Diachronous dawn of Africa's Middle Stone Age: New $^{40}Ar/^{39}Ar$ ages from the Ethiopian Rift

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ABSTRACT

The Middle Stone Age (MSA) of Africa, like the Middle Paleolithic of Europe, is thought to represent a time period wherein toolmakers acquired significant increases in cognitive abilities and physical dexterity. Existing data fail to resolve whether the MSA emerged gradually, abruptly, or discontinuously, and whether this industry reflects the activity of *Homo sapiens*. Here we present new $^{40}Ar/^{39}Ar$ geochronological data revealing that advanced MSA archaeology at two sites in the main Ethiopian Rift is older than 276 ka, much older than technologically comparable MSA archaeology from elsewhere. An age of 183 ka for a unit farther upsection, along with the technological stasis observed throughout the section, indicates that similar technology was used here for ~93 ka. These results suggest that MSA technology evolved asynchronously in different places, and challenge the notion of a distinct time line for either the appearance of the MSA or the disappearance of the earlier Acheulean. These and other recent results indicate that the oldest known MSA consistently predates fossil evidence for the earliest *Homo sapiens*.

ARCHAEOLOGY AND PALEONTOLOGY IN THE LATE-MIDDLE PLEISTOCENE

The nature and timing of the transition from the Acheulean period of the Early Stone Age to the Middle Stone Age (MSA) is not well understood. Generally, a shift was made from larger Acheulean hand axes, picks, and polyhedra, to smaller, more diverse MSA artifacts (McBrearty and Brooks, 2000). The tools of the MSA are characterized by points, blades, and other tools that are often made by the Levallois technique, which utilizes prepared cores and thus seems to require "more complex cognitive abilities" (Bar-Yosef and Dibble, 1995 p. *x*) than those seen in the Acheulean. However, in recent years it has become apparent that this transition was quite complex, as hand axes and MSA tools have been found together at some sites (Clark et al., 2003) and Levallois technology has been recorded at localities otherwise considered Acheulean (McBrearty, 2003). Most well-dated and documented MSA sites postdate 130 ka. However, a few sites hint at a much earlier origin of the MSA. These include Malewa Gorge, Kenya, dated to before ca. 240 ka by K-Ar (Evernden and Curtis, 1965); Twin Rivers, Zambia, dated to before 265 ka by U-series on speleothems (Barham and Smart, 1996); and Cartwright's site at the Kinangop Plateau, Kenya, also dated by K-Ar to before 439 ka (Evernden and Curtis, 1965). Although the old age from Cartwright's site is intriguing, its accuracy is questionable, as stratigraphic relationships at this locality are not clear (Evernden and Curtis, 1965) and the K-Ar method is highly susceptible to contamination by older grains. The oldest MSA archaeology whose age is well documented occurs in the Kapthurin Formation in Kenya, where single crystal $^{40}Ar/^{39}Ar$ dating indicates that it is older than 284 ± 24 ka (Deino and McBrearty, 2002). (Uncertainties are given at the 2σ level here and throughout, with the possible exception of K-Ar ages published by Laury and Albritton [1975] and Wendorf et al. [1994], for which confidence levels were not reported.) In contrast, hominids at Herto in Ethiopia utilized what appears to be a technology transitional between the Acheulean and MSA as recently as 160 ka (Clark et al., 2003). The appearance of MSA-typical technology may indicate a shift in tool-making abilities, whereas the persistence of Acheulean technology might be expected to be spatially heterogeneous, depending on such variables as available source materials and cultural circumstances. Understanding the relationships and intertwining of these two stone tool traditions in Africa will require precise chronometry often lacking for key sites across the continent.

