Chronology of the Later Stone Age and Food Production in East Africa

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Evidence from several archaeological sites in sub-Saharan Africa suggests that the transition to modern human technology, marked by the change from the Middle to the Later Stone Age (LSA), occurred first in East Africa. Enkapune Ya Muto rockshelter, in the central Rift Valley of Kenya, contains the oldest known archaeological horizons spanning this transition. Radiocarbon and obsidian hydration dates from this 5.6-m deep cultural sequence show that the Later Stone Age began substantially earlier than 46,000 years ago. Ostrich eggshell beads were made 40,000 years ago. Early dates for the LSA and beads may have implications for the origin and dispersal of modern human behaviour and modern humans out of Africa.

This site also contains the only known occurrences dating to the Middle Holocene dry phase in highland Kenya and Tanzania, as well as occurrences that span the transition from hunting and gathering to food production, and from the Neolithic to the Iron Age. The adoption of domestic animals by indigenous Eburran hunter-gatherers in highland East Africa occurred gradually between 4900 and 3300 uncorrected radiocarbon years BP and the Neolithic/Later Iron Age transition occurred around 1300 BP.

Keywords: MIDDLE STONE AGE, LATER STONE AGE, NEOLITHIC, IRON AGE, EAST AFRICA, HUMAN EVOLUTION, RADIOCARBON, OBSIDIAN HYDRATION, COSMOGENIC NUCLIDES, PALEOLITHIC ORNAMENTS.

Introduction

Enkapune Ya Muto rockshelter (EYM), located in the central Rift Valley of Kenya, contains a 5.6-m deep sequence of archaeological occurrences spanning substantial portions of the Later Holocene and the middle of the Upper Pleistocene. It was initially excavated in 1982 to fulfil three objectives: (1) to find archaeological occurrences dating to the Middle Holocene dry phase in highland East Africa; (2) to test a model of forest-savanna ecotone preference for Holocene hunter-gatherers; and (3) to document the transition to food production during the later Middle Holocene (Ambrose, 1984a). These objectives were all fulfilled (Ambrose, 1984b, 1986; Ambrose & DeNiro, 1989; Ambrose & Sikes, 1991; Marean, 1992).

One new Middle Stone Age (MSA) and two new early Later Stone Age (LSA) lithic industries were revealed beneath an erosional unconformity. Further excavations were undertaken in 1987 in order to obtain a more complete Late Pleistocene cultural sequence and accurate dates for the MSA/LSA transition. Radiocarbon and obsidian hydration dates indicate that this transition may have occurred by 50,000 BP. The younger early LSA industry is associated with evidence of ostrich eggshell bead manufacture, dated to 39,900 BP. This paper describes the chronology of the cultural sequence at EYM and its implications for the origin of modern human behaviour in East Africa, the relationship between Mid/Late Holocene climate change and the chronology of the transition to food production, and the dating of the transition to the Later Iron Age.

Dating the transition to modern human behaviour

The transition to “modern” human behaviour in sub-Saharan Africa is marked by the change from the MSA to the LSA stone tool industrial complex. This is equivalent to the Middle/Upper Paleolithic (MP/UP) transition in northern Africa and western Eurasia (Klein, 1989a, 1992; 1995). Flake-based stone tool industries made on radial and levallois cores with prepared (faceted) platforms in the MSA and MP were replaced by blade- and small flake-based industries, usually made on cores with plain platforms in the LSA and UP. Ground bone tools and perforated ornaments became common in the LSA and UP, and resource exploitation and socio-territorial organization patterns begin to resemble those of recent hunter-gatherers (Binford, 1989; Klein, 1989a,b, 1992, 1995; Ambrose & Lorenz, 1990). Deacon (1989, 1992, 1995; Deacon & Wurz, 1996) has proposed that the MSA Howiesons Poort Industry in South Africa, which dates to approximately 60–80,000 BP, reflects fully modern human behaviour because it contains several characteristic
features of the LSA, including exchange of formal blade-based backed tools made on exotic lithic raw materials and intra-site spatial organization patterns around hearths. However, Klein (1989) and Ambrose & Lorenz (1990) argue that the Howiesons Poort does not reflect fully modern behaviour because its resource exploitation patterns seem less effective than those of the LSA in similar environmental contexts. Unlike the LSA, the Howiesons Poort also lacks ground bone artefacts and art.

The transition to modern technology is thought to have occurred earliest in East Africa, and may have spread by stimulus diffusion and/or migration out of Africa via the Sinai Peninsula to western and northern Eurasia by 47–40,000 BP (Klein, 1989a, 1992, 1995; Lahr & Foley, 1994). Proof of an East African origin remains equivocal because the transition appears to be at or beyond the practical limits of radiocarbon dating, around 40–45,000 years BP (Aitken, 1990; Taylor, 1996), and other dating methods provide less reliable estimates of age.

