Long-distance stone transport and pigment use in the earliest Middle Stone Age

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Previous research suggests that the complex symbolic, technological, and socio-economic behaviors that typify Homo sapiens had roots in the middle Pleistocene <200 ka, but data bearing on human behavioral origins are limited. We present a series of excavated Middle Stone Age sites from the Olorgesailie Basin, southern Kenya, dated ≥295 to ~320 ka by 40Ar/39Ar and U-Series methods. Hominins at these sites made prepared cores and points, exploited iron-rich rocks to obtain red pigment, and procured stone tool materials from ≥25-50 km distance. Associated fauna suggests a broad resource strategy that included large and small prey. These practices imply significant changes in how individuals and groups related to the landscape and one another, and provide documentation relevant to human social and cognitive evolution.

The Middle Stone Age (MSA) comprises a diverse group of African industries characterized by the absence or rarity of large cutting tools (LCTs: Acheulean handaxes and cleavers), the presence of prepared core (Levallois) technologies, and regional/temporal variation in weapon armatures (1–3). Later MSA industries contain varying frequencies of small retouched bladelets and geometric artifacts (4), small unifacially- and bifacially-worked points, and larger lanceolate and bone points (5, 6). African MSA sites are associated with the oldest known fossils attributed to H. sapiens, dating between ~195 ka and ~350 ka (7–9). After 130 ka, late Pleistocene MSA sites mostly from the north and south temperate zone extremities of the continent document some of the oldest beads (10, 11), complex geometric designs (12, 13), lithic projectile armatures interpreted as arrow- or dart-tips (14, 15), paint production (16), heat treatment of lithics (17), and expanded resource use including fishing and shellfish collecting (18, 19).

While these late Pleistocene behaviors are thought to reflect advanced cognitive abilities for learning, imitation, working memory, planning, and recursive technological innovation, their middle Pleistocene or earlier antecedents have remained obscure. Evolutionary explanations for the middle Pleistocene enlargement of relative brain size, largely overlapping the modern H. sapiens range, include: a shift to larger social groups or networks (20), greater foraging, technological and social adaptability in the face of more rapid and unpredictable climate fluctuations (21) and the development of symbolic expression (22).

Middle Pleistocene evidence >200 ka for the emergence of these new cognitive and social behaviors is limited to a small number of isolated sites/site complexes, mostly in tropical and sub-tropical Africa and also in the northwest (8, 23–26). The most extensive record in both chronological coverage and individual excavations is from the Kaphthurin Formation in Kenya (27–30).

Olorgesailie is a ~65 km² paleolake basin in the southern Kenya rift where over 75 years of research have documented Acheulean sites in the Olorgesailie Formation, dated from 1.2 Ma to 499 ka (31, 32). In 2001-2011, the Smithsonian team investigated sites in the younger Oltulelei Formation (33, 34). Seventeen excavations were conducted in Localities B and G in the Oltulelei Fm, including 11 in the Olkesiti Member (Fig. 1). The five oldest sites are described here (35). The oldest (~305-320 ka) and the youngest (~295 ka) (32) yielded some of the earliest evidence for MSA lithic industries lacking...
These MSA sites occur in a topographically complex paleo-landscape marked by repeated channel erosion and filling, periodic influxes of volcanicslastics, tectonic shifts, and spring-deposited tufas (33, 34). The oldest MSA sites in Locality B (BOK-1E, BOK-3; Fig. 1) directly overlie channel-deposited gravels representing initial aggradation after the long (~180 kyr) erosional hiatus between the Olorgesailie and Oltulelei Fms. These gravels postdate the ~499 ka capping age of the former and predate the tephras overlying the BOK-1E occupations, ~305 ka (32). Site BOK-2 is slightly higher stratigraphically and underlies the ~305 ka tephras and a ~302 ka tuff, while BOK-4 is again slightly younger at ~298 ka (Fig. 1).

In eastern Locality G, the Olorgesailie Fm is absent in most outcrops. We infer that the well-developed red paleosol containing the GOK-1 lithic industry formed after Olorgesailie Fm deposition ceased ~500 ka. Archeological site formation in the GOK-1 red soil was followed by a widespread erosional unconformity. A U-series date of 277 ± 1.8 ka in deposits overlying the unconformity provides an upper limit for the age of GOK-1. Subsequent volcanicslastic units above the unconformity at GOK-1 are dated ~220 ka (32). The lithic industry shares with the two oldest sites in Locality B comparable percentages of diagnostic MSA elements (table S3). No LCTs were found in the extensive GOK-1 excavations. Together, the stratigraphic context and flaked stone artifacts suggest that the age of GOK-1 is comparable to or possibly older than the early Locality B MSA sites (Fig. 1).