The fossil record of *Homo sapiens* and other closely related species during the late-middle Pleistocene is similarly unresolved. Debate continues over the species assignments of some fossils (i.e., Omo 2), the relationships between various species, and even the existence of some species (Rightmire, 2008; Tattersall and Schwartz, 2008). The apparently oldest fossils assigned to *H. sapiens* are from the Kibish Formation in the Omo, bracketed by $^{40}Ar/^{39}Ar$ dates to between 104 ± 14 ka and 196 ± 4 ka, with an inferred age of 195 ± 10 ka (McDougall et al., 2005). *H. sapiens* from Herto are dated by $^{40}Ar/^{39}Ar$ to between 160 ± 4 and 154 ± 14 ka (Clark et al., 2003). Existing geochronological evidence seems to indicate that the earliest MSA predates the first appearance of *H. sapiens*, but it is to be expected that fossils are more poorly preserved and initially less abundant than lithic artifacts. Thus, the Signor-Lipps effect (Signor and Lipps, 1982) would tend to make the archaeological record of *H. sapiens* appear to predate its fossil record.

With mounting geochronological support for MSA industries older than ca. 250 ka, it is increasingly clear that evidence for this technological revolution precedes the evidence for the appearance of anatomically modern people in Africa, but not necessarily of archaic *H. sapiens* or other closely related members of the genus *Homo*. Understanding the nature of these technological and biological changes, particularly in light of the global climatic changes evident in the late-middle Pleistocene, will require intensified paleoanthropological efforts and explorations.

GADEMOTTA FORMATION

Gademotta and Kulkuletti are located on the flanks of a collapsed caldera ~2 km apart and ~5 km west of Lake Ziway in the Main Ethiopian Rift Valley (Fig. 1A; GSA Data Repository Fig. DR1[1]). The Gademotta Formation is found at the type locality of Gademotta (Fig. 1B) and elsewhere on Gademotta Ridge, including Kulkuletti (Fig. 1C). It was deposited on the Kulkuletti Volcanics, some of which were dated by Vogel et al. (2006) to ca. 1.3 Ma. The forma-

[1]GSA Data Repository item 2008241, analytical methods, results from unit 5 at Gademotta, Figures DR1 (location map), DR2 (age probability diagrams and inverse isochron for sample K2), DR3 (age spectrum and inverse isochron for sample G3), DR4 (age probability diagrams for sample K1), DR5 (age probability diagrams for samples G1 and G2) and DR6 (age probability diagram and inverse isochron for Malewa Gorge sample KA963), and complete Ar isotopic and geochemical data, is available online at www.geosociety.org/pubs/ft2008.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

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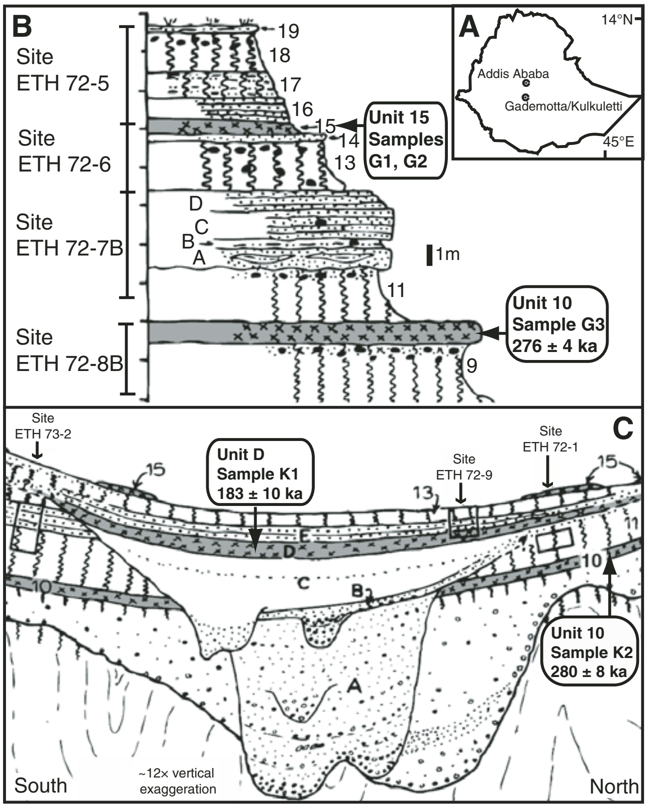

Figure 1. Geographic and stratigraphic placement of archaeology at Gademotta and Kulkuletti. A: Map showing location of Gademotta and Kulkuletti within Ethiopia. B: Stratigraphic section of Gademotta Formation at type locality. C: Cross section of Gademotta Formation at Kulkuletti. For B and C, unit numbers are shown to right of section. Sampled tuffaceous units are shaded in gray. Artifacts are represented with black ovals. Adapted from Laury and Albritton (1975). Reproduced with permission.