Radiocarbon dates in sedimentary sequences become asymptotic with depth around 40–50,000 BP, usually due to contamination with younger carbon while buried, or during excavation, storage and sample preparation (Haas, Holliday & Stuckenrath, 1986; Chappel, Head and Magee, 1996). Other methods of dating this crucial time period, including uranium disequilibrium series (U, Th, Pa) of carbonates and fossils (Schwarz, 1992), amino-acid racemization (AAR) of avian eggshell and bone (King & Bada, 1979; Brooks et al., 1990; Johnson & Miller, 1997), thermoluminescence (TL) of burned flints (Mercier, Valladas & Valladas, 1995), electron spin resonance (ESR) of tooth enamel (Grün, 1993), optically stimulated luminescence (OSL) of sedimentary quartz (Aitken, 1994) and obsidian hydration (Michels, Tsong & Nelson, 1983) can be used to date sites older than 40,000 years, but all require site-specific calibrations and assumptions about geochemistry, background radiation, linearity of signal uptake, temperature history, soil moisture and/or diagenetic processes. Dates older than 40,000 BP produced by these techniques are thus intrinsically questionable because they cannot be compared to radiocarbon dates. Fission track (Wagner, 1996) and single crystal laser fusion (SCLF) $^{40}$Ar/$^{39}$Ar can provide accurate dates on stratified volcanic tephra from archaeological sites as young as 2000 BP (Hu et al., 1994; Chen et al., 1996; Renne et al., 1997), but have rarely been reported for MSA and LSA sites (Manega, 1993).

Where radiometric calibration of these methods can be applied to horizons younger than 40,000 BP, greater confidence can be placed in such dates on older horizons in the same sites. However, radiocarbon dates must also be calibrated. Calibration of the Late Pleistocene radiocarbon scale with high precision U-series dating (Bard et al., 1990) demonstrates radiocarbon dates are approximately 3000 years too young by 30,000 BP. If this rate of deviation was constant, dates on 42,000-year-old materials would be approximately 5000 years too young (Bischoff et al., 1994). However, deviation rates were not constant. They reflect variations in the earth’s magnetic field strength (dipole moment), especially at c. 40–45,000 BP, when there was a substantial reduction in dipole moment during the Laschamp geomagnetic reversal event (Meynadier et al., 1979). Cosmogenic nuclide production increased for several millennia, making radiocarbon dates on materials formed after 45,000 BP approximately 3500–5000 years younger than their true age (Raisbeck et al., 1987; Mazaud et al., 1991; Sternberg & Damon, 1992; Laj, Mazaud & Duplessy, 1996). Atmospheric radiocarbon production apparently doubled during this event. Gaps and inversions in radiocarbon dates should occur around 43–38,000 BP (Sternberg & Damon, 1992), and have been found in dated MP/UP sequences in the Levant and western Europe (Ambrose, 1997).

Obsidian hydration and AAR dates have been used to date Late Pleistocene sites in Africa. Where dates are calculated using modern temperatures they should be considered minimum age estimates because temperatures were on average 4–6°C lower during the Pleistocene (Schroeder & Bada, 1973; Bonnefille, Roeland & Guiot, 1990), which would have decreased reaction rates (Miller et al., 1992; Johnson & Miller, 1997; Jones, Sheppard & Sutton, 1997; Miller, Magee & Jull, 1997). Obsidian hydration and AAR rates can be calibrated where associated with radiometric dates and this permits reconstruction of paleotemperatures (Miller, Magee & Jull, 1997). Radiocarbon production rates were higher and more variable than at present for most of the Late Pleistocene (Laj, Mazaud & Duplessy, 1996), so radiocarbon dates will be underestimated. Paleotemperatures will be overestimated and reaction rates and racemization and hydration dates underestimated. Therefore an additional correction of radiocarbon dates for variation in dipole moment should be incorporated into hydration and racemization rates and paleotemperature estimates.

In Europe and western Asia the chronology of the MP/UP transition is becoming better known through radiocarbon, TL and U-series dating. It apparently occurred around 47–43,000 BP in the Sinai Peninsula and Levant (Marks, 1983; Phillips, 1994; Schwarz, 1994; Bar-Yosef et al., 1996; Rink et al., 1996) and 43–38,000 BP in Europe and Siberia (Koslowski, 1988; Goebel, Derevianko & Petrin, 1993; Bischoff et al., 1994; Strauss, 1994; Goebel & Aksenov, 1995; Mercier, Valladas & Valladas, 1995; Rink et al., 1996). U-series and TL dates from the oldest western European sites are several millennia older and are considered more reliable than coeval radiocarbon dates (Bischoff et al., 1994; Mercier, Valladas & Valladas, 1995). As in the Levant, the difference between radiocarbon and other dates in western Europe is consistent with increased
cosmogenic nuclide production during the Laschamp event (Ambrose, 1997).

In North Africa, the earliest Upper Paleolithic occurrences are found in coastal Libya, at Haua Fteah and Hagfet ed Dabba caves, dated to about 40,000 BP (McBurney, 1967). Nazlet Khtare 4, a chert mining site in the upper Nile Valley of Egypt, is associated with nine radiocarbon dates between 31,000 and 35,000 BP (Vermeersch et al., 1984). The latest Middle Paleolithic occurrence at Sodmein Cave, Red Sea Hills, Egypt, has tool types like the MP/UP transition Emiran Industry in different parts of southern Africa.

