

$^{40}Ar/^{39}Ar$ dates were obtained for six previously undated horizons, four on the newly identified circum HAT tuffs (Fig. 1 and Table S2). Our first round analysis was conducted at the Geological Survey of Japan geochronology laboratory (by K.U., M.S., and M.K.), which produced a set of single-crystal $^{40}Ar/^{39}Ar$ dates that was largely congruent with the stratigraphic field evidence. We furthermore obtained independent dates of three tuffs considered crucial in interpreting the ∼1.6- to 1.75-Ma Konso Formation Acheulean assemblages at the Berkeley Geochronology Center (by P.R.R.). The details of the methods and the full results of the single-crystal $^{40}Ar/^{39}Ar$ dating are presented in *SI Text*, Tables S2–S4, and Figs. S4 and S5. The dates presented in the text and Fig. 1 are based on weighted means of 5 to ∼25 sanidine crystals of each tuff after iteratively omitting grains with ages that were more than 2 SDs away from the initially calculated arithmetic mean. The weighted means were then converted to ages that correspond to those based on an FCs age of 28.2 Ma (54). The uncertainties referred to in the text and Fig. 1 are the simple SDs of the grain population. The population SD can be taken as a reasonable indication of actual uncertainty of the tuff ages considering both experimental and other errors, such as potential grain population heterogeneity (*SI Text*).

The KGA6-A1 site comprises four excavation loci in an area of ∼16 × 6 m. Five in situ archeological horizons were recognized from just below the KYT1 to about 2 m above the KYT2 tuff. Three of these horizons exhibit tool assemblage characteristics compatible with an Oldowan technological attribution. Both Locus C and a stratigraphically higher, more limited occurrence at Locus A exhibited large flake-based blanks. At Locus C, a 4 × 5 m excavation yielded in situ bifacial tools (n = 4), whereas another 24 were concentrated within ∼1 m adjacent to the in situ excavation margin, suggesting a recently washed out lag accumulation. The remaining specimens were found farther down slope of the Locus C northern margin. The excavation plan and stratigraphic column of Locus C are presented in Fig. S3.

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