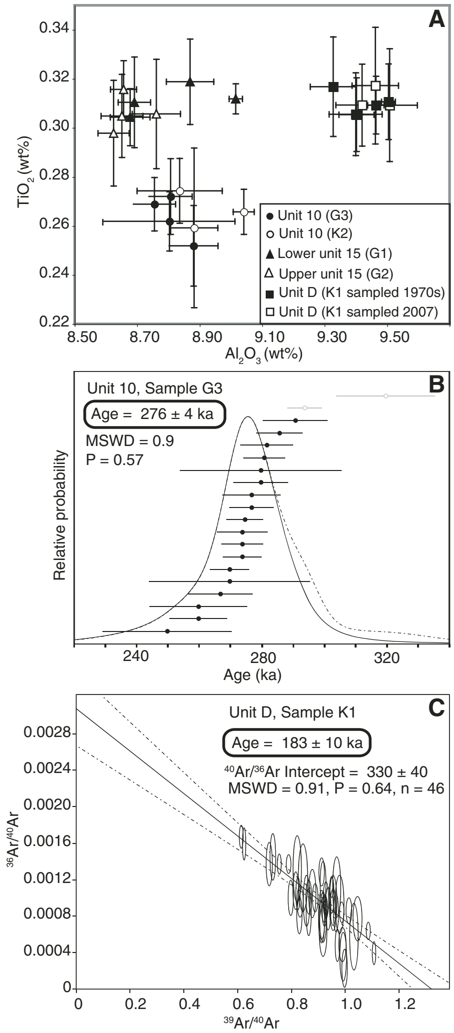

Figure 2. Geochemical and geochronological results. A: Glass shard geochemistry from sampled units at Gademotta and Kulkuletti. Filled squares were sampled in the 1970s by original excavators; open squares were sampled by us in 2007. Geochemical similarity of these two samples validates our interpretation of the stratigraphy. Error bars represent 1σ based on multiple analyses on each glass shard. B: Age probability spectrum for $^{40}Ar/^{39}Ar$ isochron ages for sanidines from unit 10 at Gademotta (G3). MSWD—mean square of weighted deviates. C: Inverse isochron of single crystal total fusion analyses for sanidines from unit D at Kulkuletti (K1).

tion consists largely of volcaniclastic sediments and paleosols that can be divided into two portions: a lower section consisting mainly of lahar deposits and lacking artifacts, and a paleosol-rich upper section containing abundant artifacts. The upper section begins with Laury and Albritton's (1975) unit 9, wherein small Final Acheulean hand axes are found at the base of the unit (Wendorf et al., 1975, 1994). The upper part of unit 9 and overlying units in the Gademotta Formation (Fig. 1B) contain distinctive MSA artifacts, including medium to large retouched points and scrapers, some of which were made by Levallois technology. These artifacts display "enormous variability in the sense of technology and retouched tool forms" (Schild and Wendorf, 2005 p. 130, 135). Obsidian is by far the most common raw material in all units and was obtained from flows in the underlying Kulkuletti Formation (Vogel et al., 2006), which contains rhyolite flows and silicic tuffs and disconformably underlies the Gademotta Formation. There is very little evidence for cultural change throughout the MSA sequence, apart from two trends noted by Wendorf et al. (1975). These include a lower percentage of bifacial tools upsection, and an increase in upper Paleolithic-type tools in the highest excavation. Wendorf et al. (1975) also remarked on the lack of consistent change in the frequency of the Levallois technique and tool size through time. Unlike some other early MSA localities (i.e., the Kapthurin Formation), the oldest MSA at Gademotta and Kulkuletti is not preceded by assemblages with Sangoan or Fauresmith characteristics, regarded by some workers as transitional to the Acheulean.