In equatorial Africa, the MSA/LSA transition seems substantially earlier than in southern Africa. The LSA at Matupi Cave, Zaïre, has a charcoal radiocarbon date >40,700 BP (Van Noten, 1977). In the Semliki Valley, Zaïre, MSA sites with bone harpoons have discordant TL, ESR and U-series dates ranging from 82,000 to 174,000 BP (Brooks et al., 1995; Yellen et al., 1995). These harpoons should be directly dated to confirm their extraordinary age. Shum Laka rockshelter in Cameroon (de Maret, Clist & van Neer, 1987) has an LSA occurrence at the base of the sequence, associated with dates of 30,300 and 31,700 BP (Cornelissen, 1996).

Tanzania has several sites with LSA occurrences of substantial antiquity. At Kisese II rockshelter, a transitional MSA/LSA industry (“Second Intermediate”) with small convex scrapers and ostrich eggshell beads (Inskipp, 1962), has a radiocarbon date on ostrich eggshell of 31,480 BP (Deacon, 1966). At Mumba rockshelter, an MSA/LSA industry (the Mumba Industry) in middle and upper Bed V, has many backed microliths and ostrich eggshell beads. Six radiocarbon and U-series dates on shell and bone range from 23,600 to 65,700 BP, including a date of >37,000 BP on snail shell carbonate. The Bed IV/V interface is radiocarbon dated on snail shell to 36,900 BP (Mehlman, 1989, 1991). The overlying MSA/LSA Nasera Industry in lower Bed III has radiocarbon dates on ostrich eggshell of 27,000 and 33,200 BP (Mehlman, 1989; Brooks & Robertshaw, 1990). Backed microliths are rare, but several hundred ostrich eggshell beads and two bored stones were recovered. At Nasera rockshelter, Level 6, the Nasera Industry has three radiocarbon dates on bone “collagen”, one 230Th and one AAR date on bone, ranging from 18,500 to 26,000 BP. The overlying LSA Lemuta Industry in levels 5 and 4 has four radiocarbon dates from 14,800 to 21,600 BP on bone apatite and “collagen” (Mehlman, 1989, 1991). The Lemuta Industry in the Naisiusiu Beds at Olduvai Gorge was originally dated on bone “collagen” to 17,550 BP (Leakey et al., 1972). Concordant AAR and AMS radiocarbon dates on ostrich eggshell and SCLF 40Ar/39Ar now suggest an age of ≥42,000 BP for this industry (Manega, 1993).

Five sites at Lukenya Hill, Kenya, have radiocarbon dates on bone apatite and “collagen” ranging from 12,000 to 21,500 BP (Gramly & Rightmire, 1973; Merrick, 1975; Gramly, 1976; Miller, 1979; Ambrose, 1984a). Improved methods of pretreatment (Krueger, 1991) have produced apatite dates for Lukenya site GvJm46 as old as 29,950 BP (C. M. Nelson and...
H. W. Krueger, pers. comm.). These should be considered minimum estimates of the age of the LSA until confirmed by charcoal radiocarbon or other dating methods. Prospect Farm, in the central Rift Valley of Kenya, contains MSA and early LSA horizons dated by obsidian hydration (Michels, Tsong & Nelson, 1983). Artefacts of phase 3 of the Prospect Industry (MSA) produced dates of 46,500 to 53,100 BP. Phase 4 (Second Intermediate) dates between 45,700 and 53,500 BP. The overlying early LSA dates to 21,800–32,500 BP. These should be considered minimum estimates of ages because cooler temperatures prior to 12,000 BP (Schroeder & Bada, 1973; Bonnefille, Roeland & Guiot, 1990) would have reduced hydration rates.

This brief survey of dated sites indicates the MP/UP boundary appears to be approximately 40–43,000 BP in Europe and southern Siberia, and 43–47,000 BP in Western Asia and the Sinai Peninsula. The sparse record of North Africa also suggests an age of around 40–47,000 BP. The MSA/LSA transition is likely to be at least 40,000 BP at Border Cave (Beaumont, de Villiers & Vogel, 1978), Matupi (Van Noten, 1977), Mumba, Nasera (Mehlman, 1989), Olduvai Gorge (Manega, 1993) and Prospect Farm (Michels, Tsong & Nelson, 1983), but the accuracy and validity of these dates can be questioned. Evidence from Enkapune Ya Muto rockshelter, presented below, reinforces evidence that the LSA began in East Africa earlier than 40,000 BP.

Dating the transition from foraging to food production in East Africa

Many radiocarbon dates for the Neolithic Era and earlier Holocene on bone collagen and bone apatite have been rejected as unreliable (Collett & Robertshaw, 1983). The rejection of apatite dates has some justification (Grün et al., 1997; Koch, Tuross & Vogel, 1997), but rejection of collagen dates seems unwarranted. The transition from hunting and gathering to food production, marked by the presence of cattle and caprines (sheep and goats), is dated to 4000 BP in northern lowland Kenya (Barthelme, 1985). Pottery traditions (Nderit and Ileret) that are usually associated with domestic animals are dated on charcoal as early as 5000 BP in northern Kenya (Robbins, 1972), suggesting pastoralism appeared by this date.