All early Locality B sites are in fine-grained silty or sandy sediments that represent low energy sedimentation in channel-fill settings above the basal gravels. Absence of preferential orientation of long axes and presence of abundant artifacts <2 cm (table S2) together with large cores, grindstones, and hammerstones (table S3) indicate that the artifact assemblages were deposited by hominins in or near inactive channels followed by only minor post-depositional sorting or winnowing. Sets of refitted obsidian artifacts at BOK-2 and -4 (figs. S3 and S4 and table S2) further indicate the integrity of the artifact assemblages.

Most artifacts at all but one of the Olkesiteti Member sites were made on local volcanic rocks with 1-8% of obsidian and chert (table S4). Even within the lavas, preferences for fine-grained rocks are evident in the predominance of Mt. Olorgesailie basalt, which lacks visible phenocrysts and was available at outcrops within 2 km. At BOK 2, however, 42% of the plotted artifacts (table S5) are obsidian, which has no known local usable outcrop or conglomerate source. Compositional analysis of 688 obsidian artifacts from BOK-2 and -4 was carried out by several techniques including X-ray Fluorescence (XRF) and Neutron Activation Analysis (NAA) to determine probable sources, based on a large database of known provenience. ~78% of the Olorgesailie samples are attributed to seven source groups located in direct lines from 25 to 50 km from the BOK sites in five different directions. A small number of samples were from more distant sources (Fig. 3). Given the rugged terrain of the southern Kenya Rift, the walking distance would have been considerably longer than the straight-line distance. For four occupation horizons at BOK-2, the source diversity and distance are least in the oldest level and greatest in the youngest (Fig. 3, insets).

Large obsidian flakes and cores weighing 60-90 g, refit sequences (figs. S3 and S4), low cortex ratios, and the presence of >46,000 obsidian pieces <2 cm at BOK-2 and 226 at BOK-4 (tables S2 and S4) indicate that obsidian was brought in as raw material and worked on site rather than imported as finished artifacts. Average cortex ratios on whole flakes are low (0-25%) for both local and exotic common materials in the Locality B sites (table S4). Long-distance obsidian transport at Olorgesailie precedes previously documented occurrences (30) by ~80-100 kyr.

The second most common exotic raw material is green, brown, or white chert, which has not been chemically sourced. The distinct artifact levels at BOK-2 represent multiple re-occupations, rare in open-air sites, but also evident at BOK-1E and GOK-1, indicating repeated visits to focal landscape points, likely related to resource availability.

Analysis of lithic technology (Fig. 3, fig. S5, and table S3) at all four sites supports attribution to the MSA rather than the Acheulean. First, no large cutting tools were recovered in the excavations, although a few surface finds of core-axes and picks with trihedral points and unfinished bases were recovered on a red-soil surface below GOK-1; such artifacts are typical of middle Pleistocene early post-Acheulean industries in eastern and central Africa (30) (fig. S1). Second, diverse technological sequences recovered in situ included prepared cores, especially Levallois, or asymmetrical cores (Fig. 2, H and I, and fig. S5); other core strategies include the production of blade and bladelet cores (Fig. 2G), bipolar cores on small chert and obsidian nodules, and discoidal and multi-platform cores. Third, the desired end-products were predominantly small- to medium-sized flakes (~5 cm average length), especially flakes that were relatively thin (table S4). Fourth, flat invasive retouch was used to shape some of the points and more rounded ‘ovates.’

Classic MSA end-products at the Locality B sites reflect innovation and standardization not present earlier. These include pointed forms (Fig. 2 and table S3) both unretouched and retouched at BOK-2, BOK-4, and BOK-1E. Retouched points were preferentially made on obsidian at BOK-2 and on chert at BOK-4. The bases of some points have been thinned or modified in a manner typical of hafting (Fig. 2, D and F). Perforators, side- and end-scrappers, notched and denticulate pieces, and other retouched forms are present at all three sites. At BOK-2, a series of short end-scrappers on obsidian
flakes occur, as well as very small scrapers on flakes (fig. S2).

In summary, the industries of these early sites fit within the scope of African industries grouped as MSA in the diversity of artifact forms and technological approaches to tool manufacture.

Over 2000 faunal remains of 23 larger (>2 kg) mammalian taxa, micromammals, reptiles, birds, and fish were recovered from the Locality B sites in association with the lithics; these remains carry implications for reconstructing both human behavior and paleoenvironments and are presented in detail in (34). Surface markings document human use. Carnivores remaines are rare and do not suggest a den concentration, nor were dens or burrows present in the excavated sediments. The most common taxa include equids, suids, eland, kudu, an extinct alcelaphin (*Damaliscus hypsodon*), springbok, bat-eared fox, springhare, and a root rat. The presence of many relatively smaller taxa suggests direct predation by humans rather than scavenging, as small taxa remains are unlikely to survive initial consumption by primary predators. Comparable recent African forager reliance on small mammals including small carnivores is documented in table S8.