The great age attributed to Gademotta and Kulkuletti has played a key role in establishing the antiquity of the MSA industry. Based on early K-Ar dating, Gademotta and Kulkuletti were believed until recently to contain the oldest known MSA artifacts with an age of 235 ± 5 ka for unit 10 (Wendorf et al., 1994). This age has been surpassed by an age of 284 ± 24 ka from the Kapthurin Formation (Deino and McBrearty, 2002). We present new $^{40}Ar/^{39}Ar$ and geochemical data from tuffs in the Gademotta Formation that establish substantially older ages than those previously published for the archaeology at the Gademotta and Kulkuletti sites.

Unit 10 of Laury and Albritton (1975) is an ~1-m-thick tuff with large (2–4 mm diameter) phenocrysts of sanidine and aegirine-augite found at both Gademotta (sample G3) and Kulkuletti (sample K2) that was previously dated by K-Ar on alkali feldspars to 181 ± 6 ka (sampled at Kulkuletti) (Laury and Albritton, 1975) and then to 235 ± 5 ka (sampled at Gademotta) (Wendorf et al., 1994) (Figs. 1B and 1C). The unit overlies both the Final Acheulean hand axes and the lowermost MSA archaeology. Glass shards from unit 10 sampled at Gademotta and Kulkuletti have similar geochemistry (Fig. 2A), confirming the stratigraphic correlation between the two sites and highlighting the discrepancy between the K-Ar dates. Our $^{40}Ar/^{39}Ar$ age results for sanidine from this unit are summarized as probability and inverse isochron diagrams shown in Figure 2B and Figures DR2 (Kulkuletti), and DR3 (Gademotta). For the Kulkuletti sample (K2), single-crystal total fusion analyses clearly identify the presence of two xenocrysts; when these grains are omitted, the remaining analyses yield a weighted (by inverse variance) mean age of 297 ± 11 ka (Fig. DR2B). However, when these same data are viewed on an inverse isochron diagram (Fig. DR2C), the presence of excess Ar is seen in the initial $^{40}Ar/^{36}Ar$ value

(332 ± 24), which is higher than the conventional atmospheric value of 295.5 ± 0.5 (Nier, 1950); although a recent study has redetermined the atmospheric $^{40}Ar/^{36}Ar$ ratio (Lee et al., 2006), we use 295.5 provisionally so as to conform with the value currently used by the geochronological community. Since isochrons do not require assuming an initial $^{40}Ar/^{36}Ar$ ratio, the atmospheric $^{40}Ar/^{36}Ar$ ratio is largely irrelevant and the isochron age of 280 ± 8 ka is considered to be the most reliable age for unit 10 at Kulkuletti.

Sanidine crystals from the Gademotta sample (G3) of unit 10 were sufficiently large for step-heating experiments. A representative age spectrum and isochron are shown for one crystal of sanidine in Figure DR3. Steps with ^{40}Ar values <2 times the blank value were removed from consideration. Isochrons with mean square of weighted deviates (MSWD) <0.25 or >2.5, or with probability P <0.1 or >0.9, were omitted from the weighted average calculation. The presence of excess Ar is revealed by many inverse isochrons, as the weighted average of initial $^{40}Ar/^{36}Ar$ ratios for crystals used in the weighted mean age calculation below (320 ± 17) is significantly greater than the atmospheric value. The inverse variance weighted mean of isochron ages from most crystals (outliers were rejected by the modified 2σ criteria used by Isoplot [Ludwig, 2003]) provides the most reliable age for this unit, 276 ± 4 ka (Fig. 2B).