In southern highland Kenya and northern Tanzania there is a pronounced gap in radiocarbon dates between 6000 and 3300 BP (Ambrose, 1984a). The transition to food production in this region is marked by the appearance of pottery and domestic animals in sites younger than 3300 BP. Because of this chronological gap, the most basic questions about the transition to food production in the highlands remain unanswered. Was the transition gradual, resulting from the adoption of domesticates by indigenous hunter–gatherers, or abrupt, by a process of assimilation by immigrant farmers and herders? The Holocene deposits at Enkapune Ya Muto rockshelter span this gap with 16 wood charcoal radiocarbon dates between 3000 and 6300 BP (Table 1). These radiocarbon dates, combined with faunal analysis by Marean (1992), provide an answer to this question.

Stratigraphy and Chronology of Enkapune Ya Muto

Enkapune Ya Muto rockshelter (also known as Twilight Cave, GtJi12) is located on the Mau Escarpment, west of Lake Naivasha in the Kenya Rift Valley (36°09'E, 0°50'S, elevation 2400 m). Excavation in 1982 (Ambrose, 1984b) comprised a 2 × 2 m test pit with a 1 × 4 m step trench extending to the talus slope (Figure 1); an additional 10 m² were excavated in 1987. Bedrock was reached at a maximum depth of 5-54 m below the surface. Pre–Neolithic macro- and microfaunal assemblages were analysed by Marean (1992; Marean, Mudida & Reed, 1994). The site is located in close proximity to many major obsidian sources in the Naivasha basin (Merrick & Brown, 1984) and virtually all flaked stone artefacts were made of this material. In the stratigraphical description below, the acronyms for the strata reflect their cultural affiliations, colour, texture and/or other physical properties.

Charcoal for radiocarbon dating was abundant and well-preserved in the Holocene, but rare and poorly preserved in the Pleistocene levels. Radiocarbon dates are presented in Table 1. Decomposed charcoal from the Pleistocene levels was collected with sedimentary matrix by trowel and placed directly into aluminium foil. The carbonate fraction of ostrich eggshell from one stratum was also dated. Pretreatment procedures for dating ostrich eggshell carbonate are described in the notes to Table 1. Obsidian hydration dates (Table 2) were determined by Michels using rate constants appropriate for the chemical composition of the artefacts (Michels, Tsong & Nelson, 1983).

Stratigraphy and radiocarbon dating

The IA (Iron Age) and ELM (Elmenteitan Neolithic) strata comprise approx. 100 cm of wood ash and silts. The IA levels contain pottery of the Lanet Tradition, characterized by twisted-cord roulette decoration (Bower et al., 1977). The Elmenteitan/Iron Age boundary, 45–55 cm below the surface, dates to 1295 BP. ELM contains typical Elmenteitan stone tools made on large punch-struck blades, and predominantly undecorated pottery with lug handles (Bower et al., 1977; Nelson, 1980; Ambrose, 1985). The base of ELM dates to 2595 BP. The fauna is mainly cattle and caprines (Ambrose, 1984b).

BSS comprises approximately 20 cm of aeolian Brown fine Sandy Silts, dated to 2570 and 2610 BP. HTL is a compact layer (Hard and Tacky when moist)
of caprine dung ash up to 35 cm thick, with inverted dates of 2820, 2330 and 2560 BP. Lithic and ceramic artefacts from BSS and HTL are scarce and culturally undiagnostic. Caprines dominate the fauna. BS1 is approximately 6 cm of Brown fine Sandy silt with undiagnostic caprines. BS1A is 30 cm of light Red-Brown fine silts, dated to 3390 BP. Lithic artefacts belong to phase 5 of the Eburran Industry (Ambrose, 1985). BS1B is 80 cm of ISGS-1746, with high densities of Eburran lithics and bone, but no pottery. BS1 includes one cow, one caprine and five wild bovid species (Marean, 1992). Blue-grey Volcanic Ash (VA1) up to 33 cm thick, dated to 3125 BP, seals underlying strata. RBL2.1 is a thick bed of hearths and wood ash, divided into three main strata. RBL2.1a, dated to 3990 BP, contains one caprine and five wild bovid species (Marean, 1992). RBL2.1b is 170 cm of ISGS-1742, dated as Fraction 1 (F1), and the final 46.1% was dated as Fraction 2 (F2). RBL2.1b5 is 70 cm of ISGS-1742, dated to 4860 BP. RBL2.1b includes one cow, one caprine and five wild bovid species (Marean, 1992). RBL2.1b5 is 70 cm of ISGS-1742, dated to 4860 BP. RBL2.1b includes one cow, one caprine and five wild bovid species (Marean, 1992).
Kenya. RBL2.2 and RBL2.3 date to 5265 and 5365 BP, respectively. They have well-preserved lenses of uncarbonized to partly carbonized fine grasses that probably served as bedding. Extremely high species and habitat diversity is sustained in these strata (Marean, 1992). RBL1 and RBL2 reflect extremely high intensity occupation of the rockshelter, when climate was similar to or slightly more humid than at present, and the forest/savanna ecotone was in the site’s vicinity.