Given the age of the sites, of particular interest are mineral pigments from two of the five sites: BOK-1E and GOK-1. Within the upper artifact horizon at BOK-1E were 86 rounded geochemical analysis of the rock by LA-ICP-MS (fig. S8, A and streaks on this stone are grinding striations (Fig. 4C), while lyzed by SEM-EDS consists mainly of calcite with fluorite in- concretionary lumps of soft dark mineral. One nodule ana- cal origin. Microscopic examination revealed that the red #6 had two opposing holes initially thought to be of geologi- in the uppermost and one (#6) in the middle unit. Specimen stries and patches were recovered in the red soil, one (#7) serv grinding striations (supplementary text S6). The evidence from the five oldest MSA sites at Olorgesailie has multiple implications for understanding human behav- ioral evolution. First, this evidence indicates that distinctive technological features of the African MSA reflecting innova- tion, standardization, and new cognitive abilities were al- ready developed in eastern Africa before 300 ka. Second, the repeated occurrence of exotic raw materials from multiple distant sources as cores, knapping products and finished ar- tifacts, and the quantities involved suggest a new behavior in the human repertoire: the formation of networks of exchange or procurement over a significant area. At least two sources were used in the oldest level at BOK-2, and 4-6 sources in the later horizons of this site and at BOK-4 (Fig. 3). The formation of extended networks and social connections is an important universal aspect of ethnographically-documented hunter- gatherer adaptations to unpredictable environments as an ef- fective strategy for risk-mitigation (39, 40). Expanded social networks are one possible explanation for the middle Pleisto- cene expansion of the human brain (20), although evidence supporting this social expansion >300 ka was not previously available. Along with improved lithic technology, particularly stone-tipped weapons, and a more diverse economic strategy suggested by the faunal remains, larger-scale social relation- ships would have provided a buffer against increased climate variation and resource unpredictability (34, 39, 40).

In a Kalahari environment comparable to that implied by the BOK sites, fauna, isotopes, and other indicators (34), modern hunter-gatherer families maintain contacts with exchange partners of up to 100 km distance, but generally range over only a 20 km radius annually (39). Thus the distances implied by the range of obsidian procurements somewhat ex- ceeds the likely home range in the Olorgesailie environment of a small family-based band but are consistent with ex- change network sizes of modern people in a similar en- vironment. The absence of this pattern from the underlying

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Acheulean levels (34) indicates that this major transition in human social and cognitive behavior occurred prior to 300 ka but postdated 500 ka. Finally, the apparent association of early pigment use and expanded social networks implied by the repetitive use of exotic raw materials from multiple sources suggest that the pigment itself may also have been of social and symbolic importance.

REFERENCES AND NOTES


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SUPPLEMENTARY MATERIALS
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Materials and Methods
Supplementary Text
Figs. S1 to S10
Tables S1 to S15
References (41–76)
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Fig. 1. Composite geological sections of Localities B and G early MSA sites, showing archeological sites, artifact levels (red dashes), and dated tuffs. Insets – bottom left: location of the Olorgesailie Basin; center: relationship of Localities B and G to Mt. Olorgesailie; bottom right: Locality B site locations.
Fig. 2. MSA artifacts from BOK sites. (A) Levallois point (Olorgesailie basalt), (B) Levallois point (obsidian), (C to F) small obsidian MSA points with flat invasive retouch (acute-angled bases in side view), (G) single-platform blade core, (H and I) obsidian Levallois cores. Point (F) refits onto core (I). (D) and (F) bulbs removed by retouch. (A) and (E): BOK-4; others: BOK-2.
Fig. 3. Location of major obsidian sources. Sources matched chemically to Olorgesailie MSA artifacts by X-Ray Fluorescence (XRF) and Neutron Activation Analysis (NAA) at the University of Missouri Research Reactor (MURR) and/or by XRF at the National Museums of Kenya (NMK). Insets: chemical plots showing use of multiple sources in basal and upper levels at BOK-2 and at BOK-4. Source Group 2 is an unknown source.
Fig. 4. MSA pigments from Olorgesailie. (A and B) GOK-1. (C to E) BOK-1E. (A) Large ochre block (#6) with two opposing holes (white arrows) and abraded red area. (A1) Smaller lower hole with chop marks made by sharp, straight-edged tool (white arrows), gouge mark (blue arrow) in lower left corner, vertical walls left and right. (A2) Top view of larger block. (A3) Larger upper hole with chop marks (white arrows, gouge mark lower left). (A4) Close-up of abraded red area showing striations. (B) Smaller block with red streaks and notch upper left. (B1) Close-up of notch showing chop marks (white arrows). (C) Surface section of a BOK-1E lump, showing diatoms (white arrows), possible cyanobacterium (yellow arrow), and manganese infillings. (D) and (E) pigment examples from BOK-1E.
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