The other previously dated tuff is unit D of Laury and Albritton (1975). Unit D is a thick, gray, pumiceous lapilli tuff found in the gully-fill sequence at Kulkuletti and previously dated as 149 ± 13 ka (Wendorf et al., 1975) (Fig. 1C). A sample of this unit (UAKA73–132) was obtained from Paul Damon's archives at the University of Arizona, where the original K-Ar geochronology reported by Wendorf et al. (1975) was performed. Glass shards from this sample are geochemically identical to those from our sampling of unit D (sample K1) (Fig. 2A), validating our stratigraphic interpretation and thus our ability to place accurate age constraints on previously excavated archaeology. An age probability diagram of single crystal total fusion analyses of sanidine (Fig. DR4A) clearly identifies a single xenocryst at 1.19 ± 0.01 Ma. Closer examination (Fig. DR4B) indicates a non-Gaussian distribution of remaining crystals. Among these, three discrete groups exist. The largest, and youngest, group has a weighted mean age of 190 ± 5 ka; a smaller group has a weighted mean age of 288 ± 7 ka; and a single crystal has an age of 392 ± 15 ka. The age of the single crystal differs from both groups by >4σ and is clearly a xenocryst. The age of the second group is within error of the age of the underlying unit 10, described above, and is reasonably explained by xenocrystic contamination from that unit. The youngest group, with an age of 190 ± 5 ka, likely represents the eruption age of the tuff. An inverse isochron (Fig. 2C) including only crystals from that group indicates the presence of excess argon (initial $^{40}Ar/^{36}Ar$ = 330 ± 40) and yields an age of 183 ± 10 ka, which is considered the most reliable age for unit D.

Dating was also attempted on unit 15 at Gademotta (samples G1 and G2) of Laury and Albritton (1975), but the sample proved to be highly contaminated and did not yield a juvenile population. Details are provided in the Data Repository (see footnote 1).

In the interest of clarifying the ages of other MSA sites, we sought to evaluate the age of ca. 240 ka reported by Evernden and Curtis (1965) for a tuff overlying MSA archaeology (Stillbay variant) at Malewa Gorge, southern Kenya. We obtained a sanidine separate from the sample archive of the former University of California Berkeley K-Ar lab of sample KA 963, the sample originally analyzed by Evernden and Curtis (1965). Single-crystal total fusion analyses of 10 grains yield a weighted mean age of 100 ± 32 ka (Fig. DR6A), while the inverse isochron indicates an initial $^{40}Ar/^{36}Ar$ ratio (293.9 ± 3.8) indistinguishable from the atmospheric value, and an age of 102 ± 16 ka (Fig. DR6B). The isochron age is considered the most reliable estimate of the tuff's eruption age.

DISCREPANCIES WITH PREVIOUS GEOCHRONOLOGY

Previously reported K-Ar ages for Kulkuletti (Wendorf et al., 1975) and Gademotta (Wendorf et al., 1994) are distinctly younger than the $^{40}Ar/^{39}Ar$ ages reported here. Xenocrystic contamination (Lo Bello et al., 1987), excess ^{40}Ar, incomplete laboratory degassing (Webb and McDougall, 1967; McDowell, 1983), and alteration can bias apparent ages obtained by the K-Ar method. The presence of xenocrysts in each sample demonstrated by our single-crystal work suggests that contamination almost certainly affected the K-Ar ages, but the fact that previously reported ages are significantly younger than the $^{40}Ar/^{39}Ar$ ages reported here suggests that incomplete degassing was the prevailing issue at Gademotta and Kulkuletti, and outweighed the effects of virtually inevitable contamination and documented excess ^{40}Ar. Variance in the extent of xenocrystic contamination and degassing can also explain the significant discrepancy between K-Ar ages obtained for unit 10 at Kulkuletti (Wendorf et al., 1975) and Gademotta (Wendorf et al., 1994). These significant discrepancies underscore the importance of applying the $^{40}Ar/^{39}Ar$ method to those sites previously dated by K-Ar. At Malewa Gorge, single-crystal total fusion analyses of 10 grains do not reveal xenocrysts. However, since K-Ar geochronology for samples of this age, using methods available in 1965, requires analysis of thousands of grains, xenocrystic contamination is the likely cause for the older ages obtained by Evernden and Curtis (1965) using the K-Ar method. As our results remove this site from its possible place among the more ancient MSA representatives, it is dismissed from further consideration herein.