The coarse Dark Brown Sand and silt (DBS1) has conformable dates of 5220, 5470 and 5785 BP. Artefact densities decrease, and microfauna, rodent burrows and rolled artefacts from the underlying deposit increase with depth, reflecting intense vertical mixing by rodent bioturbation. The faunal assemblage includes more closed habitat species (Marean, 1992; Marean, Mudida & Reed, 1994). The site was occupied less intensively as closed habitats began to encroach on the site.
The second Volcanic Ash (VA2) seals RBL3, a coarse, sandy, Red-Brown Loamy gravel lag deposit, comprising heavily abraded obsidian artefacts of indeterminate industrial affinities and small numbers of comparatively undamaged Eburran Phase 4 artefacts. Closed habitat species predominate (Marean, 1992; Marean, Mudida & Reed, 1994), suggesting forest in the site’s vicinity. This lag deposit probably formed when the shelter’s dripline was active during the early Holocene wet phase. A date of 6350 \( \pm 1000 \) BP, from an undisturbed hearth sealed directly beneath VA2, dates the ashfall and cessation of erosion. This erosional event reworked sediments and artefacts that may have been deposited between 6350 and 35,800 BP. Closed habitats surrounded the site during the formation of RBL3 and occupation intensity increased through DBS1 as rainfall decreased and the forest ecotone approached the site.

The third Volcanic Ash (VA3) is dense and compact, and protected the underlying deposits from erosion. The Dark Brown gritty Loam (DBL1) contains extremely high artefact densities (approx. 63,900 pieces of flaked stone) and a faunal assemblage heavily fragmented by trampling and compaction, with few identifiable specimens. The associated lithic industry, named the Sakutiek Industry (Figure 3), is dominated by typical LSA tool types, including thumbnail end scrapers and outils écailles, and has low frequencies of backed microliths. It also contains low frequencies of thin, parti-bifacially flaked small knives, flattened discoids, discoidal cores and faceted platform flakes, which are typical of MSA and Second Intermediate industries. Ostrich eggshell was abundant, comprising 13 complete beads, 12 bead preforms and 593 shell fragments (Figure 4). A small charcoal sample (approximately 300 mg of carbon) from DBL1.2 was dated after 3 years of storage to 16,300 \( \pm 1000 \) BP (Table 1). A small split of a large sample of charcoal-impregnated sediment from level DBL1.2, analysed within 2 months of excavation and dated to 29,300 \( \pm 750 \) BP, was considered unreliable because of its low carbon content. The remainder produced a large amount of carbon, for a more reliable date of 35,800 \( \pm 550 \) BP. Ostrich eggshell from DBL1.3 (the base of DBL1) produced radiocarbon dates of 37,000 \( \pm 1100 \) and 39,900 \( \pm 1600 \) BP on the shell exterior and interior, respectively. The latter date is more reliable because it is on the shell fraction best-protected from contamination. DBL1 reflects high intensity occupation, including evidence of on-site manufacture of ostrich eggshell beads, probably during a warm phase of marine oxygen isotope stage 3.

The underlying Grey Gravels (GG1, GG2) with intercalated layers of Orange gravelly Loamy sand (OL) have an average thickness of 1·15 m and a maximum thickness of 1·7 m. Artefact and bone densities are extremely low. Obsidian artefacts are fresh and sharp, and the gravel is poorly sorted and angular. There was insufficient charcoal or bone for radiocarbon dating. A unique blade-based LSA lithic industry, named the Nasampolai Industry, occurs throughout GG/OL. It is dominated by very large backed blades and geometric microliths, with low frequencies of outils écailles, scrapers and burins. Several backed blades have traces of red ochre opposite the unmodified edge (Figure 5), suggesting hafting parallel to the long axis. The Nasampolai Industry is not obviously transitional from the MSA, and does not closely resemble the blade-based Howiesons Poort MSA industry of Southern Africa because it lacks radial core preparation and faceted platform flakes. Several backed blades have traces of red ochre opposite the unmodified edge (indicated by light stippling in Figure 5), suggesting hafting parallel to the long axis. The deposit is apparently wind-deflated and must have originally been substantially thicker. GG/OL thus represents a very long period of ephemeral occupation earlier than 40,000 BP.

The basal horizon is a dark Red-Brown to dark brown gritty Loam (RBL4). It contains low densities of bone and flaked stone. The flake-based MSA lithic
industry is named the Endingi Industry. Flakes with faceted platforms and radial dorsal scar patterns pre-dominate (Figure 6). Outils écaille’s and scrapers are the dominant tool types. Three backed microliths were recovered from the first two levels. Two flakes have traces of red ochre and one small ochre-stained lower grindstone was recovered. A sample of carbonized sediment and decomposed charcoal from a hearth, submitted almost 2 years after excavation, dates to >26,000 BP. Two samples combined from adjacent levels, submitted 4 years after excavation, were dated to 29,280 ± 540 BP. A large sample of carbonized sediment and decomposed charcoal from a hearth, submitted for dating 6 months after excavation, dates to 41,400 ± 700 BP. The samples with younger dates have probably absorbed modern contaminants during storage (Haas, Holliday & Stuckenrath, 1986). The date of 41,400 on RBL4.1 must be a minimum estimate of its true age because this horizon is about 1·2 m below DBL1, which is dated to 39,900 BP, and the intervening 1·2 m of wind-deflated grey gravels probably represent a very long period of accumulation. RBL4 probably represents sparse occupation of the rockshelter during early oxygen isotope stage 3 or stage 4.

**Obsidian hydration dating of Pleistocene artefacts**

The three Pleistocene lithic industries have also been dated by obsidian hydration, using rate constants previously determined for the obsidian sources on which the artefacts were made (Michels, Tsong & Nelson, 1983). Rate constants and temperatures used for calculating the dates are described in the legend to Table 2. Calibration of amino acid racemization dates on bone at Lukenya Hill indicates a 6°C average paleotemperature difference (Schroeder & Bada, 1979). Since Upper Pleistocene temperatures were probably 4–6°C cooler than at present (Schroeder & Bada, 1979; Bonnefille, Roeland & Guiot, 1990), the dates were calculated at the present temperature and at 5°C less than at present.

The Sakutiek Industry (LSA) in DBL1 dates to 18,860 BP with present temperature (T) and 35,350 BP at T = 5°C. Relatively close agreement between the temperature-adjusted hydration date and the radiocarbon date of 35,860 suggests the average temperature at the site over the last 40,000 years was slightly more than 5°C cooler than at present. However, increased cosmogenic nuclide flux at this time has probably made the radiocarbon date a few thousand years too young, so the average Pleistocene temperature was probably even cooler.

Obsidian of the Nasampolai Industry (LSA), from approximately 30–45 cm below the top of GG, dates to 24,760 BP at the present temperature and 46,410 BP at T = 5°C. The Endingi (MSA) industry dates to 17,320 BP at present temperature and 32,458 BP at T = 5°C. This does not agree with the associated radiocarbon date of 41,400 BP and should be rejected. The original hydration layer has probably spalled and reformed, a phenomenon also observed on MSA artefacts from Prospect Farm (Michels, Tsong & Nelson, 1983).

The beginning of the LSA at EYM can be estimated by calculating sediment deposition rates in the Grey Gravel stratum. The maximum rate, which provides the minimum estimate of age, can be calculated by dividing the difference in age between the oldest radiocarbon date plus 1 s.d. for DBL1.3 (41,500) and the hydration date minus 1 s.d. for GG1.3 (43,648) by their average difference in depth (approximately 38 cm), and multiplying by the average thickness of the stratum.

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**Figure 3.** Ostrich eggshell beads from the base of Stratum DBL1, associated with the Sakutiek lithic industry. (a–g) complete beads; (h–l) beads and shell fragments broken during manufacture.
(approximately 115 cm). At the absolute maximum deposition rate of 57 years/cm, the LSA began by at least 46,500 BP. However, if the obsidian hydration date of 46,410 for the top third of GG1 is accurate, and the base of DBL is 39,900 BP, then the average deposition rate was approximately 167 years/cm and the LSA may have begun earlier than 55,000 BP. The best estimate of the age of the beginning of the LSA is probably somewhere between dates calculated from the maximum and mean deposition rates, and thus around 50,000 BP.

**Discussion and Conclusions**

*The transitions to food production and the Later Iron Age*

Radiocarbon dates from EYM provide new insight into the timing of important economic and technological transitions during the Holocene. The date of 1295 BP for the Elmenteitan Neolithic/Iron Age transition is consistent with evidence from other sites in the Rift Valley (Ambrose, 1984c, 1985). Dates for the beginning of the Elmenteitan of 2600 BP are younger.
than at Njoro River Cave, where it dates to 3100 BP (Merrick & Monaghan, 1984). This difference in dates should not raise questions about the cultural affinities of the Njoro people. Low artefact densities and undiagnostic lithic and ceramic traditions in BSS and HTL make it impossible to determine the cultural affinities of these pastoralists. However, immigrant Elmenteitan and Savanna Pastoral Neolithic populations were evidently contemporary with the makers of the Eburran Industry after 3300 BP (Ambrose, 1984a, 1985).

The earliest pastoral pottery traditions at EYM (Salasun, Ilaret and Nderit) are dated to 4860 BP, but are not associated with domestic animals. Dates on Nderit sites in northern Kenya as old as 5000 BP (Robbins, 1972) have been rejected without apparent justification (Collett & Robertshaw, 1983), but should be reconsidered given the date for similar ceramics at EYM. Marean’s (1992) faunal analysis demonstrates that domestic caprines appear in EYM at 3990 BP, 870 years after pottery suggests contact with pastoralists from northern Kenya. The adoption of pastoralism by Eburran hunter-gatherers was thus gradual and not completed until 3280 BP.

**Chronological gap in the Middle Holocene**

The sequence at EYM fills a substantial gap in the radiocarbon chronology of the East African highlands between 6000 and 3300 BP that correlates with a period of drier climate (Richardson, 1972). Carbon isotope analysis of soil profiles in the Naivasha basin demonstrates the forest/savanna ecotone rose to higher altitudes during this dry phase (Ambrose & Sikes, 1991). Eburran hunter-gatherers may have preferred to settle

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**Figure 5.** Shaped stone artefacts of the Nasampolai Industry (earliest LSA) from stratum GG. (a–i) backed blades and geometric microliths; (j) end and denticulate side scraper; (k, l) double burins. Stippling on (b), (c), (f) and (i) indicates the location of traces of red ochre.
on this ecotone and followed it to higher altitudes
during the dry phase and to lower altitudes during the
Early Holocene wet phase. High intensity occupation
of EYM by hunter–gatherers, associated with forest
and savanna species (Marean, 1992; Marean, Mudida
& Reed, 1994) during this arid period, is consistent
with the model of ecotonal settlement preference
(Ambrose, 1986).