ANTIQUITY OF THE MIDDLE STONE AGE

The Middle Stone Age has previously been shown to extend back to before 284 ka in the Kapthurin Formation. Although only limited data were published for the tuff dated to 284 ± 24 ka in the Kapthurin Formation (Deino and McBrearty, 2002), there is a suggestion of evidence for excess ^{40}Ar in the $^{40}Ar/^{39}Ar$ data in the form of a correlation between $^{40}Ar/^{36}Ar$ and apparent age for individual analyses. An isochron fit to all the data for this tuff yields an age of 279 ± 40 ka, with initial $^{40}Ar/^{36}Ar$ = 304 ± 38 and MSWD = 1 (A. Deino, 2008, personal commun.). Our significantly more precise new ages for Gademotta and Kulkuletti render the oldest MSA at these sites indistinguishable in age from that found in the Kapthurin Formation. Furthermore, MSA artifacts from the upper part of unit 9, which underlies unit 10 and is thus older than 276 ± 4 ka, display tool variability and complexity that rival assemblages from many much younger Upper Paleolithic sites (Schild and Wendorf, 2005). As seen in Figure 3, comparison of typologically equivalent tools (blades and points) shows that Gademotta unit 9 artifacts more closely resemble the much younger (80–100 ka) MSA from the site of Aduma in the Middle Awash of Ethiopia (Yellen et al., 2005) than the contemporaneous Kapthurin ones. It should be noted, however, that the vast majority of artifacts from Gademotta and Kulkuletti, and many at Aduma, were made from obsidian, while Kapthurin has relatively few tools made from this material. Since obsidian is among the raw materials most conducive to Levallois technology, the advanced appearance of the very early MSA at Gademotta and Kulkuletti may be more related to the simple circumstance of proximally available raw materials than to the developmental stage of the toolmakers.

Our results indicate a significantly longer age span for archaeology between the Gademotta tuffs 10 and D (93 ± 11 ka) than was suggested by the previous K-Ar data. This indicates, in view of Wendorf et al.'s (1975) conclusion of technological stasis within the MSA here, that the Gademotta and Kulkuletti toolmakers modified their techniques and tool functions little over a time span of ~100 ka. These new $^{40}Ar/^{39}Ar$ ages indicate that the MSA artifacts at Gademotta and Kulkuletti are among the oldest currently known to represent this lithic industry. Moreover, the relatively advanced character of the MSA found here suggests the existence of significantly older, more primitive MSA archaeology that has yet to be discovered and/or dated.

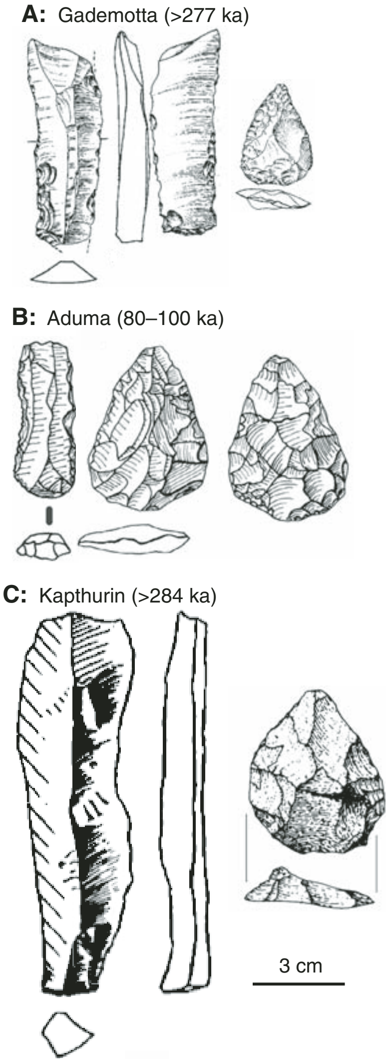

Figure 3. Artifacts from various African Middle Stone Age (MSA) sites. A: Blade and point from Gademotta, Ethiopia Site ETH-72B, dated as older than 276 ka. Reproduced with permission (Schild and Wendorf, 2005). B: Retouched blade and classic MSA point from Aduma, Ethiopia, ca. 80–100 ka. Reproduced with permission (Yellen et al., 2005). C: Blade and point from Kapthurin Formation, Kenya, dated as older than 284 ka. Reprinted from the *Journal of Human Evolution*, v. 30, S. McBrearty, L. Bishop, and J. Kingston, Variability in traces of Middle Pleistocene hominid behavior in the Kapthurin Formation, Baringo, Kenya, p. 563-580, © 1996, with permission from Elsevier.

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