The gap in chronology also spans the gradual tran-
sition to food production among indigenous hunter–
gatherers who made the Eburran lithic industry. This
transition began at 4860 BP, marked by the appearance
of pottery that in northern Kenya is associated with
domestic animals. The transition was completed by
3280 BP when domestic animals finally dominate the
faunal assemblage in BS1. Drier climate during this
period may have rendered highland environments
marginal for food production, thus delaying and
prolonging this transition (Ambrose, 1984a).

Integrating the local record of the spread of food
production with continental chronologies requires cali-
bration to an absolute time scale by adjusting radiocar-
bon dates for past variation in the production of
atmospheric radiocarbon (Stuiver & Kra, 1986). Tree
ring-calibrated dates (Table 1) (Stuiver & Reimer,
1993) for the earliest pottery and domestic animals at
EYM show they appeared by 5597 and 4220 calibrated
years BP, respectively. Fully pastoral sites appear in
highland East Africa at c. 3470 calibrated years BP.
Domestic cattle first appeared in North Africa after
8000 BP (Clutton-Brock, 1993), but the spread of
pastoralism south of the Sahara apparently did not
occur until later than c. 4000 radiocarbon years BP
(Smith, 1984). The first domestic animal in the Cape
Province, South Africa, is dated to c. 2060 cal. years
BP, but domestic-dominated faunas are all younger
than 1700 BP (Sealy & Yates, 1994). Pastoralism thus
appeared in South Africa c. 1400 years after it was
established in the East African highlands. Domestic
animals apparently spread from north to south in
several brief episodes separated by long periods of
stasis. The spread from northern to equatorial Africa
may have been delayed by climate-induced shifts in
the position of tsetse-infested floral zones (Smith, 1984),
but the spread to southern Africa may not be
associated with any obviously climatic changes.

The antiquity of the Later Stone Age
Radiocarbon samples from Upper Pleistocene levels at
EYM with low carbon contents, and which were small
and/or stored for long periods (2–4 years) before
analysis, had systematically younger ages than large
samples dated soon after excavation. Previous studies
of carbonized sediments dated soon after excavation
and redated 3–4 years later show significant decreases

Figure 6. Shaped stone artefacts of the Endingi (MSA) industry from stratum RBL4. (a–c) backed crescents; (d) triangular flake point with
alternate lateral retouch and a burin or impact scar at the distal end; (e) oblique end scraper; (f) outil écaille; (g, h) whole flakes, with red ochre
indicated by stippling on the platform and dorsal surface of (g) and platform, dorsal and ventral surface of (h); (i) whole flake with faceted
platform from a radially prepared core.
The overlying Holocene strata, which are 3.25 m thick, are unlikely to be intrusive from higher strata. Ostrich eggshell beads associated with the Sakutiek Industry provide a minimum age of 39,900 BP for the earliest LSA. Temperature-calibrated obsidian hydration dates demonstrate that the MSA/LSA transition is probably significantly older than 46,000 BP in East Africa, and is thus older than the MP/UP transition (Emiran Industry) and the early UP (Ahmarien Industry) dated to c. 47-43,000 BP in the Levant (Marks, 1983; Phillips, 1994; Schwartz, 1994; Bar-Yosef et al., 1996).

Dates of 37–39,900 BP on ostrich eggshell from the bead workshop in DBL1 at EYM confirm early dates for these artefacts at Mumba-Höhle (Mehlman, 1989), Kissese (Deacon, 1966), Boomplas (Deacon, 1995) and Border Cave (Beaumont, de Villiers & Vogel, 1978; Miller et al., 1992). The Sakutiek Industry in DBL1 may also provide the most reliable estimate of the age of the thumbnail scraper-dominated occurrences at Lukanya Hill site GvJm46, dated to between 19,000 and 30,000 BP on bone apatite (Miller, 1979; C. M. Nelson & H. W. Krueger, pers. comm.), and GvJm22, dated to 17,000 BP on bone “collagen” (Gramly, 1976). As noted above, redating of the Naisiusiu LSA industry increased its age from 17,000 (Leakey et al., 1972) to 42,000 BP (Manega, 1993). If all published bone apatite dates from Lukanya are also systematically young, the true age of the Lukanya Homo sapiens cranium at site GvJm22 (Gramly & Rightmire, 1973), may be substantially older than 17,000 BP.

The Sakutiek Industry (second LSA) at EYM has technological and typological features of a transitional MSA/LSA industry like the Magosian, but is far from the MSA/LSA boundary. Assemblages that appear transitional are thus not necessarily closest in time to the MSA/LSA transition. The underlying Nasampolai Industry is fully LSA and is not obviously transitional from the MSA. It does not closely resemble the blade-based Howiesons Poort MSA industry of Southern Africa (Singer & Wymer, 1982) or the Mmba and Nsera industries in Tanzania (Mehlman, 1989; 1991), both of which have large backed microliths, like the LSA, but also have bifacial and unifacial points and radially prepared cores and flakes, like the MSA. Although the lithic industries at EYM and Mumba differ, patterns of change through time are similar because earlier industries have more backed tools than later ones.

**Significance of ostrich eggshell beads for the origin of modern human behaviour**

Ostrich eggshell beads associated with the Sakutiek Industry are unlikely to be intrusive from higher strata. The overlying Holocene strata, which are 3.25 m thick and exposed over 16 m² in the excavation, contain 76 whole beads, one bead preform (1.48 beads/m³) and 222 unworked ostrich eggshell fragments. DBL1, which is 30–40 cm thick and exposed over only 6 m², contains 13 complete beads, 12 bead preforms broken during drilling or grinding (11.9 beads and preforms/m³) and 593 shell fragments. Radiocarbon dating of the ostrich eggshell from which beads were made demonstrates that beads were manufactured by 39,900 ± 1600 BP, confirming early dates for such beads elsewhere in Africa (Inskeep, 1962; Deacon, 1966; Beaumont, de Villiers & Vogel, 1978; Mehlman, 1989; Miller et al., 1992; Deacon, 1995). Applying a correction for increased cosmogenic nuclide production could move this date back approximately 3500 years (Raisbeck et al., 1987; Mazaud et al., 1991; Sternberg & Damon, 1992; Laj, Mazaud & Duplessy, 1996).

These beads may mark the dawn of an era of new artefact manufacturing techniques (drilling and grinding) and of personal adornment, but may also mark a far more significant innovation in modern human behaviour. Among modern Kalahari !Kung San hunter-gatherers, beads are one of the most important items used in a system of gift-giving and exchange. This institutionalized system of delayed reciprocity, called *hxaro*, functions to strengthen networks of regional social and economic relationships that serve as a social safety net, enhancing survival in marginal environments (Wiessner, 1982, 1986). *Hxaro* partners are sought with individuals who live in areas with complementary resources: 24% of partners live 50–100 km away, and 9% live more than 100 km away. The word for sewn beadwork is synonymous with the word for *hxaro* gifts, and beadwork is considered an appropriate gift for all occasions (Wiessner, 1986). This suggests great antiquity for the use of ostrich eggshell beads in the *hxaro* system of gift exchange.

Deacon (1992; 1995) has proposed that standardized backed tools on exotic raw materials in the Howiesons Poort, 70,000 years ago, mark the initiation of trade networks like those of modern San. Arrows are indeed widely traded among the !Kung at present (Wiessner, 1983). Although I agree with Deacon that it is likely that people travelled longer distances and may have had intergroup exchange during the Howiesons Poort (Ambrose & Lorenz, 1990) it is difficult to prove or refute the hypothesis that this class of stone artefacts had acquired such symbolic value. Inferring symbolic meanings of non-utilitarian items such as beads is less ambiguous. Mitchell (1996) suggests that *hxaro* gift exchange networks were established in southeastern southern Africa by the early Holocene or terminal Pleistocene, based on the presence of marine shell and ostrich eggshell beads in areas of the interior of southern Africa where both materials do not naturally occur. If ostrich eggshell beads manufactured in eastern and southern Africa 40–45,000 years ago were made for a *hxaro*-like delayed reciprocity system, then they may signify the invention of a symbolic marker for a social
security system that permitted behaviourally modern humans to survive in more risky environments.

Significance of ostrich eggshell beads for the expansion and dispersal of modern humans

Mitochondrial DNA studies indicate that modern human populations expanded within and outside of Africa around 40,000–75,000 BP (Harpending et al., 1993; Sherry et al., 1994; Mountain & Cavalli-Sforza, 1997; Watson et al., 1997). The invention of modern human technology in sub-Saharan Africa is considered to have been a prime mover in this demographic expansion (Harpending et al., 1993; Sherry et al., 1994). The appearance of the LSA at EYM well before 46,000 BP provides support for the hypothesis of a technologically mediated population expansion in Africa. Equatorial East Africa may have been the source area for this radiation because it may have been a refuge from the harsh climate of the last ice age, but direct evidence for population expansion in the early LSA is lacking (Ambrose, in press). Sub-Saharan Africa apparently had a larger population size than other continents during the last ice age (Relethford & Harpending, 1994), and thus may have had the largest reservoir of knowledge on which to base new innovations (Ambrose, in press). One may further speculate that if ostrich eggshell beads reflect an enhanced symbolic system of socially mediated risk-minimization and social solidarity, this may have facilitated population increase in Africa, the spread of modern humans out of Africa and the replacement of archaic human populations in Eurasia.

Chronology and geographical area of origin of modern human behaviour

The archaeological sequence of EYM seems to provide support for Klein’s (1989a, 1992, 1995) hypothesis of an equatorial East African origin for modern human behaviour. However, an origin anywhere in humid equatorial Africa cannot be discounted. Moreover, the chronology of the origin of many aspects of modern human behaviour is still uncertain. More sites spanning this transition in Ethiopia, Central and West Africa should be excavated and dated by accurately calibrated methods (Renne et al., 1997) before East Africa is considered the Garden of Eden for modern human behaviour.

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